ABSTRACT

YUILL, JAMES JOSEPH. Defensive Computer-Security Deception Operations: Processes, Principles and Techniques. (Under the direction of Dr. Mladen Vouk and Dr. Ana I. Antón.)

This dissertation is concerned with the processes, principles and techniques that are involved in deception-operations for computer-security defense. In this work, computer security deception-operations are defined as the planned actions taken to mislead hackers and thereby cause them to take (or not take) specific actions that aid computer-security defenses. Computer security researchers have investigated hackers' use of deception to attack networks and the deceptive honeypot systems used to defend networks. However, relatively little has been done to systematically model and examine computer security deception-operations. This work addresses these issues by focusing on deception for computer-security defense. The four main contributions of this dissertation are:

1) <u>A process model for deception operations</u>: this model, which is based on military deception theory and practice, provides deception planners with a framework for conducting deception operations. The framework includes a set of processes, principles and techniques.

2) <u>A process model of deceptive hiding</u>: this model aids the defender in developing new hiding techniques and in evaluating existing techniques. Deceptive hiding is modeled as defeating the target's discovery processes: direct observation, investigation based on evidence, and learning from others.

3) <u>Two novel deception-based intrusion detection systems</u>: the two deception models informed the design and evaluation of these systems. The *Honeyfiles* system extends the network file system to provide bait files for hackers. These files trigger an alarm when opened. The *Net-Chaff* system employs computer-impersonations to detect and contain hacker's network scans within an intranet.

4) <u>Experiments and evaluation</u>: a prototype Honeyfile system was implemented, and the Net-Chaff system was simulated and modeled analytically. This work, and subsequent

experimentation, provide exploratory and confirmatory assessment of the two deception models. The experimental portion of this work reveals that: (a) when the Honeyfiles prototype is deployed on a deceptive network, and when subjected to hacking, it is observed to be an effective means for intrusion detection, and (b) the Net-Chaff system can reliably detect and contain intranet scans before they access vulnerable computers.

DEFENSIVE COMPUTER-SECURITY DECEPTION OPERATIONS: PROCESSES, PRINCIPLES AND TECHNIQUES

by

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Dedicated to the Memory of Jim Settle, FBI (ret.)
in gratitude for his friendship, support and tutelage,
without which I could not have completed this work

Biography

Jim Yuill has over twenty years of experience in computer-related work. He has a B.S. in Computer Science from North Dakota State University and a Masters of Computer Science from North Carolina State University. While at NCSU, Jim taught over a dozen graduate and undergraduate courses. Jim also worked for IBM in operating-systems development.

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- **Ken DeLavigne**, IBM, ret.: this research is also based on prior study in software engineering, quality, Austrian Economics, and writing. Ken was my mentor when I worked at IBM, and he advised me in these studies. I have benefited much from his wisdom.

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Nomenclature

CND	computer network defense
computer security	in this dissertation, the term refers to computer-security defenses, unless stated otherwise
critical vulnerability	an enemy vulnerability that permits friendly forces to destroy an enemy capability that he needs to function effectively
deception exploit	a statement of how the target-action will benefit CND. See *deception objective*
deception objective	the desired result of the deception operation; it consists of: 1) the intended *target action*, and 2) the *deception exploit.*
deception-operation	for computer security, it is the planned actions taken to mislead hackers and thereby cause them to take (or not take) specific actions that aid computer-security defenses
deception story	an outline of how the computer system will be portrayed so as to cause the target to adopt the *desired perception*, and take the intended *target action*
deception planner	the person who plans, develops and carries out the deception operation
denial	see hiding
desired perception	what the target must believe in order for it to take the intended *target action*
footprinting	a hacker's use of publicly available information to learn about an organization and its network
hiding	we consider hiding to be deceptive if it intends to mislead, and hiding that is not intended to mislead is referred to as *denial*. See *showing*.
Honeyfiles	a system that extends the network file system to provide bait files for hackers. These files trigger an alarm when opened.
honeynet	a network of honeypots
honeypots	computer systems that are designed to be probed, attacked or compromised by hackers
intelligence	information and knowledge obtained through observation, investigation, analysis, or understanding
intelligence source	something that is used by the hacker to learn about the network.

Net-Chaff	a system that employs computer-impersonations to detect and contain hacker's network scans within an intranet
planner	see deception planner
ruse	a trick designed to deceive
scan-and-attack	a type of scan, in which the scan probes include an attack
showing	deception includes showing what is false and hiding what is real. See *hiding*.
target	the person the deception operation seeks to deceive
target action	a statement of what the hacker is to do (or not do) at some time and location. It is always stated in terms of specific actions. See *deception objective.*

1 Introduction

The research reported in this thesis provides models for designing and conducting defensive deception operations. The models are based on the underlying nature of deception and were, as much as possible, made independent of the current technologies. The models provide a framework for conducting deception operations and include a set of processes, principles and techniques that were examined and validated as part of the current work. The deception models informed the design and implementation of two deception-based intrusion detection systems: Honeyfiles and Net-Chaff. The Honeyfiles system extends the network file system to provide bait files for hackers and trigger an alarm when opened. The Net-Chaff system impersonates computers at an intranet's unused addresses. By using simple and large-scale impersonations, Net-Chaff can effectively detect and contain hackers' intranet scans. A prototype Honeyfile system was implemented, and Net-Chaff was simulated and modeled analytically. This work provides exploratory and confirmatory assessment of the two deception models.

1.1 Problem statement

After many years of research and development, computer security remains an error-prone task, and computer security's chronic problems call for new approaches. One component of tools and techniques for achieving security can be deception. In everyday security, deception plays a relatively prominent role, e.g., leaving the living room lights on to make burglars think someone is at home. However, in information technology, deception is often not used, or it plays an implicit role rather than an explicit one. Deception works in a fundamentally different way than conventional security methods. Conventional security tends to work directly on, or against, the hacker's actions, e.g., to detect them or to prevent them. Deception works by manipulating the hacker's thinking, to make him act in a way that is advantageous to the defender. Being fundamentally different, deception can be strong where conventional security is weak (and vice-versa). While deception is not always useful, it can be an important and effective way of compensating for conventional security's inherent vulnerabilities, and it may be advantageous to combine the two explicitly.

In computer security, an advantage of deception is that it can pit the defender's strengths against the hacker's weaknesses. Hackers often rely heavily, if not exclusively, on a single source of information—data acquired via the network. Often, the network-based data can be manipulated to the defender's advantage. Furthermore, when a hacker first arrives at the network, he [1] must learn about the network by investigating it. The investigation includes scanning and perusing the network itself and computers attached to it. The hacker's investigation process, combined with this initial naiveté, can create an unavoidable and predictable conduit for deception. Typically, the network defender has physical control of his network, and he knows it well. The defender can exploit the hacker's investigation process to supply him with falsehood and thereby attack his decision-making process.

Deception is an integral part of human nature and experience. There are legitimate, even necessary, reasons for deceiving others, as in sports and games. Deception is a frequent theme of history, literature, drama, and marketing. Consumers routinely exercise counter-deception. However, few people use deception in the calculated manner needed for computer security. As the military deception literature reveals, effectively deceiving an adversary is a job skill, and it requires an understanding of deception processes, principles and techniques [JDD96, USA88, USM89]. Deception can be used to attack hackers' decision-making processes; thus deception provides an offensive security measure—something computer security defenders sorely lack.

1.2 Scope of this research

Computer-security deception is defined as the planned actions taken to mislead hackers and to thereby cause them to take (or not take) specific actions that aid computer-security defenses.[2] The deception aims to mislead the hacker into a predictable course of action or inaction that can be exploited [Dew89]. Tricking a hacker, and making him think a certain way, is important only as a step toward getting him to make the decision that will result in the desired action [JDD96]. Thoughts without action are of little computer security

[1] Unless stated otherwise, this paper's masculine pronouns refer to both men and women.

[2] This definition is adapted from the U.S. DoD definition of military deception [JDD96].

value. Deception includes showing what is false and hiding what is real [BW82, Wha82]. We consider hiding to be deceptive if it intends to mislead, and hiding that is not intended to mislead is referred to as *denial*.

In this dissertation, the term *computer security* refers to computer-security defenses, unless stated otherwise. Some of this dissertation's other terms are defined as: 1) *deception planner*, or *planner:* the person who plans, develops and carries out the deception operation, 2) *deception operation:* the planned development and deployment of a deception-based computer security measure, 3) *target:* the person the deception operation seeks to deceive, 4) *intelligence:* information and knowledge obtained through observation, investigation, analysis, or understanding, 5) *ruse:* a trick designed to deceive. (A glossary appears after the table of contents.)

The **scope** of this research is deception-operations for computer-security defenses. Deception can be used to provide or enhance computer-security, including incident response, intelligence, detection, and prevention. The research focuses primarily on the design and conduct of deception operations for thwarting attacks and for collecting intelligence. Honeypots are currently one of the most widely used defensive deception technologies [Spi02]. This work does not focus on honeypots, but it uses them to explore, illustrate, verify, and validate principles. Additionally, counter deception (i.e., detecting hackers' deceptions) and legal issues concerning the use of deception are not addressed. Hackers' use of deception and deception for counter attacks (i.e., hacking hackers) are also out of scope. However, using deception to thwart, or attack, the hacker's decision-making process is one of the research's primary topics.

This research consists of three parts. Two parts are deception models, and an overview of them is presented next. The third part are systems that use description, experiments with them, and evaluation of their effectiveness.

1.3 Research overview

1.3.1 Deception process models

Two types of process models were developed for use in computer-security.

- **Process models for deception operations:**

A set of descriptive and predictive models was developed for use in computer-security deception operations. These models are formed by synthesizing the principles in the extensive and disparate military-deception literature, and by adapting them for use in information technology and computer security. Two other sources are used in developing the deception-operation models presented here. They are the computer security literature and this research's experimental and analytical findings. The contribution of these models is their extensive coverage of the deception-operation process, their derivation from the stated sources, and their application to computer security.

The principles of military deception are highly applicable to computer-security deception. The principles are well documented in the military deception literature (as described in Chapter 2), and they are based on millennia of experience and thought. The military deception literature is extensive, and it is also disparate, as the sources cover different aspects of deception. This research also draws upon the intelligence deception-literature (also described in Chapter 2). An additional research source is private communications and collaboration with a deception expert who has had extensive experience in both military and intelligence deception. This expert has significant insights that do not appear in the deception literature.

Deception operations vary in the purposes they serve, the networks on which they are used, and the different types of hackers they target. Some deceptions are simple and reliable; for example, ping scans can be easily and predictably deceived. In contrast, other deceptions are complex and uncertain; for example, a honeynet can be large, and there can be many servers with extensive false content. Although deception operations vary widely, there are deception processes, principles and techniques that are applicable to many, or even all, deception operations. Handel, a theoretician of military deception, has observed:

"The basic principles and objectives of reinforcing the desires and perceptions of the deceived will not change, since human nature and the psychological mechanism of human perception are ever the same. In terms of its forms and the means employed, deception will, like war itself, change as new weapons and technologies appear [Han85]."

For this research, the deception models describe how deception can be used to advantage in computer security. The models describe the processes followed in deception operations, and they describe the principles and techniques for developing and conducting deception operations.

- **A process model of deceptive hiding:**

A second part of the research is a novel model of deceptive hiding. The model addresses one component of deception operations, and it extends existing hiding models. The model is intended for use in developing new hiding techniques and for evaluating existing hiding techniques. It characterizes deceptive hiding in terms of how it defeats the underlying processes that an adversary uses to discover a hidden item. An adversary's process of discovery can take three forms: direct observation (sensing and recognizing), investigation (evidence collection and hypothesis formation), and learning from other people or agents. Deceptive hiding works by defeating one or more elements of these processes.

1.3.2 Systems, experiments, and evaluation

A significant component of deception research requires analysis of human nature. Often, human behavior and nature are not amenable to quantification, so qualitative analysis needs to be applied, such as an appropriate non-quantitative deception process-model. Further, although deception is an integral part of human life, computer-security deception operations are not. Consequently, to learn more about deception operations, the third part of the research involves the development of a prototype, simulation, and analytical models, as well as their use in experiments and evaluation. [3]

The two deception models informed the design and implementation of two deception-based intrusion detection systems. These implementations, and subsequent experimentation,

[3] These insights on research method are from F.A. Hayek, Nobel laureate [Hay52].

provide exploratory and some confirmatory assessment of the two deception models. One of the systems is a deception-based intrusion detection system called *Honeyfiles*. A honeyfile is a bait file that is intended for hackers to open, and when the file is opened, an alarm is set off. For example, a file named *passwords.txt* could be used as a honeyfile on a workstation. Hackers who gain unauthorized access to the workstation will be lured by the file's name, and when they open the file an alarm will be triggered. Honeyfiles are implemented as a file server enhancement, and the file server's users can make any of their files a honeyfile. A prototype Honeyfile system was built. The system was tested by deploying it on a deceptive network and, when subjected to hacking, was observed to be an effective means for intrusion detection.

The second system impersonates computers on an intranet for the purpose of detecting and stopping hackers' port scans. The system is called *Net-Chaff*, and it impersonates computers at the intranet's unused addresses. Net-Chaff only impersonates computers below the application layer, as this greatly simplifies the implementation, yet still affords significant advantages over scanners. When Net-Chaff detects a scan, it blocks the scanner's network access via the intranet's routers. Further, Net-Chaff's use of deception can significantly slow down scans, reduce the usefulness of scan findings, and lure follow-on attacks against Net-Chaff's impersonated computers. Net-Chaff uses concepts from existing deception-based security systems (e.g., honeyd [Hon05]), and it combines and applies them in a novel way.

Net-Chaff's use of deception, and its ability to thwart scans, were assessed using simulations and analytical models. They confirm that the Net-Chaff system can effectively thwart scans and that deception plays a significant role in the process. In military theory, a *critical vulnerability* is an enemy vulnerability that permits friendly forces to destroy an enemy capability that he needs to function effectively [MC97]. Network scanning is a key step in hackers' reconnaissance, and this makes network scanning's vulnerability to deception a critical vulnerability for hackers.

1.4 Expected uses and benefits of this research

Although appealing, deception appears to be used only sparingly in computer security. Furthermore, at present, the computer security literature does not appear to address, in depth, the general processes and principles of deception operations. This research provides such deception models, for developing deception skills and knowledge. Also, this research presents two novel deception-based computer security tools that can be used for detecting and preventing attacks.

The overarching expectation is that deception can significantly improve the current state of computer security. Deception may even be essential in compensating for the intrinsic limitations of conventional security. There is strong precedent for these expectations. In adversarial contests observed throughout history—among both men and beasts—deception plays a pervasive and significant role [BW82].

The rest of this dissertation is structured as follows. Chapter 2 discusses background information and related work. Chapter 3 presents the deception framework, its process and associated models. Chapter 4 discusses two deception-based security devices that aid in intrusion detection: Honeyfiles and Net-Chaff. Chapter 5 discusses how this work has been evaluated and presents the key lessons learned. Chapter 6 provides a summary of contributions and limitations of this work, as well as plans for future work.

2 Background and related work

This chapter summarizes the deception and computer-security literature related to this dissertation. This summary is based on extensive surveys of: 1) the literature on deception processes for computer security, war fighting, and intelligence, 2) the prior work on scanning and scan defenses, that is related to the Net-Chaff system, and 3) deception use in honeypots and other computer security tools. The background and related work from these surveys is presented in the following three subsections,.

2.1 Deception processes

This dissertation includes two models of deception processes. They are the models of deceptive hiding and the models for designing computer-security deception operations. This section surveys the prior work related to the general areas these models address.

2.1.1 An overview of deception processes

Deception is a form of perception in which a target is intentionally led to an incorrect perception, through the actions of another [Wha82]. Deception, as illustrated in Figure 3.1.1-1, is distinguished from unintentional acts of misrepresentation and from self-induced acts of misrepresentation (self-deception).

Hiding and showing are both present in any act of deception [BW82]. When showing the false, the truth must also be hidden. When something is hidden, something else is shown instead, even if only implicitly. Further, deceptions are often constructed of multiple ruses, employing both hiding and showing. For example, a honeypot can deceptively impersonate (i.e., show) a network server, while deceptively hiding a keystroke logger. When a deception uses both hiding and showing, the deception may be characterized as hiding or showing, according to the planner’s primary intent. For instance, a server’s banner is modified to display a false model and version number. The banner is showing falsehood, but the primary intent is hiding the server’s true model and version from hackers and worms.

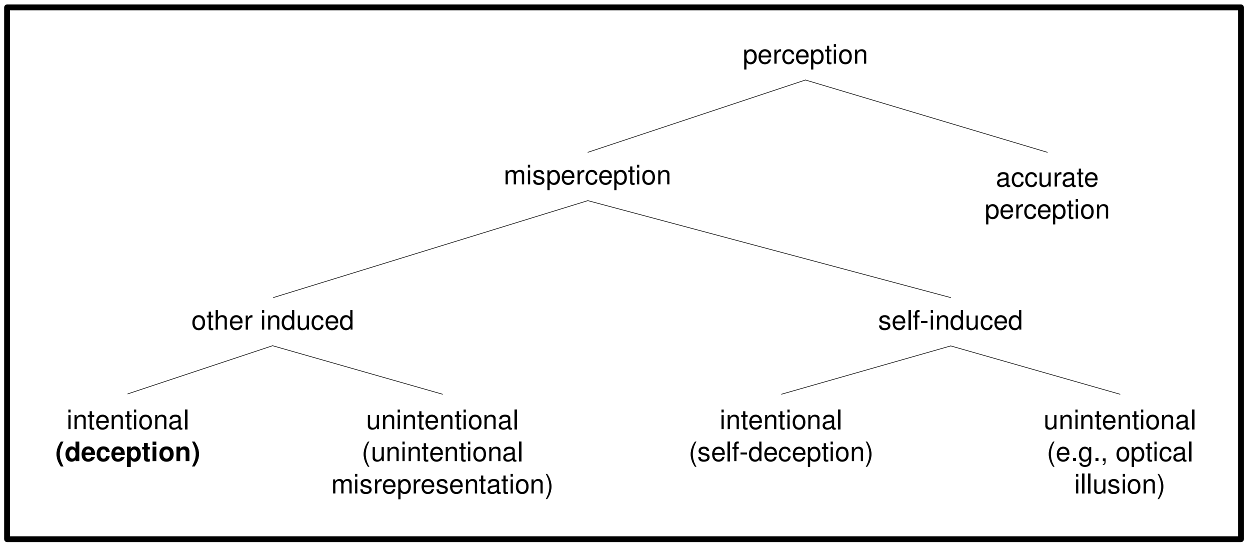
perception
misperception
accurate perception
other induced
self-induced
intentional (deception)
unintentional (unintentional misrepresentation)
intentional (self-deception)
unintentional (e.g., optical illusion)

Figure 3.1.1-1 : Deception as a form of perception (adapted from [Wha82])

Bell and Whaley offer a taxonomy of deceptive techniques based on three ways of hiding: masking, repackaging, and dazzling; and three ways of showing: mimicking, inventing, and decoying [BW82]. This taxonomy has been used in both the military and computer security literature [USM89, Jul02]. The military deception literature also lists common types of battlefield deceptions, examples being camouflage, feints (fake attack-initiation), ruses (tricks designed to deceive), demonstrations (fake force deployment), and displays (the showing of fake military forces or equipment, e.g., inflatable tanks) [USA88, Dew89, FN95]. Cohen [Coh98] and Rowe and Rothstein [RR04] have shown how these can be applied to computer network defense. Rowe and Rothstein have also published a taxonomy of deception techniques based on semantic cases in computational linguistics such as agent, instrument, location-from, time-at, and purpose [RR04]. In addition, Rowe has developed a taxonomy for deception in virtual communities [Row05b]. The taxonomy applies primarily to computer misuse, and not to computer security.

The hiding model presented in this dissertation extends this earlier work on deception taxonomies. The model shows how deceptive hiding can be understood in terms of processes, mainly the discovery processes used by a target to acquire information. Particular hiding techniques work by defeating elements of these processes.

2.1.2 Deception processes in computer science

Some computer-security literature addresses, at least in part, deception itself. Fred Cohen led a major deception-research project at Livermore Labs [CLP01, CMS01, Coh98, Coh00]. His research attempted to statistically characterize the general effectiveness of deception [CMS01]. The results are of very limited applicability, since such results cannot adequately address the wide variation in the causative effects in general deception-operations. Cohen has also applied military deception principles to computer security, though he only draws from one source on military history and a small collection of military deception techniques [Coh98].

Rowe and Rothstein have built a probability model based on military deception techniques. The model is intended for assessing the usefulness of those techniques [RR04]. Unfortunately, the deception model overly simplifies complex phenomena and the probability model appears to be mathematically flawed. For example, the "appropriateness" of a deception technique is assigned a number, and that number is used in an equation to rank deceptions. However, that number is not a cardinal value, but an ordinal value, so its use in an equation is not valid nor meaningful.

Two Australian researchers are addressing the process and principles of deception [Hut04, HW00, HW01, HW02]. They present high-level conceptual models for understanding deception, and the models include deception for both offense and defense. The models are general and do not provide the level of detail needed for designing specific deception operations.

2.1.3 Military deception processes

This dissertation presents a model for designing computer-security deception operations. The model was developed by synthesizing the military and intelligence deception literature, and applying it to computer security. Deception is a key focus of the military and intelligence communities [YDF06]. Three U.S. military deception-manuals provide deception models for different aspects of deception operations. The Joint manual addresses deception planning for command and control warfare (C2W) [JDD96]; the Army manual addresses tactical deception [USA78, USA88]; and the Marine Corps manual addresses strategic deception [USM89]. Useful models are also found in books written by soldiers and intelligence analysts with expertise in deception [Dew89, Heu81, Mur80]. Civilian researchers, from academia, intelligence contractors, and defense contractors, have also provided deception models for warfighting [CIA80, DH82b, FN95, Han85]. In all of this literature, each source addresses a subset of deception. Consequently, the literature contains a disparate collection of deception processes and principles. Prior to this dissertation, the only known attempt to synthesize this literature is by the author of the Marine Corps manual, which addresses strategic deception, not tactical deception [USM89]. In contrast, this dissertation provides a comprehensive synthesis of the military and intelligence literature's disparate deception models, and its focus is primarily on the tactical use of deception.

2.2 Scanning and scan defenses

A major component of this dissertation is the Net-Chaff system, the purpose of which is scan defense. The related work for Net-Chaff is in the areas of scanning and scan defenses. They are presented in the following two sections.

2.2.1 Scanning

Net-Chaff's purpose is to defend against hackers' active scans. An overview of scanning is provided here, and it frames the aspects of scanning that are relevant to Net-Chaff. Further details on scanning are provided with the Net-Chaff description in Chapter four.

Arkin defines active scanning as, "a technology, which uses stimuli (packets) in order to provoke a reaction from network elements. According to responses, or lack thereof, received from the queried network elements, knowledge about a network and its elements will be gathered" [Ark05]. Passive scanning is an alternative form of scanning. It learns about network elements by observing network traffic. Research comparing active and passive scanning indicates that the two techniques find largely disjoint sets of information [WLZ06]. A major disadvantage of passive scanning is that a significant percentage of its discoveries can take a very long time, e.g., weeks. Hereafter, active scanning will be referred to as simply "scanning", except when it must be differentiated from passive scanning.

There are three major applications of scanning, and each includes tools, techniques and research that are relevant to Net-Chaff. 1) There are numerous stand-alone scanning tools, and they are used by hackers and network administrators [MSK03]. One of the best-known scanners is nmap [Fyo04]. 2) Scanning is also incorporated in programs that are used to find vulnerable systems and break into them. These programs include vulnerability scanners (such as Nessus [Nes06]) and worms [Naz04]. 3) Scanning is a topic of research and development within the field of network management [TB98, VVZ02]. Scanners are incorporated in network management tools, to perform network discovery. Scanning tools and techniques will be described in chapter 4.

A number of studies have been conducted to analyze Internet hacking activity, including the prevalence and content of scans. Monitoring any portion of the Internet address space reveals incessant activity [PYB04]. There are on-going projects that continuously monitor and report Internet hacking activity [DS06, ISC06]. On the Internet, scanning occurs constantly, and in high volume [JPB04, PYB04]. For instance, traffic logs from the Lawrence Berkeley National Laboratory (LBNL) were examined for an arbitrarily-chosen day [JPB04]. It showed that 138 different remote hosts scanned LBNL addresses, with a total of about 8 million connection attempts. A more detailed study found that 13,000 remote scanners had probed LBNL addresses on a particular day.

Other research of Internet scanning activity involves monitoring large numbers of unused IP addresses on the Internet [HA05, PYB04, YBP04]. These monitoring systems have been referred to by several names, including *Internet sinks*, *network telescopes, Internet motion sensors, and black holes.* Hereafter, we will refer to systems that monitor large numbers of IP addresses as *sinks*. The traffic sent to unused addresses has been termed *background radiation* [PYB04]. It is nonproductive traffic that, in general, is either malicious (from flooding, vulnerability scans, and worms) or benign (from misconfigurations). Analysis of Internet background radiation shows that it is not only incessant, but also “complex in structure, highly automated, frequently malicious, potentially adversarial, and mutates at a rapid pace” [PYB04]. Internet background radiation poses significant challenges for intrusion detection.

In contrast, Net-Chaff works within a secure intranet. This intranet has a secure perimeter that provides good, though not perfect, protection from direct Internet access. Net-Chaff is not intended for use on networks that are directly accessible from the Internet, e.g., typical campus networks. Scans on the Internet are incessant (part of the background “noise”), and thus far, there appears to be little that can be done to stop them.

We are not aware of formal published research on the incidence of scans within such secure intranets, although a lot of anecdotal evidence exists, as well as a number of internal reports in a wider range of organizations However, it is reasonable to assume that within this environment, unauthorized scans are relatively infrequent, and worthy of detection, containment and investigation. Sources of scans within protected intranets include attacks from authorized personnel (i.e., insiders), worm-infected laptops, and unintended network paths through the perimeter [Naz04].

Insider attacks can come from employees and contractors, and also from trusted networks (e.g., VPN connections from business partners). The Wall Street Journal reports that “23% of 229 U.S. organizations with more than 1,000 employees had at least one internal security breach in 2004, while another 27% didn't know whether or not their networks had ever been compromised -- from inside or outside” [Yua05]. The Code Red and Nimda worms were able to deeply penetrate protected networks [Naz04].

2.2.2 Scan defenses

In this section, Net-Chaff is compared and contrasted with the prior work on scan defenses. The prior work is analyzed relative to Net-Chaff’s distinctive features. These are the features that, collectively, make Net-Chaff unique. The prior work is presented in the following three subsections. The first subsection compares and contrasts each of Net-Chaff's distinctive features with similar prior-work. Next, whole systems that are similar to Net-Chaff are presented. The third subsection describes scan defenses that work differently than Net-Chaff.

Before analyzing the prior work, a summary of **Net-Chaff's distinctive features** is needed. Net-Chaff is used within a secured intranet. It's primary purpose is to detect and contain scans, and its primary objective is to contain scans before they can access vulnerable computers. The Net-Chaff system detects scans by monitoring traffic to a large number of unused addresses within the intranet. There are two ways that Net-Chaff slows down scans, to prevent them from accessing vulnerable computers before containment: 1) a relatively large number of unused addresses, and 2) the Net-Chaff system's low-level impersonations. Net-Chaff's performance is analyzed using analytical models and a simulation, and both are based on detailed calculations of scanners' probe rates. Most of Net-Chaff's individual features exist in prior work. Net-Chaff combines and applies these features in a novel way.

There is a tremendous amount of prior work on scan defenses. It comes from a number of sources, and they are summarized here. This summary describes broad categories of the prior work. For each of the categories, an example of the prior work is cited. In the sections that follow, specific instances of the prior work are described and cited. For scan defenses, research and development has been carried out in academia (e.g., [JX04]), industry (e.g., [PSN04]) and in the open-source community (e.g., [Ras01]). Scan-defense systems have been developed, including prototypes (e.g., [WOK05]), open-source systems (e.g., [Ras01]), and products (e.g., [PSN04]). Scan defenses include prevention (e.g., [WSM04]), detection (e.g., [Ras01]), containment (e.g. [PSN04]), and also intelligence collection and analysis (e.g., [YBP04]). The three primary areas in which scan-defense work has been performed are: 1) defenses specifically for scans (e.g., [Ras01]), 2) worm defenses (e.g., [WOK05]), and 3) intrusion detection systems (e.g. [BFP03]).

Most worms use active scanning to find new victims [Naz04]. These worms are referred to as *scanning worms*. Hereafter, scanning worms will be referred to as simply *worms*, unless differentiation of worm types is needed. The exponential growth of worms results in huge volumes of network scans. Many worm-defense systems detect worms via their scanning (e.g., [PSN04]). However, worm detection involves more than scan detection, since not all scanners are worms [GSX04]. Some worm-defense systems contain worms (e.g., [PSN04]). There are a number of intrusion detection systems that include scan detection (e.g. [BFP03]). However, in general, intrusion detection systems are concerned with a wide variety of attacks, and not just scans. Hereafter, the term *scan defense* will be used to refer to any type of defense against scans, unless differentiation of the type of defense is needed.

2.2.2.1 Prior work related to Net-Chaff's distinctive features

Each of Net-Chaff's distinctive features are compared and contrasted with the related prior work:

- **Secure-intranet environment**

Net-Chaff is designed for use within a secured intranet. Here, it is assumed that unauthorized scans are infrequent and each warrants investigation. Also, the intranet environment provides the centralized control needed to implement automated containment, and to prevent source-address spoofing. Collectively, these attributes of secured intranets provide significant opportunities for scan defenses. However, there appears to be little in-depth research on these scan-defense opportunities. We are only aware of three systems that focus on the opportunities for scan detection and containment for the secure intranet environment. They are Arbor Network's product Safe Quarantine [PSN04], and two LAN-based products from Mirage Networks [MN06] and ForeScout [For04a, For04b]. These systems are described in the next section.

Scan defense for the Internet is very different from scan defense for secure intranets. This is due to the Internet's much larger size, larger volumes of traffic and scans, and the lack of centralized control. Research on the requirements for Internet worm-containment show the problem is extremely difficult [MSV03]. These requirements are not applicable to scan containment for Net-Chaff, as its environment is so different. Internet scan defenses will be described later.

- **Monitoring unused addresses to detect scans**

Net-Chaff detects scans by monitoring traffic to unused addresses. Typically, many of a scan's probes are to unused addresses. Such probes can be used to detect scans, as the traffic is anomalous relative to benign traffic. There are two ways that network traffic can be monitored, to detect scanners' probes of unused addresses: 1) unused addresses can be assigned to a monitoring system. Packets sent to those addresses are delivered to the monitor via network routing. Net-Chaff uses this technique, as do several other systems which will be described shortly. 2) Alternatively, a system can sniff network links to monitor traffic to unused addresses. To filter-out benign traffic, the system must know which addresses are unused. They can be specified a priori, or the system can deduce which addresses are unused. Unused addresses can be identified by their lack of traffic (e.g., they do not send ARP broadcasts) and also by failed connections (e.g., ICMP host unreachable messages). There are several systems that monitor traffic to unused addresses by sniffing network links, and they are described later.

Network intrusion detection systems (NIDSs) typically monitor network links, and attempt to identify intrusions from amidst the legitimate traffic. There are a number of significant difficulties and challenges with this approach [Naz04, RSM03, Spi02]. Monitoring an entire network can be very difficult, as many links may need to be monitored. The large volume of legitimate traffic makes it difficult to accurately detect intrusions: 1) often, intrusions make-up a very small portion of the traffic. 2) The large volumes of traffic make it difficult to examine events over long time-scales. (Hackers use slow scans to exploit this weakness in NIDSs.) 3) When multiple links are monitored, it is difficult to aggregate this data and obtain a network-wide view of events. (Hackers use distributed scans to exploit this weakness in NIDSs.) Aggregation is difficult due to the huge volumes of data, the need for real-time detection, and also, the asymmetric routing of full-duplex connections (e.g., TCP) [RSM03].

Net-Chaff performs monitoring by assigning a very large number of unused addresses to its monitoring systems (the Net-Chaff WAN and LAN servers). This technique provides significant advantages over monitoring network links: 1) the volume of traffic is much smaller, 2) there is little or no legitimate traffic, and 3) network-wide surveillance is much easier. Research in intrusion detection for high speed network links has found that real-time monitoring becomes difficult, if not impossible, at very high speeds [LPV04]. As an alternative, they recommend monitoring unused addresses because, there, the signal to noise ratio is much higher.

There are other systems, in addition to Net-Chaff, that assign unused addresses to a monitoring system, for the purpose of detecting scans. Spitzner discusses honeypot's use of unused addresses, for intrusion detection and for collecting intelligence on hackers [Spi02]. However, traditional honeypots typically use a small number of unused addresses. Also, traditional honeypots typically require labor-intensive log reviews, which make them unsuitable for a real-time IDS [DQG04]. Recently, researchers have developed a honeypot system, called Honeystat, that uses many unused addresses for worm detection [DQG04].

As described earlier, Internet sinks monitor large numbers of unused Internet addresses [HA05, PYB04, YBP04]. iSink is one such system, and it has the added feature of providing deceptive replies to scanners' probes of the unused addresses [YBP04]. iSink is further described in the next section. There are other intrusion detection systems that monitor a large number of unused addresses, and they include a distributed Internet IDS [YBJ04] and two network worm-detection systems [JX04, WVG04].

As described earlier, traffic to unused addresses can also be monitored by sniffing network links. There are scan and worm detection systems that attempt to learn, or deduce, which addresses are unused [For04a, For04b, MN06, SJB04, PSN04]. honeyd is a honeypot system that can learn unused addresses by monitoring a LAN for unanswered ARP requests [Hon05]. honeyd has been adapted for use in detecting scans [YLM04]. It is further described in the next section. There are other systems that monitor unused addresses, and the addresses are specified by human operators [HC04, TK02].

- **Slowing down scans**

Net-Chaff uses a large number of unused addresses to slow down the rate at which scans probe vulnerable computers. This helps reduce the average number of vulnerable computers a scan can access prior to containment. We are not aware of any other scan-defense systems that use a large number of unused addresses for these purposes, especially for IPv4. However, the idea of thwarting scans via a large address space is not novel; others have observed that the large address space in IPv6 makes scanning very difficult [ZGT05].

To slow down scans, Net-Chaff also uses low-level impersonations at the unused addresses. There are a number of scan-defense systems that use deception at unused addresses. However, most of them use deception to elicit responses from scanners, in order to better identify them [DQG04, JX04, Spi02, YBJ04, YBP04, YLM04]. Some scan-defense systems use deceptive replies to confuse and misinform scans [Bec01, HC04, XDM01]. We know of two deception techniques that are used to slow down scans. One is La Brea, an it is described in a later section [LaB05]. The other deception technique is used by firewalls.

We have observed that firewalls can slow-down scans by dropping disallowed packets. Nmap's source code reveals that it interprets dropped packets as an indicator of congestion [Fyo04]. The dropped packets can induce nmap to reduce its scanning rate, retransmit packets, and delay probe transmission. However, if host-firewalls drop scan packets, then those hosts can potentially be discovered by an "inverse scan" [Ark01]. Normally, routers send ICMP host-unreachable messages in response to packets that are sent to unused IP addresses. An inverse scan works by sending probes and looking for addresses that generate no reply. Routers can defeat inverse scans by not sending ICMP host-unreachable messages. Alternatively, hosts can defeat inverse scans by using a host firewall that sends false ICMP host-unreachable messages [Rus02].

Net-Chaff uses low-level deceptions in order to simply its use of deception. These deceptions work below the application layer, and they also include a *null server*, which accepts data, and provides random replies or no reply. Deception that provides application-layer content can be much more complex, difficult, and costly, e.g., deceptive web-servers. Spitzner classifies honeypot systems according to the degree of user interaction that they support, and the categories range from *high interaction* to *low interaction* [Spi02]. A low interaction system provides simple application-layer impersonations, and typically, the impersonation can be easily detected by a hacker. We are not aware of other research that focuses on the use of low-level deceptions, as a simple means for slowing-down scans.

- **Scan containment**

Net- chaff uses intranet routers to contain scans. Other systems that do this are Arbor Network's "Safe Quarantine" [PSN04] and CyberTrace [JX04]. PSAD is a firewall-based system that detects scans, and contains them by blocking sources [Ras01]. There are also systems that monitor intranet links for scans, and block scans over those links [HCL06, WSP04]. There are two LAN-based products that detect worms, and they contain infected hosts by sending them spoofed packets that disable communications, such as TCP RST and ARP [For04a, For04b, MN06]. Similarly, La Brea replies to scanners with packets that can potentially put them in a long wait-state [LaB05]. Systems have been proposed for worm containment using host-based firewalls [TK02]. An alternative to containment is throttling, which reduces scanning rates by dropping a portion of the packets sent [SJB04, Will02]

- **Performance models**

Another contribution of the Net-Chaff work is its performance analysis, which includes both analytical models and simulations. There are systems that have features similar to Net-Chaff's. Among those systems, some have analytical models or simulations. However, these analytical models and simulations do not appear to be applicable to Net-Chaff [CGK03, GSX04, JX04, WKO05, WVG04, ZGT05]. The reason is that the modeled systems work differently than Net-Chaff, or have different objectives.

There has been a substantial amount of research on modeling the growth of worms, and the research includes analytical models and simulations [Naz04]. These models show that worm growth is exponential and difficult to contain. They also show the need for stopping scanning-worms before they can access a single vulnerable computer, which is Net-Chaff's objective.

2.2.2.2 Scan-defense systems similar to Net-Chaff

The prior section examined the prior work relative to Net-Chaff's individual features. This section describes scan-defense systems that, as a whole, are most similar to Net-Chaff.

There are two systems for worm detection and containment that are intended for use on enterprise networks. Arbor Network's product Safe Quarantine detects worms by monitoring network links for signs of worm scanning and propagation [PSN04].[4] It automatically contains worms by blocking them at intranet routers. An important contribution of this product is its emphasis on not inadvertently blocking critical operations. To avoid this, it learns normal network traffic, to know what traffic should not be blocked. Net-Chaff differs from Safe Quarantine in that Safe Quarantine does not use unused addresses to slow down scans, nor does it use deception to slow-down scans.

Another enterprise network solution for worm detection and containment is CyberTrace, and it is an academic research project [JX04]. It uses unused addresses to detect worms. It automatically contains worms by blocking them at intranet routers. An important contribution of this system is its use of intranet routers to create an Internet sink, using unused Internet address-spaces. When worms within the enterprise network scan the Internet, they are likely to probe these address spaces. CyberTrace differs from Net-Chaff in that it assumes a network that is largely open to the Internet, such as a campus network. Also, CyberTrace focuses exclusively on worms, and not scanning in general. It does not use unused addresses to slow down scans, nor does it use deception to slow-down scans.

Researchers at the University of Wisconsin have developed an Internet sink, called iSink, and it also provides deceptive replies [YBP04]. The system is intended for studying Internet background radiation, so its purpose and functionality are very different from Net-Chaff's. However, it makes two significant contributions that can be applied to Net-Chaff's implementation and deployment. The iSink system includes requirements analysis and system designs for providing deceptive replies to large volumes of scan probes. iSink's techniques for generating its rudimentary deceptions could be used by Net-Chaff in generating its low level impersonations. iSink was deployed on several lightly populated class B networks. Its routing techniques, for unused addresses, could also be used for Net-Chaff deployments.

[4] Currently, Arbor Networks does not sell this product. It appears the product may have been sold to ISS and

La Brea is a system that attempts to suspend scanners, including scanning worms [LaB05]. It does this by providing deceptive replies to probes sent to unused addresses on a LAN. It detects these probes by monitoring the LAN for unanswered ARP requests. La Brea attempts to suspend a scanner by sending it a TCP packet that is crafted to put the scanner in a long wait state. It appears that La Brea could be easily countered by scanners that detect this unusual TCP packet, or by scanners that work asynchronously [MSV03]. Researchers have investigated La Brea's potential use for thwarting Internet worms [CGK03]. Net-Chaff and La Brea are clearly differ in the environments in which they are used, the ways they monitor unused addresses, and the ways they use deception.

honeyd is another system that provides deceptive replies to connections sent to unused addresses [Hon05, Pro04]. honeyd can detect traffic sent to unused addresses by monitoring a LAN for unanswered ARP requests. Alternatively, unused addresses can be assigned to honeyd. honeyd simulates honeypots at the unused IP addresses, and it has the potential for a diverse set of interactive responses. One proposed use of honeyd is to thwart scanning by 1) providing deceptive replies that confuse and deter scanners, and 2) coupling honeyd with an IDS for scan detection [Pro04]. However, no further details are provided about this system. Another proposed use of honeyd is to counter-attack scanning worms on the Internet, and thereby stop them from spreading [Pro04]. Math models are developed for the proposed system. They show that stopping an Internet worm would require hundreds of thousands of honeypots. A significant problem with this system is that it requires knowledge of a vulnerability that can be exploited to counter-attack the worm. An exploit for the vulnerability is also required. This would be especially difficult for new worms.

Researchers have extended the honeyd system for use in scan detection [YLM04]. Their system is called HPDS. It works at the LAN level and impersonates computers at five fixed addresses. Researchers working on the iSink system found that honeyd, "has significant scalability constraints that make it inappropriate for monitoring large IP address ranges" [YBP04]. Net-Chaff differs from honeyd and HPDS in the scale of unused addresses that it

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incorporated within its product *Proventia Network ADS*.

works with. A bigger difference with these honeyd-based systems is that they do not provide containment of scans, in general, on an intranet.

There are two noteworthy LAN-based products that detect and contain worms. One is from Mirage Networks [MN06] and the other from ForeScout [For04a, For04b]. These systems sniff traffic on a LAN, and detect worms based on their traffic patterns, e.g., packets sent to unused addresses. They implement containment by sending specially crafted packets to infected hosts, such as TCP RST and spoofed ARP packets. An important contribution from these systems is that they are designed to be installed on a LAN, with little or no modification to the LAN. In contrast, Net-Chaff deployments can potentially require significant changes to a network, e.g., converting to the 10.0.0.0 address space. We were unable to find enough information on these products to adequately assess how they work, and what their limitations are. A major difference between these products and Net-Chaff, is that they only protect a LAN.

Researchers have experimented with systems that detect scans on a network link, and send deceptive replies in response. CTCP is a system that works on an edge router that proxies connections to the Internet [HC04]. Incoming connections to nonexistent or blocked ports are redirected to a system that provides deceptive replies. The intention is to render port scans useless by making it appear that all ports are open. There is a similar system, called IEDP, that runs on a firewall [XDM01]. A major difference between these systems, and Net-Chaff, is that they only work on network choke points that control network access.

2.2.2.3 Scan defenses different than Net-Chaff

There has been much research and development for scan-defenses, and the majority of it is fundamentally different than Net-Chaff. This section describes the prior work on scan-defenses that is dissimilar to Net-Chaff.

2.2.2.3.1 Monitoring operational network traffic

In the scan-detection work with which we are familiar, the majority of it involves monitoring operational traffic. *Operational traffic* is the network traffic carried by normal network links, and it includes legitimate and benign traffic, as well as scans and attacks. Net-Chaff is distinguished from the scan-detection work for operational traffic, as that work must deal with the problem of identifying scan traffic that is mixed in with legitimate traffic. This section provides an overview of the scan-detection work that involves monitoring operational traffic. This overview shows the types of problems and solutions that have been addressed.

Scan detection has been investigated for different volumes and types of operational traffic. Research related to high-bandwidth environments includes scan detection on backbone routers [RSM03, SBB04, SYB06] and on high-speed networks (i.e., 10s of Gbps) [GZC06]. Scan detection research has also focused on networks [HCL06, SHM02, WKO05] and smaller local networks (e.g., LANs) [JPB04, SJB04, WSP04]. For network scan detection, the use of mobile agents has been investigated [FA04]. Researchers have also focused on scan detection within Internet traffic [QH04, ZGT05].

A large assortment of scan detection techniques have been researched for operational traffic. Much of the scan-detection research introduces novel detection techniques that attempt to solve the problem of finding scans within large volumes of legitimate data. An overview of that research follows.

Commercial and open-source intrusion detection systems (IDSs) typically detect scans by using a threshold-based detection mechanism [JPB04, RSM03, SHM02]. This detection mechanism works by looking for X probes in a rolling window of Y seconds. Examples of such systems will be given in section 2.2.2.3.2 (page 24). Net-Chaff uses a simple threshold-based detection mechanism, and its use of other detection techniques is left as a topic for future research.

Another commonly-used means for scan detection is scans' large number of failed connections. There are systems that detect scans by monitoring traffic for failed connections [JPB04, RSM03, WSP04]. There are also systems that detect scanning worms in this manner [CR05, SJB04, TK02]. There is a similar technique for detecting worm growth, and it works by monitoring network traffic for changes in volume, much of which is due to worm scanning [ZGT05].

Researchers have investigated probabilistic techniques for scan detection. These techniques have been used to rapidly detect scans [JPB04], to detect slow scans [SHM02], and to achieve accurate detection in real-time [LK02]. Researchers have also investigated scan detection techniques based on statistical analysis of network traffic [TRB06], and on the use of fuzzy systems [DJK01].

There are other forms of anomalous traffic that are generated by scans, and that can potentially be used to identify scans within operational traffic. Researchers have investigated techniques for detecting scans based on anomalous sequences of connections [QH04], asymmetries in traffic [HCL06], and anomalous numbers of half-open connections from a source [SBB04]. Another technique detects scans by identifying connections for which no host-name look-up was made via DNS [WKO05].

There are scanning techniques that use unusual or malformed packets for the purpose of evading detection or for fingerprinting a host's operating system [Ark01, Fyo97]. These scan packets provide a signature that can be used to detect scans, and two systems that uses this technique are Snort [BFP03] and psad [Ras01].

2.2.2.3.2 Scan detection systems

This section describes some of the most well-known scan detection systems that work by monitoring operational traffic. Research in intrusion detection includes four systems whose scan detection capabilities are often cited. The Network Security Monitor (NSM) was the first NIDS, and it was also the first NIDS to detect scanning [SHM02]. It uses a threshold-based detection mechanism. Another system is Bro. It uses a threshold-based detection mechanism, and it also monitors failed connections [JPB04]. The Graph Based Intrusion Detection System (GrIDS) detects scans by building graphs of activity where the nodes represent hosts, and the edges represent traffic between hosts [SHM02]. The EMERALD system constructs statistical profiles for subjects, and compares their short and long-term behavior. One way it detects scans is a sudden increase in the volume of SYN packets, for example, from a particular source IP-address [SHM02].

Levchenko, et al., list IDS products that detect scans, and the vendors include

Checkpoint, Cisco, ForeScout, Juniper, NetScreen, and Network Associates [LPV04]. They indicate that these products monitor operational traffic. In addition, there are a number of open-source tools that perform scan detection. Two of the most prominent are Snort [BFP03] and psad [Ras01]. Both use threshold-based detection mechanisms, and they can also detect several known scan-packet signatures. Snort is a commonly used NIDS and the de facto standard in small stub networks [SYB06]. Scan detection is just one of its intrusion detection functions. psad focuses primarily on scan detection, and it works with Linux's iptables rule-sets, e.g., as part of a Linux firewall [Ras01].

McClure, et al., make the observation that most IDSs are configured by default to detect only very noisy or clumsy port scans [MSK03]. They state that an IDS must be "highly sensitized" and "fine-tuned", or stealthy scans will "go completely unnoticed".

2.2.2.3.3 Other scan defenses

Net-Chaff's scan-defenses primarily involve detection and containment. There are several other types of scan defenses that have been researched and/or used in practice. Research has been performed on visualizing scans, and the purpose of visualization includes rapid comparison and identification of large numbers of network scans [MMB05]. There are a number of techniques used to prevent scanning [XDM01]. Firewalls and systems that perform network-address-translation (NAT) are well known techniques for blocking scanners. Another well known technique is to configure servers so they listen on unconventional ports. Routers can be configured to limit or drop certain ICMP messages that scanners elicit to learn about the network [Ark01, XDM01]. Beck describes techniques to evade scanners' attempts to fingerprint host operating systems [Bec01]. *Protocol scrubbing* involves filtering and modifying traffic to ensure there are no malformed or unusual packets [WSM04]. Such packets can be used by scanners to elicit information or evade intrusion detection systems.

2.2.3 Summary of scanning and scan defenses

There is a large volume of work on scanning and scan defenses. The work on scanning reveals how hackers work, and what Net-Chaff must defend against. Net-Chaff is concerned with scanning within a protected intranet. The incidence of scanning on the Internet is a topic of much past and current research. However, we are not aware of any in-depth research on the incidence of scanning within a protected intranet.

Most of the prior work on scan defense is concerned with operational traffic. Net-Chaff is differentiated from this work by its technique of monitoring traffic to large numbers of unused addresses. Most of Net-Chaff's distinctive features are found in prior work. However, Net-Chaff combines and applies these features in a novel way. Of the systems that are most similar to Net-Chaff, they all work differently and/or have different objectives. In addition, there does not appear to be any in-depth prior work on two of Net-Chaff's distinctive features. They are Net-Chaff's techniques for slowing down scans prior to containing them, by using large numbers of unused addresses and by using deceptive replies. This dissertation includes analytical models and a simulation for evaluating Net-Chaff's performance. There does not appear to be prior work on scan-defense that includes similar analytical models or simulations.

2.3 Deception use in honeypots and other tools

Although appealing, deception appears to be used only sparingly for computer security. The primary use of deception is with honeypots, and that work is summarized here. A survey was made of deception use in other computer security tools, and that work is also summarized. The use of deception for scan-defense systems was described in the prior section. The dissertation's Honeyfile system is a deception-based computer security tool, and it does not appear to exist in the prior work.

An extensive survey of computer-security tools that use deception was conducted in 2003. The primary sources were two popular web-sites that disseminate security tools: SecurityFocus [5] and Packet Storm [6]. For each site, its tools database was searched using deception-related terms such as *trick*, *spoof*, and *hide*. The search showed that aside from

[5] http://www.securityfocus.com

[6] http://www.packetstormsecurity.org

honeypots, deception did not appear to be widely used for computer security. Over 75 tools were found. Many of them are public-source prototypes that do not appear to be widely used nor known. However, some of the tools were very useful as examples in the dissertation's deception models. The tools provide concrete illustrations for the abstract models.

Honeypots are computer systems that are designed to be probed, attacked or compromised by hackers [Spi02]. Typically, a honeypot contains servers and content that are attractive to hackers. Also, the honeypot is typically placed on a network where hackers will likely encounter it. Currently, the primary uses of honeypots are collecting intelligence about hackers and detecting attacks. A honeynet is a network of honeypots. In the honeypot literature, the primary topics include: design and construction [CDF04, Spi02], specific honeypot devices [Cha04b, Hon05, LaB05], monitoring hackers [Bal04, HP04], deployment [Góm04, Hoe04], incident investigations [JLG04, OL04, RBB04], legalities [Cha04a, MW03, Row05a], hacker intelligence [Chu03, Fis04, HP04], hacker countermeasures to honeypots [Cor04, DHK04, Kra04]. To date, there has been very little discussion of deceptive data on honeypots. It appears that honeypots are typically deployed with stock operating systems and servers, but with no user or application data. Aside from this dissertation, there has been little discussion of general deception processes and principles for honeypot operations.

2.4 Summary

This chapter provided a summary of the literature surveys and the surveys of prior work that were conducted for this research. The initial finding is that there has been very little work done on deception processes for computer security. The extensive military and intelligence deception-literature was described. It provides a very useful starting point for developing the two novel process-models. The use of deception in computer-security tools, including honeypots, was also discussed. The Honeyfiles system is a novel contribution of this dissertation, and it is discussed further in subsequent chapters. There has been a tremendous amount of research and development in scanning and scan defenses. An extensive review of that work was given, especially as it relates to Net-Chaff. Most of Net-Chaff's distinctive features are found in prior work. However, Net-Chaff combines and applies these features in a novel way. This dissertation includes analytical models and a simulation for evaluating Net-Chaff's performance. There does not appear to be prior work on scan-defense that includes similar analytical models or simulations.

3 Deception framework

This chapter introduces the deception framework, which is comprised of the deception-operation process model and the hiding model.

3.1 Deception operation process

This section explains how deception can be used to advantage in computer security, including incident response, intelligence, detection, and prevention. It describes the process followed in deception operations, and it describes principles and techniques for developing and conducting deception operations. This work focuses on deception principles that are of enduring use, and independent of current technologies. For instance, honeypots are currently one of the most widely used deceptions. Honeypots are employed in the discussion to illustrate principles, but honeypots are not the primary focus.

Deception is an integral part of human nature and experience. However, few people use deception in the calculated manner needed for computer security. As the military deception-literature reveals, effectively deceiving an adversary is a job skill [JDD96, Mur80, USA88]. The principles of military deception are well documented in the military deception-literature, and they are based on millennia of experience and thought. Herein, we adapt principles of military deception to computer security deception.

3.1.1 An overview of deception operations

In this section, basic deception concepts and terminology are presented, followed by a description of the deception-operation process.

3.1.1.1 Basic concepts and terminology

Computer security deception is defined as being those actions taken to deliberately mislead attackers (i.e., hackers) and to thereby cause them to take (or not take) specific actions that aid computer security.[7] Deception aims to mislead the hacker into a predictable

[7] This definition is adapted from the U.S. DoD definition of military deception [JDD96].

course of action or inaction that can be exploited [Dew89]. Tricking the hacker, and making him think a certain way, is important only as a step toward getting him to make the decision that will result in the desired action [JDD96]. Thoughts without action are of little computer security value.

The scope of this section is deception for computer security defense. It focuses on the tactical use of deception for a computer network, including its assets. The key deception terms (deception planner, deception operation, target, intelligence, and ruse) are defined in Chapter 1 and in the glossary. An additional term employed in this section is CND (computer network defense).

3.1.1.2 The deception-operation process

The deception-operation process involves complex adversarial relationships and complex engineering systems. Although the overall process can be complex, there is a basic deception-process that is followed in almost all operations. This basic deception-process is shown in Figure 3.1.1.2-1, and it is described below.[8] In this section, references to process steps in the figure are **bolded**. Similarly, references to sub-steps are *italicized*. Due to the complexity of deception operations, this basic process is a simplified conceptual model, and it focuses on the components found in successful deception operations. The model is not meant to provide a complete description of all deception operations' elements and interactions.

[8] This basic deception-process was adapted from a draft written by our colleague Dr. Bowyer Bell.

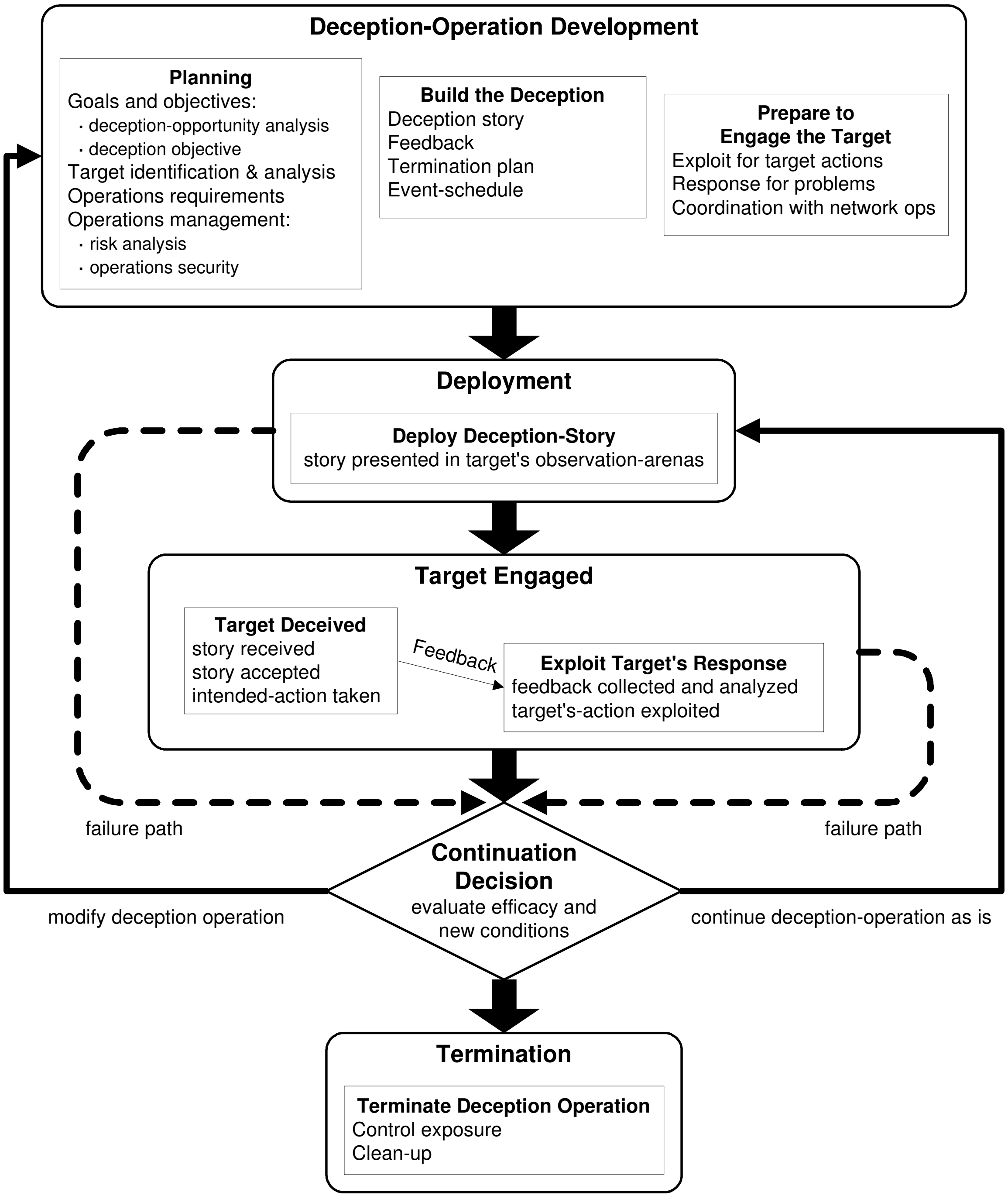

Deception-Operation Development
Planning
Goals and objectives:
· deception-opportunity analysis
· deception objective
Target identification & analysis
Operations requirements
Operations management:
· risk analysis
· operations security
Build the Deception
Deception story
Feedback
Termination plan
Event-schedule
Prepare to Engage the Target
Exploit for target actions
Response for problems
Coordination with network ops
Deployment
Deploy Deception-Story
story presented in target's observation-arenas
Target Engaged
Target Deceived
story received
story accepted
intended-action taken
Feedback
Exploit Target's Response
feedback collected and analyzed
target's-action exploited
failure path
failure path
Continuation Decision
evaluate efficacy and new conditions
modify deception operation
continue deception-operation as is
Termination
Terminate Deception Operation
Control exposure
Clean-up

Figure 3.1.1.2-1 : The basic deception process

- **Deception-Operation Development**

The deception operation begins with step 1: **Deception-Operation Development** (top-most box in figure). The deception operation's plan, deception, and means for engaging the target are developed, roughly in that order. *Planning* is an iterative process that is conducted throughout the deception operation. Its first step is recognition of the need or opportunity to deceive a target. What must be done in deception planning, and often is not, is to determine the result desired from the deception. Mere acceptance of the deception may not be advantageous, and it may in fact prove costly. For example, a clever honeypot could attract an unwanted horde of script kiddies, and hiding a host's log files may make the hacker uncertain of the evidence he's left, prompting him to erase the entire file system, just to be safe (e.g., "rm –rf /"). Thus deception is a means, not an end. The objective of a deception operation is: 1) to induce the target to take some specific action—perhaps to do nothing, and 2) to exploit that action, or otherwise use it to advantage.

Deception operations are ultimately against individual hackers, so planning includes identification of the deception targets, and analysis of their vulnerabilities to deception. Planning also involves risk analysis and operations security to ensure the deception is not revealed to the target.

To induce the target to take the intended action, a deception story is designed (step 1, sub-step 2 in figure), and it is implemented using various ruses. The deception story is presented to the target in his observation arenas. Typically, the most effective observation arenas are the target's intelligence sources. One of the primary ruses used in computer security are honeypots, and they have proven useful for detecting attacks and for collecting intelligence about hackers [Spi02]. A honeypot can contain servers and content that are attractive to hackers, and it can be placed where hackers' network scans (a hacker intelligence source) are likely to encounter it.

- **Deployment**

The deception operation is **deployed** (step 2, second rounded box in figure) by presenting the deception story to the target in his observation arenas. This is a key transition in the deception process, as the deception operation is now out of the planner's control until the return of feedback that suggests an appropriate response. The deception story is maintained until it is received by the target. This can occur almost immediately, as with honeypots on a network's so-called demilitarized zone (DMZ). Alternatively, the deception story might be maintained for months or years before being received, as might occur with an intranet honeypot used for detecting insider hacking.

- **Target Engaged**

The **target is engaged** (step 3, third rounded box in figure) once he receives the deception story. The target is successfully *deceived* when he receives the deception story, accepts it, and, as a consequence, takes the intended action.

Feedback channels provide information about the target's reception of the deception story and his response to it. The ultimate goal of deception operations is *exploiting the target's response*.[9] This occurs after the feedback is collected and analyzed, and it is known that the target has taken the intended action. For honeypots, feedback channels are an essential feature. For example, Symantec's ManTrap honeypot can record much of a hacker's activity, including network traffic, process activity, and keystrokes [Spi02]. ManTrap can also detect hacker activity and send alerts.

The deception story exerts control on the target, manipulating him at a distance. Such manipulation may be intended to have a very short existence. For instance, BackOfficer Friendly (BOF) is a honeypot that can impersonate unauthorized remote-access servers, like BO2K [Spi02]. Servers such as BO2K are installed by hackers via Trojan horses. BOF's impersonation is superficial and its ruse can quickly be discovered by the hacker, but not before he is detected. Other deceptions may be intended to last indefinitely. For example, a fake VPN interface can be used to draw attention away from a network's real VPN interface. The deception is intended to last indefinitely.

[9] Thanks to Fred Feer for showing us how the exploit is the deception operation's ultimate goal. In the military deception literature that we have read, the exploit's central role is under-emphasized.

- **Continuation Decision and Termination**

A **continuation decision** (step 4, diamond in figure) is made for the deception operation, based on its efficacy and the current situation. The process can be terminated, continued as-is, or modified, in which case the process returns to deception-operation development. **Termination** (step 5, last box in figure), occurs when the deception story has achieved its purpose and is no longer needed, or when the target discovers the ruse. The target often discovers the ruse when his response to it is exploited. For example, hardware keystroke-loggers are dongles that attach to the keyboard cable. Their effectiveness depends on stealth: they are located behind the computer, appear to be a normal part of the cable, and few people know about them. When a hacker is confronted with evidence from a keystroke logger, the ruse will probably become apparent. Thus, it can no longer be used against him or his accomplices. Terminating the deception involves controlling exposure of the ruse, so it might be used again, as well as cleaning-up its affects upon computer systems and personnel.

- **Complexities in the deception process**

Real-world deception operations tend to be more complex than the basic deception-process shown in Figure 3.1.1.2-1. Two of the major sources of complexity are: 1) multiple deception stories and 2) operational failures. Such complexity can be understood in terms of the basic deception-process.

Deception operations may involve multiple deception stories, and there can be multiple actions intended for the target to take. The stories and actions may be inter-related, requiring them to be conducted in parallel or serially. Furthermore, there can be multiple targets. For such deception operations, the basic process portrayed in Figure 3.1.1.2-1 is used, but its components may occur more than once: multiple deception stories are developed; there are multiple deployments; and there are multiple target-engagements.

There are a plethora of problems that can cause a deception operation to fail. For example, the deception will fail if: the deception story isn't received; the target discovers the ruse; the story is not interpreted as intended; or the intended action isn't taken. Such problems can be modeled as departures from a successful deception operation. Two types of failure are shown by the dashed lines in Figure 3.1.1.2-1. If the target does not receive the deception operation, then the leftmost failure path is taken. If the target receives the deception, but he is not deceived, or the exploit fails, then the rightmost failure path is taken.

The remainder of this section focuses on deception-operation planning and on building the deception story.

3.1.2 Deception planning

"A prince or general can best demonstrate his genius by managing a campaign exactly to suit his objectives and his resources, doing neither too much nor too little." [Cla32]

— Carl von Clausewitz

Deception-operation planning provides direction for the operation by developing its goals, objectives and requirements.[10] In conjunction, the targets are analyzed to learn their vulnerabilities to deception.

3.1.2.1 Deception opportunity analysis

Deception opportunity analysis identifies ways deception can be used to support computer network defense (CND). For the deception operation to be effective, it should be fully integrated with the overall CND effort. The deception operation must be compatible with, and coordinated with, the network's security and production operations. Deception is not an end in itself, and it should not be used simply because there are clever ways to trick hackers.

3.1.2.2 The deception objective

"...it became a creed [among deception planners] to ask a General, 'What do you want the enemy to do,' and never, 'What do you want him to think?'" [Mur80]

— Dudley Clark, WWII deception planner

The deception objective is the desired result of the deception operation; it consists of:

1) the intended *target action*, and

---

[10] This planning process is adapted from the U.S. Joint Forces' deception process [JDD96].

2) the *deception exploit.*[11]

The target-action is a statement of what the hacker is to do (or not do) at some time and location. It is always stated in terms of specific actions, such as, “cause the targets' attacks against our server to be performed, instead, against the honeypot server”. A statement such as “have the hacker think that the honeypot server is the real server” is not a target-action, rather, it is a desired perception (described in section 3.1.3). Having the hacker think a certain way is important only as a step toward getting him to make the decision that will result in the intended action. Thoughts without action are of little security value.

The deception exploit is a statement of how the target-action will benefit CND, e.g., through attack detection, prevention, or response. The deception exploit may include actions to be taken against the target, following the target-action. For instance, the prior example's deception exploit would be, “for successful attacks against the honeypot, the honeypot will record the attack and send an alert.” Some deception exploits do not require taking action against the target, e.g., when using a ruse to confound operating system (OS) fingerprinting, the deception exploit is thwarting attacks that depend on accurate OS fingerprinting.

The deception operation's ultimate goal is successful completion of the deception exploit. The deception-story and ruses are just means for inducing the target-action. After the story is deployed, feedback is analyzed to determine when the target-action is taken. The deception exploit can go into effect after the action is taken.

3.1.2.3 Target identification and analysis

“It was so important to the deception work to be able to put oneself completely in the mind of the enemy, to think as they would think on their information, and decide what they would do.” [Mon78]

— WWII deception planner

Deception attacks the target's perception and his thinking process, so effective deception requires intelligence on who the target is, how he works, and how he thinks.

[11] The *deception objective* is adapted from the U.S. Joint Forces deception manual [JDD96]. However, its *deception objective* only consists of the *target action*. We include the *deception exploit* with the deception-objective, as it is the deception-operation's ultimate objective.

Computer-security systems face a wide variety of threats. Howard classifies hackers primarily by their intentions: professional criminals, corporate raiders, hackers, vandals, terrorists, and spies [How98]. Hackers also vary widely in their capabilities and physical locations. It is possible to create deceptions that are effective against a wide variety of hackers. For example, Cohen, et al., have conducted experiments in which a particular deception worked against both undergraduate neophyte-hackers and seasoned penetration-testers [CMS01].[12] However, for deception operations, if a specific type of target can be identified, then its unique vulnerabilities to deception can be exploited. For example, script-kiddies' have a youthful naiveté that is vulnerable to deception.

An understanding of how hackers work reveals their vulnerabilities to deception and how those vulnerabilities can be exploited. Fortunately, much is understood about how hackers work, as the complexity of hacking compels hackers to use publicly available tools and information. There are many books on hacking techniques [MP01, MSK03], and the Honeynet Project has reported the findings from their extensive surveillance of hackers [HP04].

Outsider hackers (non-insiders) are almost always naive about the networks they hack. A hacker's experience and skills are often asymmetric with the experience and skills needed for the network he is hacking. For example, hackers typically have never legitimately worked on a network, or in an organization, like the ones they are hacking. Even if a hacker has a high degree of technical skill, he may be naive about the network's topology and operations, as well as the network personnel's language and culture.

An understanding of how hackers think also reveals vulnerabilities to deception and how those vulnerabilities can be exploited. The key elements of the hacker's thinking are his: 1) intentions, 2) perceptions, 3) decision-making process, and 4) his psychological vulnerabilities to deception. The hacker's particular psychological vulnerabilities to deception can also be used to advantage. For example, the hacker Matt Singer was reportedly

[12] The experiments tested the efficacy of a device that apparently creates many imposter computers on a network. However, the paper does not appear to describe the device in detail.

obsessive, compulsive and undisciplined in his hacking [FM97]. Such shortcomings significantly limit a hacker's ability to carefully and critically examine ruses. A number of books provide insights into how hackers think: chronicles of prolific hackers [FM97, Sto89], the aforementioned findings from the Honeynet Project's surveillance [HP04], and a sociologist's study of hacker culture [Tho02].

3.1.2.4 The target's intelligence sources

"Provided the enemy has an efficient intelligence service, provided he is capable of reacting to what he sees, or thinks he sees, he can apparently be taken in again and again." [Bar52]

— WWII deception planner

"I wanted to watch the cracker's keystrokes. . . The best solution was to lure him to a sacrificial machine and tap the connection. . . [We] did construct such a machine, ***[but] never managed to lure anyone interesting to it****."* [Che92] [13]

— Bill Cheswick

When implementing the deception story, the planner's goal is that the story be received by the deception target (i.e., hacker), believed, and interpreted as intended. Such manipulation of an adversary can be very difficult and problematic. Fortunately, the target provides an opportunity the planner can exploit to achieve his goal: in the course of hacking, the target eagerly seeks particular information, and this presents an opportunity for using the target's intelligence sources to communicate the deception story. Simply put, an *intelligence source* is something that is used by the target to learn about the network. The U.S. DoD defines an intelligence source as *"the means or system that can be used to observe and record information relating to the condition, situation, or activities of a targeted location, organization, or individual. An intelligence source can be people, documents, equipment, or technical sensors"* [JDD01].

Hackers' intelligence sources take a variety of forms, and two of the primary sources are network-scanners and network sniffers. A web-site can be either an intelligence source, or the object of an attack, depending upon how the target uses it. Some of the most useful

[13] emphasis added

intelligence sources are network-administration tools such as traceroute and ping. Also, any network client can be used as an intelligence source, e.g., telnet, FTP, and web clients. In social engineering, insiders are used as unwitting intelligence sources. A description of hackers' intelligence sources can be found in books on hacking techniques. For example, McClure, et al. list four types of hacker intelligence-sources: 1) *footprinting*, which is the use of publicly available information to learn about an organization and its network, 2) scanning to learn about the network topology and its devices, 3) *enumeration*, which is scanning for particular computer-security vulnerabilities, and 4) *pilfering*, which involves searching systems for passwords and exploitable trust relationships [MSK03].

Designing the deception story requires an understanding of the target's intelligence sources and observation arenas. The implemented parts of the deception story must be observable by the target's intelligence sources, e.g., a port scan. Otherwise, the target cannot receive the story. Also, there are several types of vulnerabilities in the target's intelligence process that are helpful to know and exploit: 1) the single sources of information that he may rely upon, as deception is easier when the ruse will not be cross-validated (e.g., remote hackers often just rely upon network data), 2) the information he uses that is superficial and easily misrepresented, as with a ping scan, 3) the investigations he performs when he is naive and thus easily duped, as during his initial network reconnaissance, and 4) the intelligence processing of the hackers' automated agents, such as worms' network scans, since their simplicity and determinism may be easily duped.

3.1.3 The deception story

To induce the target to take the intended action, a deception story is designed, and it is implemented using various ruses. The deception operation's objective is to induce a specific target-action that benefits CND. The *desired perception* is what the target must believe in order for it to take the intended action [JDD96]. The *deception story* is an outline of how the computer system will be portrayed so as to cause the target to adopt the desired perception, and take the intended action. This section presents principles and techniques for developing the deception story.

Often, determining the desired perception can be difficult, as it requires an understanding of how the target works and thinks. Generally, it is much easier to reinforce an existing belief than to establish a new one [Heu81]. For example, if a deception story involves the portrayal of a high-volume web site, then computer-savvy hackers that break into the site will reasonably expect to see multiple web servers, load balancing, and a multi-tiered architecture. A technique for ensuring the target action is taken is to make the target believe the target-action is in his best interest. Ideally, the target will perceive the intended action as compelling, and alternative actions as untenable.

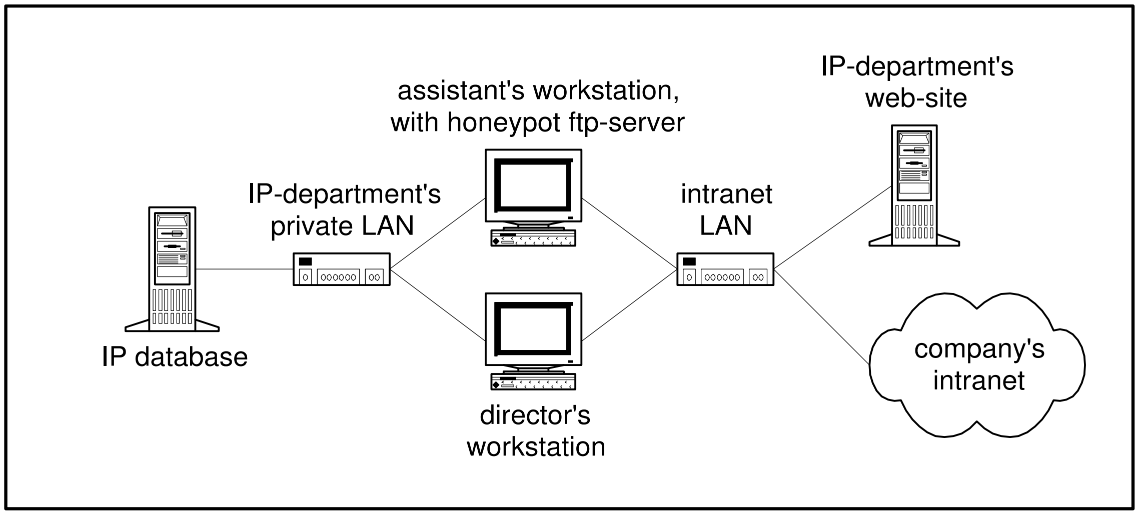


Figure 3.1.3-1 : The intellectual-property (IP) deception operation

The principles presented in this section are illustrated by an example deception operation, and it is descriptively named the *intellectual-property (IP) deception operation.* The purpose of the operation is to protect a company's intellectual-property database. The IP database is a collection of trade secrets, recorded in various formats such as MS Word and AutoCAD. The database is maintained by the company's IP department, and the department's director and his assistant have exclusive access to it. The IP department's intranet web-site describes the department, and the procedure for employees to submit trade secrets. Submissions are made by copying files to a shared folder on the assistant's workstation, and the assistant stores the files on the IP database. The database is kept on a single computer, and the computer is on a private LAN that can only be accessed by the director and his assistant. This example is illustrated in Figure 3.1.3-1.

The target of the IP deception operation is a hacker who attempts to gain unauthorized access to the IP database. The intended target-action is one that reveals the target's presence and intent, but does not compromise computer security. The deception exploit is attack detection and the recording of forensic evidence. The desired perception is an exploitable vulnerability that provides access to the IP database. The deception story is a vulnerable FTP server on the assistant's workstation. The FTP server will appear to be a particular make and version that has a buffer-overflow vulnerability.

3.1.3.1 Essential design-criteria

For a deception story, its essential design-criteria [DH82b, JDD96, USA78] are that it be:

Plausible: the story must be plausible from the target's perspective. Consequently, it should appear *appropriate* from both an engineering and operations perspective. Also, it must appear to be something the defender is *capable* of doing. The story should be *consistent* with real systems and operations, as well as being internally consistent.

Receivable: The story must be something the target's intelligence is capable of receiving and interpreting as intended.

Verifiable: If the target will verify the story through multiple intelligence sources, then the story should be portrayed through more than one source. For example, to avoid honeypot web sites, a target can verify web sites he discovers by searching for links to them from real web-sites.

Efficacious: For the story to be efficacious**,** it must be received, and it must effectively induce the desired perception and target-action.

Implementable: The story must be something the deception planner is capable of implementing.

The IP deception-operation example illustrates the above design-criteria: the deception operation's story is *plausible* to insiders because the IP assistant is *capable* of installing an insecure FTP server. File transfers are *consistent* with the assistant's job responsibilities, as described on the IP web-site. Also, the FTP server's vulnerability is *consistent* with other security problems on the intranet. The vulnerable FTP server is visible to a port scan, which is the target's expected means of *receiving* intelligence. The IP web-site's description of the assistant's file-transfer responsibilities helps to *verify* the story. The story is potentially *efficacious* as the FTP server's vulnerability is the target's only known means for accessing the IP database. The story can be *implemented* using a COTS (commercial off-the-shelf software) honeypot, such as Specter [Spi02].

3.1.3.2 Design principles

For a deception story, some of the key design principles are:

Inducing the target-action. The target-action is easier to induce if it something the target is predisposed to doing, such as: 1) something he is already planning to do, 2) something he normally does, or 3) something he wants to do. In the IP deception operation, the target is hackers who are seeking to steal intellectual property. It is expected that the target will first locate and study the IP department's web-site. From it he will learn that the director and his assistant maintain a repository of intellectual property, and that their computers are promising pathways to the repository. It is anticipated that the hacker will scan these computers for vulnerabilities, and then attempt to exploit a vulnerability that provides easy and stealthy root access. Both of the computers are kept very secure by their users and by the IT department. The honeypot FTP server is expected to be the only vulnerability that the target encounters, making it compelling to attack.

Making the story believable. In general, it is easiest to persuade the target to believe something he already expects. Also, it can be easy to deceptively portray things that are normally hidden from the target. Often, the target only expects to find limited information about something that is hidden, in which case that is all that needs to be portrayed. In the IP deception operation, the IP database is one of the company's major assets. Hackers will expect the database to be highly secure and difficult to access. The deception story would not be very believable if it portrayed a fake IP database that could be accessed and compromised in a trivial way, e.g., via a misconfigured readable file-share.

Preventing the target from uncovering the deceptions. The deception story's falsehood should be kept to a minimum. The truth is much stronger than a lie, and it can be difficult to maintain a lie over time. Also, minimizing falsehood makes the deception story easier to implement. Some techniques for minimizing falsehood are: 1) make the story simple, 2) weave the story into the truth, 3) provide no more detail than is necessary, and 4) impersonate things that are normally concealed from the target, as he will only expect to see bits and pieces of information about them, and only those pieces of information need to be portrayed. The IP deception operation illustrates these points: its deception story is a small extension to real systems and operations (items 1 and 2, above). The story is implicitly verified by information on the real IP web-site, and by the real workstation that runs the FTP honeypot (item 2, above). Using a different example for items 3 and 4: when impersonating a subnet that is protected by a stealthy firewall, only a few expected signatures may have to be shown.

Another way to prevent the deception story from being uncovered is to minimize the target's scrutiny of the deceptions. Three techniques for doing this are: 1) the deceptions can be communicated to the target via his less scrutinizing intelligence capabilities. If the target cannot examine the deception closely, he will be less likely to detect it. 2) Deceptions can be communicated to the target when he has little time to scrutinize them, and 3) the deceptions can portray things of which the target has little understanding. A good example of when hackers have little time to observe is during extensive port scanning. When many ports are to be scanned, each scan must be quick, and thus superficial. Such scans are easy to deceive, and the deception is fairly reliable. For example, ping scans can be easily and reliably deceived by fake echo-reply packets.

Ensuring the target receives the story. In the course of hacking, the target eagerly seeks particular information; this presents an opportunity for using the target's intelligence sources to communicate the deception story to him. In the IP deception operation, the IP web-site is one of the target's intelligence sources. Also, the deception story included a vulnerable FTP server on the IP workstation because it is something the target can see, and is likely to see. Designing the deception story requires an understanding of the target's intelligence sources and observation arenas.

Revealing the story. A technique for revealing the deception story is to provide the story in bits and pieces and then let the target piece the story together by inference [Dew89, USM89]. The technique is consistent with the target's intelligence activities, as they normally acquire information in bits and pieces. A weakness of the technique is the risk of misinterpretation, as the small amounts of information might be reasonably interpreted in a variety of different ways.

Implementing the story. Usually, only parts of the deception story will need to be implemented. Some of the story will be tied to the truth and portrayed by real systems and operations. Some of the story can be notional, implied by the parts of the story that are real and that are implemented.

To determine what parts of the story to implement, one must understand how the target receives the deception story, and what he expects to see [JDD96]. For the IP deception operation, the target's intelligence collection is expected to begin with the IP web-site. It will be followed by a port-scan of the two IP workstations. The target will then investigate the listening ports for vulnerable servers. Most likely, the target will not expect to be deceived nor detected, so he will trust what he sees, and he will act boldly and quickly.

The target's intelligence and investigative capabilities determine how he receives the deception story. The deception planner must determine the things the target would expect to see if the deception story was true. For the IP deception operation, the target will expect the

IP department's workstations to be secure, but he will look for accidental vulnerabilities. The target will use a port-scanner to find network servers on those workstations. He'll examine the servers for exploitable vulnerabilities, such as the buffer-overflow vulnerability on the FTP server *WUFtpd Version 2.5.0* [CER99]. The target will expect an FTP server to present its login interface. A buffer-overflow attack normally crashes a server, or it provides access to a root shell. The target will not expect the IP database itself to be easily accessible on the intranet, due to its value and security.

Having determined how the target discovers the deception story, and what he expects to see, the planner can then determine the parts of the story to implement. For the IP deception operation, the real IP web-site and workstations will portray themselves. An FTP honeypot will impersonate a vulnerable FTP server, as the target expects. However, the honeypot does not need to simulate, nor provide, root-shell access. After several failed attacks, the target will simply give up, and attribute the failures to system idiosyncrasies. Nothing needs to be portrayed regarding the IP LAN. The target's knowledge of it is speculative, and he will expect it to be hidden and inaccessible.

Realism. For each part of the deception story that is implemented, the deception planner will need to determine its degree of realism. The realism needed is a function of: 1) the target's intelligence capabilities, and 2) the time the target has available to analyze the situation and take appropriate actions [FN95]. Often, minimal realism is needed for deceptions that the target has little time to observe and analyze [FN95]. For example, hackers have little time to observe during extensive port scanning. When many ports are to be scanned, each probe must be quick, and thus superficial. Such scans are easy to deceive, and the deception is fairly reliable. In general, it is best to design the deception story so that the amount of realism needed is kept to a minimum.

3.1.4 Summary of the deception operations model

The deception process' basic components are illustrated in Figure 3.1.1.2-1 (page 31). In deception planning, we have observed that it is very easy for the deception operation's trickery to become enthralling and captivating, and cause the planner to lose sight of the real objective. The *deception objective* is the desired result of the deception operation; it consists of: 1) the intended *target action*, and 2) the *deception exploit.* The deception operation's ultimate goal is successful completion of the deception exploit. The deception operation's trickery is just a means for inducing the target-action. In particular, the *desired perception* is what the target must believe in order for it to take the intended action. The *deception story* is an outline of how the computer system will be portrayed so as to cause the target to adopt the desired perception, and take the intended action.

For the deception operation to be successful, the deception story must be: received by the target, believed, interpreted as intended, and the story must induce the target action. Such manipulation of an adversary can be difficult and problematic. Fortunately, the target provides an opportunity that the deception planner can exploit: in the course of hacking, the target eagerly seeks particular information, and his intelligence processes can be used to communicate the deception story to him. In addition, feedback channels are needed to provide information about the target's reception of the deception story, and his response to it.

3.2 Hiding model

Hiding things is common practice in computer security. Routinely, systems and files are hidden using firewalls and access controls, and data are encrypted. These common forms of hiding typically work by denying information to potential hackers. Another way to hide things is by using deception. Deception is a promising means for computer security, as seen with honeypots [Spi02]. This section examines the use of deception as a means of hiding things from hackers.[14]

Deceptive hiding can be used in a wide variety of computer security applications. One such application involves hiding information about a network's topology, vulnerabilities, and assets from hacker reconnaissance (e.g., scanning). The honeypot "honeyd," for example, intercepts connections to unused network addresses and impersonates computers at those addresses [Spi02]. Its ruse makes it difficult for hackers to find real computers and to scan the network without being detected. Deception can also be used to hide computer-security devices, including firewalls, intrusion detection systems, keystroke loggers and honeypots. For example, a firewall can send fake ICMP "host unreachable" messages in response to disallowed packets, making it appear that the firewall, and computers behind it, are not on the network.

We define *computer security deception* as the actions taken to deliberately mislead hackers and to thereby cause them to take (or not take) specific actions that aid computer security [JDD96]. Often, for deceptive hiding, the objective is to cause the hacker to not take a particular action, such as accessing a server.

Furthermore, computer security deception aims to mislead a hacker into a predictable course of action or inaction that can be exploited or otherwise used to advantage [Dew89]. In general, one wants to avoid actions that cause the hacker to act dangerously or unpredictably. For example, suppose a system administrator hides network logs to prevent hackers from

[14] This section appears in a copyrighted journal paper [YDF06]. It is reprinted here by permission. There are some minor differences between this section and that paper.

erasing their tracks. If a hacker does not find expected logs, he may erase the entire hard drive, just to be safe. An important aspect of deception planning, therefore, is anticipating such unintended consequences and taking actions to mitigate their effect.

We will refer to the thing being hidden as the *hidden item*. It includes anything that needs to be hidden for computer security, such as assets, vulnerabilities, data, processes, and even network agents, including people. Items are hidden from an agent, human or computer. The agent whom the item is hidden from will be referred to as the *target*. In the context of computer security, the target is a hacker or his automated agent (e.g., a worm). For deception operations, the adversary who is being deceived is referred to as the *deception target*. For deceptive hiding, the target of hiding is also the deception target.

This section explains how deceptive hiding works in terms of how it misleads, or tricks, a particular target (i.e., hacker). However, the deception planner's ultimate purpose is not to mislead the target, but to improve computer security in some specific way. In the experience of the author, deception's trickery can be alluring and intriguing, making it is easy to lose sight of the deception's ultimate purpose.

This work describes deceptive hiding through a process model. The model's purpose is to provide a framework for understanding, comparing, and developing methods of deceptive hiding. Although the model is based on general principles and techniques that are domain-independent, the focus is on the model's application to computer security. The goal is to help the security professional evaluate, compare, configure, and use existing deceptive hiding techniques (e.g., honeyd); and to help explore possibilities when creating new techniques.

The model characterizes methods of deceptive hiding in terms of how they defeat the underlying processes that a target uses to discover the hidden item. This process is decomposed into three means of discovery: direct observation (sensing and recognizing), investigation (evidence collection and hypothesis formation), and learning from other people or agents. Although the focus is on deceptive hiding, many of the concepts are also relevant to non-deceptive hiding.

The next section introduces the process of deceptive hiding. Subsequent sections describe the three means of discovery and how they can be defeated; a final section concludes.

3.2.1 The process of deceptive hiding

Bell and Whaley categorize deceptions as hiding and showing [BW82, Wha82]. *Deceptive hiding* conceals or obscures a thing’s existence or its attributes in a way that intentionally misleads the target. It is distinguished from *denial*, which may also involve hiding, but without the intent to mislead. Denial simply withholds information from the target. Encryption, which overtly conceals a message but not its existence, is an example. Steganography, on the other hand, which aims to hide the existence of a communication, is deceptive, as it uses a misleading data carrier (e.g., text is hidden in the low-order bits of an image file in such manner that the text is not visible to the naked eye).

Deceptive showing makes something that doesn't exist appear as if it does by portraying one or more of its attributes. For example, after several unsuccessful logins, a computer can continue to prompt for passwords, but ignore them and not permit login. The computer is deceptively showing login prompts.

Hiding keeps the deception target from knowing about the hidden item’s existence or its attributes. As a result, the target will be unaware of the item, certain it does not exist, uncertain of its existence, or left with incomplete or inaccurate information about it. Hiding can prevent discovery of the hidden item, or it can make discovery more difficult or time consuming.

There are three different ways a target can discover a particular item:

1. direct observation of the item,
2. investigation based on evidence of the item, and
3. learning about the item from other people or agents.

These three means of discovery comprise the target’s *discovery process*. Hiding works by defeating this process, which is driven by two elements: capabilities and a course of action. The target's *discovery capabilities* are defined as the resources, skills, and abilities he has for discovery. The *discovery course-of-action* is the way he carries out the discovery process; it includes how, when and where the target looks for things. This suggests that the target's discovery process can be defeated by affecting either the target's capabilities or the target's course of action. For instance, installing a firewall can ensure a hacker's port scan is not capable of directly observing a computer's servers. Alternatively, deploying an enticing honeypot could divert the hacker's course-of-action so that his port-scans reveal the honeypot rather than the hidden servers.

We assume the deception target intends to discover the hidden item. Another way to hide is to affect the target's intentions. For example, a hacker may be deterred from scanning for and attacking vulnerable systems if he believes he will be caught and punished. Hiding by altering intentions is not addressed herein. We now examine each of the three discovery processes and how they can be defeated.

3.2.2 Direct observation

When hacking a network, much of what the hacker knows about the network is learned by direct observation. For example, a hacker's port scan allows him to observe a network's computers and servers. Once a hacker gains access to a computer, he can use system utilities to observe the computer's resources, such as files, programs, and running processes; and he can use application programs to observe business and user data. Also, the hacker can use network clients to observe servers and their contents. We first describe the discovery process and then examine how hiding can defeat that process.

3.2.2.1 The discovery process for direct observation

The discovery process for direct observation involves *sensing* and *recognizing*. The process is illustrated in Figure 3.2.2.1-1. The deception target observes using his own human sensors, e.g., his eyes. He may also rely upon one or more external sensors, such as a network port scanner or packet sniffer. Information flows to and from the sensors over media (e.g., network cables, routers, and computer monitors). The hidden item is observed within the environment in which it resides (e.g., a private computer network). When a human target receives sensory input, recognition occurs within his brain. Recognition is a cognitive process involving knowledge and understanding. Recognition can be performed by using human or artificial intelligence.[15] Discovery occurs when the hidden item is identified (i.e., recognized) based on expected patterns.

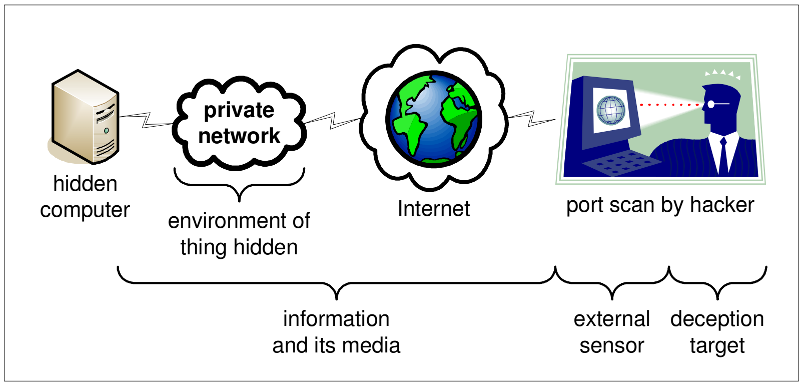


Figure 3.2.2.1-1 : The process of direct observation, illustrated by a computer-security example

A sensor receives information and conveys it to the target in a form that is useful to him. The sensor can convey information to the target in a variety of ways. For instance, when the target observes a computer and uses his eyes as the sensor, the information is conveyed to him is a visual image. When he observes the computer by using a port scanner as a sensor, the information is conveyed to him descriptively via text. Typically, sensors work in a deterministic manner, and their operation is based on mechanisms such as software and electronics (e.g., the port scanner), or physiology (e.g., eyes). Recognition, on the other hand, is much less deterministic. The target might miss identifying something even if it is seen,

[15] Recognition can also be performed by using animals, e.g., bloodhounds, but it is not likely in computer security.

especially if the target does not know what patterns to look for. Recognition depends on knowledge and intelligence, real or artificial.

The target's sensor and recognition capabilities are considered to be distinct elements in the model. In practice, however, both capabilities may be present in a single device. A network intrusion-detection system (NIDS), for example, can have a sensory component consisting of a packet sniffer and a recognition component based on matching packet information against attack signatures or statistical anomalies.

The target can discover things by actively searching for them or through passive observation. Discovery involves bringing the sensors to bear upon a hidden item. The hidden item is then distinguished and recognized from within the environment in which it resides.

3.2.2.2 How hiding defeats direct observation

Hiding defeats direct observation by defeating the targets sensor(s) and/or recognition. The *sensor* is defeated if it does not provide him with distinguishable information about the hidden item. For example, when steganography is used to hide text within a picture, the target's sensors (graphics browser and eyes) cannot distinguish the text data.

Recall that the target's discovery process can be defeated by: 1) defeating his discovery capabilities, or 2) defeating his course of action, in discovery. For direct observation, this means preventing the target's sensor capabilities, or the way the sensor is used, from providing distinguishable information about the hidden item. One way to achieve this is by altering an element of the discovery process that is external to the deception target and his sensors. Such elements include the hidden item's location, appearance or environment, or the information flows to the sensor. For example, placing a firewall between a server and the Internet would alter the information flows between the server (hidden item) and the hacker's port scanner (sensor), and thereby defeat the scanner's capabilities. Alternatively, the hacker's use of the scanner could be defeated by altering the server's location, e.g., the server could be placed on a subnet that the hacker is not likely to scan.

Hiding can also be achieved by taking direct action against the target's sensor capabilities or his use of the sensor. For example, launching a denial of service attack against the hacker's computer could impair his use of the port scanner.

Table 3.2.2.2-1 summarizes and illustrates the options for defeating sensors. The first column lists the general types of actions outlined above, while the second provides greater specificity and examples. (Subsequent tables in this section follow this format.) The table provides the deception planner with a framework for evaluating and developing hiding techniques. The action-types listed in the first column are intended to be exhaustive and mutually exclusive. The body of the table presents a broad, though not exhaustive, collection of common hiding techniques for deception and denial. Some hiding techniques affect multiple elements of the discovery process, so they could be placed in multiple tables or categories within a table.

Table 3.2.2.2-1 : Hiding techniques that defeat the target's sensors

Action Type	***Ways to Defeat Sensor*** (sensor does not provide distinguishable info. about the hidden item)
alter location of hidden item	place the hidden item where the target is not likely to observe: • place critical files in obscure directories place the hidden item where the target's sensors cannot observe: • hide laptop behind NAT (network address translation) device • hide information within a cover medium, using steganography

Table 3.2.2.2-1 (continued) : Hiding techniques that defeat the target's sensors

Action Type	***Ways to Defeat Sensor*** (sensor does not provide distinguishable info. about the hidden item)
alter appearance of hidden item	make the hidden item not reflect information to sensor: • computer eludes ping scans by not replying to pings make the hidden item blend in with background: • password file given non-descriptive name, to elude hackers' automated searches for files named 'pass*' alter the hidden item's appearance, so the target's sensor is not capable of observing it: • encrypt message (the target can observe the cipher text, but not the plain text)
alter environment of hidden item	create noise in environment: • add bogus files to make it harder to find critical ones alter components in environment to prevent access to the hidden item: • hide network data from sniffers by replacing Ethernet hubs with switches
alter information flows to sensor	alter information needed by sensor: • router drops incoming pings to hide its network's computers from ping scans • delay responses to login attempts so hacker does not have time to guess password add components to communication path • firewall added to prevent certain flows to or from computers on network
diminish target's sensor capabilities	disable or degrade the sensor: • perform a DoS attack against a hacker's port-scanner reduce the target's time available for observation • quickly detect and stop target's reconnaissance, such as port scans
misdirect target's use of sensor	cause the target to observe at the wrong place or time • create a diversion for the hacker

The target's *recognition process* attempts to identify the hidden item from the information provided by his sensors. Assuming the sensors provide distinguishable information about the hidden item, the target's recognition is defeated if he is not able to identify the hidden item from the sensory input. For instance, to hide a virtual private network (VPN) server on a demilitarized zone (DMZ), three honeypot VPN servers could be added to the DMZ. A hacker's port scan reveals all four VPN servers, but he is unable to recognize which is real.

The target's recognition process can be defeated by:

1) defeating his recognition capabilities, or
2) defeating his course of action, for recognition.

His recognition capabilities are a function of: 1) his cognitive abilities (human or artificial), 2) his skill and experience in identifying the hidden item from the information provided by the sensor, and 3) his available resources, including time. His course of action includes how, when and where he recognizes things, which are all influenced by his expectations. For example, a hacker would expect, and more readily recognize, banking-industry security devices on a bank's network than on a typical home-network.

Table 3.2.2.2-2 illustrates how a target's recognition process can be defeated in order to hide. The table's first column is the same as in Table 3.2.2.2-1. The reason is that recognition is defeated by the same types of actions that are used to defeat sensors. Table 3.2.2.2-2's second column lists specific hiding techniques applicable to defeating recognition.

Table 3.2.2.2-2 : Hiding techniques that defeat the target's recognition

Action Type	***Ways to Defeat Recognition*** (the hidden item cannot be identified from info. provided by sensor)
alter location of hidden item	locate where the target observes, but does not expect the hidden item: • put sensitive document files in a software application's directory

Table 3.2.2.2-2 (continued) : Hiding techniques that defeat the target's recognition

Action Type	***Ways to Defeat Recognition*** (the hidden item cannot be identified from info. provided by sensor)
alter appearance of hidden item	disguise the hidden item by making it mimic something expected in environment: • use ports that make a server appear like a workstation to scanners make the hidden item appear as something the target does not recognize: • use unconventional names for sensitive files
alter environment of hidden item	make things in the environment resemble the hidden item: • place a highly valuable workstation on a LAN with many workstations that have low value, but that appear the same to hackers' scans
alter information flows to sensor	generate false information that is received by the sensor, but misleads recognition • *honeyd* thwarts scanning by impersonating computers at unused IP addresses • *nmap*'s decoy port-scan hides the scan's source address by sending many packets with fake source addresses
diminish target's recognition capability	disable or degrade the recognition process: • exhaust hacker by overwhelming him with false information reduce target's time available for recognition • stop hacker before he recognizes critical systems and information prevent target from acquiring understanding needed to recognize hidden item • limit publication of information that could aid hacker
misdirect target's recognition process	cause target to expect something other than the hidden item • misinform hacker about identity of network elements

3.2.3 Investigation

Investigation is a means of discovery that infers a thing's existence from evidence rather than direct observation. Investigation is used in many domains, for example law enforcement (determining guilt based on evidence) and health care (diagnosing illness from symptoms).

In general, investigation is used to discover a thing that existed in the past when it was either not directly observed or a reliable recording of the observation is not available (e.g., computer log, video tape, or witness' testimony). Investigation is also used to discover things that exist in the present, but which cannot be directly observed. Things in the future can be anticipated based on indicators, but cannot be investigated because evidence of them does not exist. The investigation process involves induction and deduction. Moreover, investigations can be simple and ad hoc, or involve extensive application of scientific methods (such as forensics to investigate crimes).

Hackers often use investigation to obtain information about the current state of a victim network's topology, as well as its defenses, vulnerabilities, and assets. For example:

By acquiring a network's computer names, a hacker might be able to deduce which computers are vulnerable [MSK99]. Computers with names containing "test" such as "test-network-gateway," may be indicative of systems that have not been configured securely.

A variety of techniques are available for obtaining evidence that reveals firewalls and their access control lists (ACLs) [MSK99]. Firewalking can reveal which ports are open or blocked by a firewall [GS98].[16]

Email sent to a public newsgroup can reveal the internal IP address of a sending computer that is otherwise hidden by a NAT device.

Investigation is the first phase of most network attacks. Deceptive hiding can be used to defeat these and other hacker investigations. When using deceptive hiding for computer security, the hacker is the investigator and deception target. When hiding things from investigation, the investigator is an adversary. Viewing an investigator as an adversary is somewhat unusual, as investigators are normally the "good guys", e.g., policemen and scientists. Of course, when the hacker himself is hiding things, the cyber cops become the investigators.

[16] Firewalking sends a TCP packet with an IP TTL field set to one hop beyond the firewall. If the reply is the ICMP error message "time to live exceeded in transit", then it is evidence that the TCP port is open. If there is no reply, or the reply is the ICMP error message "communication administratively prohibited", then it is evidence that the TCP port is blocked.

We first describe the process of investigation, and then turn to how that process can be defeated. Our treatment of the investigation process is adapted from David Schum's excellent research on investigation for jurisprudence [Sch99].

3.2.3.1 The investigation process

Investigation is an iterative process of creating *hypotheses* and acquiring *evidence* about the thing being investigated. Typically, the investigator works with incomplete evidence, so there can be many plausible hypotheses that are consistent with the evidence. At any point during the process, the investigator can either develop new hypotheses based upon the available evidence or search for new evidence to answer questions relating to his current evidence and hypotheses. As the investigation unfolds, each piece of new evidence reduces the number of possible hypotheses and inspires the creation of more accurate and detailed hypotheses. New evidence suggests new questions and hypotheses, and these in turn drive the collection of further evidence. The information and understanding obtained is cumulative.

There are two types of hypotheses that the investigator develops and works with: discovery hypotheses and collections hypotheses. *Discovery hypotheses* explain that which is being investigated in terms of available evidence, and they culminate in the recognition or discovery of the hidden item. *Collections hypotheses* explain where additional evidence might be found, and they guide the investigator's search for new evidence. New evidence can be acquired through direct observation (section 3) or from other people or agents (section 3.2.4). The collected evidence may include false and irrelevant information that misleads the investigator.

Investigations vary in the amount of evidence collected and hypotheses formed. Some are simple and produce immediate results. For example, after breaking into a computer and detecting evidence of a hidden keystroke logger, a hacker could immediately conclude that the computer is a honeypot. Other investigations are more complex, requiring the investigator to combine multiple pieces of evidence acquired over time. Instead of discovering a keystroke logger, the hacker might observe that he cannot create outgoing connections and that the computer contains no user data. By observing these conditions over time and considering them together, he deduces the machine is a honeypot.

The process of investigation requires creativity. It also requires deliberate choices. Investigation comes at a cost, so the investigator cannot follow every hypothesis and seek evidence to answer every possible question. He will be limited by his resources, including his available time, to collect, process, and retain evidence. How the investigation proceeds will depend upon the investigator's resources and the choices he makes about how the resources are used. If his choices are bad, he will make false hypotheses, collect the wrong evidence, and waste his resources on useless paths of investigation.

Evidence often has a temporary existence, which can pose significant problems during the initial investigation. As time progresses, an increasing amount of evidence will no longer be obtainable. For example, log files are eventually erased or destroyed, and peoples' memory fades. The investigator needs to gather and preserve evidence before the opportunity is lost. However, much useful evidence may not be discernable at the beginning of the investigation. The discernment of evidence requires understanding of the case, and the investigator acquires understanding over time. The investigator can reduce the loss of temporarily-available evidence. By making many hypotheses, and very general hypotheses, the investigator can collect a large amount of evidence that is potentially useful. However, the investigator has limited resources for collecting and storing evidence.

Investigation is a necessary first phase of most network attacks. Further, the investigation process is weakest at the beginning of an investigation, as just described. Thus, in hackers' network-attack process, their initial network investigation can be a *critical vulnerability* [17], and relatively easy for defenders to exploit.

3.2.3.2 How hiding defeats investigation

The inherent difficulties of investigation can be exploited through deception. If evidence is hidden, the investigator may form false hypotheses, ask erroneous questions, and

[17] A *critical vulnerability* is a vulnerability that permits us to destroy some capability without which the enemy cannot function effectively [USM97].

pursue futile investigation tracks. He may terminate what would have been a fruitful track. In situations where several pieces of evidence are needed to discover a thing, it may suffice to hide some of the evidence in order to prevent discovery. In situations where evidence has a limited lifetime, it may be enough to interfere with the start of the investigation or delay its progress.

The target's investigation process is defeated if he does not recognize the hidden item, or if his recognition is made sufficiently uncertain. This can be accomplished by defeating either of the subprocesses that comprise the investigative process: evidence collection and the creation of discovery hypotheses.

The target's *evidence collection process* includes his creation of collections hypotheses and his acquisition of information. This process is defeated by preventing him from obtaining the evidence needed for recognition. Two types of actions can be taken to defeat the target's evidence collection:

1) alter the evidence available in the environment, i.e., do not create evidence, hide evidence, or destroy evidence, and
2) weaken the target's evidence-collection process by diminishing his capabilities or by misdirecting his actions. See Table 3.2.3.2-1.

The target's evidence collection can be defeated more effectively if his search for evidence can be anticipated. There are two common searches for evidence that are especially vulnerable. The first are superficial searches, which result when many things must be examined, and time limitations prohibit a thorough examination. For example, a hacker's network scan may involve examining thousands of computers. To speed up the process, hackers often first perform a superficial ping scan to locate running computers. They then perform a port scan on the running computers. Such superficial examinations can be very vulnerable to deception. Second are predictable searches for evidence performed by computer programs. These searches lack human intelligence. For instance, hackers use open-source vulnerability scanners, and these scanners look for specific types of evidence. Hiding evidence from popular hacker tools can defeat a large portion of the hacker investigations on a network.

Table 3.2.3.2-1 : Hiding techniques that defeat the target's evidence collection

Action Type	***Ways to Defeat Evidence Collection*** (the necessary evidence is not collected)
block evidence creation	find a way to do things so evidence is not created: • configure outgoing mail server to remove sender's IP address from mail headers
hide evidence	hide evidence that could be acquired by direct observation (section 3.2.2) or learned from other people or agents (section 3.2.4)
destroy evidence	destroy evidence before the target can collect it, either at once or by entropy over time • remove sensitive information from memory and disk after use
diminish target's evidence-collection capabilities	reduce the target's time available for collection • quickly detect and abort hackers before they find critical information • delay the target's evidence collection, so that it exceeds his available time
misdirect target's evidence-collection	misdirect the target's collection activities, to keep him away from necessary evidence, e.g., create false evidence that causes the target to look for evidence in the wrong places confuse the target, so he can't form the collection or discovery hypotheses needed to obtain necessary evidence, e.g., create false evidence that contradicts real evidence reduce the target's perceived reliability of necessary evidence, e.g., create false evidence that is of the same type as the real necessary evidence, and allow the target to learn that false evidence has been created

The other way to hide from investigation is by defeating the target's creation of discovery hypotheses. However, it is only necessary when the target is able to obtain the evidence needed for recognition. Hiding is accomplished by preventing the target from creating the discovery hypotheses needed for recognition. There are two ways to defeat his creation of discovery hypotheses:

1) ensure the target is not capable of creating the necessary discovery hypotheses, and
2) ensure the target's process of creating discovery hypotheses does not lead him to recognize the hidden item.

Table 3.2.3.2-2 elaborates.

Table 3.2.3.2-2 : Hiding techniques that defeat the target's creation of discovery hypotheses

Action Type	***Ways to Defeat the Creation of Discovery Hypotheses*** (even if the target has the necessary evidence, he cannot create the necessary discovery hypotheses)
diminish target's capabilities for creating discovery hypotheses	cause target's capabilities to be insufficient, e.g., reduce target's available time
misdirect target's creation of discovery hypotheses	mislead target, e.g., create false evidence, or hide true evidence, and thereby cause the target to form incorrect discovery hypotheses
	confuse target, so he can't form the necessary discovery hypotheses, e.g., create false evidence that contradicts real evidence

3.2.4 Learning from other people or agents

The third way a deception target can discover something is to learn about it from another entity. This section describes the learning process and how it can be defeated.

3.2.4.1 The learning process

The learning process is a discovery process wherein the deception target learns of the hidden item from a *discovery agent*. The discovery agent can be a person or a device with sensor and recognition capabilities, such as a software agent. The agent discovers the hidden item through its own discovery process, which can be direct observation, investigation, or learning. The agent then reports the discovery, and the report is communicated to the target. The report can be sent directly to the target (e.g., via an email), or recorded and placed somewhere accessible to the target (e.g., a website). The discovery agent may act autonomously or under the direction of the deception planner or the target. Figure 3.2.4.1-1 illustrates.

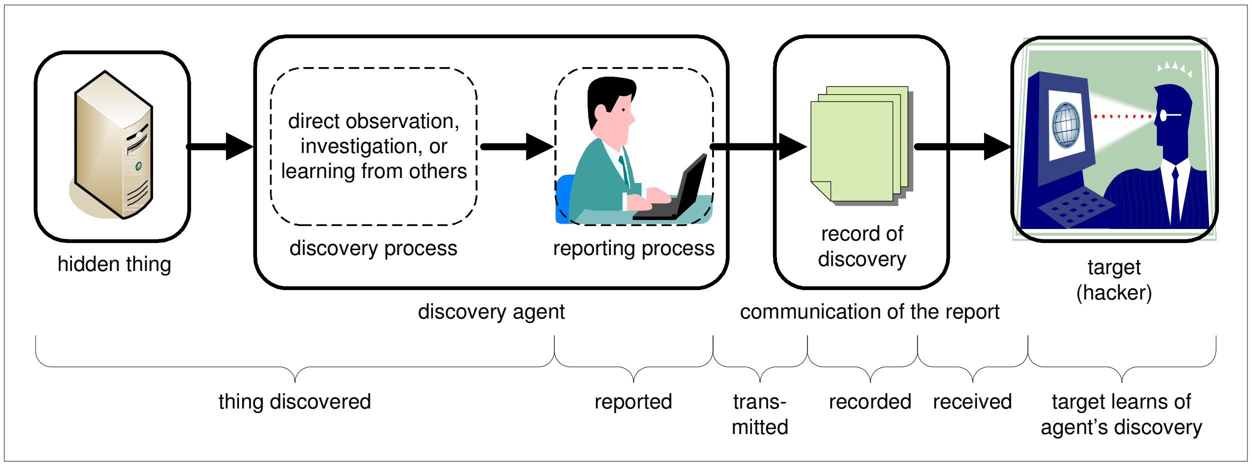


Figure 3.2.4.1-1 : How the target learns from other people's, or agents', discoveries

In practice, the target may learn of a thing through a series of agents, e.g., the target learns of the thing from person A, who learned of it from person B, and so on, the first person having acquired it from direct observation or investigation.

Hackers acquire much of their knowledge from others. For instance, through footprinting they learn about a victim's network from publicly available information [MSK99]. Typical sources include DNS servers, which record the IP addresses and domain names of computers on a network, and company websites, which may contain information about the company's networks. Hackers also learn through distribution lists, chat channels, and other online forums.

3.2.4.2 How hiding defeats learning

Hiding defeats the learning process by defeating the discovery agent, communication of the report, or the target's recognition. The *discovery agent* is defeated if it does not discover the hidden item or attempt to report it. The *communication of the report* is defeated if the report is not successfully transmitted, recorded, or received by the target (assuming the discovery agent has attempted to communicate the report). The *target's recognition* is defeated if the target does not learn of the hidden item from the report (assuming the target has received the report). Table 3.2.4.2-1 elaborates.

Table 3.2.4.2-1 : Techniques for hiding when the target learns from other people's, or agents', discoveries

Action Type	***Ways to Defeat the Discovery Agent*** (the hidden item is not discovered and reported)
hide item from discovery agent	hide item from the agent's direct observation (section 3.2.2) • give unused addresses on a network fake names to hide real computer-names in reverse DNS lookups. hide item from the agent's investigation (section 3.2.3)
alter discovery agent's reporting process	instruct discovery agents under control of deception planner to omit hidden item from reports • omit high-valued assets from published network diagrams • omit sensitive network information on public technical-support forums
diminish discovery agent's capabilities for serving target	cause discovery agent to not serve target: • bribe or "turn" hackers who serve as discovery agents for others • detect and remove a hacker's network sniffers (discovery agents) degrade capabilities of discovery agents: • modify a hacker's sniffers so they garble captured data. The hacker may regard them as too problematic to use on the network. interfere with target's directions to the discovery agent: • install a firewall to block a hacker's access to an installed sniffer

Table 3.2.4.2-1 (continued) : Techniques for hiding when the target learns from other people's, or agents', discoveries

Action Type	*Ways to Defeat Communication of the Report* (the hidden item is not successfully communicated)
alter transmission or receipt of report	block the transmission or receipt of the report • configure firewall to drop outgoing ICMP packets, which are used by the hacker tool LOKI to communicate covertly
alter recorded report	falsify or destroy the recorded report • when a hacker's vulnerability scanner (discovery agent) is found running on a computer inside a network, falsify or erase the recorded results.
Action Type	*Ways to Defeat the Target's Recognition* (the target does not learn of the hidden item from the report)
affect report	confuse target by causing discovery agent to report things resembling hidden item • honeyd impersonates many vulnerable computers, causing a hacker's vulnerability scanner to return an overwhelming number of false positives.
diminish target's learning capability	cause the target's learning resources to be insufficient • reduce the target's time available for the report, e.g., law enforcement's aggressive pursuit of a hacker causes him to spend more time on evasion and defense, and thus he has less time for learning about his victims' networks.

3.2.5 Summary of the hiding model

This section explained deceptive hiding in terms of defeating the target's discovery process. The model includes three means of discovery: direct observation (sensing and recognizing), investigation (evidence collection and hypothesis formation), and learning from other people or agents (discovery by an agent, report communication, and target recognition). For each, hiding defeats one or more of the components of the discovery process. This is accomplished by ensuring that the target is not capable of discovering the hidden item or that the target's course-of-action does not lead him to discover the hidden item.

The process model offers a conceptual framework for developing new deceptive hiding techniques and for evaluating existing techniques. The model also offers a common frame of reference for collaboration among security professionals. When hiding a particular thing, the deception planner can determine which discovery methods the target is likely to use. For each method, the tables of hiding techniques can be used to consider the possible ways to hide.

The hiding model is applicable to both deceptive hiding and non-deceptive hiding (i.e., denial). Non-deceptive hiding defeats the target’s discovery process, but without misleading him.

4 Deception-based intrusion detection systems

This chapter introduces two deception-based security devices: Honeyfiles and Net-Chaff. The *Honeyfiles* system extends the network file system to provide bait files for hackers. These files trigger an alarm when opened. The *Net-Chaff* system employs computer-impersonations to detect and contain hacker's network scans within an intranet.

4.1 Net-Chaff: deception-based scan detection and containment

A system for defending against scans was designed and then modeled analytically and by simulation. The system is named *Net-Chaff*, as it uses deception-based countermeasures. Its capabilities include: scan detection, automated scan containment, and a simple means for monitoring the whole network. The Net-Chaff analysis (Chapter 5) indicates that the system can provide substantial improvements over current scan defenses such as NIDSs [Naz04]. The Net-Chaff design uses, for the most part, existing computer-security components, but Net-Chaff combines and applies them in a novel and strategic way.

Net-Chaff is intended to defend against hacker scans within a protected intranet, e.g., inside a corporate network. One condition for installation of Net-Chaff is that this intranet must be comprised of routed LANs. Net-Chaff detects scans by monitoring traffic to the intranet's unused addresses. This monitoring technique provides significant benefits for accurate and rapid scan detection. Net-Chaff also impersonates computers at the unused addresses, which can impede scanner's progress and improve Net-Chaff's defensive effectiveness. Once Net-Chaff detects the scan, it then attempts to isolate the scanner from the network. This is done by locating the router interface for the scanner's LAN, and setting the router's access control list (ACL) to block the scan packets. In addition, the router can be directed to tunnel scanning packets back to Net-Chaff, which impersonates computers and further monitors the scan.

This section describes how Net-Chaff works, and it frames Net-Chaff's requirements for defending against scans. This section's scope is limited to Net-Chaff's architecture and requirements. The subsections that follow cover Net-Chaff's environment (including assumptions about scanners and intranets), its architecture, and its requirements (including scanning-related requirements and performance objectives). The analysis of Net-Chaff's effectiveness, and its use of deception, is presented later, in Chapter 5.

4.1.1 Environment and assumptions

Net-Chaff is intended for defending intranets from hackers' active scans. Active scanning is one of the primary techniques hackers use to obtain information about a network [MSK99]. Active scanning involves sending probes to network addresses, to determine if a computer is at the address, and to obtain information such as the computer's operating system type and the services it is running [MSK99]. Hereafter, *active scanning* will be referred to as simply *scanning*. Scans are also used to obtain network information, including router topology and firewalls' filtering-rules. When a scan probes a network address, the probe may just collect information, or it may attempt to attack directly, in which case the scan is referred to as a *scan-and-attack*. A scan-and-attack example is the Sapphire worm that sends a single UDP attack packet to randomly chosen addresses [Naz04]. Hacker's scanners can be implemented as stand-alone programs (e.g., nmap), or as components of hacking tools such as worms and vulnerability scanners (e.g., Nessus) [MSK99].

Scanning is an initial step in many, perhaps most, network attacks. Scanning can be performed very quickly, and this enables hackers to rapidly find and exploit network vulnerabilities and assets. For example, Internet worms can infect hundreds of thousands of computers within hours [Naz04]. Their rapid spread is due to quick scanning and intrusion, and because of their self-replicating nature, the growth of infection can be exponential. Net-Chaff's primary objective is to quickly detect and stop scans in order to prevent them from obtaining information needed to carry out attacks. Net-Chaff has the potential for stopping attacks before they start and for preventing worms from spreading. Additional information on scanning, including references, is provided in section 4.1.3.1.

Net-Chaff is intended for use within a protected intranet, e.g., inside a corporate network. A protected intranet has a secure perimeter that restricts access from the outside, e.g., firewalls and DMZs protect the intranet from Internet attacks [CIS01]. It is assumed that the perimeter is not impenetrable, but that it is fairly secure. Consequently, scanning is a rare and significant event within this intranet, and these scans should be detected, contained, and investigated rapidly. In contrast to secured intranets, scanning on the open Internet occurs frequently. As an indicator, in 2003, researchers determined that intrusion attempts on the Internet were on the order of 25 billion per day [YBU03]. Thus, scans from the Internet will be frequent on a secure intranet's perimeter. While most will not pass the perimeter, those that do may cause considerable harm if they lead to compromise of an internal machine, and from there, attack other internal machines, e.g., as with worms. Inside a secure perimeter, individual computers may be less resistant to attack and infection, e.g., due to a false sense of security from the intranet perimeter.

One of the major assumptions we make about an intranet in which Net-Chaff operates is that the intranet is routed, i.e., it consists of LANs that are connected by one or more internal routers. This is not an unusual assumption. Most large enterprise networks have such an architecture. In contrast, Net-Chaff is not designed for use on a flat switched network (i.e., Ethernet) with a firewalled gateway. Net-Chaff could be extended for use on such networks, but that is left for future research.

4.1.2 Net-Chaff system

This section describes the Net-Chaff system and how it works. Net-Chaff has four functional roles: 1) impersonation, 2) scan detection, 3) scan containment, and 4) scan surveillance.

4.1.2.1 Intranet use

Net-Chaff works by monitoring traffic to the intranet's unused addresses, and by impersonating computers at the unused addresses. While almost all of the traffic to unused addresses is typically accidental, some of it may be from hackers, e.g., from scans and attacks from compromised machines within the intranet [Spi02]. In a well controlled environment, scans will make up a very small portion of the non-broadcast traffic sent to used addresses, but they may make up a very large portion of the non-broadcast traffic to unused addresses. Thus, it can be much easier to detect scans by monitoring traffic to unused addresses, rather than to used addresses. By impersonating computers at the unused address, Net-Chaff can also: slow down scans, reduce accuracy of scan findings, improve scan detection sensitivity, bait hackers into follow-on attacks, and obtain information for incident response and forensics. Net-Chaff's deception objectives are further discussed in section 4.1.3.2

This work focuses on using Net-Chaff on IPv4 networks. However, many of the concepts can be applied to IPv6 networks. In IPv4, an intranet can be a single large address space, or it can be subdivided into any number of subnets, e.g., using Classless Internet Domain Routing (CIDR). Also in IPv4, an intranet can use the reserved class A network (10.0.0.0). For most intranets, this provides a large number of unused addresses and a high ratio of unused to used addresses. For example, a large corporate intranet with 20K computers would have over 16M unused addresses, and a ratio of 800 unused addresses for every used address. Also, the subnets can be designed to spread-out the computers over the address space. When using Net-Chaff, scans of such a network would likely encounter many impersonated computers before finding a real computer.

Net-Chaff's operation is illustrated in Figure 4.1.2.1-1, and its numbered items, e.g., (1), are referenced in the descriptions. In the figure, the intranet contains a gateway router that is connected to the Internet. In this work, only a single gateway is considered and solutions for multiple gateways are left for future research. The "clouds" in the figure represent *used subnets*, i.e., subnets that contain real computers. Each used subnet is a local area network (LAN), and the LANs are connected to intranet routers. In contrast to used subnets, *unused subnets* contain no real computers. It is assumed that there is one LAN per used subnet, and vice versa. Also, each LAN is connected to one router interface. It is possible to adapt Net-Chaff for use on networks with different configurations of LANs, subnets, and routers, but it is beyond the scope of this research.

Net-Chaff manages some or all of the intranet's unused subnets. Traffic to the unused subnets is routed to the *Net-Chaff WAN server* (1). There, Net-Chaff's impersonation component deceptively portrays computers on the unused subnets. In reality, the impersonated computers are non-existent. Router manufacturers, and researchers working on network-abuse monitoring, have developed a simple way of collecting packets destined to unused subnets on an intranet [YBP04]. The intranet routers are assigned a static default route that forwards those packets to a single network location. This technique can be used to route packets to the Net-Chaff WAN server.

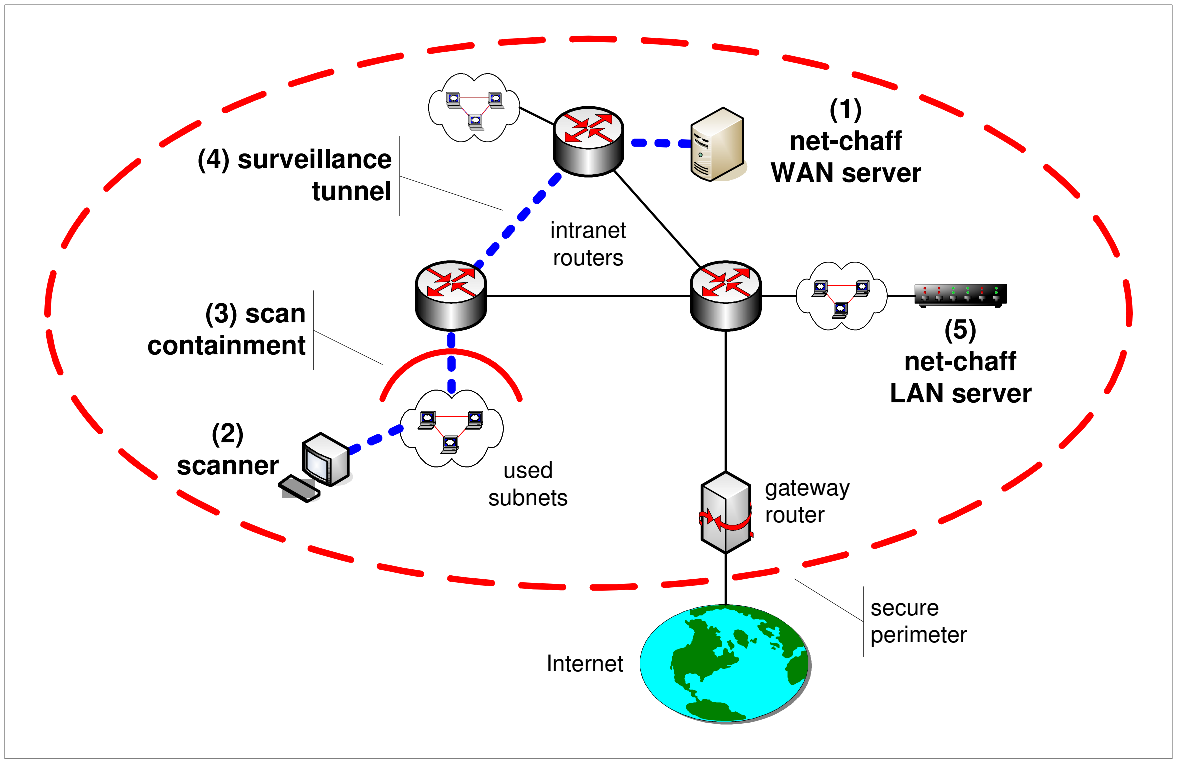


Figure 4.1.2.1-1 : Net-Chaff architecture

4.1.2.2 Impersonation

Net-Chaff's impersonation component replies to scans, to make it appear that there are computers at the unused addresses. Net-Chaff uses *low-level* impersonations of computers and servers. These are typically simple impersonations that are made by using packet-data below the application layer. This data includes the TCP/IP packet headers that establish communication between computers and that control routing. For instance, a computer can be impersonated by sending a TCP ACK packet in response to a half-open TCP scan [Fyo97]. In addition, Net-Chaff's low-level impersonations would include a rudimentary server that is referred to as a *null server*. It can be configured to return no data or random data, and it can be implemented as a TCP or UDP server.

Low-level impersonations are used because they are relatively easy to implement and they can effectively deceive many types of scans. To scan a large number of addresses, scans must be fast. Thus, many scans' probes use small amounts of data below the application layer, and the probes' interactions with computers are simple. Such probes can be easily deceived; a good example is an ICMP ping scan. It probes an address by sending an echo-request packet. A computer can be impersonated by simply sending a fake echo-reply packet in response. In contrast to low-level impersonations, application-level impersonations can be much more difficult to implement and a different impersonation would be needed for each type of server, e.g., FTP and HTTP. When scans do probe at the application-layer, the low-level impersonations are still effective for slowing down the scans and for obtaining information about the scans.

4.1.2.3 Detection

In the Net-Chaff WAN server, the detection component monitors the incoming traffic to the unused subnets, and it detects possible scans (2). Net-Chaff's impersonation component crafts replies to the incoming packets. To build Net-Chaff's detection and impersonation components, there are two problems that must be solved. First, scanners can use fake source addresses in the packets they send, and such spoofing can prevent detection of the scan source. Net-Chaff solves this problem by using known spoofing countermeasures. To reduce spoofing from the Internet, the gateway router can drop packets from the Internet if their source addresses is an address in the intranet space. To protect against spoofing from within the intranet, one can use intranet routers. The intranet routers can be configured so that a packet from a directly-attached subnet must have a source address from that subnet, or the packet is dropped. This simple solution restricts spoofing to addresses within the scanner's subnet. Further steps can be taken to prevent spoofing from individual intranet computers; however, these solutions are more complex and more expensive [CIS04].

The second implementation problem is Net-Chaff's performance requirements. The Net-Chaff server can potentially receive a high rate of scan packets, and thus it needs to be capable of generating impersonations at a high rate. Research in Internet abuse monitoring has produced techniques for generating high rates of computer impersonations [YBP04]. Some of the impersonations are too simple for use with Net-Chaff, but the techniques could be extended for use in the Net-Chaff WAN server.

4.1.2.4 Containment

There are two steps in the process of stopping a scan—detection and containment. Once the scan is detected, it is necessary to isolate (or block) the scanner from the network, to prevent further scanning and attacks. Isolating the scanner is carried out by Net-Chaff's containment component. For scans from within the intranet, Net-Chaff locates the router interface for the subnet from which the scan originated. Net-Chaff then modifies the router's access control list (ACL) to block the scan packets (3). The router could drop packets from the scanner's IP address, or if fake source addresses are being used, the router could drop all packets from the scanner's subnet. Other possible containment techniques include performing a denial-of-service attack against the scanner (e.g., a packet flood), and instructing a managed (Ethernet) switch to block the scanner's LAN or VLAN access. For scans originating from the Internet, Net-Chaff can block them at the gateway router. Some, or all, of the incoming Internet traffic could be blocked. If the Net-Chaff WAN server is receiving scans from the Internet, there is likely to be serious problems in the intranet's perimeter security, e.g., its firewall.

A key attribute of Net-Chaff's performance is its ability to prevent scans from finding real computers. To discuss this, several terms must be defined. Net-Chaff's *detection time* is the time from when the scan starts until the time it is detected. Net-Chaff's *blocking time* is the time from when the scan is detected until the time it is isolated from the network. Net-Chaff's *containment time* is the time from when the scan starts until the time it is contained, which is also the sum of the detection and blocking times. The scanner's ability to get information about real computers is primarily a function of: 1) Net-Chaff's containment time, 2) the scan rate, and 3) within the network, the number of real computers, unused addresses, and addresses managed by Net-Chaff.

Net-Chaff's containment function also involves slowing-down scans, and it does this in two ways. Net-Chaff uses a large number of unused addresses, and they reduce the rate at which scanners probe real computers (i.e., real computers per probe). Net-Chaff also reduces the scanners' probe rates (i.e., probes per unit time). This is accomplished by using impersonations that cause the scanner to send more data than it otherwise would for a probe. Also, Net-Chaff can insert delays in the impersonations' replies. The delays slow down scans that suspend probe transmission when waiting for replies, e.g., scans that are serial, or not fully parallel.

A drawback of automated containment is the risk of unwarranted service outages to individual addresses, especially for critical network operations [PSN04]. Unwarranted network service outages can be caused by false positives, and by containment of benign scans. Net-Chaff can mitigate such risks. One solution is to use different containment criteria, depending on the value of the contained computer. For instance, a critical system could be contained only when scan detection is highly certain, or when dangerous scans are detected, e.g., from malicious worms. Arbor Network's worm-containment system employs a different solution for mitigating unwarranted network outages. This system monitors router logs to learn the network's normal communication paths, and its containment rules do not block those paths [PSN04].

4.1.2.5 Surveillance

Having contained the scan, Net-Chaff's surveillance component will set-up and conduct surveillance on the scan. For scans originating within the intranet, Net-Chaff builds a network tunnel between the scanner's subnet and the Net-Chaff server (4). For scans originating from the Internet, Net-Chaff builds a network tunnel between the gateway router and the Net-Chaff server. All of the scanner's packets are sent over the tunnel to the Net-

Chaff WAN server, including attempted scans of real computers. The primary objectives of surveillance are to confirm the scan and to collect intelligence for incident response and forensics. During surveillance, Net-Chaff's impersonation component will craft deceptive replies that: aid surveillance, reduce scan accuracy, and waste the scanner's time and other resources. This dissertation focuses on Net-Chaff's other components, and further design of the surveillance component is left for future research.

4.1.2.6 Net-Chaff LAN servers

Net-Chaff can also defend against scans within used subnets. This is done by deploying *Net-Chaff LAN servers* (5) on used subnets. A Net-Chaff LAN server is assigned all, or a portion, of the unused addresses within a used subnet. To enhance Net-Chaff's capabilities, the intranet's used subnets can be designed to be lightly populated by real computers, thus leaving a large number of unused addresses. For example, an 8 bit subnet has 254 addresses that can be assigned to computers. If half the addresses are used by real computers, there will be 127 unused addresses.

When the intranet's used addresses are grouped together in the address space, they are vulnerable to rapid discovery by sequential scans. Also, the grouping of used addresses can substantially reduce Net-Chaff's scan detection capabilities, as a sequential scan could encounter relatively few unused addresses. Ideally, for Net-Chaff, the intranet's used addresses would be randomly distributed within the entire address space, to avoid the problems from grouping. However, such a distribution is generally impractical. A more feasible solution might be for the used subnets to be randomly distributed within an address space. Also, within each used subnet, its used addresses could be randomly distributed. The distribution of used addresses is a topic left for future research.

When a Net-Chaff LAN server receives packets, it tunnels them to the Net-Chaff WAN server (1) for use in scan detection. The Net-Chaff LAN server also contains an impersonation component that crafts replies to the scanner. Containment and surveillance are performed by the WAN server, as described earlier. It is not necessary for all used subnets to have a Net-Chaff LAN server. However, if Net-Chaff LAN servers are not used, then it can be easy to detect the unused subnets that are managed by Net-Chaff's WAN server, i.e., only those subnets will have Net-Chaff impersonations.

4.1.2.7 Expected uses and benefits

Net-Chaff's expected uses and benefits fall into three categories: intrusion detection, intrusion prevention and intrusion response. A secure intranet environment affords a number of benefits for intrusion detection. Under our assumptions, monitoring traffic to unused addresses amplifies Net-Chaff's ability to detect scans, especially when the ratio of unused to used addresses is large. It is expected that Net-Chaff would receive packets primarily from five sources: hackers' scans, scans used for network management, end-users' addressing mistakes, broadcast packets from routers and network servers, and possibly other benign scans. The network management scans can be identified by restricting them to specific source addresses. Addressing mistakes, broadcast packets and benign scans are assumed to be low in volume and/or easily identified. The hackers' scans may be of several types. Most hacker scans are expected to be easily and accurately identified because of abnormalities such as packet volume, distinctive access patterns to addresses and ports, or unique signatures in the packets themselves (e.g., intentionally mal-formed packets) [Ark01, Naz04]. Of course, it is possible for hacker scans to be disguised to hide amongst the benign packets that Net-Chaff sees, but this would greatly limit scan capabilities. The advantage of Net-Chaff is that, by design, it filters out most of the legitimate traffic. This filtering amplifies the relative occurrence of harmful traffic and makes it more conspicuous. It provides Net-Chaff with a more sensitive anomaly detection mechanism and thus has a better chance of detecting disguised packets.

In contrast to Net-Chaff's monitoring of unused addresses, it is typical for network intrusion detection systems (NIDS) to monitor traffic over active network links. On these links, it can be very difficult to accurately identify malicious traffic from amidst the relatively large volumes of legitimate traffic [Naz04]. As far as the author knows, there are few systematic approaches that are constructed to deal comprehensively with intranet scans. One such system is Arbor Network's Safe Quarantine. Its detection mechanism faces the same difficulties as typical NIDSs, as it monitors the network's router logs [PSN04].

Another benefit from a secure intranet is that internal hacker scans are expected to be relatively infrequent, which allows Net-Chaff to log and analyze (e.g., correlate) all scan activity over long periods of time. The logs can be used for incident response and forensics, including the identification of new types of scans. Of course, once a new type of scan is identified, there are incident response concerns, such as where, why and how it occurred. In addition, Net-Chaff's long-term logs and log-analysis can also be used to detect slow scans. Detecting slow scans has been difficult for NIDSs that monitor network links, as the high volume of traffic limits logging capabilities [Naz04].

Net-Chaff is able to exploit scanning's inherent weaknesses. Scanning is used to explore unknown portions of the network. As a consequence, it is essentially impossible for active scans to avoid the unused addresses monitored by Net-Chaff. Further, as mentioned earlier, scans tend to use simple packets that can often be deceived to advantage. Also, Net-Chaff should be able to detect many active scans based on their anomalous traffic volume and traffic patterns. Many new and unknown scanners, including worms, should have these same types of detectable traffic.

Net-Chaff's secure intranet environment also affords advantages for intrusion prevention and response. For many such intranets, scan containment and response would be worthwhile, and even necessary, due to the potential losses associated with a scan, e.g., an infected laptop or internal hacker. Automated containment, which carries its own perils, should be possible due to: rapid and accurate detection, access to routers' ACL's, and domain knowledge that can be used to reduce the risks of automated containment.

In a routed intranet, it is fairly straightforward for a single Net-Chaff server to provide network-wide monitoring of traffic to the intranet's unused addresses. In contrast, it is difficult for an NIDS to provide network-wide monitoring of all network links, because of the number of links that need to be "spanned" or "tapped", and the volume of legitimate traffic. In addition, the intranet provides opportunities to shape network traffic so that scans are detectable, e.g., the use of router ACLs in preventing source-address spoofing.

Ultimately, Net-Chaff's effectiveness must be assessed relative to its ability to thwart hacking, both manual and automated. In the overall hacking process, scanning is often a key initial step [MSK99]. Scanning has been one of hackers' strengths, as it often allows them to obtain useful network information quickly, accurately and stealthily. By rapidly detecting and containing scans, Net-Chaff can stop scan-initiated hacking, when it first starts. This makes scanning a critical vulnerability for hackers. In fact, Net-Chaff should be able to prevent worms from spreading on an intranet because it not only detects scans, but also contains the source. NIDS developers have identified three conditions that must be met to stop worms, and Net-Chaff fulfills all of them: 1) "the worm must be detected and characterized before it has a chance to infect a critical mass of hosts", 2) "worm suppression must be accomplished nearly automatically, without jeopardizing critical business processes", and 3) "detection and suppression must be applied to the internal network as a whole, not just at the Internet perimeter" [PSN04].

One of the major benefits of the Net-Chaff concept is that it can increase intranet security without affecting legitimate network operations. Intranets often have a highly-secure network perimeter, but relatively low security within the perimeter. The internal network is a trusted environment and its low security makes operations much easier, e.g., file sharing. However, for commercial organizations, it is estimated that 50% of security problems originate internally [Yua05]. Net-Chaff offers a means for countering such internal threats without making legitimate operations more difficult or costly on daily basis. Of course there is a cost for Net-Chaff itself, including: the deployment of appropriate routing engines and network design, system installation, and on-going operating costs.

4.1.3 Requirements

This section presents Net-Chaff's primary requirements. They provide the basis for the Net-Chaff analysis, which is presented in Chapter 5. First, scanning is presented, from Net-Chaff's perspective. Then, Net-Chaff's performance objectives are presented.

4.1.3.1 Scanning

This section describes hacker scanning, from the perspective of system requirements for Net-Chaff. Arkin defines scanning as, "a technology, which uses stimuli (packets) in order to provoke a reaction from network elements. According to responses, or lack thereof, received from the queried network elements, knowledge about a network and its elements will be gathered" [Ark05]. A scan consists of one or more probes. The scan packets sent to learn about a network address will be referred to as a scan *probe*. Within a probe, an individual packet is referred to as a *probe packet.* The packets received in response to a probe are referred to as a *probe reply*, or a *probe response.*

A probe can consist of one or more packets, and the packets may, or may not, be synchronized. A probe's successful completion may, or may not, require a reply from the address being probed. Figure 4.1.3.1-1 illustrates. (A) is a single-packet probe with no required response, e.g., a single-packet UDP attack, used in a scan-and-attack. (B) shows a single-packet probe, with a required response, e.g., an ICMP ping. (C) is a multi-packet probe, that is synchronized with a required probe response, e.g., as in a TCP half-open scan [Fyo04]. There are many other possible combinations of probes and responses.

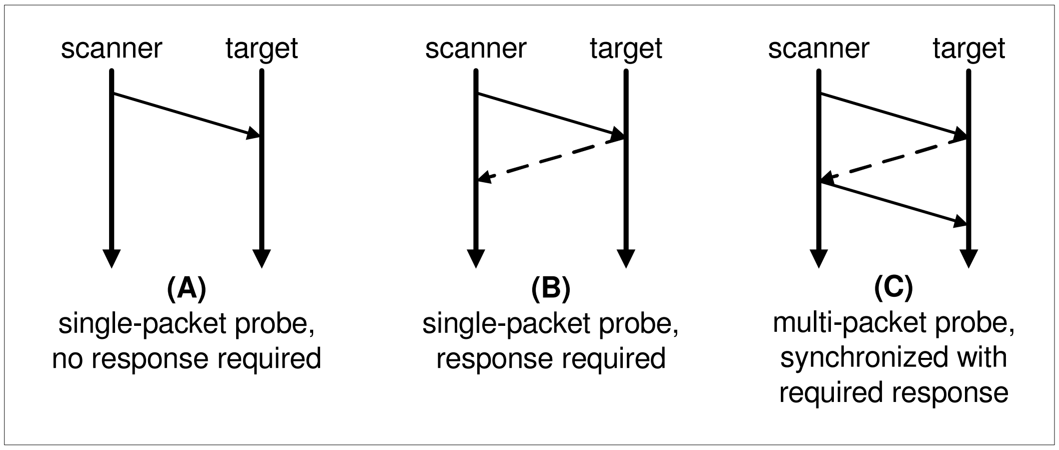


Figure 4.1.3.1-1 : Examples of probe types

4.1.3.1.1 Scan objectives

The overall objective of scanning is to obtain some information about a network and its computers. There are various types of scans, and they can be categorized according to the type of information that they obtain [Ark01, MSK03, VVZ02]. The types of scans that are most relevant to Net-Chaff are listed in **Table 4.1.3.1.1-1**. These scans are widely used, and Net-Chaff's low-level impersonations are intended to counter them. There are other types of scans, but those that the author is aware of are similar to these scans from the perspective of how Net-Chaff counters them. Two examples are application-layer vulnerability scans and processor fingerprinting. The scan-and-attack is listed in the table's last row, and it was defined earlier (section 4.1.1). The scan-and-attack is unlike other scans, as it includes an attack. Other types of scans just collect information and may be a predecessor to an attack.

Table 4.1.3.1.1-1 : Common types of scans, categorized by the scan objective

Scan name	Scan objective	Examples
host scan	find computers	often one small packet per host, e.g., ICMP ping, ACK ping, ARP request
port scan	find servers	sends one or more packets per port (TCP or UDP)
O/S fingerprinting	determine a host's operating system type	send a set of packets that elicit responses unique to a particular O/S; typically does not work well if no servers are running on the host
server fingerprinting	determine a server's make and version	banner grabbing; for TCP, requires opening a full connection to a server
network mapping	locate routers and determine what hosts and routers are connected to them	traceroute; there are several ways of tracing routes through the network; probes are invariably multi-packet and require replies
firewalking	determine a firewall's filtering rules, and what hosts and servers lie behind it	use packets with an IP TTL that expires one hop past the firewall; typically a multi-packet probe that requires replies

Table 4.1.3.1.1-1 (continued): Common types of scans, categorized by the scan objective

scan-and-attack	compromise computer	attempt connection, and if successful, launch attack; for TCP, this a multi-packet probe that is synchronized with required replies

4.1.3.1.2 Combining scans with attacks

For hackers, scans are a part of the larger hacking process. There are general techniques for using scans within the hacking process, and they will be referred to as *scan-usage techniques*. Three common techniques are described here, and they are modeled from the perspective of Net-Chaff design and analysis. Specific examples are given to illustrate the models. The examples will also be used in the evaluation of Net-Chaff in chapter 5.

Scan-and-attack: S*can-and-attack* works by choosing addresses and directly attacking them. This is a simple technique, and it has been used in worm propagation [Naz04]. For example, the Sapphire worm conducts a UDP scan-and-attack. It uses a single UDP attack packet, which it sends to random addresses. The packet is approximately 400 bytes, and it carries the code both to break into hosts, and to propagate itself.

A second example of scan-and-attack is provided, using TCP. It is loosely modeled after the Slapper worm's web-server attack [Naz04]. **Figure 4.1.3.1.2-1** illustrates. In this model, the scanner randomly chooses addresses and attempts to connect to them. If a web-server is not accessible, an ICMP message is returned. If a server is accessible, TCP OPEN is performed, then the server sends its banner, and finally, the scanner sends a single 400-byte attack packet. This TCP scan-and-attack uses a multi-packet "probe" that is synchronized with required responses from the probed host, and that also contains attack code.

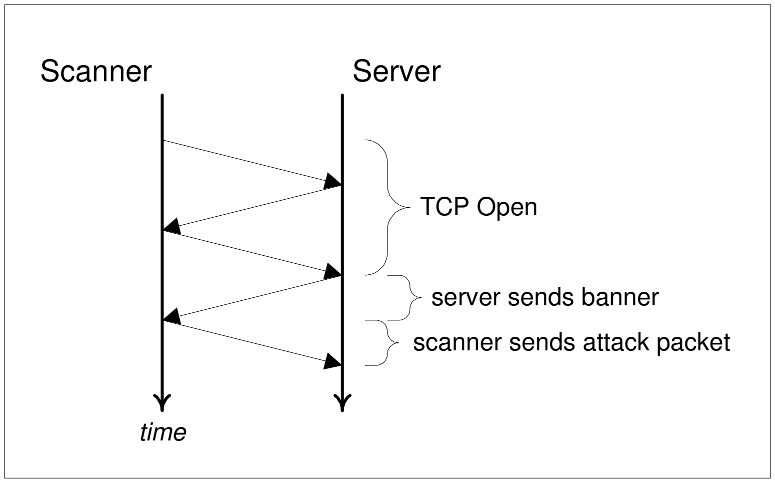


Figure 4.1.3.1.2-1 : TCP scan-and-attack

Filtering scan: The second scan-usage technique is called a *filtering scan*. This scan is the first part of a two-step process. In the first step, the filtering scan locates prospective computers, and in the second step, the prospective computers are accessed. Typical forms of access are an additional filtering scan, and/or an attack. While step one can be a single-packet probe, it does require a reply from the scanned host. The algorithm for filtering scans is:

```
WHILE (addresses left to scan)
        perform the filtering-scan on a set of addresses
        access prospective computers found
END WHILE
```

For the filtering-scan, the set of addresses scanned can vary in size from one to the whole network. On networks protected by Net-Chaff, an effective technique is to use the filtering scan until a prospective computer is found, and then access that computer. From the perspective of the attacker, this model can maximize the number of prospective computers accessed before containment. Often, the filtering scan's purpose is to provide efficiency over direct access to the addresses, e.g., speed-up the scan. For the hacker, a filtering scan is useful if:

[(time for filtering scan on all addresses) + (time to access prospective computers)] <
(time to directly access all addresses)

This calculation applies when the number of successful accesses is the same with, or without, the filtering scan. This is often the case when there are no scan defenses.

As an example, a filtering scan could be used to speed-up the UDP scan-and-attack that was presented earlier. It sends a 400-byte UDP packet to network addresses, but typically, the targeted UDP server only runs at a small fraction of those addresses. A UDP scan, such as the one offered by nmap [Fyo04], could be used as a filtering scan. This scan's probes use a 0-byte UDP packet. If an ICMP message is received in reply, then the targeted port is inaccessible, otherwise, the port may be open. The UDP scan could be performed quickly by using parallel scanning techniques to continuously transmit probes. This filtering scan could prevent sending the 400-byte attack packet to addresses without servers, and thereby speed-up the overall attack.

Information-retrieval scan: The third scan-usage type is the *information-retrieval scan***.** From Net-Chaff's perspective, this scan just involves the collection of information for some later purpose. If the scan discovers computers, any attempts to attack the computers, or further access them, occur after Net-Chaff has contained the scan. Examples of this scan include host scans, such as ICMP ping, and port scans, such as UDP scans and TCP SYN scans [Fyo04]. If a filtering scan is used, and prospective computers are not accessed before containment, then the filtering scan will look the same as an information-retrieval scan.

4.1.3.1.3 Scan tactics and techniques

Numerous scanning techniques have been implemented in many different scanning tools [Ark99, Fyo04, MSK03, VCI99]. McClure, et al., provide a review of scanning process and methods, and they describe five scanners than run on Unix, seven that run on Windows, and two fingerprinting tools [MSK03]. They also describe numerous scanning and fingerprinting techniques. Some of the scanning tactics and techniques are especially relevant in the Net-Chaff context, and they are summarized here.

4.1.3.1.3.1 Address-selection

For each scan probe, the scanner chooses an address from the network space. There are several address-selection techniques used by hackers, including worms [Fyo04, Naz04]. The techniques that are most relevant to Net-Chaff are those that are effective on intranets. Two types of address selection are *sequential* and *random*. For a given address range, address selection can be made sequentially (i.e., address n+1 is selected after address n), or addresses can be selected randomly.

There are two techniques for choosing random addresses. The most efficient technique chooses addressees from among those that have not already been chosen. Borrowing from probability theory, this selection technique will be referred to as *sampling without replacement*. The other technique randomly selects addresses from within the entire address space, which is *sampling with replacement*. The latter is less efficient because an address can be selected more than once. In addition, when there are multiple simultaneous scans (e.g., a distributed scan), an address can be probed more than once, unless the scanners' use sampling without replacement in a coordinated way.

A technique that is used by worms is called *island hopping*. It selects addresses randomly, but addresses near the scanner are more likely to be selected. This technique takes advantage of the tendency for computers to be clustered in the Internet space. As the worm propagates, its descendents will be more likely to select addresses near themselves. The island hopping technique can also be adapted for use in scanners that do not propagate. The scanner would randomly choose addresses, and once a computer is found, the scanner would then choose addresses near that computer. Borrowing from the numerical optimization field, if a successive set of addresses does not yield a result, an attacker may chose to "hop" elsewhere by deliberately choosing random addresses at remote locations, to see if it can hit another "island."

4.1.3.1.3.2 Scan performance

Three scan performance-attributes are: speed, accuracy, and stealth. These attributes typically counter each other, i.e., improving one may degrade another.

Speed: There are a number of known techniques for increasing scan speed. A single scanner can send probes in parallel, rather than serially [Fyo04, VVZ02]. Further parallelization can be achieved by using distributed scans [Ark05, VCI99]. Arkin presents scanning techniques that reduce the amount of probe data needed for fingerprinting [Ark01]. Increasing scanning bandwidth, on the part of the attacker, can speed-up scans. However, there is a risk of degrading network performance and dropping scan packets, which can cause the scan to be detected or get incomplete information [Ark05, Fyo04, TB98].

To scan a large number of addresses quickly, it is advantageous for probes to use: a small number of packets, small-sized packets, and packets that can be easily sent in parallel. This makes simple host and port scans appealing, such as ICMP ping, and TCP SYN scans [Fyo04]. In general, such fast scans will be vulnerable to Net-Chaff's low-level impersonations. Further, all scans that are not one-packet scan-and-attack probes do require some response which can be delayed or made misleading, in order to provoke more dwell time over an address.

Accuracy: For a particular type of scan, accuracy of the information that the scanner receives back is affected by dropped packets, which can occur when the scan exceeds the available bandwidth [Fyo04]. Another affect on scan accuracy is firewalls that intentionally do not reply to scans [Rus02]. The lack of a reply has the same result as a dropped packet. In addition, scanners can receive deceptive reply-packets that result in false positives and false negatives. Honeypots can defend in this way, as well as individual hosts, through host-firewalls and deceptive services such as Portsentry [Row06].

Flow-control is a challenging problem for scanners, and it can be used to the defender's advantage. The network capacity can vary unpredictably by time and location, so for scans to be accurate, they typically need to be performed at a conservative rate [Fyo04]. The reduced scanning speeds will aid Net-Chaff's containment process. Further, when Net-

Chaff does not reply to scan packets, the scanner is likely to suspect dropped packets and retransmit them, as nmap does [Fyo04].[18] Such retransmissions will reduce the effective scan rate.

Stealth: Scan stealth has to do with avoiding detection. One way that an NIDS detects scans is by their distinctive traffic patterns, such as a high data volume, or a high flow rate of probes [e.g., Gof02, Ras04, Zhe04]. Stealth techniques for scan traffic include: scanning from multiple sources, slow scans, the selection of random addresses and ports (serial sequences are easily detected), etc. [Ark99, Naz04, Fyo04, VCI99]. Scans can also be hidden by exploiting specific NIDS weaknesses, many of which have to do with resource limitations in monitoring high volumes of traffic [e.g., Gof02]. Examples include the use of fragmented packets (if not reassembled, then scan signatures are hidden), slow scans (exceed the detection timeframe), invalid packets (may not be logged, e.g., if out of order, or the header is incorrect) and so on [Ark99, Fyo04].

Decoy scans attempt to hide the scan's true source address by sending many copies of the real scan packets, but with fake source addresses [Ark99, Fyo04]. One basic stealth technique is to not generate high volumes of traffic that visibly impact normal network operations [Fyo04, TB98, Zhe04]. Another form of stealth is scanning techniques that pass through network filters such as firewalls [Ark99, MSK03]. One thing in common for all stealth techniques listed here is that they have little, or no, effect against Net-Chaff's detection and containment capabilities.

4.1.3.1.3.3 Scanning techniques

This section discusses scanning techniques that are especially relevant for Net-Chaff.

Scan scope: Scans can be differentiated by their scope on the network [Naz04]. A *host scan* is a scan of multiple services or protocols on a single host; for example a scan of all "Well Known Ports" ports (1-1024) on a particular web server. A *network scan* is a scan of one or more services on multiple hosts; for example a scan for web servers at all intranet

[18] See the nmap source code.

addresses. Scanning many ports on a single machine can be very time consuming [Wol02]. Thus host scans tend to be used on specific computers that are of particular interest. On the other hand, network scans would typically be used to survey the network for particular vulnerabilities or assets. Net-Chaff is intended primarily for use against network scans, as there is little reason for performing host scans against most Net-Chaff managed addresses.

Banner grabbing: The Net-Chaff null server can be configured to return no data, or random data. In either case, if the scanner connects to the server, as with banner grabbing, then the scanner can potentially detect the impersonation. However, the purpose of the Net-Chaff null server is not to be believed at the application layer, but to slow down the scan.

Firewalking: Firewalking uses ICMP and traceroute-like packets to attempt to discover computers behind a firewall, and to discover the firewall's filtering rules [Ark99, Ark01]. This scanning technique presents opportunities for Net-Chaff to use its low-level impersonations to impersonate both a firewall and the hosts that lie behind it. This follows one of the deception principles from chapter 3: an item that is expected to be hidden can often be impersonated by providing simple indicators of its existence. Within the intranet, Net-Chaff can impersonate internal firewalls, and even perimeter firewalls—to defend against external scans that have penetrated the perimeter.

O/S fingerprinting: Operating system fingerprinting works largely by detecting peculiarities in the operating system's networking stack [Ark01, Bec01, Fyo02, WWJ03]. Probes are sent to elicit replies that are unique to particular operating systems. Two causes for these unique replies are ambiguities in network protocol specifications and optional features of protocols. Another cause of unique replies is protocol implementation errors. Whereas Net-Chaff's low-level impersonations are relatively easy to implement, accurately impersonating a particular network stack's idiosyncrasies could be extremely difficult. One solution is for Net-Chaff to use real operating systems to generate replies to O/S fingerprinting scans. This problem is left for future research.

Inverse mapping: Firewalls are often configured to hide computers by not replying to disallowed packets. On the other hand, routers are configured, by default, to send ICMP messages in reply to undeliverable packets [Bar95]. When both of these conditions exist, scanners can find hidden computers via probes for which there is no reply. This scan technique is called *inverse mapping* [Ark01]. One way to prevent inverse mapping is to configure routers so they do not send revealing ICMP messages. There is increasing appeal, within intranets, to deliberately do this for security and to reduce unnecessary traffic. Net-Chaff's deceptions must take into account the network's use of non-response for scan probes. This problem is left for future research.

4.1.3.2 Performance objectives

This section describes Net-Chaff's primary performance objectives: its tactical objectives and its deception and hiding objectives. Net-Chaff defends against hackers' active scans. Net-Chaff's *tactics* have to do with its interactions with hackers and their scans; these tactics were described earlier, and examples include the techniques for scan detection and containment. Net-Chaff's *tactical objectives* are its specific goals for defending against scans. For example, one goal of containment is to reduce scanner's access to vulnerable systems. An understanding of Net-Chaff's tactical objectives is necessary for understanding its design, evaluation and deployment.

Net-Chaff uses deception and hiding as a means to achieve its tactical objectives. These uses of deception and hiding were described earlier, e.g., Net-Chaff's low-level impersonations. Also, deception and hiding are the focus of this dissertation. Net-Chaff's *deception and hiding objectives* are the specific goals for its uses of deception and hiding. As an example, one objective of the low-level impersonations is to slow-down scans prior to containment. An understanding of Net-Chaff's deception and hiding objectives is necessary for evaluating and employing these means for scan defense.

4.1.3.2.1 Tactical objectives

Net-Chaff's tactical objectives fall into two categories:

- defending against scans, and
- defending Net-Chaff itself.

Net-Chaff's objectives for defending against scans can be divided into three sub-categories:

- detecting and containing scans,
- thwarting hackers after containment, and
- obtaining information needed for incident response.

In detecting and containing scans, Net-Chaff's ultimate objectives are to reduce the scanner's access to the network, and especially access to high-valued and vulnerable systems. As will be shown in the next chapter, calculations can be made to estimate the number, and types, of computers that scanners can access before containment.

There are three ways that Net-Chaff thwarts hackers after containment. First, Net-Chaff's impersonations can insert false positives within the hacker's scan results, and thereby reduce the usefulness of the information obtained. Secondly, if hackers later act on these false positives, then the access can be detected by Net-Chaff. Thirdly, Net-Chaff provides information needed for incident response, including the scan source and scan techniques used. Net-Chaff obtains this information through detection and surveillance, and its impersonations induce the scanner to send more information than it would otherwise to unused addresses.

Net-Chaff's objectives for defending itself can be divided into two sub-categories. Net-Chaff must thwart hackers in their attempts to:

- hack the Net-Chaff systems themselves, including the Net-Chaff WAN and LAN servers, and the router containment functions, and
- detect or circumvent Net-Chaff's deceptions.

Preventing hacking of the Net-Chaff systems involves standard host and network security-measures, including protection from denial-of-service (DoS) attacks. For instance, both the detection and containment capabilities can potentially be degraded by packet floods. However, Net-Chaff's system security, and protection from DoS attacks, are not being addressed by this research. This research does address defenses for thwarting hacker's attempts to detect or circumvent Net-Chaff's deceptions, as discussed in the following section.

4.1.3.2.2 Deception and hiding objectives

This section discusses Net-Chaff's deception and hiding objectives, as defined earlier. Hiding includes both deceptive and non-deceptive hiding. Ultimately, deception and hiding are used to achieve Net-Chaff's tactical objectives.

Net-Chaff's detection and containment functions rely upon a large number of unused addresses. The unused addresses serve to hide real systems from the scanner. Even without Net-Chaff and its deceptions, the unused addresses reduce the rate at which real computers are probed (i.e., real computers per probe); we will refer to this effect as *passive hiding* because it is independent of Net-Chaff. Assigning a large number of unused addresses to Net-Chaff makes detection occur quickly, and it enables the impersonations to reduce the scanners' probe rate (i.e., probes per unit time). Net-Chaff's *active hiding* techniques include impersonation, detection, containment, and surveillance. The next chapter presents analytical models that calculate the unused addresses' contributions to Net-Chaff's detection and containment capabilities.

Deception planning was presented in chapter 3. In review, its key element is the *deception objective*, which is the desired result of the deception operation; it consists of: 1) the intended *target action*, and 2) the *deception exploit*, which explains how the target action is used to advantage. The *desired perception* is what the target must believe in order for it to take the intended action. The *deception story* is an outline of how the computer system will be portrayed so as to cause the target to adopt the desired perception, and take the intended action.

In deception-planning for Net-Chaff, a deception objective is needed for each of its uses of deception. **Table 4.1.3.2.2-1** lists Net-Chaff's uses of deception for defending against scans. Each row describes a particular use of deception. The first column states its deception exploit. The deception exploit is described in terms of the tactical objectives that it supports. The second column describes the target action that is to be exploited. The third column gives an example deception (story) that is intended to induce the target action.

Table 4.1.3.2.2-1 : Net-Chaff's uses of deception for defending against scans

Deception Exploit	Intended Target Action	Example Deception (Story)
reduce the number of real computers accessed before containment	slow down the scan by causing the scanner to send extra packets or to wait	low-level impersonations induce scanners to send more data than they would to unused addresses; impersonations can use delays to slow serial scans
detect scans quickly (relative to the number of addresses probed), and detect scans accurately	cause the scanner to send packets whose signatures make detection faster and more reliable	low-level impersonations induce scanners to send more information than they would to unused addresses
acquire information needed for incident response	cause the scanner to send packets that reveal its: capabilities, intentions, course of action	
provide false positives that reduce the usefulness of the scan results and thereby hide real systems	cause the scanner to receive false positives	low-level impersonations provide false positives for many scan types

Another use of deception involves detecting attacks that occur after the scan. Even when the scan is contained, the attacker may later access or attack the systems discovered by the scan. By providing false positives, the attacker can be induced to later access addresses where Net-Chaff provides impersonations. Net-Chaff can potentially detect and contain such follow-on access. The knowledge gained from detecting the original scan can help in detecting the follow-on access, and it can also provide lead-time for containing the follow-on access.

Net-Chaff's tactical objectives include defending Net-Chaff itself, and deception is a means for doing that. Specifically, deception is used to thwart hacker's attempts to prematurely discover:

- Net-Chaff impersonations, and
- unused portions of the network.

Deceptive hiding is used to prevent such discoveries. (This is a form of Net-Chaff's active hiding.) For instance, Net-Chaff uses low-level impersonations, and a scanner can always discover such deceptions by connecting to the null server. However, making such connections, for every Net-Chaff managed address, can be very time consuming. As a countermeasure, hackers could find indicators that allow scanners to detect Net-Chaff managed addresses, without connecting to every null server. For example, a routed intranet is configured so that all used subnets have a gateway at host address 1 within the subnet. Further, each gateway has UDP port 123 open for NTP (network time protocol). If the Net-Chaff-managed subnets do not impersonate such a gateway at host address 1, then the entire subnet can be detected as a fake, simply by probing port 123 at host address 1.

Net-Chaff must hide indicators that allow scanners to prematurely detect impersonations and the unused portions of the network. We will refer to this as *hiding Net-Chaff*. Deception is used to hide Net-Chaff, and the deception objective consists of: 1) the target action is to not detect Net-Chaff impersonations prematurely, and 2) the deception exploit is to allow Net-Chaff's impersonations to work as intended, without being detected prematurely. In fact, when it comes to using false positives to reduce the usefulness of information-scan results, it is essential that the scanner does not recognize impersonations as such before containment.

The scanner's efforts to prematurely detect impersonations, and the unused portions of the network, are referred to as *Net-Chaff detection.* The hiding model from Chapter 3 can be used to understand how Net-Chaff can hide its impersonations. In general, to detect Net-Chaff impersonations, the scanner will use the discovery process of *investigation.* The hiding model explains how the scanner's investigation process can be defeated in order to hide Net-Chaff. The scanner cannot observe Net-Chaff directly, but it can potentially detect evidence of impersonations. Net-Chaff can hide by simply not creating the evidence that the scanner needs for Net-Chaff detection. This is accomplished by making the low-level impersonations adequately realistic. The degree of realism needed depends on the scanners' detection capabilities, and also, cost-benefit constraints.

The hiding of impersonations limits the amount of impersonation that can be used. For example, to slow down all possible port scans, a Net-Chaff-managed subnet can impersonate servers at every address and every port. However, such impersonations could be detected by simply pinging a port that real servers are unlikely to use, e.g., 50383. Thus, hiding Net-Chaff-managed subnets requires that most ports be closed. This limits the use of impersonation and its benefits in detecting and slowing-down scans.

From the above we see that Net-Chaff's hiding objectives can conflict with its other objectives. However, many scanners will not attempt to detect Net-Chaff, so a portion of the Net-Chaff-managed addresses could use impersonation without regard to detection. For instance, some Net-Chaff managed subnets could be "tar-pits" that are maximized for slowing down scans, without regard to detection. These subnets can use low-level impersonations extensively, and also, other delay tactics such as those used by LaBrea [LaB05]. To defend against scanners that attempt to detect Net-Chaff, the intranet's other subnets can be optimized for hiding Net-Chaff.

4.1.4 Summary

Net-Chaff is intended for defending against hacker scans within a protected intranet, e.g., inside a corporate network. This chapter described how Net-Chaff works. Net-Chaff's major functions are scan detection, scan containment and scan surveillance. Net-Chaff works by monitoring an intranet's unused addresses. It also impersonates computers at the unused addresses, which can impede scanner's progress and improve Net-Chaff's defensive effectiveness. Net-Chaff appears to provide substantial improvements over current scan defenses, including a simple and effective means for monitoring the whole network and detecting scans. The Net-Chaff design uses, for the most part, existing computer-security components, but Net-Chaff combines and applies them in a novel way. This section also framed Net-Chaff's requirements for scan defense. These requirements provide the basis for the Net-Chaff analysis, which is presented in Chapter 5.

4.2 Honeyfiles: deceptive files for intrusion detection

The Honeyfiles system is described in a conference paper [YZD04]. The paper is in the appendix.

5 Evaluation

This chapter presents evaluations of the two deception process-models discussed in previous chapters, within the context of the two novel intrusion detection systems: Net-chaff, and Honeyfiles.

5.1 Net-Chaff

This section analyzes Net-Chaff's performance, including its use of deception. This analysis will be referred to as *the Net-Chaff analysis*, and it includes analytical and simulation models of Net-Chaff's performance. In addition, Net-Chaff is analyzed from the perspective of the hiding model presented in chapter 3. The model is used to understand the role of hiding in Net-Chaff's functionality and performance. This section also includes discussion of Net-Chaff's limitations and Net-Chaff-related future research.

Net-Chaff's performance objectives were presented in chapter 4, and they include its tactical objectives and its deception and hiding objectives. The Net-Chaff analysis presented here addresses a subset of these objectives. The performance objectives addressed are:

- **reduction in the scanner's access to the network** being protected, and especially access to high-valued and vulnerable systems on that network. Net-Chaff does this by detecting and containing scans. The analytical models focus on calculating the number, and types, of computers that scanners can access before containment. The **primary metric** is the number of vulnerable computers accessed by the scanner, before the scan is contained.
- **the use of deception and hiding** to achieve Net-Chaff's tactical objectives. The Net-Chaff analysis focuses on Net-Chaff's primary uses of deception and hiding. They include: 1) the use of low-level deceptions, and large numbers of unused addresses, to slow-down scans, and 2) the use of low-level deceptions to provide false positives that reduce the usefulness of the scan results.

Net-Chaff can be used in many different contexts, each with varying security objectives, network topologies, and scanning threats. This analysis models one such context for Net-Chaff deployment, but the models are adaptable to other contexts. This context includes an enterprise network configuration and the three scan types described in chapter 4: scan-and-attack, filtering scans, and information-retrieval scans.

The Net-Chaff analysis is presented in the following subsections. The analytical models are presented first. The simulation is presented next, and it is used to verify the analytical models. The hiding analysis is then presented. Net-Chaff's limitations and future research are also analyzed. A final section summarizes the findings from the Net-Chaff analysis.

5.1.1 Analytical models

We next present the analytical models as they apply to Net-chaff's performance, for what this work considers typical networks and scans. The analytical models are based on the scanners' probe rates, so they are referred to as the *rate-based models*.

5.1.1.1 Definitions, assumptions, context and environment

This section presents assumptions and descriptive models that form the basis on which the analytical models are constructed. The descriptive models build on the Net-Chaff design and requirements presented in chapter 4.

5.1.1.1.1 Scanners

Scanner performance is modeled assuming a best-case, or very favorable, environment for the attacker, in order to show worst-case outcomes for Net-Chaff. Discussion here focuses on a single scanner rather than a group of scanners. Multiple scanners are addressed in the next section.

A scanner is assumed to run on one attacking computer. The scanner uses one full-duplex network connection. When the scanner sends or receives a packet, it does so at a fixed rate, e.g., 1Mbps. This rate will be referred to as the scanner's *available bandwidth*. It is assumed the network link is symmetrical and operates in duplex mode, e.g., each direction supports 1Mbps. It is assumed that the scanner can only send one packet at a time through its network connection to the intranet under consideration.

It is also assumed that the scanner sends probes and receives probe replies, and these two tasks occur in parallel (duplex mode). The scanner probes random addresses on the intranet. The three scanning techniques of interest here are scan-and-attack, filtering scan, and information retrieval scan. We consider two random-selection techniques: sampling with replacement and sampling without replacement. Scanners can use other techniques for address selection, but this is left to future research.

The scanner's **rate** is measured in probes-per-second. An average probe transmission rate is calculated, based on the number of packets sent and the bandwidth used. Definitions and models of the scan rates and probes are further described in section 5.1.1.1.3.

The network in which scanning takes place is assumed to have no packet drops (ideal router queues, no media limitations, etc.). However, scan targets may intentionally drop probe packets. Packet delays are assumed to be finite and within acceptable ranges for normal network operations. To model latency, an average value for the network is specified. As used here, *latency* is defined as being the duration of the one-way trip: the time from just after a packet is transmitted to the time when the packet's last bit arrives at the destination's network interface. Packet transmission times are a function of the packet size and the bandwidth used by the scanner. Round trip times, e.g., for ICMP ping, include the transmission times of the outgoing packet and its reply packet, and also the latency to and from the target.

5.1.1.1.2 Net-Chaff

This section describes models of the Net-Chaff system, including its scan-defense mechanisms, performance, and environment. In this model, the Net-Chaff detection mechanism functions by counting probes. Scan detection (by Net-Chaff) occurs once a certain number of probes have been received from the scanner. This number is called the *detection threshold*. In practice, Net-Chaff can use additional probe detection mechanisms that provide an improvement over this simple threshold-based mechanism. For example, some scans can be very quickly identified by a unique fingerprint in their packet headers, such as the absence of TCP flags in nmap's *Null* scans [Fyo04]. The threshold-based detection model was chosen because it is simple, and it provides a worst-case view of Net-Chaff.

From Net-Chaff's perspective, the scan is a sequence of probes, ordered by the time of their initial transmission. Figure 5.1.1.1.2-1 illustrates. Probe destinations are chosen randomly, and probes can go to Net-Chaff-managed addresses or to real computers. Probes can also go to *unallocated addresses*, which are not allocated to either real computers or to Net-Chaff. It is assumed that the Net-Chaff WAN server receives packets in the order in which their transmission started. This is an approximation, as in practice, the WAN server receives packets sent directly from the scanner, and those forwarded from the Net-Chaff LAN servers. Also, in practice, the packets' ordering can be changed, and packets dropped, due to routing, possibly over multiple paths.

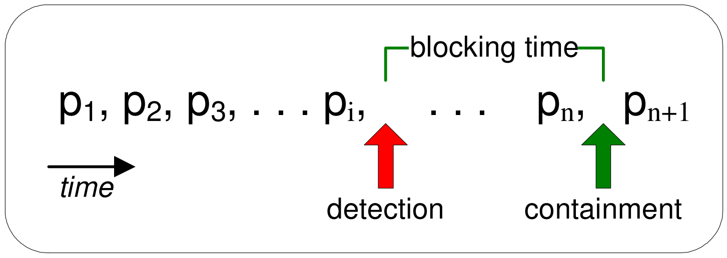

blocking time
$p_1, p_2, p_3, \ldots p_i, \quad \ldots \quad p_n, \; p_{n+1}$
time
detection
containment

Figure 5.1.1.1.2-1 : Scan probes, from Net-Chaff's perspective

Let the detection threshold be **z** packets, and let probe $\mathbf{p_i}$ be the $\mathbf{z}^{\mathbf{th}}$ probe sent to a Net-Chaff-managed address (z <= i). In the figure, detection occurs when probe $\mathbf{p_i}$ arrives at the Net-Chaff WAN server. Once Net-Chaff detects the scan, it then initiates containment. The time from detection to when containment goes into effect will be called the *blocking time* (b). From the figure, **n** probes will have been sent at the point of containment. However, at this point, any probes that are in progress ("in flight") will not be completed. Consequently, the number of completed probes will be less than or equal to **n**.

The Net-Chaff analysis focuses on an individual scanner. It is assumed that this scanner uses a single source-address. Multiple scanners can be modeled by repeated application and interleaving of the model of an individual scanner. For each intranet subnet, and for the Internet gateway, containment will be initiated by the first scan that is detected there. When a scanner uses multiple source addresses, the scan will appear to Net-Chaff as multiple scanners.[19] When Net-Chaff detects multiple scanners, it could lower its detection threshold, to better counter the threat. The analysis of Net-Chaff's interactions with multiple scanners is left for future research.

The following variables are used in this context. Of course, the true averages, or mean values, are limits that are achieved as the number of network scans approaches infinity. In practice all averages will be estimates of the mean value.

$\bar{C}$	the average number of probes that a scan completes prior to containment
$\bar{C}_i$	the average number of probes that a scan completes prior to containment, and that have a probe response of type **i**. Probe-response types are discussed in the next section.

Two important outcome variables are:

$\bar{C}_{VULN}$	the average number of vulnerable computers that a scan accesses, prior to containment
$\bar{C}_{AFF}$	the average number of computers that respond affirmatively to the scan, prior to containment; it is used for analysis of the information-retrieval scan.

5.1.1.1.3 Probes

Analytical models shown here are for: a) the UDP and TCP scan-and-attacks, b) a filtering scan with the UDP scan-and-attack, and c) an information retrieval scan that uses ICMP ping (see chapter 4 for scan descriptions). These specific examples are used to

[19] As described in chapter 4, the Net-Chaff design assumes that intranet routers drop packets from a directly attached subnet if the packet's source address is not from that subnet.

illustrate scan outcomes. The analytical models can be adapted to other scan types.

Scan probes are modeled for the purpose of calculating scan outcomes at the point of containment. Probes are categorized according to the type of probe response that is received. The categories are referred to as *probe-response types*. Table 5.1.1.1.3-1 lists the probe-response types used in the analytical models, for the servers that are being probed, e.g., web servers. The category “no server present” refers to the responses received when there is no server at the address being probed. For this model, it is assumed that the response is an ICMP message, such as “host unreachable” or “port unreachable”. The categories in Table 5.1.1.1.3-1 are for analyzing Net-Chaff’s effects on scans. Additional probe categories can be used to analyze affects from additional deception sources, such as honeypots, and firewalls. These additional categories, and their analyses, are discussed in section 5.1.1.5.

Table 5.1.1.1.3-1 : Probe-response types

Responder	Probe-Response Type	Symbol Used in Models
Net-Chaff	server impersonation	nc_imp
	no server present, e.g., ICMP “host unreachable” message	nc_ns
real computer	secure server	sec
	vulnerable server	vuln
	no server present, e.g., ICMP “host unreachable” message	ns

Net-Chaff analysis is performed for a particular type of scan and a particular network configuration. The network configuration includes specification of the *probe-response types’ distribution* on the network. For each probe-response type, the number of addresses that respond in that way are specified. The location of those addresses is not relevant in this analysis because the scanner chooses addresses randomly.

Probe transmission is modeled by calculating a *probe rate* for each probe-response type. The rate is in probes per second. The rate is an estimate, and it is calculated differently for serial and parallel probe transmission (see discussion below). These calculations are described here, using the example TCP scan-and-attack from chapter 4.

For a serial scan, the scanner processes one probe at a time, and a new probe is started immediately after a probe ends. A probe ends once it has finished the latter of: sending its final probe packet, or receiving its final probe response. The *probe completion time* is the amount of time it takes to complete a probe, and it is the difference between the probe's start and end times. For a particular probe-response type, it is assumed that all probes have the same probe completion time. The time to process a single probe can be calculated based on: the transmission time [20] for the probe packets and their replies, the order in which packets are sent, latency, and any delays at the scanner and at the probe destination. More detailed probe-rate calculations are provided with the analytical models.

The serial transmission of probes, for the scan-and-attack example, is illustrated in Figure 5.1.1.1.3-1. For the first probe, transmission of its first packet begins at time t_1. The probe is completed when transmission of its last packet ends, at time t_2. The probe completion time is (t_2-t_1). Also, at time t_2, transmission begins for the second probe's first packet. Due to network latency, the first probe's last packet will arrive at the server after t_2. For scan-and-attack probes that are sent serially to an accessible server, the probe rate can be estimated as $1/(t_2-t_1)$ probes-per-second. When a serial scan is contained, the number of probes that are in progress is at most one. For probes to Net-Chaff, it can use delays to reduce the effective probe rate, though the scanner can have time-out mechanisms that limit the affects of Net-Chaff's probe delays.

[20] The transmission time is based on the packet size and the bandwidth used by the scanner.

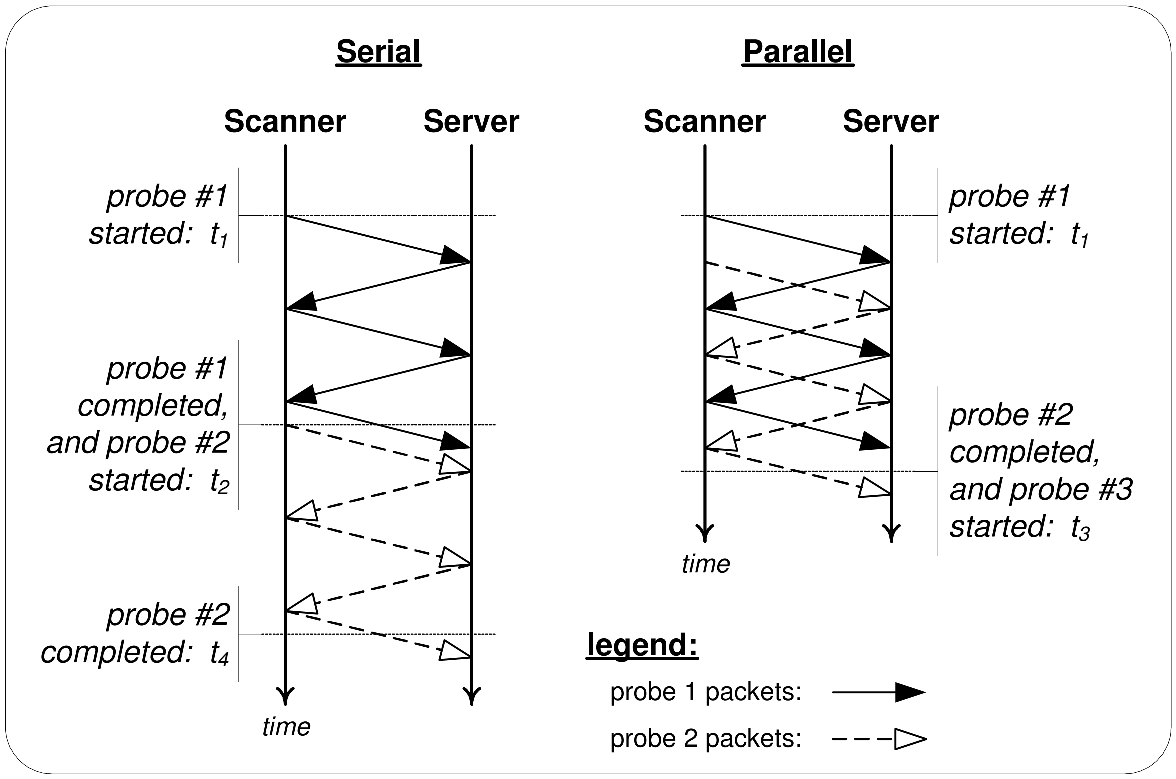


Figure 5.1.1.1.3-1 : TCP scan-and-attack probes, using serial (non-interleaved) and parallel (interleaved) transmission

For most probe-response types, the scanner can interleave its processing of probes to increase its effective throughput. This increased throughput is achieved without increasing the scanner's available bandwidth. In particular, when processing a probe, the time spent waiting for replies can be used to send packets for other probes. This will be referred to as a *parallel scan*. The scan is parallel in the sense that the scanner interleaves its processing of two or more probes. As stated earlier, the scanner model assumes that probe packets themselves are sent one at a time (so strictly speaking, from the packet perspective, both serial and parallel scans are packet-serial). It is assumed that probe reply packets are received and processed in parallel with the sending of probe packets.

The *fully parallel* scan constantly sends packets. To ensure probe completion, it only starts a new probe when there are no packets to be sent for partially-completed probes.

When there are packets to be sent for more than one partially-completed probe, then packets for the oldest probe are sent first. For the Net-Chaff analysis involving parallel scans, fully parallel scans will be modeled, as they provide upper-bound estimates of scanning rates.

The interleaving of probe processing, for the scan-and-attack example, is illustrated in Figure 5.1.1.1.3-1. Two probes are interleaved. For the first probe, transmission of its first packet begins at time t_1. The second probe is completed when transmission of its last packet ends, at time t_3. For scan-and-attack probes that are sent in parallel to an accessible server, an estimate of the probe rate is $2/(t_3-t_1)$ probes-per-second. This assumes all probes conform to this duration.

When a parallel scan is contained, the number of probes in progress would be, at most, the maximum number that are interleaved. For probes to Net-Chaff, Net-Chaff can use delays to increase the number of interleaved probes, though the scanner can have time-out mechanisms that limit the effects of Net-Chaff's probe delay. For a fully parallel scan, Net-Chaff's delays will not alter the probe rate.

5.1.1.2 Rate-based models

This section presents the analytical models that were developed for the Net-Chaff analysis. They are referred to as the *rate-based models*. The models are based on three characteristics of the Net-Chaff environment: 1) the probe rates for each of the probe-response types, 2) the ratios of the probe-response types on the network, and 3) the scanner's use of random address selection.

5.1.1.2.1 Average probe-rate

The rate-based models calculate scan outcomes based on the *average network probe rate* ($\bar{\mathbf{x}}$). It is an estimate of the scanner's probe rate for the network, and it is measured in probes per unit time (the unit used here is seconds). The average is over the probe rates for all probe-response types. The rate is estimated for a particular type of scan and a particular network configuration. This section explains how $\bar{\mathbf{x}}$ is calculated, and it continues the discussion of probe rates from section 5.1.1.1.3.

Regarding notation, single variables that appear within paragraphs are in **bold** font style, to avoid being overlooked. Variables within equations will be represented in regular font style, i.e., not bold. This includes equations within paragraphs and those on a separate line. A variable that appears in bold in one place, and regular font-style in another place, is the same variable.

The equation for calculating the average network probe rate ($\bar{\mathbf{x}}$) is presented in top-down fashion. The high-level equation is presented first, and then its components are developed. To begin, some notation and terms are needed. The set of probe-response types is defined as **S**, and **i** is a particular probe response type (**i** is an element of **S**). Let $\mathbf{x_i}$ be the probe rate for **i**, expressed in probes per second. $\mathbf{x_i}$ will be referred to as an *individual probe rate* as it is the rate for an individual probe-response type.

Let a *scan* be defined as a scanner's probes of **n** randomly-selected addresses, where ($n \geq 1$). When the scanner selects addresses without replacement, the **n** probes will not contain duplicate addresses. Also, the maximum value for **n** is $\mathbf{N_T}$. When selecting with replacement, then the **n** probes can contain duplicate addresses. In this case, there is no maximum value for **n**. These scan attributes apply to all equations that calculate probe rates and numbers of probes, e.g., $\bar{\mathbf{C}}_\mathbf{i}$ (section 5.1.1.1.2).

Within a scan's **n** addresses, let $\mathbf{n_i}$ be the number of addresses with probe-response type **i**. Let $\mathbf{r_i}$ be the ratio of probes with probe response type **i**, in the scan:

$$r_i = n_i / n \tag{1}$$

$$\sum_{i \in S} r_i = 1 \tag{2}$$

The derivation of $\bar{\mathbf{x}}$ can be more easily shown by first deriving the average network probe rate for an arbitrary scan of **n** probes. This is represented as $\bar{\mathbf{x}}^{\#}$, and it is simply the average over the probe rates for the probe-response types.

$\bar{\mathbf{x}}^{\#}$ is calculated based on the $\mathbf{x_i}$ rates, and the $\mathbf{r_i}$ ratios. In the computer performance-modeling literature, it is shown that the *weighted harmonic mean* can be used to calculate an average rate for a set of time-based rates that occur disproportionately [Jai91, Smi88]. The rates are represented as an amount per unit-time, e.g., probes per second. The rates occur disproportionately in that they occur for different amounts. For example, each $\mathbf{x_i}$ applies to $\mathbf{n_i}$ probes, and each of the $\mathbf{n_i}$ values can be different.

Equation (3) shows the weighted harmonic mean calculation, for $\bar{\mathbf{x}}^{\#}$. The average is over the probe rates for the probe-response types. The weights are the $\mathbf{r_i}$ values. They sum to 1, and each $\mathbf{r_i}$ represents the fraction of the scan's probes that are performed at rate $\mathbf{x_i}$.

Smith notes that the equation for the weighted harmonic mean may lack intuitive appeal [Smi88]. He shows that it is equivalent to taking the total amount and dividing it by the total time, e.g., **n** probes divided by the total time it takes to complete the **n** probes. This equivalent form can be derived from equation (3). Let $\mathbf{t_{pi}}$ be the probe-completion time for probe-response type **i**, then $\mathbf{t_{pi}}$ is the inverse of $\mathbf{x_i}$, as shown in equation (4). Equation (5) is derived by multiplying the right-hand side of equation (3) by (n / n), and by using equations (1) and (4). Equation (5) is **n** probes divided by the total time it takes to complete the **n** probes, and it is equivalent to equation (3).

$$\overline{x^{\#}} = \frac{1}{\sum_{i \in S} r_i / x_i} \qquad (3)$$

$$t_{pi} = 1 / x_i \qquad (4)$$

$$\overline{x^{\#}} = \frac{n}{\sum_{i \in S} n_i * t_{pi}} \qquad (5)$$

Next, the average network probe rate $\bar{\mathbf{x}}$ is developed, based on equation (3). Again, the average is over the probe rates for the probe-response types. Techniques for calculating $\mathbf{r_i}$ and $\mathbf{x_i}$ are presented next. The parameters for calculating $\mathbf{r_i}$ include:

$\mathbf{N_T}$	total number of addresses on the network
$\mathbf{N_i}$	number of network addresses that return probe-response type i (i.e., one of the types listed in Table 5.1.1.1.3-1)
j	an index for scans, i.e., scan 1, scan 2, ... scan j
$\mathbf{n_{sj}}$	the number of probes in scan j
$\mathbf{n_{sji}}$	the number of probes in scan j, with probe-response type i

The average value for $\mathbf{r_i}$ can be calculated, and it is represented as $\bar{\mathbf{r}}_\mathbf{i}$. Its derivation is shown below. As described earlier, the scanner randomly chooses **n** addresses, and $\mathbf{n_i}$ of them are of probe-response type **i**. As defined in equation (1), $\mathbf{r_i}$ is (n_i/n). Thus, the average value of $\mathbf{r_i}$ can be calculated as the expected value: $E(n_i/n)$. In probability theory, the value (n_i/n) is called the *proportion of successes*, and the calculation of its expected value, $E(n_i/n)$, is shown in the equation (6) [HMG03]. In equation (7), $E(n_i)$ is the expected number of responses with probe-response type **i**. When the scanner chooses addresses with replacement, $E(n_i)$ is the expected value for a binomial distribution, which is $(n*(N_i/N_T))$. When the scanner chooses addresses without replacement, $E(n_i)$ is the expected value for a hypergeometric distribution, which is also $(n*(N_i/N_T))$. Since $\bar{\mathbf{r}}_\mathbf{i}$ is an expected value, it is the average achieved in the limit, over an infinite number of scans.

$\bar{r}_i = E\left(\frac{n_i}{n}\right) = \frac{1}{n}E(n_i)$	(6)
$E(n_i) = n\left(\frac{N_i}{N_T}\right)$	(7)
$\bar{r}_i = \frac{N_i}{N_T}$	(8)

$\bar{\mathbf{r}}_\mathbf{i}$ can be used to calculate $\bar{\mathbf{x}}$ as shown in equations (9) and (10). This $\bar{\mathbf{x}}$ is based on $\bar{\mathbf{r}}_\mathbf{i}$, so it too is an average that is achieved in the limit, over an infinite number of scans.

$\bar{x} = \frac{1}{\sum_{i \in S} \bar{r}_i / x_i}$ —from (3)	(9)
$\bar{x} = \frac{N_T}{\sum_{i \in S} N_i / x_i}$ —from (8) and (9)	(10)

Equation (10) is a model of the average network probe rate, and its purpose is to provide an estimate of scan outcomes. The model uses a single number to represent each individual probe rate ($\mathbf{x}_\mathbf{i}$). However, when scanning a real network, an individual probe rate ($\mathbf{x}_\mathbf{i}$) can vary, depending on the behavior of the probe recipients and their network paths. For instance, there can be variations in processor delays and network latencies. What is needed for $\mathbf{x}_\mathbf{i}$ is an estimate that is representative of the probe rate over the network. The two measures of rate that are used here are maximum and average rates, though other measures could be used, such as a median rate. The individual probe rates ($\mathbf{x}_\mathbf{i}$) are calculated differently for serial and parallel scans, as explained in the following subsections.

5.1.1.2.1.1 Serial scans

This section shows how the individual probe rates can be estimated for serial scans. The TCP scan-and-attack was described in chapter 4, and in section 5.1.1.1.3 of the present chapter. The calculation of one of its individual probe rates is shown as an example. The scan's individual probe rates depend on whether there is a server at the probed address. When there is no server, the probe sends the initial packet for TCP OPEN, and the response is an ICMP reply. From Table 5.1.1.1.3-1, this applies to the probe-response types nc_ns and ns. When there is a server at the probed address, the packet exchange will be as shown in chapter 4. From Table 5.1.1.1.3-1, this applies to the probe-response types nc_imp, sec, and vuln.

The probe rate will be shown for probes to Net-Chaff-managed addresses, where the probe response is an ICMP reply (i.e., probe-response type nc_ns). A serial scan is assumed. The probe completion time is the amount of time it takes to complete a probe (defined in section 5.1.1.1.3), and in this case it consists of:

1) time for scanner to transmit initial packet for TCP OPEN +
2) latency from scanner to Net-Chaff server (WAN or LAN) +
3) intentional delay by the Net-Chaff server, if any +
4) time for Net-Chaff server to transmit reply packet +
5) latency between Net-Chaff server and scanner

The probe completion time is the sum of list-items 1 to 5, above. Not included in the list is the internal processing conducted on the scanner and server hosts. This processing is assumed to be negligible. It is also assumed that the probes to the Net-Chaff WAN and LAN servers take the same amount of time, i.e., list-items 2 to 5 are the same. If they did not take the same amount of time, then each server would need a different probe-response type (e.g., nc_ns_WAN and nc_ns_LAN).

An average individual probe rate ($\bar{\mathbf{x}}_\mathbf{i}$) can be estimated. The parameters needed are:

$\mathbf{A_i}$	the set of addresses on the network with probe-response type **i**

q	an address in the set $\mathbf{A_i}$, i.e., $q \in A_i$
$\mathbf{t_q}$	the probe completion time (defined in section 5.1.1.1.3) for address **q**
$\mathbf{x_q}$	the probe rate for address **q**. It is equal to $(1 / t_q)$.

$\bar{\mathbf{x}}_\mathbf{i}$ is an average rate that is achieved when randomly probing addresses in $\mathbf{A_i}$. In such cases, each of the addresses in $\mathbf{A_i}$ is equally likely to be probed, and the likelihood is $(1 / |A_i|)$. The weighted harmonic mean can be used to calculate $\bar{\mathbf{x}}_\mathbf{i}$, as shown in equations (11) and (12). The weights are $(1 / |A_i|)$, and they are the same for each address in $\mathbf{A_i}$.[21] Nominally, the weights are realized in the limit, i.e., an infinite number of random probes to addresses with probe-response type **i**. Consequently, the equations for $\bar{\mathbf{x}}_\mathbf{i}$ are realized in the limit, for an infinite number of scans.

$$\bar{x}_i = \frac{1}{\sum_{q \in A_i} \frac{(1/|A_i|)}{x_q}} \tag{11}$$

$$\bar{x}_i = \frac{|A_i|}{\sum_{q \in A_i} t_q} \quad \text{—by simplifying (11)} \tag{12}$$

In addition, an upper-bound for $\mathbf{x_i}$ can be calculated as $(1 / \min(t_q))$. The term $\min(t_q)$ is the minimum value of $\mathbf{t_q}$, among all **q** in $\mathbf{A_i}$.

For a serial scan, the individual probe rates can be calculated independently of each other. For a scan of **n** probes, the probe response types are not all of the same type.

[21] When the weights are all the same, the weighted harmonic mean is the same as the harmonic mean. The weighted harmonic mean is used here to illustrate the role of the limit, for the weights.

However, for a serial scan, the individual probe rates ($\bar{x}_i$) are not affected when the probes responses are of different types. The reason is that, for any given probe, its probe completion time only depends on its response type. The completion time is independent of the probe-response types of all prior and subsequent probes. (The context for this probe behavior is the Net-Chaff analysis' network model.)

5.1.1.2.1.2 Parallel scans

This section shows how the individual probe rates can be estimated for parallel scans. Each individual probe rate ($\mathbf{x_i}$) is calculated as a maximum rate for a fully parallel scan, and it is represented as $\mathbf{x_{max\_i}}$. Fully parallel scans were described in section 5.1.1.1.3

An estimate is made for the maximum possible rate ($\mathbf{x_{max\_i}}$), and it is based on the bandwidth used by the scanner. The parameters used are:

W	scanner bandwidth in bits per second (bps)
$\mathbf{Y_i}$	the total number of bytes the scanner sends for a probe with response type i

$\mathbf{x_{max\_i}}$ is estimated as:

$$x_{max\_i} = W / (Y_i * 8) \qquad (13)$$

It is assumed that the scanner receives probe-responses in parallel with probe transmission. Also, it is assumed that $\mathbf{Y_i}$ is greater than or equal to the number of bytes the scanner receives for a probe with response type **i**. $\mathbf{x_{max\_i}}$ is not affected by the probe completion time (defined in section 5.1.1.1.3). However, lengthening the probe completion time will increase the maximum number of probes that are "in progress" (i.e., partially completed) at a given time.

For a fully parallel scan, the individual probe rates can be calculated independently of each other. For a scan of **n** probes, the probe response types are not all of the same type. However, for a fully parallel scan, it will be assumed that the individual probe rates ($\mathbf{x}_{\mathbf{max\_i}}$) are not changed when the probe responses are of different types. The individual probe rates are the maximum possible, based on available bandwidth; therefore, the individual probe rates could not increase when the probes responses are of different types. To calculate a best-case for $\bar{\mathbf{x}}$, the individual probe rates are assumed to not decrease.

5.1.1.2.2 Containment time

Most of the Net-Chaff analysis is concerned with scan outcomes, at the point of containment (as defined in section 5.1.1.1.2) This requires calculation of the containment time, as a function of the detection threshold and the blocking time, as will be shown here.

The time it takes for the detection threshold to be reached is calculated first. The variables and parameters include:

z	the detection threshold, as defined in section 5.1.1.1.2
$\mathbf{N_{NC}}$	the total number of addresses that are managed by Net-Chaff
$\bar{\mathbf{r}}_{\mathbf{nc}}$	$\bar{\mathbf{r}}_{\mathbf{i}}$ for probes sent to Net-Chaff managed addresses. Using equation (8), it is calculated as (N_{NC}/ N_T).

A scanner randomly probes a network that is protected by Net-Chaff. Eventually, a probe is sent that arrives at a Net-Chaff server and causes the detection threshold to be met. Let $\mathbf{n_Z}$ be the number of probes up to, and including, the probe that causes the detection threshold to be met. Let $\bar{\mathbf{n}}_{\mathbf{Z}}$ be the average value of $\mathbf{n_Z}$ that is achieved in the limit, over an infinite number of scans. An estimate for $\bar{\mathbf{n}}_{\mathbf{Z}}$ is:

$$\bar{n}_Z = z / \bar{r}_{nc} \qquad (14)$$

This calculation is an upper bound as it includes some probes after the $\mathbf{z}^{\mathbf{th}}$ probe sent to Net-Chaff. However, the number of these probes is less than (1 / $\bar{r}_{nc}$), which is typically less than 2. Also, this calculation assumes that probes arrive, at the Net-Chaff WAN server, in the order that the scanner sends them. In practice, probes may not arrive in this order, as they can be sent directly, or forwarded from a Net-Chaff LAN server. An adjustment for this will be made in the next set of equations.

Let $\mathbf{t_{nz}}$ be the amount of time it takes the scanner to complete $\mathbf{\bar{n}_Z}$ probes, at the average network probe rate ($\mathbf{\bar{x}}$). $\mathbf{t_{nz}}$ is calculated by equation (16).

$\bar{n}_Z = t_{nz} * \bar{x}$	(15)
$t_{nz} = [z / (\bar{r}_{nc} * \bar{x})]$ —from (14) and (15)	(16)

Let $\mathbf{\bar{d}}$ be the average detection time. $\mathbf{t_{nz}}$ can be used as an upper bound for the average scan detection time $\mathbf{\bar{d}}$, as scan detection will typically occur before $\mathbf{t_{nz}}$. For instance, Net-Chaff can detect a probe upon receipt of the probe's first packet, but the probe could complete later, and even much later when there are multi-packet probes and large latency.

$\mathbf{\bar{d}}$ can be estimated as shown in equation (17). Since $\mathbf{\bar{d}}$ is a function of $\mathbf{\bar{n}_Z}$ and $\mathbf{\bar{x}}$, it is an average that is achieved in the limit, as the number of scans approaches infinity. When the difference between $\mathbf{\bar{d}}$ and $\mathbf{t_{nz}}$ is significant, the average difference ($\boldsymbol{\lambda}$) can be estimated and subtracted from $\mathbf{t_{nz}}$. $\boldsymbol{\lambda}$ can also include an adjustment for probes that arrive out-of-order at the Net-Chaff WAN server, as described for equation (14). $\boldsymbol{\lambda}$ is an average over an infinite number of scans. For the Net-Chaff analysis, we will assume $\boldsymbol{\lambda}$ is zero.

$\bar{d} = [z / (\bar{r}_{nc} * \bar{x})] - \lambda$ —from (16)	(17)

Now, the average containment time ($\mathbf{\bar{c}}$) can be calculated. It involves the blocking time, which is assumed to be a constant here. In practice, a worst case or average value could be used. Since $\bar{c}$ is a function of $\bar{d}$, it is an average over an infinite number of scans.

b	the blocking time, as described in section 5.1.1.1.2

$$\bar{c} = \bar{d} + b \quad \text{—by definition of containment time, and from (17)} \qquad (18)$$

When the scanner selects addresses without replacement, the maximum number of probes is the network size ($\mathbf{N_T}$). Also, the maximum containment time is the time it takes to probe the whole network. When the scanner selects addresses with replacement, there is no limit to the number of probes, as any address can be selected multiple times. The time it takes to probe $\mathbf{N_T}$ addresses, on average, is represented as $\mathbf{\bar{t}\_N_T}$, and it can be calculated as shown in (19). The average is over an infinite number of scans.

$$\bar{t}\_N_T = N_T / \bar{x} \quad \text{—from definition of } \textit{rate} \qquad (19)$$

5.1.1.2.3 Primary performance model

As described in section 5.1.1.1.2, most of the calculations for the Net-Chaff analysis are based on the following values:

$\bar{C}$	the average number of probes that a scan completes prior to containment
$\bar{C}_i$	the average number of probes that a scan completes prior to containment, and that have a probe response of type **i**.

These values can now be estimated as shown below. Since they are based on $\bar{c}$, $\bar{x}$ and $\bar{r}_i$, the averages are achieved in the limit, as the number of scans approaches infinity. There can be partially completed probes at the point of containment. For a serial scan, there is at most one. For a fully parallel scan, they are the probes that are currently “in progress”. In the equations, **ε** is an estimate of the average number of partially completed probes. The average is over an infinite number of scans. For the Net-Chaff analysis, we will assume **ε** is zero, to calculate best-case outcomes for the scanner.

$\bar{C} = (\bar{x} * \bar{c}) - \varepsilon$ —from (10) and	(20)
$\bar{C}_i = \bar{r}_i * ((\bar{x} * \bar{c}) - \varepsilon)$ —from (8) and (20)	(21)

5.1.1.2.4 Network and scan models

We next discuss Net-Chaff performance for representative networks and scanners. A template for network and scanner configurations is used, and it's described here. Also, there are several default configurations that are used in the performance analysis, and they too are described here.

Table 5.1.1.2.4-1 shows the template for the network's distribution of real computers and Net-Chaff-managed addresses. Under the column *Symbol*, $\mathbf{N_i}$ represents the total number of addresses on the network, of type **i**. Default configurations are shown for class A and B networks. They will be referred to as the *default class A network* and the *default class B network*, respectively. These configurations represent large corporate networks with 20K addresses assigned to real computers. The *unassigned addresses* are those that are not assigned to real computers nor Net-Chaff.

Table 5.1.1.2.4-1 : Computer distribution on network

Computer Distribution on Network	Symbol	Default Class A Network	Default Class B Network
total network addresses	$\mathbf{N_T}$	2^{24}	2^{16}
addresses assigned to real computers	$\mathbf{N_R}$	20K	20K
unassigned addresses	$\mathbf{N_{UN}}$	5K	5K
addresses assigned to Net-Chaff	$\mathbf{N_{NC}}$	$2^{24} - 25K$	$2^{16} - 25K$

Table 5.1.1.2.4-2 shows the template for the distribution of probe-response types on the network. Default configurations are shown for a scan whose target is web servers. The probe-response type distributions are shown as percentages of the computer distributions shown in Table 5.1.1.2.4-1. Here, among the Net-Chaff-managed addresses, 5% are web-servers. Among the real computers, 1% are secure web-servers, and in addition, 1% are vulnerable web-servers.

Table 5.1.1.2.4-2 : Probe-response type distribution on network

Probe-Response Type		Symbol	Default Network Distribution for a Web-Server Scan
Net-Chaff	server impersonation	**nc_imp**	$N_{nc\_imp} = \lfloor (0.05 * N_{NC}) \rfloor$
	no server present	**nc_ns**	$N_{nc\_ns} = N_{NC} - N_{nc\_imp}$
real computers	secure server	**sec**	$N_{sec} = \lfloor (0.01 * N_R) \rfloor$
	vulnerable server	**vuln**	$N_{vuln} = \lfloor (0.01 * N_R) \rfloor$
	no server present	**ns**	$N_{ns} = N_R + N_{UN} - N_{sec} - N_{vuln}$

Probe rates are calculated as a function of the transmission bandwidth used by the scanner and the packets sent. The probe rates are also a function of the average latency over the network. (Latency was defined in section 5.1.1.1.1.) Delays and host-processing times at the scanner and its targets are assumed to be zero, for simplicity, and to model worst case outcomes for Net-Chaff. Probe-rate calculations are specified below, for the scan examples presented earlier. Table 5.1.1.2.4-3 lists the parameters that are used.

Table 5.1.1.2.4-3 : Parameters for probe rate calculations

W	bandwidth used by scanner and targets, in bits per second (bps)
L	average latency, in seconds. It is assumed to be the same, to and from the scanner.
S_i	total size of a packet of type **i** (e.g., a packet used in TCP OPEN), in bytes. The size includes network layers from Ethernet and above

Calculations for individual probe rates, for TCP scan-and-attack, are shown in Table 5.1.1.2.4-4 and Table 5.1.1.2.4-5, and example calculations are given. The calculations were explained in section 5.1.1.2.1.

Table 5.1.1.2.4-4 : Packets used in TCP scan-and-attack

S_T	size of each TCP OPEN packet: 64 bytes
S_I	size of ICMP packet indicating the target is unreachable: 64 bytes
S_B	for TCP scan-and-attack, size of packet holding server's 40-byte banner: 98 bytes
S_A	for TCP scan-and-attack, size of packet holding 400 byte attack payload: 458 bytes

Table 5.1.1.2.4-5 : Calculations for individual probe rates, for TCP scan-and-attack

Transmission Type	**Probe Target**	**Individual Probe-Rate Calculations**	**Example Calculations** W = 1Mbps, L = 0.001
serial	no server	1 / ([(S_T + S_I) / (W/8)] + [2 * L])	330.7
	server	1 / ([(3*S_T + S_B + S_A) / (W/8)] + [4 * L])	100.2
fully parallel	no server	(W/8) / S_T	1953.1
	server	(W/8) / (2*S_T + S_A)	213.3

For the information-retrieval scan, a web-server TCP ping-scan will be modeled. Table 5.1.1.2.4-6 shows the calculations for the individual probe rates. The scan's probes just test for an accessible web server. For each probe, the scanner sends the first packet from TCP OPEN. If the destination is an accessible web server, it will reply with the second TCP OPEN packet. All other destinations are assumed to send an ICMP packet in reply. For simplicity, it's assumed that all probe packets, and replies, are the same size.

Table 5.1.1.2.4-6 : Calculations for individual probe rates, for the web-server TCP ping-scan

Transmission Type	**Individual Probe-Rate Calculations**	**Example Calculations** W = 1Mbps, L = 0.001
serial	1 / ([(2 * S_T) / (W/8)] + [2 * L])	330.7
fully parallel	(W/8) / S_T	1953.1

For the UDP scan-and-attack, the individual probe-rate calculation is simple, as the rate is the same for all addresses. It is shown in Table 5.1.1.2.4-7. The packet size is:

S_{UA}	size of each UPD attack packet: 458 bytes

Table 5.1.1.2.4-7 : Calculation for individual probe rate, for the UDP scan-and-attack

Individual Probe-Rate Calculation	**Example Calculation** W = 1Mbps, L = 0.001
$(W/8)\ /\ S_{UA}$	272.9

The UDP scan-and-attack can potentially be sped-up by using a filtering scan, as was described in chapter 4. The present section's network templates and default configurations are applicable to this scan. The individual probe-rate calculations are shown in Table 5.1.1.2.4-8. The filtering scan sends zero-byte UDP probe packets. Addresses without a server will result in a probe response that is an ICMP message. Addresses with a web-server result in a UDP probe-response packet. For simplicity, it's assumed that all of the filtering scan's packets are the same size:

S_{UF}	size of UDP filtering-scan's packets: 64 bytes

Table 5.1.1.2.4-8 : Calculations for individual probe rates, for the UDP filtering-scan with an attack

Transmission Type	Probe Target	Individual Probe-Rate Calculations	Example Calculations W = 1Mbps, L = 0.001
serial	no server	$1 \ / \ ([(2 * S_{UF}) / (W/8)] + [2 * L])$	330.7
	server	$1 \ / \ ([(2*S_{UF} + S_{UA}) / (W/8)] + [2 * L])$	149.5
fully parallel	no server	$(W/8) \ / \ S_{UF}$	1953.1
	server	$(W/8) \ / \ (S_{UF} + S_{UA})$	239.5

5.1.1.3 Performance overview

This section provides an overview of Net-Chaff's performance. This analysis focuses on Net-Chaff's ability to reduce scanners' access to vulnerable computers. Each of the three scan types is analyzed. The rate-based models are used to estimate the average number of vulnerable computers accessed by the scans. This value is represented by $\mathbf{\bar{C}_{VULN}}$, as defined in section 5.1.1.1.2 (page 97). Further, this analysis is based on the network configurations specified in the prior section (5.1.1.2.4), including the default network configurations specified in Table 5.1.1.2.4-1 (page 115), and the probe-response types specified in Table 5.1.1.2.4-2 (page 115). The networks' vulnerable computers have probe-response type *vuln*.

$\mathbf{\bar{C}_{VULN}}$ can be calculated as a function of the average containment time ($\bar{c}$). The function is represented as $\bar{C}_{VULN}(\bar{c})$. It is shown below, and the dependent variable ($\bar{c}$) is in bold, for clarity.

$$\bar{C}_{VULN}(\bar{c}) \ = \ \mathbf{\bar{c}} * (\bar{r}_{vuln} \ * \ \bar{x}) \quad \text{—from (21), with } \varepsilon \text{ assumed to be zero} \qquad (22)$$

$\bar{c}_{VULN}(\bar{c})$ is a linear equation with slope $(\bar{r}_{vuln} * \bar{x})$ and y-intercept 0. $\bar{\mathbf{x}}$ is calculated for each scan type, as described in Table 5.1.1.2.4-3 (page 116) through Table 5.1.1.2.4-8 (page 119). The term $(\bar{r}_{vuln} * \bar{x})$ gives the average rate at which vulnerable computers are accessed by the scan. The rate is in units of vulnerable computers per second, and the average is over an infinite number of scans.

The next subsection shows Net-Chaff's performance for each of the three scan types. The subsequent subsection presents a model for calculating the likelihood that one or more computers are compromised, for a given value of $\bar{\mathbf{c}}_{\mathbf{VULN}}$.

5.1.1.3.1 Analysis of the scan types

The performance of the TCP scan-and-attack, for the default network configurations, is shown in Table 5.1.1.3.1-1. The serial and parallel transmission types are shown. The parallel scan is fully parallel, as defined in section 5.1.1.1.3. Also, three different scanning bandwidths are shown: 1Kbps represents a slow scan; 1Mbps is a relatively fast scan, and 1Gbps provides a practical upper-bound. The column heading $(\bar{r}_{vuln} * x)$ represents $(\bar{r}_{vuln} * \bar{x})$, and the bar over the **x** is omitted due to type-setting limitations. Similarly, the column heading **t_N$_\mathbf{T}$** represents $\bar{\mathbf{t}}$**_N$_\mathbf{T}$**. The column $\bar{\mathbf{t}}$**_N$_\mathbf{T}$** is the average time it takes to scan $\mathbf{N_T}$ addresses, and it is calculated using equation (19). Also, this is the average time it takes to scan the whole network when selecting addresses without replacement. These table-heading definitions apply to the following tables as well.

Table 5.1.1.3.1-1 shows that the rates of compromise $(\bar{r}_{vuln} * \bar{x})$ are directly proportional to the bandwidth, for the fully parallel scans, e.g., the rate of compromise at 1Mbps is 1,000 times the rate at 1Kbps. This property does not hold for serial scans as they are also governed by the network latency. The rate of compromise is high for the parallel scan at 1Gbps on a class B network, and the rate is relatively low for the other scenarios.

Table 5.1.1.3.1-1 : Rates of compromise (computers per second) for the TCP scan-and-attack

network class	trans. type	1Kbps		1Mbps		1Gbps	
		$r_{vuln} * x$	t_N_T	$r_{vuln} * x$	t_N_T	$r_{vuln} * x$	t_N_T
B	serial	0.00252	79277.7	0.930	215.1	1.471	136.0
	parallel	0.00458	43685.4	4.578	43.7	4578.188	0.04
A	serial	0.00001	21371629.2	0.004	56566.9	0.006	35251.8
	parallel	0.00002	12089464.4	0.017	12089.5	16.543	12.1

Outcomes for the TCP scan-and-attack, at 1Mbps and 100Mbps are shown in Figure 5.1.1.3.1-1 and Figure 5.1.1.3.1-2, respectively. Their y-axis is in log scale. (In Figure 5.1.1.3.1-2, the two middle lines are very close to one another, but they are not identical.) These outcomes indicate that Net-Chaff has the potential for stopping worms from spreading. This requires that the average number of compromised computers ($\bar{C}_{VULN}$) be less than one. For the class A network, the requisite containment times appear achievable. It's not clear whether containment could occur quickly enough for the class B network, with fully parallel scanning at, or above, 100Mbps. At 100Mbps, for $\bar{C}_{VULN}$ to be less than one, the containment time must be less than 0.001 seconds, which may not be achievable in practice. One solution is to allocate computers only the bandwidth they need, e.g., by using rate-limiting routers. Typically, most computers need less than 100Mbps. Also, further research is needed to learn the specific containment speeds that are possible with the current network technology.

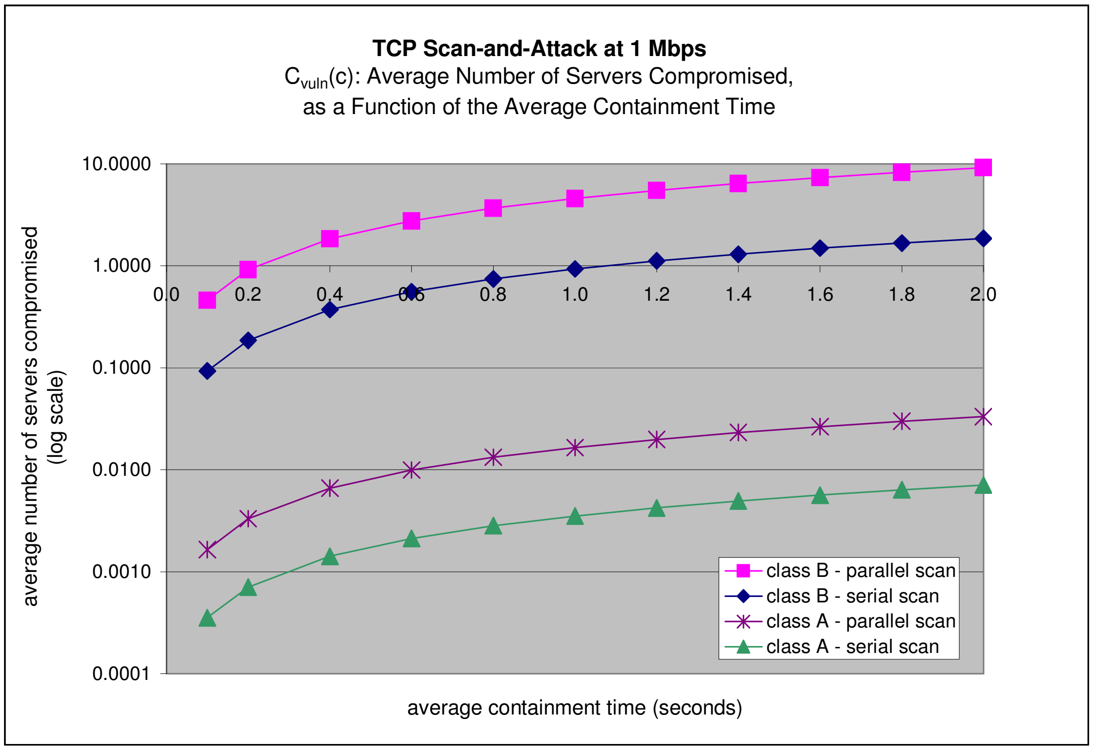


Figure 5.1.1.3.1-1 : TCP scan-and-attack at 1Mbps

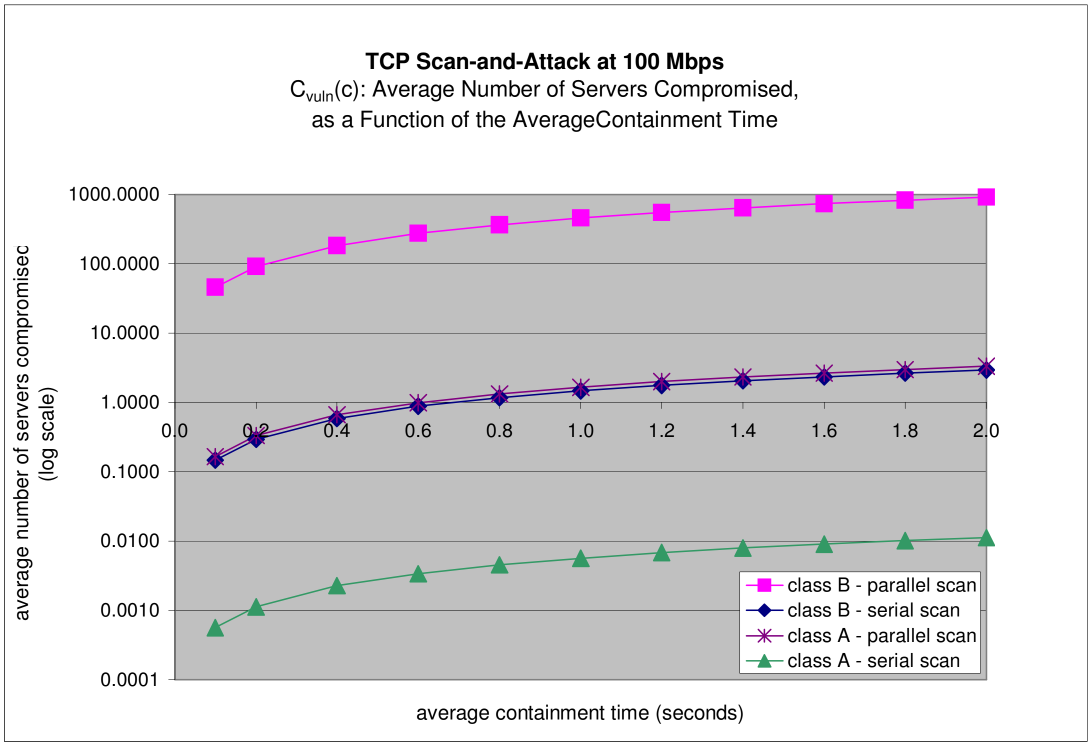


Figure 5.1.1.3.1-2 : TCP scan-and-attack at 100 Mbps

The performance of the UDP scan-and-attack, with a filtering-scan, is shown in Table 5.1.1.3.1-2. Rates of compromise are shown for the UDP scan-and-attack: with serial and fully-parallel filtering scans, and with no filtering-scan. It can be seen that the filtering scans improve performance, except for the serial filtering-scan at 1Gbps, and this is due to the latency in the serial probes. Performance issues for containment are very similar to those described for the TCP scan-and-attack. Outcomes for the UDP scan-and-attack, with a filtering scan, at 1Mbps, are shown in Figure 5.1.1.3.1-3.

Table 5.1.1.3.1-2 : Rates of compromise for the UDP scan-and-attack with a filtering-scan

network class	filter scan	1Kbps		1Mbps		1Gbps	
		r_{vuln} * x	t_N_T	r_{vuln} * x	t_N_T	r_{vuln} * x	t_N_T
B	none	0.000833	240123.9	0.833	240.1	832.90	0.24
	serial	0.002627	76128.8	0.966	207.1	1.52	131.15
	parallel	0.004712	42443.3	4.712	42.4	4712.17	0.04
A	none	0.000003	61471719.4	0.003	61471.7	3.25	61.47
	serial	0.000010	20283892.3	0.004	53804.8	0.01	33574.68
	parallel	0.000017	11660403.2	0.017	11660.4	17.15	11.66

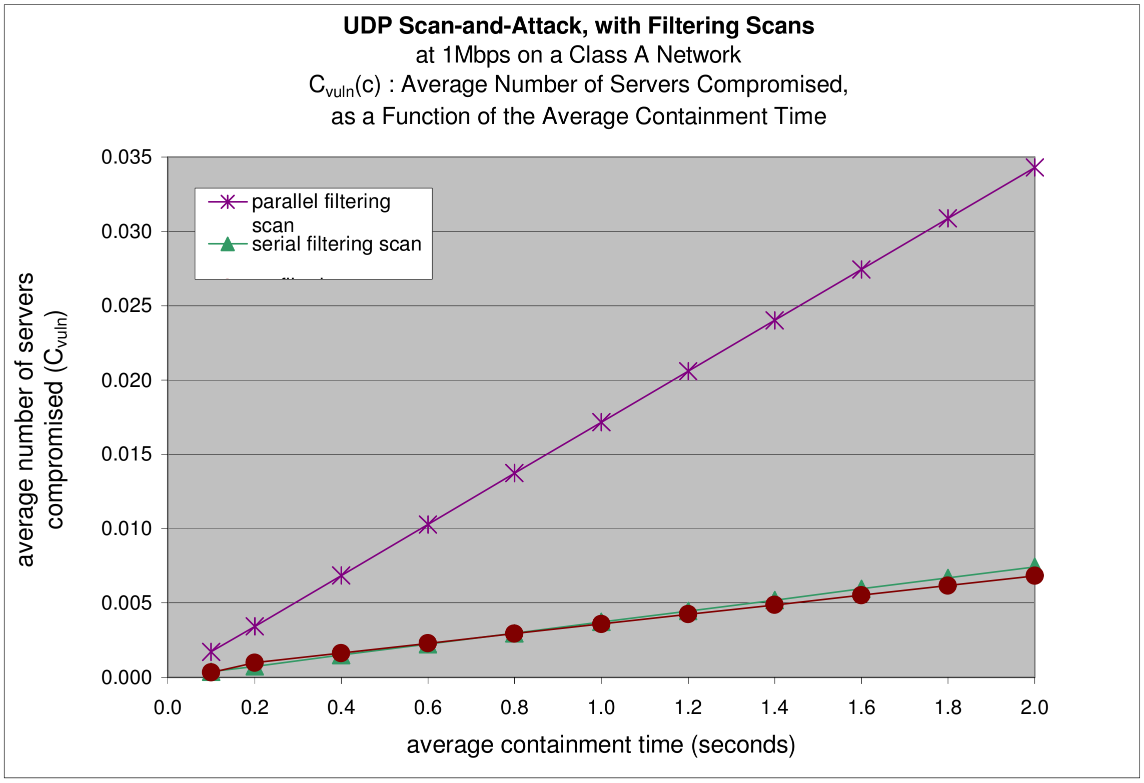


Figure 5.1.1.3.1-3 : UDP scan-and-attack with filtering-scans

The performance of the information-retrieval scan, in the default network configurations, is shown in Table 5.1.1.3.1-3. TCP ping is modeled. ($\bar{r}_{vuln}$ * $\bar{x}$) is the average rate at which the scan finds vulnerable computers (probe-response type vuln). ($\bar{r}_{aff}$ * $\bar{x}$) is the average rate at which the scan receives affirmative replies (probe-response types: nc_imp, sec, and vuln). These averages are over an infinite number of scans. Figure 5.1.1.3.1-4 shows outcomes for the information-retrieval scan, at 1Mbps on a class A network. The graph plots $\bar{C}_{VULN}(\bar{c})$ and $\bar{C}_{AFF}(\bar{c})$. $\bar{C}_{AFF}$ was defined in section 5.1.1.1.2 (page 97), and $\bar{C}_{AFF}(\bar{c})$ is calculated as shown below:

$$\boxed{\bar{C}_{AFF}(\bar{c}) \ = \ \bar{\mathbf{c}} * (\bar{r}_{aff} * \bar{x}) \quad \text{—from (21)} \qquad\qquad (23)}$$

Ideally, scans should be contained before they access a single vulnerable computer. This appears feasible for all but the fully parallel scan on a class B network. In addition, the scanner receives a substantial amount of noise relative to the number of vulnerable computers discovered. In particular, the ratio between ($\bar{r}_{aff}$ * $\bar{x}$) and ($\bar{r}_{vuln}$ * $\bar{x}$) ranges from approximately 10:1 to 100K:1, depending on the scan type and network.

Table 5.1.1.3.1-3 : Rates of discovery for the information-retrieval scan

network class	trans. type	1Mbps			1Gbps		
		r_{vuln} * x	r_{aff} * x	t_NT	r_{vuln} * x	r_{aff} * x	t_NT
B	serial	1.009	12.2	198.2	1.525	18.5	131.14
	parallel	5.960	72.3	33.6	5960.464	72300.4	0.03
A	serial	0.004	16.5	50734.3	0.006	25.0	33571.61
	parallel	0.023	97.6	8589.9	23.283	97557.2	8.59

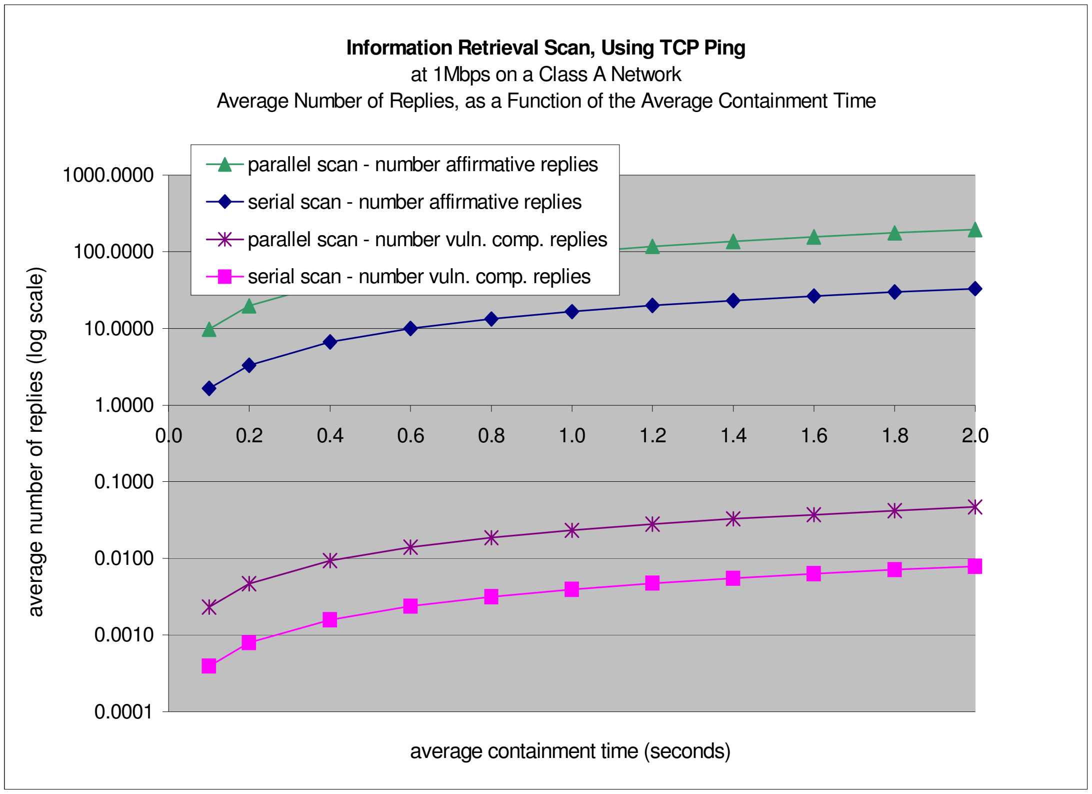


Figure 5.1.1.3.1-4 : The information-retrieval scan

5.1.1.3.2 The likelihood of compromise

As defined earlier, $\bar{\mathbf{C}}_{\mathbf{VULN}}$ is the average number of computers that are compromised, prior to containment (equation (22)). For a given value of $\bar{\mathbf{C}}_{\mathbf{VULN}}$, it would be useful to know the probability that the scan will access one or more vulnerable computers. An example will help to illustrate. For a particular Net-Chaff deployment, the rate-based models are used to estimate scan outcomes. For worst-case scan scenarios, $\bar{\mathbf{C}}_{\mathbf{VULN}}$ is estimated to be 0.5. However, given that $\bar{\mathbf{C}}_{\mathbf{VULN}}$ is 0.5, what is the probability that such scans would compromise one or more vulnerable computers, before being contained? This probability will be represented by the variable $\mathbf{P}_{\mathbf{vuln}}$, and it is calculated as a function of $\bar{\mathbf{C}}_{\mathbf{VULN}}$. The remainder of this section shows how $\mathbf{P}_{\mathbf{vuln}}$ can be calculated. This calculation is especially useful for assessing Net-Chaff's ability to stop worms from spreading.

$\mathbf{P}_{\mathbf{vuln}}$ is calculated differently, depending on whether the scanner selects addresses with, or without, replacement. However, in both cases, the first step is to determine the number of probes (n) that the scanner performs for a particular value of $\bar{\mathbf{C}}_{\mathbf{VULN}}$. The parameter N_{vuln} is the number of vulnerable computers on the network:

$\bar{C}_{VULN} = \bar{r}_{vuln} * n$ —$\bar{C}_{VULN}$ is an average over an infinite number of scans	(24)
$n = \bar{C}_{VULN} * (N_T / N_{vuln})$ —from (24) and (8)	(25)

The next step is to calculate the probability that **n** probes will access no vulnerable computers. This probability will be represented by the variable $\mathbf{P}_{\mathbf{no\_vuln}}$. In general, $\mathbf{P}_{\mathbf{vuln}}$ is calculated as:

$P_{vuln} = 1 - P_{no\_vuln}$	(26)

Let $\mathbf{N}_{\mathbf{not\_vuln}}$ be the number of network addresses that do not contain a vulnerable server, so that:

$$N_{not\_vuln} = N_T - N_{vuln} \qquad (27)$$

When the scanner selects addresses with replacement, then (N_{not_vuln} / N_T) is the probability that a probe will access a computer that is not vulnerable. Therefore, when selecting (scanning) **n** addresses with replacement, $\mathbf{P_{no\_vuln}}$ can be calculated using equation (28), below. $\mathbf{P_{vuln}}$ can be calculated using equations (28) and (26).

$$P_{no\_vuln} = (N_{not\_vuln} / N_T)^n \quad \text{— since probes are independent} \qquad (28)$$

The other case to consider is when the scanner selects addresses without replacement. In this case, the probability that a probe will access a computer that is not vulnerable depends upon the number of prior probes. When selecting (scanning) **n** addresses with replacement, $\mathbf{P_{no\_vuln}}$ can be calculated using equation (29), below. $\mathbf{P_{vuln}}$ can be calculated using equations (29) and (26).

$$P_{no\_vuln} = \prod_{i=1}^{n} \left((N_{not\_vuln} - i + 1) \;/\; (N_T - i + 1) \right) \qquad (29)$$

Figure 5.1.1.3.2-1 shows the calculations of $\mathbf{P_{vuln}}$ for the default class A and B networks, and the two address selection techniques, for a total of 4 curves. The calculations are based on equations (28) and (29). The $\mathbf{\bar{C}_{VULN}}$ values shown range from 0 to 6.6, in increments of 0.2. Although these curves are for different network sizes and different address selection techniques, they are almost identical. For each $\mathbf{\bar{C}_{VULN}}$ value, four calculations are made (one for each curve), and the difference among the four calculations was always less than 0.002. The similarity among these curves suggests the opportunity for modeling $\mathbf{P_{vuln}}$ using the Poisson distribution, which will be described next.

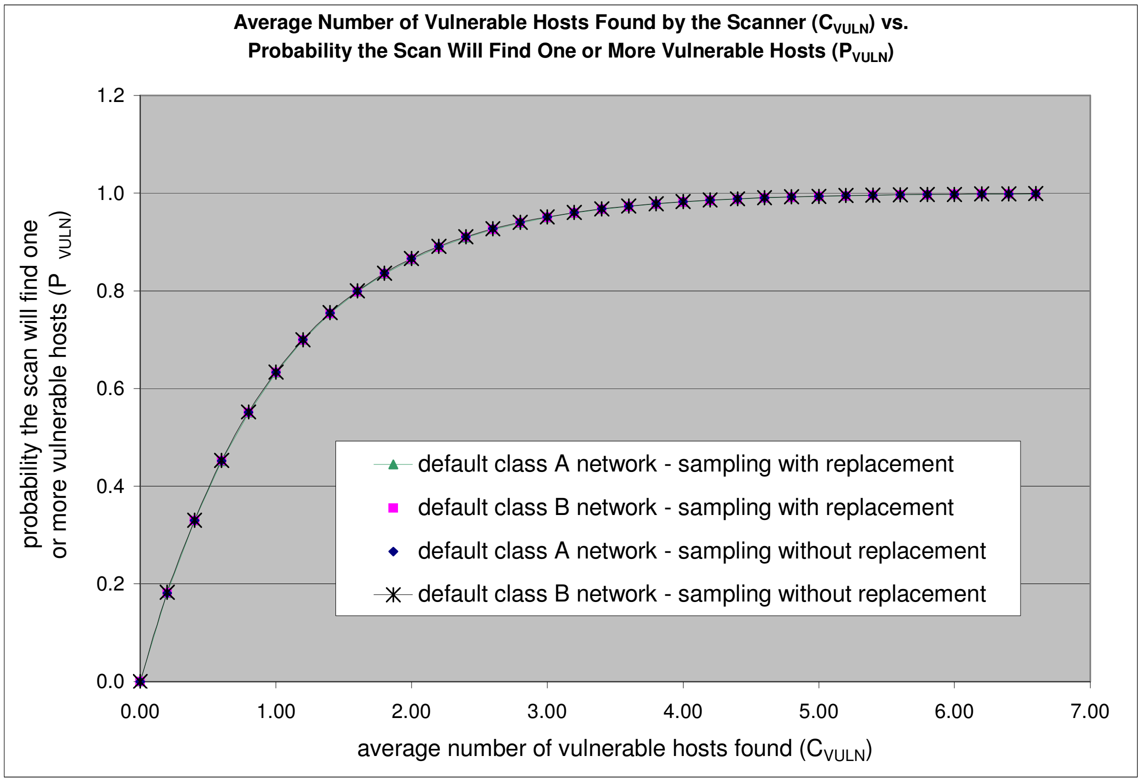


Figure 5.1.1.3.2-1 : Calculations of P_{VULN} for the default networks

For typical Net-Chaff scenarios, $\mathbf{P_{VULN}}$ can be calculated using the Poisson distribution's probability mass function (PMF). By using the Poisson PMF, a single equation can be used to calculate $\mathbf{P_{VULN}}$, and the equation is shown below. The equation is applicable for address selection with, and without, replacement. Further, this equation is only dependent upon $\mathbf{\bar{C}_{VULN}}$, and it applies to a wide range of network sizes and Net-Chaff configurations (see equation (35) on page 131).

$$P_{vu\ln} = 1 - e^{-(\bar{C}_{VULN})}$$

The derivation of this equation is shown in the remainder of this section. In overview, the following are shown: 1) in typical Net-Chaff scenarios, the binomial distribution can be used to calculate $\mathbf{P_{no\_vuln}}$ for both address selection with replacement, and without replacement. 2) Further, in these scenarios, the binomial distribution can be approximated by the Poisson distribution. Thus $\mathbf{P_{no\_vuln}}$ can be calculated using the Poisson PMF. A more detailed explanation follows.

When selecting addresses with replacement $\mathbf{P_{no\_vuln}}$ can be modeled using the binomial distribution. Equation (28) calculates $\mathbf{P_{no\_vuln}}$ for address selection with replacement. This equation can be derived from the binomial distribution's PMF. The PMF is shown in equation (30), with parameters **y** (number of successes), **p** (probability of success) and **m** (number of samples). To derive equation (28) from the PMF: **y** is set to zero; **m** is the number of probes, as calculated in equation (25); **p** is (N_{vuln} / N_T), and (1-p) is (N_{not_vuln} / N_T).

$$p(y;m,p)=\binom{m}{y}p^{y}(1-p)^{m-y} \quad \text{for y = 0, 1, 2, . . . m} \tag{30}$$

When selecting addresses without replacement $\mathbf{P_{no\_vuln}}$ can be modeled using the hypergeometric distribution. Equation (29) calculates $\mathbf{P_{no\_vuln}}$ for address selection without replacement. This equation can be derived from the hypergeometric distribution's PMF. The PMF is shown in equation (31), with parameters **y** (number of successes), **T** (population size), **U** (number of elements in the population that constitute success) and **m** (sample size). To derive equation (28) from the PMF: **y** is set to zero; **T** is set to $\mathbf{N_T}$; **U** is set to $\mathbf{N_{vuln}}$, and **m** is the number of probes, as calculated in equation (25).

$$\mathrm{p(y;T,U,m)}=\frac{\binom{\mathrm{U}}{\mathrm{y}}\binom{T-U}{m-y}}{\binom{T}{m}} \tag{31}$$

From probability theory, it is known that the hypergeometric distribution can be approximated by the binomial distribution [Dev91]. This is possible when, from equation (31), the population size (T) is much larger than the sample size (m). For the Net-Chaff analysis, this condition holds when the network size is much larger than the number of probes that occur before containment, i.e., when $(n \ll N_T)$, for **n** as calculated in equation (25). In such cases, if the scanner selects addresses without replacement, $\mathbf{P_{no\_vuln}}$ can be calculated by using the binomial PMF, i.e., equation (28).

Thus, for many typical Net-Chaff scenarios, $\mathbf{P_{no\_vuln}}$ can be modeled by the binomial distribution, when selecting addresses with, or without, replacement. Further, from probability theory, it is known that the binomial distribution can be estimated by the Poisson distribution [Dev91]. The Poisson PMF is shown in equation (32). It calculates the probability of exactly **v** occurrences, where: **v** is a non-negative integer, and **α** is a positive real number that represents the expected number of occurrences during a *given interval.*

$$\mathrm{p}(\mathrm{v};\alpha) = \frac{e^{-\alpha}\alpha^{v}}{v!} \qquad (32)$$

The binomial distribution can be estimated by the Poisson distribution under a requisite condition. It is that, for the binomial PMF (equation (28)), **m** be very large and **p** be very small. For the Net-Chaff analysis, this condition holds when many probes occur before containment, i.e., **n** is large, as calculated in equation (25). For Net-Chaff, **p** is (N_{vuln} / N_T), which is typically very small. In Figure 5.1.1.3.2-1, the calculations are made for the default class A and B networks, and for $\bar{C}_{VULN}$ values ranging from 0 to 6.6. For the $\bar{C}_{VULN}$ value of 1.0, **n** is 83886 and 327, for the default class A and B networks, respectively. For the default class A and B networks, **p** is 0.00001 and 0.003, respectively. These values appear to meet the conditions for using the Poisson distribution as an approximation for the binomial distribution.

Under the requisite condition just given, the binomial PMF can be approximated by the Poisson PMF, as shown in equation (33) [Dev91]. The parameters **y**, **m** and **p**, are as defined for the binomial PMF. To use equation (33) to calculate $\mathbf{P_{no\_vuln}}$: **y** is set to zero; **m** is the number of probes, as calculated in equation (25), and **p** is (N_{vuln} / N_T). However, (m*p) reduces to $\bar{\mathbf{C}}_{\mathbf{VULN}}$, as shown in equation (34). The Poisson distribution can be used to calculate $\mathbf{P_{no\_vuln}}$ and $\mathbf{P_{vuln}}$ as shown in equations (35) and (36), respectively. If equation (36) is plotted in Figure 5.1.1.3.2-1, it produces a curve that is almost identical to the four curves that are there. More specifically, for each value of $\bar{\mathbf{C}}_{\mathbf{VULN}}$, the result calculated is within 0.002 of the results for the four curves.

$$p(y;(m*p)) = \frac{e^{-(m*p)}(m*p)^y}{y!} \tag{33}$$

$$(m*p) = \{ (\bar{C}_{VULN} * (N_T / N_{vuln})) * (N_{vuln} / N_T) \} = \bar{C}_{VULN} \tag{34}$$

$$P_{no\_vu\ln} = e^{-(\bar{C}_{VULN})} \quad \text{—from (33) and (34), and since } y = 0 \tag{35}$$

$$P_{vu\ln} = 1 - e^{-(\bar{C}_{VULN})} \quad \text{—from (26) and (35)} \tag{36}$$

In summary, $\mathbf{P_{vuln}}$ can be calculated using the Poisson PMF, as shown in equation (36). The equation is only dependent upon $\bar{\mathbf{C}}_{\mathbf{VULN}}$. The shape of the curve is almost identical to the curves shown in Figure 5.1.1.3.2-1. The equation is an approximate solution for many typical Net-Chaff scenarios, including scans that randomly select address with, and without, replacement. In particular, it is applicable when the following conditions are met: **n** is large, for **n** as calculated in equation (25); (n **<<** N_T), and the ratio (N_{vuln} / N_T) is very small. Further, Figure 5.1.1.3.2-1 shows that if $\bar{\mathbf{C}}_{\mathbf{VULN}}$ is less than one, then a worm can potentially spread, but it is not likely to spread very far. The likelihood of worm spread can be calculated using the equations derived here, and the calculation is left for future research.

5.1.1.3.3 Summary

This section used the rate-based models to estimate Net-Chaff's performance. The analysis focused on Net-Chaff's ability to prevent scanners from accessing vulnerable computers. Fast scanner performance was calculated by modeling scans with small-sized probes, high bandwidth, and fully parallel probe transmission. A large corporate network was modeled, with 20K computers and 200 vulnerable computers. Typical Net-Chaff deployments were modeled, with a moderate amount of impersonations for slowing down scans. In practice, scans could be further slowed by using more impersonations, and the "tar-pits" described in chapter 4.

The analysis indicates that Net-Chaff can effectively contain scans for many typical networks and scan types. The scan-and-attack analysis indicates that Net-Chaff has the potential for stopping worms from spreading. To stop worms, a scan's average number of compromised computers ($\bar{C}_{VULN}$) must be less than one. For the class A network, the requisite containment times appear to be achievable in practice, given current technology. However, in many class B networks the requisite containment times may not be achievable for fully parallel scans at, or above, 100Mbps. Further research is needed to learn the specific containment speeds that are possible with the current network technology.

Net-Chaff's performance in containing information-retrieval scans is similar to its performance for containing scan-and-attack scans. In addition, information-retrieval scans receive a substantial amount of noise from Net-Chaff, relative to the vulnerable computers discovered.

For a given value of $\bar{\mathbf{C}}_{\mathbf{VULN}}$, it would be useful to know the probability that the scan will access one or more vulnerable computers. This probability will be represented by the variable $\mathbf{P}_{\mathbf{vuln}}$, and it is calculated as a function of $\bar{\mathbf{C}}_{\mathbf{VULN}}$. The Poisson PMF can be used to calculate $\mathbf{P}_{\mathbf{vuln}}$. This calculation provides an approximate solution for many typical Net-Chaff scenarios. It indicates that if $\bar{\mathbf{C}}_{\mathbf{VULN}}$ is less than one, then a worm could potentially spread, but not far.

5.1.1.4 Elements of Net-Chaff performance

One of Net-Chaff's primary objectives is reducing the average number of vulnerable computers that are accessed by scanners ($\bar{\mathbf{c}}_{\mathbf{VULN}}$). This section analyzes the elements of Net-Chaff that determine $\bar{\mathbf{c}}_{\mathbf{VULN}}$. The purpose of the analysis is to understand: 1) how to effectively configure Net-Chaff deployments, and 2) the role of deception in reducing $\bar{\mathbf{c}}_{\mathbf{VULN}}$.

An equation for estimating $\bar{\mathbf{c}}_{\mathbf{VULN}}$ was given earlier (equation (22) on page 119), and it is repeated below. As the equation shows, $\bar{\mathbf{c}}_{\mathbf{VULN}}$ is determined by three factors: the containment time ($\bar{c}$), the average network scan rate ($\bar{x}$), and the proportion of vulnerable computers on the network ($\bar{r}_{vuln}$). $\bar{\mathbf{c}}_{\mathbf{VULN}}$ and each of its factors are an average achieved over an infinite number of scans. Any percentage reduction in a factor will result in the same reduction in $\bar{\mathbf{c}}_{\mathbf{VULN}}$, e.g., cutting $\bar{\mathbf{c}}$ in half will cut $\bar{\mathbf{c}}_{\mathbf{VULN}}$ in half.

$$\boxed{\bar{c}_{VULN} = \bar{c} * \bar{x} * \bar{r}_{vuln} \qquad (22)}$$

The following three subsections examine each of the three $\bar{\mathbf{c}}_{\mathbf{VULN}}$ factors, respectively. Most of the analysis is illustrated by showing outcomes for the fully-parallel TCP scan-and-attack running at 100Mbps. The scan occurs on the default class A network. (This scan and network were defined in section 5.1.1.2.4 on page 114.) This scenario represents an effective Net-Chaff deployment vs. a fast scan. Also, the analysis focuses on the example web-server scans, including Net-Chaff impersonations for web-servers (i.e., probe-response type nc_imp), and vulnerable web-servers (i.e., probe-response type vuln).

5.1.1.4.1 Containment time

An equation for estimating the average containment time ($\bar{c}$) was given earlier (equation on page 59), and it is repeated below. It is the sum of the average detection time ($\bar{d}$) and the blocking time (b). An equation for estimating the average detection time ($\bar{d}$) was given earlier (equation (17) on page 112), and it is also repeated here.

$\bar{c} = \bar{d} + b$	
$\bar{d} = [z / (\bar{r}_{nc} * \bar{x})] - \lambda$	(17)

This section examines how $\bar{\mathbf{c}}_{\mathbf{VULN}}$ can be reduced by altering the parameters in equations (17) and . The blocking time can be reduced by technical means, e.g., speeding up communication with the blocking routers. $\bar{\mathbf{c}}_{\mathbf{VULN}}$ can be expressed as a function of the blocking time, with all other parameters kept constant. The function is represented as $\bar{c}_{VULN}(b)$. It is shown below, and the dependent variable is in bold, for clarity. It is a linear equation, with slope $(\bar{x} * \bar{r}_{vuln})$. For Net-Chaff deployments, this equation can be used to asses the benefits of reducing the blocking time.

$\bar{c}_{VULN}(b) = \mathbf{b} * (\bar{x} * \bar{r}_{vuln}) + (\bar{d} * \bar{x} * \bar{r}_{vuln})$ —from (22) and

Figure 5.1.1.4.1-1 shows $\bar{c}_{VULN}(b)$ for a TCP Scan-and-Attack. (Due to type-setting limitations, the graph's labels omit the bar over $\bar{\mathbf{c}}_{\mathbf{VULN}}$.) A fully parallel scan is modeled, using 100Mbps. The default class A network is used. The detection threshold (z) is 500 probes, and the slope is 1.654 . In this case, reducing **b** is a potentially effective technique for reducing $\bar{\mathbf{c}}_{\mathbf{VULN}}$.

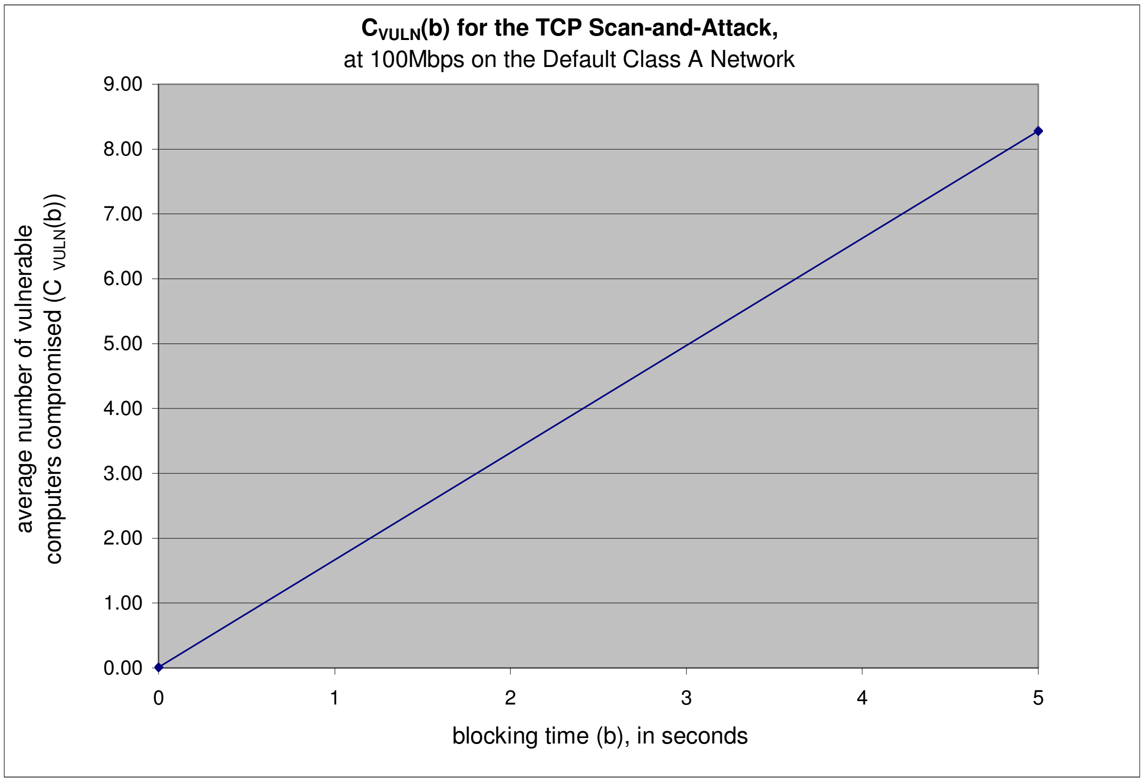


Figure 5.1.1.4.1-1 : $\bar{C}_{VULN}$(b)

For Net-Chaff deployments, $\bar{\mathbf{d}}$ can be reduced by reducing the detection threshold (z). $\bar{\mathbf{C}}_{\mathbf{VULN}}$ can be expressed as a function of the detection threshold, with all other parameters kept constant, i.e., $\bar{C}_{VULN}(z)$. The derivation of $\bar{C}_{VULN}(z)$ is shown below. In equation (38), its $\boldsymbol{\lambda}$ term is assumed to be negligible, and it is omitted in equation (39). $\bar{C}_{VULN}(z)$ is a linear equation with slope ($\bar{r}_{vuln}$ / $\bar{r}_{nc}$). Typically, ($\bar{r}_{vuln}$ / $\bar{r}_{nc}$) is small. Thus, changes in **z** typically have a relatively small affect on $\bar{\mathbf{C}}_{\mathbf{VULN}}$. For example, in the default class A network the ratio ($\bar{r}_{vuln}$ / $\bar{r}_{nc}$) is 0.00001. In addition, requirements for detection accuracy will limit the amount **z** can be reduced.

$$\bar{C}_{VULN} = (b + \bar{d}) * \bar{x} * \bar{r}_{vuln} \quad \text{—from (22) and} \qquad (37)$$

$\bar{C}_{VULN} = (b + ([z / (\bar{r}_{nc} * \bar{x})] - \lambda)) * \bar{x} * \bar{r}_{vuln}$ —from (17) and (37)	(38)
$\bar{C}_{VULN}(z) = \mathbf{z} * (\bar{r}_{vuln} / \bar{r}_{nc}) + (b * \bar{x} * \bar{r}_{vuln})$ —from (38) and omitting λ	(39)

Figure 5.1.1.4.1-2 shows $\bar{C}_{VULN}(z)$ for a TCP Scan-and-Attack. A fully parallel scan is modeled, using 100Mbps. The default class A network is used. The blocking time (b) is 0.250 seconds and the slope is 0.00001. In practice, decreasing **z** from 2,000 to 500 would have no appreciable affect on $\bar{\mathbf{C}}_{\mathbf{VULN}}$, but it may reduce detection accuracy substantially.

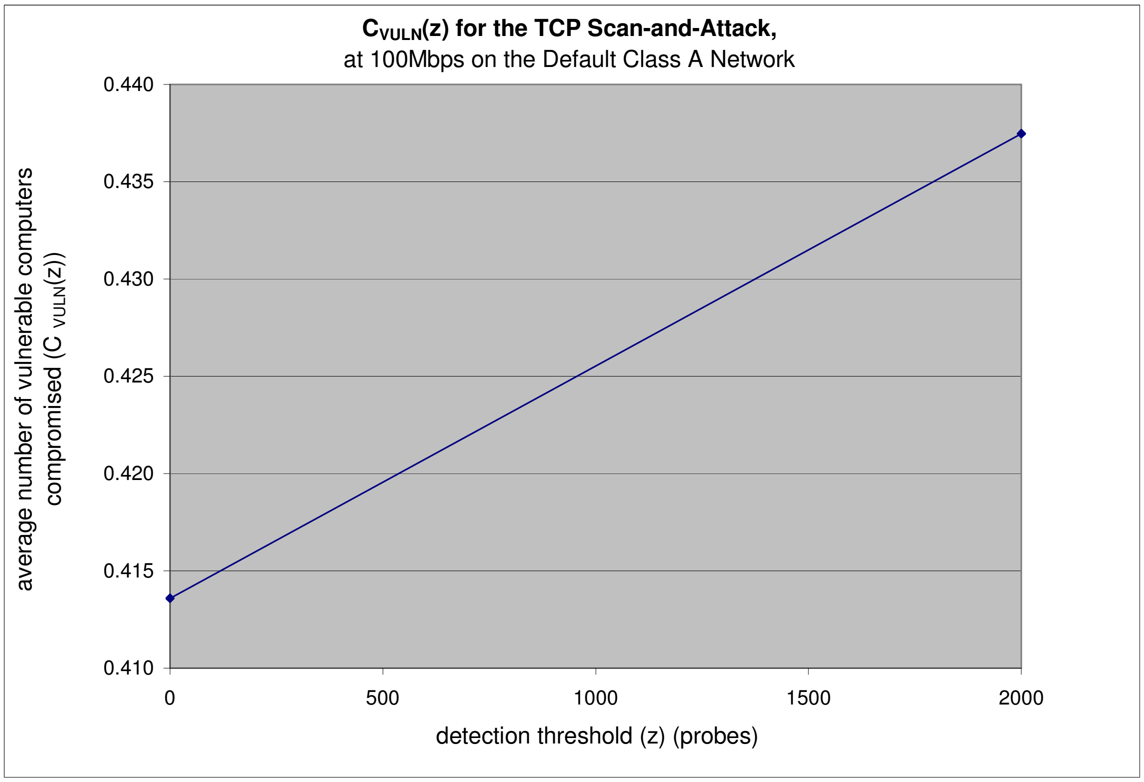


Figure 5.1.1.4.1-2 : $\bar{C}_{VULN}(z)$

Net-Chaff detects scans by monitoring the probes sent to the addresses it manages. $\bar{\mathbf{d}}$ can also be reduced by increasing $\bar{\mathbf{r}}_{\mathbf{nc}}$, which is the ratio between the Net-Chaff managed addresses and the total number of network addresses, i.e., (N_{NC} / N_T). $\bar{\mathbf{C}}_{\mathbf{VULN}}$ can be expressed as a function of $\bar{\mathbf{r}}_{\mathbf{nc}}$ (i.e., $\bar{C}_{VULN}(\bar{r}_{nc})$), with all other parameters kept constant:

$$\boxed{\bar{C}_{VULN}(\bar{\mathbf{r}}_{\mathbf{nc}}) = (1/\bar{\mathbf{r}}_{\mathbf{nc}}) * (z * \bar{r}_{vuln}) + (b * \bar{x} * \bar{r}_{vuln}) \quad \text{—by reordering (39)} \qquad (40)}$$

Increasing $\bar{\mathbf{r}}_{\mathbf{nc}}$ causes $\bar{\mathbf{C}}_{\mathbf{VULN}}$ to decrease at a rate proportional to $(1/\bar{r}_{nc})$, if all other parameters remain constant. Thus, scan detection can be improved by increasing $\bar{\mathbf{r}}_{\mathbf{nc}}$, but this provides diminishing marginal reductions in $\bar{\mathbf{C}}_{\mathbf{VULN}}$, i.e., the slope of $(1/\bar{r}_{nc})$ is $(-1 / (\bar{r}_{nc})^2)$.

In practice, when $\bar{\mathbf{r}}_{\mathbf{nc}}$ is changed, some of the other parameters in equation (40) typically do not remain constant. For example, an increase in $\bar{\mathbf{r}}_{\mathbf{nc}}$ will usually result in a decrease in $\bar{\mathbf{x}}$, which also reduces $\bar{\mathbf{C}}_{\mathbf{VULN}}$. This will be further addressed in the next section.

Figure 5.1.1.4.1-3 shows $\bar{C}_{VULN}(\bar{r}_{nc})$ for a TCP Scan-and-Attack. $\bar{\mathbf{r}}_{\mathbf{nc}}$ is the independent variable, and all other parameters are kept constant. A fully parallel scan is modeled, using 100Mbps. The blocking time (b) is 0.250 seconds and the detection threshold (z) is 500 probes. The default class A network is used, with one exception. In this case, Net-Chaff is not using impersonations, in order to make $\bar{\mathbf{x}}$ constant. $\bar{\mathbf{r}}_{\mathbf{nc}}$ is calculated as (N_{NC} / N_T). $\mathbf{N_T}$ is fixed for the class A network, and $\mathbf{N_{NC}}$ is varied. $\bar{\mathbf{r}}_{\mathbf{nc}}$ ranges from 0.1 up to the maximum value, which is close to 1.0.

This scenario and graph reveal design principles for Net-Chaff deployments. If the Net-Chaff managed addresses do not appreciably slow down a scan, their usefulness lies solely in scan detection (i.e., as calculated by $\bar{\mathbf{d}}$). Further, for the purpose of scan detection, Net-Chaff may only need to monitor a small fraction of the network addresses. For example, in Figure 5.1.1.4.1-3 increasing $\bar{\mathbf{r}}_{\mathbf{nc}}$ beyong 0.2 provides relatively little reduction in $\bar{\mathbf{C}}_{\mathbf{VULN}}$.

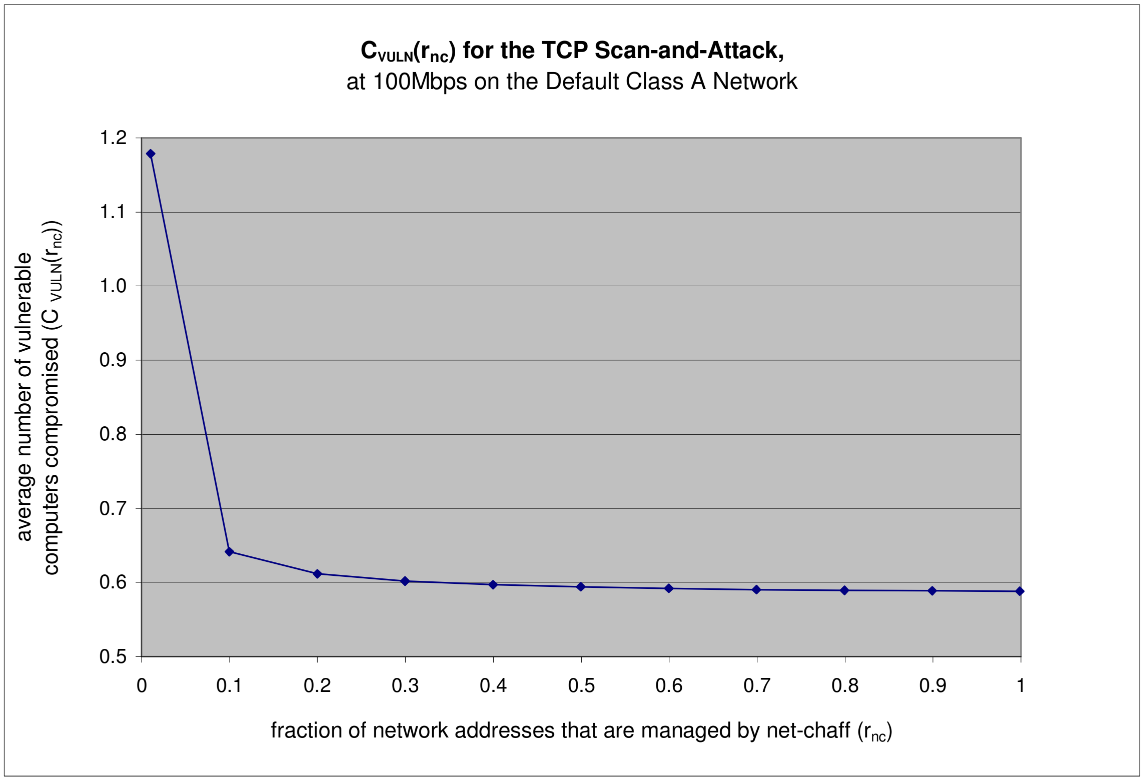


Figure 5.1.1.4.1-3 : $\bar{C}_{VULN}(\bar{r}_{nc})$

5.1.1.4.2 The average network probe rate

This section analyzes how Net-Chaff's low-level impersonations can be used to reduce the average network probe rate ($\bar{x}$), for typical Net-Chaff deployments. Net-Chaff can reduce $\bar{\mathbf{x}}$ by deceptive probe responses, including no response. The low-level impersonations can cause the scanner to send extra packets and thereby slow it down. Also, by not sending expected replies, Net-Chaff can cause the scanner to retransmit packets. Further, Net-Chaff can use delays to slow scanners that suspend transmission while they await replies, e.g., serial scans. Additional delay techniques can be used, such as the "tar pits" described in chapter 4. This section focuses on reducing probe rates through the use of Net-Chaff's low-level impersonations. Analysis of other types of Net-Chaff responses, or delays, are left for future research.

This analysis is based on the equation for $\bar{\mathbf{c}}_{\mathbf{VULN}}$, and it uses an expanded form that is shown in equation (41). The expanded form is derived from equation (38). Again, the $\boldsymbol{\lambda}$ term is assumed to be negligible, so it is omitted in equation (41).

$$\bar{c}_{VULN} = ([b * \bar{x}] + [z / \bar{r}_{nc}]) * \bar{r}_{vuln} \quad \text{—from (38) and omitting } \lambda \qquad (41)$$

The average network probe rate ($\bar{\mathbf{x}}$) can be estimated by using the equations derived in section 5.1.1.2.1 (page 103). That section's equation (9) will be used in this analysis, and the equation is repeated here:

$$\bar{x} = \frac{1}{\sum_{i \in S} \bar{r}_i / x_i} \qquad (9)$$

There are two ways $\bar{\mathbf{x}}$ can be reduced for Net-Chaff deployments:

- the individual probe rates (x_i) can be reduced for Net-Chaff's probe-response types. However, as mentioned earlier, this section focuses on reducing $\bar{\mathbf{x}}$ via low-level impersonations. Further reducing Net-Chaff's probe-response types is beyond the scope of this research.
- $\bar{\mathbf{r}}_{\mathbf{i}}$ can be increased for Net-Chaff's slow probe-response types (see equation (8) on page 107). This involves increasing the proportion of network addresses that use Net-Chaff's slow probe-response types. For the example web-server scans, the proportion of impersonations would be increased, i.e., (N_{nc_imp} / N_T) (see Table 5.1.1.2.4-2 on page 115).

Regarding the latter bullet, there are three techniques for increasing the number of addresses that use Net-Chaff's slow probe response types. All three of the techniques can reduce $\bar{\mathbf{x}}$, and two of the techniques provide additional effects that further reduce $\bar{\mathbf{c}}_{\mathbf{VULN}}$. The three techniques are described below.

- **The network size (N_T) is kept fixed, as well as the number of Net-Chaff managed addresses (N_{NC}).**

In this case, to reduce $\bar{\mathbf{x}}$ the percentage of slow probe-response types is increased, for the Net-Chaff managed addresses. For the example network and web-server scan, the number of Net-Chaff managed addresses with server impersonations is represented as $\mathbf{N_{nc\_imp}}$. This technique would increase $\mathbf{N_{nc\_imp}}$ while keeping $\mathbf{N_{NC}}$ fixed. A limitation of the technique is that the percentage of Net-Chaff impersonations must be kept low enough to prevent counter-deception, as was discussed in chapter 4.

This technique's effectiveness can be estimated, for reducing $\bar{\mathbf{x}}$ and $\bar{\mathbf{C}}_{\mathbf{VULN}}$. The fraction of Net-Chaff-managed addresses with server impersonations is (N_{nc_imp} / N_{NC}). Figure 5.1.1.4.2-1 shows $\bar{\mathbf{x}}$ as a function of (N_{nc_imp} / N_{NC}). $\mathbf{N_{NC}}$ is fixed and $\mathbf{N_{nc\_imp}}$ is varied. A fully parallel TCP Scan-and-Attack is modeled, using 100Mbps. The default class A network is being used, with the exception that $\mathbf{N_{NC}}$ is varied. The blocking time (b) is 0.250 seconds and the detection threshold (z) is 500 probes. For the default class A network, the number of Net-Chaff managed addresses (N_{NC}) is more than 99% of the network, so the maximum value for $\bar{\mathbf{r}}_{\mathbf{nc\_imp}}$ (i.e., (N_{nc_imp} / N_T)) is almost one. The decrease in $\bar{\mathbf{x}}$ is due to the increase in its $\bar{\mathbf{r}}_{\mathbf{nc\_imp}}$ term; thus the graph is roughly proportional to (1 / $\bar{r}_{nc\_imp}$).

Figure 5.1.1.4.2-2 shows $\bar{\mathbf{C}}_{\mathbf{VULN}}$ as a function of (N_{nc_imp} / N_{NC}). The network and scan parameters are the same as those used for Figure 5.1.1.4.2-1. $\bar{\mathbf{C}}_{\mathbf{VULN}}$ is being reduced solely by a decrease in $\bar{\mathbf{x}}$.

Figure 5.1.1.4.2-2 reveals a design principle for Net-Chaff deployments when (N_{NC} / N_T) is large (e.g., near 1). For the Net-Chaff managed addresses, a small percentage of impersonations can potentially reduce $\bar{\mathbf{C}}_{\mathbf{VULN}}$ significantly. For example, in Figure 5.1.1.4.2-2 if (N_{nc_imp} / N_{NC}) is increased from 0 to 0.2, then $\bar{\mathbf{C}}_{\mathbf{VULN}}$ is reduced by more than half. Beyond a certain point, increasing the percentage of impersonations not only risks counterdeception, but it may also provide relatively little reduction in $\bar{\mathbf{C}}_{\mathbf{VULN}}$.

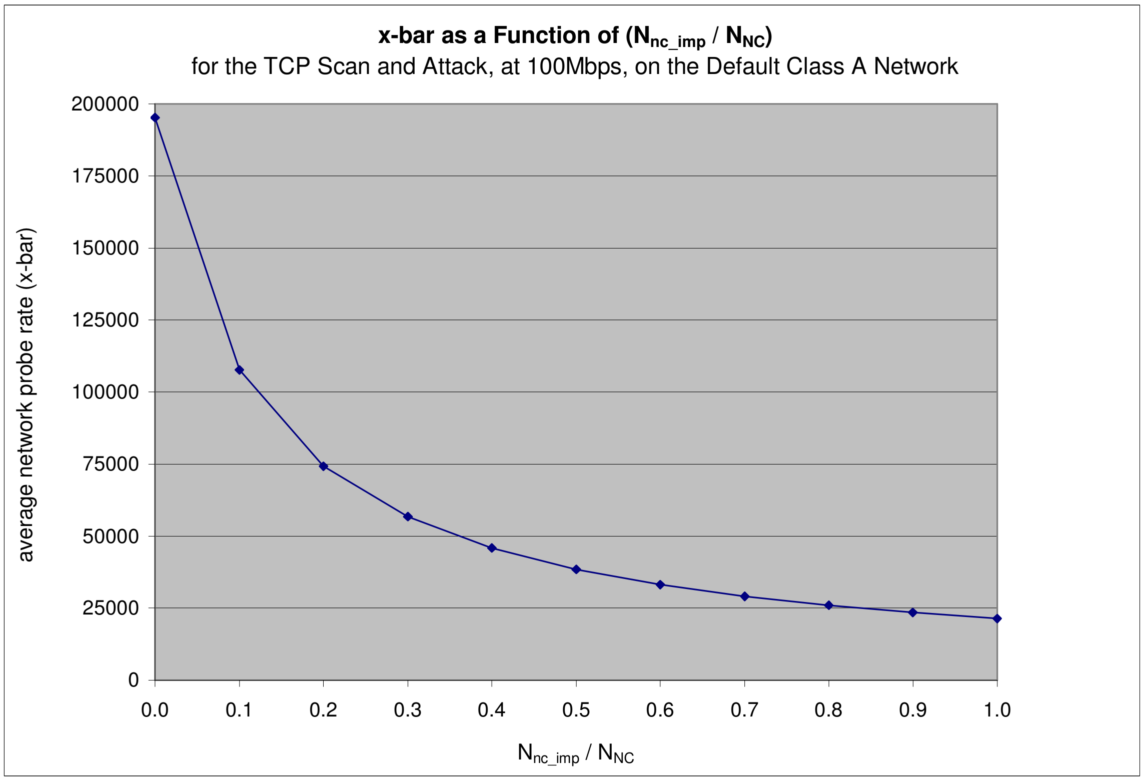


Figure 5.1.1.4.2-1 : $\bar{x}$ as a function of (Nnc_imp / N_{NC})

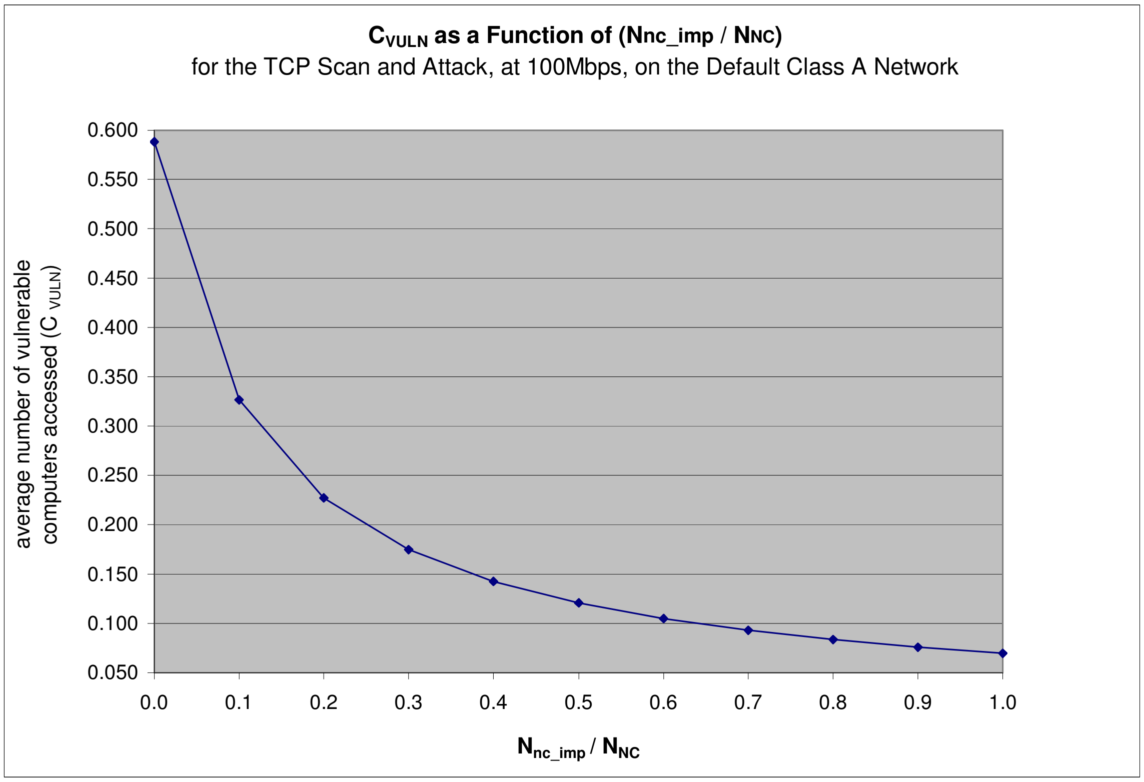


Figure 5.1.1.4.2-2 : $\bar{C}_{VULN}$ as a function of (Nnc_imp / N_{NC})

- **The network size (N_T) is kept fixed, but the number of Net-Chaff managed addresses (N_{NC}) is increased.**

In this case, the addresses added to Net-Chaff would typically be taken from the set of unassigned addresses (see Table 5.1.1.2.4-2 on page 115). Impersonation will be used for some, or all, of the addresses added to Net-Chaff. Collectively, the additional addresses will have a lower average probe rate when managed by Net-Chaff than when they were unassigned. This technique reduces $\bar{\mathbf{C}}_{\mathbf{VULN}}$ in two ways. Among the parameters in equation (41): it reduces $\bar{\mathbf{x}}$, and it increases $\bar{\mathbf{r}}_{\mathbf{nc}}$.

This technique's effectiveness can be estimated, for reducing $\bar{\mathbf{x}}$ and $\bar{\mathbf{C}}_{\mathbf{VULN}}$. The maximum number of addresses that Net-Chaff can potentially manage is equal to the size of the network, minus the number of addresses assigned to real computers. Using the network parameters defined in Table 5.1.1.2.4-1 (page 115), this value is ($N_T - N_R$). The number of addresses managed by Net-Chaff is a fraction of those that it can potentially manage: ((N_{NC} / ($N_T - N_R$) $\leq$ 1).

Figure 5.1.1.4.2-3 shows $\bar{\mathbf{x}}$ as a function of (N_{NC} / ($N_T - N_R$)). N_T and N_R are fixed, and N_{NC} is varied. The default class A network (Table 5.1.1.2.4-1 on page 115) is being used, with the exception that $\mathbf{N_{NC}}$ is a variable. There are 20K addresses assigned to real computers, so ($N_T - N_R$) is more than 99% of the network addresses. A fully parallel TCP Scan-and-Attack is modeled, using 100Mbps. The blocking time (b) is 0.250 seconds and the detection threshold (z) is 500 probes. The figure graphs $\bar{\mathbf{x}}$ for three different amounts of impersonations, calculated as percentages of $\mathbf{N_{NC}}$. The decrease in $\bar{\mathbf{x}}$ is due to the increase in its $\bar{\mathbf{r}}_{\mathbf{nc\_imp}}$ term.

Figure 5.1.1.4.2-4 shows $\bar{\mathbf{C}}_{\mathbf{VULN}}$ as a function of (N_{NC} / ($N_T - N_R$)). The calculations were made using equation (41). The network and scan parameters are the same as those used for Figure 5.1.1.4.2-3.

Figure 5.1.1.4.2-4 reveals a design principle for Net-Chaff deployments when (N_R / N_T) is small (e.g., near 0). Assigning a small fraction of the unused addresses to Net-Chaff can potentially reduce $\bar{\mathbf{C}}_{\mathbf{VULN}}$ significantly. For example, in Figure 5.1.1.4.2-4 if (N_{NC} / ($N_T - N_R$)) is increased from 0.01 to 0.2, then $\bar{\mathbf{C}}_{\mathbf{VULN}}$ is reduced by more than half.

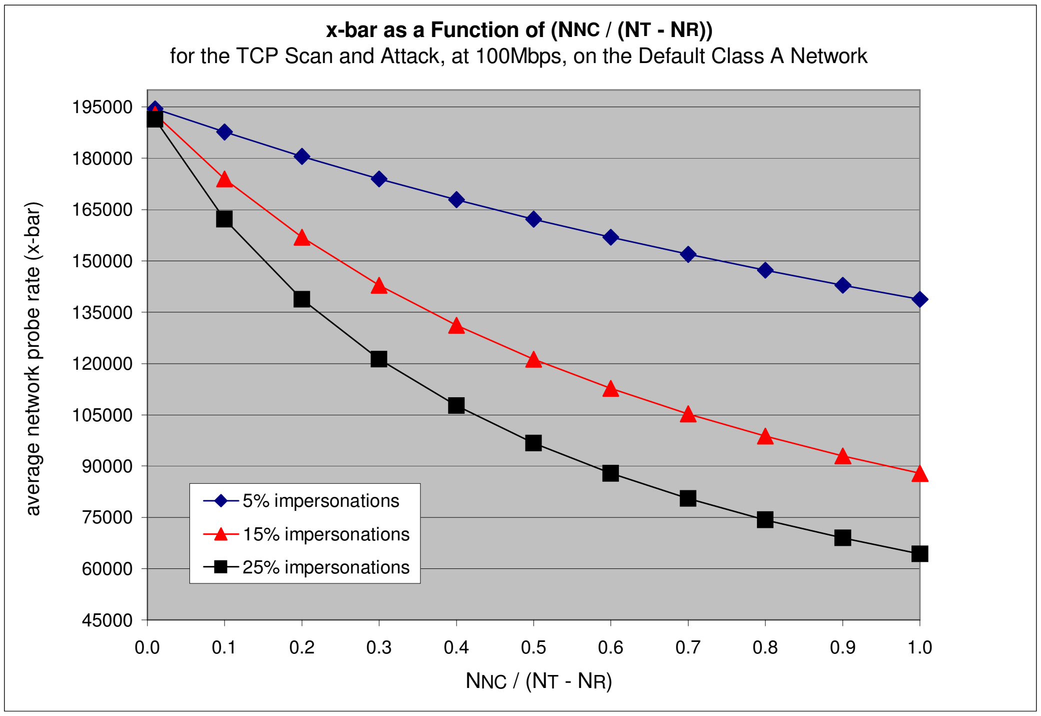


Figure 5.1.1.4.2-3 : $\bar{x}$ as a function of (N_{NC} / (N_T - N_R))

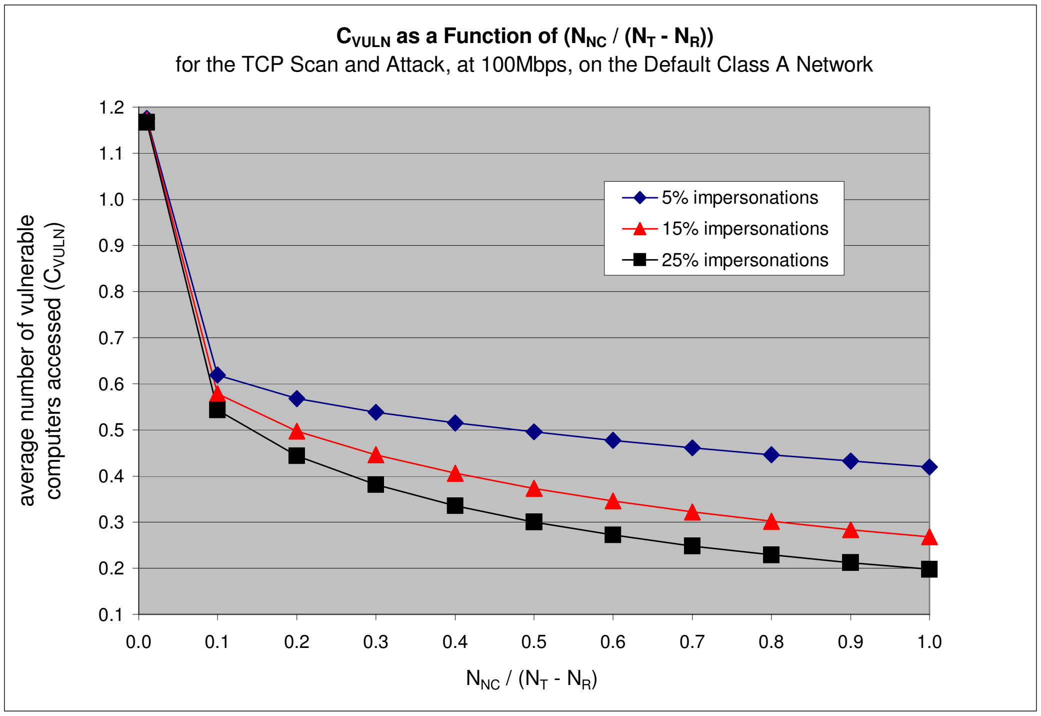


Figure 5.1.1.4.2-4 : $\bar{C}_{VULN}$ as a function of (N_{NC} / (N_T - N_R))

- **The network size (N_T) is increased, and all new addresses are assigned to Net-Chaff (N_{NC}).**

With Net-Chaff, increasing the network size would typically involve converting a class B network to the reserved class A network. For the Net-Chaff managed addresses, the distribution of the probe-response types would likely stay the same, e.g., (N_{nc_imp} / N_{NC}) would stay the same (see Table 5.1.1.2.4-2 on page 115). The Net-Chaff-managed addresses would typically have a slower average probe rate than the other network addresses. This technique of increasing the address space is especially effective as it reduces $\bar{\mathbf{c}}_{\mathbf{VULN}}$ in three ways. Among the parameters in equation (41): it typically reduces $\bar{\mathbf{x}}$, and it always increases $\bar{\mathbf{r}}_{\mathbf{nc}}$ and decreases $\bar{\mathbf{r}}_{\mathbf{vuln}}$.

This technique's effectiveness can be estimated for reducing $\bar{\mathbf{x}}$ and $\bar{\mathbf{c}}_{\mathbf{VULN}}$. Figure 5.1.1.4.2-5 shows $\bar{\mathbf{x}}$ as a function of the network size (N_T). The x-axis scale is $\log_2$, and the values shown range from a class B network (2^{16} addresses) up to a class A network (2^{24} addresses). The default network specifications are being used, with the exception that N_T varies in size. A fully parallel TCP Scan-and-Attack is modeled, using 100Mbps. The blocking time (b) is 0.250 seconds and the detection threshold (z) is 500 probes. The figure graphs $\bar{\mathbf{x}}$ for three different amounts of impersonations, calculated as percentages of $\mathbf{N}_{\mathbf{NC}}$.

Figure 5.1.1.4.2-6 shows $\bar{\mathbf{c}}_{\mathbf{VULN}}$ as a function of (N_T). The calculations were made using equation (41). The network and scan parameters are the same as those used for Figure 5.1.1.4.2-5.

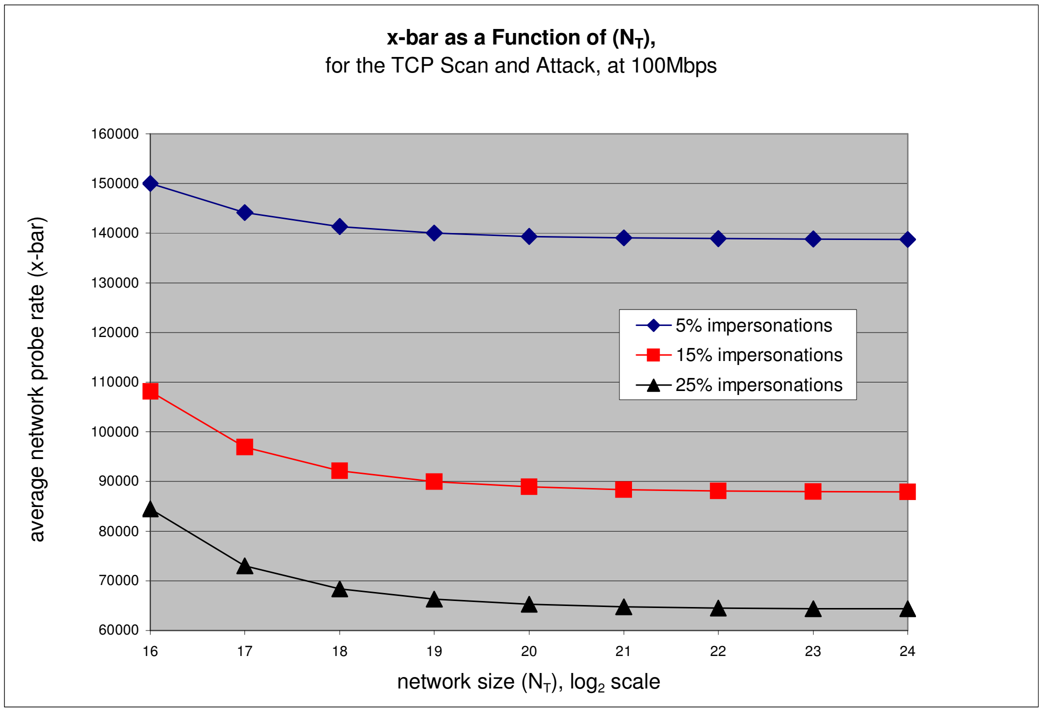


Figure 5.1.1.4.2-5 : $\bar{x}$ as a function of N_T

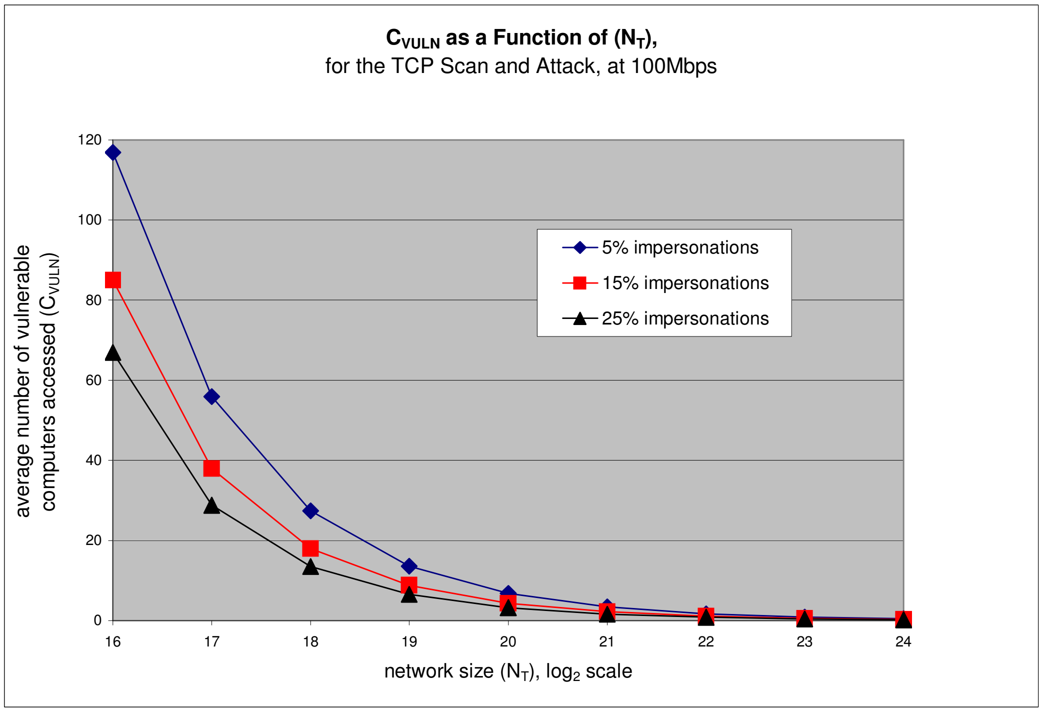


Figure 5.1.1.4.2-6 : $\bar{C}_{VULN}$ as a function of N_T

5.1.1.4.3 The proportion of vulnerable computers in scans: $\bar{r}vuln$

Within scans, the average proportion of vulnerable computers is represented by $\bar{\mathbf{r}}_{\mathbf{vuln}}$ (see equation (8) on page 107). It is calculated as the ratio of network addresses assigned to vulnerable computers, i.e., (N_{vuln} / N_T). For a given average network probe rate ($\bar{\mathbf{x}}$), $\bar{\mathbf{r}}_{\mathbf{vuln}}$ determines the rate at which vulnerable computers are probed, i.e., the number of vulnerable computers probed per second. This rate is calculated as ($\bar{x}$ * $\bar{r}_{vuln}$), as described earlier with equation (22) (page 133).

$\bar{\mathbf{C}}_{\mathbf{VULN}}$ is proportional to $\bar{\mathbf{r}}_{\mathbf{vuln}}$, as shown by equation (22). $\bar{\mathbf{C}}_{\mathbf{VULN}}$ can be reduced by reducing $\bar{\mathbf{r}}_{\mathbf{vuln}}$. There are two practical ways to reduce $\bar{\mathbf{r}}_{\mathbf{vuln}}$. One is to decrease the number of vulnerable computers on the network, e.g., by improving host security. The other way is to increase the size of the network's address space. The added addresses are unused, and ideally they would be assigned to Net-Chaff, to obtain further reductions in $\bar{\mathbf{C}}_{\mathbf{VULN}}$, as described in the prior section.

In the example network configuration, the default class B network has 200 vulnerable servers, and an $\bar{\mathbf{r}}_{\mathbf{vuln}}$ value of 0.003. By converting to a class A address space, the $\bar{\mathbf{r}}_{\mathbf{vuln}}$ value would be 0.00001. In general, if a class B network is converted to a class A address space, then the $\bar{\mathbf{r}}_{\mathbf{vuln}}$ value for the class A network will be 0.004 of its value for the class B network. The added addresses are unused and they substantially improve Net-Chaff's performance. More specifically, $\bar{\mathbf{C}}_{\mathbf{VULN}}$ for the class A network would also be 0.004 of its value for the class B network, if $\bar{\mathbf{r}}_{\mathbf{vuln}}$ is the only parameter that differs for the two networks. However, if the added addresses are assigned to Net-Chaff, $\bar{\mathbf{C}}_{\mathbf{VULN}}$ will be further reduced for the class A network, as described earlier.

Figure 5.1.1.4.3-1 shows $\bar{\mathbf{r}}_{\mathbf{vuln}}$ as a function of the network size (N_T), for a network with 200 vulnerable computers. The x-axis is in $\log_2$ scale, and it ranges from the number of addresses in a class B network, up to a class A network.

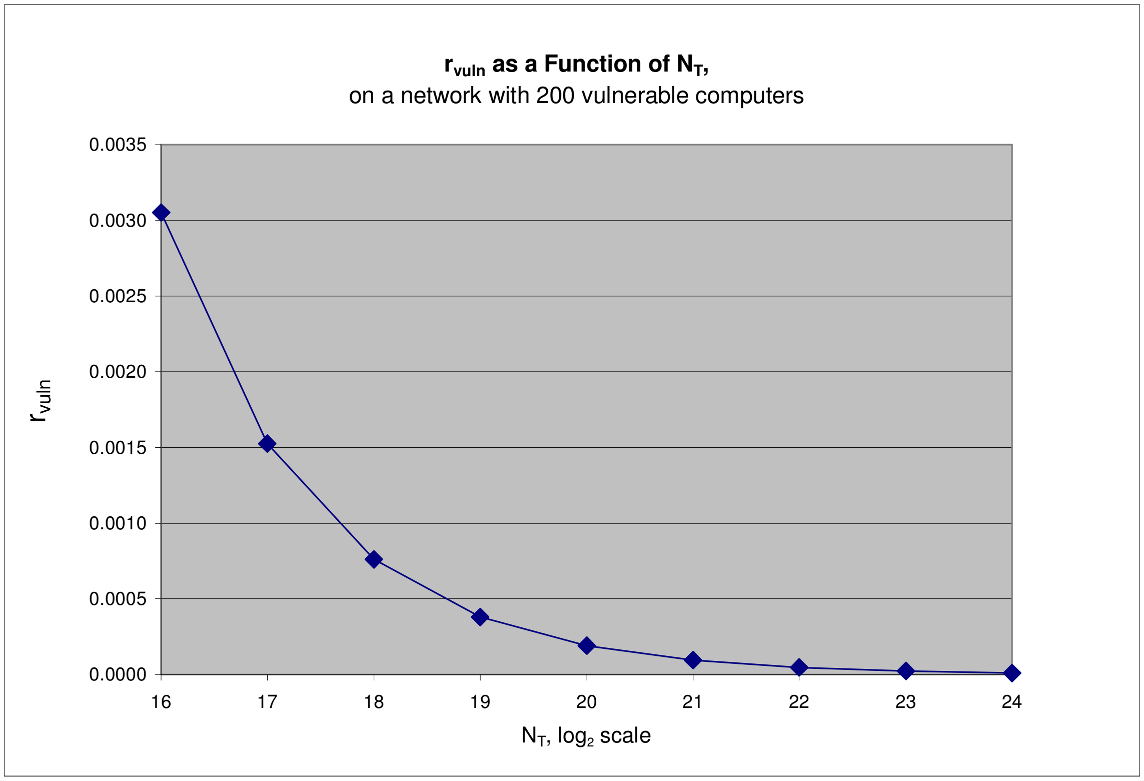


Figure 5.1.1.4.3-1 : $\bar{r}_{vuln}$ as a function of the network size (N_T)

When a network has a large number of unused addresses, relative to the number of vulnerable computers, then the unused addresses serve to hide the vulnerable computers. This is the *passive hiding* that was described in chapter 4. Passive hiding's affect on $\bar{\mathbf{r}}_{\mathbf{vuln}}$ and $\bar{\mathbf{C}}_{\mathbf{VULN}}$ can be quantified. Without the unused addresses, $\bar{\mathbf{r}}_{\mathbf{vuln}}$ would be (N_{vuln} / N_R). With the unused addresses, $\bar{\mathbf{r}}_{\mathbf{vuln}}$ is (N_{vuln} / N_T). For example, in the default class A network, 20K addresses are assigned to real computers, of which 200 addresses are assigned to vulnerable computers. (N_{vuln} / N_R) is 0.01, and (N_{vuln} / N_T) is 0.00001. In general, $\bar{\mathbf{r}}_{\mathbf{vuln}}$ with the unused addresses is (N_T / N_R) times smaller than $\bar{\mathbf{r}}_{\mathbf{vuln}}$ without the unused addresses. In the example, (N_T / N_R) is approximately 1,000. $\bar{\mathbf{r}}_{\mathbf{vuln}}$ is a factor in calculating $\bar{\mathbf{C}}_{\mathbf{VULN}}$, as shown by equation (22). Therefore, passive hiding's affect on $\bar{\mathbf{r}}_{vuln}$ will ultimately have the same affect on $\bar{\mathbf{C}}_{\mathbf{VULN}}$.

5.1.1.4.4 Summary

This section analyzed the elements of Net-Chaff deployments that affect its performance. The purpose of the analysis is to understand: 1) how to effectively configure Net-Chaff deployments, and 2) the role of deception. The analysis focused on the example web-server scan, which includes Net-Chaff impersonations and vulnerable web-servers. For a Net-Chaff deployment, this analysis is applicable to other servers as well.

Net-Chaff's performance is evaluated in terms of the average number of vulnerable computers compromised by a scan ($\bar{c}_{VULN}$), and the equation is repeated below. Each term in the equation was analyzed with respect to reducing $\bar{\mathbf{c}}_{\mathbf{VULN}}$.

$$\boxed{\bar{c}_{VULN} = ([b * \bar{x}] + [z / \bar{r}_{nc}]) * \bar{r}_{vuln} \qquad (41)}$$

The average network probe rate ($\bar{x}$) can be reduced by Net-Chaff's deceptions. As shown by equation (9) (page 107), $\bar{\mathbf{x}}$ can be reduced by slowing down the probe rate for Net-Chaff's probe-response types, i.e., decreasing $\mathbf{x_i}$ for Net-Chaff's probe-response types. Alternatively, $\bar{\mathbf{x}}$ can be reduced by increasing the proportion of Net-Chaff's slow probe-response types on the network, i.e., increasing $\bar{\mathbf{r}}_{\mathbf{i}}$ for Net-Chaff's probe-response types. The analysis focused on increasing the proportion of Net-Chaff's low-level impersonations on the network, i.e., increasing $\bar{\mathbf{r}}_{\mathbf{nc\_imp}}$. Three techniques for increasing $\bar{\mathbf{r}}_{\mathbf{nc\_imp}}$ were examined. The most effective technique was to increase the network size, and assign all new addresses to Net-Chaff. This reduces $\bar{\mathbf{c}}_{\mathbf{VULN}}$ in three ways: 1) it typically reduces $\bar{\mathbf{x}}$, 2) it always increases $\bar{\mathbf{r}}_{\mathbf{nc}}$, and 3) it always decreases $\bar{\mathbf{r}}_{\mathbf{vuln}}$. Converting from a class B network to a class A network can be the most effective way to reduce $\bar{\mathbf{c}}_{\mathbf{VULN}}$, as Net-Chaff's performance is improved in these three ways.

$\bar{\mathbf{c}}_{\mathbf{VULN}}$ can also be reduced by reducing the containment time. There are three Net-Chaff parameters that can be configured to reduce the containment time: 1) the blocking time (b) can be reduced by technical means. The reduction in $\bar{\mathbf{c}}_{\mathbf{VULN}}$ is proportional to ($\bar{x} * \bar{r}_{vuln}$). 2) The detection threshold (z) can be reduced, but doing so may reduce detection accuracy. Also, when $\bar{\mathbf{r}}_{\mathbf{nc}}$ is large (e.g., near one), and $\bar{\mathbf{r}}_{\mathbf{vuln}}$ is very small, then reductions in **z** will cause relatively insignificant reductions in $\bar{\mathbf{C}}_{\mathbf{VULN}}$. These conditions are typical for effective Net-Chaff deployments. 3) $\bar{\mathbf{r}}_{\mathbf{nc}}$ is calculated as the ratio of Net-Chaff-managed addresses to the total number of addresses (N_{NC}/N_T). $\bar{\mathbf{r}}_{\mathbf{nc}}$ can be increased to speed-up scan detection. The speed-up in scan detection provides diminishing marginal reductions in $\bar{\mathbf{C}}_{\mathbf{VULN}}$, i.e., $\bar{C}_{VULN}(\bar{r}_{nc})$ is proportional to $(1/\bar{r}_{nc})$.

$\bar{\mathbf{C}}_{\mathbf{VULN}}$ is proportional to $\bar{\mathbf{r}}_{\mathbf{vuln}}$, as shown by equation (41). There are two practical ways to reduce $\bar{\mathbf{r}}_{\mathbf{vuln}}$. One is to decrease the number of vulnerable computers on the network. The other way is to increase the size of the network's address space. The added addresses are unused. When a network has a large number of unused addresses, relative to the number of vulnerable computers, then the unused addresses serve to hide the vulnerable computers. This passive hiding reduces $\bar{\mathbf{C}}_{\mathbf{VULN}}$ to the same extent that $\bar{\mathbf{r}}_{\mathbf{vuln}}$ is reduced, and the reduction can be calculated, as shown earlier.

Net-Chaff's deceptions serve to slow down scans. However, increasing the fraction of Net-Chaff impersonations (N_{nc_imp}/N_{NC}) provides diminishing marginal reductions in $\bar{\mathbf{C}}_{\mathbf{VULN}}$. For instance, when almost all network addresses are managed by Net-Chaff (i.e., $(N_{NC} / N_T) \approx 1$), then a small percentage of impersonations (e.g., $(N_{nc\_imp}/N_{NC}) \approx 0.2$) may reduce $\bar{\mathbf{C}}_{\mathbf{VULN}}$ significantly. Beyond a certain point, increasing the percentage of impersonations can not only risk counterdeception, but it may also provide relatively little reduction in $\bar{\mathbf{C}}_{\mathbf{VULN}}$.

5.1.1.5 Taxonomy of probe-response types

A central component of the rate-based models is the taxonomy of probe-responses. The taxonomy's categories are probe-response types. Such a taxonomy was presented in section 5.1.1.1.3 (page 99). This taxonomy was developed for the example networks and scans that are used for the Net-Chaff analysis. The rate-based models can also be used to analyze other types of networks and scans. However, a different taxonomy of probe-responses may be required. This section describes how the taxonomy of probe-response types can be modified for use with other networks and scans. Also described are probe-response types from deception-based security devices other than Net-Chaff, e.g., honeypots. In this section, the taxonomy of probe-responses will be referred to as simply *the taxonomy*.

The taxonomy is used by the rate-based models, and it models the network and scanner that are being analyzed. The rate-based models' primary calculations are: 1) the average number of vulnerable computers accessed by the scan ($\bar{\mathbf{C}}_{\mathbf{VULN}}$, e.g., see equation (22) on page 119), and 2) the average number of affirmative responses received by the scan ($\bar{\mathbf{C}}_{\mathbf{AFF}}$, e.g., see equation (23) on page 124). The former calculation is used for all three scan types: scan-and-attack, filtering scans, and information-retrieval scans. The latter calculation is just used for information-retrieval scans.

In general, the taxonomy must include the probe-response types needed to calculate $\bar{\mathbf{C}}_{\mathbf{i}}$, where $\mathbf{i}$ is a probe-response type whose outcome is of interest, e.g., $\bar{\mathbf{C}}_{\mathbf{VULN}}$ or $\bar{\mathbf{C}}_{\mathbf{AFF}}$ (see equation (21) on page 114). The probe-response types are modeled relative to the scanner's capabilities. For example, the probe-response type for vulnerable servers (e.g., vuln) only includes servers that are vulnerable to attack by the scan that is being analyzed. Probe-response types are also needed for calculating the average network probe-rate ($\bar{x}$) (see section 5.1.1.2.1 on page 103).

In addition to Net-Chaff, there are other security devices that use deception. The taxonomy will need to include probe responses from these devices if their scan outcomes are of interest (i.e., $\bar{\mathbf{C}}_{\mathbf{i}}$), or if they affect $\bar{\mathbf{x}}$. For example, LaBrea is a deceptive device that can potentially stop a serial scan [LaB05]. If LaBrea is deployed, and it significantly affects $\bar{x}$, then it will need its own probe-response type. As another example, a certain honeypot has a vulnerable web-server that is used for collecting intelligence. Many of these honeypots are deployed on the network being analyzed. To calculate the average number of honeypots accessed by scans, the honeypots would need their own probe-response type.

Firewalls often use deceptive replies in response to disallowed packets. For example, firewalls can simply not reply to disallowed packets [Rus02]. This can delay scanners in two ways: 1) serial scanners can be slowed down if they wait a long time for a reply, and 2) scanners may interpret the non-response as a dropped packet, and retransmit the probe, perhaps multiple times. If this deception is used for many network addresses, it can reduce scanners' average network probe rate ($\bar{x}$). Consequently, a probe response-type would be needed for this deception. Another deception used by firewalls involves sending false-negative replies to scanners [Rus02]. For example, the firewall can send an ICMP host-unreachable message in response to a TCP ping. For the Net-Chaff analysis, its taxonomy is sufficient for calculating $\bar{x}$ (see Table 5.1.1.1.3-1 on page 100). The deceptive probe-response would simply be included in the category "no server present" (ns).

5.1.2 Simulation

A simulation was used to verify the rate-based models. The simulation is a model of scans on a network that is protected by Net-Chaff. A web-server TCP ping-scan was simulated. This type of scan was also analyzed by the rate-based models in section 5.1.1.3.1 (page 120). The simulation model is *packet-based*, as it models the transmission and reception of scan packets on the network. Overall, the simulation's packet-based model is slightly more accurate than the rate-based models. The simulation was implemented as a Java program, and it consists of 1,600 lines of code.

Three different network-scan scenarios were modeled. For each of these scenarios, both the simulation and rate-based models were used to calculate the *Net-Chaff outcomes*. The Net-Chaff outcomes are defined as: 1) the average number of scanner probes that are completed prior to containment ($\bar{C}$), 2) the average number of affirmative replies received, prior to containment ($\bar{C}_{AFF}$), 3) the average number of affirmative replies received from vulnerable computers, prior to containment ($\bar{C}_{VULN}$), and 4) for a given value of $\mathbf{\bar{C}_{VULN}}$, the probability that a scan will probe one or more vulnerable computers (P_{vuln}). These outcomes were described earlier for the rate-based models (in section 5.1.1.1.2 on page 97, and section 5.1.1.3.2 on page 126). The calculations made by the simulation and rate-based models were compared. The results are very similar, which corroborates the rate-based models.

The Net-Chaff simulation is described in the following two subsections. The first subsection describes the simulation's design. The second subsection describes how the simulation was used, and how it verifies the rate-based models.

5.1.2.1 Design

An overview of the simulation design is presented first, and further details follow.

5.1.2.1.1 Overview

The simulation contains parameters for configuring its models of the network, the scanner, and Net-Chaff. The simulation is *configured* by specifying these parameters.

The *network scan* is simulated, and the simulation is carried out in two stages. In the first stage, the scan itself is simulated. All of the network addresses are probed (Net-Chaff does not contain the scan). For each probe, its outcome is recorded in a relational database (RDB). The *probe outcome* is defined as: 1) the probe's response type, 2) the response's arrival time at the scanner, and 3) as applicable, the probe's arrival time at the Net-Chaff WAN server.

In the second stage, the RDB is used to calculate scan outcomes that would occur with Net-Chaff containment. Scan outcomes are calculated for a particular detection threshold and blocking time. The *scan outcomes* are defined as: 1) the number of scanner probes that are completed prior to containment (C), 2) the number of affirmative replies received, prior to containment (C_{AFF}), and 3) the number of affirmative replies received from vulnerable computers, prior to containment (C_{VULN}). These three scan outcomes are very similar to the first three Net-Chaff outcomes. The difference between them is that scan outcomes are calculated for a particular scan, and Net-Chaff outcomes are calculated as averages over many scans, as will be explained.

In calculating scan outcomes, the detection threshold (z) and blocking time (b) are referred to, collectively, as the *containment parameters*. A particular pair of z and b values will be referred to, collectively, as a *containment-specification*. The simulation's configuration-parameters include a *set of containment-specifications*. The set consists of **n** pairs of **z** and **b** values: $((z_1,b_1), (z_2,b_2), \ldots (z_n,b_n))$. In the second stage of the simulated network-scan, scan outcomes are calculated for each of the containment-specifications. The scan outcomes are stored in an RDB.

The Net-Chaff analysis is concerned with scans that use random address-selection. Therefore, the Net-Chaff outcomes must be calculated over many network scans, i.e., the average values $\bar{C}$, $\bar{C}_{AFF}$, and $\bar{C}_{VULN}$, and the probability value P_{vuln}. To make these calculations, the overall simulation process is carried out in two steps. First, many simulated network scans are preformed, e.g., 300. All of these network scans use the same simulation configuration, including the same containment-specifications. In the second step of the simulation, the Net-Chaff outcomes are calculated for each of the containment-parameter specifications. The calculations are made using all of the scan outcomes from the simulated network scans. When this overall simulation process is performed, it is referred to as a *simulation run*. The overall simulation process is shown in Figure 5.1.2.1.1-1, in pseudo-code format.

```
perform simulation run:
• first step: perform simulated network scans
    o j = number of simulated network scans to perform
    o FOR i = 1 to j DO:
        ▪ perform a simulated network scan:
            • first stage: simulate random probe of all network addresses
            • second stage: for each of the containment-specifications,
              calculate the scan outcomes: $C$, $C_{AFF}$, $C_{VULN}$
    o END FOR loop
• second step: calculate the Net-Chaff outcomes: $\bar{C}$, $\bar{C}_{AFF}$, $\bar{C}_{VULN}$, and $P_{vuln}$
    o for each of the containment-specifications:
        ▪ calculate the Net-Chaff outcomes, over all of the simulated network scans
```

Figure 5.1.2.1.1-1 : Overall simulation process

The simulation design is further described in the following two subsections. The first subsection describes the network scan. The second subsection describes how the Net-Chaff outcomes are calculated for a simulation run.

5.1.2.1.2 Network scan

The simulated network-scan is performed in two stages, and each stage is further described:

5.1.2.1.2.1 First stage: probe all addresses

In the first stage of the simulated network-scan, the scan's probes are simulated, as well as their responses. The entire network is scanned (Net-Chaff does not contain the scan). The simulation models three system components: the network, scanner, and Net-Chaff servers. The simulation of these components is described below.

- **The network simulation:**

A class B network is simulated. The network is represented by an array, and each array element models an address in the network. Thus, the array has 2^{16} elements. Each array element specifies an address and the type of probe-response from the address.

For a simulation run, its configuration-parameters specify the distribution of probe-response types on the network. For each probe-response type, the specifications state how many addresses are assigned that response type. These specifications are used to initialize the network array. The location of the probe-response types in the network does not matter because the scanner chooses addresses at random.

The simulation uses the probe-response types listed in Table 5.1.2.1.2.1-1. They are similar to the probe-response types used for the rate-based models' examples. However, for the simulation, there are separate probe response-types for the Net-Chaff WAN and LAN servers. The simulation models the Net-Chaff WAN and LAN servers separately, but the rate-based models does not differentiate between them.

Table 5.1.2.1.2.1-1 : The simulation's probe-response types

Probe-Response Type		Symbol
Net-Chaff WAN server	server impersonation	**ws_imp**
	no server present	**ws_ns**
Net-Chaff LAN server	server impersonation	**ls_imp**
	no server present	**ls_ns**
real computers	secure server	**sec**
	vulnerable server	**vuln**
	no server present	**ns**

- **The scanner simulation**

A fully parallel scan is modeled. The scanner sends probe-packets serially (i.e., one at a time) and continuously. Each probe is simulated. The address to be probed is chosen randomly, from among the addresses that have not been probed (i.e., addresses are chosen *without replacement*). For each probe, the simulation determines the following: 1) the start time for probe transmission, 2) the probe-response type and when it is received by the scanner, and 3) the probe's arrival time at the Net-Chaff WAN server, if applicable. The latter two events are recorded in an RDB.

The simulation has *probe timing-parameters* that specify how much time the probe-events take. The probe timing-parameters are: 1) for the TCP ping-scan, all probes use the same initial packet, and its transmission time is specified. 2) For each of the probe-response types, its probe completion time is specified (i.e., the time from the start of probe transmission to the receipt of the probe response). 3) For probes to Net-Chaff-managed addresses, the probes' arrival time at the Net-Chaff WAN server is specified (i.e., the time from the start of probe transmission to when the WAN server receives the probe). The probe timing-parameters are based on the simulation's *transmission parameters*: 1) the scanner's bandwidth (a constant), and 2) the packet size (the same for all probe packets), and 3) the network latency (an average over the network).

The scanner receives probe responses, and each response is recorded in an RDB table, as illustrated in Table 5.1.2.1.2.1-2. Each entry records the time the response was received by the scanner, and the response-type.

Table 5.1.2.1.2.1-2 : Probe responses, as recorded in the RDB table

time response was received:	t_1	t_2	t_3	t_4	t_5	t_6	t_7	...
probe-response type:	ws_imp	ws_ns	ls_ns	sec	sec	vuln	ws_imp	...

- **Simulation of the Net-Chaff WAN and LAN servers**

Probes can be sent directly to the Net-Chaff WAN server, or they can be forwarded to the WAN server via a Net-Chaff LAN server. Thus, probes addressed to the Net-Chaff WAN and LAN servers require different probe timing-parameters. For this reason, the simulation has different probe-response types for the Net-Chaff WAN and LAN servers.

For the probes sent to a Net-Chaff-managed address, their arrival time at the Net-Chaff WAN server is recorded in an RDB table, as illustrated in Table 5.1.2.1.2.1-3. The table is sorted by the time field.

Table 5.1.2.1.2.1-3 : Probe arrival times at the Net-Chaff WAN server, as recorded in the RDB table

probe arrival time:	t_A	t_B	t_C	...

5.1.2.1.2.2 Second stage: calculate scan outcomes

In the second stage of the simulated network-scan, the scan outcomes are calculated. As described earlier, these are the outcomes that would occur with Net-Chaff containment. The scan outcomes are: C, C_{VULN}, and C_{AFF}. Scan outcomes are calculated for each of the containment-specifications. The calculations are based on the probe outcomes from the first stage.

An example calculation is provided using the example RDB tables in the prior section. For the containment-specification, the detection threshold is 3, and the blocking time is T. Table 5.1.2.1.2.1-3 shows the detection threshold is reached at time t_C, and consequently, containment occurs at time (t_C+T). Table 5.1.2.1.2.1-2 is used to calculate the scan outcomes. For instance, if $t_6 <= (t_C+T) < t_7$, then C is 6, C_{VULN} is 1, and C_{AFF} is 4.

The scan outcomes are stored in an RDB table, as illustrated by Figure 5.1.2.1.2.2-1. The first row contains the field names, and the second row contains the results from the prior example. The table uses a composite key that consists of the table's first three fields. The network-scan ID is assigned sequentially for each of the **j** simulated network-scans, i.e., 1, 2, 3, . . . **j**.

network-scan ID	**detection threshold**	**blocking time**	**C**	**C_{VULN}**	**C_{AFF}**
1	3	T	6	1	4

Figure 5.1.2.1.2.2-1 : RDB table for storing scan outcomes

The simulation's containment model is slightly more accurate than the one used for the rate-based models. For the rate-based models, the calculation of $\bar{\mathbf{n}}_{\mathbf{Z}}$ (equation (14) on page 111) involved two minor inaccuracies that are not present in the simulation model: 1) the rate-based model assumes that probes arrive at the Net-Chaff WAN server in the order that the scanner sends them, and 2) the calculation of $\bar{\mathbf{n}}_{\mathbf{Z}}$ includes some probes after the $\mathbf{z}^{\mathbf{th}}$ probe sent to Net-Chaff. In addition, the rate-based model has some minor inaccuracies in the calculation of $\bar{\mathbf{C}}$ (equation (20) on page 114) and $\bar{C}_i$ (equation (21) on page 114). These equations rely on estimates of the number of partially completed probes at the point of containment. The simulation model avoids all of these inaccuracies because it is packet-based, and because it uses separate probe-response types for the Net-Chaff WAN and LAN servers. However, the inaccuracies are minor for typical Net-Chaff deployments. As will be shown, there is little difference between the Net-Chaff outcomes calculated by the simulation and rate-based models.

5.1.2.1.3 Net-Chaff outcomes

In the first step of a simulation run, the simulated network-scans are performed. In the second step of the simulation run, the Net-Chaff outcomes are calculated. They are: $\bar{\mathbf{C}}$, $\bar{\mathbf{C}}_{\mathbf{VULN}}$, $\bar{\mathbf{C}}_{\mathbf{AFF}}$, and $\mathbf{P}_{\mathbf{vuln.}}$ The Net-Chaff outcomes are calculated for each of the containment-specifications, as described below.

Some notation is needed first:

- **Notation for the whole simulation run:** let **C_S_set** be the set of containment-specifications that are used for the simulation run. **C_S** is a particular containment-specification in **C_S_set**.
- **Notation for the first step of a simulation run:** **C** is one of the scan outcomes, and it was defined earlier as the number of scanner probes that are completed prior to containment. For a particular simulated network-scan, let $\mathbf{C}_{\mathbf{C\_S}}$ be the value of **C** for the containment-specification **C_S**. For each simulated network scan, $\mathbf{C}_{\mathbf{C\_S}}$ is calculated for each containment-specification. $\mathbf{C}_{\mathbf{VULN}}$ is also a scan outcome, and it was defined earlier as the number of affirmative replies received from vulnerable computers, prior to containment. $\mathbf{C}_{\mathbf{VULN\_C\_S}}$ is the value of $\mathbf{C}_{\mathbf{VULN}}$ for **C_S**.

- **Notation for the second step of a simulation run:** $\bar{\mathbf{C}}$ is a Net-Chaff outcome, and it was defined earlier as the average number of scanner probes that are completed prior to containment. Let $\bar{\mathbf{C}}_{\mathbf{C\_S}}$ be the value of $\bar{\mathbf{C}}$ for the containment-specification **C_S**. For a simulation run, $\bar{\mathbf{C}}$ is calculated for each containment-specification, i.e., $\bar{\mathbf{C}}_{\mathbf{C\_S}}$ is calculated for each **C_S** in **C_S_set**.

The Net-Chaff outcomes are calculated as follows:

- $\bar{\mathbf{C}}_{\mathbf{C\_S}}$ is calculated for each containment-specification. For a particular **C_S**, $\bar{\mathbf{C}}_{\mathbf{C\_S}}$ is calculated as the average $\mathbf{C}_{\mathbf{C\_S}}$ value, over all simulated network-scans.
- $\bar{\mathbf{C}}_{\mathbf{AFF}}$ and $\bar{\mathbf{C}}_{\mathbf{VULN}}$ are calculated in the same manner as $\bar{\mathbf{C}}$. $\bar{\mathbf{C}}_{\mathbf{AFF}}$ and $\bar{\mathbf{C}}_{\mathbf{VULN}}$ are calculated for each containment-specification. Also, the average is calculated over all simulated network scans.
- $\mathbf{P}_{\mathbf{vuln}}$ is calculated for each containment-specification. Let $\mathbf{P}_{\mathbf{vuln\_C\_S}}$ be the value of $\mathbf{P}_{\mathbf{vuln}}$ for the containment-specification **C_S**. Let **num_vuln** be the number of simulated network scans for which $\mathbf{C}_{\mathbf{VULN}}$ is greater than zero. Let **j** be the number of simulated network-scans in the simulation run. $\mathbf{P}_{\mathbf{vuln\_C\_S}}$ is calculated as (num_vuln / j).

5.1.2.2 Experiments

The simulation was used to verify the rate-based models. Three simulation runs were performed, and the simulation results were compared with results from the rate-based models. This section describes the simulation runs, and how they verify the rate-based models.

5.1.2.2.1 The simulation runs

Three simulation runs were performed, and they are labeled A, B, and C. Each simulation run represents a particular network-scan scenario. The scenario models a typical Net-Chaff deployment, and a typical network and scan. Each simulation run used a different distribution of probe-response types. Table 5.1.2.2.1-1 shows the distributions, and it specifies the number of network addresses assigned to each probe-response type. Simulation runs A, B, and C are representative of networks with a small, medium and large number of computers, respectively. There are two types of real servers: secure and vulnerable. 10% of the real servers are vulnerable. The simulation's transmission parameters (defined in section 5.1.2.1.2.1 on page 155) are the same for all simulation runs: 1) the scanner bandwidth is 500Kbps; 2) the packet size is 60 bytes, and 3) the average network latency is 0.0003 seconds. These parameters are representative of a fairly fast scan, over a network with extremely low latency. For each simulation run, 300 simulated network scans were performed.

Table 5.1.2.2.1-1 : Probe-response distributions for the three simulation runs

Simulation Run	Real Computers			Net-Chaff	
	secure server	vulnerable server	no server present	server impersonation	no server present
A	432	48	32	48,735	16,287
B	1,296	144	96	47,903	16,095
C	6,480	720	480	42,911	14,943

For each simulation run, the Net-Chaff outcomes are calculated for a set of containment-specifications. Each of these sets is specified in Table 5.1.2.2.1-2. The table will be explained, and its columns are cited in italics. Each row in the table specifies a simulation run (*Sim. Run*). A simulation run's set of containment-specifications is the pair-wise combination of the *detection thresholds* (z) and *blocking times* (b) that are specified. For each simulation run, the detection thresholds and blocking times have values that grow exponentially. These distributions are used in order to focus on values that are likely in practice, but the distributions also include extreme values. For each *set of containment-specifications*, its *size* is specified. Also, the containment-specification with the *longest* *containment time* is specified. It is specified in terms of its **z** and **b** values, and its Net-Chaff result $\bar{\mathbf{C}}$. Over the three simulation runs, there is a combined total of 432 containment-specifications (i.e., 108+108+216 = 432).

Table 5.1.2.2.1-2 : Containment-specifications for the simulation runs

Sim. Run	detection thresholds (z, number of packets)	blocking times (b, seconds)	set of containment-specifications	
			size	longest containment time
A	$2^0, 2^1, \ldots 2^{11}$	$2^{-12}, 2^{-11}, \ldots 2^5$	216	z=2048 and b=32, $\bar{C}$=35397
B, C	$2^0, 2^1, \ldots 2^{11}$	$4^{-6}, 4^{-5}, \ldots 4^2$	108	z=2048 and b=16, $\bar{C}$=18986

5.1.2.2.2 Simulation results vs. rate-based models

In total, the three simulation runs use 432 containment-specifications. For each of the 432 containment-specifications, both the rate-based models and the simulation were used to calculate the Net-Chaff outcomes: $\bar{\mathbf{C}}$, $\bar{\mathbf{C}}_{\mathbf{AFF}}$, $\bar{\mathbf{C}}_{\mathbf{VULN}}$, and $\mathbf{P}_{\mathbf{vuln}}$. The outcomes from the rate-based models and simulation were then compared. The comparisons for $\bar{\mathbf{C}}$, $\bar{\mathbf{C}}_{\mathbf{AFF}}$, $\bar{\mathbf{C}}_{\mathbf{VULN}}$ are described first, and the comparisons for $\mathbf{P}_{\mathbf{vuln}}$ are described separately.

- **Simulation vs. rate-based models for: $\bar{\mathbf{C}}$, $\bar{\mathbf{C}}_{\mathbf{AFF}}$, and $\bar{\mathbf{C}}_{\mathbf{VULN}}$**

Let **C_S** be one of the 432 containment-specifications. Let $\bar{\mathbf{C}}_{\mathbf{C\_S\_sim}}$ be the value of $\bar{\mathbf{C}}$ that is calculated for **C_S**, using the simulation. Similarly, $\bar{\mathbf{C}}_{\mathbf{C\_S\_rate}}$ is the value of $\bar{\mathbf{C}}$ that is calculated for **C_S**, using the rate-based models. Similar variables are defined for the values calculated for $\bar{\mathbf{C}}_{\mathbf{AFF}}$ (i.e., $\bar{\mathbf{C}}_{\mathbf{AFF\_C\_S\_sim}}$ and $\bar{\mathbf{C}}_{\mathbf{AFF\_C\_S\_rate}}$) and for $\bar{\mathbf{C}}_{\mathbf{VULN}}$ (i.e., $\bar{\mathbf{C}}_{\mathbf{VULN\_C\_S\_sim}}$ and $\bar{\mathbf{C}}_{\mathbf{VULN\_C\_S\_rate}}$).

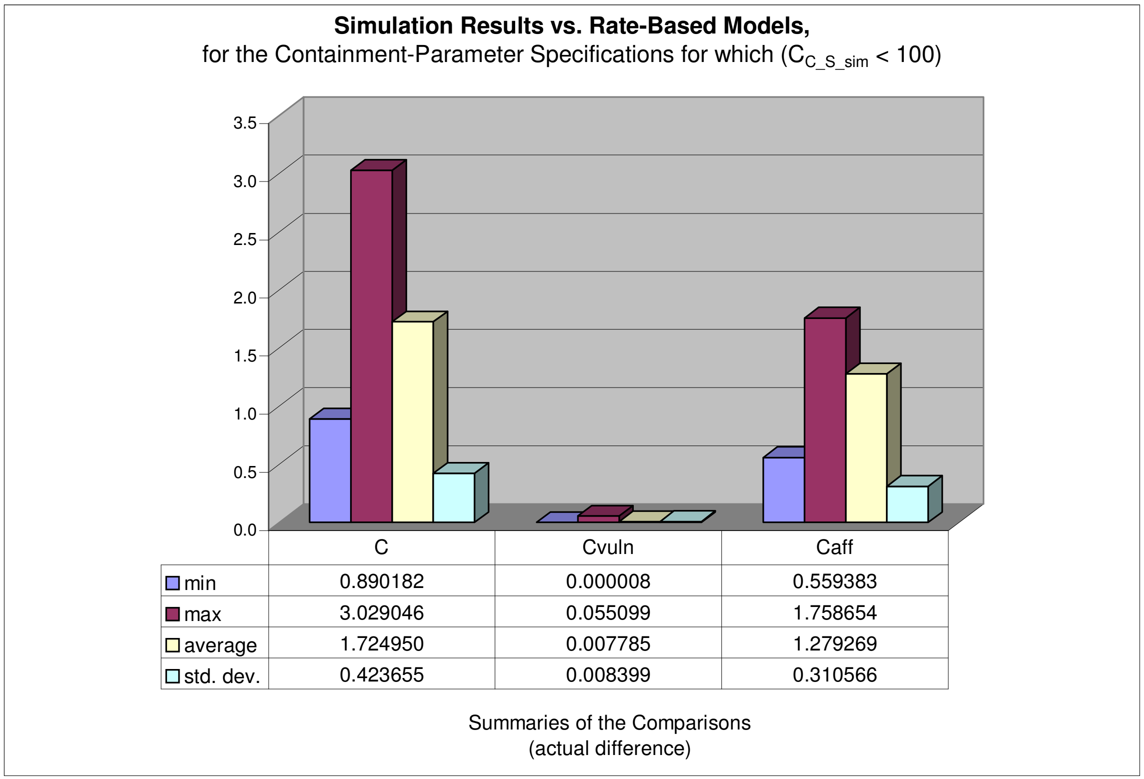
For $\bar{\mathbf{C}}$, $\bar{\mathbf{C}}_{\mathbf{AFF}}$, and $\bar{\mathbf{C}}_{\mathbf{VULN}}$, their outcomes from the rate-based models and simulation are compared. How the outcomes are compared depends upon the length of the scan. The 432 containment-specifications are divided into two subsets. The *short-scan subset* is made-up of the containment-specifications for which ($\bar{C}_{C\_S\_sim} < 100$). The subset consists of 130 containment-specifications. The *longer-scans subset* is made-up of the containment-specifications for which ($\bar{C}_{C\_S\_sim} \geq 100$). The subset consists of the remaining 302 containment-specifications.

For the *short-scan subset*, the outcomes from the rate-based models and simulation are compared using the following algorithm: 1) For each element of the short-scan subset, the results obtained for $\bar{\mathbf{C}}$ are compared using the equation: $ABS(\bar{C}_{C\_S\_sim} - \bar{C}_{C\_S\_rate})$, where ABS is the absolute-value function. 2) To summarize these comparisons, the average value for $ABS(\bar{C}_{C\_S\_sim} - \bar{C}_{C\_S\_rate})$ is calculated, over the subset. The minimum, maximum and standard deviation are also calculated. These values are shown in Figure 5.1.2.2.2-1, under the column labeled "C". (In Figure 5.1.2.2.2-1 and Figure 5.1.2.2.2-2, the bars that indicate average (as in $\bar{\mathbf{C}}$) are omitted due to type setting limitations). 3) The outcomes for $\bar{\mathbf{C}}_{\mathbf{AFF}}$, and $\bar{\mathbf{C}}_{\mathbf{VULN}}$ are compared in the same manner as $\bar{\mathbf{C}}$. These comparisons are also summarized in Figure 5.1.2.2.2-1, and they are under the columns labeled "C_{AFF}" and "C_{VULN}", respectively.

For the *longer-scans subset*, the results from the rate-based models and simulation are compared using the following algorithm: 1) For each element of the longer-scans subset, the results obtained for $\bar{\mathbf{C}}$ are compared using the equation: $(ABS(\bar{C}_{C\_S\_sim} - \bar{C}_{C\_S\_rate}) / \bar{C}_{C\_S\_sim})$, where ABS is the absolute-value function. 2) To summarize these comparisons, the average value for $(ABS(\bar{C}_{C\_S\_sim} - \bar{C}_{C\_S\_rate}) / \bar{C}_{C\_S\_sim})$ is calculated, over the subset. The minimum, maximum and standard deviation are also calculated. These values are shown in Figure 5.1.2.2.2-2, under the column labeled "C". 3) The outcomes for $\bar{\mathbf{C}}_{\mathbf{AFF}}$, and $\bar{\mathbf{C}}_{\mathbf{VULN}}$ are compared in the same manner as $\bar{\mathbf{C}}$. These comparisons are also summarized in Figure 5.1.2.2.2-2, and they are under the columns labeled "C_{AFF}" and "C_{VULN}", respectively.

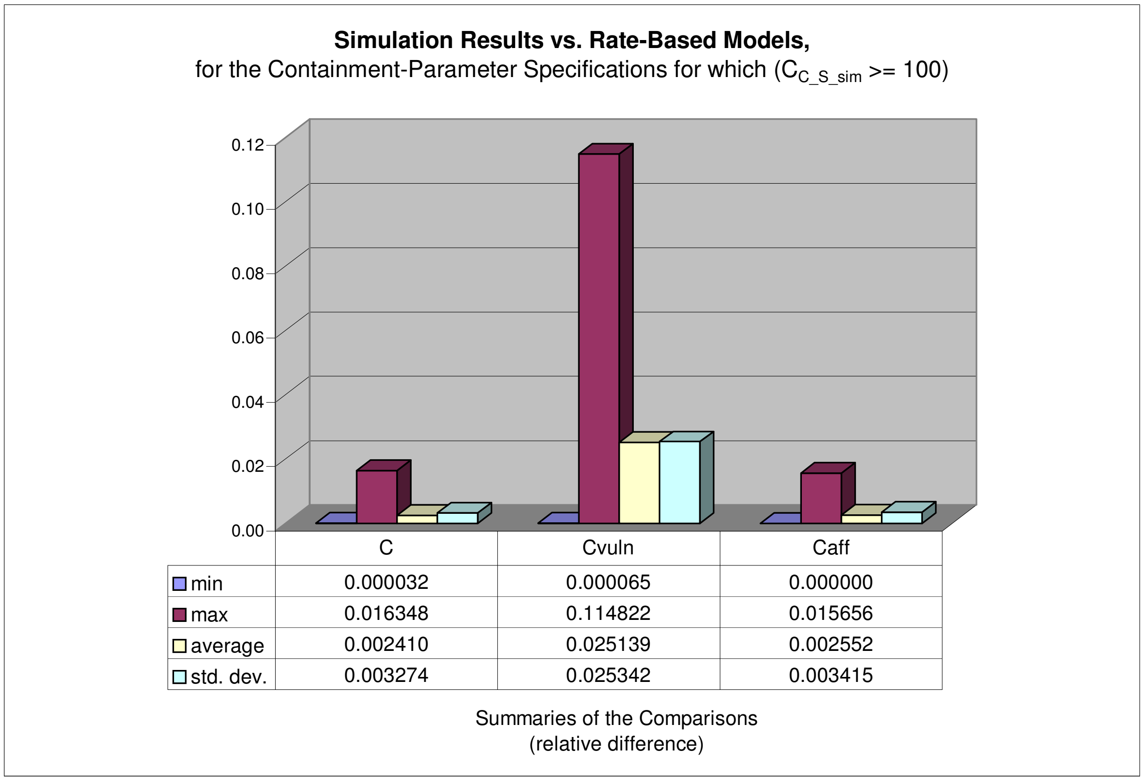
For the short-scans subset, the results are compared using actual differences, e.g., $ABS(\bar{C}_{C\_S\_sim} - \bar{C}_{C\_S\_rate})$. The relative differences were not used, as some are very large;

however, for short scans, the actual difference is more significant in Net-Chaff planning. For the longer-scans subset, the results are compared using relative differences, e.g., (ABS($\bar{C}_{C\_S\_sim}$ - $\bar{C}_{C\_S\_rate}$) / $\bar{C}_{C\_S\_sim}$). Figure 5.1.2.2.2-1 and Figure 5.1.2.2.2-2 show that the results from the rate-based models and simulation are very similar. For the purpose of Net-Chaff planning, the average differences are extremely small, and even the maximum differences are small. Thus the simulation results serve to corroborate the rate-based models' calculation of **$\bar{C}$, $\bar{C}_{VULN}$**, and **$\bar{C}_{AFF}$**.



	C	Cvuln	Caff
▨ min	0.890182	0.000008	0.559383
▨ max	3.029046	0.055099	1.758654
▨ average	1.724950	0.007785	1.279269
▨ std. dev.	0.423655	0.008399	0.310566

Figure 5.1.2.2.2-1 : Simulation results vs. analytical models for ($\bar{C}_{C\_S\_sim}$ < 100)



	C	Cvuln	Caff
🟦 min	0.000032	0.000065	0.000000
🟥 max	0.016348	0.114822	0.015656
🟨 average	0.002410	0.025139	0.002552
□ std. dev.	0.003274	0.025342	0.003415

Figure 5.1.2.2.2-2 : Simulation results vs. analytical models for ($\bar{C}_{C\_S\_sim} \geq 100$)

- **Simulation results vs. rate-based models for: P_{vuln}**

The rate-based models and the simulation were also used to calculate $\mathbf{P_{vuln}}$, which is the probability that a scan will probe one or more vulnerable computers, for a given value of $\bar{C}_{VULN}$. The outcomes from the rate-based models and simulation were compared, as described below.

In the simulation, $\mathbf{P_{vuln}}$ was calculated for each of the 432 containment-specifications. $\mathbf{P_{vuln}}$ values are plotted in Figure 5.1.2.2.2-3, for the containment-specifications whose $\mathbf{P_{vuln}}$ value is less than or equal to 0.997. Larger values of $\mathbf{P_{vuln}}$ were not plotted as they are not relevant for Net-Chaff planning. There are 325 containment-specifications whose $\mathbf{P_{vuln}}$ value is less than or equal to 0.997.

From the rate-based models, $\mathbf{P_{vuln}}$ can be calculated using the Poisson distribution, as was shown in equation (36) (page 131). This equation is also plotted in Figure 5.1.2.2.2-3. From the figure, it can be seen visually that the simulation results were very similar to the results from the equation. In addition, a quantitative comparison was made between the simulation results and the results from the equation. The comparison was made as described below.

Let **C_S** be one of the 325 containment-specifications for which ($P_{vuln} \leq 0.997$). Let $\mathbf{P_{vuln\ \_C\_S\_sim}}$ be the value of $\mathbf{P_{vuln}}$ that is calculated for **C_S**, using the simulation. Similarly, $\mathbf{P_{vuln\ \_C\_S\_rate}}$ is the value of $\mathbf{\breve{C}}$ that is calculated for **C_S**, using equation (36).

The results from the simulation and equation (36) are compared using the following algorithm: 1) For each of the 325 containment-specifications, the values obtained for $\mathbf{P_{vuln}}$ are compared using the equation: ABS($P_{vuln\_C\_S\_sim}$ - $P_{vuln\_C\_S\_rate}$), where ABS is the absolute-value function. 2) To summarize these comparisons, the average value for ABS($P_{vuln\_C\_S\_sim}$ - $P_{vuln\_C\_S\_rate}$) is calculated, over the subset. The minimum, maximum and standard deviation are also calculated. This summary is shown in Table 5.1.2.2.2-1. The results from the rate-based model and simulation are very similar. For the purpose of Net-Chaff planning, the average difference is extremely small, and even the maximum difference is small. Thus the simulation results serve to corroborate the rate-based model's calculation of $\mathbf{P_{vuln}}$.

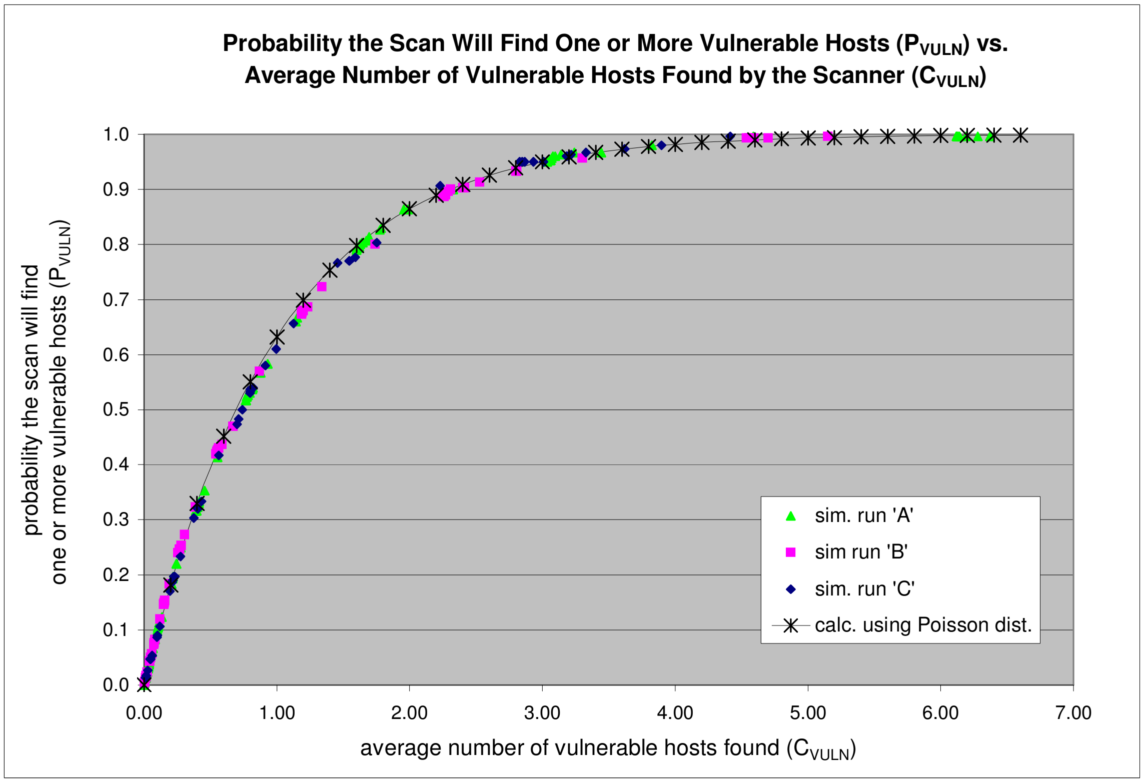


Figure 5.1.2.2.2-3 : Simulation results vs. analytical models for P_{vuln}

Table 5.1.2.2.2-1 : Summary of comparison using ABS($P_{vuln\_C\_S\_sim}$ - $P_{vuln\_C\_S\_rate}$)

minimum	maximum	average	standard deviation
0.000	0.030	0.006	0.006

5.1.2.3 Summary

This section described a simulation that was used to verify the rate-based models. A web-server TCP ping-scan was simulated. Three different network-scan scenarios were modeled. For each of these scenarios, both the simulation and rate-based models were used to calculate the Net-Chaff outcomes: $\bar{\mathbf{C}}$, $\bar{\mathbf{C}}_{\mathbf{AFF}}$, $\bar{\mathbf{C}}_{\mathbf{VULN}}$, and $\mathbf{P_{vuln}}$.

The results from the rate-based model and simulation were compared by measuring the differences between them. For the purpose of Net-Chaff planning, the average differences were extremely small, and even the maximum differences were small. Thus the simulation results serve to corroborate the rate-based model's calculation of the Net-Chaff outcomes.

5.1.3 Hiding analysis

Net-Chaff hides real computers from scanners. This section analyzes Net-Chaff from the perspective of the hiding model presented in chapter 3. The model is used to understand the role of hiding in Net-Chaff's functionality and performance. From the perspective of the hiding model, hackers' scanning can be viewed as a discovery process, and Net-Chaff hides real systems by defeating this process. Net-Chaff uses both deceptive and non-deceptive hiding, and both are analyzed.

Ultimately, Net-Chaff uses hiding to achieve its tactical objectives. Net-Chaff's primary uses of hiding include: 1) scan containment is used to hide real systems from scans, 2) impersonations are used to hide real systems from information-retrieval scans, and 3) Net-Chaff's deceptions are hidden, to counter hackers' counter-deception. These uses of hiding involve one or more hiding techniques.

In the following subsections, each of these uses of hiding is analyzed. The hiding model is used to categorize each of the hiding techniques according to how it defeats the hacker's discovery process. References to the model's categories are in italics. As described in the model, a hiding technique can affect multiple elements of the discovery process, so it could be placed in multiple categories. For each hiding technique, only its primary affect is categorized.

5.1.3.1 Hiding real systems via containment

Net-Chaff's containment process hides real systems from scanners. The containment process uses several different hiding techniques. This section analyzes these hiding techniques from the perspective of the hiding model. These techniques hide real systems by defeating the scanners' *direct observation*. From the perspective of the hiding model, the scanner is a *sensor*.

Net-Chaff's primary hiding technique is the use of routers to block scanners' access to the intranet. From the perspective of the hiding model, this hiding technique *defeats the sensor* (scanner) by *altering the information flows* to it.

Net-Chaff also hides real systems by slowing down the scan during the containment time. Specifically, Net-Chaff reduces the rate at which vulnerable computers are probed, i.e., the number of vulnerable computers probed per second. This rate is calculated as ($\bar{x}$ * $\bar{r}_{vuln}$), as described earlier with equation (22) (page 133). Thus, decreasing either factor, $\bar{\mathbf{x}}$ or $\bar{\mathbf{r}}_{\mathbf{vuln}}$, serves to hide real systems.

Net-Chaff's low-level impersonations are used to decrease $\bar{\mathbf{x}}$ (as described in section 5.1.1.4.2 on page 138). The factor $\bar{\mathbf{r}}_{\mathbf{vuln}}$ is decreased by configuring the network so that it has a relatively large number of unused addresses (as described in section 5.1.1.4.3 on page 147). Both of these hiding techniques *defeat the sensor* (scanner). They do so by *altering the environment of the hidden item*, by *creating noise in the environment*.

Reducing Net-Chaff's containment time also serves to hide real systems (as described in section 5.1.1.4.1 on page 133). This hiding technique serves to *defeat the sensor* (scanner). It *diminishes the target's sensor capabilities*, by *reducing the target's time available for observation*.

5.1.3.2 Hiding real systems via false positives

Net-Chaff's impersonations also help to hide real computers from information-retrieval scans (as described in section 5.1.1.3.1 on page 120). In the scan results, the real computers can be hidden by the voluminous false positives created by Net-Chaff's impersonations. How this hiding technique works depends upon the type of scan results and how they are used by the hacker. A typical example is given.

A hacker uses a TCP ping-scan to find web servers. The scan returns ten network addresses that respond affirmatively to the ping scan. In reality, nine of the responses are impersonations. If the scan results are printed and perused by a hacker, he cannot distinguish the real web-server from the impersonations. From the perspective of the hiding model, the hacker uses the scanner for *direct observation*. In this case, the hacker's direct observation is defeated by *defeating his recognition* of the real web-server. More specifically, the hacker's recognition is defeated by the impersonations which *alter the information flows to the sensor*.

5.1.3.3 Preventing counter-deception

Net-Chaff must hide indicators that allow scanners to prematurely discover impersonations and the unused portions of the network. The hiding model can be used to understand how Net-Chaff can hide these things. These issues were discussed with the Net-Chaff system design in chapter 4. To recap, the hacker cannot *directly observe* Net-Chaff, but he can potentially discover Net-Chaff by *investigation*. From the perspective of the hiding model, Net-Chaff is hidden by defeating the hacker's investigation process. Specifically, Net-Chaff is hidden by *not creating the evidence* that the hacker needs for Net-Chaff detection. This is accomplished by making the impersonations adequately realistic. The degree of realism needed depends on the scanners' detection capabilities, and also, cost-benefit constraints. Examples are provided in chapter 4.

5.1.3.4 Summary

Ultimately, Net-Chaff uses hiding to achieve its tactical objectives. The hiding model was used to analyze Net-Chaff's uses of hiding, as well as its hiding techniques. Net-Chaff's primary uses of hiding include: 1) scan containment is used to hide real systems from scans, 2) impersonations are used to hide real systems from information-retrieval scans, and 3) Net-Chaff's deceptions are hidden, to counter hackers' counter-deception. These uses of hiding serve distinct and different purposes. The containment process is noteworthy, as it uses several different hiding techniques.

The hiding analysis reveals the role of hiding in Net-Chaff's functionality and performance. These findings are incorporated in the Net-Chaff system design, and the Net-

Chaff performance analysis. Citations were given for the places in the dissertation where the findings are incorporated.

5.1.4 Limitations

This section analyzes the limitations of the Net-Chaff system. It also analyzes the limitations of the Net-Chaff evaluation. The dissertation's Net-Chaff research, itself, has limitations. The scope of the research is limited to the design and evaluation of the Net-Chaff architecture. The results indicate that Net-Chaff can effectively detect and contain scans. However, additional research is needed to further assess Net-Chaff's viability. This additional research will be discussed in the next section, which addresses Net-Chaff's future research.

- **Limitations of the Net-Chaff system:**

For the Net-Chaff system, there are limitations in the functions it provides and in the types of networks it protects. Net-Chaff's primary functions are to detect and block scans. A limitation of Net-Chaff's surveillance capabilities is that it only sees traffic sent to the unused addresses that it manages. It does not see traffic sent to computers on the intranet, nor traffic sent from the intranet to other networks. Net-Chaff is limited to detecting active scans that access a sufficient number of unused addresses. Active scans that avoid unused addresses will not be detected. An example is the scan of an address range that is densely populated by computers, such as the lower addresses of a subnet. Net-Chaff cannot detect passive scanning. Another limitation of Net-Chaff's detection capabilities is the possibility of false positives from benign scans. To prevent false positives, Net-Chaff must be provided with signatures that identify benign scans, e.g., their source addresses. A limitation of Net-Chaff's blocking function is that it blocks whole subnets, rather than just scan traffic. This limitation is related to Net-Chaff's solution for scan probes with spoofed source addresses. Less disruptive blocking systems are possible, but left for future research.

Another limitation of Net-Chaff is the types of networks it can protect. The network requirements for using Net-Chaff were specified in chapter 4. To use Net-Chaff, a network must already meet these requirements, or it must be modified to meet them. Some of these requirements significantly limit the types of networks that can use Net-Chaff. In particular, Net-Chaff is used on secured intranets in which scans can be accurately identified amidst the traffic to unused addresses. Also, for containment to work, the intranet routers must support the blocking function, and the consequences of automated containment must be acceptable. Another limitation is that Net-Chaff requires a large number of unused addresses, and it must be possible to route their traffic to the Net-Chaff servers. Further, the network's used subnets need to be tactically distributed among the unused subnets. The Net-Chaff performance analysis shows the network parameters that affect Net-Chaff's performance (see section 5.1.1.4). These parameters determine Net-Chaff's suitability for a particular network. For instance, Net-Chaff is only suitable for networks in which the scan bandwidth is sufficiently low and the number of unused addresses sufficiently high. As an example, Net-Chaff may not be useful on a class B network that can be scanned at a rate of 1 Gbps.

There are also limitations related to Net-Chaff's installation and on-going operations. Installing Net-Chaff may require modifying the network, so that Net-Chaff can be used effectively, as just discussed. Installing a Net-Chaff LAN server at each, or many, LANs can be costly. Also, the Net-Chaff installation requires configuring intranet routers to perform several essential tasks: routing traffic to the Net-Chaff WAN server, blocking scans, and dropping packets with spoofed source addresses. Maintaining the router configurations will be an on-going administration task.

- **Limitations of the Net-Chaff evaluation**

The Net-Chaff evaluation uses analytical models and a simulation, and their primary limitations are examined. Net-Chaff's performance is dependent upon specific attributes of networks and scans, so Net-Chaff's performance analysis must be for specific network topologies and types of scans. Consequently, the Net-Chaff evaluation was limited to a small number of typical networks and typical scans. However, the analytical models can be applied to other types of networks and scans.

There were limitations in the scan functions that were modeled. The Net-Chaff analysis only considered random address selection. Scanners use several other types of address selection techniques, as described in chapter 4. Sequential address selection was not analyzed, but it is highly relevant, as networks can have sizable addresses-ranges that are densely populated by computers. In addition, the Net-Chaff analysis only considered a single scanner. However, the single-scanner model can be extended to analyze multiple scanners.

There are noteworthy limitations in the analytical models and simulation, themselves. A major limitation is that their accuracy cannot yet be tested relative to actual Net-Chaff deployments. Consequently, their accuracy is only as good as their untested assumptions. A limitation of the analytical models is that their results are average values that apply in the limit for an infinite number of scans. Consequently, the models do not calculate the outcome for an individual scan, nor for a small number of scans. There is a limitation in the simulation's ability to verify the analytical model. The simulation models a scan whose probe types all have the same individual probe rate (see section 5.1.1.2.1). Consequently, the simulation's verification of the analytical model does not cover cases in which there is variation in the individual probe rates. There is also a noteworthy limitation in the Net-Chaff performance analysis. Empirical data on actual blocking times was not available, and this limits the conclusions that can be drawn regarding Net-Chaff's effectiveness.

5.1.5 Future research

The dissertation's Net-Chaff research is limited to the design and evaluation of its architecture. The results indicate that Net-Chaff can effectively detect and contain scans. However, there are additional design problems that must be solved before Net-Chaff can be implemented. Its appears that viable solutions can be found for these design problems, but it is not entirely certain. Those design problems are described here. In addition, this section presents several optional features that could be added to enhance Net-Chaff.

Net-Chaff's use of unused addresses has been described. However, further design is needed, and there are several problems that must be solved. An intranet routing scheme is needed for the unused addresses; this requires further investigation and the development of specific solutions. There are two other systems that address intranet routing for unused addresses, and their solutions may be useful [Pro04, YBP04]. A solution is also needed for assigning unused addresses to the Net-Chaff LAN server. honeyd's scheme of appropriating addresses with unanswered ARP requests may be problematic [Pro04]; also, compatibility with DHCP systems is necessary. Another problem that must be addressed is how to best distribute a network's unused addresses among the addresses assigned to computers. In addition, Net-Chaff's detection mechanism needs to be fully designed. A simple threshold-based detection mechanism was proposed. However, the detection mechanism must provide sufficient accuracy for automated containment. It must include capabilities for recognizing and ignoring benign scans.

Net-Chaff's servers generate low-level impersonations. Impersonation is a complex problem and specific solutions must be designed. Analysis is needed to determine what specific probes will be received and what specific responses will be provided. One of the most challenging problems is providing responses for probes used for O/S fingerprinting, as accurately impersonating network stacks could be extremely difficult. Another open problem is scans that map the network topology, such as traceroute. However, it may be possible to just drop those scan packets at the intranet routers. Solutions are also needed for an unused subnet's impersonation of a used subnet. Chapter 4 discussed counter-deception problems for this type of impersonation.

In general, scanners' counter-deception opportunities must be analyzed when designing the impersonations. Scanner's counter-deception can include the use of information sources other than scans. For instance, reverse DNS look-ups could be used to find a network's unused addresses. In general, Net-Chaff's impersonation requirements can be reduced by using techniques that prevent scanners from obtaining information. For example, DNS systems can be configured so they do not provide reverse look-ups. Also, many forms of O/S fingerprinting can be prevented by having routers drop certain ICMP packets [Ark01].

Further design is needed for the Net-Chaff WAN and LAN servers. This includes capacity-planning and the processing of incoming and outgoing traffic. The iSink system has a promising solution for handling large volumes of scan probes and for generating replies [YBP04]. If the Net-Chaff servers can generate large volumes of replies, then network DoS problems must be considered. Another Net-Chaff problem is that Net-Chaff LAN servers are, collectively, expensive to purchase and administer. Future research should consider alternative solutions that do not require a Net-Chaff device at each LAN, e.g., the use of IP tunneling on the subnets' routers. An additional design problem is the specific containment techniques that will be used. Challenges include supporting different types of routers and minimizing the blocking time. In general, Net-Chaff's system-designs should include defenses for possible scanner countermeasures and hacker attacks.

Net-Chaff was designed mostly from an academic perspective of how networks should work. Additional investigation is needed to analyze Net-Chaff's compatibility with a wide variety of real-world networks, including their design and operations. Some of the phenomenon that is of interest includes: routing, blocking capabilities, the availability of unused addresses, potential access-control problems (e.g., firewalls), and vulnerabilities to counter-deception. Empirical research is also needed to examine the contents of traffic sent to unused addresses on secured intranets. This is necessary for testing Net-Chaff's hypothesis that secure intranets provide an environment where scanning: 1) occurs infrequently, 2) can be accurately detected, and 3) warrants automated containment. Empirical data on the performance of typical scans is needed, to make the analysis of Net-Chaff's performance more informed and accurate.

The research that was just proposed is intended to refine the design of the Net-Chaff system that is described in this dissertation. In addition, there are a number of ways to expand and enhance Net-Chaff's functionality. The Net-Chaff architecture includes a surveillance component, and its design is left for future research. Net-Chaff is intended for use with a particular network topology, and it was specified in chapter 4. It includes LANs, subnets, intranet routers and a single gateway. Net-Chaff could be extended for use in other topologies, such as those with multiple gateways, or a single LAN protected by a firewall. One of the most promising ways to improve Net-Chaff is to use large IPv6 networks and thereby assign huge numbers of unused addresses to the Net-Chaff servers. There are other researchers who have observed that the large address space in IPv6 makes scanning very difficult [ZGT05].

A limitation of the existing Net-Chaff design is its simple threshold-based detection mechanism. Additional detection mechanisms could be used to speed-up detection and to improve detection accuracy. There has been much prior research on scan detection mechanisms, as described in chapter 2, and it may be applicable to Net-Chaff. There are also limitations in Net-Chaff's blocking system, and there are a number of ways it can be improved. The system currently blocks whole subnets, but techniques can be developed to reduce the scope of blocking to individual addresses, or to a specific types of traffic. Another way Net-Chaff can be improved is through the use of additional delaying techniques, including the "tar pits" described in chapter 4.

5.1.6 Summary of the Net-Chaff analysis

This section summarizes the Net-Chaff analysis. Net-Chaff's performance objectives were presented in chapter 4, and they include its tactical objectives and its deception and hiding objectives. The Net-Chaff analysis addresses a subset of these objectives:

- Net-Chaff's ultimate objectives are to reduce the scanner's access to the network, and especially access to high-valued and vulnerable systems. The primary metric is the number of vulnerable computers accessed by the scanner, before the scan is contained.
- Net-Chaff uses deception and hiding to achieve its tactical objectives. The Net-Chaff analysis focuses on Net-Chaff's primary uses of deception and hiding. They include: 1) the use of low-level deceptions and large numbers of unused addresses, for slowing-down scans, and 2) the use of low-level deceptions to provide false positives that reduce the usefulness of the scan results.

Section 5.1.1 (page 96) presented a set of analytical models for estimating Net-Chaff's performance and for analyzing its use of deception. The models are based on the scanners' probe rates, so they are referred to as the *rate-based models*. The primary metric is stated as:

$\bar{C}_{VULN}$	the average number of vulnerable computers that are accessed, prior to containment

The primary equation is:

$$\bar{c}_{VULN} = ([b * \bar{x}] + [z / \bar{r}_{nc}]) * \bar{r}_{vuln} \tag{41}$$

Section 5.1.2 (page 152) presented a simulation that was used to verify the rate-based models, and the subsection 5.1.2.3 (page 167) summarizes this work. The simulation results were very similar to the results from the rate-based models, and the similarity corroborates the rate-based models.

The rate-based models were used to analyze Net-Chaff's performance and its use of deception. The analysis is summarized here:

- **Performance overview:**

  Section 5.1.1.3 (page 119) gave an overview of Net-Chaff's performance, and subsection 5.1.1.3.3 (page 132) summarizes this analysis. Overall, Net-Chaff appears to be an effective technique for stopping many typical scans, on many typical networks. Net-Chaff even appears effective for preventing worms from spreading.

- **Elements of Net-Chaff performance:**

  Section 5.1.1.4 (page 133) analyzed the parameters that affect Net-Chaff's performance. The analysis is intended for use in configuring Net-Chaff for effective performance. Also analyzed was Net-Chaff's use of deception, and deception's contribution to Net-Chaff's performance. The subsection 5.1.1.4.4 (page 149) provides a summary.

One of the best ways to improve Net-Chaff performance is to increase the size of the address space, and assign all of the new addresses to Net-Chaff. This reduces $\boldsymbol{\bar{c}_{VULN}}$ in three ways: 1) it typically reduces scanners' average network probe rate ($\bar{x}$), 2) it always increases the fraction of network addresses that are monitored by Net-Chaff ($\bar{r}_{nc}$), and 3) it always decreases the fraction of network addresses with vulnerable computers ($\bar{r}_{vuln}$).

Net-Chaff's low-level impersonations reduce $\boldsymbol{\bar{c}_{VULN}}$ by slowing down scans, i.e., by decreasing $\boldsymbol{\bar{x}}$ in equation (41). The fraction of network addresses that use Net-Chaff impersonations is represented as $\bar{\mathbf{r}}_{\mathbf{nc\_imp}}$. $\bar{\mathbf{x}}$ can be decreased by increasing $\bar{\mathbf{r}}_{\mathbf{nc\_imp}}$. However, beyond a certain point, increasing $\bar{\mathbf{r}}_{\mathbf{nc\_imp}}$ can not only risk counterdeception, but it may also provide relatively little reduction in $\bar{\mathbf{C}}_{\mathbf{VULN}}$.

$\bar{\mathbf{C}}_{\mathbf{VULN}}$ is proportional to $\bar{\mathbf{r}}_{\mathbf{vuln}}$, as shown by equation (41). When a network has a large number of unused addresses, relative to the number of vulnerable computers, then the unused addresses serve to hide the vulnerable computers. This is the passive hiding that was described in Chapter 4. In equation (41), $\bar{\mathbf{r}}_{\mathbf{vuln}}$ represents passive hiding's affect on $\bar{\mathbf{C}}_{\mathbf{VULN}}$.

- **Taxonomy of probe response types:**

  In practice, a network may use deceptions other than Net-Chaff, to thwart scans. An example is a firewall that replies to scans with false ICMP messages stating the target is unreachable. Section 5.1.1.5 (page 150) describes some of the common forms of these deceptions. It also describes how the rate-based models can be extended to analyze the affects of these deceptions.

The hiding model was also used to analyze Net-Chaff's performance, and its use of deception. In summary, Net-Chaff's primary uses of hiding include: 1) its containment process, 2) the use of impersonations to hide real systems from information-retrieval scans, and 3) hiding Net-Chaff's deceptions, to counter hackers' counter-deception.

Finally, the Net-Chaff evaluation includes analysis of Net-Chaff's limitations, and also, topics for future research. The Net-Chaff system's primary limitations include: 1) its intrusive use of the network's address space and routers, and 2) potential problems from automated containment, including false positives and blocking whole subnets. The primary limitations of the Net-Chaff research include: 1) its untested hypothesis regarding secured intranet routers and the opportunity they present for accurately detecting scans, and 2) remaining design work is needed in order to better assess Net-Chaff's viability.

5.2 Honeyfiles

Extensive validation work was performed for the Honeyfiles system. That work is described in the Honeyfiles conference paper [YZD04], which is included in the appendix. The paper also has a section on the limitations of the Honeyfiles system. The paper gives a synopsis of the validation work. A more thorough description of the validation work is beyond the scope of this dissertation.

5.3 Deception process models

This section presents the evaluation performed for the deception process-models: the deception-operations model and the hiding model (presented in chapter 3). The evaluation is an informal case-study that is based on use of the models in developing and evaluating the Net-Chaff and Honeyfiles systems. The systems are presented in chapter 4, and the evaluation in chapter 5. The evaluation is informal in that it is based on the dissertation author's experience in using the models. Also, the analysis is limited to reporting the most noteworthy findings. For each model, parts of it were not used with the two systems, so the evaluation is limited to the parts that were used.

For each process-model, its use with each system is evaluated separately. In particular, separate evaluations are made for the use of the deception-operation model with the Honeyfiles system and the Net-Chaff system. An evaluation is made for the use of the hiding model with the Net-Chaff system. The hiding model was not used with the Honeyfiles system. The models are evaluated relative to their purpose of aiding deception planning. Each evaluation examines and reports the following: 1) how the model was used, 2) the model's usefulness (i.e., validation), 3) the model's correctness (i.e., verification [22]), and in particular, its self-consistency and veracity, 4) the parts of the model that were not used, and thus not evaluated, 4) ways to improve the model, and 5) the model's limitations.

- **Deception-operations model:**

The deception-operations model was used with Net-Chaff, to create, design and evaluate the system. The model was not only useful, but essential, in developing Net-Chaff. The model inspired the Net-Chaff design. The model reveals that the deception target's intelligence process is a key element of deception operations: the target's intelligence process can be used to reliably convey the deception to the target, and also, the target's intelligence process can be defeated by deception. Applying this to computer security led to the observations that: 1) hackers' scans can be easily deceived, 2) deception can have a predictable and reliable effect on scans, and 3) that deception could help in containing scans. The model also reveals the importance of minimizing falsehood in deception operations. This principle inspired the design of Net-Chaff's low-level impersonations.

The deception-operations model guided the Net-Chaff design process, and was key in understanding how to effectively use deception. The model of the overall deception process provided a very useful understanding of the deception-operation's lifecycle. The model's *deception objective* was indispensable for identifying Net-Chaff's specific uses of deception, and in using the deceptions effectively. The Net-Chaff system is described in chapter 4, and it includes a section on Net-Chaff's deception objectives. The model also played a critical role in evaluating Net-Chaff. The deception objectives revealed what to evaluate in assessing Net-Chaff's performance and the effectiveness of its deceptions.

Almost all of the deception-operations model is applicable to Net-Chaff. Only a small part of it was not relevant, and an example is the process for terminating deception operations. No errors were found in the model. However, a discovery was made that improves the model. Each deception objective should include a description of the tactical or strategic objectives it serves, and how it serves them. This was done with the Net-Chaff design, in its sections on tactical and deception objectives. The primary limitation of the deception-operations model is that it has not been used extensively, and its primary author does not have extensive experience with computer-security deception operations. Additional use of the model is needed to further test and improve it.

The deception-operations model was also used to design and evaluate the Honeyfiles system. That use of the model was very similar to what was just described for Net-Chaff. One exception is that the model did not inspire the creation of the Honeyfiles system, as that

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[22] Boehm elaborates on the distinction between validation and verification [Boe84].

occurred before the model was built. The model was especially helpful in understanding how to deploy individual honeyfiles. For instance, an understanding of hackers' intelligence processes is needed to effectively place and name honeyfiles. Also, system users need to understand their honeyfiles' deception objective. The model was also helpful in understanding the advantages of honeyfile deceptions: they are very simple, use little falsehood, have almost no risk, and the system provides good feedback.

The Honeyfiles system was evaluated by deploying a prototype of it on a honeynet. The deception-operations model played a key role in designing the honeynet, and especially in designing the deception story. Three computer-security students were recruited to hack the honeynet. Their hacking was observed, and they were each interviewed. The interviews revealed that key parts of the deception story were not received by the hackers. The deception-operations model was useful in understanding why this part of the deception operation failed. The failure also revealed a limitation of the model. The model lacks guidance regarding specific techniques that tend to work, and not work, based upon experience. Providing such guidance would significantly enhance the model's usefulness.

- **Hiding model:**

The hiding model is a taxonomy, and it was used to categorize the five hiding techniques used by Net-Chaff. That analysis and categorization is documented in a section within the Net-Chaff evaluation, in chapter 5. The purpose of that categorization was to test the hiding model, and to better understand Net-Chaff's use of hiding. The categorization was performed after Net-Chaff was designed, and after Net-Chaff's analytical models and simulation were completed. Therefore, the categorization was not applied to that work.

To use the hiding model, it was first necessary to identify the hiding techniques. This was the most useful information obtained. In categorizing the hiding techniques, the higher-level categories were the most informative. For example, hiding Net-Chaff from counter-deception involves defeating scanners' discovery process of investigation. Overall, the hiding model provided useful information about Net-Chaff's hiding techniques, but not essential information.

The categorization process was tedious and challenging. The categories were adequately defined, but some of the hiding techniques were not easy to categorize. For instance, one hiding technique that was difficult to categorize is Net-Chaff's use of a large number of unused addresses to reduce $\bar{\mathbf{r}}_{\mathbf{vuln}}$. Most of the difficulties in categorization may be due to the nature of the problem—such analysis can simply be difficult. However, some of the hiding model's low-level categories probably need additional clarification. Each of the five hiding techniques belongs to a different low-level category. The model has 26 low-level categories, so only a small fraction of them were used and evaluated. Additional use and evaluation of the hiding model is needed. Another intended application of the hiding model is in discovering new or alternative hiding techniques. This application of the model may prove to be more useful then applying the model to categorize known deception techniques, as was done for Net-Chaff.

- **Summary:**

This section presents the evaluation performed for the deception process-models. The evaluation is an informal case-study. The deception-operation model was extremely useful for creating, designing and evaluating the Net-Chaff and Honeyfiles systems. The most important parts of the model were found to be: 1) the model of the overall deception process, 2) the deception objective, 3) the role of the target's intelligence process, and 4) minimizing falsehood. The primary limitation of the deception-operations model is that it has not been used extensively.

The hiding model was used to categorize and analyze Net-Chaff's five hiding techniques. The model of discovery by investigation was very helpful in understanding one of the hiding techniques in particular. Although this was a very limited case-study, it indicates that the model could be useful for understanding how particular hiding techniques work. Additional use of the model is needed to further evaluate it.

6 Conclusion

This dissertation is concerned with the processes, principles and techniques that are involved in deception-operations for computer security. After years of research and development, computer security remains an error-prone task and, in some respects, perhaps a loosing battle. Computer security's chronic problems call for wholly new approaches. Deception works in a fundamentally different way than conventional security. Conventional security tends to work directly with the hacker's actions, e.g., to prevent them or to detect them. Deception manipulates the hacker's thinking to make him act in a way that is advantageous to the defender. Being fundamentally different, deception can be strong where conventional security is weak.

6.1 Main contributions of this work

In computer security, relatively little has been done to systematically model and examine deception operations. This work addresses these issues by focusing on deception for computer-security defense. The four main contributions of this dissertation are:

1) A process model for deception operations: this model, which is based on military deception theory and practice, provides deception planners with a framework for conducting deception operations. The framework includes a set of processes, principles and techniques. The model was extremely useful for creating, designing and evaluating the two novel approaches to intrusion detection and defense: the Net-Chaff and Honeyfiles systems. The most important parts of the model are: 1) the model of the overall deception process, 2) the deception objective, 3) the role of the target's intelligence process, and 4) the principle of minimizing falsehood.

2) A process model of deceptive hiding: this model aids the defender in developing new hiding techniques and in evaluating existing techniques. Deceptive hiding is modeled as defeating the target's discovery processes: direct observation, investigation based on evidence, and learning from others. The hiding model was used to categorize and analyze

Net-Chaff's five hiding techniques. The model of discovery by investigation was particularly helpful in understanding one of the hiding techniques. Although this application of the model was a very limited, it indicates that the model could be useful for understanding how particular hiding techniques work.

3) Deception-based intrusion detection systems (IDSs): the two deception models informed the design and evaluation of the two IDS systems. (a) The Net-Chaff system employs computer-impersonations to detect and contain hacker's network scans within an intranet. Net-Chaff's primary performance objective is to contain scans before they can access vulnerable computers. The primary advantages of the system are: 1) it is deployed on a secure intranet where scans are infrequent and warrant containment, 2) a large number of unused addresses are used to rapidly and accurately detect scans, and to slow down them down, 3) deception is also used to slow down scans, 4) automated containment.

(b) The Honeyfiles system extends the network file system to provide bait files for hackers. These files trigger an alarm when opened. The primary advantages of the system are: 1) honeyfiles can be difficult for hackers to avoid, 2) honeyfiles can detect unauthorized access gained through unknown attacks, and 3) end-users can create honeyfiles and receive alarms, and this can make false alarms infrequent and easy to handle.

4) Experiments: (a) the Net-Chaff system was evaluated by using analytical models and a simulation. The simulation was used to verify the analytical models. The analytical models were used to evaluate Net-Chaff's performance. The evaluation included several typical networks and several typical scans. Worst-case Net-Chaff performance was modeled. For many typical network and scan scenarios, it appears that Net-Chaff could reliably contain scans before they access a single vulnerable computer. This would prevent scanning worms from spreading. The analytical models were also used to examine the parameters that affect Net-Chaff's performance. This application of the models can be used to configure Net-Chaff deployments for good performance.

(b) A prototype of the Honeyfiles system was constructed. The prototype was deployed on a deceptive network and subjected to hacking. There, the Honeyfiles system was observed to be an effective means for intrusion detection.

6.2 Limitations of this work

The limitations of the two deception models and the two IDSs are analyzed in chapter 5. A short summary of that analysis is given here:

- **The deception models:** the primary limitation related to the deception models is the limited time that was available for this work. This meant that the models have not been extensively used nor evaluated as one would like.

There are also some practical limitations of the IDS solutions developed.

- **Net-Chaff:** the Net-Chaff system's primary limitations include: 1) its intrusive use of the network's address space and routers, and 2) potential problems from automated containment, including false positives and blocking whole subnets. The primary limitations of the Net-Chaff research include: 1) its untested hypothesis regarding secured intranet routers and the opportunity they present for accurately detecting scans, and 2) remaining design work is needed in order to better assess Net-Chaff's viability.
- **Honeyfiles:** the Honeyfiles system's primary limitations include: 1) honeyfiles may not be viable in file spaces that require regular searching, and 2) honeyfiles require end-user involvement and skill.

6.3 Future work

Future work for the two deception models and the two IDSs is summarized here. This work will address some of the limitations identified in the previous section, and it will also explore new avenues related to deception-based IDSs:

- **The deception models:** additional use and evaluation of both models is needed. Further, the deception-operations model lacks guidance regarding specific techniques that tend to work, and not work, based upon experience. Providing such guidance would significantly enhance the model’s usefulness. Future work for the hiding model is discussed in chapter 3. One topic for future research is extending the discovery-process models to deceptive showing. In this case, the discovery process would be manipulated to portray something false.

- **Net-Chaff:** its future work is discussed in chapter 5. Most important is the design problems that must be solved before Net-Chaff can be implemented. Its appears that viable solutions can be found for these design problems, but it is not entirely certain. Two such design problems are an intranet routing scheme for the unused addresses, and specific impersonation solutions. Also, investigation is needed to analyze Net-Chaff’s compatibility with a wide variety of real-world networks, including their design and operations.
- **Honeyfiles:** the Honeyfiles system needs to be more fully implemented, and then deployed on real networks where it can be evaluated.

7 Bibliography

Note: unless stated otherwise, all URLs were verified on, or before, May 2006.

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Appendix

The Honeyfiles system is described in a conference paper. The paper is reprinted here, starting on the next page. The paper is copyrighted, and it is reprinted here by permission. The paper's bibliographic information is:

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Proceedings of the 2004 IEEE
Workshop on Information Assurance
United States Military Academy, West Point, NY June 2004

Honeyfiles: Deceptive Files for Intrusion Detection

Jim Yuill, Mike Zappe, Dorothy Denning, and Fred Feer

Abstract: This paper introduces an intrusion-detection device named honeyfiles. Honeyfiles are bait files intended for hackers to access. The files reside on a file server, and the server sends an alarm when a honeyfile is accessed. For example, a honeyfile named "passwords.txt" would be enticing to most hackers. The file server's end-users create honeyfiles, and the end-users receive the honeyfile's alarms. Honeyfiles can increase a network's internal security without adversely affecting normal operations. The honeyfile system was tested by deploying it on a honeynet, where hackers' use of honeyfiles was observed. The use of honeynets to test a computer security device is also discussed. This form of testing is a useful way of finding the faulty and overlooked assumptions made by the device's developers.

Index terms – deception, intrusion detection, computer security, file servers

Introduction

Honeyfiles are an intrusion detection mechanism based on deception. Specifically, a honeyfile is a bait file that is intended for hackers to open, and when the file is opened, an alarm is set off. For example, a file named *passwords.txt* could be used as a honeyfile on a workstation. Hackers who gain unauthorized access to the workstation will be lured by the file's name, and when they open the file an alarm will be triggered.

The concept of deploying bait files against hackers was pioneered by Cliff Stoll during his investigation of the German hackers who had penetrated his system at Lawrence Berkeley Labs, and elsewhere, in search of defense information that could be sold to the KGB [1]. To determine the origin of the attacks, Stoll needed a way of keeping the hackers on-line long enough to trace their connection. This was done by creating bait files that would appeal to the hackers and keep them occupied. The honeyfiles described in this paper extends Stoll's concept to an automated intrusion-detection system for end users. It monitors all file accesses and provides alarms whenever the bait files are accessed.

Honeyfiles are implemented as a file server enhancement, and the file server's users can make any of their files a honeyfile. Alarms are sent by e-mail directly to the user, and services can be used to securely forward the e-mail to a phone or pager. With honeyfiles, detection mechanisms can be effectively deployed, as they are placed by the end users who are intimately familiar with the network's file spaces. In addition, when an alarm

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is sent, those end users can easily and effectively interpret it.

Honeyfiles can be used to detect unauthorized access to computers whose file space is mounted from a file server. For all but the smallest of organizations, standard industry practice is to store user and application data on file servers. By implementing the alarm system on the file server, honeyfiles provide defense in depth for the file server's clients. Also, in protecting the clients, honeyfiles can detect unauthorized access gained through unknown attacks, as well as unauthorized access gained through unintended file-access permissions.

When effectively deployed, it will be difficult for hackers to avoid honeyfiles, and honeyfiles show potential for avoiding some of the problems frequently encountered by network intrusion-detection systems (NIDSs), such as high false-positive rates and also high false-negative rates for unknown attacks. Honeyfiles offer several additional benefits, such as the opportunity to increase a network's internal security without impairing its normal operations. Further, the honeyfile system can be used to detect unauthorized access to real files (in addition to bait files), and this provides substantial advantages over alternative techniques such as cryptographic checksums for detecting file modification.

A prototype honeyfile system has been implemented on the Network File Server (NFS), and it has been tested by subjecting it to hackers. Honeyfiles, and the prototype, are further described in the following sections.

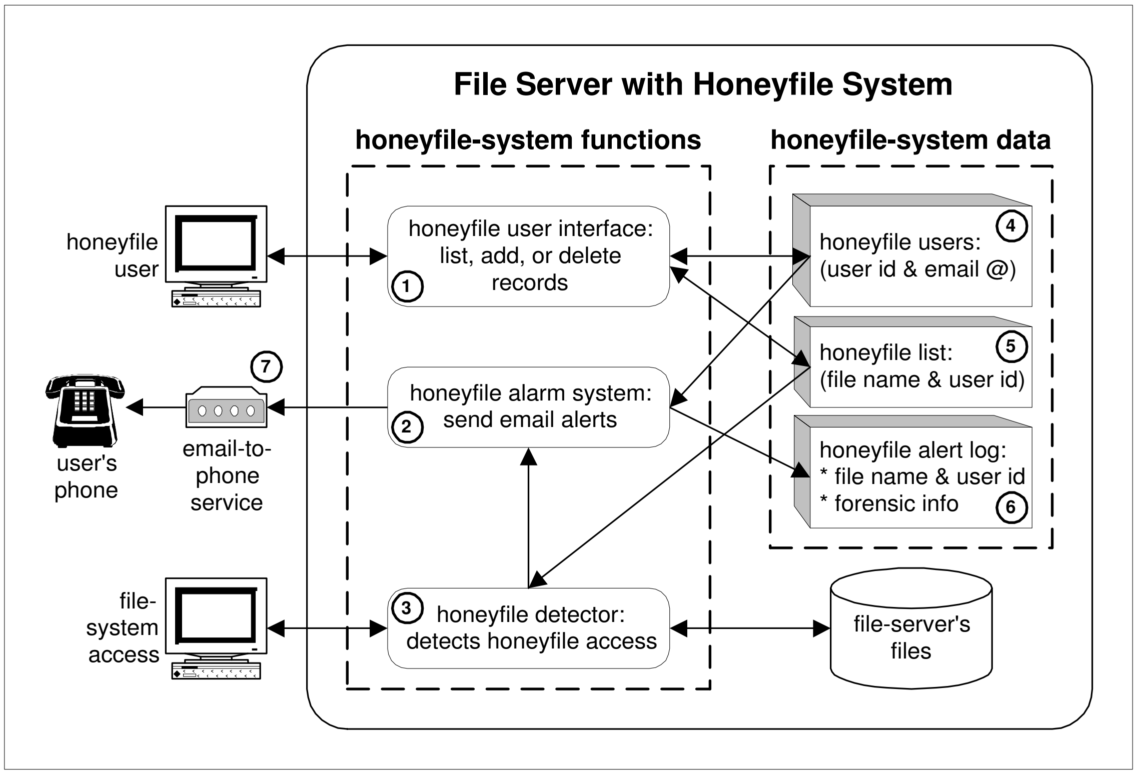
File Server with Honeyfile System
honeyfile-system functions
honeyfile-system data
honeyfile user
honeyfile user interface: list, add, or delete records
1
honeyfile users: (user id & email @)
4
honeyfile list: (file name & user id)
5
7
honeyfile alarm system: send email alerts
2
user's phone
email-to-phone service
honeyfile alert log: * file name & user id * forensic info
6
file-system access
3
honeyfile detector: detects honeyfile access
file-server's files

Figure 1 : The honeyfile system

The Honeyfile System

Honeyfiles are implemented by a *honeyfile system*, and it provides the necessary file-system and alarm functions. The file-system functions are implemented as an enhancement to a network file server, as illustrated in Figure 1. The system's components are numbered in the figure and their descriptions follow.

Any file within the user's file space can be a honeyfile. The honeyfile system provides an interface whereby file-server users specify their honeyfiles (1). A file records the system's honeyfiles (5). Each record contains a file name and user ID. Honeyfile alarms are sent as email messages, so the user also provides an email address to be used. The email messages are called *email alerts*, or simply *alerts.* A file records the system's users (4). Each record contains a user ID and email address.

To detect access to honeyfiles, the honeyfile system monitors all file access on the file server (3). When a honeyfile is accessed, an alert is sent (2), and it is logged (6). The alert includes the name of the opened honeyfile, and forensic information for incident response, such as the IP address of the computer that opened the file.

The network can be configured for the email alerts to be sent in a secure manner. Ideally, they will be sent to an automated service that will call the user's cell phone and digitally display the email message (7). This ensures secure delivery of the alert should the user's mail client also be compromised. Phone delivery also enables the user to be notified while away from his computer. We implemented a prototype honeyfile system for NFS, on RedHat Linux 9. We plan to distribute the prototype as open source. The prototype is working, documented and tested. This paper is an abridgement of the prototype's documentation.

Using Honeyfiles

Honeyfiles can detect the hacker's investigation and copying of files, including:

- the hacker's personal perusal of the file space. Hackers can be tricked into opening files with alluring names that indicate the file is of value.
- the hacker's use of search tools to find particular types of files, e.g., file names containing the string "password". These tools can examine file names or contents. Honeyfiles can be created to match common hacker searches.
- the hacker's use of tools like *tar* and *zip*, to copy and steal the contents of entire directories. Such copying can be detected by placing honeyfiles in directories that are likely to be stolen, and the honeyfile's name will blend in with the other files, e.g., "sysrun1.dll".

There are four types of files that are generally of interest to hackers, and that can often be used as honeyfiles:

- files with information about accessing and using other systems, such as password files (*passwords.txt)*, user manuals (*customer-accounts-system.pdf*), and security documentation (*vpn- instructions.doc)*,
- system or application programs that the hacker may run, but that authorized users would not run, such as the gcc compiler,
- files that contain evidence of the attack, such as log files, and
- files that contain information of use other than hacking, such as credit card numbers, intellectual property, expected stock market prices, and military intelligence.

A honeyfile should be named and located in such a way that its owner will not be inclined to open it accidentally. One technique is to give a honeyfile a name that appears unusual only to its owner. The unusual name can help jog the owner's memory and recognize the honeyfile. For example, a honeyfile password file could be named *complete-passwords.txt*. Its owner has no partial password files, so the prefix "complete" will help him recognize the honeyfile.[1]

Honeyfiles can contain deceptive content, such as fake user-IDs and passwords. Deceptive file-content can take on a plethora of uses and forms, and it can be used independently of honeyfiles. In order to concentrate on central honeyfile functions, this paper does not address deceptive content in honeyfiles. Instead, it focuses on honeyfile deceptions involving just file system information, i.e., the file's location and its directory entry, including its name.

Honeyfile Uses

This section addresses honeyfiles' detection capabilities, tactical capabilities, and ease of use.

Detection capabilities

Honeyfiles' detection capabilities include the following:

- Honeyfiles can detect unauthorized access to computers and file systems:

The primary strength of honeyfiles is their ability to detect unauthorized access to computers whose file-space resides on a file server. For example, a workstation stores its user file-space on a file server, and the workstation automatically mounts the file-space at boot time. If a hacker breaks into the workstation, his presence will be detected if he opens a honeyfile within the user file space.

In general, honeyfiles detect unauthorized access to the file spaces on a file server, including: **1)** compromise of the file space's user ID and password, **2)** compromise of weak or defective authentication mechanisms on the file server, e.g., NFS' notoriously weak authentication, and **3)** exploitation of errors made in granting file-space permissions, e.g., accidentally making the file space "world readable".

- Honeyfiles can be used to detect unauthorized access gained through unknown attacks:

Honeyfiles detect the hacker after he gains unauthorized or unintended access. The detection mechanism is independent of the specific techniques used to gain access. This is one of honeyfiles' primary contributions. Honeyfiles offer a unique opportunity for detecting attackers who are able to defeat conventional defenses. This makes honeyfiles especially useful for protecting high-value systems that are subject to such skilled attacks.

- Hackers can be highly vulnerable to honeyfile deceptions:

Honeyfiles take advantage of several deception vulnerabilities in most hackers' intelligence collection and analysis: **1)** when hackers initially access a file space, they must search it in order to locate valuable data. If the hacker's search can be anticipated, honeyfiles can be placed where he is likely to encounter them. **2)** The hacker's limited knowledge of the file space makes it difficult for him to discern what truly belongs there, and his naiveté makes it easy to create deceptive honeyfiles. **3)** It can be very difficult for the hacker to detect a honeyfile before opening it. The

[1] Unless stated otherwise, this paper's masculine pronouns refer to both men and women.

honeyfile deception is created using a small amount of information, i.e., the file's directory entry, and usually, there is no way for the hacker to cross-verify the information, and **4)** In most instances, if the target wants to know a honeyfile's contents, his only option is to open the file and trigger the alarm.

- Honeyfiles can be used to protect a wide variety of files and computer systems:

A honeyfile can be almost any file stored on a file server. In addition to regular data files, they can be files used by application programs, such as attachments within a mail client. For example, a company's executive email discloses corporate plans that will predictably affect the company's stock price. Such information could be extremely valuable to hackers. Security personnel can work with the executives to place honeyfiles within their mail clients. Honeyfiles can also be used to protect application programs. For example, a web-server's cgi-bin directory can be populated with empty honeyfiles named after notoriously vulnerable scripts.

- Honeyfiles show potential for avoiding some of the problems encountered by network intrusion-detection systems (NIDSs):

NIDSs are typically very weak at detecting unknown attacks, whereas honeyfiles can detect unknown attacks and even access gained through unintentional file-access permissions. Also, NIDSs can generate an exorbitant volume of false alarms. In contrast, honeyfiles show the potential for having a much lower false alarm rate. Further, with NIDSs, false alarms are often investigated by a centralized security group that does not work directly with the protected data, making investigation difficult. In contrast, honeyfile users can accurately and easily dismiss many false alarms because of their familiarity with the protected data.

Honeyfiles make it possible for alarms to be deployed by the personnel who create and manage information assets. In contrast, when NIDSs are deployed by a centralized security group, it can be difficult for them to accurately understand the network's changing information assets.

- The honeyfile system can be used to detect unauthorized access to real files, and it offers some substantial advantages over cryptographic checksums:

In addition to detecting access to deceptive honeyfiles, the honeyfile system can be used to detect access to real files. For example, when a workstation user leaves work for the day, he could use the honeyfile system to set alarms for all of his files.

The honeyfile system can be easily extended to provide alerts for honeyfiles when they are changed. A popular technique for detecting file changes involves creating and storing cryptographic checksums. The files' checksums are periodically recalculated to detect changes to the files. Tripwire is a commercial product that uses this checksum technique.

For detecting changed files on a file server, the extended honeyfile system provides two substantial improvements over the use of checksums: **1)** the honeyfile system detects changes when they occur, whereas the checksum technique detects changes during periodic, and often infrequent, execution, and **2)** the honeyfile system is simpler than the checksum technique. The honeyfile system resides on the file server and an end user only has to specify the honeyfiles. With the checksum technique, the checksums must be periodically calculated by the end user, or he must grant file access to a separate system that calculates the checksums. If the user calculates the checksums, he must securely store the binaries and checksums.

For a balanced assessment of checksums, it should be noted that checksums can protect local file systems, whereas honeyfiles can not. Also, the use of both checksums and honeyfiles can provide defense in depth for detecting file changes.

Tactical capabilities

Honeyfiles' tactical capabilities stem mostly from: **1)** decentralized deployment: the network's end users create and place alarms, and **2)** centralized implementation: the alarm mechanism resides on the file server rather than on its clients.

- By enabling end-users to create alarms, the detection mechanisms can be effectively deployed and the alerts effectively interpreted:

If honeyfiles are created and placed well, it can be difficult for hackers to avoid them, resulting in a low false negative rate. End users are intimately familiar with the data they create and manage. Honeyfiles make it possible for users to create and place alarms where they are most needed and where they will be most effective. With some basic instruction on security and honeyfile tactics, users can effectively deploy honeyfiles. Also, end users can evaluate and improve their alarms' effectiveness because they receive alerts directly. Further, end users can adapt their honeyfile use as the network and its threats change.

Honeyfile users can accurately discern between true and false positives because they create the honeyfiles and receive the alerts. For instance, if a user accidentally opens a honeyfile, the resultant alert can be recognized as a false positive. If an alert is sent when the user is not accessing his file space, the alert can be recognized as a true positive.

- Honeyfiles support defense-in-depth for the file server's clients:

Honeyfiles provide the file server's clients with an alarm system that resides outside of the client itself, and this adds a layer of depth to the client's defenses. When a hacker breaks into a client, the honeyfile's alarm mechanism is on the file server, not on the client. If the honeyfile's alarm mechanism was on the client, the alarm would be vulnerable to attack or detection by the hacker, especially when the hacker has "rooted" the client computer. Alerts are sent by e-mail, and they can be made to travel over a secure channel.

- Honeyfiles can provide the security function of deterrence, and they can support incident response:

In addition to detecting attacks, honeyfiles can deter attacks. Honeyfiles have an affect that is similar to landmines: if hackers know honeyfiles are being used, the use can dissuade them from hacking, and the use can slow hackers down by making them cautious and uncertain. Honeyfiles are also useful for incident response. Investigators can view all of the alerts for a network, and collectively, they may reveal a hacker's capabilities, intentions, or courses of action.

Ease of use

Honeyfiles' ease of use is advantageous to both end users and security administrators:

- Honeyfiles can enhance a network's internal security without impairing normal operations:

Networks typically use a relatively low level of internal security, as additional security is burdensome and costly. For example, extra access controls make resource sharing difficult, and making IDSs more sensitive increases their false alarm rates. Honeyfiles can provide a means of increasing internal security without impairing operations. Honeyfiles have little adverse affect on legitimate computer use. Also, honeyfiles can be an effective deterrent for insider hackers because they, like all other network users, will have been informed of the honeyfiles' availability and use.

- Honeyfiles are an effective deception because they can be easily created, require little falsehood, and involve little risk:

A honeyfile is integrated within a real file space, and this real context makes the honeyfile deception easy to create and difficult to detect. Also, honeyfiles themselves involve little falsehood—just a directory entry. Further, honeyfiles involve little risk.

- Implementing the alarm system on the file server makes honeyfiles available to almost all network computers:

Honeyfiles can be created by any computer that uses the file server. Honeyfiles can be used by computers with a wide variety of operating systems and file systems. The alarm system does not have to be ported to the network's various operating systems, e.g., Windows and Unix. Also, having a single alarm system makes it easier to train users.

- Implementing the alarm system on the file server centralizes security management functions:

Having a single alarm system makes the system's maintenance and defense easier, as the system resides in one place, rather than on each of the client computers. Further, having a single alarm system makes it easier for network security personnel to monitor the alarm system's overall use and effectiveness.

Enhanced Functions

Earlier sections described basic honeyfile functions, and this section describes some enhancements that greatly improve honeyfile use. These improvements have to do with maintaining realism and controlling alarms.

Operational systems change over time, and so too must most honeyfiles if they are to be believable. A file's MAC times record when it was created, last modified, and last accessed. Honeyfiles that portray in-use files must have their MAC times periodically updated. The honeyfile system can solve this problem by periodically updating MAC times, within user-defined parameters.

If deceptive content is being used, it may also need to change over time. Although deceptive content is not addressed here, there is a noteworthy technique for automatically updating a file's deceptive content. The honeyfile's contents can mirror a source file that is hidden from the target, and the honeyfile system can periodically update the honeyfile from the source.

Honeyfile use can also be improved by providing controls for selectively generating alerts. Some processes and users must be permitted to open honeyfiles without setting off alarms, such as tape-backup processes and the root user.

Honeyfile Limitations

Honeyfiles' primary limitations are as follows:

- Honeyfiles may not be viable in file spaces that require regular searching:

Honeyfiles will not be viable if file search tools generate frequent and unavoidable false alarms. The honeyfile system could accommodate searches by enabling users to temporarily suspend their honeyfiles' alerts. However, a suspension function introduces vulnerabilities: users may forget to resume honeyfile alerts, and the function could be hacked.

- Honeyfiles are appropriate for file spaces that are accessible to one person or a small group:

Honeyfiles are likely to be problematic if placed in a file space that is used by many people. Honeyfile information would have to be communicated to the group. Also, false alarms may be frequent and difficult to investigate.

- Honeyfiles have tactical weaknesses that limit their use:

Like most deceptions, honeyfiles provide uncertain effectiveness against an individual attack. Many other security measures, such as strong encryption, are much more certain. Also, honeyfile use will be limited if the target does not tend to explore the file system.

There are some circumstances in which honeyfiles can be defeated. There are ways in which a hacker can identify real files, and if he opens only them, he will avoid honeyfiles. For example, a hacker can use a keystroke logger to learn what files are being used, and then open only them. Another honeyfile vulnerability is overloading of the alert mechanism.

- Honeyfiles require end-user involvement and skill:

Effective honeyfile deployment requires user participation. It cognitively taxes users by requiring them to manage and track honeyfiles. Also, it requires users to have some security savvy as well as adeptness with computers. Not all users will have the time or skills needed to use honeyfiles. However, security personnel can provide some simple training that will be sufficient for many users. Another potential cost of honeyfiles is the inadvertent deception of friendly personnel.

Using a Honeynet to Test Honeyfiles

The honeyfile system was tested by deploying it on the honeynet and thereby subjecting it to hacking. Three hacking incidents were observed, and each involved a different hacker. The three hackers were students from North Carolina State University who are skilled in computer security. The hackers accessed a honeyfile system containing error reports and manuals for a mainframe system. Each of the hackers was detected by at least one honeyfile. The hackers did not find the file space very interesting, and they did not search it diligently. This suggests that honeyfiles are more likely to be detected if they are near the file space's root, where the hacker will start searching.

Honeynets show much promise as a means for testing security devices. They provide a realistic setting in which hackers can test the device. The testing can be performed unwittingly by real hackers or by those recruited for the task. There is a significant advantage in using testers from outside of the security device's development team. Outside testers may reveal the developers' faulty and overlooked assumptions. Such errors are a common source of security vulnerabilities, and they are very difficult for developers to find themselves.

Building the honeynet was non-trivial and substantially more time consuming than we expected. Constructing deceptive files, file content, and system footprints (e.g., file time-stamps) was especially challenging, as all the falsehood had to be made consistent and believable.

Conclusion

After years of research and development, computer security remains an error-prone task and, in some respects, a loosing battle. Computer security's chronic problems call for wholly new approaches. Deception works in a fundamentally different way than conventional security. Conventional security tends to work directly with the hacker's actions, e.g., to prevent them or to detect them. Deception manipulates the hacker's thinking to make him act in a way that is advantageous to the defender. Being fundamentally different, deception can be strong where conventional security is weak. Honeyfiles are a promising tool for intrusion detection. They offer significant advantages where conventional intrusion detection is weak. A prototype honeyfile system has been constructed and tested, and we plan to distribute it as open source.

References

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