# ABSTRACT

RAMASWAMY PAVITHRA. Comparison of end-to-end QoS Reservation Schemes in Next Generation Networks. (Under the direction of Dr. Harry. G. Perros.)

Increasing demand for network services has led the network providers and equipment vendors to consider ways to provide better Quality of Service (QoS) for these services. In the Internet today, there is a little or no interaction between the network access providers and the network service providers. Several organizations such as, the Telecommunication standardization sector of International Telecommunication Union (ITU-T), the European Telecommunications Standards Institute (ETSI), and the 3rd Generation Partnership Project (3GPP) are involved in the standardization of a general QoS control architecture to bring the network access and application services to one common framework known as the Next Generation Network (NGN).

In this thesis, we have studied the establishment of a connection with end-to-end QoS assurances that spans over a number of heterogeneous wireless and wireline networks, namely, a Wireless Local Area Network (WLAN), a Worldwide Interoperability for Microwave Access (WiMAX), a Metro Ethernet, a Multiprotocol Label Switching (MPLS)-based and a Differentiated Services (Diffserv)-based Wide Area Networks (WANs). The end-to-end QoS architecture that we have studied follows the ITU-T NGN QoS control architecture where the connection setup signaling uses the 3GPP IP Multimedia Subsystem (IMS) signaling. Within this context, we have studied the QoS interactions between the component network architectures, developed a mapping of QoS parameters across the various networking technologies, and identified the four different schemes for QoS reservation. These schemes are: local segmentation push scheme, local segmentation pull scheme, end-to-end push scheme and end-to-end pull scheme. Using simulation techniques, we compared the connection setup time performance of these four schemes.

Our results indicate that the pull mode schemes that involve the user terminals to initiate the QoS reservation perform better than the push mode schemes that involve the IMS core network elements to initiate QoS reservation. This combined with the advantage of the

localized QoS reservation makes the local segmentation pull mode QoS reservation scheme has a lower connection setup time compared to other schemes.

# Comparison of end-to-end QoS Reservation Schemes in Next Generation Networks

by
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# DEDICATION

To my family …

# BIOGRAPHY

Pavithra Ramaswamy was born on 30th September, 1980 in Jabalpur, India. She received her Bachelor of Engineering degree, majoring in Computer Science and Engineering, from Government College of Engineering, Tirunelveli, India in the year 2001. She worked as a consultant engineer in the Avionics division of Aeronautical Development Agency (ADA), India from March 2002 to November 2003. She worked as a Lead Engineer in HCL Technologies Cisco Offshore Development Center, India from 2004 to 2007. She is currently a Master's student in the Department of Computer Science at North Carolina State University, Raleigh, USA.

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I would like to thank my parents for encouraging me to always aim higher in life. I would also like to thank them and my family for believing in me and supporting me. I would like thank my friends Prashant and Gayatri for all the fun times and listening to me when I needed them most.

I especially want to thank my husband, Anirudh, for being extremely patient and supportive whenever I needed it. He has always given me strength and hope during the tough times. I would not be here without his guidance and support.

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# Chapter 1

# Introduction

As the demand for voice, video and other real-time services are growing in the packet-based Internet, the services and the network access providers are continually investing large amounts of resources to accommodate the high rise in bandwidth requirements and to provide better Quality of Service (QoS). The Next Generation Network (NGN) is seen as an evolution of the Internet towards a converged platform supporting different kinds of services across heterogeneous networks with finer control of QoS. Various organizations such as, the Telecommunication standardization sector of International Telecommunication Union (ITU-T), the European Telecommunications Standards Institute (ETSI), and the 3rd Generation Partnership Project (3GPP), are involved in the standardization of a generalized QoS control architecture that is applicable across different network architectures. In this thesis, we focus on studying the applicability of the ITU-T NGN QoS control architecture. Specifically, we propose and analyze various signaling approaches to establish an end-to-end connection with QoS assurance.

This chapter is organized as follows. In the following sections we give the background related to our work. In section 1.2, we review the existing literature in the area of the end-to-end QoS assurance in NGN and discuss our contributions to the field. In section 1.3, we sketch a broad outline of the thesis. Finally in section 1.4, we describe how the thesis is organized.

## 1.1 Background

The ever increasing demand and popularity of applications such as Voice over IP (VOIP), Video on Demand (VOD) and Internet Protocol Television (IPTV), favored by the massive deployment of diverse access technologies, has triggered the need for guaranteed QoS across heterogeneous networks. Although there are ongoing efforts within several standards organization towards defining a generalized QoS control architecture, there are many aspects that need to be considered for its deployment in the heterogeneous and decentralized Internet [26]. Firstly, as the Internet is composed of a number of Autonomous Systems (AS) that are largely independent, the solutions should allow compatible QoS policies across these domains. Secondly, since various network technologies that compose the end-to-end path have different requirements in terms of bandwidth, delay and forwarding capabilities, it is important to design a single unified solution that works well with all the technologies. Thirdly, the solution should be able to cope with a large number of users, as any complex fine-grained solution would hamper the network scalability requirements. Fourthly, it is essential to consider using off-the-shelf network equipment, to restrict any changes to the existing network protocols and to support different application signaling protocols without any major architectural changes. Finally, it is of utmost importance that the solution should be able to provide certifiable performance over a sufficiently large percent of the time.

In the recent past, there have been many research efforts in this area addressing one or more of the above mentioned aspects. Mingozzi et al [26] proposed EuQoS, a European project to define a NGN architecture, and discussed the major results obtained in their field trails. The authors sketched an outline of their system architecture at the user end that provides a customized interface for all applications to request for QoS. Further, they discussed the QoS reservation process in the core network using the two models that they employ namely, hard and loose model. In the hard model, they have used a customized version of the Border Gateway Protocol (BGP), called EQ-BGP, to find an end-to-end path with QoS assurance for every session. In the loose model, they have used admission control mechanisms to allow the new sessions to use pre-established paths. They also presented some results from the experimental validation conducted in their testbed for the setup times. While the authors claimed that their system supports any application signaling protocol, they did not mention clearly the aspects such as, the interaction between their system and the signaling protocols, the stage at which the QoS invocation begins at the customer premises and how it initiates QoS reservation at the core. Also, their solution requires modifications to many network protocols such as, BGP and Next Step in Signaling (NSIS).

Another European project named WEIRD [29] focused on integrating WiMAX into the NGN framework with end-to-end QoS guarantees. Angori et al [27] and Castrucci et al [26] discussed the general architecture and the QoS control mechanisms in the proposed architecture. The authors described the various functions embedded in the Customer Premises Equipment (CPE), WiMAX Base Station (BS) and Access Service Network Gateway (ASN-GW) in the WiMAX portion of their architecture that can handle the signaling and interactions with the application proxy servers to initiate the establishment of QoS. They claimed to support both Session Initiation Protocol (SIP) and legacy application signaling. When SIP signaling is used, they proposed to use QoS provisioning in the WiMAX access network and NSIS towards the Diffserv core. However, when the legacy signaling methods are used, they proposed using the NSIS protocol across the WiMAX access and the core networks. This work describes the general architecture towards QoS resource signaling without paying much attention to the actual signaling involved. The authors also have not focused on the mapping QoS metrics across different technologies in the access and the core networks.

Jiao, Chen and Liu [30] proposed a framework to support IP Multimedia Subsystem (IMS) over Worldwide Interoperability for Microwave Access (WiMAX). The authors have laid out an architecture of the WiMAX network integrating the IMS functional elements. Further, they gave the IMS signaling sequence when a user in the WiMAX network requests a service involving QoS reservation. In addition to this, they gave a mapping of QoS parameters across SIP Session Description Protocol (SDP), WiMAX, Resource Reservation Protocol (RSVP) and Diffserv. In this work, the authors concentrate on the QoS assurance specifically in the WiMAX region and mark the packets with Diffserv code points for transmission through the core. As we know, Diffserv provides service differentiation but it does not provide QoS guarantees, and consequently, the end-to-end QoS guarantee cannot be assured with this framework.

There are several other papers that have concentrated only on a specific area such as, QoS resource reservation, application signaling and QoS assurance in access network. Park and Kang [31] proposed a new QoS resource reservation mechanism to overcome the flaws of the traditional QoS signaling protocols and to ensure end-to-end QoS. Weber et al [32] summarized the NGN architecture defined by the standards organizations, pointed out the flaws and proposed an architecture for QoS reservation in the core. Mani and Crespi [33] discussed mapping IMS functionality to WiFi access networks and described three phases to achieve it.

## 1.2 Thesis Description and Contribution

Several researchers have studied how to map the QoS functional entities to real network elements. However, as discussed in the previous section, most of these papers either concentrate on the access side with a focus on Layer 2 QoS mechanisms, or on high-level solutions with not enough details about the protocols and mechanisms used in metro/access/core networks. In this thesis, we consider the establishment of a connection with end-to-end QoS constraints that spans over a number of heterogeneous wireless and wireline networks, namely, Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), Metro Ethernet, Multiprotocol Label Switching (MPLS)-based and Differentiated Services (Diffserv)-based Wide Area Networks (WANs). The end-to-end QoS architecture under study follows the ITU-T NGN QoS architecture [1] with the connection setup triggered using the 3GPP IMS [2] signaling. Within this context, we have identified four different schemes for QoS signaling, examined the end-to-end performance of those schemes using simulation techniques, and compared their performance. We have also studied the QoS architectures of the different component networks and proposed a possible mapping of QoS parameters across the different architectures.

Figure 1.1 shows the reference architecture that we have used in this thesis. We have considered WiMAX [3] as the last mile with the WLAN in the home premises. The WLAN Access Point (AP) acts both as a WiMAX Subscriber Station (SS) and an AP. Multiple WiMAX Base Stations (BS) can be connected to an Access Service Network Gateway (ASN-GW) in the WiMAX network through a Metro Ethernet access network where the traffic will be aggregated using Provider Backbone Bridging Traffic Engineered (PBB-TE) tunnels [4]. The ASN-GW can be seen as an edge router (such as, Broadband Remote Access Server (BRAS)) that connects to different network domains in the WAN in order to enable communication with other access networks for peer to peer communication or with a service provider network for various service demands provided by application servers. We have considered two options in the WAN, namely, MPLS enabled and Diffserv enabled. We have used these two flavors of WAN to explain the different approaches for QoS signaling.

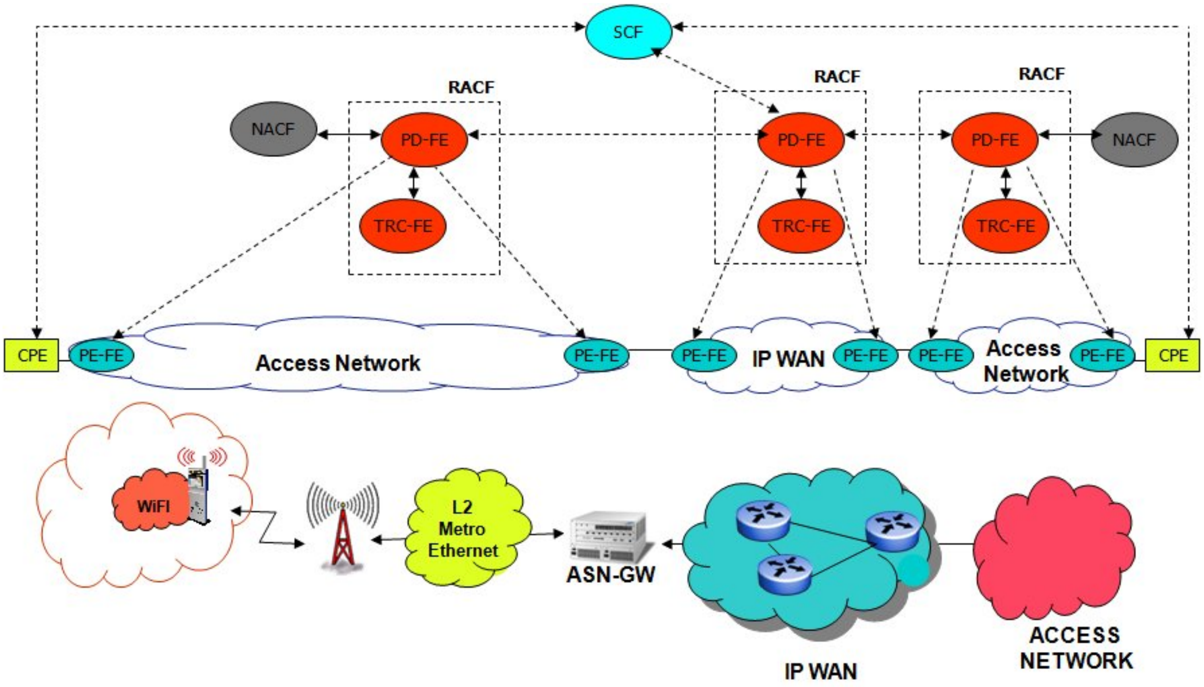


Figure 1.1: The Reference Architecture

The upper half of Figure 1.1 shows the QoS control architecture defined by ITU-T. According to this architecture, the network is divided into two distinct planes, namely, service stratum and transport stratum. The Service Control Function (SCF) is defined in the service stratum to handle the application level signaling. The Resource Admission and Control Function (RACF) comprises of the Policy Decision Function Element (PD-FE) and the Transport Resource and Control Function Element (TRC-FE). It takes care of the policy management and resource control at the transport level. The Network Attachment Control Function (NACF) is the network subscription database that is consulted by the RACF during the connection establishment. While each functional element plays a specific role in the architecture, ITU-T has defined these as logical entities giving operators complete freedom to realize the same. There are several reference points defined between the logical entities to facilitate communication. The figure also shows a high level mapping between the ITU-T NGN functional elements and the reference network under study. As the ASN-GW manages the WiMAX access network and it is positioned at the edge, we propose that the RACF functionality should be implemented in it. Similarly, every domain in the core should have a node with the RACF functionality in it.

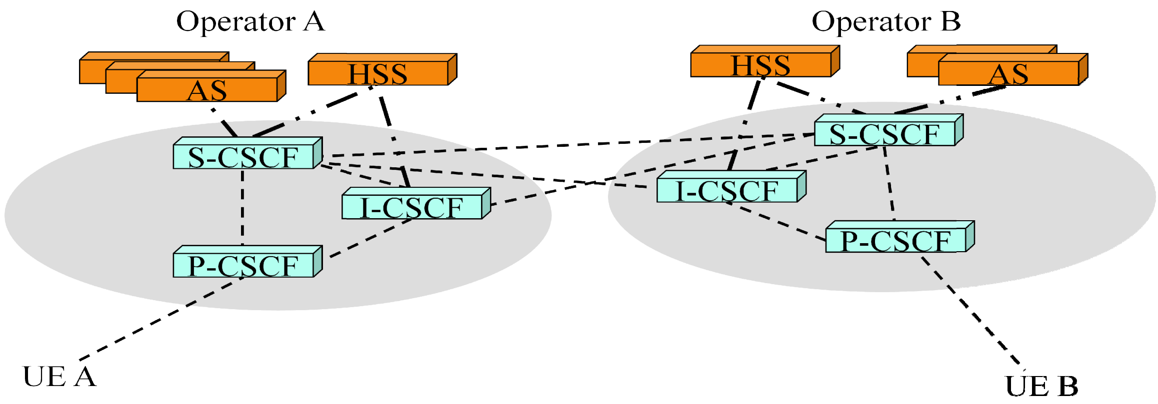


Figure 1.2: The 3GPP IMS

ITU-T defines two different QoS control modes based on the QoS signaling support in the customer premises equipment, namely, Push and Pull modes. We have investigated the QoS signaling using these modes for the different flavors of the WAN considered. We have used the IMS architecture, shown in Figure 1.2, to realize the Service Control Function (SCF) in the reference network. Also, we have proposed to have the Proxy Call Session Control Function (P-CSCF) functionality in the edge device (ASN-GW in our case) which is the first node in the IMS architecture that any User Equipment (UE) would contact during a connection establishment. As the ASN-GW has also been assumed to host the PD-FE (RACF) functionality, the combined P-CSCF and PD-FE would make it act like a Session Border Controller (SBC) that is commonly deployed for VoIP services.

## 1.3 Thesis Organization

The rest of the thesis is organized as follows. In chapter 2, we give an overview of the QoS architectures of the various component networks in our reference network. In chapter 3, we explain the IMS signaling exchange for the push and the pull modes; presents the details of the QoS signaling exchanges for four different scenarios and discuss the QoS interactions and parameter mapping across the component networks. In chapter 4, we compare these four QoS reservation scenarios using simulation techniques. Finally, in chapter 5, we summarize the results obtained in the thesis and provide directions for future research.

# Chapter 2

# QoS Architectures in Reference Network

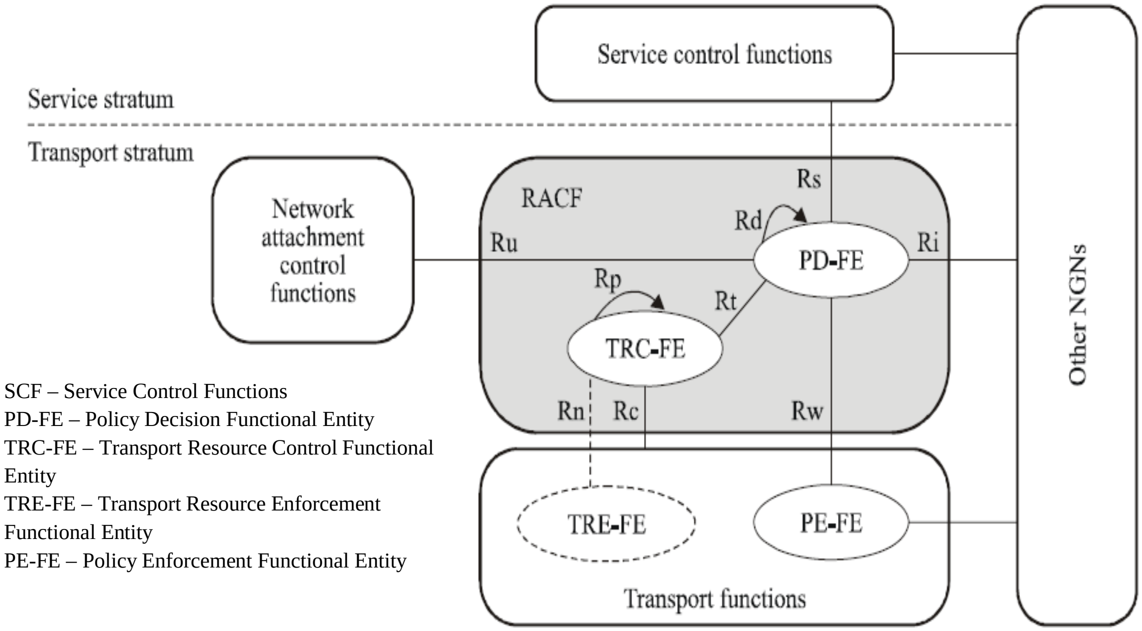
In this chapter, we present a survey of the QoS architectures in the reference network studied in this thesis, as shown in Figure 1.1. First, we describe the functional elements, different scenarios for signaling and the overall architecture of the ITU-T NGN and 3GPP IMS. Then, we furnish some details of the SIP methods used by IMS. Subsequently, we give an overview of the QoS architectures of the component networks in the access portion of our reference network such as WLAN, WiMAX and PBB-TE, and present a brief summary of the MPLS and Diffserv architectures. Finally, we conclude the chapter with a detailed description of NSIS and other related protocols that we have used in this work.

## 2.1 The NGN-IMS QoS Architecture

This section gives an overview of the NGN architecture proposed by ITU-T and the IMS architecture proposed by 3GPP. Although there are other organizations besides ITU-T that have been working on the NGN QoS architecture, the ITU-T architecture is more generalized with greater flexibility covering both fixed and mobile networks. ITU-T does not recommend a specific application level or transport level signaling protocol. The IMS signaling plane has been viewed as one of the choices for application level signaling in NGN as it uses the SIP for signaling that is used commonly in many applications in the Internet and also it has already been experimented and studied for cellular environment.

### 2.1.1 The ITU-T NGN Architecture

Figure 2.1 shows the QoS control architecture proposed by ITU-T. This architecture is logically partitioned into the service and transport strata. In the transport stratum, RACF controls the policy decision and admission control. The CPE may connect to the PE-FE in the access network and PE-FE can reside at the network boundary that interconnects with other NGNs. Other NGNs may include either access networks, core networks or both. The PD-FE is connected to NACF in access networks. At least one PD-FE needs to be deployed in an administrative domain with associated PE-FE and TRC-FE. Depending on the business model and implementation choices, RACF may be present in the access network, the core network or both. Implementation and physical configuration of PD-FE and TRC-FE are flexible; they can be centralized or distributed. In the service stratum, SCF interacts with PD-FE for policy decision and network resource authorization. SCF can interact with PD-FE in core, access or both the domains. Depending on the implementation, the SCF can be present at the access, core or both. The following paragraphs explain the functional entities in detail:



SCF – Service Control Functions
PD-FE – Policy Decision Functional Entity
TRC-FE – Transport Resource Control Functional Entity
TRE-FE – Transport Resource Enforcement Functional Entity
PE-FE – Policy Enforcement Functional Entity

Figure 2.1: ITU-T RACF QoS Control Architecture

**Service Control Functions:** SCF in different domains can interact with PD-FE through the Rs reference point. SCF handles the service level signaling messages from the CPE (if the CPE supports service level signaling) and makes requests for transport resources to PD-FE. SCF shall provide information to PD-FE to identify the media flows and also provide QoS characteristics of the flow. SCF shall indicate when the resource needs to be committed if two stage resource reservation is required. SCF may request resource usage information from PD-FE for charging and billing.

**Network Attachment Control Functions:** NACF provides Authentication, Authorization and Accounting (AAA) functions, IP address allocation for user equipments, location management and optionally per-user configurations.

**Policy Decision Functional Entity:** PD-FE handles the resource request from SCF via the Rs reference point as well as from PE-FE via the Rw reference point. The PD-FE checks the resource requests based on the service information, network policy rules and transport subscription information, and then it interacts with TRC-FE via the Rt reference point to know the current resource state of the access/core network to take the final decision. PD-FE shall also perform the Gate Control to install and enforce final admission decision.

**Transport Resource Control Functional Entity:** TRC-FE performs some basic functions such as network resource maintenance, network topology maintenance and technology dependent decisions. It collects and maintains the network and resource status information. It uses this information to perform the resource-based admission control when PD-FE requests for resources. TRC-FE ensures that requests from PD-FE match the transport dependent policy rules.

**Policy Enforcement Functional Entity: The** PE-FE enforces the network policy rules as instructed by the PD-FE on a per-subscriber and per-flow basis. Basic functions of the PE-FE include enabling or disabling packet filtering for a IP flow, rate limiting and bandwidth allocation, traffic classification and marking, traffic policing and shaping, NAT/PAT and collecting and reporting resource usage information.

**Transport Resource Enforcement Functional Entity:** TRE-FE enforces the transport resource policy at the aggregate level as instructed by TRC-FE.

Based on the capability of a CPE, ITU-T has identified three types of CPEs:

(1) Type 1 – CPE without QoS negotiation capability both at service and transport level.
(2) Type 2 – CPE with QoS negotiation capability only at service stratum (no transport level QoS signaling supported)
(3) Type 3 – CPE with QoS negotiation capability at transport and service strata.

In order to handle different types of CPE and transport QoS capabilities, there are two different QoS control modes proposed by ITU-T:

(1) Push Mode – In this mode, the SCF determines the QoS requirements on behalf of the CPE if the CPE is of Type 1 or extracts the QoS requirements from the signaling messages at the service strata for the other types of CPEs. SCF then sends a request to the RACF for authorization and QoS reservation. RACF makes the authorization and resource control decision based on the policy rules and autonomously instructs the transport functions to enforce the policy decision. This mode can be particularly used for the first two types of CPE that lack the QoS negotiation capability at the transport level.

(2) Pull Mode – In this mode, the QoS reservation happens in multiple phases. In the first phase, the SCF extracts the QoS requirements from the signaling messages at the service strata and sends a request to the RACF for authorization. RACF makes the authorization decision based on policy rules and if the resources are authorized, it sends an authorization decision (optionally a token) to the CPE. In the next phase, the CPE initiates a QoS request to the transport function, which consults the RACF (using the authorization token, if present) for authorization and admission control. Finally, the RACF responds with the policy decision for enforcement. This mode applies only to Type 3 CPEs as this requires CPEs with transport level QoS negotiation capability.

There are two basic procedures for QoS control have been described namely the SCF-requested QoS control procedure and CPE-requested QoS control procedure. These are described below:

**The SCF-requested QoS Control Procedure:**

This procedure is initiated by resource request from SCF as shown in Figure 2.2. SCF sends resource initiation request to PD-FE that makes resource and admission control decisions and pushes the same to the network nodes. This is an example for Push Mode operation.

(1) A Resource Initiation Request (RIR) is triggered at SCF by an event like a service request through application layer signaling.

(2) SCF determines/derives the QoS parameters for the media flows of the given service and sends a request to PD-FE via the Rs reference point.

(3) On receipt of RIR, PD-FE checks if the requested QoS and media flow description are consistent with the network policy rules and the transport subscription as per the NACF.

(4) The PD-FE determines which access and core networks are involved in the media flow. If there are TRC-FE instances in the involved network then the PD-FE sends an RIR (availability) to the TRC-FE to check the resource availability in that network.

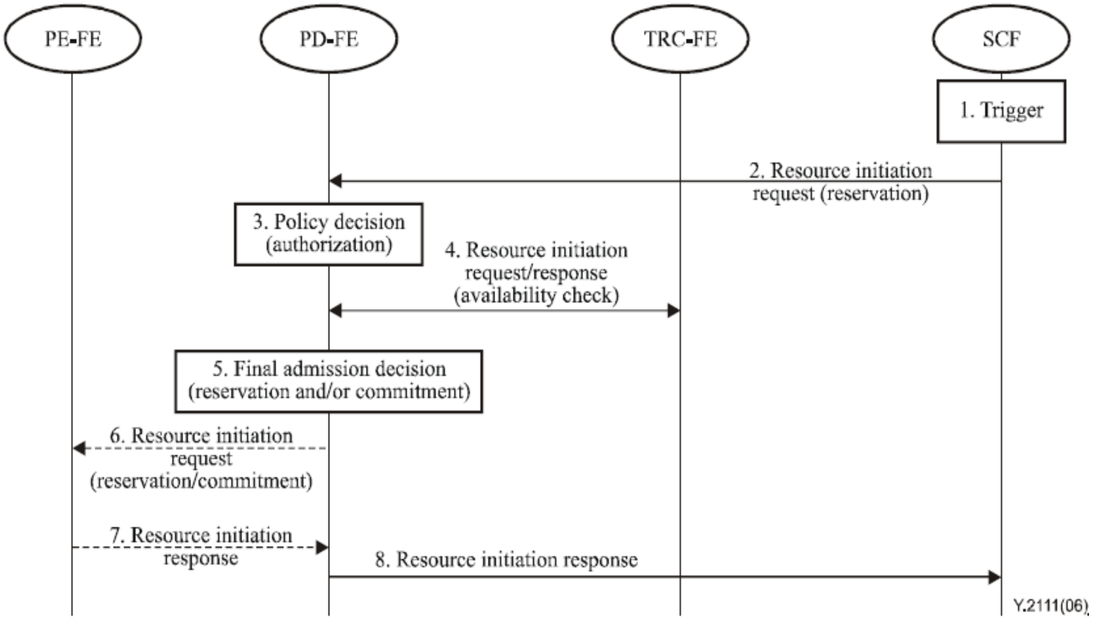


Figure 2.2: The SCF-requested QoS Resource Reservation

(5) The PD-FE makes the final admission decision based on the results of steps 3 and 4. If the media flow is not admitted, the PD-FE sends a RIP with the rejection reason back to the SCF.

(6) The PD-FE may send an RIR to PE-FE to enforce the admission decision. Alternatively, it might just ask the PE-FE to install the admission decision and later send a separate RIR to enforce the same.

(7) The PE-FE installs (or enforces) the admission decision and sends a response to the PD-FE.

(8) The PD-FE sends a RIP back to SCF.

**The CPE-requested QoS Control Procedure:**

The CPE-requested QoS reservation procedure, as shown in Figure 2.3, invoked by a dedicated path-coupled (per-flow QoS signaling message that passes only through the nodes on the data path) QoS signaling message from the CPE for a given flow is an example for pull mode where the resource decisions are pulled from PD-FE.

(1) A Resource Decision Request (RDR) is usually triggered by a request indicated through the QoS signaling from the CPE to reserve the required resources for the given flow.

(2) Based on the QoS request from the CPE, the PE-FE will send an RDR with flow description and QoS parameters to the PD-FE across the Rw reference point to pull the admission control decisions from the PD-FE.

(3) On receipt of the RDR, the PD-FE will send a Resource Action Request (RAR) to the SCF to retrieve the service information of the flow if the SCF had previously requested the QoS initial authorization related to the flow. The SCF-requested initial authorization procedure is usually triggered by a service establishment signaling message.

(4) The PD-FE checks if the flow description, the required QoS resources and the service information are consistent with network policy rules held in the PD-FE and the transport subscription in the NACF.

(5) The PD-FE determines which access and core networks are involved in the media flow. It sends a Resource Information Request (RIR) to the TRC-FE instance(s) involved within the networks found to find out the resource status information.

(6) The PD-FE makes admission decision based on the steps 4 and 5.

(7) If the RDR from the PE-FE is admitted, the PD-FE would send a resource decision response to install the final admission decision in the PE-FE.

ITU-T NGN architecture [1] presents various example scenarios for different modes of operation, positioning of the SCF and interaction between PD-FEs. The operator is free to implement one or modify based on the requirements. In our work, we plan to have the PD-FE at the edge between access and core network of the session originating end to act as an interface to the SCF and other PD-FEs at the core.

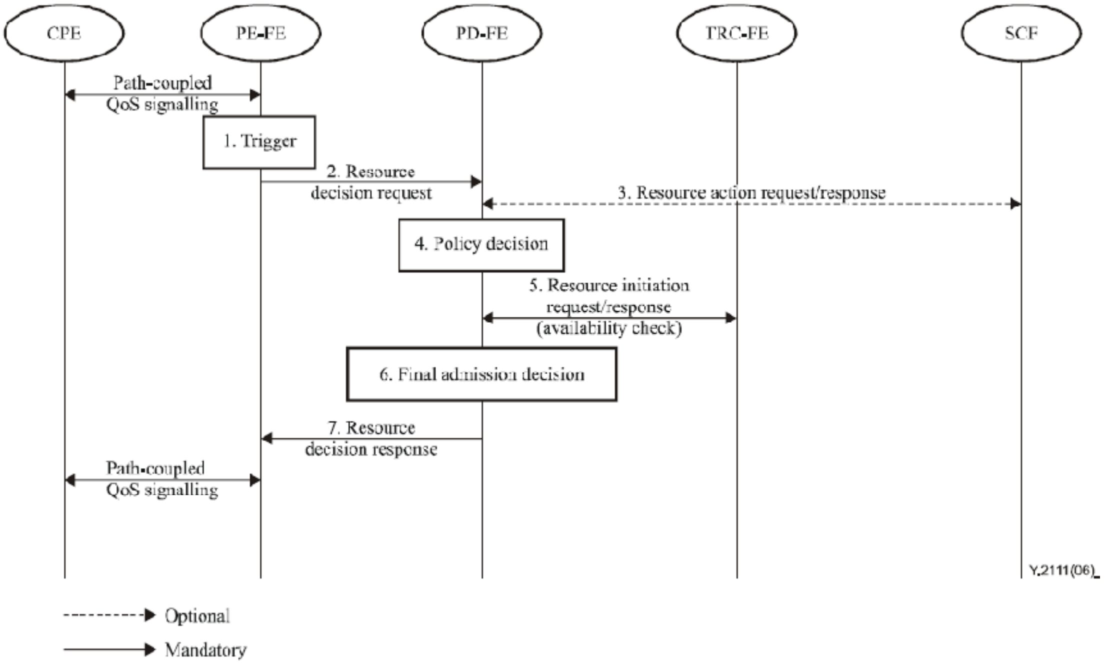


Figure 2.3: The CPE-requested QoS Control Procedure

### 2.1.2 The 3GPP IMS Architecture

IP Multimedia Subsystem [2] proposed by 3GPP for 3G cellular network provides an open architecture with standard interfaces for service developers. The main goal of the IMS was to provide operators with ability to charge the users per-session or per-flow, provide better QoS and enable integration of different services from multiple vendors. The IMS is a collection of functions linked by standardized interfaces. 3GPP allows the implementers the freedom to combine or split a function according to their need. Figure 2.4 shows the general architecture of the IMS. User Equipment (UE) connects to the IMS network via the Gm interface which can be a radio link/WLAN/ADSL link. The remainder of the figure shows one or more user databases called Home Subscriber Servers (HSS) and Subscriber Location Functions (SLF), one or more SIP servers known as Call/Session Control Functions (CSCF), Application Servers (AS), Media Resource Functions (MRF), Breakout Gateway Control Functions (BGCF) and PSTN gateways. The following paragraphs explain the key functions in detail:

**HSS and SLF:** HSS is the central repository for user-related information. It has user-subscription information like location information, security information, user profile information and the S-CSCF allocated to the user. If there are multiple HSS in a network then SLF can be used to locate the HSS for the subscriber. It maps the subscribers to a HSS.

**Proxy-CSCF (P-CSCF):** P-CSCF is the first point of contact in the IMS network for an IMS terminal. P-CSCF acts as a proxy server for the IMS terminal that forwards all the signaling messages to and from the IMS terminal to the IMS network. A P-CSCF is allocated to the IMS terminal during IMS registration. Additionally, P-CSCF can perform security associations with the IMS terminal to offer integrity protection, provide authentication to the user so that the IMS terminal need not authenticate with the rest of the nodes in the IMS network, can verify the correctness of signaling messages originating from a terminal and also can compress/decompress the signaling message to save network bandwidth. P-CSCF can be located either in the home/visited network if the network and the terminal support mobility.

**Interrogating-CSCF (I-CSCF):** The I-CSCF is a proxy server located at the edge of an administrative domain. When a signaling message needs to be forwarded to the network where the destination terminal is located, the I-CSCF acts as the first point of contact in that network. The I-CSCF forwards the messages to the S-CSCF of the destination terminal. The I-CSCF is always located in the home network of the terminal.

**Serving-CSCF (S-CSCF):** The S-CSCF is the central node in the signaling plane. The S-CSCF interfaces with the HSS using DIAMETER to download the user profile settings. The

S-CSCF finds the appropriate next hop server in the destination network where the signaling messages are destined for. The S-CSCF also takes care of applying network policy rules. It also interfaces with Application Servers. The S-CSCF is always located in the home network of the terminal.

**Application Server (AS):** The AS is an entity that hosts and executes services.

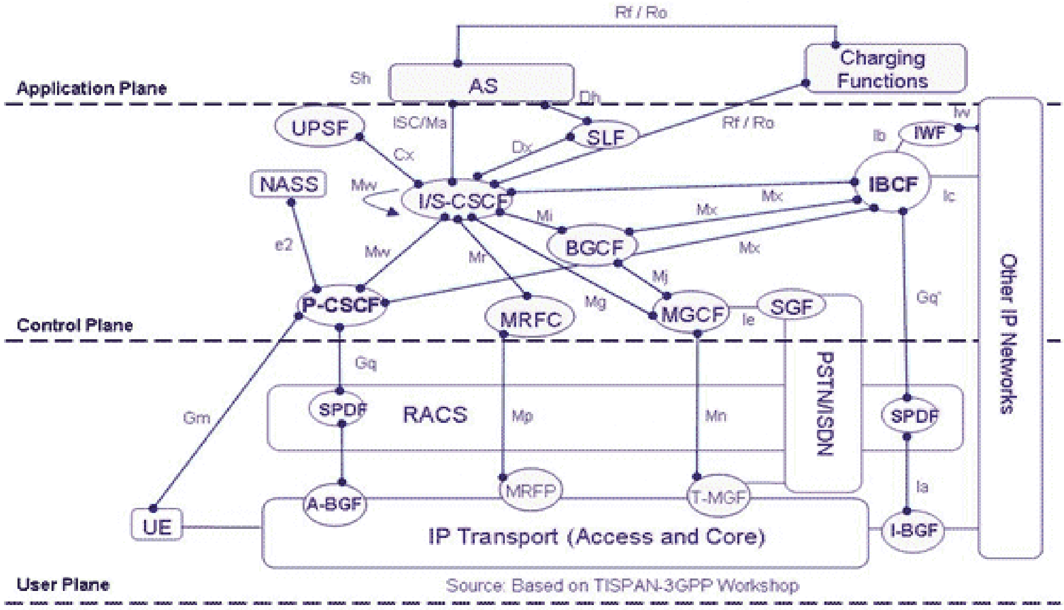
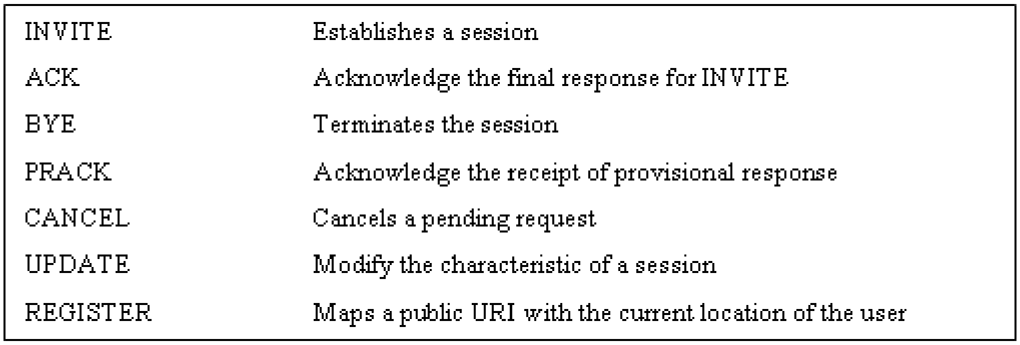


Figure 2.4: The 3GPP IMS Architecture

**Media Resource Function (MRF):** The MRF provides a source of media in the home network. It provides the home network with the ability to play announcements, mix media streams, transcode between different codecs, obtain statistics and do any sort of media analysis.

The IMS uses SIP for its signaling plane. The main idea behind SIP is to deliver the session descriptions to the user once the user has been located in a network. SIP is a session description format independent protocol. The Session Description Protocol (SDP) is the most widely used with SIP for session description. It has session level as well media level information. Information like IP address, port number and codecs to be used for the flow can be encoded in the session description. SIP is based on HTTP so it is a request-response protocol. Clients send requests and servers answer with responses with zero or more provisional responses. SIP users are identified using a SIP URI that is similar to an email address with a username and a domain name. It can also have other parameter chosen by the operator. SIP requests and responses are identified by methods that convey the purpose of the request. Common method types are shown in Figure 2.5.

The IMS users need to register to the P-CSCF before any IMS transaction could begin. The three basic types of transactions that SIP defines are: regular transactions, INVITE-ACK transactions and CANCEL transactions. The type of a particular transaction depends on the request initiating it. Regular transactions are initiated by any request except for INVITE, ACK or CANCEL. In a regular transaction, the destination receives a request and generates a final response that terminates the session with zero or more provisional responses. An INVITE-ACK transaction involves an INVITE transaction, an ACK transaction, zero or more provisional responses and a final response. User terminal generates an ACK on receipt of final 200 (OK) for the INVITE and generates an ACK request, which is not responded to. A CANCEL transaction is initiated by a CANCEL request associated with the previous transaction. A CANCEL transaction is similar to regular one except that the final response is generated by the next hop rather than the destination. Figure 2.6 shows the transactions discussed.



| | |
|---|---|
| INVITE | Establishes a session |
| ACK | Acknowledge the final response for INVITE |
| BYE | Terminates the session |
| PRACK | Acknowledge the receipt of provisional response |
| CANCEL | Cancels a pending request |
| UPDATE | Modify the characteristic of a session |
| REGISTER | Maps a public URI with the current location of the user |

Figure 2.5: SIP Methods

There are several extensions to SIP that are proposed to handle various scenarios like acknowledgements for provisional responses, preconditions for session establishment, event notification to track changes in resource and status, etc. There are SIP and SDP extensions that have been proposed to handle such scenarios. In our work, as we are interested in looking into session establishment and QoS assurance, we would primarily be focusing on the INVITE-ACK transaction with extensions for provisional responses.

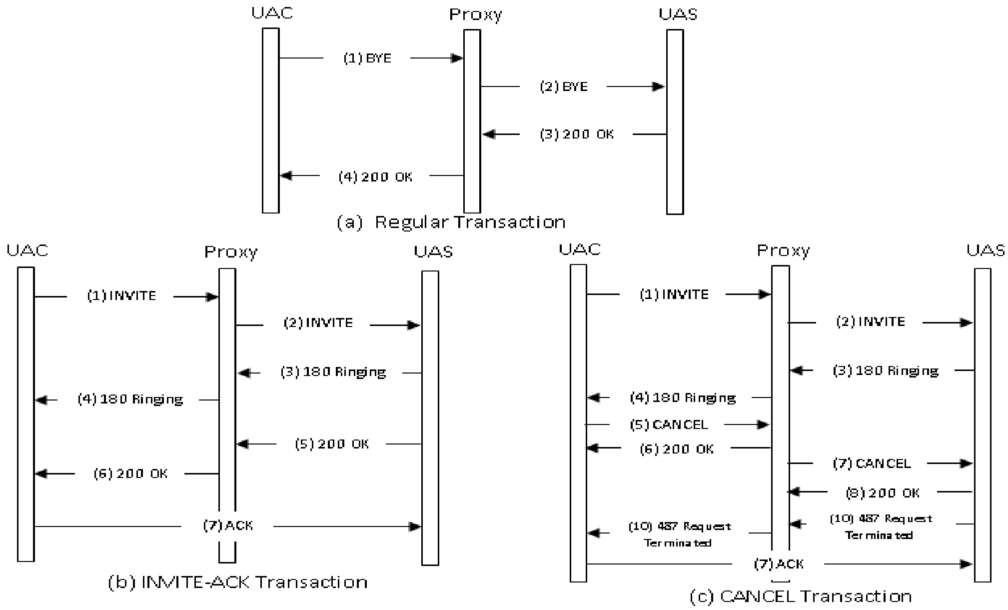


Figure 2.6: SIP Transactions

## 2.2 QoS Architectures in Access Network

### 2.2.1 The WLAN QoS Architecture

The Basic architecture of 802.11a/b/g [5] employs Distributed Coordination Function (DCF) or Point Coordination Function (PCF) to arbitrate the channel access among the stations participating in the network. The fundamental access method of 802.11 MAC is a DCF known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). For a station to transmit, it senses the medium to determine if other station is transmitting. If the medium is not busy, the transmission may proceed. The CSMA/CA algorithm mandates a gap of minimum specified duration exist between two contiguous transmissions. A transmitting station should ensure that the medium is idle for a specified duration before attempting to transmit. If the medium is found to be busy then the station waits for the medium to be idle and starts a random back-off timer. The back-off timer is then decremented every time the medium is idle until it reaches zero and then the station begins transmission. The CSMA/CA protocol is designed to reduce the collision probability between multiple stations accessing a medium, at the point where the collisions most likely occur.

DCF also provides a way to reserve the channel for a duration using Request to Send (RTS) and Clear to Send (CTS) frames that has the duration field specifying the duration for which the channel would be reserved. MAC level ACK is also supported with this mechanism.

PCF uses a Point Coordinator that generally operates at the Access Point (AP). PCF provides contention free access by acting as a polling master to poll stations for transmissions. It starts a Contention Free Period (CFP) to begin polling by acquiring the channel for a defined period of time. Stations transmit with a smaller inter frame duration than the DCF mechanism thereby gaining priority over the frames that wait to contend for the medium. Once the CFP is over, the stations can resume contending for the channel until the beginning of the next CFP.

The aforementioned channel access mechanisms do not provide QoS to the wireless stations in the network. 802.11e [6] was proposed to introduce Quality of Service to the basic architecture. A new function called the Hybrid Coordination Function (HCF) has been included to enhance DCF and PCF with QoS specific mechanisms and frame subtypes. HCF uses two access mechanisms namely, Enhanced Distributed Channel Access (EDCA) and Hybrid Coordination Function Controlled Channel Access (HCCA). EDCA is an enhancement to the DCF based on contention-based channel access. HCCA works on the basis of controlled channel access similar to Point Coordination Function. Stations can obtain transmission opportunities both by using the contention-based channel access called EDCA TXOP and the contention-free channel access called HCCA TXOP or polled TXOP. This function uses a centralized coordinator entity called the Hybrid Coordinator (HC) that is co-located with AP. In a WLAN network that supports QoS, the AP is referred to as QAP and the stations are referred to as QoS STAs. Before presenting the details of the two mechanisms mentioned above, we will briefly discuss about the inter frame space.

**Inter-Frame Space:** The time interval between frames is called the IFS. The IFS values are independent of the stations bit rate and it is fixed for each physical layer. Five different IFSes are defined to provide priority levels for the access to wireless media namely, Short Inter Frame Space (SIFS), PCF Inter Frame Space (PIFS), DCF Inter Frame Space (DIFS), Arbitration Inter Frame Space (AIFS) and Extended Inter Frame Space (EIFS). SIFS is the shortest of the IFSes. SIFS will be used when an STA has seized the medium and keeps it for the duration of the frame exchange sequence that has to be performed. Using the smallest gap between transmissions of a frame sequence would prevent other stations that have to wait for a longer duration for the medium to be idle, from accessing the medium, thus giving higher priority for the frame sequence that is in progress. PIFS is used by a station when operating under PCF to gain priority access to the medium at the start of a Contention Free Period (CFP) or to announce a channel switch frame. DIFS is used by stations operating under DCF to wait for the medium to be idle for this period and their back-off timer have expired before they begin transmission. AIFS has been introduced for EDCA in 802.11e. AIFS is defined for each Access Category (AC) and a QoS station transmitting frames under that AC has to wait for a period of EIFS - DIFS + AIFS (AC) plus any back-off timer before it starts transmission. EIFS is used in DCF and EDCA in case the previous frame resulted in an error. Figure 2.7 shows the different IFSes.

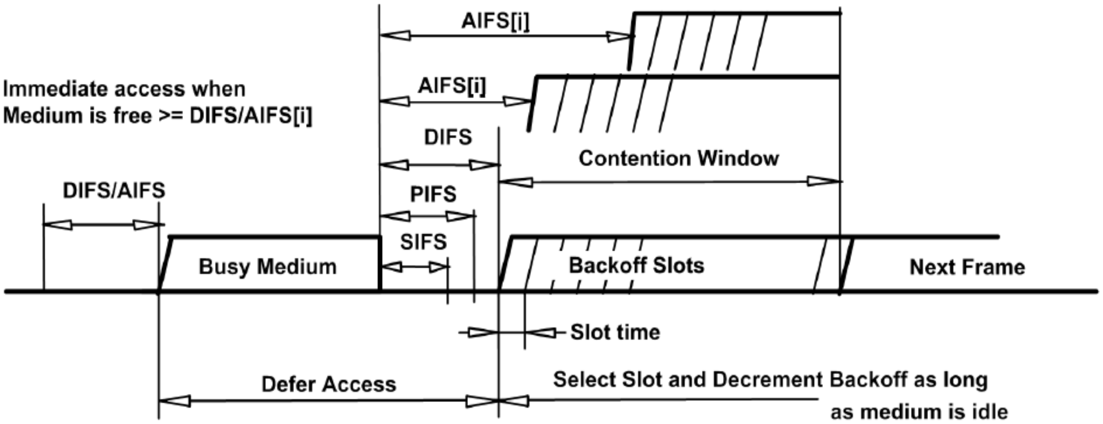


Figure 2.7: Inter Frame Space

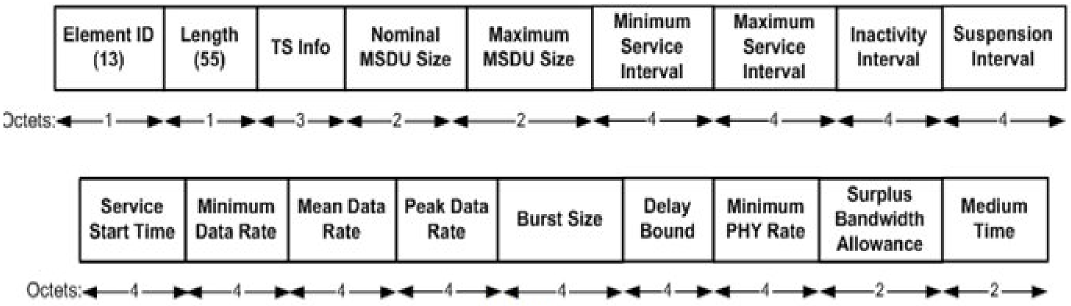
The EDCA mechanism offers prioritization of traffic by differentiating traffic into one of four access categories (ACs) namely, Background traffic (AC_BK), Best effort traffic (AC_BE), Video traffic (AC_VI) and voice traffic (AC_VO) based on User Priority (UP). There are eight UPs supported and each one maps to one of the four ACs as shown in Table 2.1. For each AC an enhanced variant of DCF, Enhanced Distributed Channel Access Function (EDCAF) contends for its TXOP using a set of EDCA parameters from EDCA parameter set element advertised by AP or default values when no such EDCA parameter set element is received. Each AC has different values of the minimum contention window (CW) size, maximum contention window (CW) size, DIFS and AIFS. Traffic prioritization is achieved by having different values for these parameters for different ACs. ACs with higher priority like AC_VO and AC_VI will have lower CW size and smaller AIFS giving them frequent access to the wireless media than the others. Contention within a QoS STA between multiple EDCAF is resolved based on priority so that the EDCAF with lower priority ACs behave as though there was an external collision in the medium. Each AC has a separate queue, CW and AIFS defined for a QBSS by QAP that is advertised in Beacon or probe frames or the defaults specified in [6] are used. The stations resolve contention for channel access between multiple QoS STAs within an AC by choosing a random back-off timer that varies depending on the AC.

Table 2.1: UP to AC Mapping for EDCA

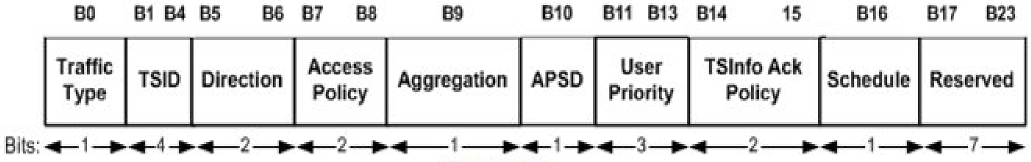
| | **User Priority** | **Access Category** | **Traffic Type** |
|---|---|---|---|
| Low | 1 | AC_BK | Background |
| ↓ | 2 | AC_BK | Background |
| | 0 | AC_BE | Best Effort |
| | 3 | AC_BE | Best Effort |
| High | 4 | AC_VI | Video |
| | 5 | AC_VI | Video |
| | 6 | AC_VO | Voice |
| | 7 | AC_VO | Voice |

The HCCA mechanism offers parameterization of traffic using signaling, scheduling and admission control. HC is a type of centralized coordinator with higher priority to wireless media than the QSTAs thereby having higher priority to transfer MSDUs to non-AP QSTAs and allocate TXOPs to non-AP QSTAs. HC differs from PC in PCF as HCF frame sequences may be used among QSTAs both during the Contention Period (CP) and the Contention Free Period (CFP). HC in QoS AP schedules TXOPs to QoS STAs during CFP using QoS (+) CF-Poll frame (HCCA TXOP) and optionally during Controlled Access Phase (CAP) in CP using QoS (+) CF-Poll frame (Polled TXOP). HCCA method defines a super frame containing a contention-free period followed by a contention-period. HCCA gains control of the media as needed to send QoS traffic to QSTAs and to issue QoS (+) CF-Poll frames by waiting for shorter between transmissions than the STAs using the EDCA procedures. The duration value set in the frame exchange sequence reserves the medium to permit completion of current sequence. When the HC needs to access the WM to start CFP or issue TXOP, it senses the media and if it were found idle for one PIFS then the HC would transmit a frame with the duration id set to cover the CFP or TXOP. Between every non-final frame exchange sequence during a TXOP, the holder of TXOP would wait for one SIFS period. HC would reclaim the wireless media after the duration of PIFS after the TXOP.

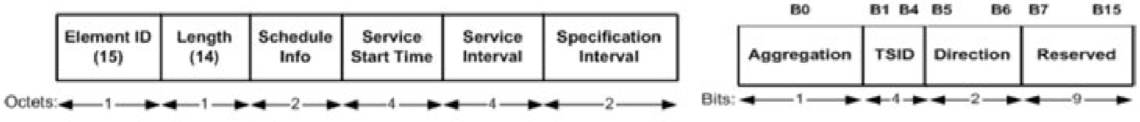
There are two admission control mechanisms in HCF namely, contention-based access and controlled access. Contention based admission control is used for ACs for which the WLAN network requires admission control in EDCA mode. QAP would indicate such ACs by setting the Admission Control Mandatory (ACM) field in the EDCA parameter set element that is used to indicate other EDCA parameters for the AC. If a QSTA does not support admission control, it has to use the EDCA parameters of the lower priority AC that does not require admission control. An ADDTS request frame needs to be transmitted by a QSTA to the HC in order to request admission of traffic in any direction employing an AC that requires admission control. The ADDTS request frame would contain a TSPEC element containing the set of parameters that define the characteristics and QoS expectations of a traffic flow. TSPEC element allows a QSTA to specify an extensive set of parameters as shown in Figure 2.8(a). The fields that are unspecified can be set to 0 by the QSTA. The ADDTS request frame would contain the UP associated with the traffic and would have the EDCA set as the access policy. The QAP associates the received UP to the appropriate AC as per Table 2.1. The QAP can either accept or reject the request based on the scheduling and resource state. If the QAP accepts the request it would include the medium time in the TSPEC element in the ADDTS response frame.



(a) TSPEC Element



TS Info Field



(b) Schedule Element

Schedule Info Field

Figure 2.8: TSPEC & TS Info Elements

In controlled channel access, the HC is responsible for granting or denying a Polling Service (PS) to a Traffic Stream (TS) based on the parameters in the associated TSPEC. If the TS is admitted, the HC is also responsible for scheduling the access based on the negotiated TSPEC parameters. The HC should not modify or tear down the admitted TS unless requested by the QSTA or at the expiry of the expiration timer. Once the TS has been admitted, the scheduler would service the non-AP QSTA during an SP. An SP is a contiguous timer that starts at fixed intervals of time specified in the Service Interval field in the Schedule Element during which a set of one or more downlink frames and/or one or more polled TXOPs are granted to QSTA. A minimum set of TSPEC parameters such as Mean Data Rate, Nominal MSDU size, Minimum PHY rate, Surplus bandwidth Allowance, and at least one of Maximum Service Interval or Delay Bound are required for the HC to calculate the service schedule. If any of the above parameters are not non-zero in the ADDTS request frame, then the HC may replace the unspecified parameters with non-zero values and admit the stream or reject the stream. The service schedule is communicated to the QSTA via the Schedule Element in the ADDTS response frame. The HC may update the service schedule at any time and send it out.

Figure 2.8 (b) shows the schedule element. The TSID and Direction fields in the TSPEC element identify the TS. Optionally, the TCLAs element can be used to classify the incoming MSDUs to specific TSes. It is sent with the ADDTS request and response frames. Each MAC frame can be associated to a TS using the Traffic Identifier (TID) in the QoS control field which can take values from 0 to 15. The first eight values 0 to 7 are directly associated with the User Priority and map to one of the four Access Categories. The values from 8 to 15 if present in a frame are mapped to the corresponding TSPEC (TSID) defined for that STA. The format of an 802.11e MAC frame and QoS Control subfield are shown in Figure 2.9.

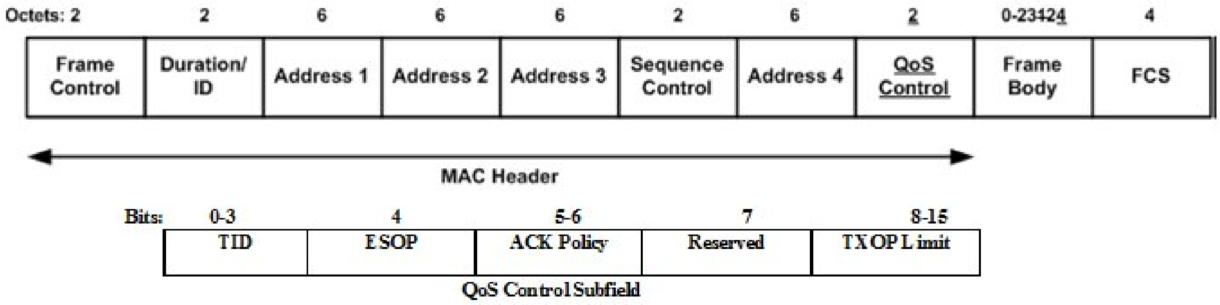


Figure 2.9: The 802.11e MAC Frame Format

### 2.2.2 The WiMAX QoS Architecture

WiMAX is a QoS-based connection-oriented protocol defined in IEEE 802.16 [3]. A WiMAX Base Station (BS) does the scheduling, management and admission control of all the connections from the Subscriber Stations (SS). The WiMAX MAC layer is divided into three sub-layers:

(1) The Service-specific convergence sub-layer (CS) that classifies external data and associates them to the appropriate connections identified by Connection Identifiers (CID) and Service Flow Identifiers (SFID). This may also include additional services like Payload Header Suppression (PHS). Various CS specifications are provided to interface with different higher layer protocols (Ethernet, IP, ATM, etc).

(2) The MAC Common Part Sub-layer (CPS) that provides core MAC functionality of system access, bandwidth allocation, connection establishment, and connection maintenance.

(3) The Security Sub-layer that provides authentication, security key exchange and encryption.

The 802.16 MAC defines Service Flow as a unidirectional flow of MAC service data units (SDU) on a connection that is provided a particular QoS.

A service-specific CS resides on top of the MAC CPS. Currently, there are two CS specifications provided: ATM CS and Packet CS. The ATM CS is a logical interface that associates different ATM services to MAC CPS SAP. It classifies the incoming ATM cells and performs PHS if required and delivers the CS PDUs to the appropriate MAC SAP. The ATM CS PDU contains the ATM CS header and the payload. As ATM connections can be Virtual Path (VP)-switched, where all Virtual Circuits (VC) within an incoming VP are mapped to an outgoing VP, or Virtual Circuit (VC)-switched, where the input VCI/VPI are switched individually to output VPI/VCI, the ATM CS differentiates these two types of connections during PHS. A classifier is defined as a set of matching criteria, such as VPI and VCI and a reference CID applied to each ATM cell entering the ATM CS. When an ATM cell matches the criteria, it is delivered to the MAC SAP identified by the CID. The packet CS that resides on top of MAC CPS is responsible for classification of higher layer PDUs into the appropriate connections with optional suppression of the payload header. The packet CS is used for transport of all packet-based protocols such as IP, PPP and Ethernet. The Packet CS PDU contains the packet SDU in the payload and an optional PHS Indicator field. A classifier is a set of protocol specific matching criteria along with a classifier priority and a reference CID applied to each packet entering the packet CS. If a packet matches the specified matching criteria then the packet is delivered to the appropriate CID. Service flow characteristics of a connection identify the QoS for that connection and several classifiers may be matched to a service flow. Classifier priority can be used to order the application of classifiers to the packet. Choice of specific classification capabilities is dependent on implementation.

The 802.16 MAC can operate in Point-to-Multipoint (PMP) or Mesh mode. We will be focusing on the PMP mode. Each SS has a 48-bit MAC address that uniquely identifies it during the initial ranging and authentication with the BS. The MAC is connection-oriented with a 16-bit CID to identify the connection. SSes perform network entry procedures while entering the Wimax network during which two pairs (uplink and downlink) of management connections (basic and primary) are established with the BS. A third pair of management connection (secondary) may be optionally set up for managed SSes. The BS MAC and SS MAC use the basic connection to exchange short, time-urgent MAC management messages. The primary management connection is used to exchange longer, more delay-tolerant MAC management messages. The secondary management connection is used to transfer delay-tolerant, standards based (DHCP, TFTP, SNMP, etc) messages. For bearer services, the BS sets up the connections once the SS gets registered based on the provisioning of information. There can be a total of up to 64,000 CIDs.

In PMP mode, the wireless link operates with a centralized Base Station (BS). The downlink from the BS to the SSes operates on a PMP basis and the BS is the only transmitter in this direction so it operates without having to coordinate with other stations except for the overall time division duplexing (TDD) that may divide time into uplink and downlink transmission periods. 802.16 PHY supports Frequency Division Duplex (FDD) and TDD modes. It uses a frame size of 0.5, 1 or 2 ms [4]. This frame is divided into physical slots for the purpose of bandwidth allocation and identification of PHY transitions. In the TDD variant, the uplink sub-frame follows the downlink sub-frame. In the FDD variant, both the uplink and downlink sub-frames are coincident in time but are carried on separate frequencies. The downlink is generally a broadcast link and transmissions to specific stations are identified in a MAC message called the Downlink MAP (DL-MAP), where the burst start times for a specific SS are given. Figure 2.10 shows the downlink sub-frame with the DL-MAP for the current frame followed by the uplink-MAP (UL-MAP) for the specified time in future. The SSes check the CID in the received PDUs and retain only those addressed to them. The SSes share the uplink to the BS on a demand basis. Based on the class of service, the SS may be issued continuing rights to transmit or it can be granted the rights based on the request from a user.

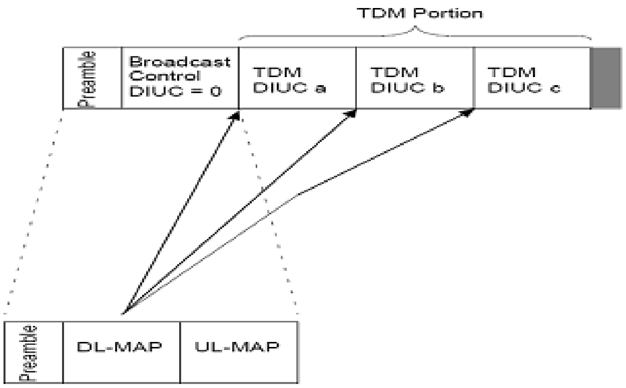
There are four different uplink scheduling mechanisms defined to control contention between different user connections and are implemented using unsolicited bandwidth grants, polling and contention procedures. For the purposes of mapping to services on SSes and associating varying levels of QoS, all data communication is in the context of a connection. The principle mechanism for providing QoS is to associate packets traversing the MAC interface into a service flow identified by a connection. A service flow is a unidirectional flow of packets that is associated with the QoS parameters for the PDUs that are exchanged on the connection. Service flows exist both in the uplink and downlink direction and all service flows are associated with a 32-bit SFID. Connections are associated with service flows to provide a reference against which to request bandwidth.

MAC PDU is the data unit exchanged between the MAC layers of the BS and its SSes. Each PDU would begin with a fixed length MAC header followed by variable length payload and an optional CRC. There are two header formats defined distinguished by the HT field namely, Generic MAC header and Bandwidth Request header. Except for bandwidth request MAC PDUs that have no payloads, MAC PDUs contain management messages or convergence sub-layer data. Figure 2.11 shows the MAC PDU and the two header types. There are five types of MAC sub-headers that are supported out of which three are most commonly used. The three most commonly used sub-headers are:

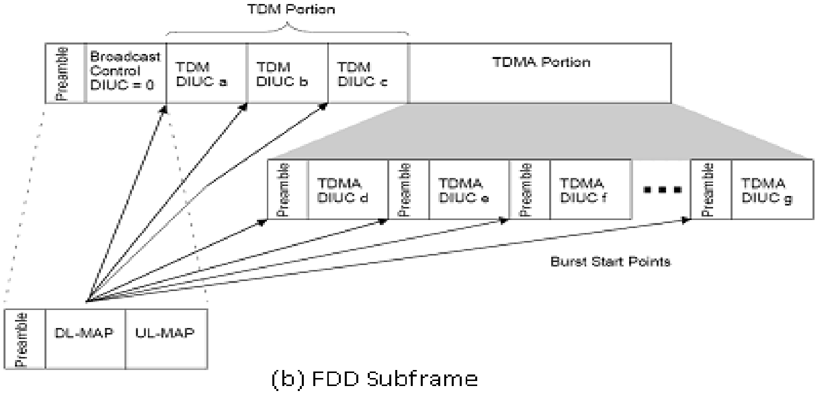
(1) Grant Management Subheader used by an SS to convey bandwidth management needs to the BS. This is a per-PDU sub-header and if present, it follows the generic MAC header in a PDU.

(2) Fragmentation Sub-header contains information about the presence and position of any fragments in the PDU. This is also a per-PDU sub-header and if present, it follows the generic MAC header in a PDU.

(3) Packing Sub-header used to indicate the packing of multiple SDUs in to a single PDU. This is a per-SDU sub-header.



(a) TDD Subframe



(b) FDD Subframe

Figure 2.10: Downlink Sub-frame Structure

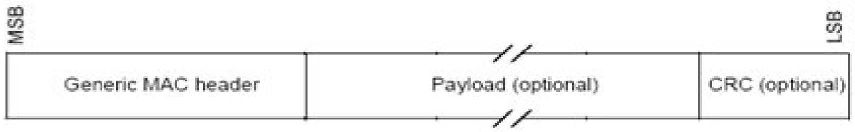
Scheduling services represent the data handling mechanisms supported by the MAC scheduler for data transport on a connection. Every connection is associated with a service that defines the QoS parameters for the connection. The service and its parameters are selected during connection establishment. Outbound transmission scheduling selects the data for transmission in a particular frame and is performed by the BS in the downlink and by the SS in the uplink. The major factors that are taken in to consideration for scheduling in addition to those that are dependent on implementation are such as, scheduling service for the specified service flow, values assigned for the service flow, availability of data for transmission and the capacity of the granted bandwidth.

Uplink request/grant scheduling is performed by the BS to provide an SS with opportunities to request bandwidth for uplink transmissions and to grant the requests. The scheduling service and the QoS parameters selected for a service flow enables the BS scheduler to know the expected throughput and latency needs and hence the BS can provide polls and/or grants at appropriate times. Four scheduling services are provided:

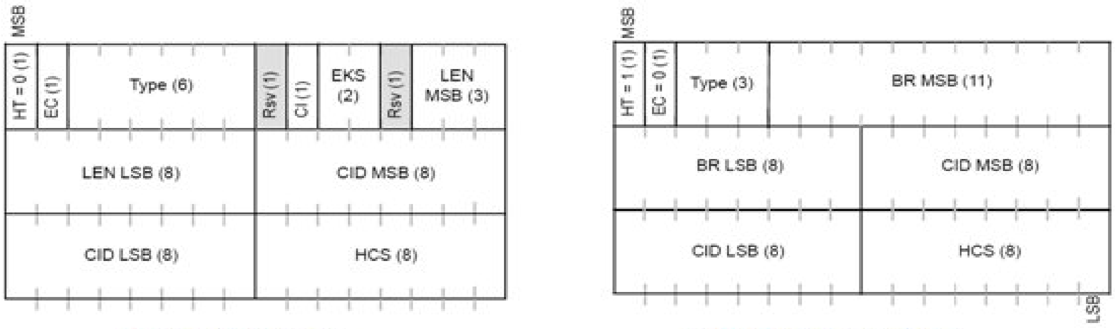
(1) Unsolicited Grant Service (UGS): This service is designed to support real-time service flows that generate fixed size data packets on a periodic basis such as T1/E1 and VOIP without silence suppression. The BS offers transmission opportunities to the SS at periodic intervals determined by the Maximum Sustained Traffic Rate parameter specified for this service. With this service, the overhead and latency of an SS bandwidth request is eliminated and thus it is well suited for real-time needs. An SS subscribed to this service for a connection is prevented from requesting bandwidth for that connection during any contention request opportunities. The grant management sub-header is used to send the status of UGS connections back to the BS. The Slip Indicator (SI) bit of the grant management subheader is set if the connections' transmit queue depth is exceeded. The mandatory QoS flow parameters defined for this service are Maximum Sustained Traffic Rate, Maximum Latency, Tolerated Jitter and Request/Transmission policy. The Minimum Reserved Traffic Rate parameter, if present, would be set to the same value as Maximum Sustained Traffic Rate.

(2) Real-Time Polling Service (rtPS): This service is designed to support real-time service flows that generate variable size data packets on a periodic basis such as MPEG videos. The BS offers periodic unicast request opportunities to let an SS specify the size of the grant. The BS would offer periodic unicast request opportunities even if the previous requests are unfulfilled. Therefore an SS subscribed to this service for a connection is prevented from using contention request opportunities for that connection. The

parameters defined for this service are Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Maximum Latency and Request/Transmission policy.



(a) MAC PDU Format



(b) Generic MAC Header

(c) Bandwidth Request Header

Figure 2.11: 802.16 MAC PDU

(3) Non-Real-Time Polling Service (nrtPS): This service offers unicast polls on a regular basis, which is usually of the order of a second or less. An SS subscribed to this service for a connection can also use contention request opportunities and unsolicited Data Grant in addition to the unicast request opportunities. The parameters defined for this service are Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Traffic Priority and Request/Transmission policy.

(4) Best Effort Service (BE): This service is designed for best effort traffic. An SS subscribed to this service for a connection can use contention request opportunities. With this service, an SS can also use unicast request opportunities and unsolicited Data Grant if available in addition to contention request opportunities. The parameters for this service are Maximum sustained Traffic Rate, Traffic Priority and Request/Transmission policy.

SSes use the request mechanism to request bandwidth in the uplink. The requests can be standalone using Bandwidth Request header or piggybacked using the Grant Management Sub-header. As the physical conditions can change, the requests only consider the number of bytes needed to carry the MAC header and payload and not the PHY overhead. The requests can be transmitted during any uplink allocation except during the initial ranging period when the SSes initialize with the BS to perform network entry procedures. The bandwidth requests can be incremental or aggregate. The type field in the bandwidth request header indicates if the request is incremental or aggregate. The piggybacked requests have to be incremental as there is no type field in the Grant Management Sub-header. Due to the self-correcting nature of the request/grant protocol, SSes occasionally use aggregate request and similarly, aggregate requests are required to avoid collisions for broadcast/multicast requests. Bandwidth requests reference individual connections while the bandwidth grants are addressed to the SS's basic CID. Therefore no explicit reason is given when the SS receives shorter transmission opportunity than it originally requested for. Unicast polling of SS is achieved by allocating data grant that defines a period in the UL-MAP to the SS's basic CID. The SS can use this data grant to request bandwidth for any of its connections. When the BS does not have sufficient bandwidth to poll the SSes individually, it uses multicast or broadcast polling directed to multicast/broadcast CID. Only SSes requiring bandwidth use the transmission opportunity to request bandwidth. Collisions can be resolved by truncated binary exponential back-off with the initial back-off window and the maximum back-off window controlled by the BS. The BS advertises the values to all the SSes. Another method of polling is to use the Poll Me (PM) bit in the Grant Management Sub-header. The SSes with active UGS connections can set this bit in the MAC PDU and let the BS know that the non-UGS connections needs to be polled. The BS uses the regular mechanisms to poll the SS.

### 2.2.3 PBB-TE Architecture

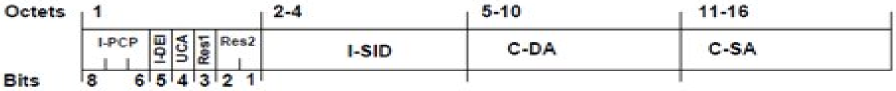
IEEE 802.1ah [7] provides the Provider Backbone Bridge amendment to the MAC layer definition of the Virtual Bridged Local Area Networks (802.1ad – VLAN). The basic standard for delivering Virtual LAN (VLAN) service is 802.1Q where the VLAN is identified using a 12-bit VLAN ID in the VLAN Tag [20]. Although 4096 VLANs are sufficient in the enterprise network this does not scale well for the service provider and also the provider needs to make sure that customer tags do not overlap with one another in their network. 802.1ad Provider Bridges were introduced to solve this problem by adding another level of VLAN Tag called S-VLAN to the original VLAN Tag that was renamed as Customer VLAN (C-VLAN) Tag. This offers scalability as well as separation of customer VLANs in the service provider network. There are two potential problems with this approach:

(1) Scalability – The 12-bit S-VLAN ID can only create 4096 different service VLANs in the provider network.

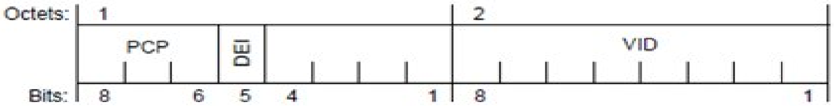
(2) MAC Addresses – It is necessary that the customer MAC addresses are visible in the provider network in order to make the forwarding decision. This creates security concern for the customers and heavy burden on the provider to maintain the long list of MAC addresses that could change frequently.

The 802.1ah standard specifies the operation of Provider Backbone Bridge Networks (PBBN) that addresses the issues seen with Provider Bridge Networks (PBN).

A PBBN consists of a set of Backbone Edge Bridges (BEBs) interconnected by a set of Backbone Core Bridges (BCBs) using Backbone VLANs (B-VLAN). B-VLANs are similar to S-VLANs and are identified using a 12-bit VLAN ID. A BEB encapsulates the customer frames, VLAN tags and data of customer frames by adding Backbone Source MAC (B-SA) and Destination MAC (B-DA) addresses, a service instance identifier called “I-Tag” and B-VLAN identifier called “B-Tag”. The format of the two additional tags I-Tag and B-Tag are shown in Figure 2.12. The I-Tag encapsulates the customer MAC addresses and introduces a 24-bit Backbone Service Identifier (I-SID) that allows the service provider to scale up to $2^{24}$ services instances in the PBBN. By introducing B-SA and B-DA, the customer network is completely hidden from the service provider core. An Ethernet frame from a Provider Bridge Network (Q-in-Q) or a customer network with a C-VLAN tag at UNI (BEB) is encapsulated along with the Backbone MAC addresses, I-Tag and B-Tag that is used by the PBBN switches to forward the frames. The BCBs are just provider bridges that read the B-Tag to forward the frames inside the PBBN. The B-Tag format is the same as the S-VLAN Tag used in the Provider Bridge Networks (802.1ad). As the customer VLAN (C-VID and S-VID) is completely hidden in the backbone network, the provider can use overlapping values for the B-VID. The service identifier (I-SID) provides an additional layer of service differentiation than that provided by B-VID.



(a) I-TAG



(b) B-TAG

Figure 2.12: PBBN Tags

802.1ay [11] called PBB – Traffic Engineering (TE) is a further enhancement to 802.1ah that enables provisioning of Ethernet tunnels with QoS, resiliency and OAM characteristics. The switches still behave fundamentally the same as the traditional Ethernet switches, forwarding data to the intended destination based on the forwarding tables, with the difference that the forwarding tables are not populated using the traditional MAC learning mechanisms. Instead, it is provided directly by the management plane or control plane. This results in a prescribed predetermined path through the network. This path is called as Ethernet Switched Path (ESP). A PBB-TE region is formed by the set of PBBs that allow an external agent control over the subset of VIDs. The PBB-TE/ESP-TE service is then achieved by encapsulating the customer frame to the appropriate ESPs. The ESP Traffic Engineering (ESP-TE) tunnels can be provisioned statically or using control plane signaling or through an external agent. An ESP is a unidirectional tunnel identified by a three tuple:

<ESP-SA, ESP-DA, ESP-VID>

where,

- ESP-SA is the Backbone MAC address of the backbone port on the source BEB
- ESP-DA is the Backbone MAC address of the backbone port on the destination BEB
- ESP-VID is the Backbone VLAN ID

An ESP can be configured to provide different types of service using point-to-point ESP where the 3-tuple identifies individual MAC addresses or point-to-multipoint ESP where the 3-tuple identifies the source MAC and a group MAC for the destination address [11]. ESP-VID for the forward and reverse path for an ESP point-to-point tunnel can have different VIDs. Only the ESP-DA and ESP-VID is used to make the forwarding decisions. ESP-VID is used to identify the path to a particular destination thus allowing up to $2^{12}$ different paths through the network to a given destination.

In [11] and [12], the GMPLS extensions for provisioning of ESPs in a PBBN have been discussed. When provisioning an ESP using GMPLS, the ESP-DA and ESP-VID are carried in the generalized label object and are assigned hop-by-hop using the same label within a domain similar in operation to transparent optical networks. Papadimitriou [14] discusses the GMPLS extensions to support the bandwidth profile parameters specified by MEF 10.1. [15] MEF 10.1 introduces the ingress and egress bandwidth profiles which include a set of traffic parameters applicable to a sequence of service frames referred to as bandwidth profile parameters:

(1) Committed Information Rate (CIR): is the average rate up to which the network is committed to transfer frames and meets its performance objectives.
(2) Committed Burst Size (CBS): defines the maximum number of information units available for the burst of frames sent at the interface speed to remain CIR-conformant.
(3) Excess Information Rate (EIR): is the average rate in excess of CIR up to which the network may transmit frames.
(4) Excess Burst Size (EBS): defines the maximum number of information units available for the burst of frames sent at the interface speed to remain EIR-conformant.
(5) Color Mode (CM): indicates if the color-aware or color-blind property is applied to a bandwidth profile
(6) Coupling Flag (CF): allows the choice between the two modes of operation of rate enforcement algorithm.

MEF 10.1 discusses other traffic parameters like Frame Delay and Frame Delay variation performance for an ESP, which are measured based on the ingress to the ESP at a BEB to the egress from the ESP at the destination BEB. These parameters are not defined hop-by-hop and are not handled in Papadimitriou [14].

## 2.3 QoS Architectures in the Core Network

### 2.3.1 Differentiated Services

Differentiated Services (Diffserv) architecture provides QoS guarantees on an aggregate of flows [16]. Diffserv can be used to provide service differentiation in a network for different classes of traffic. The ingress router classifies the incoming traffic into classes and also performs the policing of the traffic. The traffic classes are called Behavior Aggregates. A classified packet is marked using a set of markings known as Differentiated Services Code Point (DSCP). The markings can be stored in the DS field [17] in the IP header of a packet. Based on the marking in a packet, a router in a Diffserv domain treats the packet according to the scheduling and queueing rules associated with its class.

The set of controls such as, queue selection, scheduling priority for transmission out of the router, and packet dropping priority is known in the Diffserv architecture as Per Hop Behavior (PHB). Each PHB is designed so as to satisfy the SLA associated with the particular class of traffic. The following four types of PHB have been defined:

(1) Expedited Forwarding (EF) class – This class is used to support applications with lower delay and jitter thereby having higher priority at the processing nodes.

(2) Assured Forwarding (AF) class – This class is defined to support data applications with assured bandwidth requirements. The packets submitted to this class will be forwarded with a high probability as long as the class rate submitted by the user does not exceed a predefined contracted rate. AF class has four sub classes namely, AF1x, AF2x, AF3x and AF4x, where x denotes the decreasing order of drop priority from 1to 3.

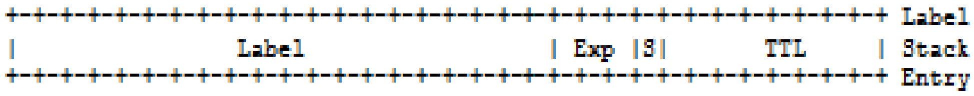
(3) The Default PHB class – This class is ambiguously defined with no committed resources and yet cannot be starved by other classes. This class could be supported with some nominal bandwidth allocation.

(4) Class Selector (CS) PHB – This class is defined to support backwards compatibility with IP precedence setting in a packet.

Diffserv does not specify the actual scheduling and queueing algorithms required to support each PHB.

### 2.3.2 Multi Protocol Label Switching

Multi Protocol Label Switching – Traffic Engineering (MPLS-TE) [18] provides the capability to setup traffic-engineered tunnels over the MPLS network through which aggregate traffic trunks with specific bandwidth requirements can be routed. MPLS-TE mechanisms provide capabilities to associate the incoming packets to traffic trunks, identify their constraints and find a path through the network that satisfies the constraints (constraint-based routing). A 4-byte label header as shown in Figure 2.13 with 20-bit label identifying a tunnel or a connection is attached to the incoming packet at the ingress to the MPLS network. Routers interior to the MPLS network then associate the packet to a connection based on the label. Thus, the scheduling decision and queue selection for the packet is done based on the constraints associated with a connection.



```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ Label
|                Label                  | Exp |S|       TTL     | Stack
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+ Entry
```

Label: Label Value, 20 bits Exp: Experimental Use, 3 bits S: Bottom of Stack, 1 bit TTL: Time to Live, 8 bits

Figure 2.13: MPLS Header

MPLS provides capability to setup a connection using either the OSPF next hop routing or explicit routing. Bandwidth is allocated in every router along the path taken by a connection through the MPLS network and service differentiation is achieved using the 3-bit EXP field shown in the MPLS header. The incoming packets are generally policed at the ingress edge of the MPLS network to ensure that the traffic is conformant and a scheduler in each router makes sure that the packets on a specific connection are transmitted according to their priority and requested quality of service.

In order to support Diffserv over MPLS, the DSCP settings in the IP header needs to be mapped to the 3-bit EXP field. There are two options available depending on the number of PHBs required:

(1) If the network supports up to 8 PHBs, then each DSCP can be mapped to a unique EXP value. An LSP whose PHB is inferred from the EXP bits are called E-LSP, where E stands for EXP inferred.

(2) If more than 8 PHBs are supported, then they cannot be mapped to a unique EXP value. To solve this issue, the label is used to convey the PHB and the EXP field can be used to convey the dropping priority. Thus, the PHB is determined from both the label and EXP value. Such an LSP is called L-LSP, where L stands for Label inferred. A router associates a specific label with a PHB at connection setup.

## 2.4 Next Steps in Signaling (NSIS)

Next Steps in Signaling [21] suite of protocols is a framework to support signaling information of a data flow along its path in the network. This protocol is simplified by assuming that the path taken by the data flow is computed independently of signaling and signaling messages simply interact with the nodes along the data path. Additionally, it is limited only to handle unicast flows. This protocol is similar to RSVP with two generalizations, namely, an end-to-end deployment of NSIS protocol is not always required, and signaling can be used for purposes other than just QoS reservation. In view of this, the signaling protocol stack is divided into a generic lower layer and layer specific to each signaling application.

The NSIS protocol is structured into two layers, namely, the NSIS transport layer and the NSIS signaling layer. The NSIS transport layer is responsible for the transport of signaling messages. This transport layer is independent of the signaling application. General Internet

Signaling Transport (GIST) is an example of an NSIS transport layer protocol. The NSIS signaling layer is responsible for defining message formats and sequences specific to a particular signaling application. The NSIS Signaling Layer Protocol (NSLP) is an example of a signaling layer protocol. Transport layer protocols only operate between adjacent NSIS Entities (NE) and end-to-end aspects are left to the upper layer. Any two NSIS entities that communicate directly are said to be in a "peer relationship". When there is a signaling message ready to be sent from a NE, it is given to transport layer along with the information about the flow that takes care of forwarding it to the next hop. The next hop here does not necessarily mean next "IP hop".

The state related to a data flow is installed and maintained on the NE along the data flow path through the network and it is not mandatory for all the nodes along the data path to have NEs. Either one or both of them can store some state information about the other but there is no assumption that they establish a long-term relationship. NSIS supports two basic paradigms for resource reservation signaling namely, Path-coupled signaling and Path-decoupled signaling. In Path-coupled singling, the signaling messages are routed only through the NEs that are on the data path. In Path-decoupled signaling, the signaling messages are routed to NEs that are not assumed in the data path but are aware of it. The current framework only concentrates on the path-coupled case. Signaling can be triggered by user applications, network management, network events etc. In NSIS, a wider variety of possible signal exchanges such as end-to-end, edge-to-edge and end-to-edge are supported. With NSIS, the signaling layer protocols in the NEs store per-flow state information. Signaling messages can be used to install, modify, refresh or read this information from the network elements. NSIS also provides the applications with the functionality of associating signaling messages pertaining to one or more data flows of an application session. This allows the support of scenarios where the data flows belonging to an application session have to be managed and treated together. New flows can be added and old ones can be deleted during the lifetime of a session.

QoS NSLP [22] is a protocol that enables establishing and maintaining of states at the nodes along the path taken by a data flow for the purpose of providing forwarding resources for that flow. The operation of QoS NSLP is independent of the QoS model (QoSM) of the underlying network where the QoS reservation is signaled. However, the information that is carried by the QoS NSLP message is specific to a QoSM and it is used to establish and maintain QoS reservation states. The term QNE is used to refer to the NE that supports QoS NSLP. The NSLP module in a QNE delivers this information to the Resource Management Function (RMF) specific to a QoSM which would then make use of it to take policy and admission control decisions. Examples of QoSM include Differentiated Services, Integrated Services and Y.1541. The QoS NSLP does not deal with the behavior of the RMF or the information related to each QoSM that it carries but it does provide interoperability required at the signaling protocol level to support various QoSM.

QNI is the term used to refer to the QNE that initiates a QoS resource reservation request and QNR is the term used to refer to the last NE in the sequence of QNEs that receives a reservation request. There are four message types defined in QoS NSLP:

(1) RESERVE – This is the only message that can be used to manipulate the QoS reservation state in QNEs. It can be used to create, modify, refresh and remove such states.

(2) QUERY – This message can be used to request information along the data path without making a reservation. The information obtained can then be used to make reservations or admission control at QNEs. The QUERY message does not change the reservation state in the QNEs.

(3) RESPONSE – This message is used to convey the result of previous RESERVE request or QUERY messages. This can include explicit confirmation for the resource request signaled in a RESERVE message, or a response to a QUERY message or an error code if a QNE or QNR is unable to process the message.

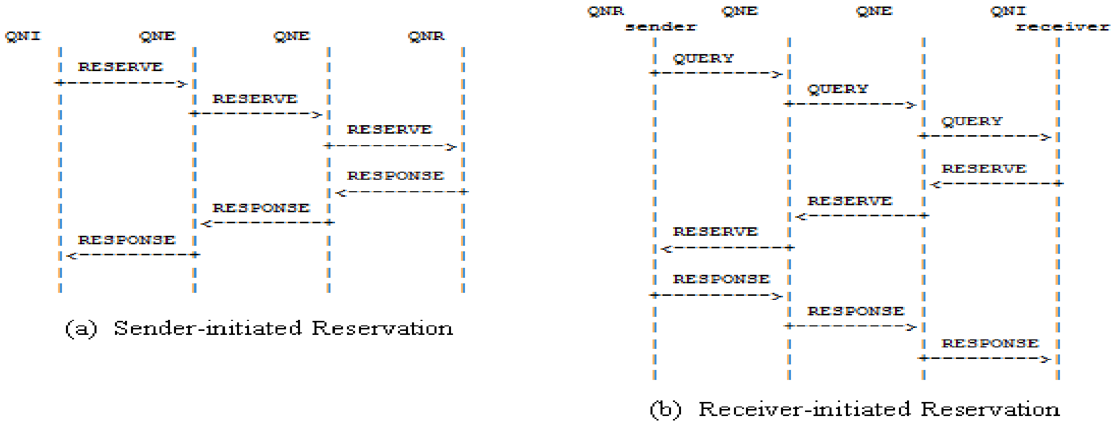
(4) NOTIFY – This message is also used to convey information to a QNE. They differ from RESPONSE messages in that they are asynchronous and need not refer to any particular state or previously received message.

The QoS NSLP is based on a soft state peer-to-peer refresh mechanism. So, the QoS NSLP messages are sent peer-to-peer and each QNE considers its upstream or downstream peer to be the source of each message. Each protocol message has a common header identifying the message type and various flag bits. QoS NLSP messages contain three types of objects namely, Control Information objects, QoS Specification (QSPEC) objects and Policy objects. Control information objects carry general information related to QoS processing such as sequence numbers and information on whether a response is required. QSPEC objects describe the resources that are required, which depends on the QoSM being used. They can also carry control information used by the RMF to process these messages. Policy objects contain data used to authorize reservation of resources. The QoS NSLP supports both sender-initiated and receiver-initiated reservations.

For a sender-initiated reservation, the RESERVE messages travel in the same direction as the data flow that is being signaled for, i.e., from the QNI to the QNR. To make a reservation, the QNI constructs a RESERVE message containing a QSPEC object specific to the QoSM describing the required QoS parameters. This message is passed to the NTLP to be delivered to next QNE. It is delivered to the QoS NSLP in the next QNE, which examines the message and passes it to the RMF for policy and admission decisions specific to the QoSM. Then it performs appropriate actions based on QSPEC object in the message. The QoS NSLP then generates a new RESERVE message to be forwarded to the next QNE. Similar processing is performed in all the QNEs up to the QNR. Once the QNR processes the RESERVE message, it would generate a RESPONSE if there were a request for the same in the RESERVE message. The RESPONSE is forwarded peer-to-peer along the reverse path to the QNI. The QSPEC that is generated by the QNI is called the initiator QSPEC and it can be changed or modified by a QNE at the edge of an administrative domain. A Local QSPEC can be generated at the ingress QNE that the QNEs in the domain can understand and the initiator QSPEC is then encapsulated with that local QSPEC. On the egress, the local QSPEC is removed and the message is passed on to the next QNE with initiator QSPEC.

For receiver-initiated reservations, RESERVE messages travel in the opposite direction i.e. QNI is at the receiver side of the data flow. To make a receiver-initiated reservation, the

QNR constructs a QUERY message, which can contain a QSPEC object specific to the QoSM. The QUERY message in this case needs to have a flag called RESERVE-INIT set. This QUERY message is used to trigger a reservation from the QNI so the request for a RESPONSE is not set in the QUERY. The QUERY message can be used to gather information such as the resource availability along the path to the QNI, which is carried in the QSPEC object. The receiver detects the RESERVE-INIT flag set in the QUERY message and it constructs a RESERVE message using the information received in the QUERY. The RESERVE is then forwarded peer-to-peer along the reverse path that the QUERY message travelled. The QNR, on receipt of the RESERVE message, generates a RESPONSE if a request for a RESPONSE is included in the RESERVE message. Figure 2.14 shows the examples of sender-initiated and receiver-initiated reservation approach.



(a) Sender-initiated Reservation

(b) Receiver-initiated Reservation

Figure 2.14: Examples of Reservation

The QoS NSLP supports two different types of bidirectional reservations by binding two sender-initiated reservations one for each direction of data flow and by binding a sender-initiated reservation for data flow in forward direction with a receiver-initiated reservation for data flow in the reverse direction. When binding two sender-initiated reservations, RESERVE messages from QNIs on either end can be bound by setting the BOUND_SESSION_ID object in both the messages to each other's SESSION_ID. In the second case, the QNI on one end sends a RESERVE message for reserving resources in the forward direction and a QUERY message to initiate reservation in the opposite direction.

These two messages can be bound using a BOUND_SESSION_ID object. Binding reservations can help while tearing down the sessions. When one session gets torn down, the other one can also be torn down. Similarly, aggregate reservations are also supported by binding multiple RESERVE message pertaining to different flows.

A generic QSPEC template is provided in [23] to allow interoperability between various QoSMs. The QSPEC is made of QSPEC objects and parameters. There are four QSPEC objects defined namely, QoS Desired, QoS Available, QoS Reserved and Minimum QoS. QoS Desired is used to describe the resources the QNI desires to reserve and is a read-only object that is always included in RESERVE message. The parameters included in this object are never over-written. QoS Available is a read-write object that is used to collect information on the resources available along the path. Each QNE is expected to inspect this object and if the resources available are less than what a parameter has currently then the QNE updates the parameters with the current values. This object reflects the bottleneck of the resources currently available on the path. QoS Reserved is a read-only object used to reflect the resources reserved. Minimum QoS is used to define a range of acceptable QoS levels by including both the desired QoS value and the minimum acceptable QoS in the same message. Each QNE updates the QoS Available object and if it drops below the value of minimum QoS then the reservation fails and it is aborted.

There are three flags that are used in QSPEC processing namely, M flag, N flag and E flag. The M flag is set by the QNI for each QSPEC parameter it populates that must be interpreted by downstream QNEs. The N flag is set by the QNEs that do not support a QSPEC parameter. If the parameter is marked with M flag then the reservation fails else the N flag is set against the QSPEC parameter and reservation proceeds. The E flag is set by the QNE if it supports the parameter but cannot meet the resources requested. This causes reservation failure. QSPEC objects contain QSPEC parameters. There are a number of common QSPEC parameters defined and additional parameters can be defined for the specific QoSM. Some important QSPEC parameters are listed below:

(1) The Traffic Model (TMOD) parameter is a mandatory parameter to be included in the initiator QSPEC by the QNI and is mandatory for all the downstream QNEs to

interpret. The TMOD parameter has four sub-parameters: Rate (r), Bucket Size (b), Peak Rate (p) and Minimum Policed Unit (m). All four of the sub-parameters must be included with the TMOD and can be used to describe the traffic source. First three parameters are 32-bit IEEE floating point numbers and the last one is a 32-bit integer in network byte order. Rate and Peak Rate are expressed in bytes/second. The parameters b and m are expressed in bytes. A single TMOD parameter can be used to signal parameters for a single rate token bucket and for cases where two sets of token bucket parameters are needed (e.g. Diffserv AF traffic); two TMOD parameters could be used.

(2) The Path Latency parameter is expressed as a 32-bit unsigned integer. Latencies are average values reported in units of one microsecond. Path latency includes propagation, packet processing and queueing delay. A QNE with a resolution of less than one microsecond should report the unused portion as zeroes. The total latency can be as high as $2^{32} - 2$. If the sum of the latency across different elements exceeds $(2^{32} - 2)$ then the advertised delay should be reported as indeterminate = $2^{32} - 1$. A QNE that does not support this parameter should raise the N flag and can add a lower bound of the delay to this or leave this component as is.

(3) The Path Jitter parameter is expressed as a combination of four statistics represented by 32-bit unsigned integers describing the jitter distribution. Path Jitter comprises STAT1 that represents variance; STAT2 representing 99.9 percentile, STAT3 representing minimum latency and STAT4 is reserved. The path jitter is a combination of the above four values. Jitter stats are reported in units of one microsecond and a QNE that does not support this resolution should report the unused portion as zeroes. The total jitter computed across various elements in the path cannot exceed $(2^{32} - 2)$. If it does, then the value of jitter is set to the mean indeterminate value = $2^{32} - 1$. A QNE that does not support this parameter raises the N flag and either leaves the parameter as is or adds a lower bound to this value. A QNE that cannot compute its local path jitter should set its path jitter to the indeterminate value.

(4) The Path Loss parameter is expressed as 32-bit IEEE floating point number. The PLR (is this PLP or PLR) is reported in the units of $10^{-11}$. A system with resolution less than this must report the unused portion as zeroes. The total PLR across all the QNEs should

be no more than $10^{-2}$. In the event of the value exceeding this, the value is set to a mean indeterminate PLR = $10^{-1}$. A QNE that does not support this parameter raises the N flag and either leaves the parameter as is or adds a lower bound to this value. A QNE that cannot accurately predict its local PLR should set its value to the mean indeterminate value.

(5) The Path Error parameter is expressed as 32-bit IEEE floating point number. The PER is reported in the units of $10^{-11}$. A system with resolution less than this must report the unused portion as zeroes. The total PER across all the QNEs should be no more than $10^{-2}$. In the event of the value exceeding this, the value is set to a mean indeterminate PLR = $10^{-1}$. A QNE that does not support this parameter raises the N flag and either leaves the parameter as is or adds a lower bound to this value. A QNE that cannot accurately predict its local PLR should set its value to the mean indeterminate value.

(6) The Y.1541 QoS class parameter indicates the Y.1541 QoS class that the reservation is signaled for. The values are from 0 through 7.

Some other parameters defined are slack term – to describe the difference between the desired delay and delay obtained using the bandwidth reservation, excess treatment – to describe the actions if the traffic is in excess, preemption/defending/restoration priorities for path preemption and restoration, PHB class parameter to indicate the PHB class for which the reservation is triggered and DSTE class parameter. The parameters Path Latency, Path Jitter, Path Loss and Path Error are cumulative parameters so an individual QNE cannot decide whether in the desired path characteristic is available and hence cannot decide whether reservation fails. So, when these parameters are included in QoS Desired object, the QNI should include a QoS Available object with these values populated for its outgoing link (and optionally incoming link) to facilitate collecting this information. Every QNE would then update the corresponding values in the QoS Available object. The composition rule for path latency, loss and error is the summation with a clamp on the maximum value. The composition function for path jitter is the combination of various statistics describing path jitter with a clamp on the maximum value.

### 2.4.1 Y.1541 QoSM

Y.1541 QoSM [24] is based on the ITU-T recommendation Y.1541 network's QoS classes and related signaling requirements. Y.1541 proposes grouping of services into QoS classes defined according to the desired QoS performance objective. The classes group objectives for one-way IP packet delay, IP packet delay variation, IP packet loss ratio, etc supporting wide range of user applications. The QoS classes apply to a packet flow where Y.1541 defines a packet flow as the traffic associated with the given connection or connectionless stream having the same source address, destination address, class of service and session identification. The characteristics of the QoS classes are summarized in Table 2.2.

Table 2.2: Y.1541 QoS Classes

| **QoS Class** | **Application Type** | **Mean Delay Upper Bound (in ms)** | **Delay Variation (in ms)** | **Loss Ratio** |
|---|---|---|---|---|
| Class 0 | Real-time, highly interactive | 100 | 50 | $10^{-3}$ |
| Class 1 | Real-time, interactive applications | 400 | 50 | $10^{-3}$ |
| Class 2 | Highly interactive transaction data | 100 | U | $10^{-3}$ |
| Class 3 | Interactive transaction data | 400 | U | $10^{-3}$ |
| Class 4 | Low loss only | 1000 | U | $10^{-3}$ |
| Class 5 | U | U | U | U |
| Class 6 | High loss sensitive applications | 100 | 50 | $10^{-5}$ |
| Class 7 | High loss sensitive applications | 400 | 50 | $10^{-5}$ |

U - Unspecified

Two additional QSPEC parameters are defined for Y.1541 QoSM:

(1) TMOD Extension parameter – It has two sub-parameters Peak Bucket Size (Bp) represented as 32-bit floating-point number and Maximum Packet Size (M) represented as a 32 bit unsigned integer.

(2) Restoration Priority parameter – Represents the urgency with which a service requires successful restoration under failure conditions.

In addition to the common QSPEC parameters defined, these new parameters can also be optionally used while signaling QoS reservations in Y.1541 QoSM.

### 2.4.2 Resource Management in Diffserv QoSM

Resource Management in Diffserv (RMD) adds admission control to Diffserv networks and allows networks external to Diffserv network to reserve resources in the Diffserv network. The RMD QoS model [25] specifies the RMD specific NSLP QSPEC for expressing the resource requirements in a suitable form for simple processing by the nodes internal to the Diffserv domain. Scalability is achieved in RMD domain by limiting the edge nodes of the Diffserv domain to handle the per-flow reservation states and by having the interior nodes store only the aggregated state or no state at all.

The RMD QoSM supports two basic admission control modes, namely, reservation-based admission control and measurement-based admission control. In the reservation-based method, each QNE interior node of the RMD domain only stores one reservation state per class. The ingress QNE aggregates the individual QoS requests into PHB traffic classes and signals the changes in the class reservations as required. The resources quantified in terms of bandwidth units, are requested dynamically per PHB and reserved on demand in all nodes from the ingress to the egress. The measurement-based algorithm, on the other hand, continually monitors the traffic levels and available resources. It admits flows that are within what is available at the time of request. There is no need to store reservation states or to release the resources in the QNE interior nodes.

In RMD QoSM, apart from the QNI and QNR nodes, the other important nodes are the QNE ingress and QNE egress nodes. These nodes form the edges of the RMD domain. These also store and maintain the NTLP and NSLP state information. All the RMD interior nodes are NSLP aware but they are NTLP stateless. Also, depending on the admission control mode supported, the interior nodes are either NSLP reduced state nodes (reservation-based method) or NSLP stateless nodes (measurement-based method).

Figure 2.15 shows the basic RMD QoSM signaling. A RESERVE message constructed by the QNI with an initiator QSPEC is sent towards the QNR. When it reaches the QNE ingress nodes in the path, an RMD QSPEC is constructed based on the initiator QSPEC. This RMD QSPEC is then sent towards the egress QNE through the interior nodes. QNE interior nodes in the path processes this intra-domain RESERVE` message and check the resources available using one of the admission control methods. The original RESERVE message is sent towards the egress QNE, bypassing the interior nodes of the domain. Once the RESERVE` reaches the egress QNE and if the reservation is successful in each interior QNE, then a RESPONSE` is generated by the egress QNE and sent towards the ingress QNE. The RESERVE message is then forwarded towards the QNR.

RMD QoSM only supports sender-initiated reservations. RMD QoSM object combination carried by RESERVE message only contains QoS Desired object and the RESPONSE message only contains QoS Reserved object. The QoS Desired and QoS Reserved QSPEC objects consist of the following parameters:

(1) Bandwidth - It carries the peak data rate to be reserved
(2) PHB class - It carries the DSCP class for which the reservation is signaled.
(3) Admission Priority – It specific setup priority which is used for preemption.

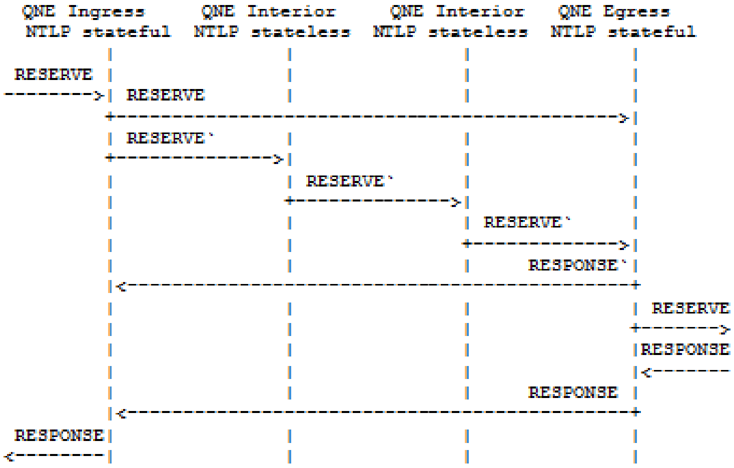


Figure 2.15: Basic RMD QoSM Signaling

Apart from the QSPEC parameters, the traffic handling directives contains other fields, namely, Per Hop Reservation (PHR) container and Per Domain Reservation (PDR) container. PHR container contains traffic handling directives for intra-domain communication and reservation. PDR container contains traffic handling directives that is needed for edge-to-edge communication.

# Chapter 3

# QoS Interworking, Signaling and Mapping of QoS Parameters

In this chapter, we present the IMS signaling flows for the push and the pull modes and discuss the interactions between QoS architectures in the reference network. We also present the QoS signaling details for two different approaches for QoS reservation in the reference network, namely, local segmentation QoS reservation and end-to-end QoS reservation. Finally, we conclude this chapter by showing the mapping of QoS parameters across the various architectures in the reference network.

## 3.1 IMS Signaling Flow

In this section, we present the detailed IMS message exchange diagrams for the two modes of operation namely, push mode and pull mode. We show the participating entities and the signal exchanges across those entities. We focus only on the network entities in the access and the edge portion of the reference network, as the IMS functions are co-located with these entities according to our proposed reference network. The signaling exchanges are presented for the case where the peer is another CPE. It can be easily adapted to apply to other cases such as when the peer is an application server or a gateway to a different network, such as a PSTN. Also, for simplicity, we have assumed that the type of destination access network is similar to that of the originating access network.

### 3.1.1 IMS Signaling for the Push Mode

Figure 3.1 shows the message exchanges when the Push mode is used. We assume that the QAP/SS has already completed its initial ranging procedures with the BS and it has the basic connections setup to transport the signaling messages. Similarly, it is also assumed that the QSTA has completed its required security association with QAP. The dotted lines show the QoS signaling that happens as a part of a session signaling. There is a minor change to the

Push mode defined in ITU-T NGN architecture. QoS parameters are not pushed by the RACF to all the transport functions, as the TXOP grants in WLAN segment cannot be issued by the QAP without a QSTA requesting for it. So, in this case we assume that the Station Management Entity (SME) in the QSTA converts the SDP QoS parameters to the TXOP ADSPEC requests and sends a request to the QAP. The details at every step of the message flow are as follows.

(1) When the user initiates an application in the customer premises network, an INVITE is sent from the WLAN QSTA to the P-CSCF. It has SDP parameters describing the details about the multimedia sessions (codec, etc) that the QSTA wishes to establish.

(2) Once the SIP INVITE is received by the P/S-CSCF co-located with the BRAS, it checks for the user's service subscription from the PDF. Also, it sends a provisional (100 Trying) response message back to the QSTA.

(3) The PDF has the user's subscription details and any session specific details (such as filters for the session that the application server has to be notified about). It performs the user's subscription verification using the details and sends a response back to the P-CSCF.

(4) Once the user's service subscription is verified, the S-CSCF finds the destination domain that the INVITE needs to be sent to and it forwards the same. The INVITE gets forwarded to the callee through the I-CSCF, S-CSCF and P-CSCF in the destination network.

(5) The callee, on receipt of the INVITE, goes through the SDP offer details and frames a 183 Progress Response message along with its own choice of CODEC and session details. The P-CSCF in the destination network receives the progress response message and maps the SDP session parameters to the network QoS details. It queries the RACF co-located with the BRAS for user's network access subscription. Once the RACF sends a positive response, the progress response is forwarded to the P-CSCF in the originating network.

(6) The P-CSCF in the originating network receives the progress response and maps the SDP session parameters to the network QoS details. The P-CSCF then queries the RACF co-located with the BRAS for user’s network access subscription.

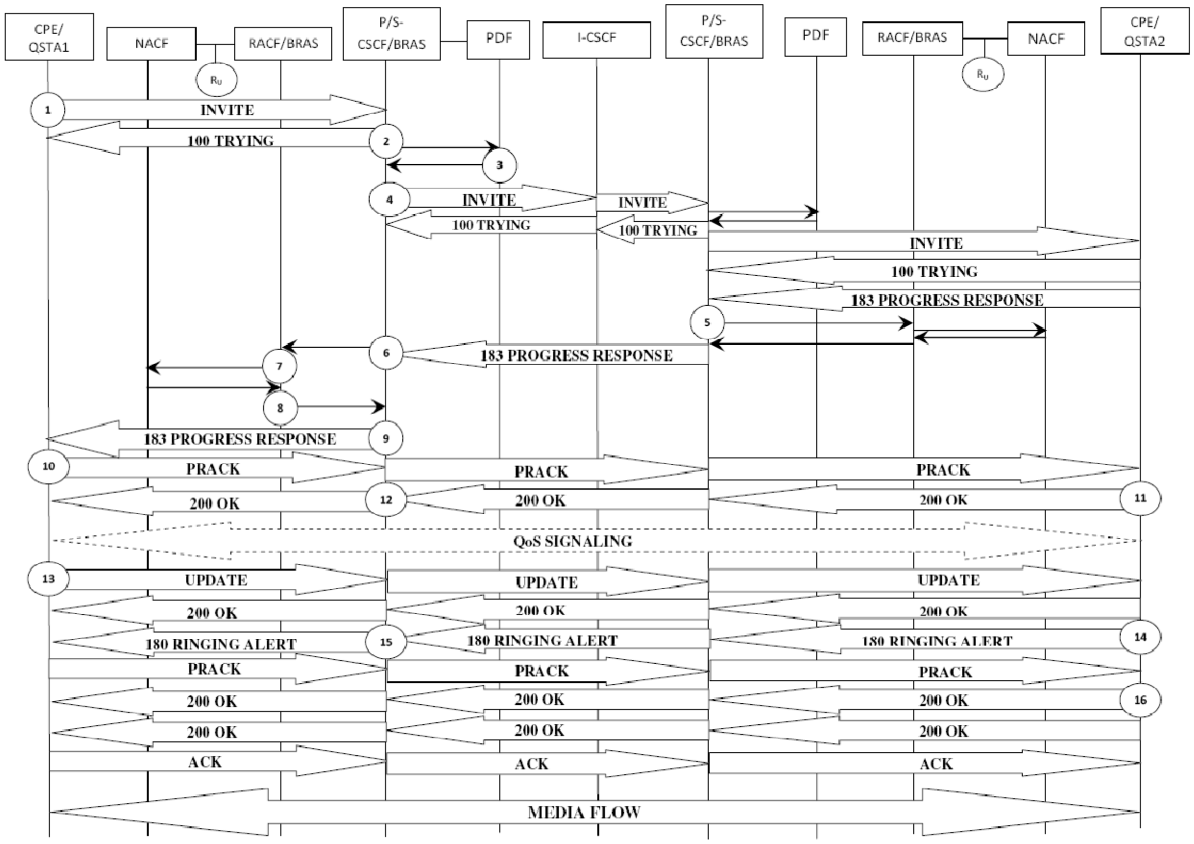


Figure 3.1: IMS Signaling flow for the Push Mode

(7) The RACF in BRAS, which is the ASN-GW for the WiMAX network, queries about the user’s network access subscription from an NACF server using RADIUS or DIAMETER.

(8) If the user’s network access subscription permits establishing a connection with the required QoS, then the result is conveyed to the P-CSCF.

(9) On receipt of a response from RACF, the progress response message is forwarded to the CPE. If the reservation/authorization fails at the RACF, the P-CSCF would send a 488 (Not Acceptable Here) to the caller CPE and send a session termination to the callee.

*Note:* If QoS authorization fails at the destination network, progress response will not be forwarded to the originating network. The P-CSCF at the destination network will handle the error.

(10) The caller CPE sends a PRACK message for the Progress Response message that it receives. If the callee had included any SDP offer in the Progress Response, then the caller can either choose to send a modified SDP offer with PRACK or just send a PRACK if it accepts the offer. If there is a new offer in the PRACK message, the P-CSCF has to perform steps 6 through 9 again; otherwise it just forwards the PRACK message to the callee.

(11) The callee sends a 200(OK) as a response to the PRACK. At this point, both the callee and the caller will have negotiated the SDP parameters and the P-CSCF will have obtained network authorization for the requested resources (following steps 6 through 9). Thus, the P-CSCF at the destination network notifies the RACF in the BRAS (optionally) to initiate QoS reservation in its access network. The P-CSCF then forwards the OK message to the P-CSCF in the originating network.

Note: The initiation of QoS reservation at the destination network depends upon the QoS reservation approach used.

(12) The P-CSCF in the originating network, on receipt of the OK message, initiates the QoS reservation. Once the QoS reservation succeeds, the P-CSCF forwards the 200(OK) to the caller.

(13) On receipt of the 200(OK), the application at the QSTA notifies the SME, which then initiates a TXOP request to the AP. Since the resources are pre-approved (in step 12), the QSTA sends an UPDATE message notifying the callee about the resource reservation at its end.

(14) The callee waits for the resource reservation at its end to be complete while it verifies the resource reservation at the caller end using the UPDATE message. Once both are satisfied, it alerts the user about the call. The callee also sends a 180 (Ringing) alert to the caller.

(15) The P-CSCF forwards the message to the caller and the caller sends a PRACK to acknowledge the receipt of the alert.

(16) A final 200(OK) is sent to the caller when the callee responds to the call. The P-CSCF instructs the RACF to commit the resources and the media flow begins.

### 3.1.2 IMS Signaling for the Pull Mode

Figure 3.2 shows the IMS message exchange for the Pull mode operation. The dotted lines show the QoS negotiation phase that takes place during the session signaling. Assumptions similar to those made in Pull mode about the initial ranging procedures for the SSs and association with the QAP for the QSTAs can be made for this mode also. The details at every step of the signaling exchange are presented as follows.

(1) When a user initiates an application at the QSTA, the application sends an INVITE message to the P-CSCF. It includes SDP parameters with the details about the multimedia sessions (Codec, etc) that the CPE wishes to establish.

(2) The P/S-CSCF in the BRAS queries the PDF to verify the user’s service subscription.

(3) The PDF has the user’s subscription details and any session specific details (such as filters for the session that the application server has to be notified about). It verifies the user’s service subscription.

(4) Once the user’s service subscription is verified, the S-CSCF finds the destination domain that the INVITE is intended for and forwards the same. The INVITE message gets forwarded to the callee in the destination domain through the I-CSCF, S-CSCF and P-CSCF in that domain.

(5) On receipt of the INVITE, the callee goes through the SDP offer details and frames a 183 Progress Response along with its own choice of CODEC and session details. The P-CSCF in the destination network receives the progress response message and maps the SDP session parameters to the network QoS details. It queries the RACF co-located with the BRAS for user’s network access subscription. Once the RACF sends a positive response, the progress response is forwarded to the P-CSCF in the originating network.

(6) The P-CSCF in the session originating network receives the Progress Response message and maps the SDP session parameters to the network QoS details. The P-CSCF also queries the RACF for user’s network access subscription.

(7) The RACF, co-located with the BRAS, which is also the ASN-GW for the WiMAX network, gets the user's network access subscription information from an NACF server using RADIUS/DIAMETER. It is then used to determine if the user's subscription allows establishment of the connection required for the application session. The RACF informs the P-CSCF of the outcome of the operation with an optional authorization token.

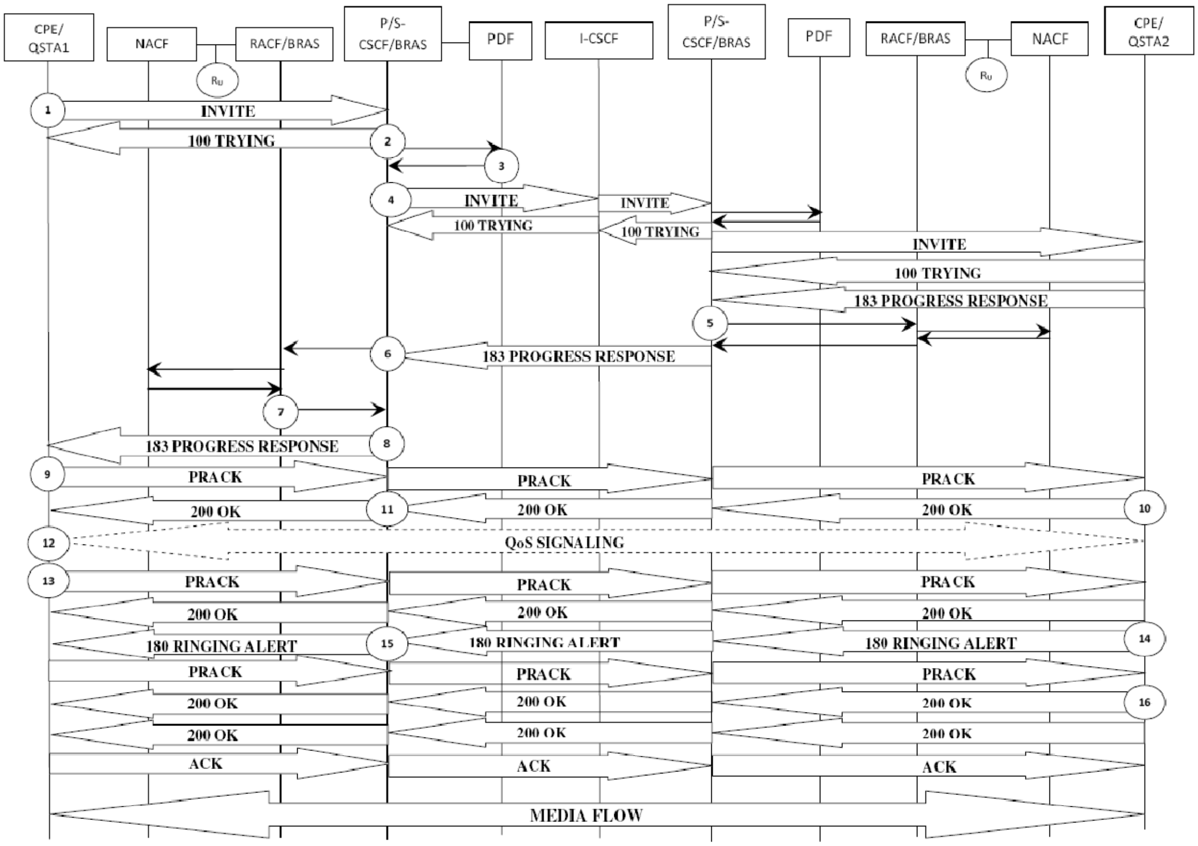


Figure 3.2: IMS Signaling flow for the Pull Mode

(8) If the answer from the RACF is positive, then the P-CSCF forwards the 183 Session Progress Response message with a description of the QoS parameters required for the session and an optional authorization token to the caller. The WLAN QAP, which acts as a residential gateway, intercepts the SIP message and records the authorization token (if present).

(9) The caller, on receipt of the progress response, responds with a PRACK with/without SDP modified offer. For simplicity, we assume that there is no modification. The P-CSCF then forwards the same to the callee. The P-CSCF at the destination network can attach the network authorization token obtained from the RACF with this message and forward it to the callee.

(10) The callee, on receipt of the PRACK, prepares a 200(OK) message to be sent to the caller. The callee then (optionally) starts QoS reservation.

Note: The initiation of QoS reservation at the destination network depends upon the QoS reservation approach used.

(11) The P-CSCF at the originating access network forwards the OK message to the caller.

(12) On receipt of the OK message, the caller (QSTA) initiates QoS reservation. At this stage, the QoS reservation signaling happens from the originating CPE to the destination.

(13) Once the QoS reservation succeeds, the caller CPE/QSTA sends an UPDATE message notifying the callee about the resource reservation at its end.

(14) The callee waits for the resource reservation at its end to be complete and checks the UPDATE message for the resource reservation at the caller side. Once the reservation status is confirmed, it alerts the user about the call and sends a 180 (Ringing) alert to the caller.

(15) The P-CSCF at the originating end forwards the message to the caller, which then sends a PRACK to acknowledge the receipt of the alert.

(16) A final 200(OK) is sent to the caller when the callee responds to the call. The P-CSCF then instructs the RACF to commit the resources and the media flow begins.

## 3.2 QoS Interworking in the Reference Network

QoS interworking between WLAN and WiMAX segments has been extensively studied and various results have been proposed. Gakhar, Gravey and Leroy [8] propose a mapping module to be implemented in the Radio Gateway (QAP/SS) to map the traffic parameters pertaining to an application flow in the WLAN segment to the ones in the WiMAX segment. Two kinds of mappings namely, prioritized mapping and parameterized mapping have been proposed. In prioritized mapping, a one-to-one correspondence between the traffic priorities in the WLAN segment and the traffic classes in the WiMAX segment has been defined. In the case of per-flow parameterized mapping, the authors have identified four generic traffic classes based on the traffic type and its QoS requirements. Then, they propose a mapping between the TSPEC QoS parameters defined in 802.11e and the QoS parameters defined in 802.16 that characterize the identified classes.

A similar approach has been suggested in Prasath, Raghu and Ma [9] where the four WLAN EDCA Access Categories are mapped to the different service classes of WiMAX. The authors briefly discuss how the traffic parameters defined for the TSPEC map to those defined for the WiMAX QoS classes, so that the QAP can directly transform the approved TSPEC to a service flow addition request in WiMAX. There are other related works where the mapping between the WLAN and the WiMAX QoS classes are defined based on the DSCP settings in the IP header.

Table 3.1: WLAN EDCA ACs to WiMAX Mapping

| WLAN Access category | Designation | Service Class of WiMAX |
|---|---|---|
| AC_BK | Background | Best Effort (BE) |
| AC_BE | Best Effort | Non-real time Polling Service (NrtPS) |
| AC_VI | Video, VOIP | Real-time Polling Service (RtPS) |
| AC_VO | Voice, T1 | Unsolicited Grant Service (UGS) |

In our work, we borrow the proposed mechanisms to map the WLAN and the WiMAX QoS parameters. Table 3.1 shows the mapping between the WLAN EDCA access categories and WiMAX QoS classes. Table 3.2 shows the mapping of the 802.11e and 802.16 traffic parameters. This table only shows the parameters that can be mapped one-to-one from WLAN to WiMAX. Some parameters are provided in one and not in the other. For instance, Jitter is provided for WiMAX connections and not for WLAN. Mapping of such parameters can be based on absolute values based on the demand for the application. An approximate mapping has been achieved based on the definition of traffic parameters in [3] and [6]. The aforementioned proposed literature ([8] & [9]) on WLAN and WiMAX QoS interworking deal primarily with mapping a single flow in WLAN to a single flow in WiMAX. In order to achieve scalability in terms of the number of flows (WiMAX connections) supported at the SS (QAP) and the number of connections per SS supported by the BS, aggregation of multiple 802.11e traffic streams into one 802.16 connection could also occur at the QAP (WiMAX SS). The details of this aggregation and scheduling are beyond the scope of this work.

Also, in order to achieve scalability, scheduling and admission control at the edge of the customer premises network (WLAN's QAP in our case), a Residential Gateway (RG) can be deployed at the QAP, which, in addition to functioning as the Access Point would also handle the session level signaling (IMS messages). The details of the IMS session handling have been adopted from [10]. The QAP, acting as an RG, intercepts the SIP signaling messages from and to the User Terminal (UT). When a response arrives for an IMS INVITE message with the media requirements described using SDP, a component in RG translates it to the WLAN QoS parameters and checks with the Call Admission Control (CAC) module in the QAP for the resources before forwarding it to the UT. If enough resources are not available, then an IMS CANCEL message is sent to the destination network to cancel the previous request and an IMS 500 (Server Internal Error) is sent to the original terminal behind the RG.

Table 3.2: 802.11e & 802.16 Traffic Parameter Mapping

| **Traffic Parameters in 802.11e** | **Traffic Parameters in 802.16** |
|---|---|
| Peak Data Rate(bps) | Maximum Sustained Traffic Rate(bps) |
| Delay Bound(μs) | Maximum Latency (ms) |
| Minimum Data Rate(bps) | Minimum Reserved Traffic Rate (bps) |
| Burst Size (bytes) | Maximum Traffic Burst (bytes) |

Traffic aggregation at the WiMAX backbone can be achieved by having multiple point-to-point ESPs between the BSs and the ASN-GW. One or more point-to-point ESP corresponding to each of the DSCP PHB classes namely, EF, AF1, AF2, AF3, AF4 and BE can be setup. The traffic parameters CIR, CBS, EIR and EBS for the ESPs can be chosen by the network provider depending on the class requirement and the number of flows of that class that needs to be aggregated at the BS. Table 3.3 gives a mapping of the WiMAX QoS classes to the ESPs. Hierarchical scheduling and admission control needs to be done at the BS during the session establishment and the media flow. Delay and jitter requirements for each ESP can be chosen depending on the class the ESP belongs (for example, EF class is used for VOIP traffic and it requires strict delay and jitter requirements). Frames from the WiMAX connections can be marked with IP DSCP value and sent out on the respective ESP to the ASN-GW. If an ESP corresponding to a traffic class fills up, another one can be provisioned or the calls can be rejected during the session setup.

Table 3.3: WiMAX to ESP QoS Mapping

| **WiMAX QoS Class** | **ESP QoS Class** |
|---|---|
| UGS | EF |
| RtPS | AF4 |
| ErtPS | AF3 |
| NrtPS | AF2 |
| BE | BE |

Traffic from the ESPs terminating at the ASN-GW can then be routed to the destination through the WAN. For simplicity, we have assumed that the access networks are connected by only one administrative domain in the WAN. In the case of WAN with the MPLS cloud, multiple MPLS-TE tunnels, one or more per DSCP classes namely, EF, AFx and BE can be established between the ASN-GW and various target destinations in the WAN that it connects to. This will create a mesh of LSPs between all the edge nodes of the core domain. Evans and Filsfils [19] show that this is a common practice in operator environment today. The LSPs can be established based on the requirement and the bandwidth allocated can be increased dynamically based on the number of ESPs that aggregate into an LSP. In a multi-domain environment, this can be extended by establishing LSPs across multiple domains using a Path Computation Element (PCE) per domain to compute the path through the domain that can fulfill the resource requirements.

In the case of WAN with the Diffserv cloud, traffic terminating at the ASN-GW can be marked with appropriate DSCP settings and routed through the Diffserv network. We have assumed that the interior nodes in the Diffserv network support reservation-based admission control per Diffserv PHB class. Per-flow or aggregate QoS reservation per Diffserv PHB class can be made in these nodes.

## 3.3 QoS Signaling in the Reference Network

This section presents details about the QoS signaling exchange that was shown as a part of the IMS signaling message exchange in the previous section. We present an overall view of the QoS signaling exchanges for the local segmentation and the end-to-end QoS reservation approaches. We also show the differences in signaling for these approaches in case of the push and the pull modes. Further, we give a detailed view of the QoS negotiations in different components of the access network that happens for a session.

### 3.3.1 The Local Segmentation QoS Reservation Scheme

The Local Segmentation (LS) QoS reservation approach is used by the IMS for the QoS reservation in the cellular networks [2]. According to this model, each UT is responsible for maintaining the appropriate QoS reservation in its respective local segment. In the case of our reference network, the access portion of the network from the CPE/UT to the BRAS forms the local segment. We have adopted this approach in our work in the sense that the QoS resource reservation signaling only takes place in the respective access networks while the QoS assurance in the core network that connects the two access networks is provided by means of pre-provisioning LSPs. During the QoS signaling, the BRAS, in the local and the peer access networks manage the admission of traffic from the respective access networks into the pre-provisioned LSPs. As the P-CSCF is co-located with the BRAS according to our reference network, the mapping of traffic flows to the ESPs from the LSP and vice-versa can be handled with the help of the IMS messages.

### 3.3.1.1 The Push Mode

Figure 3.3 shows the QoS signaling exchange for the Push mode local segmentation reservation. In the Push mode, according to the ITU-T architecture, the PD-FE/RACF is expected to push the QoS parameters to the traffic functions. In our case, it happens in two phases. In the first phase, the NSIS RESERVE message is initiated by the BRAS/RACF to setup a connection from the ASN-GW to the SS/QAP. This includes the approval of a TXOP grant for the QSTA/CPE in the customer’s premises. Then in the second phase, the QSTA has to initiate a request to utilize the pre-approved TXOP. The details at every step of the QoS negotiation message exchange are as follows.

(1) The BRAS maps service level QoS parameters received from the P-CSCF to one of the Y.1541 QoS classes. It also determines the number of flows required for the application session and the QoS parameters for the flows. The QoS parameters are determined based on the Y.1541 QoS class that applies to the session. The BRAS then initiates an NSIS RESERVE (sender-initiated reservation) to reserve resources in the direction from the BRAS to the CPE with the QSPEC parameters filled according to the QoS parameters determined. At the same time, the BRAS sends an NSIS QUERY message with the same or different QSPEC parameters depending on the requirements of the application (e.g. if there is a bidirectional flow required with different QoS requirements depending on the direction of the flow) with BOUND_SESSION_ID set to the SESSION_ID sent in the NSIS RESERVE message to initiate the resource reservation from the CPE to the BRAS.

*Note:* This signal flow assumes bidirectional traffic flow requirement for the application. Only RESERVE or QUERY might be required in case the resources need to be reserved in a single direction. Alternatively, multiple RESERVE/QUERY might be required if there are many flows in one direction.

(2) The WiMAX BS processes the NSIS RESERVE message by mapping the QSPEC parameters to the WiMAX QoS parameters and taking an admission control decision on whether a new service flow addition can be accepted. If it succeeds, then the BS initiates a DL service flow creation towards the WLAN QAP. Once the service

flow/connection is created, the BS forwards the RESERVE message to the QAP. Also, on receiving the QUERY message, the BS checks with the scheduler/admission control module if the required QoS can be satisfied. If so, it updates the QUERY message with the available QoS and forwards the request to the WLAN QAP.

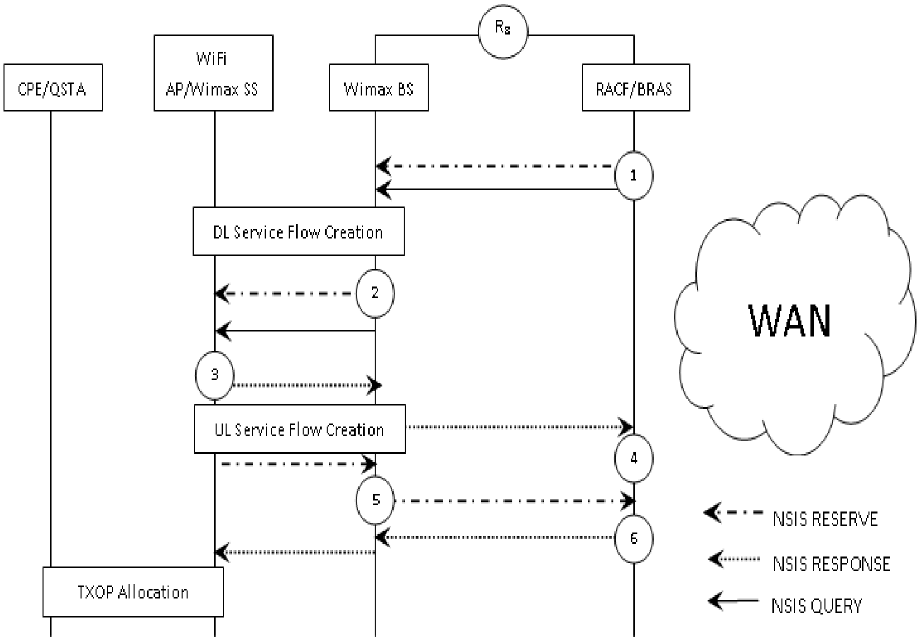


Figure 3.3: The Push Mode Local Segmentation QoS Reservation

(3) The WLAN QAP, on receipt of the RESERVE, maps the QSPEC parameters to the WLAN TSPEC parameters and takes an admission control decision on whether the flow can be admitted for the QSTA. If the admission control decision is successful, then a RESPONSE message with the QoS reserved is sent back to the BRAS. On receipt of the QUERY message, the QAP checks the QoS Available object to see if the QoS is available on the path from the BRAS. If so, then the QAP performs admission control procedures to check if the TXOP can be granted to the QSTA in the WLAN segment and a UL service flow can be created in the uplink to the BS. If it succeeds, then an NSIS RESERVE is constructed from the QUERY message to be sent to the BRAS. Before sending the RESERVE message, the QoS reservation in the uplink between the QAP/SS and BS is taken care of, by adding a new service flow using the QoS parameters received in the QUERY.

(4) The NSIS RESPONSE message reaches the BRAS confirming the QoS reservation from BRAS to CPE.

(5) The WLAN QAP, on receipt of the NSIS QUERY message, checks for the resource availability along the path from the BRAS to the QAP using the QoS Available QSPEC object in that message. If the resources are available, it takes admission control decision if an uplink flow can be admitted for the QSTA. If it succeeds, then the QAP establishes an uplink flow with the required QoS. The QAP then forms an NSIS RESERVE message copying the QSPEC parameters from the QUERY message and forwards it towards the BS.

(6) The NSIS RESERVE message for the uplink from the QAP to the BRAS reaches the BS. It takes an admission control decision on whether the service flow (identified using the packet classifier details in the RESERVE message) could be admitted to the pre-provisioned ESPs between the BS and the BRAS. If it succeeds, then the BS forwards the RESERVE message to the BRAS.

(7) The NSIS RESERVE message reaches the BRAS, which then computes the path to the destination through the WAN and sets up an LSP if it does not already exist. The BRAS then decides if the ESP that carries the new flow could be admitted to the LSP. If it succeeds, then the RESPONSE message is sent back to the QAP with the details about the QoS reservation.

#### 3.3.1.2 The Pull Mode

Figure 3.4 shows the detailed QoS signaling exchange for the pull mode local segmentation reservation. The details of the signal exchange can be described as follows.

(1) The CPE/QSTA maps the application requirements to the TSPEC QoS parameters to construct an ADDTS request for uplink from the CPE/QSTA to the QAP/SS. Also, an NSIS RESERVE message is constructed by mapping the service level QoS requirements to an appropriate Y.1541 QoS class. The ADDTS request is populated with QoS parameters in TSPEC namely, TSID, Access Policy, Direction and User Priority. The QAP, on receipt of the ADDTS request, would perform the admission

control procedure and send a response. If the ADDTS request succeeds, then an NSIS RESERVE, with the QSPEC parameters and the Y.1541 class setting, is sent to the QAP to reserve the uplink bandwidth from the QSTA to the BRAS. Also, an NSIS QUERY message is sent to the QAP with BOUND_SESSION_ID set to SESSION_ID of the RESERVE message and with the same or different QSPEC parameters based on the application needs.

*Note:* This signal flow assumes bidirectional traffic flow requirement for the application. Only RESERVE or QUERY might be required in case the resources need to be reserved in a single direction. Alternatively multiple RESERVE/QUERY might be required if there are many flows in one direction.

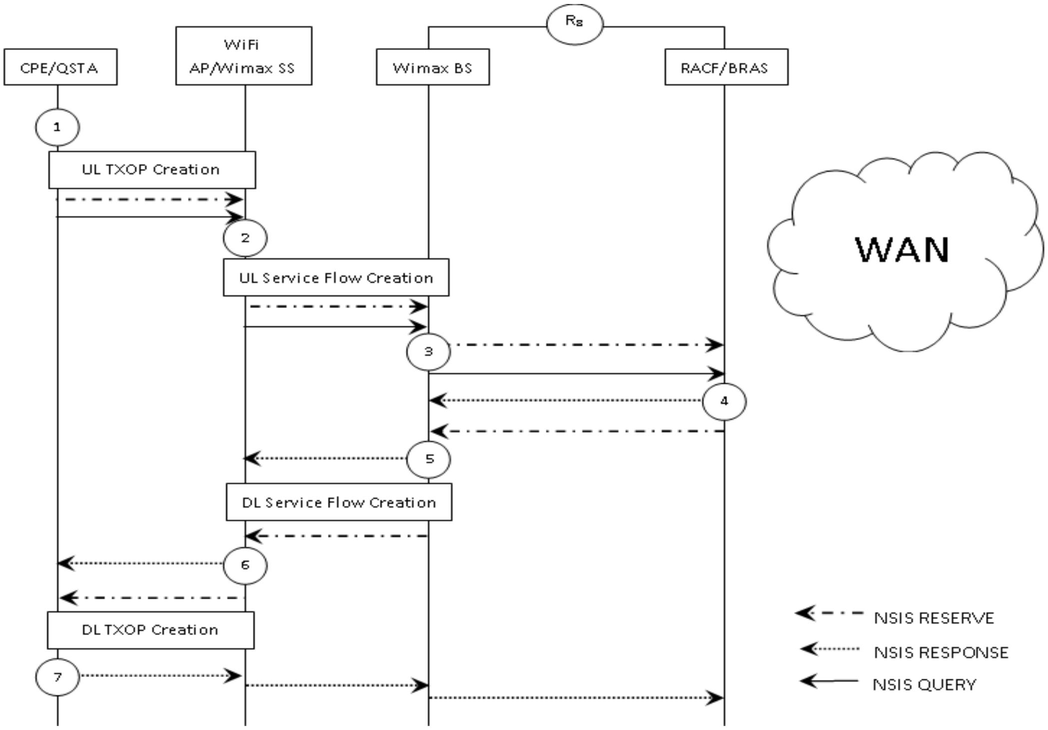


Figure 3.4: The Pull Mode Local Segmentation QoS Reservation

(2) The QAP, on receipt of NSIS RESERVE, takes the admission control decision on whether a new service flow could be admitted. If the decision is positive, it creates a UL service flow with the QoS parameters obtained from the RESERVE message. Finally, the RESERVE message is forwarded to the WiMAX BS.

Also, on receipt of the NSIS QUERY, an admission control decision is taken on whether a new service flow for the DL from the BS to the QAP/SS could be admitted. The QUERY is then forwarded to the BS with QoS Available object populated with the details about the decision.

(3) The WiMAX BS, on receipt of the RESERVE message, takes an admission control decision as to whether the new UL service flow from the WiMAX BS to the QAP can be admitted to the provisioned ESP setup between the BS and the BRAS. If it succeeds, then the mappings are configured in the BS and the RESERVE message is forwarded to the BRAS. Also, the NSIS QUERY message received from the QAP triggers admission check for a new DL service flow from BS to QAP/SS. The available QoS is filled in the QoS Available object of the QUERY message and is forwarded to the BRAS.

(4) The NSIS RESERVE message reaches the BRAS, which then computes the path to the destination through the WAN and sets up an LSP if it does not already exist. The BRAS then decides if the ESP that carries the new flow could be admitted to the LSP. If it succeeds, then the RESPONSE message is sent back to the QAP with the details about the QoS reservation. Also, on receipt of the NSIS QUERY, the BRAS checks to see if the parameters in the QoS Desired match the ones in QoS Available and in that case, it takes an admission control decision on whether to admit the flow into an ESP between the BRAS and the BS. If the resources are available, then the BRAS constructs an NSIS RESERVE message with the QSPEC parameters copied from the QUERY message and forwards it to the BS.

(5) The WiMAX BS, on receipt of the RESPONSE message, forwards it to the QAP/SS. On receipt of the RESERVE message, it takes an admission control decision on whether to admit a new service flow for the downlink between the BS and the QAP. If the service flow admission and creation succeeds, then the RESERVE message is forwarded to the QAP/SS.

(6) The QAP/SS, on receipt of the RESPONSE message, forwards it to the CPE/QSTA. The NSIS RESERVE message received from the BS triggers an admission check using the QSPEC parameters on whether to grant a TXOP to the QSTA. Once the admission decision succeeds, the RESERVE message is forwarded to the CPE/QSTA.

(7) The NSIS RESERVE at the CPE/QSTA triggers the creation of new TS using the ADDTS request/response. The CPE initiates the request to create the new TS using the parameters obtained from the RESERVE message and sends a RESPONSE once the TXOP is granted.

### 3.3.2 The End-to-End QoS Reservation

As the name applies, with the End-to-End (E2E) QoS reservation approach, the QoS reservation is signaled from the originating to the destination CPE. The caller and the callee CPEs are responsible for signaling QoS reservation for the traffic that they originate. We have assumed that the multimedia session requires bi-directional traffic flow and the CPEs (local and remote) signal a QoS reservation from both ends. NSIS is used to signal the QoS reservation from one end to the other. In this case, we have assumed that the WAN comprises a diffserv domain and the BRASs on the either side act as the ingress and egress nodes of the Diffserv domain. For simplicity, we have assumed that the BRAS acts at the ingress/egress QNE, while in reality, there can be a link that connects the BRAS to the ingress node in the diffserv domain or even another domain such as MPLS that could exist between them.

#### 3.3.2.1 The Push Mode

Figure 3.5 shows the detailed QoS signaling for the Push mode end-to-end QoS reservation. The RMD QoSM forward and reverse reservation follows the basic RMD QoSM signaling shown in Figure 2.15. The details of the signal exchange are as follows:

(1) The BRAS maps the application’s QoS requirement received from the P-CSCF to the Y.1541 QoS classes and determines the number of flows required for the application session and the QoS parameters for the corresponding flows. The QoS parameters are decided based on the different Y.1541 QoS classes and their mapping to the different applications. The BRAS, then initiates two NSIS QUERY messages with RESERVE_INIT flag set towards the originating and the destination CPEs. The PACKET_CLASSIFIER field in the QUERY message towards the originating CPE is populated with the IP address of the destination CPE as the data flow receiver and vice-

versa. This is done in order to trigger the RESERVE messages from both the ends to perform end-to-end resource reservation. Note that the BRAS can send one QUERY message towards the data flow sender if the application session only requires a unidirectional flow.

The BRAS populates the QSPEC with desired QoS parameter values that need to be reserved for the session. It also sets the BOUND_SESSION_ID to the SESSION_ID of the NSIS QUERY sent in either direction so as to bind the two sessions. The BRAS acts as the Ingress QNE to the diffserv domain, so it changes the NSLP_ID in the QUERY message header to a predefined value in order to bypass the RMD interior nodes and forwards it towards the egress QNE.

(2) On receipt of the NSIS QUERY message, the Wimax BS checks with the scheduler/admission control module if the required QoS can be satisfied. If so, it populates the availability information in the QSPEC and forwards the QUERY message to the WLAN AP.

(3) The NSIS QUERY message reaches the egress QNE in the Diffserv domain, which changes the NSLP_ID in the QUERY message header back to the original value. Then, the QUERY message gets forwarded towards the access network of the destination CPE.

(4) The WLAN AP, on receipt of the QUERY message, performs an admission control procedure to check if new TS can be admitted on the WLAN side and a UL service flow can be created for the uplink. If it succeeds, then an NSIS RESERVE is constructed from the QUERY message and before sending that the QoS reservation at the outgoing link between AP/SS and BS is taken care by adding a new service flow using the QoS parameters received in the QUERY.

(5) The NSIS RESERVE message reaches the Wimax BS from the QAP. The BS takes an admission control decision to determine whether the newly added service flow could be admitted to the pre-provisioned ESPs between the BS and BRAS. If so, it forwards the RESERVE message to the BRAS.

(6) The NSIS RESERVE message reaches the BRAS where it computes the route to the destination to determine the next hop for the RESERVE message. The BRAS, acting as

ingress QNE, performs an admission control check on whether the resources requested for the new flow can be reserved by mapping the flow to a PHB class. If it is successful, the BRAS then creates a new NSIS RESERVE message for QoS reservation in the diffserv domain using RMD QoSM procedures. The QSPEC object for the new message is constructed based on the QSPEC object in the received RESERVE message. The original end-to-end RESERVE message is then modified to bypass all the interior QNEs in the diffserv domain. Both the RESERVE messages are then forwarded toward the destination.

(7) The egress QNE, receives both the RMD RESERVE message as well as the end-to-end RESERVE message. Based on the information derived from the RMD RESERVE message, the end-to-end RESERVE is either forwarded toward the next QNE in the path to the destination or a RESPONSE is sent back to the QNI notifying the error condition. If the reservation succeeds in the diffserv domain, the egress QNE replaces the NSLP_ID in the RESERVE message header back to its original value and forwards it towards the destination CPE. In parallel, it constructs a RESPONSE message for the RMD RESERVE message and forwards it to the ingress QNE.

(8) On receipt of a RESPONSE for the RESERVE message sent, the egress QNE modifies the NSLP message header in order to bypass the processing of the message by the QNE interior nodes. It then forwards the RESPONSE message towards the QNI which is the originating CPE. The destination CPE, on receipt of the NSIS QUERY sent earlier, responds with an NSIS RESERVE message copying the QSPEC objects from the QUERY message. The egress QNE, on receipt of this message, performs an admission control check on whether the resources requested for the new flow can be reserved by mapping the flow to a PHB class. The PHB class for the new flow can be found from the Y.1541 QSPEC object. If it is successful, the BRAS then constructs a new RESERVE message for the diffserv domain using RMD QoSM procedures and forwards it towards the ingress QNE. It also modifies the end-to-end RESERVE message header in order to bypass the processing by the interior nodes.

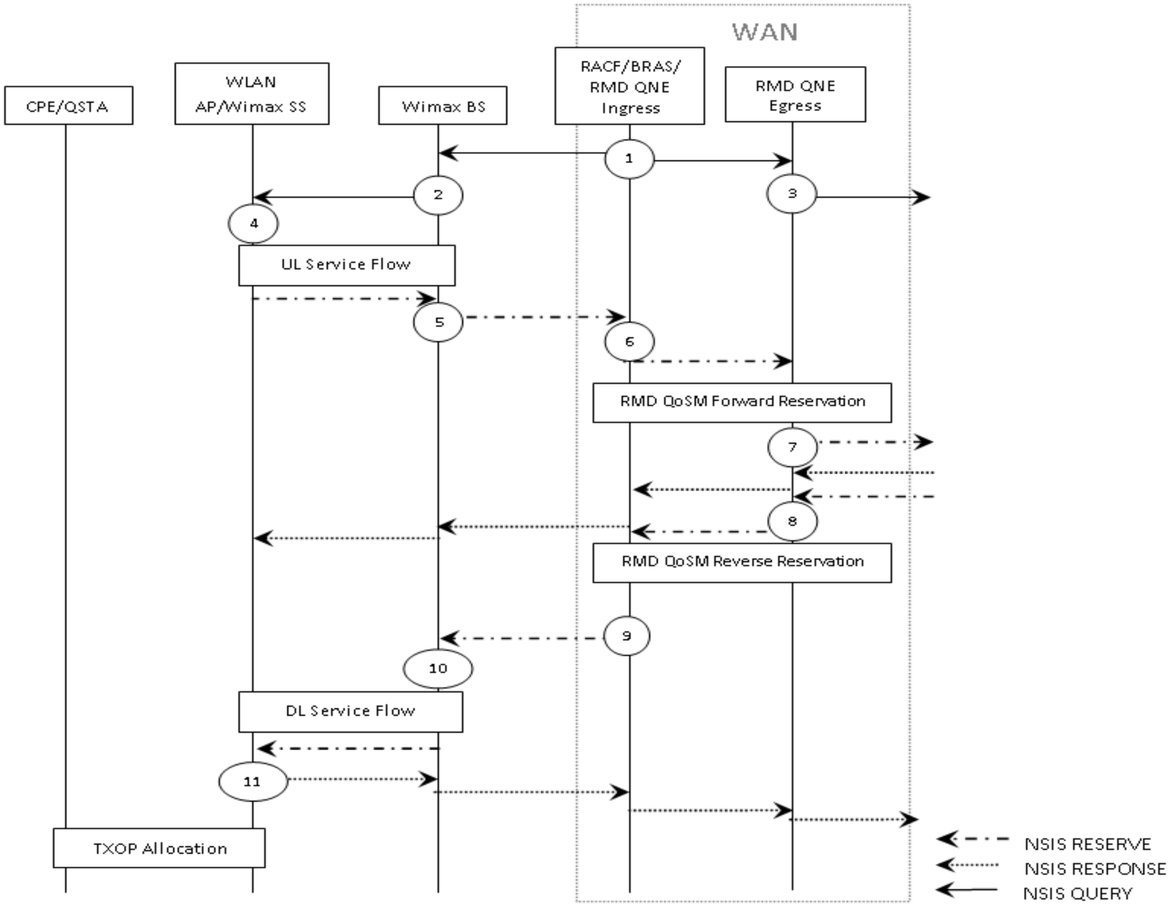


Figure 3.5: The Push Mode End-to-End QoS Reservation

(9) The ingress QNE, on receipt of the NSIS RESERVE messages, determines if the reservation in the diffserv domain was successful. If so, then it performs admission control decision as to whether the flow can be admitted in to the ESP towards the Wimax BS. In parallel, it constructs a RESPONSE message for the RMD RESERVE message and forwards it to the egress QNE. If it is successful, then the RESERVE message is forwarded towards the Wimax BS.

(10) The WiMAX BS processes the NSIS RESERVE message by mapping the QSPEC parameters to the WiMAX QoS parameters and taking an admission control decision on whether a new service flow addition can be accepted. If it succeeds, then the BS initiates a DL service flow creation towards the WLAN QAP. Once the service flow/connection is created, the BS forwards the RESERVE message to the QAP.

(11) The WLAN QAP, on receipt of the RESERVE, maps the QSPEC parameters to the WLAN TSPEC parameters and takes an admission control decision on whether the flow can be admitted for the QSTA. If the admission control decision is successful, then a RESPONSE message with the QoS reserved is sent back to the QNI which the destination CPE.

### 3.3.2.2 The Pull Mode

Figure 3.6 shows the detailed QoS reservation for the pull mode end-to-end QoS reservation. The RMD QoSM forward and reverse reservation follows the basic RMD QoSM signaling shown in Figure 2.15. The details of the signal exchange are as follows:

(1) The CPE/QSTA maps the application requirements to the TSPEC QoS parameters to construct an ADDTS request for the uplink from the CPE/QSTA to the QAP/SS. Also, an NSIS RESERVE message is constructed by mapping the service level QoS requirements to an appropriate Y.1541 QoS class. The ADDTS request is populated with QoS parameters in TSPEC namely, TSID, Access Policy, Direction and User Priority. The QAP, on receipt of the ADDTS request, will perform the admission control procedure and send a response. If the ADDTS request succeeds, then an NSIS RESERVE, with the QSPEC parameters and the Y.1541 class set is sent to the QAP to reserve the uplink bandwidth from the QSTA to the destination CPE. Also, an NSIS QUERY message is sent to the QAP with BOUND_SESSION_ID set to SESSION_ID of the RESERVE message and with the same or different QSPEC parameters based on the application needs.

*Note:* Only RESERVE or QUERY might be required in case the resources need to be reserved in a single direction. Alternatively multiple RESERVE/QUERY might be required if there are many flows in one direction.

(2) The QAP, on receipt of the NSIS RESERVE, takes the admission control decision on whether a new service flow could be admitted. If the decision is positive, it creates a UL service flow with the QoS parameters obtained from the RESERVE message. Finally, the RESERVE message is forwarded to the WiMAX BS. Also, on receipt of

the NSIS QUERY, an admission control decision is taken on whether a new service flow for the DL from the BS to the QAP/SS could be admitted. The QUERY is then forwarded to the BS with QoS Available object populated with the details about the decision.

(3) The WiMAX BS, on receipt of the RESERVE message, takes an admission control decision on whether the new UL service flow from the WiMAX BS to the QAP can be admitted to the provisioned ESP setup between the BS and the BRAS. If it succeeds, then the mappings are configured in the BS and the RESERVE message is forwarded to the BRAS. Also, the NSIS QUERY message received from the QAP triggers an admission check for a new DL service flow from BS to QAP/SS. The available QoS is filled in the QoS Available object of the QUERY message and is forwarded to the BRAS.

(4) The NSIS RESERVE message reaches the BRAS where it computes the route to the destination to determine the next hop for the RESERVE message. The BRAS, acting as an ingress QNE, creates a new NSIS RESERVE message for QoS reservation in the diffserv domain using RMD QoSM procedures. The QSPEC object for the new message is constructed based on the QSPEC object in the received RESERVE message. The original end-to-end RESERVE message is then modified to bypass all the interior QNEs in the diffserv domain. Both the RESERVE messages are then forwarded toward the destination. Also, on receipt of the NSIS QUERY, the BRAS performs an admission control procedure to check if the resources requested are available for the requested PHB class. If it is successful, the BRAS, which is also the ingress QNE in RMD domain, changes the NSLP_ID in the NSLP header of the QUERY in order to bypass the processing of QUERY within the diffserv domain. It then forwards the QUERY towards the egress QNE.

(5) The egress QNE, receives both the RMD RESERVE message as well as the end-to-end RESERVE message. Based on the information derived from the RMD RESERVE message, the end-to-end RESERVE is either forwarded toward the next QNE in the path towards the destination or a RESPONSE is sent back to the QNI setting notifying the error condition. If the reservation succeeds in the diffserv domain, the egress QNE

replaces the NSLP_ID in the end-to-end RESERVE message header back to its original value and forwards it towards the destination CPE. In parallel, it constructs a RESPONSE message for the RMD RESERVE message and forwards it to the ingress QNE. Also, on receipt of the QUERY message, it forwards it to the destination CPE.

(6) The egress QNE, on receipt of the RESPONSE from the destination CPE for the RESERVE sent earlier, forwards it to the QSTA/originating CPE. Also, on receipt of the NSIS RESERVE message from the destination CPE, which is triggered by the QUERY sent earlier, the egress QNE performs an admission control procedure to check if the new flow can be admitted to the PHB class, which is determined from the Y.1541 QSPEC object. If it is successful, then the egress QNE constructs a new RESERVE message for the RMD domain and passes the end-to-end RESERVE with the predefined NSLP_ID value to bypass the processing at the interior nodes.

(7) The BRAS/ingress QNE, checks on receipt of the RMD RESERVE message if the reservation was successful in the interior nodes. If it was, then the BRAS performs admission control procedure to check if the new flow can be admitted to the pre-provisioned ESP between the BRAS and the Wimax BS. If it is successful, then the end-to-end RESERVE message is forwarded towards the BS.

(8) The Wimax BS, on receipt of the RESERVE message, takes an admission control decision on whether to admit a new service flow for the downlink between the BS and the QAP. If the service flow admission and creation succeeds, then the RESERVE message is forwarded to the QAP/SS.

(9) The QAP/SS, on receipt of the NSIS RESERVE, triggers an admission check using the QSPEC parameters to check whether to grant a TXOP to the QSTA. Once the admission decision succeeds, the RESERVE message is forwarded to the CPE/QSTA.

(10) The NSIS RESERVE at the CPE/QSTA triggers the creation of new TS using the ADDTS request/response. The CPE initiates the request to create new TS using the parameters obtained from the RESERVE message and sends a RESPONSE once the TXOP is granted. The RESPONSE is then the forwarded towards the destination CPE.

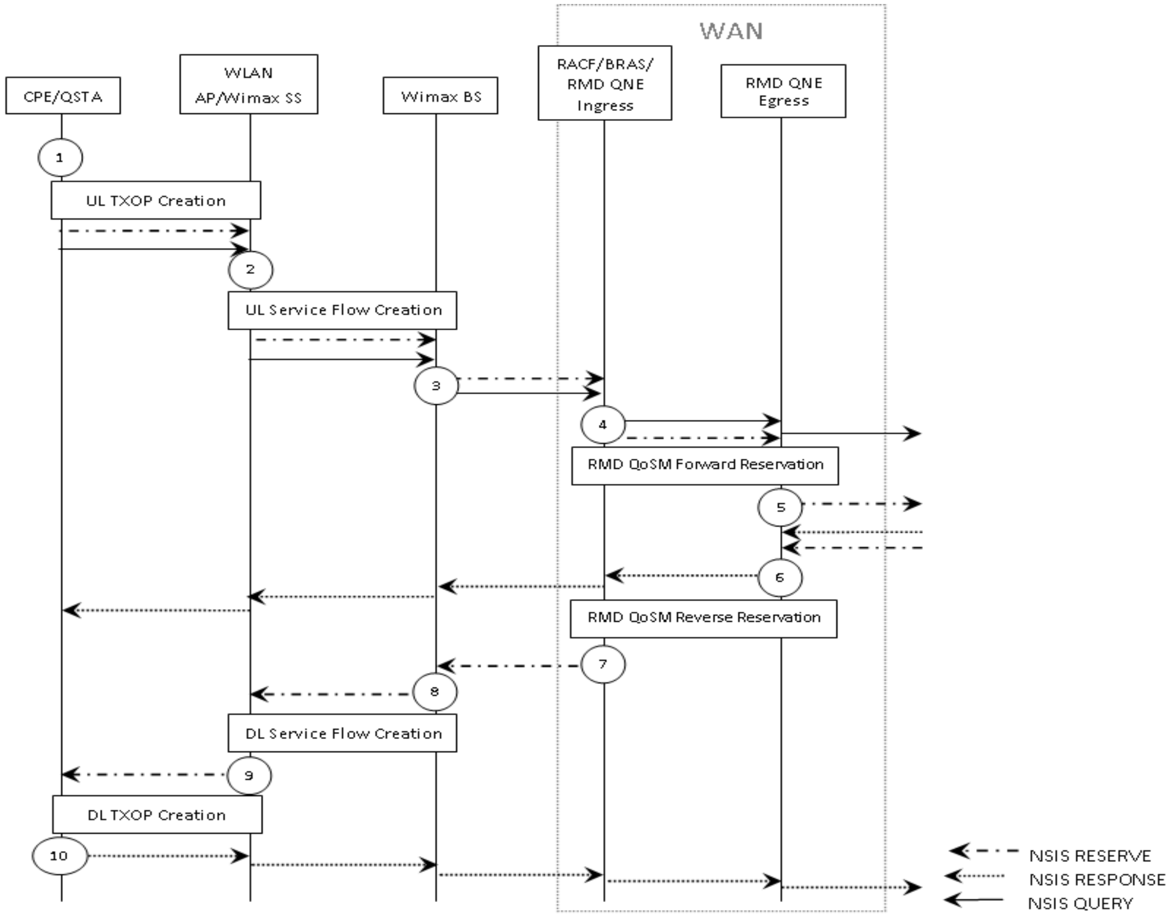


Figure 3.6: The Pull Mode End-to-End QoS Reservation

### 3.3.3 QoS Negotiation in the Access Network

As we saw in the previous section, QoS negotiations happen in the WiMAX and the WLAN segments for every session. This section presents a detailed view of the negotiations that happen to add a new uplink or downlink service flow in the WiMAX segment or to request a TXOP in the WLAN segment.

**The DL Service Flow Creation:**

Figure 3.7 shows the downlink service flow creation procedure in WiMAX. The detailed explanation of the procedure is as follows.

(1) The BS creates a service-flow ID (SFID) for the service flow. It maps the service-flow to a CID and sets the ActiveQoSParamSet to the QoS parameters obtained by mapping the NSIS Y.1541 QSPEC parameters to the WiMAX QoS parameters. It then frames a DSA-REQ message with the QoS parameters obtained and sets the packet classifier with the details about the CPE behind the QAP/SS. Finally, the BS sends the DSA-REQ to the SS.

(2) The SS confirms if it can support a new service-flow and enables the reception on the new downlink service flow being created. It sends a DSA-RSP message back to the BS.

(3) The BS enables the transmission on the service-flow and sends a DSA-ACK message to acknowledge the reception of the DSA-RSP message.

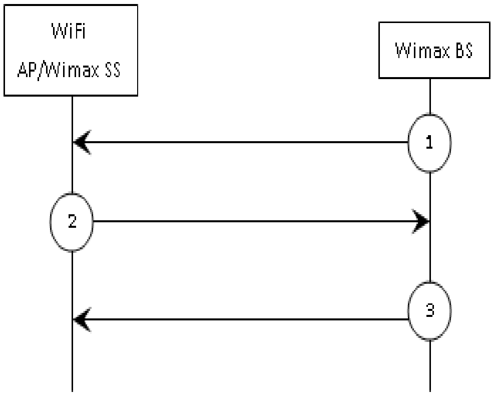


Figure 3.7: DL Service Flow Creation

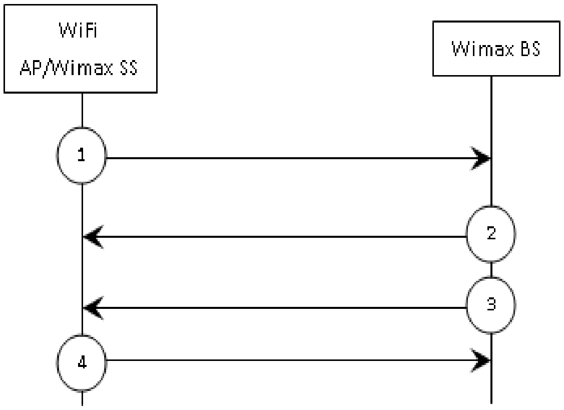


Figure 3.8: UL Service Flow Creation

**The UL Service Flow Creation:**

Figure 3.8 shows the uplink service flow creation procedure in WiMAX. The detailed explanation about the procedure is as follows.

(1) The SS/QAP frames and sends a DSA-REQ message with the QoS parameters obtained by mapping the NSIS Y.1541 QSPEC parameters to the WiMAX QoS parameters. The DSA-REQ is also filled with the appropriate packet classifier setting.

(2) The WiMAX BS acknowledges the reception of the DSA-REQ by sending a DSX-RVD message. It checks if the DSA-REQ is valid and also if a new service-flow can be created. If yes, then a new SFID is created and it is mapped to a CID. It also enables the reception on the new uplink service-flow created.

(3) The BS then sends a DSA-RSP message with the ActiveQoSParamSet set to the QoS parameters requested or modified according to the resource availability at the BS.

(4) If ActiveQoSParamSet is non-null, the SS enables transmission on the new service flow. It acknowledges the receipt of the DSA-RSP by sending a DSA-ACK message.

**The WLAN TXOP Request:**

Figure 3.9 shows the WLAN TXOP request procedure in the WLAN segment. The two-step procedure can be explained as follows.

(1) An ADDTS Request is created and sent to the QAP. In the Push mode, the QSTA sets the QoS parameters to 0 in the TSPEC as the QoS parameters is determined by the RACF and it is unknown to the QSTA. In the Pull mode, the QSTA populates the parameters in the TSPEC with the values obtained by mapping the Y.1541 QoS class to the WLAN TSPEC parameters. In both the cases, the TS Info field is populated with information such as TSID, Direction (e.g. bidirectional for VOIP), User Priority and Access Policy (EDCA).

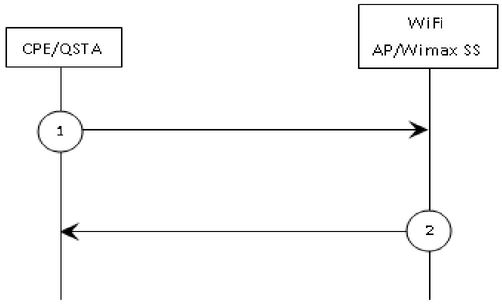


Figure 3.9: WLAN TXOP Negotiation

(2) The QAP checks if the QSTA’s request for TS addition can be approved. In the Push mode, as the admission control decision has already been taken, the QAP accepts the request. It fills the QoS parameter values granted to the QSTA in the TSPEC. In the Pull mode, the admission control decision is taken when the QAP receives the request based on the resource request and the current status of the WLAN network. Once the decision is taken, the QoS parameter values of TSPEC are copied from the ADDTS request frame or set by the QAP (in case they are modified). An ADDTS response

frame is generated with the detail about the medium time allocated to the QSTA and it is sent to the QSTA.

## 3.4 QoS Parameter Mapping

Table 3.4, 3.5 and 3.6 show the proposed mapping of the QoS parameters across various components of the reference network. The mapping is defined for the six Y.1541 QoS classes from class 0 to class 5. We have not considered classes 6 and 7 as those are defined specifically for circuit emulation services. The six QoS classes have been categorized into three stubs based on the traffic parameters that are required to characterize those classes. There are a few QoS parameters that need to be signaled for a particular Y.1541 QoS class using NSIS that might not supported by one or more component networks. In such cases, we suggest that the operators use the absolute values of those parameters determined for the specific component network.

***Note 1:*** MEF does not specify a parameter to specify path error, so the network has to populate absolute values for this field.

***Note 2:*** Maximum Latency for WiMAX network considers only the queueing delay. The BS should update the path latency parameter in the NSIS QSPEC with the propagation delay in addition to the queueing delay. Absolute values for propagation delay, path loss and path error have to be determined at the BS for the WiMAX network.

***Note 3:*** The WLAN network does not include the path jitter and path loss parameters while granting new TS. So, the absolute values for the path jitter, loss and path error have to be populated by the AP for the WLAN network.

***Note 4:*** This class can be characterized using a single rate i.e. by setting peak rate = committed rate or using dual rate depending on the operator’s choice.

***Note 5:*** As NSIS RMD QoSM only supports one bandwidth parameter, operator has to choose between peak rate or committed rate or effective bandwidth (if known already).

Table 3.4: QoS Parameter Mapping for the Classes 0 & 1

| **Application Type** | **Y.1541 QoS Class/QSPEC Parameters** | **RSVP Sender TSPEC/RSPEC Parameters** | **NSIS RMD QSPEC Parameters** | **NSIS QSPEC Parameters** | **MEF QoS Parameters** | **Wimax QoS Parameters** | **WLAN QoS Parameters** |
|---|---|---|---|---|---|---|---|
| VOIP, Video Conference and Highly Interactive | Class 0 and 1 | **Guaranteed Service:**<br>1. Token bucket rate = peak data rate<br>2. Token bucket size<br>3. ADSpec<br>(i) Cdot (Path delay)<br>(ii) Ddot (Path delay variation) | **QoS Desired:**<br>1. PHB Class = EF<br>2. Bandwidth = Peak Rate | **QSPEC Objects:**<br>1. QoS Desired:<br>(i) TMOD Parameters:<br>(a) Rate = Peak rate (bytes per sec)<br>(b) Bucket size<br>(c) Peak bucket size<br>(ii) Path Latency<br>(iii) Path Jitter<br>(iv) Path Loss Ratio<br>(v) Path Error Ratio<br>2. QoS Available:<br>(i) Path Latency<br>(ii) Path Jitter<br>(iii) Path Loss Ratio<br>(iv) Path Error Ratio | Diffserv type = EF<br>1. Committed information rate, CIR = Excess information rate, EIR (bits per sec)<br>2. Committed burst size (CBS)<br>3. Excess burst size (EBS)<br>4. Frame delay performance<br>5. Frame delay variation<br>6. Frame loss ratio<br>***(Note 1)*** | **UGS Connection:**<br>1. Minimum sustained traffic rate = Minimum reserved traffic rate (bits per sec)<br>2. Maximum Latency (ms)<br>3. Tolerated Jitter (ms)<br>***(Note 2)*** | **TSPEC Parameters:**<br>1. Peak Data Rate (bits per sec)<br>2. Delay bound (μs)<br>***(Note 3)*** |

Table 3.5: QoS Parameter Mapping for the Classes 2, 3 & 4

| **Application Type** | **Y.1541 QoS Class/QSPEC Parameters** | **RSVP Sender TSPEC/RSPEC Parameters** | **NSIS RMD QSPEC Parameters** | **NSIS QSPEC Parameters** | **MEF QoS Parameters** | **Wimax QoS Parameters** | **WLAN QoS Parameters** |
|---|---|---|---|---|---|---|---|
| Highly Interactive/Interactive Transaction data, low loss only applications, audio and video streaming | Class 2, 3 and 4 | **Guaranteed Service:**<br>1. Token bucket rate<br>2. Peak data rate<br>3. Token bucket size<br>4. ADSpec<br>(i) Cdot (Path delay)<br>(ii) Ddot (Path delay variation) | **QSPEC Objects:**<br>1. PHB Class = AF<br>2. Bandwidth = Peak Rate<br>***(Note 5)*** | **QSPEC Objects:**<br>1. QoS Desired:<br>(i) TMOD Parameters:<br>(a) Rate (bytes per sec)<br>(b) Peak rate (bytes per sec)<br>(c) Bucket size<br>(d) Peak bucket size<br>(ii) Path Latency<br>(iii) Path Loss Ratio<br>(iv) Path Error Ratio<br>2. QoS Available:<br>(i) Path Latency<br>(ii) Path Loss Ratio<br>(iii) Path Error Ratio | Diffserv type = AF1/2/3/4<br>1. Committed information rate, CIR (bits per sec)<br>2. Excess information rate, EIR (bits per sec)<br>3. Committed burst size (CBS)<br>4. Excess burst size (EBS)<br>5. Frame delay performance<br>6. Frame loss ratio | **RtPS Connection:**<br>1. Minimum reserved traffic rate (bits per sec)<br>2. Minimum sustained traffic rate (bits per sec)<br>3. Maximum Latency (ms) | **TSPEC Parameters:**<br>1. Minimum data rate (bits per sec)<br>2. Peak data rate (bits per sec)<br>3. Delay bound (µs) |

Table 3.6: QoS Parameter Mapping for the Class 5

| Application Type | Y.1541 QoS Class/QSPEC Parameters | RSVP Sender TSPEC/RSPEC Parameters | NSIS RMD QSPEC Parameters | NSIS QSPEC Parameters | MEF QoS Parameters | Wimax QoS Parameters | WLAN QoS Parameters |
|---|---|---|---|---|---|---|---|
| Email/Web Browsing | Class 5 | **Controlled-load Service:**<br>1. Token bucket rate<br>2. Peak data rate<br>3. Token bucket size | **QoS Desired**<br>1. PHB Class = BE<br>2. Bandwidth = Peak Rate<br>***(Note 5)*** | **QSPEC Objects:**<br>1. QoS Desired:<br>(i) TMOD Parameters:<br>(a) Rate (bytes per sec)<br>(b) Peak rate (bytes per sec)<br>(c) Bucket size<br>(d) Peak bucket size<br>or<br>1. QoS Desired:<br>(i) TMOD Parameters:<br>(a) Rate (bytes per sec) = Peak rate (bytes per sec)<br>(b) Bucket size<br>(c) Peak bucket size<br>***(Note 4)*** | Diffserv type = BE<br>1. Committed information rate, CIR (bits per sec)<br>2. Excess information rate, EIR (bits per sec)<br>3. Committed burst size (CBS)<br>4. Excess burst size (EBS)<br>or<br>1. Committed information rate, CIR = Excess information rate, EIR (bits per sec)<br>2. Committed burst size (CBS)<br>3. Excess burst size (EBS)<br>***(Note 4)*** | **NrtPS Connection:**<br>1. Minimum reserved traffic rate (bits per sec)<br>2. Minimum sustained traffic rate (bits per sec)<br>or<br>**BE Connection:**<br>1. Minimum reserved traffic rate (bits per sec)<br>2. Minimum sustained traffic rate (bits per sec)<br>***(Note 4)*** | **TSPEC Parameters:**<br>1. Minimum data rate (bits per sec)<br>2. Peak data rate (bits per sec)<br>or<br>1. Peak data rate (bits per sec)<br>***(Note 4)*** |

# Chapter 4

# Simulation Setup and Results

In this chapter, we describe the simulation environment used to measure the end-to-end performance of the proposed QoS reservation schemes. We have used Arena [34], a simulation modeling and analysis tool, to construct event-driven simulation models for the four different schemes. We first outline our basic assumptions across all models and provide detailed description of the different models used. We then list the values that we have chosen for various parameters used in the simulation. Finally, we discuss the results obtained from the simulation and present a comparison of the proposed schemes based on the results.

## 4.1 The Simulation Model

In this section, we describe the four simulation models, one per reservation scheme, constructed using Arena. In order to construct each simulation model, we first developed a queueing network that depicts the flow of messages involved in setting up of a connection with end-to-end QoS requirements. The reference network is the same as the one discussed in the previous chapters. These queueing networks were subsequently simulated using Arena. The queueing models presented in this chapter were drawn using the JSIMgraph application in Java Modeling Tools [35]. In the queueing network, each single server queue represents a functional entity involved in the IMS and the QoS signaling, and the infinite servers are used to represent the propagation delay between the functional entities in the network. As we wish to study the end-to-end performance of the architecture and the effects of queueing and processing delays across various functional elements on the performance, we have omitted the customer premises network in our analysis. We assume that the service requests generated by the source node indicate requests initiated by different QSTAs in a single customer premises network and they are all destined to the same destination network.

An arrival to the queueing network is treated as a new service request in the reference network and a departure from the system happens when the IMS signaling message exchange for the request is complete. Hence, an arrival of a new service request triggers the QAP in the originating network to initiate the IMS signaling by sending an IMS INVITE message. The receipt of the final IMS OK message for the INVITE denotes the completion of the connection setup and thus the departure from the system. The flow of the IMS messages follows the procedures described in chapter 3.

Figure 4.1 shows the queueing network model for the local segmentation push mode QoS reservation. The functional entities are connected according to the signaling message flow. The flow of a new connection establishment request arriving at the AP1 follows the IMS signaling flow for the push mode. The IMS message exchanges happen between AP1 and AP2 through the P/S-CSCFs. During the message exchange, when the P-CSCF1 and the P-CSCF2 receive the provisional acknowledgement message, the message is forked in the nodes named QoS_Rsv_1 and QoS Rsv_2 in order to initiate the QoS reservation in the access segment.  This QoS reservation request message arriving at the BRAS1 and BRAS2 is again forked in the nodes named QoS Rsv Init_1 and QoS Rsv Init_2 to initiate bidirectional reservation in the access segment. Two new messages namely, QoS RESERVE and QoS QUERY are created and sent towards the QAP. The completion of QoS reservation is signaled at the BRAS_1 and BRAS_2 when a QoS RESPONSE message triggered by the QoS RESERVE and QoS RESERVE message triggered by the QoS QUERY arrives at these nodes. The forked QoS reservation messages are then joined at the nodes labeled Post QoS Rsv_1 and Post QoS Rsv_2, and a response is sent back to the P-CSCFs. The P-CSCFs then join the received response to the IMS message at the join nodes named Post Rsv_1 and Post Rsv_2 when the reservation is complete. The IMS signaling then continues between AP1 and AP2 until the INVITE-ACK transaction is complete.

Similarly, figures 4.2, 4.3 and 4.4 show the queueing network models for the local segmentation pull mode, end-to-end push mode and end-to-end pull mode QoS reservations respectively. For all these models, the flow of a new connection request across different nodes in the network follows the appropriate IMS signaling flow as seen in the previous chapter and the QoS reservation initiation follows a similar approach as seen with the local segmentation push mode QoS reservation described above.

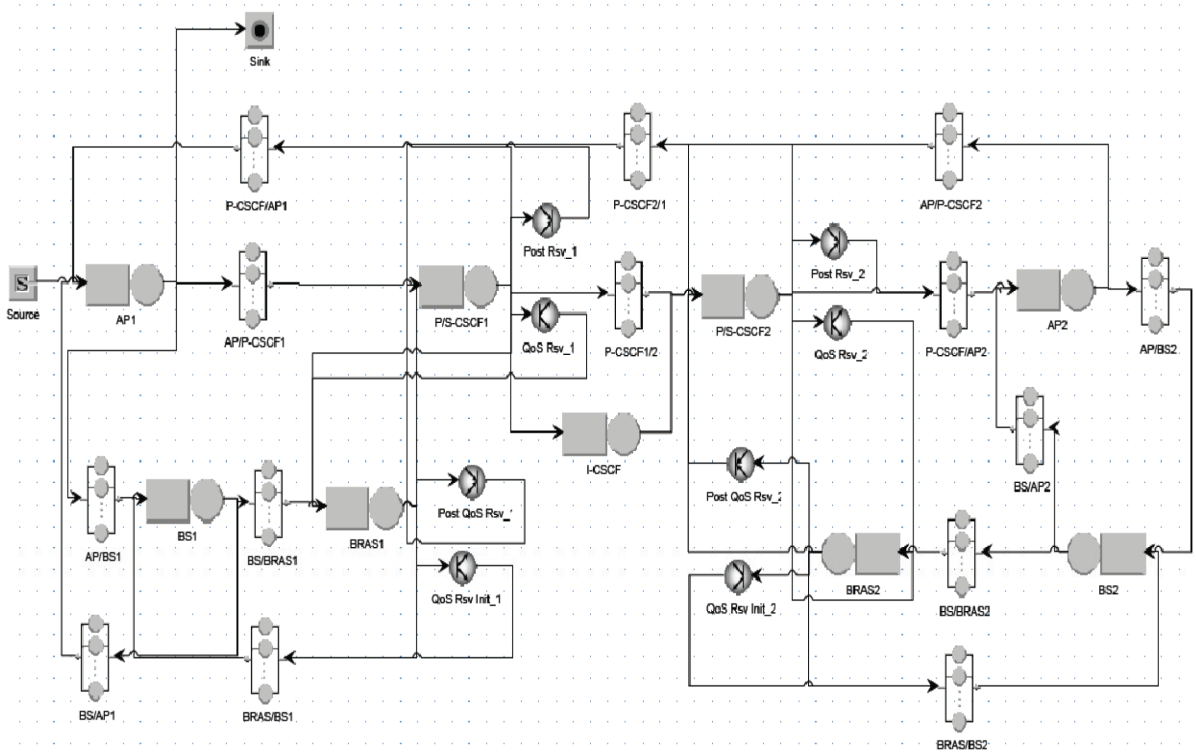


Figure 4.1: The Local Segmentation Push Model

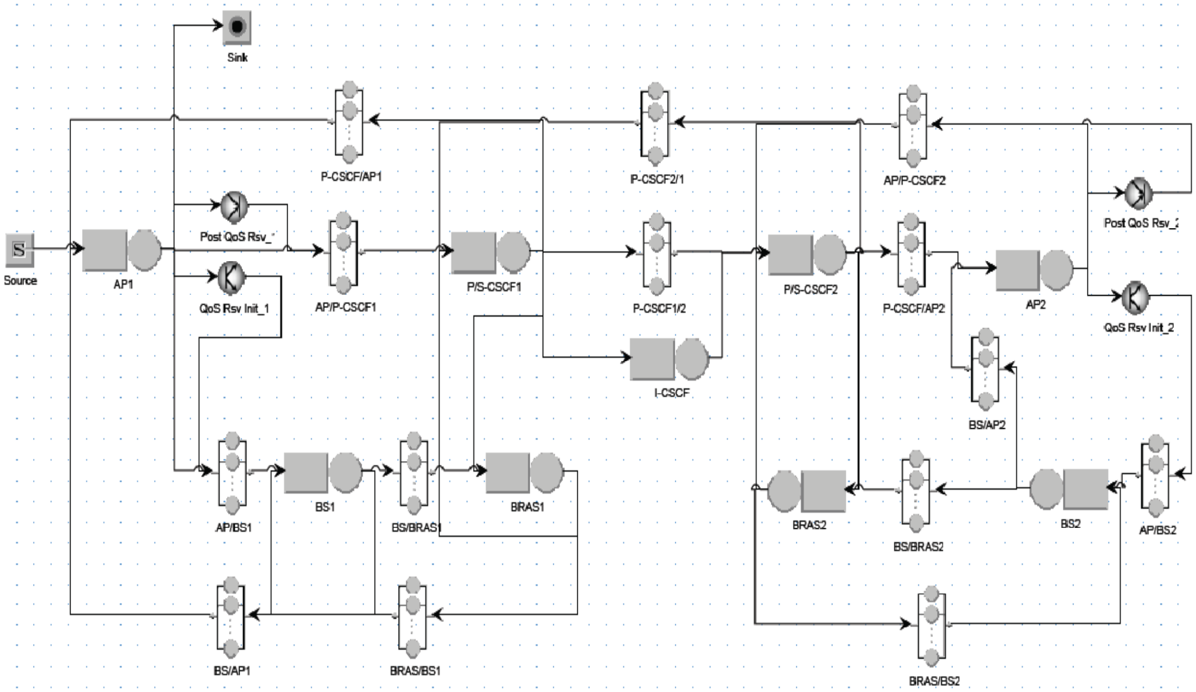


Figure 4.2: The Local Segmentation Pull Model

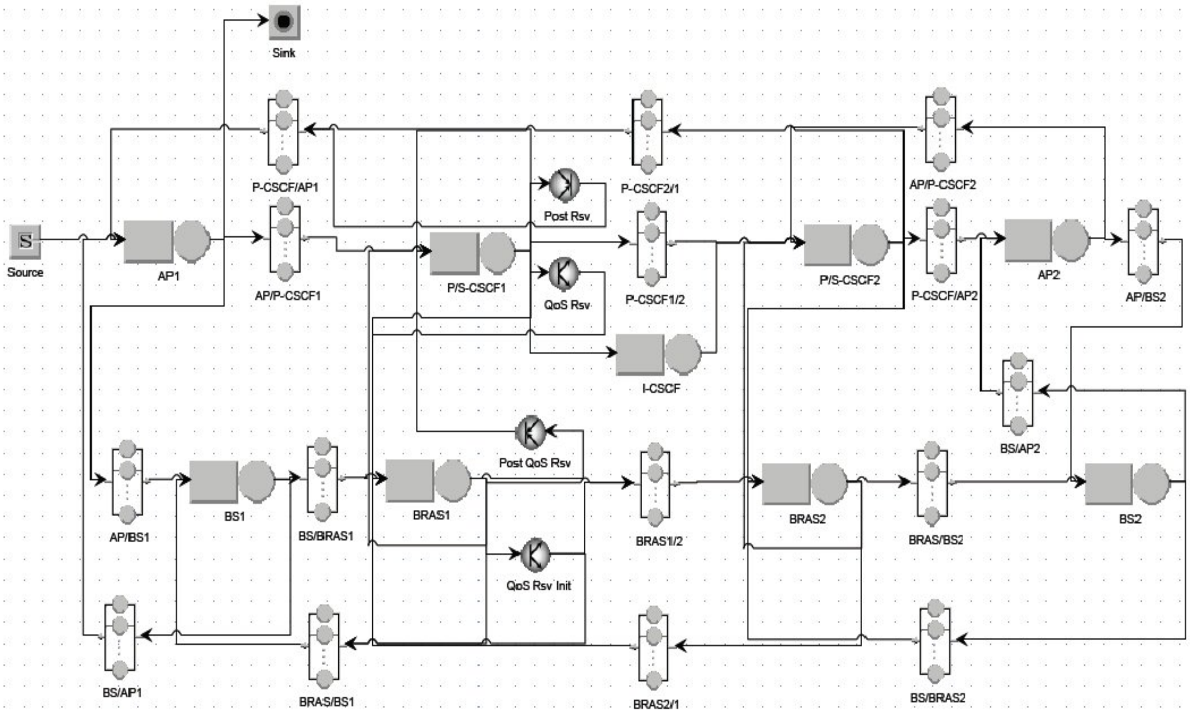


Figure 4.3: The End-to-End Push Model

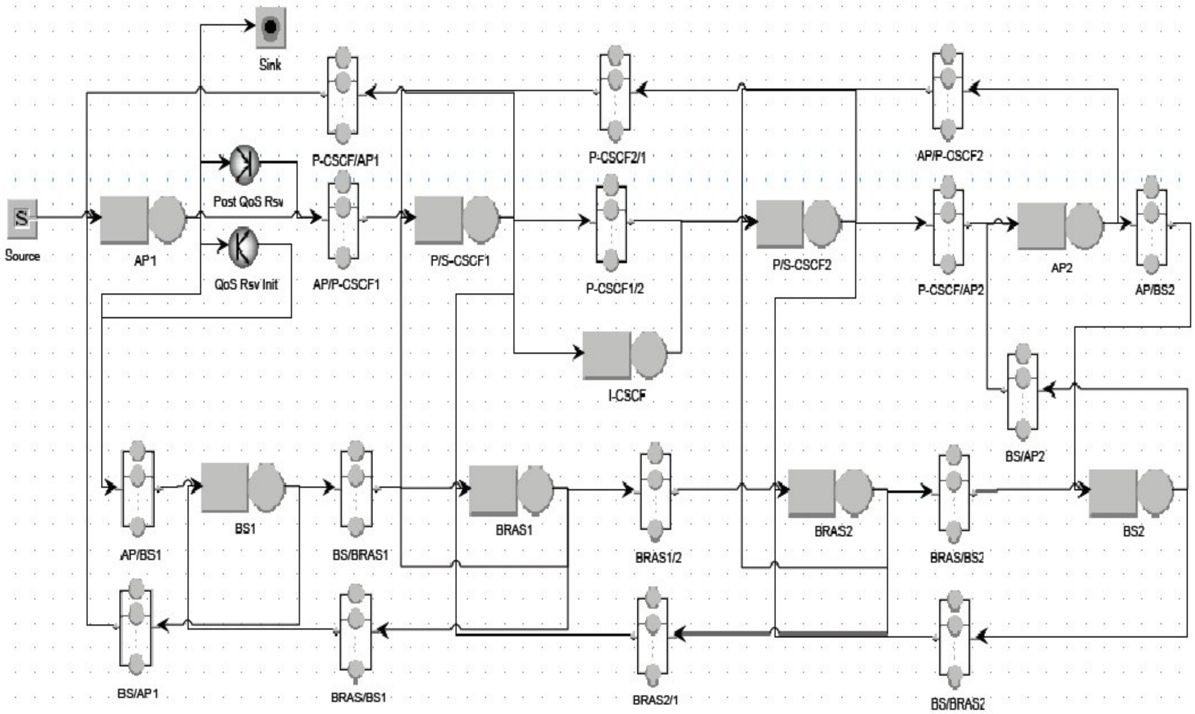


Figure 4.4: The End-to-End Pull Model

## 4.2 Simulation Parameters

In this section, we give an account of the choices that we have made for the service times and propagation delays across all the network models. We have assumed that the service requests arrive in Poisson fashion and all the service times are exponentially distributed. Table 4.1 lists our assumptions about the distance and the mean propagation delay for every link that we have used in our simulation models. The distance and the propagation delay across the links are chosen according to the ratio, AP–BS: BS–BRAS: AP–BRAS: BRAS1–BRAS2: P-CSCF1–P-CSCF2=1:2:3:5:5. The propagation delays are exponentially distributed with the mean listed in the table. The distances spanned by the links QAP – P-CSCF, QAP – BS and BRAS – BS have been assumed to be the same in the originating and destination access networks.

Table 4.1: Propagation Delay between Functional Elements

| **Links** | **Distance** (in miles) | **Mean Propagation Delay** (in msecs) |
|---|---|---|
| QAP – P-CSCF | 60 | 30 |
| P-CSCF1 – P-CSCF2 | 200 | 100 |
| QAP – BS | 20 | 10 |
| BRAS – BS | 40 | 20 |
| BRAS1 – BRAS2 | 200 | 100 |

According to Cortes, Ensor and Esteban [36], the average processing time of a 500 byte SIP message is in the order of 2 ms in the functional elements. Also, Haipeng and Mahendran [37] show how the SIP message size for the IMS messages can be reduced using efficient compression algorithms. The authors show that about 70 percent reduction in message size could be achieved. Based on this, we have chosen the mean service times of all the IMS functional elements to be 5ms across all the models. For simplicity, we have assumed the mean service times of the non-IMS elements to be the same.

## 4.3 Simulation Results and Discussion

In this section, we discuss and compare the results obtained from simulating the four QoS reservation schemes. We used the batch means method to construct the confidence interval of the end-to-end call setup time. Thirty one batches with 4000 customers per batch were run and the results from the first batch were ignored to account for the initial conditions. These confidence intervals were not plotted in the graphs as they are very small and they are not discernible.

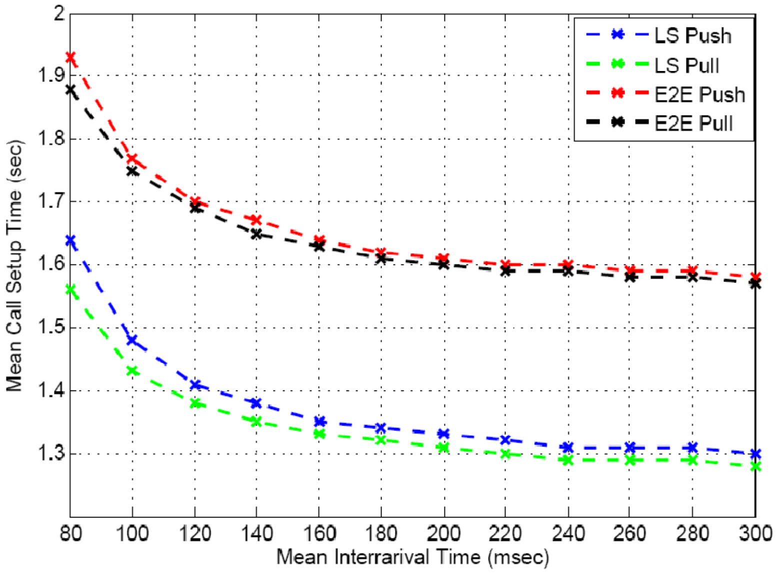


Figure 4.5: Mean Call Setup Time versus Mean Inter-arrival Time

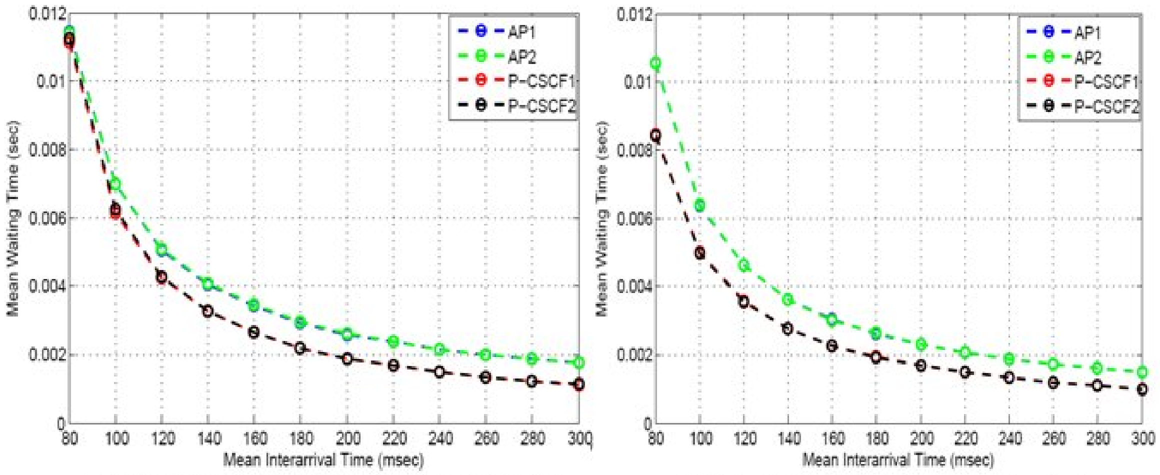
Figure 4.5 shows the mean call setup time obtained for the four reservation schemes, as a function of the mean inter-arrival time which was varied from 80 ms to 300 ms in steps of 20 ms. As can be seen, the call setup time for the end-to-end schemes are higher than the local segmentation schemes. This is primarily due to the additional propagation delay encountered in these schemes. It can also be further explained by examining Figure 4.6 that gives the mean waiting time in the four key queues AP1, AP2, P-CSCF1, P-CSCSF2, as a function of the inter-arrival time, for each of the four schemes. As can be seen from the figure, when the inter-arrival time is very long, the queues are mostly empty and the waiting time is negligible. Hence, the call setup time is dominated by the service times and propagation delay. Since the service times for all functional entities in all the four schemes are set to the same value, the difference in the call setup time is due to the additional propagation delay associated with these schemes.

It can also be noted that the call setup time for the push mode in the local segmentation as well as the end-to-end scheme is higher than the pull mode schemes when the inter-arrival time is small. As the inter-arrival time increases, the call setup time for both the modes in the local segmentation and the end-to-end schemes tend to approach each other. When the inter-arrival time is small, the call setup time is influenced by the queueing delays as well. Table 4.2 lists the number of messages that flows through each functional entity per connection setup request for the four schemes. It can be seen from the table that the APs and the P-CSCFs are the functional entities that are heavily loaded in all four cases. The queueing delay encountered in these entities is a major contributor to the call setup time.

Table 4.2: Number of messages processed by each FE per call setup request

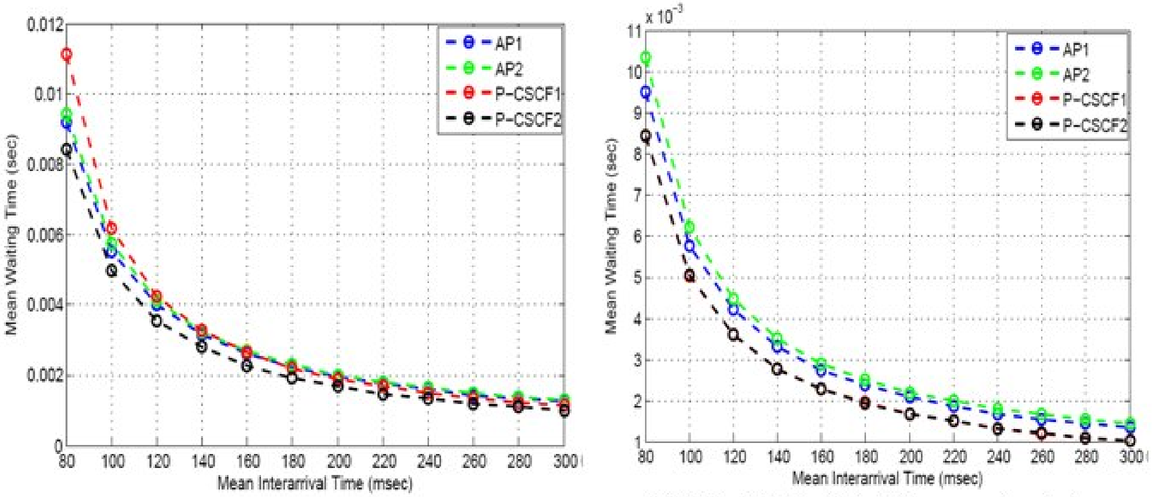
| FEs<br>Schemes | AP1/2 | BS1/2 | BRAS1 | BRAS2 | P-CSCF1 | P-CSCF2 | I-CSCF |
|---|---|---|---|---|---|---|---|
| LS Push | 10 | 7 | 4 | 4 | 11 | 11 | 1 |
| LS Pull | 10 | 7 | 3 | 3 | 10 | 10 | 1 |
| E2E Push | 10 | 7 | 7 | 6 | 11 | 10 | 1 |
| E2E Pull | 10 | 7 | 6 | 6 | 10 | 10 | 1 |

Figure 4.6 shows the increase in queueing delay at these entities with respect to the inter-arrival time. Note that in the case of push mode, as the P-CSCFs are responsible for initiating the QoS reservation as well as handling IMS messages, the waiting times and hence the queueing delay in their queues increases more rapidly than others as the inter-arrival time decreases. This leads to a higher call setup time for the end-to-end and local segmentation push schemes. It can also be noted from the figures that the queueing delays at the APs are higher than the P-CSCFs for the pull mode as the APs initiate the QoS reservation for these schemes.



(a) The LS Push QoS Reservation Scheme

(b) The LS Pull QoS Reservation Scheme



(c) The E2E Push QoS Reservation Scheme

(d) The E2E Pull QoS Reservation Scheme

Figure 4.6: Mean Waiting Time in APs and P-CSCFs versus Inter-arrival Time

Figure 4.7 shows the 95th percentile of the call setup time obtained for the four schemes, as a function of mean inter-arrival time. We used replications method to determine the 95th percentile values. Four replications with 125, 000 requests per replication were ran and first 5000 requests in each replication were discarded to account for the initial conditions. The 95th percentile value of the call setup time signifies that the call setup time obtained will be below that value 95 percent of the time. It can be seen from the figure that 95th percentile values exhibit similar characteristics to the mean call setup time values shown in Figure 4.5.

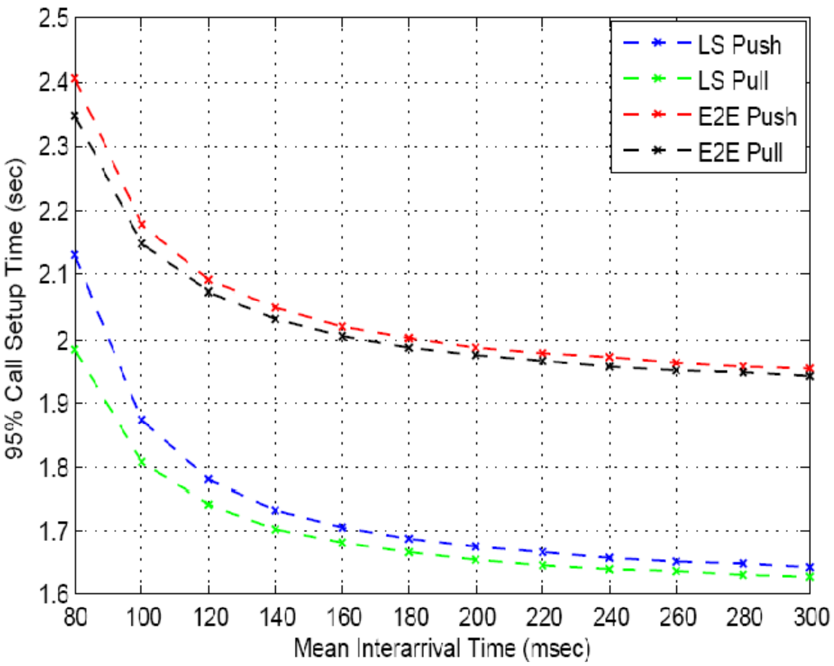


Figure 4.7: 95th Percentile Call Setup Time versus Inter-arrival Time

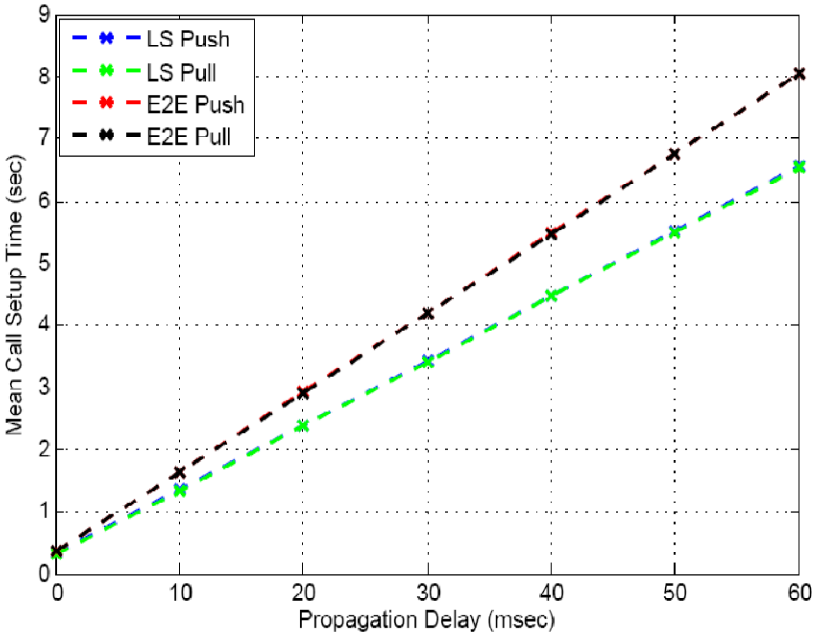


Figure 4.8: Mean Call Setup Time versus Propagation Delay

Figure 4.8 shows the results obtained by varying the propagation delay for every link in all the four models. The propagation delay across the AP–BS link was varied from 0 to 60 milliseconds and the delay across the other links was varied proportionally. The mean inter-arrival time and service time were fixed at 160 ms and 5 ms respectively. The results shown in Figure 4.5 were for a propagation delay of 10 ms. It can be seen from the Figure 4.8 that the call setup time increases linearly with the propagation delay for all the four schemes. The mean call setup time for the pull and push modes in the local segmentation and end-to-end schemes vary by a very small number so that they appear superimposed in the figure. Also, it is evident from the figure that when the propagation delay is 0 ms, the difference in the call setup time across the four schemes is close to zero. The difference then grows as the propagation delay increases.

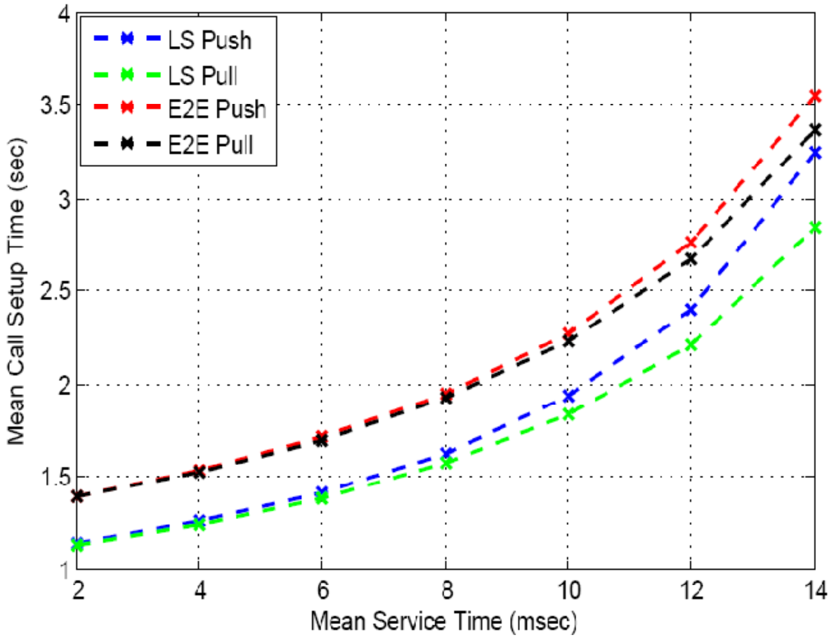


Figure 4.9: Mean Call Setup Time versus Service Time

Figure 4.9 shows the mean call setup time obtained by varying the service time of all the functional elements in all the four schemes. The mean service time was varied from 2ms to 14ms. The mean inter-arrival time and the propagation delay were fixed at 200 ms and 10 ms respectively. When the service time is lower, the call setup values for the push and pull modes tend to be close. As the service time increases, the push mode has a higher call setup time than the pull mode schemes. As seen previously, this is due to the effect of queueing at the P-CSCFs. Also, it can be noticed that the values for the local-segmentation push scheme approaches the end-to-end pull schemes for higher service time. Thus, for a given arrival rate, the benefit of local segmentation scheme in the push mode is lost if the mean service time of the CSCFs are higher.

A few observations can be made from the results presented in this chapter. The effect of propagation delay is almost the same for all the four schemes and is not as pronounced as the effect of service times. As the service time increases, the time spent per request in each FE increases, directly affecting the call setup time. This also causes the queueing in the key FEs such as, the P-CSCFs, to increase rapidly. Moreover, it can be seen that the pull mode schemes perform better than the push mode schemes. This is because, in case of the push mode schemes, as the P-CSCFs process more number of messages per call setup request than the other FEs, the waiting times at the P-CSCF queues increase faster than those of the other FEs making them the bottleneck. This is not seen in case of the pull mode as the APs handle the QoS reservation sharing the load.

ITU-T E.721 [38] recommends network grade of service parameters for circuited-switched services in ISDN. According to this document, the recommended values for call setup (post-dial delay) are 3 seconds for local, 5 seconds for toll and 8 s for international connections. The 95th percentile values are 6 seconds for local, 8 seconds for toll and 11 seconds for international connections. Considering a connection in our reference network as a local connection, it can be seen from our results that the mean and the 95th percentile call setup times are well within these values even for a low inter-arrival time of 80 milliseconds. Also, it can be noted the propagation delay in the WLAN-WiMAX link can be up to 20 milliseconds and the service time of the functional entities can be up to 12 milliseconds for the values to be within the recommended limits.

# Chapter 5

# Conclusions and Future Work

In this thesis, we considered the establishment of a connection with end-to-end QoS constraints that spans over several heterogeneous wireless and wireline networks, such as, Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), Metro Ethernet, Multiprotocol Label Switching (MPLS)-based and Differentiated Services (Diffserv)-based Wide Area Networks (WANs). The end-to-end QoS architecture under study follows the ITU-T NGN QoS architecture [1] with the connection setup triggered using the 3GPP IMS [2] signaling.

We began with presenting the signaling details for a basic session setup in the reference network using IMS messages for the two modes, namely, the push and pull modes. We then proceeded to show how the QoS interworking across various technologies such as, WLAN, WiMAX, PBB-TE, MPLS and Diffserv that are used in our reference network can be achieved. Further, we introduced four different schemes for QoS reservation in the reference network and furnished detailed signaling flows for all four schemes. We also suggested a mapping of QoS parameters across the various technologies for different classes of traffic that can be used during QoS resource reservation signaling.

We compared the four QoS reservation schemes using simulation techniques. We measured the mean call setup time for all the four schemes by varying the inter-arrival time, service time and the propagation delay. The P-CSCFs and the APs were the key functional elements those were identified as the bottleneck points in all the four schemes in our experiments. The results show that local segmentation schemes perform better than the end-to-end schemes for a given service time and propagation delay. Also, the pull mode schemes have lower call setup time than the push mode schemes for higher arrival rates. Overall, our results indicate that local segmentation pull QoS reservation scheme performs better than the others as it minimizes the effect of both propagation delay and queueing delay. Also, the call setup time values obtained are also in line with the E.721 recommendation.

Our work can be extended in the following direction:

- In this thesis, we have analyzed the schemes considering First-In-First-Out queueing discipline for all the queues at the functional elements. This can be extended to introduce priorities among the IMS messages based on several factors such as, user subscription, application type and age of a message.
- Our analysis only includes fixed WiMAX in the access portion of our reference network. This could be extended to wireline networks, mobile WiMAX and a mixture of both. In addition to that, signaling scenarios and performance related to user mobility can be investigated.
- We have used simulation techniques to evaluate the performance of our schemes. The next step would be to have a test bed implementation of the reference network in order to obtain accurate performance estimates of the proposed schemes, and compare them against the simulation data.

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