Performance Analysis of Error Recovery Schemes in High Speed Network - Part I

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1 Introduction

In recent years, the advances in fiber optics technology and the demand for the transmission of packetized voice , video, and data have brought us into a high speed communication environment. The usage of fiber optics as a communication media results in very low bit error rate. Furthermore, the increase of the transmission speed makes the propagation delay of the medium no longer negligible.

In this paper we have concentrated on the performance analysis of the error recovery schemes which are usually performed in the high speed communication environment. Basically, there are two error recovery schemes in the high speed network:

- Frame switching scheme — link-by-link error recovery approach.
  Two adjacent nodes in a path locally detect and recover from packet error or loss.
- Frame relay scheme — end-to-end error recovery approach.
  Error recovery is done solely between the source and the destination node.

We have performed a static and a dynamic analysis of the above error recovery schemes and in this paper we provide conclusion about their performance under different conditions of traffic load on and error rate in the communication system.

2 Frame Switching and Frame Relay Error Recovery Schemes

In a high speed computer communication network, there are two major error recovery schemes, the frame switching and the frame relay scheme. As shown in Fig(1), the frame switching is a link-by-link error recovery scheme, where the link layer of two adjacent nodes will perform error detection and error recovery functions. The time for each node to transmit a packet is the sum of the LLC layer processing time and the packet transmission time. If an error occurs, the packet will be retransmitted until it is correctly received by the next node. A node will keep a copy of the transmitted packet until an ACK message from the next node is received. If an ACK message of a transmitted packet is not received within a timeout period, the packet will be retransmitted. We assume that a timeout will happen if a packet is in error or lost.

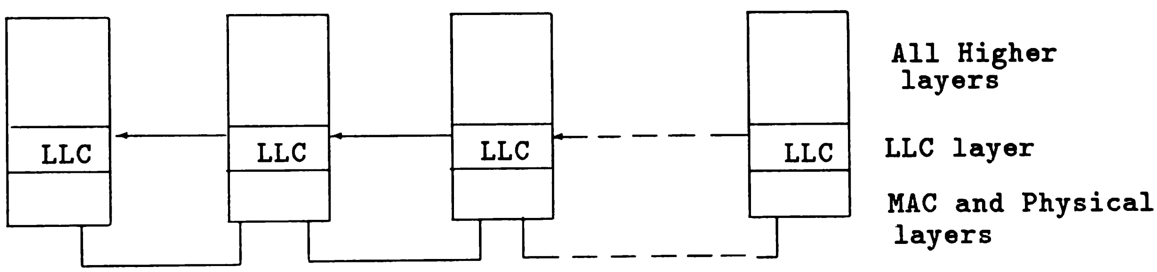


Fig1 Network layer model -- Frame Switching

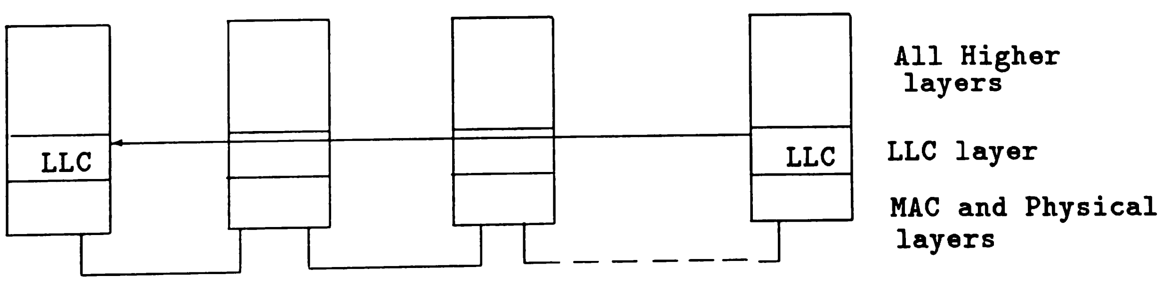


Fig2 Network layer model -- Frame Relay

Frame relay scheme, shown in Fig(2), is an end-to-end error recovery scheme, where any detected errors are corrected within peer communication between the source and the destination node of the network. In this scheme, an intermediate node will not experience the LLC processing time to transmit a packet. The source and the destination node will of course have the LLC processing time. If a packet is in error or lost during the transmission, the source node will eventually timeout and retransmit the packet. We assume that the source node has enough buffer to store the new arriving packets and the retransmitted packets until an ACK message of the packet from the destination node is received.

3 Static Analysis

In this secction we present results from a static analysis of the two schemes. In this analysis we assume that the behavior of the system is independent of traffic loading. This is clearly not realistic but the results from the analysis will provide us with a bound on the relative merits of the two schemes. In this analysis we only consider the effect of packets in error due to transmission errors. The impairments due to possible loss of a packet caused by insufficient buffer space are ignored. This is of course consistent with the assumption of traffic independent behavior.

3.1 Frame Switching — Link-by-link Scheme

In the frame switching scheme, error detection and error recovery are done in the link layer of each node in the network. If a packet can not be successfully received by a node , it is retransmitted from the preceding node.

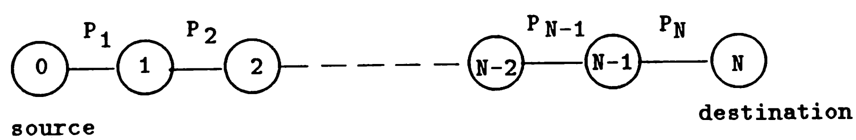


Fig3 A single path

A simple path from the source to the destination node is shown in Fig(3). For simplicity, we have assumed that the geographical distance between each node is the same. For the static analysis , we use the following definitions.

N — the number of hops needed to transmit a packet from the source node to the destination node.

ε — the bit error rate of a link.

p_i — packet length $\times\ \varepsilon$, the probability that a packet will be in error when it passes through link i.

N_r^i — $\frac{p_i}{1-p_i}$,the average number of retransmission needed to get a successful transmission from node i-1 to node i.

t_{prop} — the propagation delay in each link.

t_{packet} — the average transmission time for a packet.

t_{NAK} — the average transmission time for a NAK.

t_{LLC} — the processing time at the LLC layer.

$T_{success}$ — the average time spent in one transmission from node i-1 to node i if the transmission is successful.

T_{fail} — the average time spent in one transmission from node i-1 to node i if the transmission is not successful.

T_{fs} — the average packet delay between the transmission of a packet from the source node and the correct reception of the packet at the destination node.

In the static analysis, we neglect the queueing time. Thus, we have

$$T_{fs} = \sum_{i=1}^{N} \left[T_{success} + N_r^i \times T_{fail}\right] = \sum_{i=1}^{N} \left[T_{success} + \frac{p_i}{1-p_i} \times T_{fail}\right] \qquad (1)$$

where

$$T_{success} = t_{LLC} + t_{prop} + t_{packet}$$

$$T_{fail} = 2 \times (t_{LLC} + t_{prop}) + t_{packet} + t_{NAK}$$

3.2 Frame Relay — End-to-end Scheme

In frame relay scheme, the error recovery is done between the source and the destination node. If a packet is received in error at an intermediate node, we assume that the destination node will detect the error situation and send a NAK through the network to the source node. We also assume that the NAK message will not be in error in this analysis. If a packet is received correctly at an intermediate node, the packet will be transmitted immediately to the next node.

Let N be the number of hops in the path from the source node to the destination node and let p_i be the probability that a packet transmitted by node i-1 and received at node i is in error. Then, the probability that a transmission of a packet from the source node is received in error at node k is given by :

$$\prod_{i=1}^{k-1}(1 - p_i) \times p_k.$$

If a packet is received in error at node k , the overhead will be T_k, where

$$T_k = t_{LLC} + k \times (t_{packet} + t_{prop}) + t_{LLC} + t_{NAK} + N \times t_{prop}. \tag{2}$$

If no errors occurred in the transmission, the time to transmit a packet from the source node to the destination node is equal to T_{succ}.

$$T_{succ} = t_{LLC} + N \times (t_{packet} + t_{prop}) + t_{LLC}.$$

Let T_{fr} be the average packet delay between the transmission of a packet from the source node and the correct reception of the packet at the destination node. We find that

$$T_{fr} = \prod_{i=1}^{N}(1 - p_i) \times T_{succ} + \sum_{k=1}^{N}\left[\prod_{j=1}^{k-1}(1 - p_j) \times p_k \times (T_k + T_{fr})\right] \tag{3}$$

and solving for T_{fr}

$$\left[1 - \sum_{k=1}^{N} \prod_{j=1}^{k-1} (1 - p_j) \times p_k\right] \times T_{fr} = \prod_{i=1}^{N} (1 - p_i) \times T_{succ} + \sum_{k=1}^{N} \prod_{j=1}^{k-1} (1 - p_j) \times p_k \times T_k$$

Finally the average packet delay T_{fr} can be written as :

$$T_{fr} = \frac{\prod_{i=1}^{N} (1 - p_i) \times T_{succ} + \sum_{k=1}^{N} \prod_{j=1}^{k-1} (1 - p_j) \times p_k \times T_k}{1 - \sum_{k=1}^{N} \prod_{j=1}^{k-1} (1 - p_j) \times p_k} \quad (4)$$

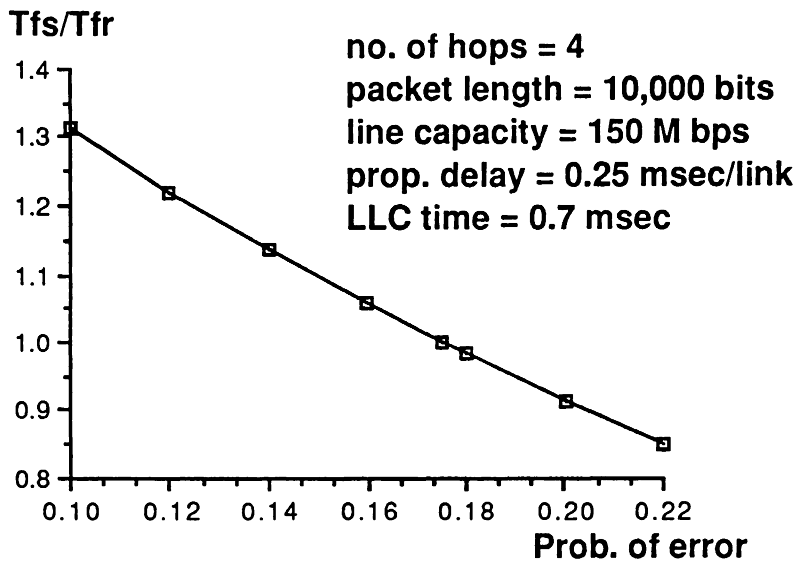
4 Results from Static Analysis

In the comparison of the results from the static analysis, we normalize the average delay based on the packet transmission time. In Fig(4), we compare the ratio of the average delay of the frame switching and the frame relay schemes, T_{fs}/T_{fr} , for different values of the packet error probability. Fig(5) shows the average end-to-end packet delay for the frame switching and frame relay schemes. The number of hops between the source and destination node is 4 for this case. The average packet size is 10,000 bits. We assume that each link has the same capacity 150 Mbps and the propagation delay for each link is 0.25 msec. The LLC processing time is set to 0.7 msec.

In Fig(6) and Fig(7), we display the case where the number of hops between the source and the destination node is increased to 12. The results indicate that with small packet error probability , the frame relay scheme has shorter packet delay than the frame switching scheme. As the error probability increases , the average packet delay of the frame relay will increase faster than the frame switching scheme. In Fig(7), we find that when the number of hops is 12, the error probability of the cross over of the two error recovery schemes will drop to 0.07.

Fig(8) shows the effect of the number of hops on the average packet delay for the two error recovery schemes. In Fig(9) , the bit error probability is selected to be $2 * 10^{-8}$ and we vary the packet length. The result indicates that when the packet length is greater than 300 K bits, the two error recovery schemes have almost the same performance.

In the static analysis, the model has been simplified . We will consider more complicated model in the dynamic analysis, but the results from the static analysis can still give us a good insight in how the two error recovery schemes perform in the high speed communication network.



Fig(4) Ratio of the delay of the two schemes

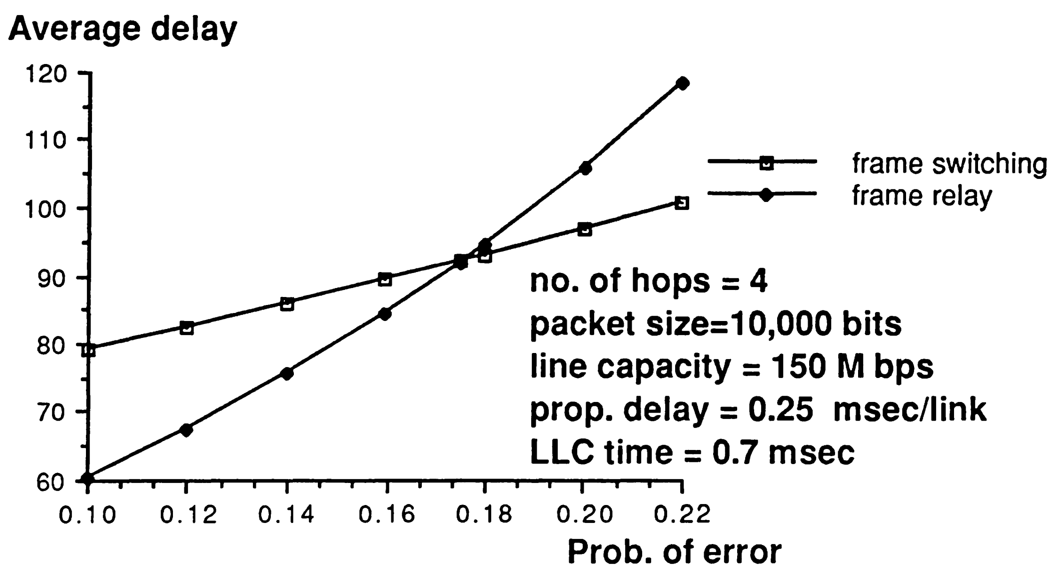
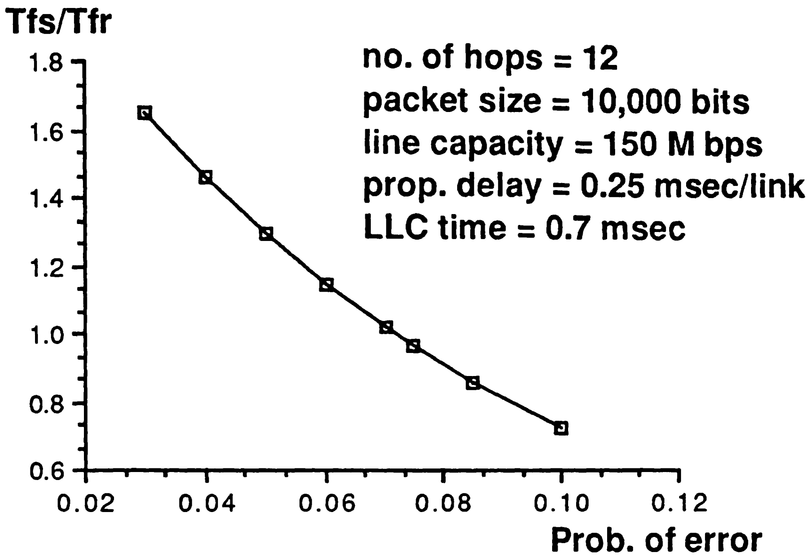
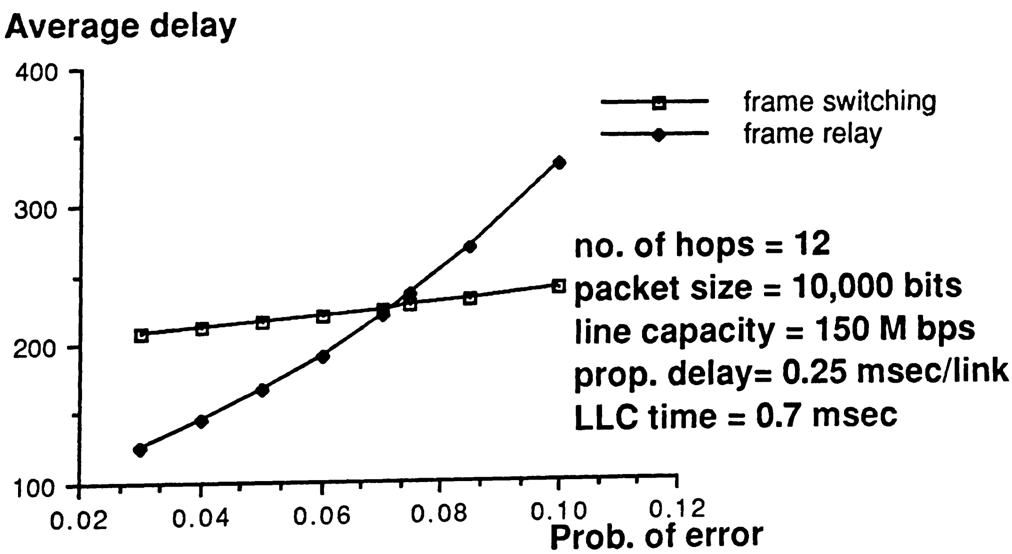


Fig (5) Average end-to-end delay



Fig(6) Ratio of the delay of the two schemes



Fig(7) Average end-to-end delay

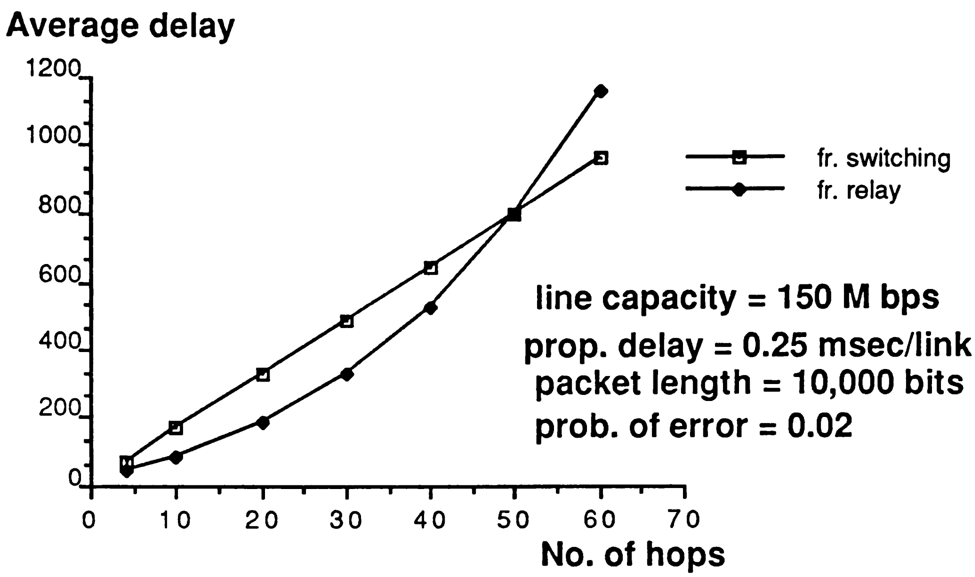


Fig (8) The effect of the number of hops

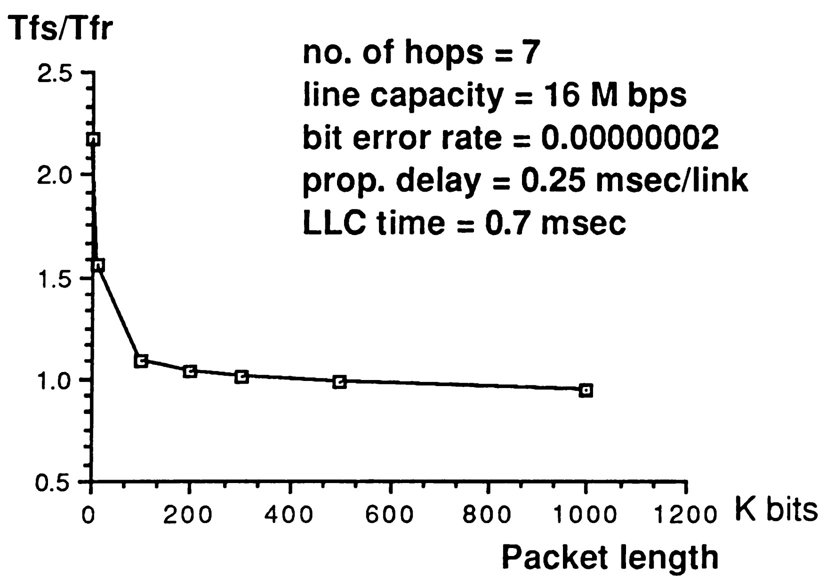


Fig (9) The effect of the packet length

5 Dynamic Analysis

5.1 Network Model

The model for the dynamic analysis will be based on a virtual circuit channel in the communication network. In this model, we will consider the effect of different factors such as channel errors, finite buffer , propagation delay, timeout mechanism, and traffic load.

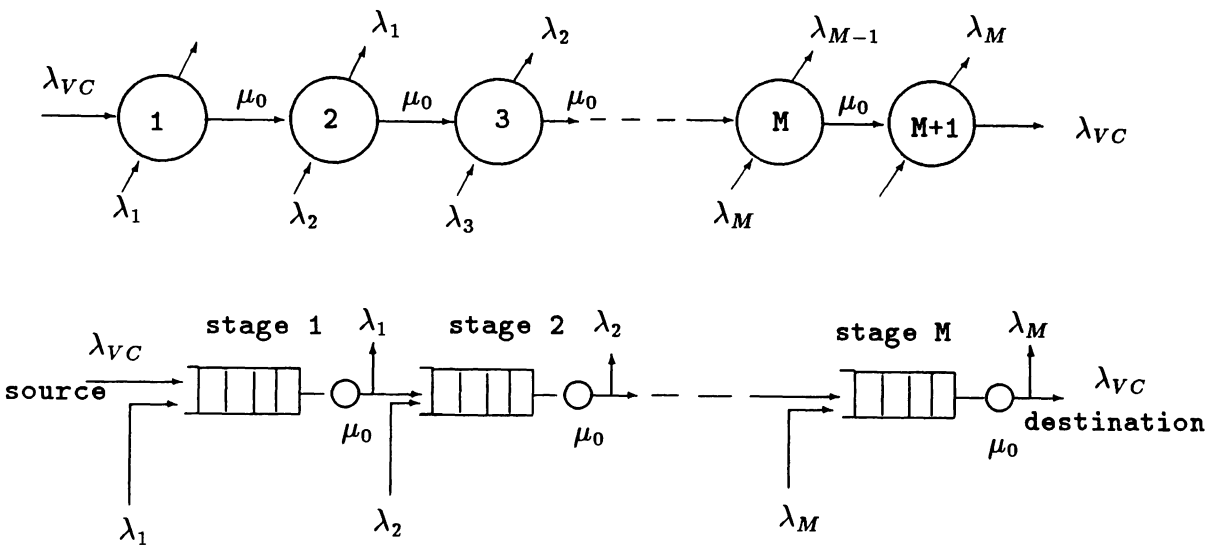


Fig 10 virtual circuit model (before capacity reduction)

A simple virtual circuit model and its corresponding queueing model are shown in Fig(10). We assume that each node will maintain a separate buffer for each virtual circuit. Let's denote the average arrival rate of the traffic along the link of the virtual circuit as λ_{VC} , the mean message transmission rate of each link as μ_0, and the external traffics at node i as $\lambda_i, i = 1,2,\cdots,M$. The external traffic will share the link capacity with the normal traffic λ_{VC}. This will cause a reduction of the link capacity for transmitting the normal traffic along the virtual circuit. By capacity reduction[4], we can get the tandem configuration of the virtual circuit as shown in Fig(11), where μ_i is the effective capacity of link i in the virtual circuit. In the following sections, we adopt the approach in [1,2] and focus on the effect of the traffic λ_{VC} to perform the dynamic analysis of the frame switching and frame relay error recovery schemes.

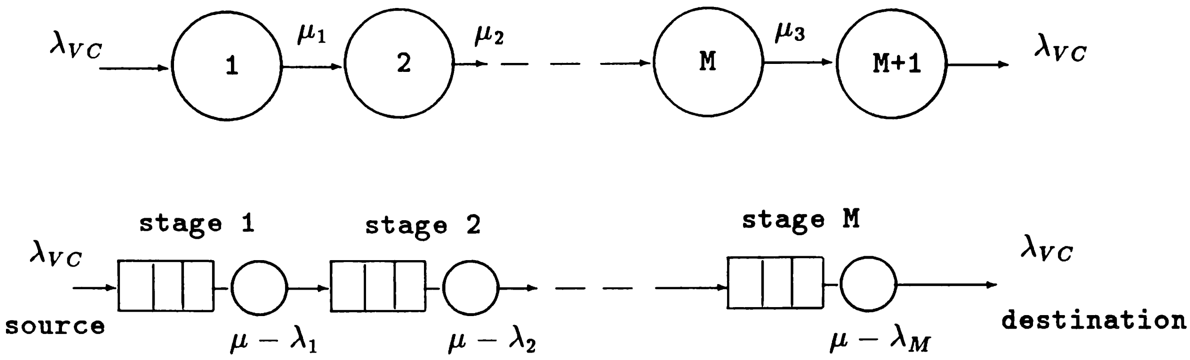


Fig 11 virtual circuit model (after capacity reduction)

5.2 Frame Relay — End-to-end Scheme

In the frame relay error recovery scheme, the function of an intermediate node is very simple. If an intermediate node receives a packet in error or the packet is received correctly but the buffer size is full, it simply discards the packet. When the timeout period is expired, the source node will retransmit the packet along the virtual circuit. If a packet is received correctly and the buffer size of the receive node is not full , the packet will be allocated a space for storage waiting for transmission. The source node of the virtual circuit will buffer the transmitted packet until an ACK message from the destination node is received. We assume that the source node has an infinite buffer size for the incoming traffic.

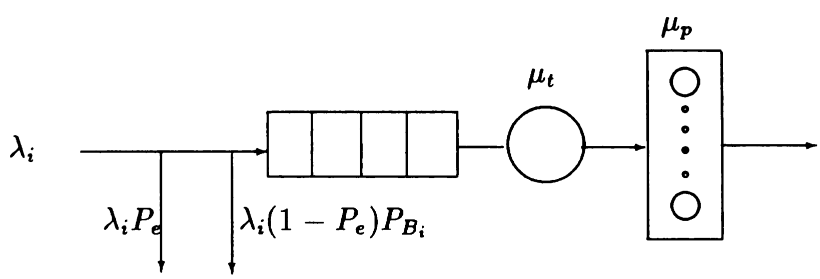


Fig 12 Single link queueing model of frame relay scheme

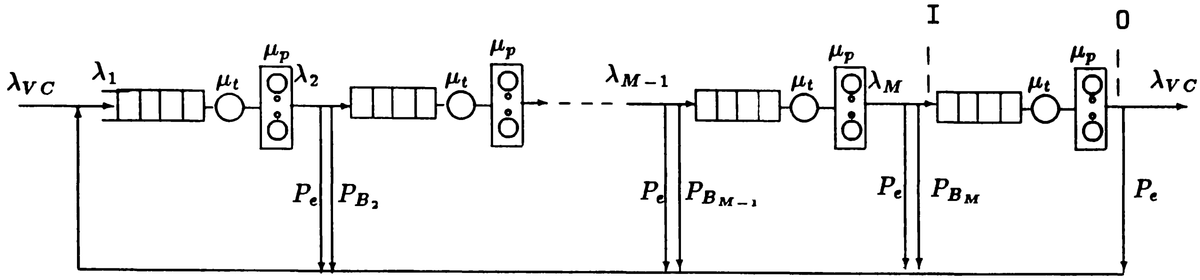


Fig 13 Complete VC queueing model of frame relay scheme

A single link and a complete virtual circuit model of the end-to-end error control are shown in Fig(12) and Fig(13) . We assume that the traffic at each node is a Poisson process with rate λ_i. So, a single outgoing link can be modeled as an M/M/1/K queueing system. K is the maximum number of packets that a node can hold for transmission. For simplicity, we assume that all the nodes along the virtual circuit have the same service rate , propagation delay and finite buffer size. We let μ_t and $1/\mu_p$ be the mean packet transmission rate of each link and the mean propagation delay time through each link respectively. With the probability P_e , a packet may be in error when it passes through a link of the virtual circuit. The steady state blocking probability of a node i is denoted as P_{B_i}. To compute the packet delay, we have to find the blocking probability P_{B_i} and the traffic rate λ_i. In steady state, the traffic rate at point I and the traffic rate at point O, see Fig(13), should be the same. We thus get

$$\lambda_M = \frac{\lambda_{VC}}{(1-P_e)^2 \times (1-P_{B_M})} \tag{5}$$

$$\lambda_i = \frac{\lambda_{i+1}}{(1-P_e)(1-P_{B_i})} \qquad ,i = 2,3,\cdots,M-1. \tag{6}$$

$$\lambda_1 = \lambda_2 \tag{7}$$

Let's define:

$$\rho_1 = \frac{\lambda_1}{\mu_t}$$

then,

$$\rho_i = \frac{\lambda_i \times (1 - P_e)}{\mu_t} \qquad , i = 2, 3, \cdots, M. \tag{8}$$

From the analysis of an M/M/1/K system, we get the blocking probability at node i to be equal to

$$P_{B_i} = Prob[n_i = K] = \frac{(1-\rho_i)\rho_i^K}{1-\rho_i^{K+1}}, i = 2, 3, \cdots, M. \tag{9}$$

Using equations (5),(8),and (9), we can solve for λ_M and P_{B_M}. Once we get the values of λ_M and P_{B_M} , we can solve for λ_{M-1} and $P_{B_{M-1}}$. With the same method, we can also find λ_i and P_{B_i}, i= 1,2,$\cdots$,M. Let n_i and N_i be the number of packets in the node i and the average number of packets in the node respectively. Thus, we have

$$N_1 = \frac{\rho_1}{1-\rho_1} \tag{10}$$

$$N_i = \sum_{j=0}^{K} Prob[n_i = j] \times j = \sum_{j=0}^{K} j \times \frac{(1-\rho_i)\rho_i^j}{1-\rho_i^{K+1}} \tag{11}$$

or

$$N_i = \begin{cases} \frac{\rho_1}{(1-\rho_1)} & , i = 1 \\ \frac{\rho_i}{1-\rho_i} - (K+1) \times \left(\frac{\rho_i^{K+1}}{1-\rho_i^{K+1}}\right) & , i = 2, 3, \cdots, M. \end{cases}$$

From Little's law, we can find the system time of a packet at node i, denoted as T_i:

$$T_i = \frac{N_i}{\lambda_{effective}}$$

$$= \begin{cases} \frac{N_1}{\lambda_1} & i = 1 \\ \frac{N_i}{\lambda_i \times (1 - P_e - P_{B_i} + P_e P_{B_i})} & i = 2, 3, \cdots, M. \end{cases}$$

For the rest of the analysis we need the following definitions:

P_i — probability that a transmitted packet from node i may not be accepted by node i+1.

P_f — probability that a transmission of a packet from the source node may fail in the middle of the virtual circuit.

n_r — number of retransmissions of a packet before it is received correctly by the destination node.

N_r — average number of retransmissions of a packet before it is received correctly by the destination node.

Timeout — end-to-end timeout interval of the virtual circuit.

t_{LLC} — LLC processing time.

T_{fr} — average end-to-end delay of a packet in the frame relay error recovery scheme.

We find that

$$P_i = P_e + P_{B_{i+1}} - P_e P_{B_{i+1}}, \qquad i = 1, 2, \cdots, M-1, \tag{12}$$

$$P_M = P_e. \tag{13}$$

and

$$P_f = \sum_{i=1}^{M} \prod_{j=1}^{i-1} (1 - P_j) P_i.$$

$$Prob[n_r = k] = (P_f)^k (1 - P_f)$$

and the average number of retransmissions

$$N_r = \sum_{k=0}^{\infty} k Prob[n_r = k] \tag{14}$$

$$= \sum_{k=0}^{\infty} k (P_f)^k (1 - P_f) \tag{15}$$

$$= \frac{P_f}{1 - P_f}. \tag{16}$$

Therefore, the average interval between a packet transmitted from the source node and its successful reception at the destination node is

$$T_{fr} = N_r \times (t_{LLC} + T_1 + Timeout) + t_{LLC} + \sum_{i=1}^{M} T_i. \tag{17}$$

5.3 Frame Switching—Link-by-link Scheme

In the frame switching scheme, the error recovery is done by two adjacent nodes along the virtual circuit. Each node of the virtual circuit will buffer a packet which has been transmitted until an ACK message for the packet is received from the next node . If an ACK message of a transmitted packet is not received within a timeout period, the packet will be retransmitted. We assume that a timeout occurs if the packet is lost or the packet is in error.

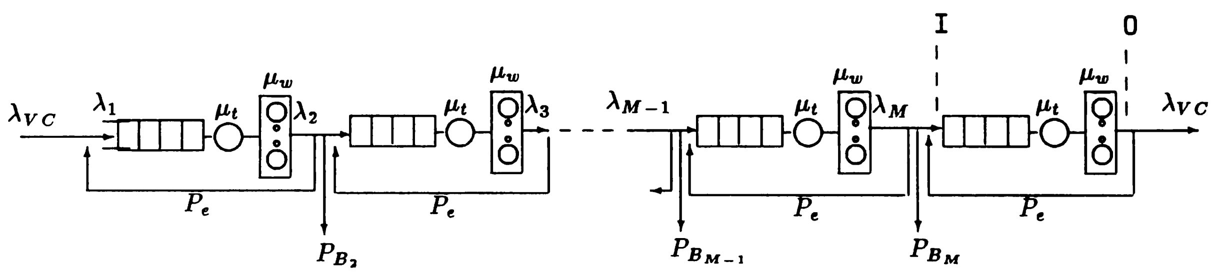


Fig 14 complete VC queueing model of frame switching

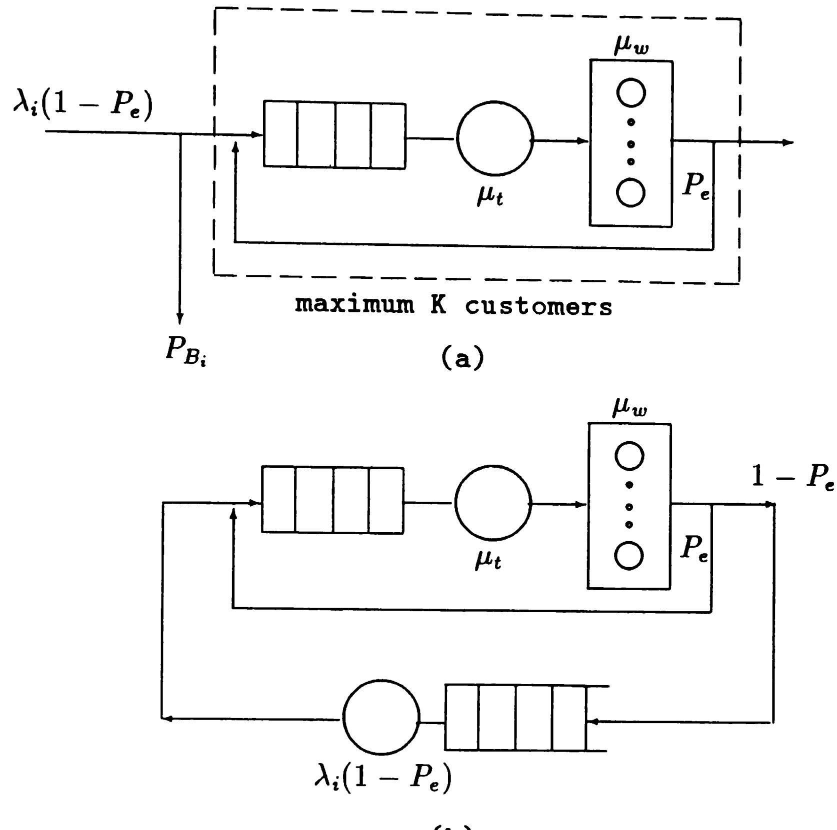


Fig 15 Single link queueing model in frame switching

A single link and complete virtual circuit queueing model of the frame switching scheme are shown in Fig(15) and Fig(14). We assume that each node of the virtual circuit has the same service rate and finite buffer size. Since the transmitted packets have to wait for an ACK message, the customers in the infinite server queue represent the packets for which a timeout period has been started. The time $1/\mu_w$ is equal to the timeout period, which is in turn assumed equal the sum of twice the propagation delay time + the LLC processing time + the NAK message transmission time. So, the actual total number of packets buffered at node i is equal to the sum of the number of packets in the transmission queue and the infinite server queues. If the number of packets buffered at node i is equal to K, all the incoming traffic will be blocked. So, the queueing system in Fig (15a) can be modeled as a closed queueing network, shown in Fig (15b).

In order to find the end-to-end packet delay, we have to find the system time at each node of the virtual circuit. Let's observe the traffic at point I and point O in Fig(14).

In steady state, the incoming traffic rate at point I is equal to the outgoing traffic rate at point O. So, we get

$$\lambda_M(1-P_e)(1-P_{B_M}) + \frac{\lambda_{VC}}{1-P_e} \times P_e = \frac{\lambda_{VC}}{1-P_e}.$$

and

$$\lambda_i(1-P_e)(1-P_{B_i}) + \lambda_{i+1} \times P_e = \lambda_{i+1}$$

i.e.

$$\lambda_M = \frac{\lambda_{VC}}{(1-P_e)(1-P_{B_M})} \tag{18}$$

$$\lambda_i = \frac{\lambda_{i+1}}{1-P_{B_i}} \quad , for \quad i = 2, \cdots, M-1. \tag{19}$$

$$\lambda_1 = \lambda_2 \tag{20}$$

Let's denote the queue with service rate $\lambda_i(1-P_e)$ in Fig(15b) to be queue 3, and queue 1 and queue 2 to be the transmission queue and the infinite server queue, respectively. We define n_1,n_2,and n_3 to be the corresponding number of customers in queue 1, queue 2, and queue 3. We now get the product form solution from the closed queueing network shown in Fig(15b) as

$$Prob(n_1, n_2, n_3) = \frac{1}{G(K)} \rho_1(n_1)\rho_2(n_2)\rho_3(n_3), \qquad n_1 + n_2 + n_3 = K. \tag{21}$$

where,

$$\rho_1(n_1) = \left(\frac{\lambda_i}{\mu_t}\right)^{n_1}$$

$$\rho_2(n_2) = \left(\frac{\lambda_i}{\mu_p}\right)^{n_2} \times \frac{1}{n_2!}$$

and

$$\rho_3(n_3) = \frac{[\lambda_i(1-P_e)]^{n_3}}{[\lambda_i(1-P_e)]^{n_3}} = 1.$$

This gives us

$$Prob(n_1, n_2, n_3) = \frac{1}{G(K)} \times (\frac{\lambda_i}{\mu_t})^{n_1} (\frac{\lambda_i}{\mu_p})^{n_2} \times \frac{1}{n_2!} \quad (22)$$

$$= \frac{1}{G(K)} \times (\rho_1)^{n_1} (\rho_2)^{n_2} \times \frac{1}{n_2!} \quad (23)$$

where G(K) is a normalization factor. Since,

$$1 = \sum_{n_1+n_2+n_3=K} Prob(n_1, n_2, n_3)$$

we get :

$$G(K) = \sum_{n_2=0}^{K} \sum_{n_1=0}^{K-n_2} \frac{(\rho_1)^{n_1}(\rho_2)^{n_2}}{n_2!}$$

The blocking probability, P_{B_i} , that all buffers in node i are full, is given by :

$$P_{B_i} = \sum_{n_1=0}^{K} Prob(n_1, K-n_1, 0) \quad (24)$$

$$= \sum_{n_1=0}^{K} \frac{1}{G(K)} \times \frac{(\rho_1)^{n_1}(\rho_2)^{K-n_1}}{(K-n_1)!} \quad (25)$$

The average number of packets in the transmission queue is N(i) . Where,

$$N(i) = \sum_{n_1=0}^{K} n_1 \sum_{n_2=0}^{K-n_1} \frac{1}{G(K)} \frac{(\rho_1)^{n_1}(\rho_2)^{n_2}}{(n_2)!}$$

From Little's law, the system time that a packet spent in the transmission queue is given by $T_1(i)$:

$$T_1(i) = \frac{N(i)}{\lambda_{effect}} \qquad ,i = 2,3,\cdots,M. \tag{26}$$

$$= \frac{N(i)}{\lambda_i(1 - P_e - P_{B_i} + P_e P_{B_i})} \tag{27}$$

Since the first node has an infinite buffer, we can model it as an M/M/1 queue . So, the system time for the first node is given by :

$$T_1(1) = \frac{N(1)}{\lambda_1} = \frac{(\frac{\rho_1}{1-\rho_1})}{\lambda_1}. \tag{28}$$

We now need the following definitions:

P_i — the probability that a packet transmitted from node i may not be accepted by node i+1.

Timeout — link timeout interval. The timeout interval is equal to $1/\mu_w$, and it begins when a transmission of a packet is completed.

n_r^i — number of retransmissions needed of a packet from node i before it is correctly received by node i+1.

N_r^i — mean value of the n_r^i.

T(i) — average delay a packet experiences passing through link i.

t_{LLC} — LLC processing time.

T_{fs} — average end-to-end packet delay in the frame switching scheme.

So, we have

$$P_i = P_e + P_{B_{i+1}} - P_e P_{B_{i+1}}. \tag{29}$$

$$P[n_r^i = k] = (P_i)^k(1 - P_i). \tag{30}$$

$$N_r^i = \sum_{k=1}^{\infty} kP[n_r^i = k] = \frac{P_i}{1 - P_i}. \tag{31}$$

$$T(i) = N_r^i \times (t_{LLC} + T_1(i) + Timeout) + t_{LLC} + T_1(i) + \frac{1}{\mu_p} \tag{32}$$

The average end-to-end packet delay for the frame switching scheme is given by:

$$T_{fs} = \sum_{i=1}^{M} T(i). \tag{33}$$

6 Results from Dynamic Analysis

In the results of the dynamic analysis, the average packet length is set to 10,000 bits, the link capacity is 150 M bps, and the propagation delay is 0.25 msec/link.

In Fig(16) and Fig(17) , we compare the average packet delay along the virtual circuit for the frame switching and the frame relay scheme. The results indicate that under low error rate condition, the frame relay scheme has better performance(shorter delay). This is due to the processing overhead in the LLC layer of the frame switching scheme. The reason why , in Fig (16) , the frame switching scheme will saturate very quickly is due to the finite buffer size problem. In the frame switching scheme, a packet will be held in a node until an ACK message from the next node is received. Since the buffer size(K=10) is too small, the blocking probability will become a important factor to the packet delay. After we increase the error probability the delay curves of the frame switching and the frame relay scheme have a cross point when the throughput is about 0.76, see Fig(18). This indicates that under light traffic the frame relay scheme can have shorter delay in wider range of traffic than the frame switching scheme. However, if we let the error probability increase more , in Fig(19), we will find that the frame switching error recovery scheme will perform better.

Fig(20) and Fig(21) show us the effect of the number of hops between the source and the destination node to the packet delay of the two error recovery schemes. The result shows that under a particular condition, if we keep the number of hops between the source and the destination node below a certain number , the frame relay scheme can have shorter packet delay. In Fig(20) and Fig(21) , we fix the number of hops, the buffer size, and the throughput to observe the effect of the error probability to the average delay of the two error recovery schemes. We find results similar to the results obtained in the static analysis.

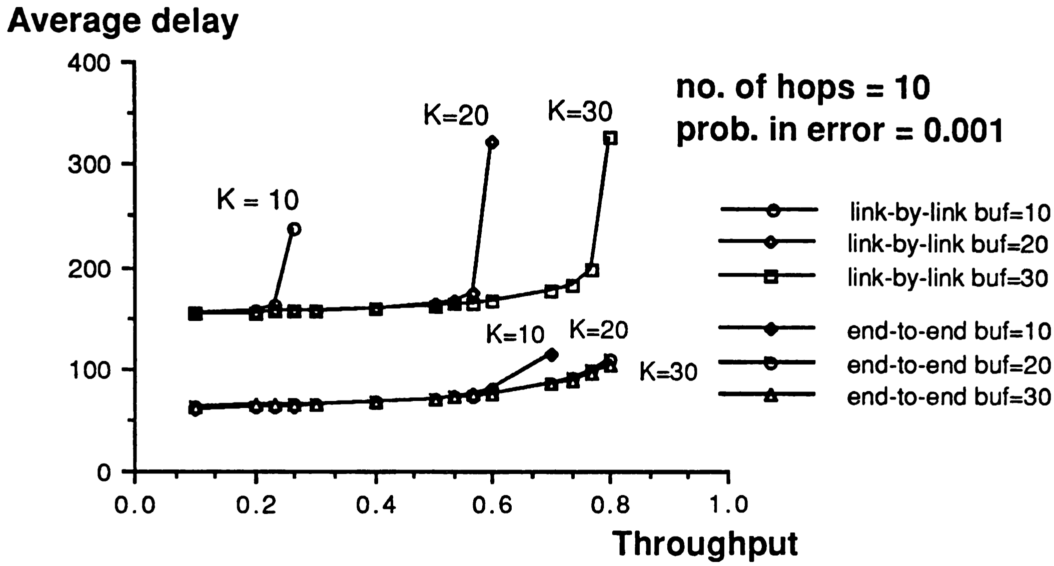


Fig (16) Average packet delay, with low error rate

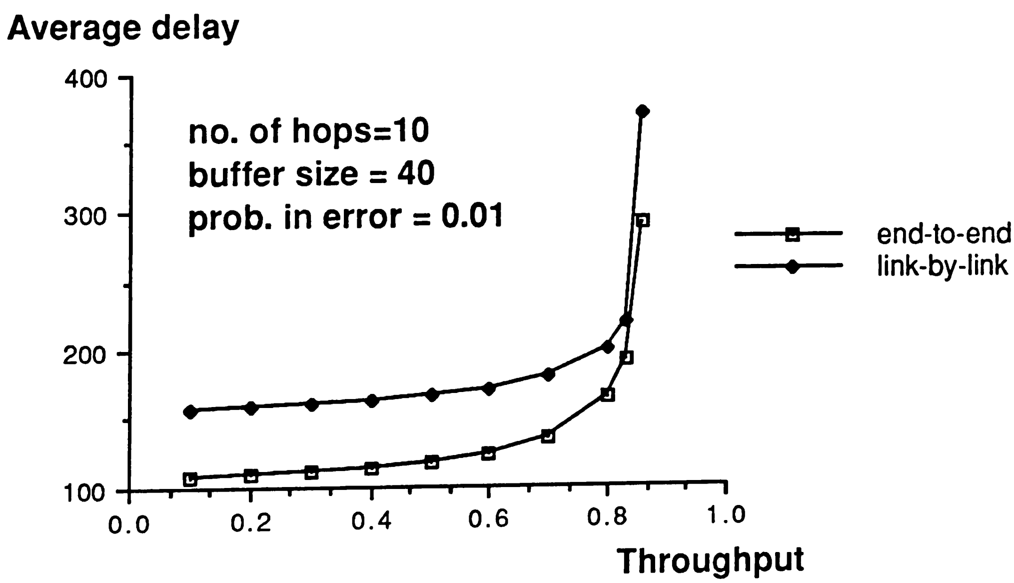


Fig (17) Average packet delay, with low error rate

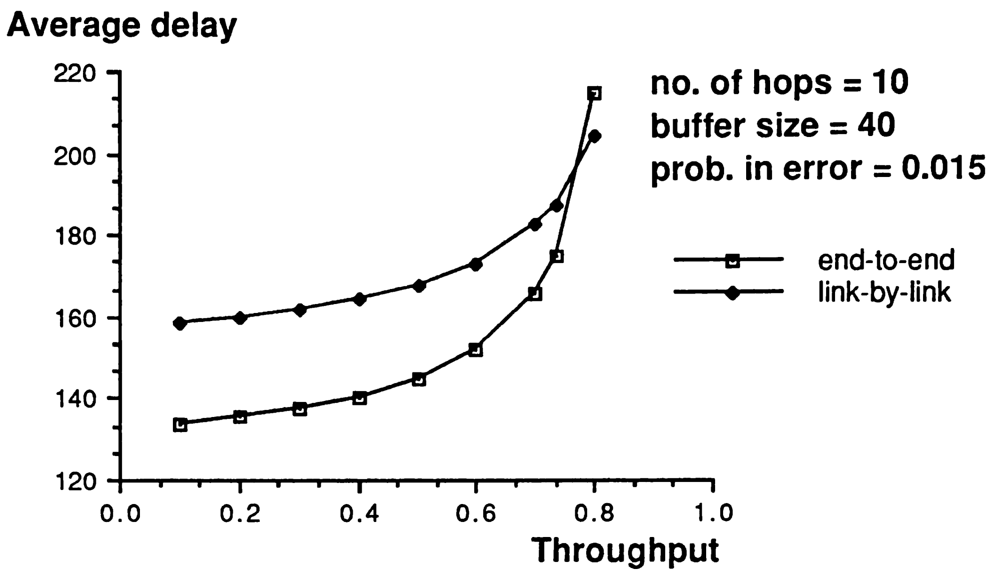


Fig (18) Average packet delay, with high error rate

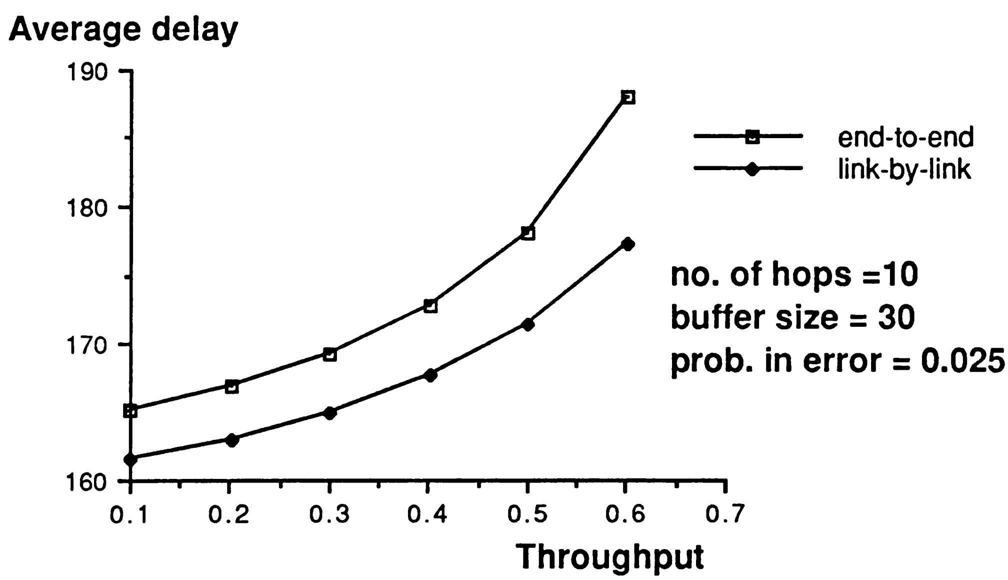


Fig (19) Average packet delay, with high error rate

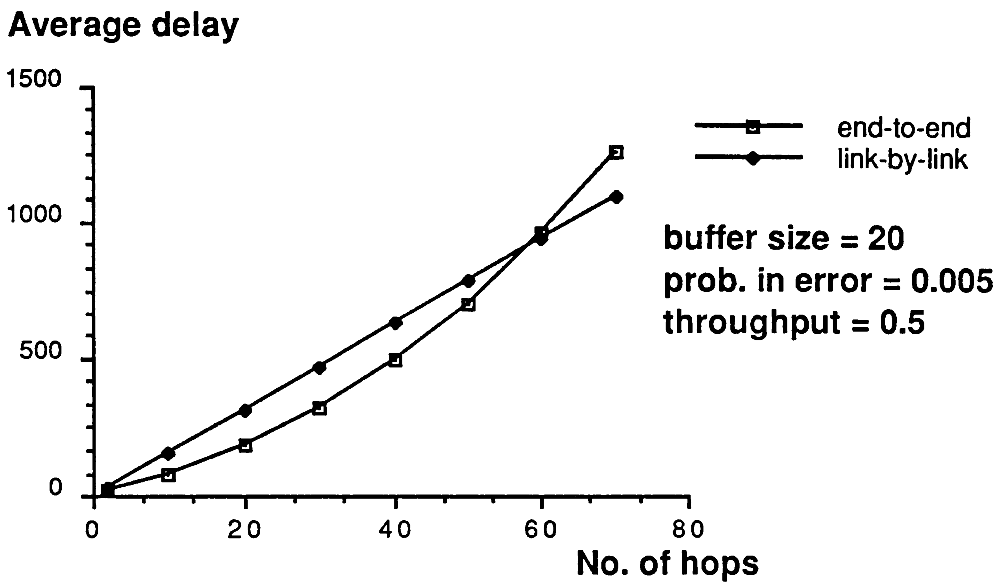


Fig (20) Effect of the number of hops, with lower error rate

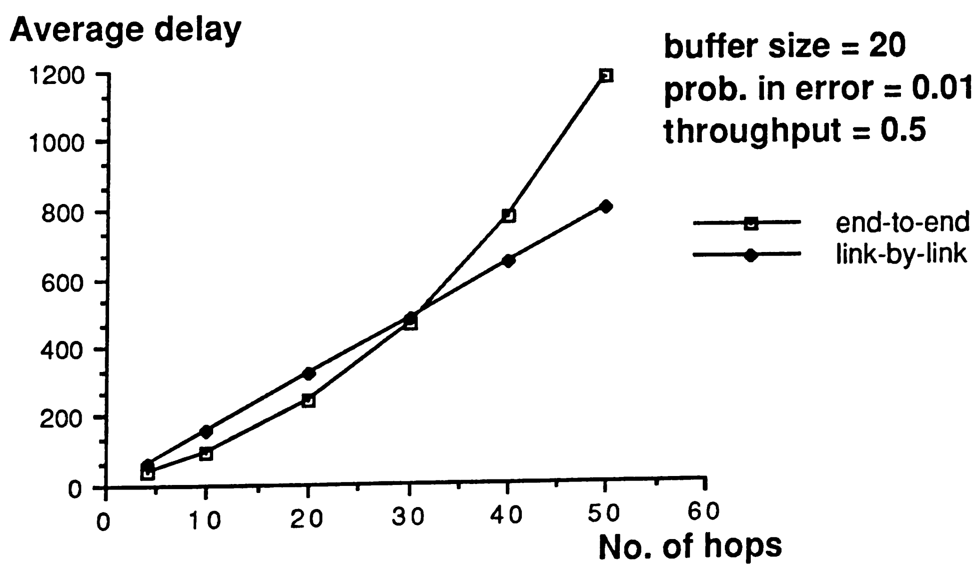


Fig (21) Effect of the number of hops, with higher error rate

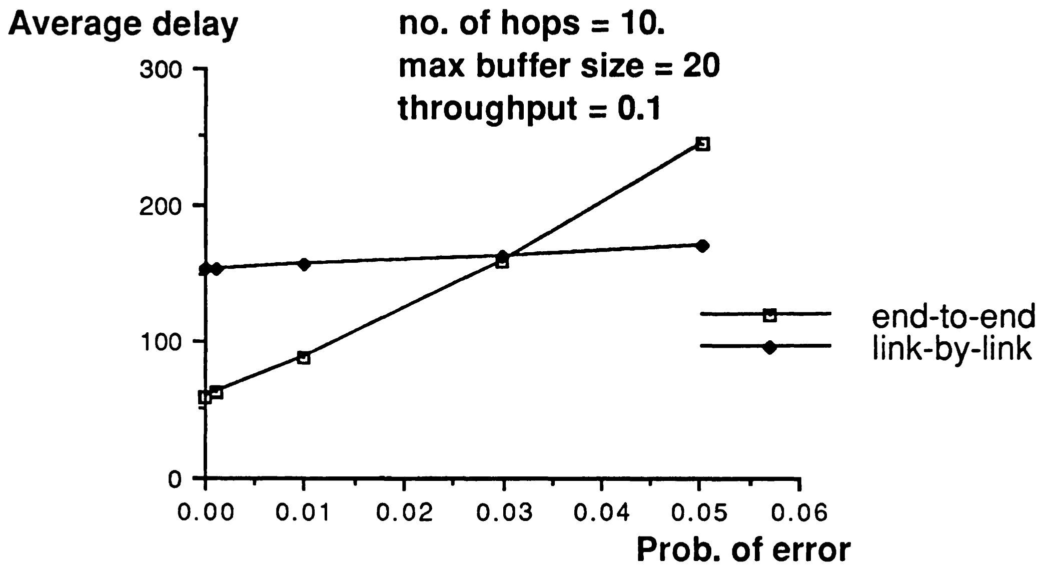


Fig (22) Frame Switching vs Frame Relay

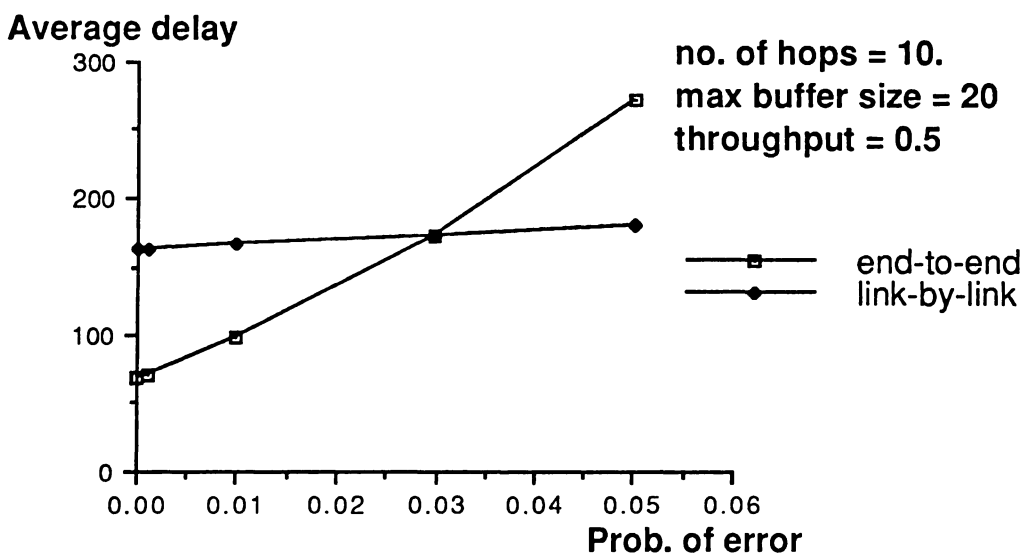


Fig (23) Frame Switching vs Frame Relay

7 Conclusion

From the above discussion, we find that the average end-to-end packet delay of the frame switching and the frame relay schemes is affected by the following parameters :

1. error rate of a packet on a link,
2. blocking probability (buffer size),
3. number of hops along the virtual circuit,
4. traffic along the virtual circuit,
5. processing overhead in LLC layer.

Processing overhead gives a fixed offset to the delay. The other factors will have a combined effect to the end-to-end packet delay.

- When the packet error rate on a link is low, the frame relay error recovery scheme can achieve shorter delay. Since the effect of the number of retransmissions in the frame relay scheme is less than the effect of the processing overhead in frame switching scheme, the frame relay scheme can perform better. Furthermore, under low error rate condition, the buffer size is a dominant factor to the delay of the frame switching scheme. If the buffer size is too small, the frame switching scheme will saturate very fast as the network traffic increases. If the error rate is high, there is a cross point of the delay between the frame switching and the frame relay scheme. This indicates that in the light traffic situation, the frame relay scheme can have shorter delay, and the frame switching scheme can perform better if the traffic load is high.
- When the traffic of the network is light, the error rate of a packet on a link is the dominant factor to the packet delay. In the high speed optical fiber network(low error rate), the frame relay error recovery scheme can achieve shorter delay.
- As the number of hops between the source and the destination node increases, the delay of the frame relay scheme will increase due to the retransmissions. If the number of hops is adequately large, the frame relay scheme will have shorter delay. However, if the number of hops is very large, the frame switching error recovery scheme can have better performance.

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