Comparison of DQDB and FDDI MAC Access Protocols

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Abstract

A comparison of the MAC access protocols of the IEEE 802.6 DQDB MAN and FDDI standards is presented. The results are derived from simulation studies, and verified by analytical approximations. The comparison is based on average packet access delays of nodes on DQDB and FDDI networks. By setting the available bandwidth of the two networks to be equal, we draw broad conclusions regarding the relative strengths and weaknesses of each protocol. The results show the relative effect of varying various network parameters such as token rotation time, geographic size of the network, number of stations and total bandwidth on packet delay for the two protocols.

1 Introduction

A new class of high speed LAN/MAN networks has recently emerged. These networks have promised to provide LAN-like performance over far larger distances and at higher speeds than existing LANs. Two such networks have gained much prominence. The IEEE 802.6 Distributed Queue Dual Bus (DQDB) MAN standard [1], having been recently approved, has yet to make its debut as a deployed network; the ANSI X3.139 FDDI standard [2], having been an approved standard since 1987, is already widely deployed.

Both the DQDB and FDDI MAC access protocols have been the focus of much attention in the literature. A number of papers have studied the skewness and asymmetry in delay for stations on a DQDB network ([7], [8]). The inclusion of the Bandwidth Balancing mechanism as part of the 802.6 standard ([1], [9]) has eliminated the extreme unfairness that used to arise in the original DQDB network under overload conditions. In this paper we look at the longer term performance of the two protocols, as they are deployed over larger distances and at higher bandwidths.

We compare the two protocols based on average packet access delays of stations on DQDB and FDDI networks. The results are derived from simulation studies, and verified by analytical approximations. The comparison is done by connecting a set of stations by either a DQDB or FDDI network. The total bandwidth available on the two networks is set to be equal. Variable length packets originate at the nodes and are transmitted on the two networks. For the DQDB network, the packets go through a segmentation process with additional overhead being added. The delay is that seen by the entire packet before being transmitted on the network. The delay averaged over all the stations is then compared for the two networks. The relative effect of varying the following parameters on the two protocols is studied: varying *T_Opr* on FDDI networks; varying geographical size, number of stations and total bandwidth on both networks.

In sections 2 and 3 brief descriptions of the two protocols are given. Since the DQDB protocol is not as widely known as the FDDI protocol, we provide a more detailed description of the DQDB protocol. Section 4 describes a reference network model and parametric variations of it that are used for comparing the two protocols. Sections 5 and 6 provide analytic expressions using results published in [3], [4] and [5]. These expressions are later used for validating the simulation results. Section 7 shows the results of the simulation study, and verifies the simulation results by comparison with the analytic expressions. Finally, section 8 provides conclusions drawn from the results.

2 IEEE 802.6 DQDB protocol

The IEEE 802.6 standard is intended to support three kinds of services: Connectionless, Connection-Oriented and Isochronous services.[1] Two underlying access

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[1] The IEEE 802.6 Standard [1] as yet only supports Connectionless services. However, the framework for Connection-Oriented and Isochronous services is provided in [1], and the details are currently under study by the IEEE P802.6j and P802.6h sub-committees, respectively.

functions are defined to support these and any other services that may be provided in the future: the Queued Arbitrated (QA) access, based on the DQDB protocol, and the Pre-Arbitrated (PA) access. The QA access supports asynchronous services such as Connectionless and Connection-Oriented data, whereas the PA access supports Isochronous services, such as voice or video. In this paper we focus primarily on the DQDB protocol which is used in access control of the QA slots.

In this section, we present a brief description of the DQDB protocol as specified in [1]. Figure 1 shows a DQDB network with N stations. Each station is connected to the network via two uni-directional buses, Bus A and Bus B. The station at the head of each bus is called the Head of Bus (HOB). The IEEE 802.6 standard supports a transport structure that is closely aligned with the CCITT BISDN ATM cell structure. Before transmission may begin, packets are segmented into 44 octet Segmentation units. A total of 9 octets of overhead are added to the Segmentation unit before it is transmitted as a 53 octet slot.

The structure of a slot is shown in figure 2. The first octet of the slot is called the Access Control Field (ACF), and the remaining 52 octets are the Segment payload. The ACF contains a Busy bit, which indicates whether the slot is busy or empty; a Segment Type bit, which indicates if the slot is to be used for Queued Arbitrated (QA) segments or Pre-Arbitrated (PA) segments; and three Request bits, to carry slot reservation requests for the three QA priorities 0, 1 and 2. The HOB of both buses is responsible for generating empty QA and PA slots at a constant rate.

We now provide a brief description of the DQDB protocol, and for simplicity, we assume that priorities do not exist. We also assume that *Bandwidth Balancing* is turned OFF.[2] The DQDB protocol is a slot reservation scheme. A station is allowed to queue one segment at a time on each bus. Once a segment is queued at a station, say for transmission on Bus A, the station makes a slot reservation on Bus A by setting a request bit on Bus B. (The two buses A and B are essentially symmetrical. For simplicity we henceforth consider transmission of data on Bus A.) This is done by waiting until a slot on Bus B appears with an empty request bit, which is then set to one.

A *Distributed Queue*, common to all the stations, is used to determine whether a queued segment may be transmitted on the next empty slot. Each station maintains the state of the Distributed Queue in a *Distributed Queue State Machine* (DQSM). An instance of the DQSM is maintained for each bus and for each of the three priorities at each station. The DQSM may be in one of two states: *Idle State*, when no segment is queued, and *Queued State* when a segment is queued in the Distributed Queue. Each DQSM maintains two counters to determine a queued segments location in a Distributed Queue. These are the RQ (ReQuest) and CD (CountDown) counters. Depending on whether the DQSM is in the Idle or Queued state, the contents of the RQ and CD counters are interpreted differently:

Idle State (No segment queued):
RQ = Number of segments queued downstream,
CD = Always zero.

Queued State (A segment queued):
RQ = Number of segments queued downstream that are *behind* in the Distributed Queue,
CD = Number of segments queued downstream that are *ahead* in the Distributed Queue.

Thus RQ + CD always gives the total number of segments that are queued downstream from the station in question. The counters are maintained by observing the passage of empty slots on Bus A, and requests on Bus B as follows.

In the Idle state, RQ is incremented each time a request appears on Bus B, and decremented (until zero) every time an empty slot appears on Bus A. When a local segment needs to be transmitted downstream, the DQSM goes from the Idle to the Queued state, and the following two actions are undertaken: (1) the RQ is copied onto the CD counter, i.e. at the time a segment is queued, the total number of segments that were downstream from the station, now become the total number of segments queued downstream that are ahead of the local segment in the Distributed Queue; and (2) RQ is then set to zero, i.e. the total number of segments queued downstream from the station and *behind* the local segment in the Distributed Queue is zero.

Once in the Queued state, RQ is incremented for every request on Bus B, whereas CD is decremented for every empty slot passing on Bus A. If the CD counter reaches zero, this implies that there are no more queued segments downstream that are ahead in the Distributed Queue, and hence the next empty slot appearing on Bus A is used to transmit the queued segment. The DQSM goes back to the Idle state before it can transmit the next segment, retaining the values of the RQ and CD counters.

3 FDDI protocol

The FDDI protocol is defined in the ANSI standard [2]. Both the architecture of the network and the protocol are very different form the DQDB protocol.

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[2] Bandwidth Balancing is a mechanism, which when turned ON, ensures fairness under overload conditions.

Figure 4(a) shows an FDDI ring with N stations. An FDDI network may also consist of a dual ring, in which the second ring is used as a backup. In our analysis we assume only a single ring. The protocol has been amply described in past papers (see e.g. [6], [12]), hence we only provide a brief description here.

The protocol is a timed token rotation protocol and can support both asynchronous and synchronous transmission of data. Access to the ring is controlled by use of a single token. The station that has the token is allowed to transmit first its synchronous and then its asynchronous packets. The durations for which it may transmit synchronous and asynchronous data are controlled by timers. We will be concentrating primarily on the asynchronous transmission in our discussion.

During the ring initialization process there is a bidding process by which the value of a parameter T_Opr is determined. It has been shown (see [11], [12]) that when synchronous traffic is present, the maximum token rotation time, or the time required for the token to go around the ring once, is given by 2 T_Opr. Hence the value of T_Opr is set by considering the maximum amount of time that synchronous traffic on each station can wait for the token.

The performance of the FDDI protocol is characterized in a large part by the token rotation time. Figure 3 shows a typical curve of the average and maximum values of the token rotation time, versus network load, for a 50Km ring with 15 stations when no synchronous traffic is present.

At low loads the token rotation time approaches Ring Latency u_a. This is the time required for the token to circulate on an idle ring. The Ring Latency depends on the Station Latency, and Cycle Time, i.e. the propagation delay in traversing the length of the ring:

$$u_a = \text{Station Latency} * N + \text{Cycle Time},$$

$$\text{Cycle Time} = \text{Ring Size} / \text{Propagation speed on fiber}.$$

In figure 3, Ring Latency is 259 microsec (as will be shown in the next section). As the offered load increases to and beyond 100%, the average token rotation time increases up to T_Opr. Since no synchronous traffic is present, the maximum token rotation time increases up to $T\_Opr + Frame\_Time$. Here $Frame\_Time$ is the time required to transmit a maximum length packet.

4 Network and traffic model used for comparison

The network topology used for the comparison is as follows. We take a symmetric network with N stations, numbered 0 to N-1, located on a circle, equi-distant from each other. Let S be the circumference of the circle. The stations could be stand-alone workstations, or bridges to Local Area Networks. These stations may now be connected by either an FDDI ring or a DQDB network. Figures 4 (a) and (b) show the two cases. For the DQDB network, let station 0 be the Head of Bus A, and station N-1 the HOB B. Clearly the length of the DQDB bus is $S*(N-1)/N$, which is slightly less than S, the size of the ring.

The comparison is made by taking a *reference case* for both the networks. A series of parametric variations are performed on the reference case, by varying a single parameter at a time, and studying its effect on packet delay on the DQDB and FDDI networks.

The reference case uses the following network parameters for both the networks. The number of stations (N) is taken to be 15. The Ring size (S) is 50 Km. In order to make a fair comparison, we set the total bandwidth available w (Mb/s), to be the same for the two protocols. Thus we set each of the two DQDB buses to have a bandwidth of $w/2$ = 50 Mb/s, and the FDDI ring to a bandwidth of w = 100 Mb/s. This sets the limit for the maximum carried throughput for the two networks to be no more than 100 Mb/s. T_Opr for FDDI is chosen to be 5 milliseconds.

We assume the following traffic model for the networks. The aggregate local traffic is made identical for all stations, with Poisson packet arrivals at an average rate of λ (packets/microsec) at each station. The packet length is exponentially distributed with an average value of $\bar{l}$ = 500 bytes. The average packet transmission time on the ring is $\bar{h} = 8\bar{l}/w$ (for the reference case, $\bar{h}$ = 40microsec). This gives a total ring utilization $\rho = N\lambda\bar{h}$, with each station equally loaded. We assume that the traffic is destined such that the traffic between each pair of stations is equal. This implies that for the ring all traffic flows in the same direction, whereas for the dual bus, the traffic is *uniformly graded*, i.e. the local traffic is split at each station onto the two buses, in proportion to the number of stations downstream on that bus. Thus station i will have $\lambda(N-i-1)/(N-1)$ packets/microsec of its local traffic going onto Bus A, and $\lambda i/(N-1)$ packets/microsec going onto Bus B.

The propagation speed on fiber is assumed to be 0.2 Km/microsecond. For FDDI the maximum allowed latency per station is 60 bits. We assume each station adds this latency to the token or packet before forwarding it on. At 100 Mb/s this gives rise to a 0.6 microsecond station latency. Thus the Ring Latency u_a, is given by $u_a = 0.6N + 5S$ microsec (for the reference case, this is 259 microsec). For DQDB the standard does not specify a maximum station latency. Thus, for the sake of comparison, we assume it is the same as that for FDDI, i.e. 60 bits, which at 50 Mb/s results in 1.2 microseconds latency per station.

5 DQDB analysis

It has been shown in [3] that by modeling each station as an M/G/1 queueing system the packet delay can be approximated as follows. Due to the symmetry of the buses, the analysis assumes that segments are transmitted on Bus A only.

We first define the following parameters. Let $\overline{b_i}$, $\overline{b_i^2}$ be the first and second moments of the number of segments per packet at each station i. If λ_i is the average number of arriving packets/slot at station i, then the slot utilization at station i is $\rho_i = \lambda_i \overline{b_i}$. Let τ be the slot transmission time. If D_i is the packet delay at station i, i.e. the time elapsed between the arrival of a packet and the complete transmission of the entire packet on the bus, then $\overline{D_i}$ the expected packet delay at station i ($i = 0, \ldots, N - 1$) has been shown in [3] to be given by:

$$\overline{D_i} = \left(\frac{\rho_i \overline{T_{a,i}^2} + (\lambda_i \overline{b_i^2} - \rho_i)\, \overline{T_{a,i}}^{2}}{2\,[1 - \rho_i \overline{T_{a,i}}]} + \overline{b_i}\,\overline{T_{a,i}} + \frac{1}{2} \right) \tau$$

using the following definitions, for $i = 0, \ldots, N-1$:

$$\overline{T_{a,i}} = \overline{T_1} + \overline{T_2}, \qquad \overline{T_{a,i}^2} = \overline{T_1^2} + \overline{T_2^2} + 2\overline{T_1}\,\overline{T_2},$$

$$\gamma_i = \sum_{j=i}^{N-1} \rho_j, \qquad \overline{T_1} = \frac{\gamma_i \overline{T_2^2}}{2\,(1 - \gamma_i \overline{T_2})},$$

$$\overline{T_1^2} = 2 \left(\frac{\gamma_i \overline{T_2^2}}{2\,(1 - \gamma_i \overline{T_2})} \right)^2 + \frac{\gamma_i \overline{T_2^3}}{3\,(1 - \gamma_i \overline{T_2})},$$

$$\overline{T_2} = \frac{1}{1 - q_i}, \qquad \overline{T_2^2} = \frac{1 + q_i}{(1 - q_i)^2},$$

$$\overline{T_2^3} = \frac{1 + 4q_i + q_i^2}{(1 - q_i)^3},$$

$$q_0 = 0, \qquad q_i = \sum_{j=1}^{i-1} \rho_j, \qquad i = 1, \ldots, N-1.$$

The total packet delay over all stations $\overline{D}$ is then:

$$\overline{D} = \sum_{i=0}^{N-1} \lambda_i \overline{D_i} / \Delta, \qquad \text{with} \qquad \Delta = \sum_{i=0}^{N-1} \lambda_i.$$

Here $T_{a,i}$ is the slot access delay at station i , or the period (in slots) between the time a segment reaches the head of the local queue at each station and the time at which it is completely transmitted on the bus. It consists of the periods T_1 and T_2: T_1 is the time a segment at station i takes to get to the head of the Distributed queue (i.e. when the CD counter reaches zero). T_2 is the time between the CD counter reaching zero, and the complete transmission of the segment. The above results have been derived in [3] by assuming that T_1 and T_2 are independent and that T_2 is an independent geometrically distributed random variable with parameter 1-q_i.

We can apply the above results to the DQDB network along with the traffic model that was described in the previous section. Since the packet lengths are exponentially distributed with average $\bar{l}$ bytes, the distribution function of the packet size is given by:

$$F(l) = 1 - e^{-l/\bar{l}}.$$

Since packets are segmented into 44 byte segmentation units, the probability that n segments are generated by a packet is given by $F(44n) - F(44(n-1))$, which can be shown to be equal to $(1-p)^{n-1}p$, with p given by:

$$p = 1 - e^{-44/\bar{l}}.$$

Hence the number of segments per packet is geometrically distributed with parameter p, and thus

$$\overline{b_i} = 1/p, \qquad \overline{b_i^2} = (2-p)/p^2.$$

For uniformly graded load λ_i for Bus A is given by $\lambda_i = \lambda\tau(N-i-1)/(N-1)$. Here λ is the average rate of packet arrival in packets/microsec at each station. Since the Bus bandwidth is w/2, the slot transmission time τ (microsec) is given by τ = 53*8/(w/2). (For the reference case, τ = 8.48 microsec.) Now we can use the equation for $\overline{D}$ given above, since the symmetry of the two buses results in an equal average delay for each bus.

We can derive the maximum value of ρ (defined as $\rho = N\lambda\bar{h}$) for the dual bus as follows. The total bus utilization in segments/slot is clearly $N\lambda\overline{b_i}\tau$. Since the maximum number of segments/slot for both buses is 2, $\lambda^{max} = 2/(N\overline{b_i}\tau)$. Substituting this into the expression for $\rho = N\lambda\bar{h}$, and using $\bar{h} = 8\bar{l}/w$, gives ρ^{max} for DQDB to be:

$$\rho^{max} = 2\bar{h}/(\overline{b_i}\tau) = (1 - e^{-44/\bar{l}})\,\bar{l}/53.$$

As $\bar{l}$ becomes large, ρ^{max} approaches 44/53, or about 0.83. This limit is due to the 9 bytes of overhead added to each segmentation unit before being transmitted as a 53 octet slot.

We note that delays are proportional to the slot transmission time τ, hence delays are inversely proportional to the bandwidth w. We also note that in the analysis above, the delays are independent of the size of the network and the station latency, but do depend on the number of stations.

The equations for the average packet delay above, are supposed to be accurate at low to medium loads, though slightly underestimating the delays. For high loads [3] gives a more complex expression for estimating the delay which takes inter-nodal distance into account, and which we will not present here.

The slot access delay $T_{a,i}$ given above, does depend on the position of the station on the bus, and for equally loaded stations, the station most downstream sees the greatest delay. This phenomenon, referred to as skewing, is well known for DQDB networks (see e.g. [7]). An upper bound (T_a^{max}) on $T_{a,i}$ for the most downstream station (and hence an upper bound on $T_{a,i}$ for all i) that has been suggested in the literature (see e.g. [13]) is:

$$T_a^{max} = 2\tau_B + N\tau.$$

Here τ_B is the bus propagation delay and total station latency: $\tau_B = S/0.2 + 1.2N$, using 0.2 Km/microsec as the propagation speed on fiber and 1.2 microsec as the station latency. $2\tau_B$ is the delay incurred for a request from the most downstream station to go all the way upstream to the HOB, and for a slot to return from the HOB to it. $N\tau$ is the additional delay in getting an empty slot, assuming all stations initially had a request queued. We have found this to be a somewhat loose upper bound from our simulations. If a station requires synchronous service, it is guaranteed one slot every T_a^{max} microseconds, giving it a maximum guaranteed bandwidth of ($44\mathrm{x}8/T_a^{max}$) Mb/s. (A protocol for providing guaranteed bandwidth that could overcome this limitation is currently being worked on by the IEEE 802.6 Working Group (see [13], [14]).)

6 FDDI analysis

It has been shown in [5] that packet delays on a symmetrical FDDI ring can be approximated by a simple expression drawn from the exact delay expression of an Exhaustive service system given in [10]. We reproduce these results below, for the special case when the stations are equally spaced around the ring.

The parameter n_d is defined as the maximum number of packets that can be transmitted by a station. It is given by

$$n_d = \left\lceil \frac{T\_Opr - u_\mathrm{a}}{h} \right\rceil.$$

Here $\lceil x \rceil$ is the smallest integer greater than or equal to x. u_a is again, the ring latency. If $\overline{n_d}$ is the average number of packets that are transmitted per station, then the maximum utilization ρ^{max} is given by

$$\rho^{max} = \frac{N\overline{n_d}\bar{h}}{N\overline{n_d}\bar{h} + u_a(N+1)}.$$

The expected packet delay for each station $\bar{D}$, for equally spaced stations on the ring, can be approximated by:

$$\bar{D} = \bar{h} + \{ u_a [(1-\rho) + 2(N+1)\rho/\overline{n_d}] +$$
$$N\lambda\overline{h^2} + (N+1)\lambda u_a^2 ((N+1)/\overline{n_d} - 1) / (N\overline{n_d}) \} /$$
$$2(1 - N\rho - (N+1)\lambda u_a/\overline{n_d}).$$

Here $\overline{h^2}$ is the second moment of the average packet transmission time. If $\overline{n_d} = n_d$, then the above equation provides an exact expression for the delay. In general, however, as stated in [5], the above equation overestimates $\bar{D}$, since at loads lower than saturation each station transmits fewer than n_d packets. As the ring latency u_a becomes large compared to the average packet transmission time $\bar{h}$, the overestimate has been known to increase. In such a case [5] provides a more complex way of more accurately determining $\bar{D}$, which we will not discuss here.

7 Parametric variations and results

A continuous time exact simulation was conducted for both FDDI and DQDB protocols. The simulations were carried out for a 1 second period in most cases, and for 5 seconds at high loads. The results are generally within an accuracy of 5% at a 95% confidence interval level (except when ρ is very close to the maximum load ρ^{max}). The performance criterion chosen was the packet delay. This is defined as the time elapsed between the arrival of a packet at a station and the complete transmission of the entire packet on either the bus or the ring.

Plots of the packet delays versus the ring utilization ρ, for both DQDB and FDDI networks are shown in figures 5(a) and 5(b), respectively. In each figure the simulation and analysis results for the *reference case* are first shown. The reference case was described in detail in section 4 and we briefly summarize some of its parameters here. It consists of $N = 15$ stations, with the ring circumference $S = 50$ Km.[3] The FDDI ring bandwidth $w = 100$ Mb/s, with each DQDB bus bandwidth being $w/2$. T_Opr for FDDI is

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[3] The length of the DQDB bus given by $S(N\text{-}1)/N$ Km can also be expressed as $S(N\text{-}1)/(0.2N\tau)$ slots. This is obtained by considering the distance spanned by a slot while propagating at a speed of 0.2 Km/microsec on fiber.

5 millisec In addition to the reference case, figure 5(a) shows results for two other networks. The first, labeled 'N=100 stations' is the same as the reference case, except the number of stations (N) is 100. The second labeled 'w=400 Mb/s' is again, the same as the reference case, except the bandwidth w is 400 Mb/s, i.e. the bus bandwidths are 200 Mb/s each. Similarly in figure 5(b) the reference case results are shown, along with three variations of the reference case: for *T_Opr* = 0.6 millisec S = 150 Km, and N = 100 stations.

For DQDB (figure 5(a)), we note that in general the analysis slightly underestimates the delay at low to medium loads, as expected. At high loads the analysis gives somewhat larger delays. We also note that the analysis shows that delays in DQDB decrease with increasing number of stations (while keeping utilization constant). This is also supported to some extent by the simulation results (see also figure 6(c)), although the effect of station latency in the simulation counteracts this effect.

For FDDI (figure 5(b)), we see that as expected, the analysis always slightly overestimates the average packet delay. For large rings the overestimate becomes larger since the ring latency becomes large compared to the packet transmission time.

More detailed results of the simulations are shown in figures 6(a)-(d). In each figure, as was done in figures 5(a) and (b), the reference case packet delays versus the ring utilization ρ, are shown along with a series of variations of the reference case. In each variation only a single parameter is changed. At the top of each curve ρ^{max} is shown. We note in general for most of the curves that at low loads DQDB always performs better. But in general there is a crossover point where FDDI starts to perform better. This crossover point varies depending on ρ^{max} and other network parameters. We now discuss each of these figures in turn.

Figure 6(a) Varying T_Opr for FDDI:

For the DQDB network, the packet delay for the reference case is shown. For the FDDI network, the packet delay for the reference case is shown (*T_Opr* = 5 millisec), along with two other curves for *T_Opr* = 0.6 millisec and 165 millisec. We note that reducing *T_Opr* reduces ρ^{max} (from 0.998 to 0.57) for FDDI. We now discuss each of these curves in turn.

T_Opr = 0.6 msec gives a maximum token rotation time of 1.2 msec. This would allow support of synchronous traffic that is time sensitive, and requires a maximum token access delay of 1.2 msec. If the DQDB network were to support similar (but low bandwidth) synchronous traffic, this would imply $T_a^{max} \leq 1.2$ msec. For a 50 km bus, at 50 Mb/s, $T_a^{max} = 2(50/0.2 + 1.2N) + N\tau$, hence $N \leq (1200 - 2\text{x}50/0.2)/(8.48 + 1.2) = 64$. Thus a 50 Km bus operating at 50 Mb/s, could provide similar synchronous service (i.e. similar access delay) for up to 64 stations on the network. The maximum guaranteed bandwidth would be limited to one slot every T_a^{max} microsec, i.e. 44x8/1200 = 0.29 Mb/s. Thus, if low bandwidth, synchronous traffic were to be present and given equivalent performance on both networks, then the asynchronous traffic, as we see from the figure, would experience lower delays on the DQDB network.

T_Opr = 5msec and 165msec results in large maximum token rotation time, and hence corresponds to no synchronous traffic being present. FDDI stations experience high delays at low load but at high loads see lower delays than the equivalent DQDB network.

Figure 6(b) Varying Geographical Size:

In the remaining figures 6(b) - (d), we assume no synchronous traffic is present, and hence a relatively large value of *T_Opr* = 5msec is chosen.[4]

We note that the FDDI delays are strongly dependent on the size of the network. This is clearly due to the dependence of Ring Latency u_a on network size. ρ^{max} goes down significantly for FDDI (95% to 70%) as we increase the network size from 50 Km to 300 Km. Although the analysis shows that DQDB delays are independent of distance, the simulation shows that packet delays do increase very marginally as the geographical size of the network increases.

Using 0.2 Km/microsec as the propagation speed on fiber, the 1.2 microsec station latency used for DQDB stations can be thought of as equivalent to an increase of internodal distance by 0.2 x 1.2 = 0.24 Km. Hence we can conclude that the effect of station latency on packet delays is also minimal for DQDB networks.

Figure 6(c) Varying Number of Stations:

Increasing the number of stations clearly slightly increases the Ring Latency in FDDI, and hence we see an increase in the FDDI delays. On the other hand, for DQDB we observe that the delays are essentially independent of the number of stations and in some cases actually *decrease* with increasing number of stations. This phenomenon is supported by the analytical expressions for DQDB, as was shown in figure 5(a).

Figure 6(d) Varying Total Bandwidth:

DQDB delays are proportional to τ, the slot transmission time, and hence are inversely proportional to the total bandwidth, whereas FDDI delays do not show a marked improvement as the bandwidth increases.

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[4] Note that a very large value of *T_Opr* (e.g. 165 msec) is not recommended (see [15]). Such values can, at high loads, result in very large delays in getting a usable token. See [15] for a guide at setting *T_Opr* values.

8 Conclusions

In general we note that FDDI and DQDB packet delays show rather dissimilar behavior. This is because FDDI packet delays depend strongly on Ring Latency u_a, whereas DQDB delays are proportional to the slot transmission time τ. These two parameters have different behavior as we saw above. These are summarized in the Table 1 below.

Increasing the geographical size or number of stations increases the Ring Latency, whereas the packet service time remains unchanged. Increasing the bandwidth does not effect the Ring Latency while reducing the packet service time. Thus we see that in terms of the above parametric variations, DQDB has the more desirable properties that a Metropolitan Area Network must have. As such, DQDB networks are more suitable for being deployed over large distances and at higher bandwidths. On the other hand FDDI Rings are limited in terms of their efficiency when being deployed over large Metropolitan Area distances.

Increasing:	FDDI Effect on: Ring Latency	DQDB Effect on: Slot transmission time
Geographic Size	increases	no change
Number of Stations	increases	no change
Bandwidth	no change	reduces

Table 1

References

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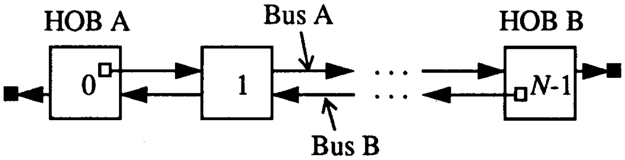


Figure 1. DQDB Network

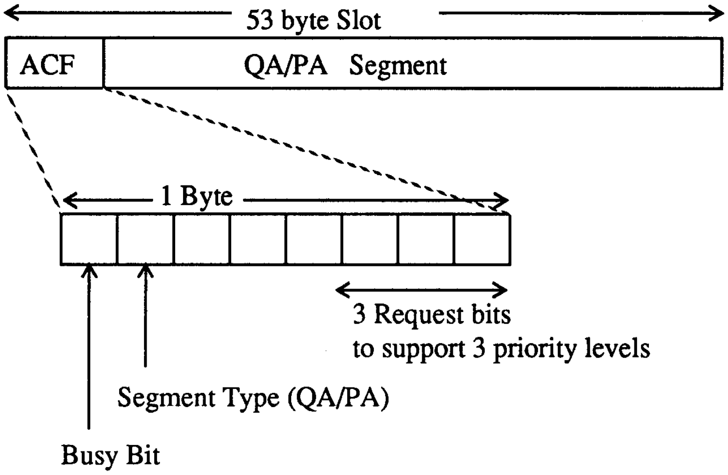
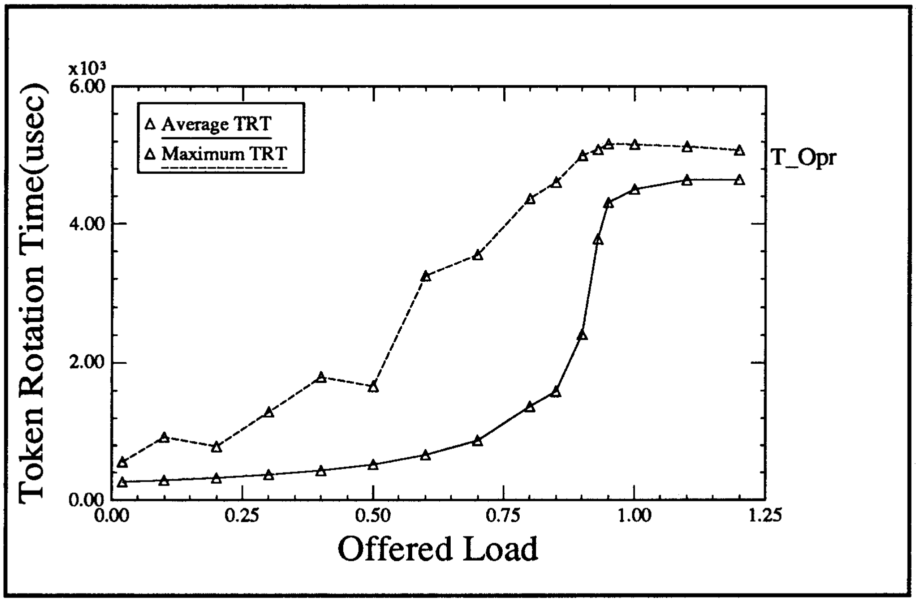


Figure 2. DQDB Slot Structure



Number of Stations = 15, Run Time = 1 sec, Average Packet Size = 500 bytes, Size Distribution = Exponential, Ring Circumference = 50 Km, Bandwidth = 100 Mb/s, T_Opr = 5 msec.

Figure 3. FDDI Token Rotation Time

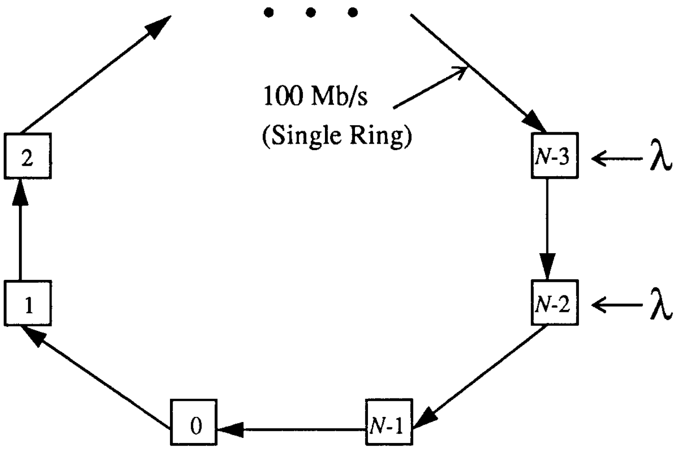


Figure 4(a) FDDI Ring

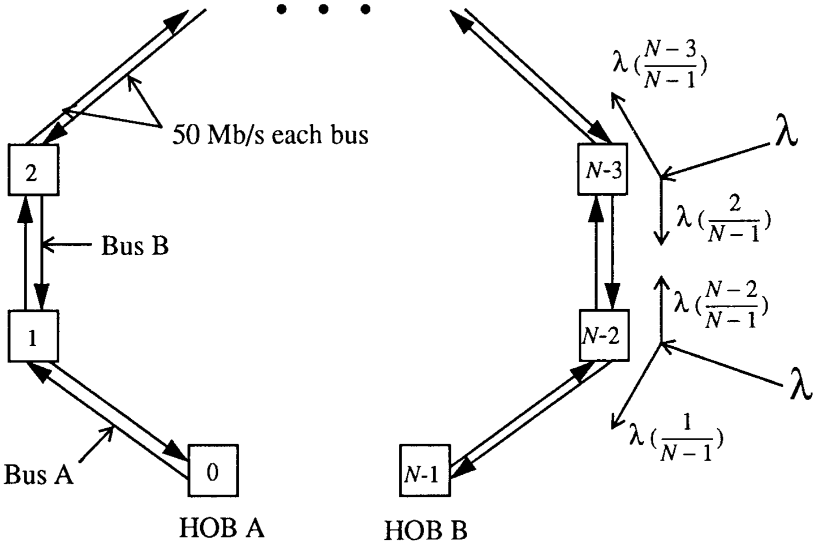
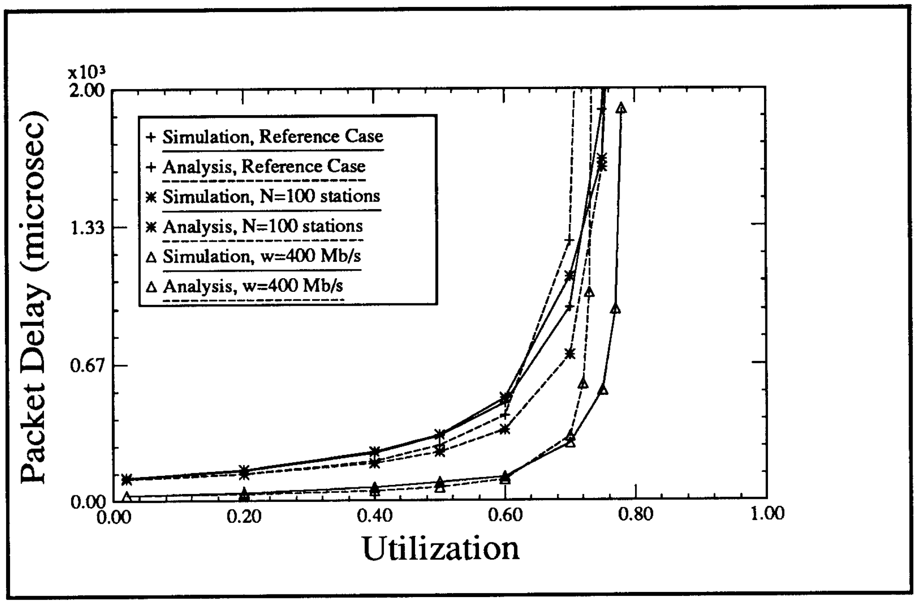
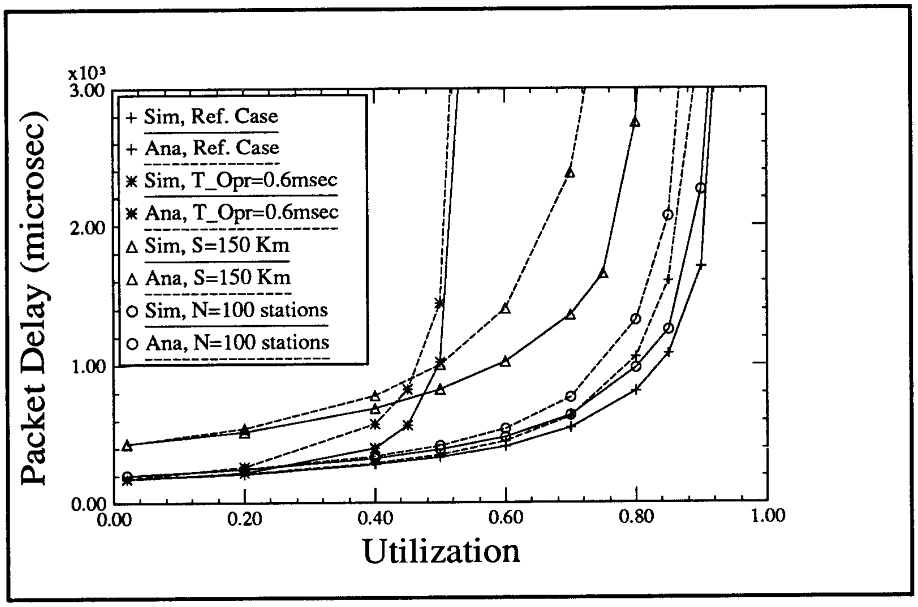


Figure 4(b) DQDB Network



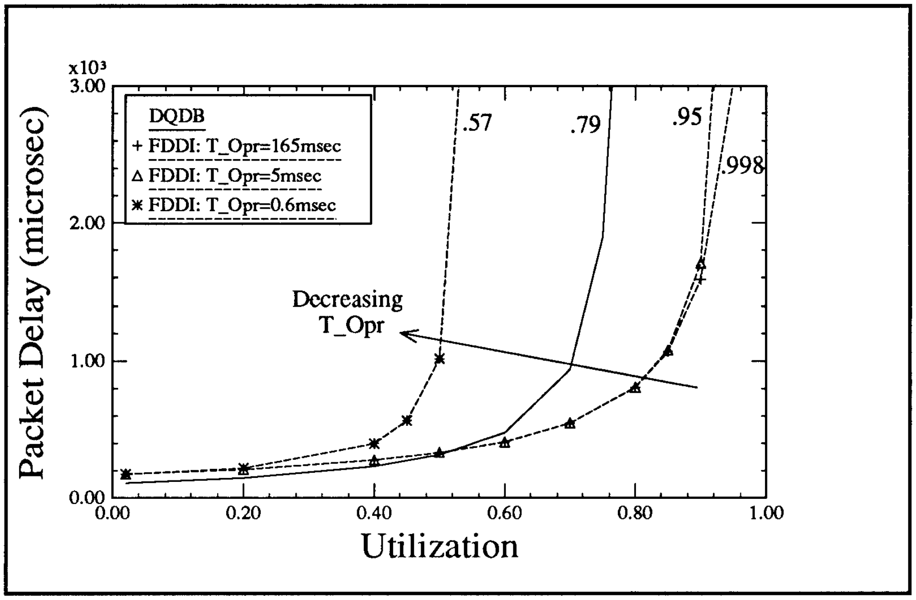
Number of Stations = 15, 100, Run Time = 1 sec, Average Packet Size = 500 bytes, Size Distribution = Exponential, Bus Length = 46.67 Km (27.52 slots), Bandwidth = 2 x 50, 2 x 200 Mb/s.

Figure 5(a) DQDB: Simulation vs. Analysis



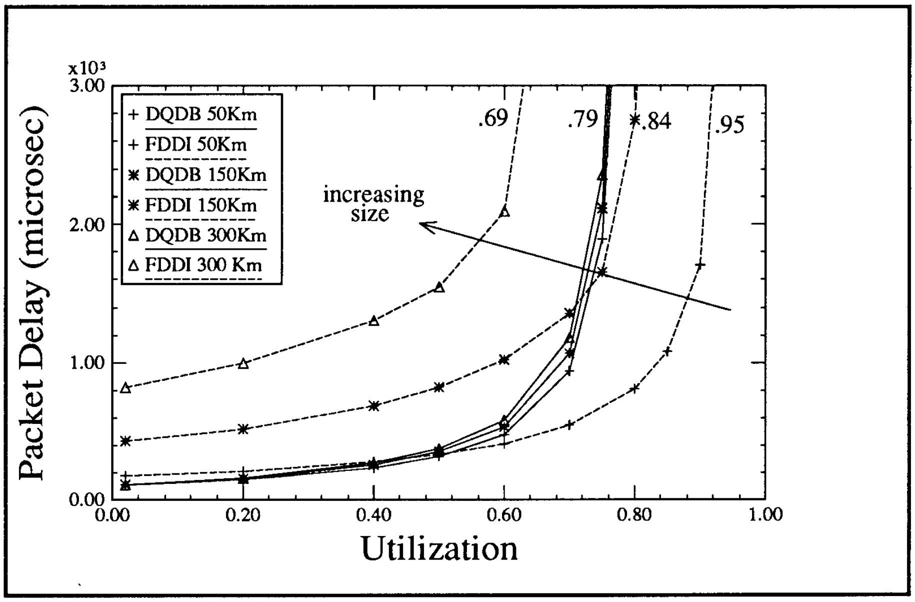
Number of Stations = 15, 100, Run Time = 1 sec, Average Packet Size = 500 bytes, Size Distribution = Exponential, Ring Circumference = 50 Km, 150 Km, Bandwidth = 100 Mb/s, T_Opr = 5, 0.6 msec.

Figure 5(b) FDDI: Simulation vs. Analysis



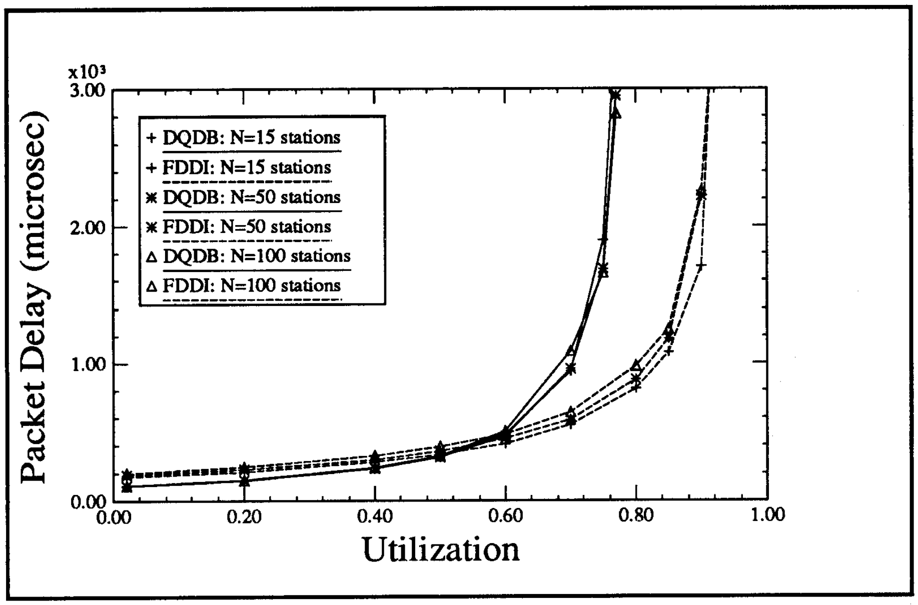
Number of Stations = 15, Run Time = 1 sec, Average Packet Size = 500 bytes, Size Distribution = Exponential.
DQDB: Bus Length = 46.67 Km (27.52 slots), Bandwidth = 2 x 50 Mb/s.
FDDI: Ring Circumference = 50 Km, Bandwidth = 100 Mb/s, *T_Opr* = 165 msec, 5 msec, 0.6 msec.

Figure 6(a) Varying *T_Opr*



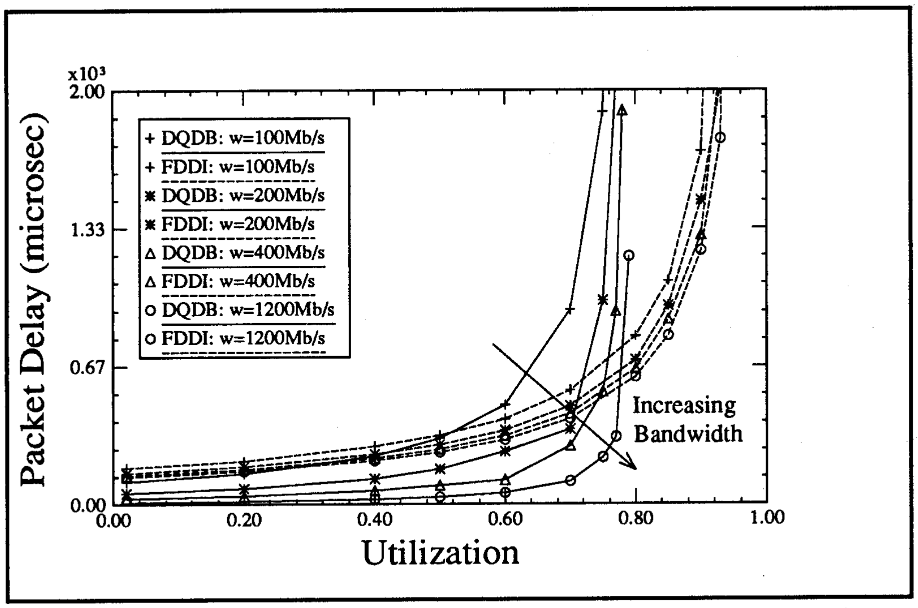
Number of Stations = 15, Run Time = 1 sec, Average Packet Size = 500 bytes, Size Distribution = Exponential.
DQDB: Bus Length = 46.67 Km (27.5 slots), 140 Km(82.5 slots), 280 Km (165 slots), Bandwidth = 2 x 50 Mb/s.
FDDI: Ring Circumference = 50 Km, 150 Km, 300 Km, Bandwidth = 100 Mb/s, T_Opr = 5 msec.

Figure 6(b) Varying Geographical Size



Number of Stations = 15, 50, 100; Run Time = 1 sec, Avg Packet Size = 500 bytes, Size Distribution = Exponential.
DQDB: Bus Length = 46.67 Km (27.52 slots), Bandwidth = 2 x 50 Mb/s.
FDDI: Ring Circumference = 50 Km, Bandwidth = 100 Mb/s, *T_Opr* = 5 msec.

Figure 6(c) Varying Number of Stations



Number of Stations = 15, 50, 100; Run Time = 0.1 sec, Avg Packet Size = 500 bytes, Size Distribution = Exponential.
DQDB: Bus Length = 46.67 Km (27.52 slots), Bandwidth = 2x50, 2x100, 2x200, 2x600 Mb/s.
FDDI: Ring Circumference = 50 Km, Bandwidth = 100, 200, 400, 1200 Mb/s; *T_Opr* = 5 msec.

Figure 6(d) Varying Bandwidth