

# Modelling of the DQDB Access Protocol and Closed-Form Approximation

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**Abstract** We present an analytic performance study of the DQDB medium access protocol. The major subject of the queueing analysis is to derive closed-form solutions, which should be easy to evaluate but deliver sufficiently accurate performance measures to study protocol behaviors. We use a decomposition of the medium access delay by means of the technique of embedded modelling. The non-isochronous station-to-station traffic matrix can be chosen arbitrarily and an amount of isochronous traffic is taken into account. Two cases are considered: i) Poisson input traffic with a continuous-time model and ii) general discrete-time traffic in conjunction with a discrete-time modeling environment. The accuracy of the approximation technique developed in this paper is appropriate for a wide range of protocol parameters.

## 1 Introduction to DQDB

The Distributed Queue Dual Bus (DQDB) access protocol is a candidate in the emerging standardization process of high-speed local area and metropolitan area networks, e.g. as being defined in IEEE 802.6. Attentions are devoted to this medium access scheme in some recent studies, both from technological and protocol performance viewpoints. Numerous simulation studies [2, 6, 15] and approximate analyses [16, 17, 18] dealing with performance aspects of various successive releases of the standardization process [1, 7, 9, 10, 11] can be found. In [15, 19] attentions are devoted to the unfair protocol behavior under overload. Some possible changes to the protocol are considered in [4] and [5] to overcome the unfairness aspects mentioned above.

Since the DQDB medium access protocol is developed for use in high-speed metropolitan area networks and large local area networks, the number of stations to be considered in performance investigations should be chosen large enough to reflect the real system environments. This choice and the according number of events needed in simulation studies will lead to excessive simulation time. To investigate sufficiently large system configurations with wide parameter ranges we need more time-efficient analytical methods.

The aim of the analysis method developed in this paper is to give solutions, which should be simple to evaluate and have a sufficient approximation accuracy over a realistic range of parameters. The analysis is composed by basic single server queues in both continuous and discrete-time domains. We use the embedded modelling technique, i.e. the service

time of the next model level is composed by random processes like the waiting time of the previous modeling level. Section 2 gives an outline of modeling steps, arising parameters and details of the analysis. Some numerical results for system configurations with different transmission speeds will be presented in Section 3.

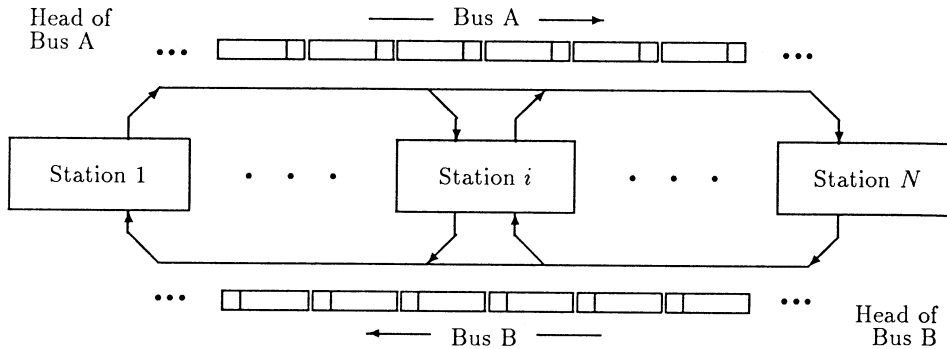


Figure 1: DQDB system structure

Some major properties of the DQDB protocol are described in the following. The transmission part of a DQDB system consists of a pair of slotted unidirectional buses flowing in opposite directions (see Fig. 1). This dual pair of busses — bus A for downstream and bus B for upstream payload traffic — operates synchronously at MAC layer. Each station is connected to both busses and is able first to read the information on the above read tap and then to write to the appropriate bus on the beneath write tap. Since the access mechanism is identical for the two busses, the description below will focus on one direction of data transfer only, e.g. the downstream payload transfer on bus A. Furthermore, in the DQDB standard proposal, a station is allowed to send data according to four priority levels. In order to simplify the description, the case of one priority level will be taken below.

When providing asynchronous services, all of the stations participate in a distributed queueing scheme, which is based on a reservation process. The aim of this scheme is to provide each station with information about the overall queueing state of the system. This shall help to achieve a system behavior that approaches a global FIFO queue.

A slot contains an access control field (ACF), a segment header and a segment payload area for isochronous or non-isochronous (asynchronous) traffic. For these different traffic types two access control modes are defined. The *pre-arbitrated* access mode is reserved for *isochronous services* like voice and video. This mode is controlled by the slot generators, which mark the preallocated slots using the BUSY bit in the ACF. Accesses of *non-isochronous* services are controlled by the station itself according to the *queued-arbitrated* [7] access mode. We will discuss the queued-arbitrated access mode in more detail.

If a station wants to transfer a non-isochronous data segment downstream using bus A, it reserves a free slot by sending a request on bus B. This is done by switching a request

bit on bus B from 0 to 1. The station continuously makes note about all requests flowing by on bus B. While the station has several separate queues for segments waiting to be transferred on both busses, the station can schedule only one segment per bus. In other words, each station has one schedule position facing each bus to prevent the station from utilizing the full bandwidth, e.g. for a long file transfer. The scheduled segment waiting to be transmitted in the station may not be sent before all preceding requests which were observed and counted on bus B are served. To do this, the station has to wait until the corresponding observed number of free segments has passed on bus A.

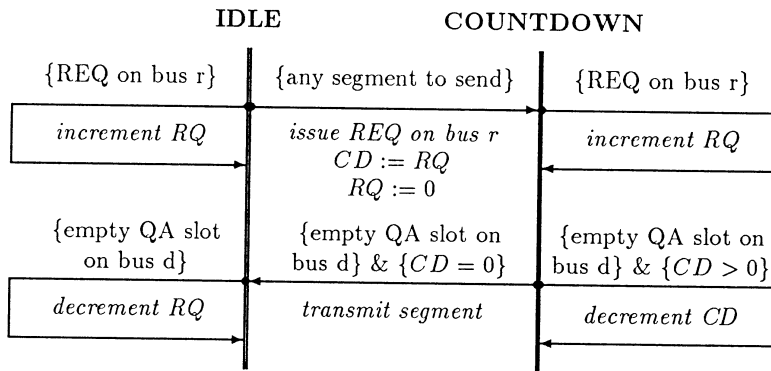


Figure 2: A simplified state transition diagram of a DQDB station

Considering only data transfer on bus A and one priority, a station can be in the following two states: IDLE and COUNTDOWN (see Fig. 2). We consider in the following the station  $i$ . For each bus and priority level the station has to maintain different counters, in particular the request counter (REQ\_CNT) and the countdown counter (CD\_CNT).

1. IDLE-state: the station has nothing to send or was on immediate transition from state COUNTDOWN. The request counter maintains the number of requested transmissions sent by stations  $i + 1, \dots, N$ . This counter is decremented upon observing a free slot flowing by on bus A and is incremented upon seeing a request passing by on bus B.
2. COUNTDOWN-state: the station has some data segments to transmit. A segment has been scheduled at time  $t_0$  for transmission. The request counter indicates the number of request arrivals after  $t_0$ . The countdown counter maintains the number of requests which arrived prior to  $t_0$  and have to be served before the scheduled segment. In this state, the countdown counter is decremented by observing a free slot flowing by on bus A while the request counter is incremented upon arrival of a new request on bus B.
3. State transitions: A state transition from IDLE to COUNTDOWN is processed as follows. The station enqueues a request to the local request queue, sets the

countdown counter to the current value of the request counter and then resets the request counter. The local request queue is represented by a third counter, called REQ\_Q\_CNT. Enqueueing a request is done by incrementing REQ\_Q\_CNT; REQ\_Q\_CNT is again decremented when a request has been put on bus B. It is important to note that this request queue operates totally asynchronous to the above data segment queueing system. The station always takes over from COUNTDOWN to IDLE after sending a segment. This is followed immediately by a backward state transition from IDLE to COUNTDOWN if there are still segments waiting in the station.

## 2 Modeling and analysis

### 2.1 System model and assumptions

We consider a network with  $N$  attached stations operating with the DQDB access protocol. The distance between station  $i$  and  $j$  is denoted by  $r_{ij}$ . The network carries both isochronous and non-isochronous traffic. The isochronous traffic (e.g., voice, video etc.) is preallocated slot-wise by the slot generator. As mentioned, in order to simplify the description of the analysis, we describe in the following the case of one priority level. Further, since we have a dual symmetrical bus system with decomposable traffic flows, it is sufficient to investigate only one data flow direction. The analysis of the other direction is analogous. Hence, we pay now attention on the downstream data traffic on bus A and the corresponding upstream request traffic on bus B. The traffic intensity of asynchronous traffic from station  $i$  to station  $j$  is denoted by  $\lambda_{ij}$  ( $\lambda_{ii} = 0$ ). Thus, the total traffic  $\Lambda_i$  generated at station  $i$  to be transferred on bus A and the total asynchronous traffic  $\Lambda$  on bus A can be written as

$$\Lambda_i = \sum_{j=i+1}^N \lambda_{ij} \quad \text{and} \quad \Lambda = \sum_{i=1}^{N-1} \Lambda_i \quad (1)$$

We denote  $p_I$  and  $(1 - p_I)$  the percentages of the isochronous traffic and the remaining bandwidth available to asynchronous traffic respectively. With  $\tau$  be the slot duration, the asynchronous bus utilization  $\rho_i$  of station  $i$  and the total asynchronous traffic  $\rho$  on bus A are

$$\rho_i = \Lambda_i \cdot \tau \quad \text{and} \quad \rho = \sum_{i=1}^N \rho_i \quad (2)$$

We observe in the following a segment, which is generated in the station  $i$  and passed across the medium access control. It is then to be transmitted to station  $j$  ( $j > i$ ). The segment itself will be transferred on bus A and its request on bus B. As depicted in Fig. 3, we take into account the following time instants, which are significant for the calculation of the segment transfer time according to the DQDB access mechanism:

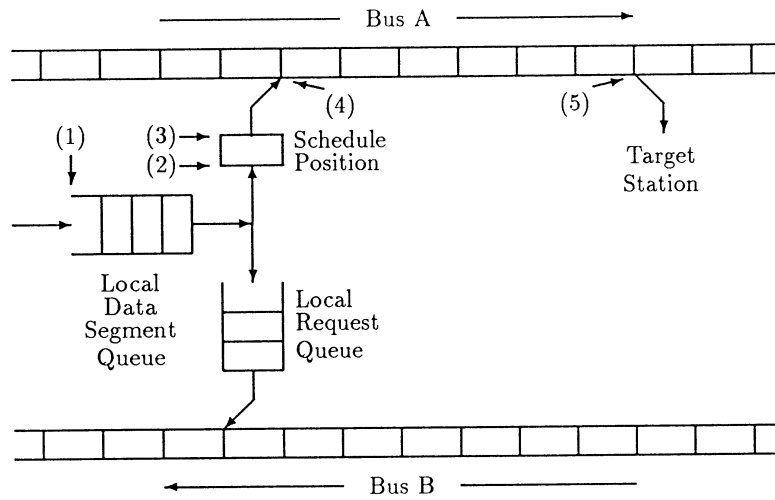


Figure 3: Sending part and modeling concept

- (1): arrival epoch of the segment
- (2): time instant, at which the observed segment is scheduled for transmission on bus A. At this time a request is created and is to be sent on bus B. The segment is ready to be transmitted, but still has to wait according to the FIFO discipline in the globally distributed queue.
- (3): the segment is at the head of the global queue and is enabled to be sent, but still has to wait for a free slot flowing by on bus A.
- (4): end of the transmission on the bus
- (5): the segment has arrived at the receiving station  $j$ .

This observation leads to a decomposition of the segment transfer time, where the following random variables (r.v.) are defined:

$T_{12}$  : r.v. for the waiting time in the local queue in station  $i$ ; each priority level has a separate local queue.

$T_{23}$  : r.v. for the waiting time in the schedule position in station  $i$ . This waiting time is dependent on the state of the global queue, in conjunction with the distributed queueing scheme.

$T_{34}$  : r.v. for the virtual transmission time (see Fig. 4)

$T_{45}$  : propagation delay from station  $i$  to station  $j$ .

Due to this observation, the medium access delay is  $T_{14}$  and the segment transfer time is  $T_{15}$ .

## 2.2 Embedded modeling and medium access delay

We will consecutively determine the distribution functions of  $T_{34}$ ,  $T_{23}$  and  $T_{12}$ , which finally deliver the distribution of the medium access delay  $T_{14}$ .

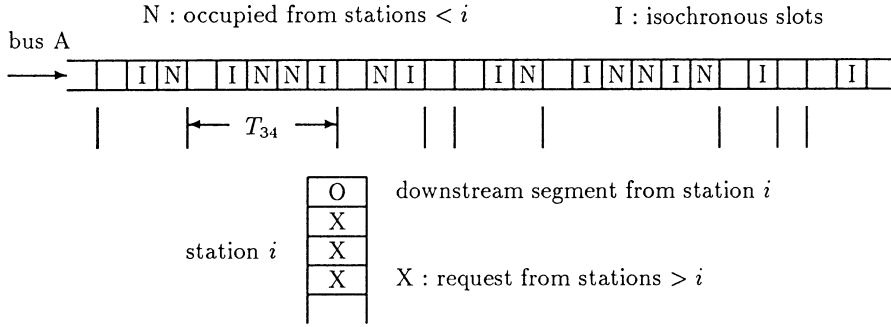


Figure 4: Virtual transmission time  $T_{34}$

The r.v.  $T_{34}$  can be interpreted as the interval between free slots seen from the station  $i$  (see Fig. 4). Station  $i$  sees a slot stream on bus A, where two types of busy slots can be observed: i) isochronous slot patterns which are periodically allocated and ii) slots already occupied by non-isochronous traffic from stations  $1, \dots, i - 1$ . The distribution of isochronous patterns on the slot stream is assumed to be uniform. We describe approximately the interval between free slots seen from station  $i$  with the following geometric distribution:

$$Pr\{T_{34} = k \cdot \frac{1}{p_I} \text{ slots}\} = q_i^{k-1}(1 - q_i), \quad k = 1, 2, \dots$$

$$\text{with } q_i = \sum_{j=1}^{i-1} \frac{\rho_j}{1 - p_I} \quad (3)$$

In the following we will point out the two cases: i) Poisson input leading to a continuous-time model and ii) general renewal input traffic which is treated in discrete-time model environments.

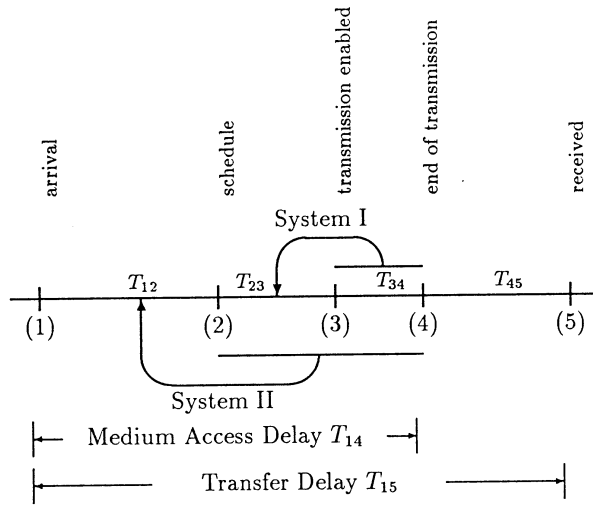


Figure 5: Segment lifetime and analysis concept

### 2.2.1 Poisson input streams

The traffic processes between stations are now assumed to be Poisson with mean arrival rates  $\lambda_{ij}$  as defined above.

The Laplace-Stieltjes transform (LST) of  $T_{34}$  is

$$\Phi_{34}(s) = \frac{(1 - q_i) \cdot z}{1 - q_i \cdot z} \quad \text{where} \quad z = e^{\frac{-st}{\rho_i}} \quad . \quad (4)$$

From modeling point of view,  $T_{34}$  is the service time seen from all segments waiting for transmission, which have been noticed from station  $i$ . We model the waiting behavior  $T_{23}$  of segments in the schedule position (cf. Fig. 3) with a standard M/G/1 system (system I of Fig. 5).

The service time of this system is  $T_{34}$ . To obtain the traffic intensity of system I we take into account all segments arrival processes of the stations  $i, i + 1, \dots, N$ . The LST of the distribution function is (see [8])

$$\Phi_{23}(s) = \frac{s \cdot (1 - \Gamma_i \cdot ET_{34})}{s - \Gamma_i(1 - \Phi_{34}(s))} \quad \text{where} \quad \Gamma_i = \sum_{j=i}^N \Lambda_j \quad . \quad (5)$$

One interesting property of system I is that the mean service time increases while the arrival rate decreases with higher number  $i$  of the observed station. From eqns. (4) and (5), we obtain the LST of the interval  $T_{24}$  between scheduling instant of the segment and the end of the segment transmission.

$$\Phi_{24}(s) = \Phi_{23}(s) \cdot \Phi_{34}(s) \quad . \quad (6)$$

As mentioned, the interval  $T_{24}$  can be seen as the virtual transmission time seen from those segments, which arrived at station  $i$  to be transferred on bus A. We describe again the waiting process in the local queue (see Fig. 3) by means of a M/G/1 system (system II in Fig. 5) with arrival and service processes to be specified. The service process is modelled using the embedded modeling technique, i.e. the service time of system II consists of waiting time components already calculated in system I. The decomposition of the medium access delay as shown in Fig. 5 is not only a time decomposition, but contains nested intervals computed by different submodels. The LST of  $T_{12}$  in system II can be given accordingly:

$$\Phi_{12}(s) = \frac{s \cdot (1 - \Lambda_i \cdot ET_{24})}{s - \Lambda_i(1 - \Phi_{24}(s))} \quad . \quad (7)$$

Finally, we arrive at the medium access delay:

$$\Phi_{14}(s) = \Phi_{12}(s) \cdot \Phi_{23}(s) \cdot \Phi_{34}(s) \quad . \quad (8)$$

To obtain the total transfer delay, the propagation delay  $T_{45}$  has to be added, which can easily be estimated from the station-to-station distance  $r_{ij}$ . Out of eqns. (3–8) values of interest like means and coefficients of variation of the medium access delay and the total transfer time can be derived. For an explicit calculation of these two values see [12].

### 2.2.2 General discrete-time input streams

In this subsection an extension of the analysis concept to deal with more general incoming traffic streams will be briefly outlined. The replacement of the Poisson process by general renewal input processes allows us to model traffic streams in real systems in a more realistic way. Thus, station-to-station traffic processes are now characterized by discrete-time random processes with the random variable (r.v.)  $A_{ij}$  having the mean  $EA_{ij} = \frac{1}{\lambda_{ij}}$  and the coefficient of variation (c.v.)  $c_{ij}$ . Accordingly, the total traffic generated at station  $i$  to be transferred downstream on bus A is the random process  $A_i$ , which is a compound process represented by a superposition of the processes  $A_{i,i+1}, \dots, A_{i,N}$ .

Again we observe a data segment, which is generated in station  $i$  and passed across the medium access control unit.

The analysis steps are similar to the above case, i.e.  $T_{i+1,i}$  is calculated out of  $T_{i,4}$  and both are used to determine  $T_{i+1,4}$  by convolution of distributions or mass functions. The main difference is that the analysis is now derived in discrete-time domain applying discrete transform and convolution algorithms. For a detailed description of this analysis see [13].



### 3 Numerical results

To illustrate the use of the analysis and to show the validation of the approximation, we consider a network with  $N = 49$  stations, which are equidistantly located on a dual bus system of length 100 kilometers. We consider two different transmission speeds: 136 Mbps and 1.2 Gbps. The slot length is chosen at 53 Bytes (48 B segment payload, 4 B header, 1 B ACF) according to the current version of the standard proposal. The percentage of isochronous traffic is taken at  $p_I = 50\%$ . In the diagrams shown, we normalized the asynchronous traffic to the available bandwidth for non-isochronous traffic streams as  $\rho^* = \rho/(1 - p_I)$ . Delays are given in  $\mu\text{sec}$ .

The comparison with simulation results shows that the analysis is sufficiently accurate for practical use.

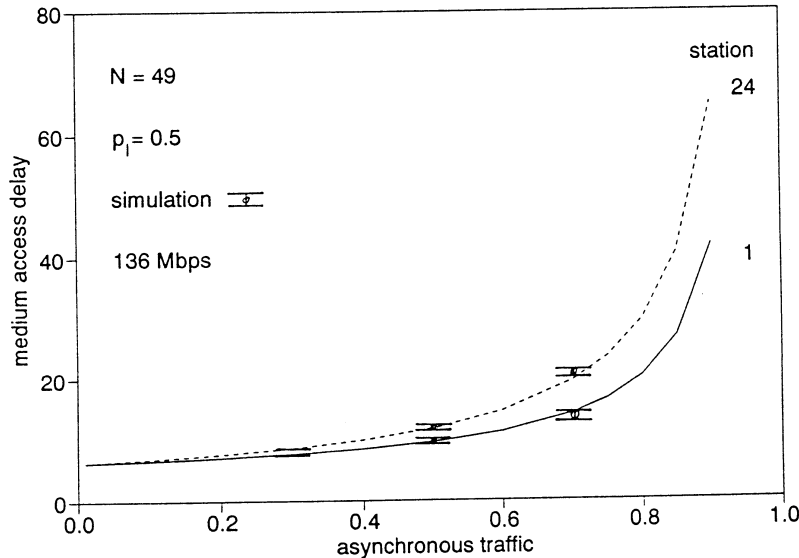


Figure 6: Medium access delay vs asynchronous traffic (a)

Figs. 6 and 7 show the mean access delays for the two transmission capacities. As expected, according to the often observed unfairness behavior of the DQDB protocol (cf. [6]), the mean access delay is station-dependent. For both configurations, the first station has the smallest access delay. Considering  $\rho < 0.8$ , the medium access delay of station  $i$  ( $i > j$ ) is larger than the one of station  $j$ . Note that the capacity limit of the entire system is defined by the station with the largest access delay. For both transmission speeds it is about 0.9. As expected the access delays of 136 Mbps system are about 9 times higher than those of the faster 1.2 Gbps system.

Adding up both directions of data transfer shows that the middle station 25 has to deal

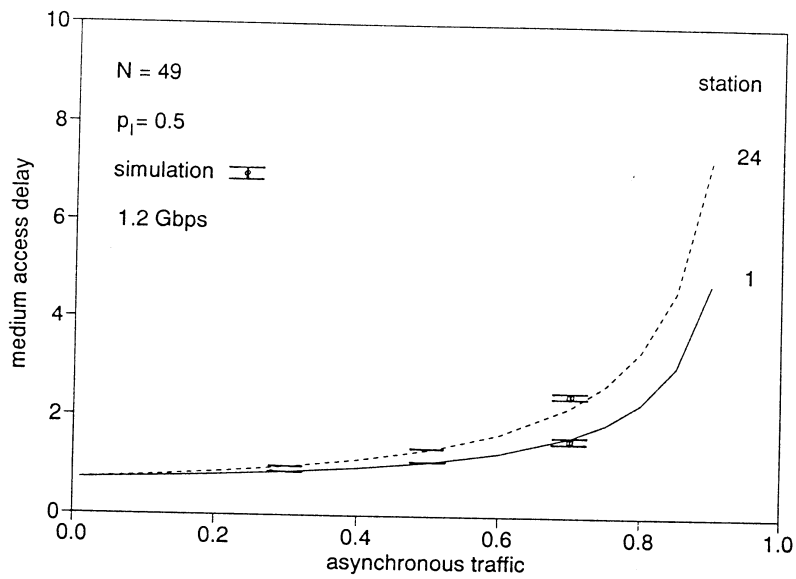


Figure 7: Medium access delay vs asynchronous traffic (b)

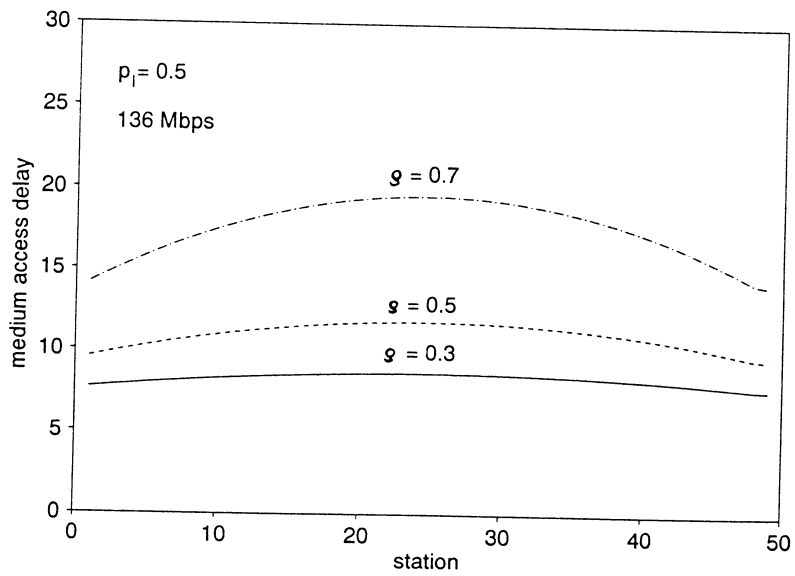


Figure 8: Medium access delay for both directions of data transfer

with the longest medium access delays (see Fig. 8 for the 136 Mbps configuration). However these differences are not very significant, especially when the traffic intensity  $\rho$  is in the region less than 0.5.

Furthermore, we should take into account that the definition of fairness in communication networks is certainly dependant on the type of traffic to be transmitted. For file transfer applications e.g., the issue of fair bandwidth sharing is of crucial interest, while for services with short messages the medium access delay fairness is essential.

Another point to be mentioned here is that the propagation delays of the middle stations are much lower on average than those of the head end stations. This effect should be taken into account when round trip delays between communicating processes are concerned (note that the transmission delay from station 1 to station 25 is about  $250 \mu\text{sec}$ ).

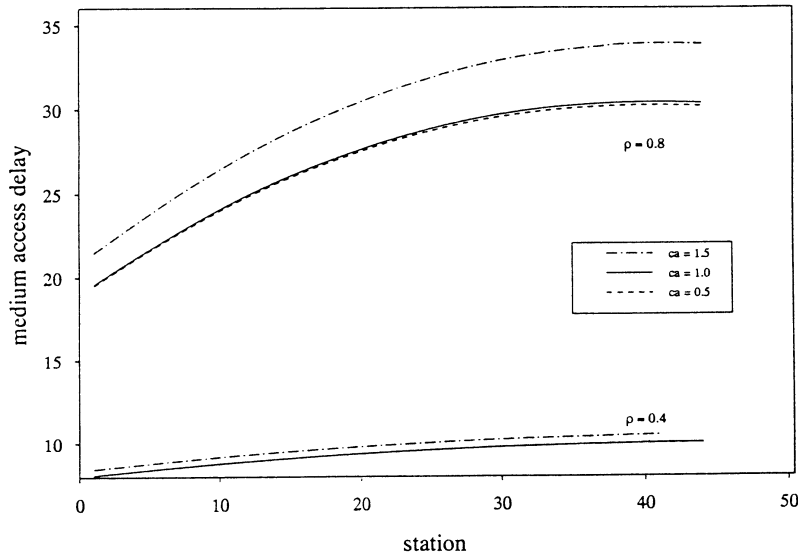


Figure 9: Dependence of medium access delay on the arrival process

Fig. 9 shows some results for different input process parameters: coefficient of variation  $c_a \in \{0.5, 1.0, 1.5\}$ . It can be observed again that the medium access delay is station-dependant, for all examined types of input processes. It is revealing that the results for  $c_a < 1.0$  are quite similar to those for  $c_a = 1.0$ .

For further detailed numerical results on the discrete time analysis in the case of general input traffic see [13].

## 4 Conclusion and outlook

An approximate performance study of the DQDB medium access protocol has been presented. The main results obtained are approximate expressions for various delays in the system like the medium access delay given in the form of Laplace-Stieltjes transform in the case of Poisson arrival streams and continuous-time analysis. In the case of general input traffic the analysis is done in discrete-time domain, where the whole distribution of the medium access delay is calculated. From these basic relationships, further measures of interest like the mean and the coefficient of variation of the mean access delay are derived, given as closed-form solutions. The analysis is based on a decomposition approach of the medium access delay, using embedded modeling technique. As shown in comparisons with simulations, the accuracy of the approximation is sufficient for a wide range of protocol parameters.

Some major properties of the DQDB access mechanism have been carried out with the analysis showing by means of numerical results: the station-location dependency of the medium access time which can be interpreted as a unfairness property of the DQDB protocol. For a practical range of operating parameters ( $\rho < 0.7$ ), the DQDB protocol nevertheless provides reasonable access delays, assuming symmetrical load.

### Acknowledgement

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