DQDB - Some New Characteristics

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Abstract

In this paper we study the DQDB bus under heavy traffic conditions. We also observe the impact of bursty traffic on the access delay. Here we especially study the impact of the third moment in the arrival process and find that the access delay decreases dramatically with an increase of the skewness, when lower arrival moments are kept constant. In fact for constant first and second moments we can obtain almost any value of the access delay by varying the third moment. Under heavy traffic conditions we found that the “normal” DQDB-unfairness is reversed. Some variants of DQDB are introduced in order to decrease the unfairness.

1 INTRODUCTION

The Distributed Queue Dual Bus (DQDB) network [IEEE 90]¹, originally called QPXS [NEW 88], which is the new standard for high speed local and metropolitan area networks in IEEE 802.6, has an access protocol which has been the topic of many studies and discussions. We believe that there still are many interesting features of DQDB, which ought to be studied further. Therefore we will in this paper have a look at the effect of different arrival processes, the behaviour of the network at very high loads, suggest a new metric for unfairness and study some minor variants of DQDB.

DQDB has so far been studied in several papers. Many papers, e.g. [DOS 89], [FRA 91], [SAU 89], have studied the behaviour via simulations. Since simulations are very time-consuming various analytical approaches have been made. In [MOR 90], [TRA 90], [TRA 89] the delay for DQDB is modelled via nested M/G/1-queues. In [FDI 90] DQDB is studied under overload conditions and in [POT 89] it is modelled as a shared processor model. By observing the fact that the flow of request bits and the flow of busy bits are of the same kind as the output from an M/D/1-queue, a tandem queue model is constructed in [JAC 90] and in [FER 90] a technique called “Formal

¹ A newer version of the standard can be found in [IEEE 94]

Definition Technique”, FDT, is used to examine the extreme behaviour of the network. In [BIS 92], [BIS 93] the station is modelled as a 2-class quasi-gated priority queue and in [STA 92], [LAN 93] this model is further developed into a three-priority queueing model. These models give upper and lower limits for the access delay. By assuming that the busy slots can be modelled as consecutive busy trains that form a sequence of i.i.d. random variables, an approximation of the bus access delay is obtained in [CON 91].

Many papers deal with the unfairness of the access delay in DQDB and how fairness can be improved, e.g. [VAN 90], [BOR 92], [CAT 91], [COV 93], [FER 92], [FRE 91], [HAH 90], [E HUA 90], [N HUA 92], [KAB 92], [KAR 92], [KIM 92], [MAR 89], [MAR 92], [SPR 91], [SUM 92], [WIL 91], [ZUK 89]. An overview on different proposed variants of DQDB (and other types of networks) and an excellent bibliography can be found in [VAN 94].

There are also many papers, e.g. [BAK 90], [BUD 90], [PUJ 90], [SCH 90], [SPA 90], which discuss how DQDB will work in different environments. Trials of DQDB (QPSX) are described in [ALB 92], [FID 89]. Finally a paper worth mentioning is [MOL 88], which gives a historical perspective of the working group IEEE 802 and why DQDB finally was chosen as IEEE 802.6 MAN.

The paper is organized as follows. In chapter two some notations and assumptions which are used through the whole paper are introduced. The behaviour of the system in congested situations is studied in chapter three. The influence of the third moment of the arrival process is studied in chapter four and in chapter five a new approach on how to study unfairness is introduced. In chapter six DQDB with some small modifications is examined and finally there are some concluding remarks and suggestions for future research in chapter seven.

2 NOTATIONS

We hope that the access protocol in DQDB is well known by the reader, so therefore we will not describe this mechanism in detail, but only stress some basic notations and assumptions.

Figure 1: The DQDB network

The network consists of two buses, called A and B. We will only look at the access delay for bus A, which means that bus B will only be regarded as a carrier of requests.

The stations will be numbered 1 to N , where the station at the beginning of bus A is 1 and the station at the end is N . Stations with lower numbers than a tagged station will be called the upstream stations and the stations with higher numbers the downstream stations.

The numerical results presented in this paper are based on simulations. The 95%-confidence interval is always less than 10% of the mean. In the simulated model the internode distance is always exactly one slot. We also assume that the amount of traffic from one station is proportional to the number of downstream stations. This means that traffic from station i to station j is equal for all pairs $(i, j) \in (N, N)$, $i \neq j$, i.e. the more upstream a station is the more traffic it generates. In other words: if we have N stations the first station has $N-1$ stations to send to and therefore it generates the traffic $(N-1)\lambda$, the second station generates $(N-2)\lambda$ and so on. Station number $N-1$ generates λ and the last station doesn't generate any traffic at all.

Furthermore we haven't used the bandwidth balancing mechanism in our simulations and calculations. The reason for this is that we have mainly been interested in the basic access algorithm in situations without overload. In these situations the influence of the bandwidth balancing mechanism is small.

3 THE ACCESS DELAY IN HIGH LOAD SITUATIONS

In this section the time between packet generations is exponentially distributed. This is of course not very realistic, but we can get a good picture of how the network behaves.

Under normal loads the access delay as a function of the station number shows up the normal unfair behaviour as seen in figure 2 below. The access delay increases with the station number and the higher load the higher differences. This unfairness comes from the fact that the requests are delayed by the propagation time.

Figure 2: Access delay at normal loads

What happens if we take a closer look at the relative difference (the quota) between the access delay for the last station and the first, i.e. AD_{24} and AD_1 ? If we study table 1

below we see that first the relative difference between the stations increases with the load, but after a certain point it starts to decrease.

<i>load</i>	AD_1	AD_{24}	$\frac{AD_{24}}{AD_1}$
0.3	0.69	0.99	1.43
0.5	0.89	1.81	2.03
0.8	1.78	6.89	3.78
0.9	3.99	13.13	3.29
0.96	10.74	24.06	2.24

Table 1: The relative difference between the access delay for last and first station

This raises a natural question: Does the unfairness decrease with the station number after a certain load? What happens if we increase the load even more? Take a look at figure 3 below. For the load 0.96 the access delay as a function of station number actually decreases! This means that we get a reversed unfairness at very high loads and that we for normal loads have a sort of limit on the unfairness.

Figure 3: Access delay at high loads

This can be explained in the following way: There are two factors which have influence on the access delay, namely the delay between the stations for the requests and the offered traffic of requests and busy slots. The stations downstream are mainly delayed due to the time it takes a request to reach all stations. This time may be long, but since these stations have no problem in sending the requests their access delay have an upper limit, since their requests sooner or later will grant them a free slot.

For the stations upstream the situation is a bit different. They see a large amount of requests, and for each request they must let a free slot pass by. The further upstream a station is, the lesser use it has of its own requests. This means that at very high loads the upstream stations will have very large access delay since they have no upper limit on the access delay.

4 THE INFLUENCE OF THE THIRD MOMENT IN AN IPP ARRIVAL PROCESS

Generally we have bursty arrival processes in computer networks. This means that we have to use something else than Markovian arrivals. One alternative is to use Markovian batch arrivals, but this kind of arrival process is not a good model of a bursty process. In [GAG 94] a Packet Train Model is presented as the best way to model the behaviour of LAN traffic and it is shown how this traffic model can be described by a MMPP (Markov Modulated Poisson Process). In this part of the paper we are only interested in how the network behaves when we change the first three moments of the arrival process and therefore we have chosen to use the IPP (Interrupted Poisson Process, a special case of the MMPP, see [LUCA, FISCH]) as an arrival process. IPP has three different parameters, which means that we can change the three first moments almost as we like.

Figure 4: Access delay for DQDB with three different sorts of arrival processes: IPP, Markovian and Markovian batch

When it comes to the third moment, the skewness, which is a normalization of the third central moment is often used. In [CRA 63] skewness is defined as

$$\frac{E\{(\tilde{t} - \bar{t})^3\}}{V\{\tilde{t}\}^{3/2}}$$

where $\tilde{t}$ is the stochastic variable, $\bar{t}$ is the mean value, $E\{(\tilde{t} - \bar{t})^3\}$ is the third central moment and $V\{\tilde{t}\}$ is the variance.

For non-negative stochastic variables low values of the skewness means that we have a short tail in the frequency function, and high values correspond to a long tail. Note that we normalize by the variance and not by the mean. A normalization by the mean may give different values of skewness for variables equally distributed around their corresponding different means.

If we lock the first and second moments of the IPP arrival process and let the third moment vary we can obtain any kind of performance. For low values of the third moment (or skewness) we can get the same behaviour as if we had Markovian batch arrivals, and for high values we get the same behaviour as if we had Markovian arrivals.

How can this behaviour be explained? Take a look at the frequency functions of the IPP arrival processes in figures 5 and 6.

Figure 5: The frequency function for the different IPP arrival processes used in the simulations in figure 4.

Figure 6: The same frequency function as in figure 5, but zoomed in.

For low third moments we get a frequency function with a large part of the probability mass close to zero and a long tail. This is similar to the frequency function for the time between arrivals in a batch arrival process: an impulse function at $t=0$ which represents that there is no time between the different arrivals in the batch and a tail

which represent the time between the different batches. This explains why we get a long access delay for low third moments.

For higher third moments we get frequency functions with a shorter tail, which look more like frequency functions for normal distributions like the negative exponential distribution. Therefore the access delay decreases as the third moment increases.

It is worth to mention that the differences for loads lower than 0.9 are smaller.

5 ON UNFAIRNESS

For none-extreme loads we have an unfairness in the access delay, as we have seen in section 3. In this section we will make some calculations to show what factors this unfairness depends on. The following notations are used in this section:

- λ : basic arrival intensity from station i to station j , $\forall i, j, i \neq j$
- τ : delay between two adjacent stations
- N : number of stations

Basically there are two factors which, besides the network load, have a large impact on the access delay for every station. First it is the number of packets that might be generated before a request from station i reaches all upstream stations, which can be calculated in the following way:

$$\sum_{k=1}^{i-1} (N-k)\lambda(i-k)\tau = \frac{\lambda\tau(i-1)i}{2} \left(N - \frac{i+1}{3}\right) \quad (1)$$

Second it is the number of requests that might have been generated before station i 's request, but still hasn't reached i , which can be calculated in the following way:

$$\sum_{k=i+1}^{N-1} (N-k)\lambda(k-i)\tau = \frac{\lambda\tau(N-i)(N-i-1)^2}{6} \quad (2)$$

If the delay was zero between the stations these factors would naturally also become zero, and we would have no unfairness problem. The difference between equation 1 and 2 becomes:

$$\frac{\lambda\tau}{6} (i(N-2)(3N-2) - N(N-1)^2) \quad (3)$$

This can be seen as an unfairness factor, UFF(i, N). This factor becomes zero for a certain value of i , called i_e (e=equilibrium):

$$i_e = \frac{N(N-1)^2}{(3N-1)(N-2)} \quad (4)$$

This means that the stations with negative UFF (station number lower than i_e) have an advantage over the stations with positive UFF.

Figure 7: The difference between the number of requests that have the possibility to come before another station's request and the number of requests that the station's request can come before (equation 3)

If we compare this with results from simulations we can see that i_e is approximately the same point as the one for which the access delay from the individual stations is the same as the total delay, where the total delay is defined as a weighted medium of the individual stations access delay:

$$\begin{aligned} AD_{tot} &= \frac{\sum_{i=1}^{N-1} \lambda_i \cdot AD_i}{\sum_{i=1}^{N-1} \lambda_i} = \frac{\sum_{i=1}^{N-1} (N-i)\lambda \cdot AD_i}{\sum_{i=1}^{N-1} (N-i)\lambda} = \\ &= \frac{\sum_{i=1}^{N-1} (N-i)\lambda \cdot AD_i}{\frac{N(N-1)}{2}\lambda} \end{aligned}$$

The total delay versus the individual delay is plotted in figures 8 and 9 below for Markovian arrivals.

The quota $\frac{i_e}{N}$ is also interesting:

$$\frac{i_e}{N} = \frac{(N-1)^2}{(3N-1)(N-2)} \quad (5)$$

When $N=3$ (the lowest meaningful value of N) the quota is $\frac{1}{2}$. This means that for very short buses and a symmetrical traffic pattern, about the first half (upstreams) of the stations experience a lower access delay compared to the mean access delay for the total bus. The other stations see a larger access delay. The quota $\frac{i_e}{N}$, i.e. the point on the bus for which stations to the "left" experience a shorter access delay, moves relatively to the left along the bus as the number of stations increases. When $N \rightarrow \infty$ the quota

becomes $\frac{1}{3}$, which means that for very long buses the first third of the stations are in favour.

Figure 8: The individual vs total access delay at low to medium loads

Figure 9: The individual vs total access delay at medium to high loads

6 VARIANTS OF DQDB

6.1 Direct Request

The possibility that a downstream packet from an upstream station gets access before a packet from a downstream station, even though the packet from the downstream station has waited longer, contributes to the DQDB-unfairness. This is possible because the upstream stations do not know how many packets are waiting in the queues at the downstream stations. This can be avoided if we let every new packet generate a request

immediately when placed in the local arrival queue, instead of sending the request first when it is in the head of the local queue. The result of this approach is shown in figures 10 and 11 (here we have used a Markovian arrivals again since we are only interested in comparing two different methods).

Figure 10: The access delay with direct request at low to medium loads

At low loads there are hardly any differences between the new approach (dir req) and normal DQDB. However as load increases to medium we can see that the network becomes a little bit less unfair.

Figure 11: The access delay with direct request at medium to high loads

However when load becomes very high a new unfairness for the stations with low numbers is introduced. The reason for this is that when a station has two packets or more waiting for access and the station is in the countdown state, then all new requests will be credited to the second packet. This means that all packets which are in the local queue get the disadvantage from the requests, even though they have been waiting longer than the packet which issued the request.

<i>load</i>	<i>Direct Request</i>	<i>DQDB</i>
0.3	0.83	0.83
0.5	1.28	1.28
0.8	3.57	3.52
0.9	7.02	7.04
0.96	16.52	15.43

Table 2: The total access delay (as defined in section 5) for the method of direct request and ordinary DQDB

6.2 Direct Request and Individual Countdown

The new unfairness, which was introduced with the direct access method can be avoided if we let every packet have its own individual countdown counter. Only the countdown counter corresponding to the last packet will be incremented with the incoming requests. When a new packet arrives, it gets a countdown counter with value zero and the countdown counter of the former last packet is fixed. The result on the access delay with this approach is shown in figures 12 and 13.

As we can see, the result of this is an access protocol which is a bit more unfair than DQDB, but the unfairness only depends on the propagation delay for the requests between the nodes.

Figure 12: The access delay with direct access and individual countdown at low to medium loads

Individual Countdown and Direct Request vs Ordinary DQDB

Figure 13: The access delay with direct access and individual countdown at medium to high loads

<i>load</i>	<i>Direct Request, Individual Countdown</i>	<i>DQDB</i>
0.3	0.83	0.83
0.5	1.27	1.28
0.8	3.46	3.52
0.9	6.64	7.04
0.96	14.95	15.43

Table 3: The total access delay for the method of direct request with individual countdown and ordinary DQDB

7 CONCLUSIONS

In this paper we have shown that there still are many characteristics of DQDB that need to be examined further. The normal assumption that the unfairness increases with load is only true up to a certain limit, though very close to 1. At very high loads we get a “reversed” unfairness. This is a feature which should be examined further.

We have also shown that DQDB performance is very dependent on the type of arrival process. New performance models of DQDB should use at least the three first moments of the arrival process.

A new way to measure unfairness for normal loads was introduced in chapter five. In chapter six we introduced two variants of DQDB, which both are very similar to ordinary DQDB, but we believe that they can be used as starting points for a new more fair MAN.

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