A new scheme for improving the fairness in BWB- DQDB

Sayed Abdel Hadi Nouh
Computers and Systems Dept., Faculty of Eng., Al-Azhar University, Cairo, Egypt

The Distributed Queue Dual Bus (DQDB) is a protocol specified by the IEEE 802.6 Standard Committee for Metropolitan Area Network (MAN) for interconnecting hosts, local area networks and workstations. A potential problem with DQDB is the achievement of fair sharing of bandwidth, in case of over- load conditions, in terms of the location of the access node for "Queued Arbitrated" (QA) slots (e.g., for data packet and ATM communications). For the sake of compensating this unfairness, the IEEE standard recommends to utilize the Bandwidth Balancing (BWB) mechanism with proper value of the system parameter named BWB- MOD. This paper presents a new strategy, to overcome the unfairness problem of DQDB protocol, named Proportional Bandwidth Balancing (PR- BWB) mechanism. The proposed scheme performs bandwidth allocations to the individual stations in such a way that the assignments are in proportion to the individual offered traffic loads. Simulation examples are employed to compare the performance of the proposed scheme with those of regular DQDB and BWB- DQDB. The simulation results provide a deep insight into the equilibrium access of data channel by all active stations. The results also show that the station throughputs are independent of the station's position and the state of the network when the overload occurs.

لقد أثبتت الدراسات والأبحاث أن شبكات الطوابير الموزعة ذات القضيب المزدوج تتميز بأداء مثالي في حالة وجود أحمال طفيفة علي الشبكة. لهذا أوصت مجموعة IEEE 802.6 باستخدام هذه الشبكة واعتبارها شبكة قياسية. هذا ومن ناحية أخرى فلقد أثبتت الدراسات أنه في حالة الحمل الزائد عن سعة الشبكة الكلية فإن أداء بروتوكول الشبكة غير كفء، وذلك لأن توزيع السعة الكلية للشبكة علي المحطات غير متساوي بالرغم من تساوي حجم الأحمال الصادرة المراد نقلها من كل محطة. هذا ولقد سميت هذه المشكلة بـ unfairness . لمعالجة هذه المشكلة أوصت مجموعة *IEEE 802.6* باستخدام تكنيك سمي *BWB* الذي يعمل مع بروتوكول الشبكة الأصلي. يقدم هذا البحث طريقة جديدة لتحقيق وتحسين عدالة توزيع سعة الشبكة الكلية علي المحطات في حالة الحمل الزائد علي الشبكة، حيث سميت هذه الطريقة PR- BWB . يقوم البروتوكول المقترح بتوزيع السعة الكلية للشبكة علي المحطات بما يتناسب مع حجم الحمل الصادر من كل محطة. كذلك تم في هذا البحث المعالجة الرياضية للبروتوكول المقترح وطريقة تنفيذه . هذا ولدراسة أداء البروتوكول المقترح والتحقق من صحته ومقارنته ببروتوكول الشبكة الأصلي (DQDB) وبروتوكول الـ BWB ، فلقد إستخدم نظام المحاكاة لشبكة الطوابير الموزعة والتي تتكون من خمسة محطات فأكثر. لقد أعطت الدراسة والنتائج المصاحبة لها نظرة عميقة علي عملية الاستخدام المتزنة للسعة الكلية بواسطة المحطات. لقد أوضحت النتائج أن بروتوكول PR- BWB يعمل علي توزيع السعة الكلية للشبكة علي المحطات المختلفة بالتناسب مع الحمل الصادر من كل محطة وأن الـ Throughput لكل محطة لا يعتمد علي موقعها في الشبكة ولا علي حالة الشبكة لحظة حدوث الحمل الزائد.

Keywords: Distributed queue dual bus, Fairness, Bandwidth balancing mechanism, Proportional bandwidth balancing mechanism

1. Introduction

The Distributed Queue Dual Bus (DQDB) is a protocol specified by the IEEE 802.6 Standard Committee for Metropolitan Area Networks for interconnecting hosts, local area networks and workstations. The topology of DQDB is based on two unidirectional buses supporting communications in opposite directions. Stations can read and write on both buses and communicate with each other by selecting the proper bus. DQDB is a slotted system and has the potential to utilize the whole channel bandwidth independent of the network span, the number of nodes and the transmission rate. The performance obtained with the DQDB access protocol is shown to approach the perfect scheduled performance under favorable conditions [1]. However, it has been reported in various publications that large propagation delay to transmission time ratios (high bit rates and large networks) can

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cause a certain degree of unfairness in access delay, which depends on the stations positions with respect to the head of bus station and the time they first start transmitting, in the sense that the stations located closer to the head of a bus may experience higher throughput and/or lower message delays, and bandwidth can be shared unevenly during long transmissions, such as file transfer [2-4]. More importantly, the unfairness is caused by the fact that an overloaded station will continuously transmit segments in one direction and requests in the other one. Stations that are located downstream from the overloaded station will find all slots filled with segments and station upstream will receive a continuous stream of requests.

To solve the unfairness problem, an enhancement to DQDB protocol, the Bandwidth Balancing (BWB) mechanism was proposed in [5] and had been chosen by the IEEE 802.6 Standard Committee to be incorporated into the DQDB protocol to remedy the unfairness problem. The BWB mechanism satisfies the bandwidth demands of lightly- loaded stations, while limiting the maximum bandwidth available to each heavily- loaded station in order to leave an unused portion of bandwidth. This unused bandwidth permits the congestion on the network to relax and allows equal sharing of the available (remainder) bandwidth among the overloaded stations. Further, the allocated bandwidths are independent of the stations' positions on the bus, and they only depend on the set of offered loads on that bus [6].

This paper presents a new strategy, to overcome the unfairness problem of DQDB protocol, named Proportional Bandwidth Balancing (PR- BWB) mechanism. The proposed scheme performs bandwidth allocations to the individual stations in such a way that the assignments are in proportion to the individual offered traffic loads. Thus, unlike BWB, the PR- BWB mechanism penalizes lightly-loaded stations as well, but it makes the allocations sensitive to the offered loads at heavily- loaded stations.

The organization of the remaining part of the paper is as follows: Section 2 describes the original DQDB access mechanism for asynchronous traffic and introduces the concept of Bandwidth Balancing (BWB). Section 3 is devoted to the description of the proposed scheme (PR-BWB) and the implementation method to realize it. In section 4 the simulation results are obtained for various possible scenarios for different network sizes. Finally, Section 5 concludes the paper.

2. DQDB medium access control protocol

DQDB is based on two unidirectional buses, which can carry traffic in opposite directions [7]. Each station can read and write on both buses. Information is carried on slots of fixed duration, generated by the slot generator at the head of each bus. The duration of a slot is equal to the size of a data segment of 44 bytes, plus the header of 9 bytes. Each slot contains in its header a busy bit and three request bits, one for each level of priority supported by the DQDB medium access protocol. We are interested in operation at only one level of priority, and hence, we will not discuss the behavior of the protocol under multi priority traffic.

The busy bit of a slot indicates whether the slot is empty. The request bit is used for making reservations of empty slots, for data segments, in the opposite direction. Since the operation in both directions is identical, we will consider data transmission in one direction only. One of the two buses is called the data channel (bus A), and the other will be called the reservation (or request) channel (bus B), as shown in fig. 1. Flow of data slots is from upstream stations to down stream stations in the data channel. Requests are placed in the reservation channel in the opposite (upstream) direction.

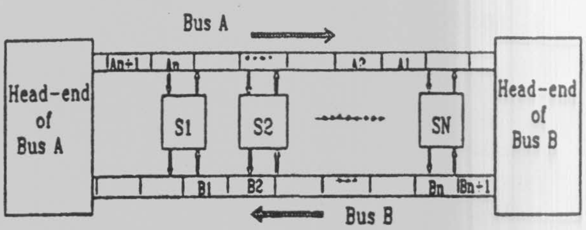


Fig. 1. DQDB network.

Each station has two counters, called the request (REQ) counter and the countdown (CD) counter. When a user is idle, only the REQ counter is in operational. While in this state, the REQ counter is incremented by one for each request detected in the reservation channel and decremented by one for each empty slot detected in the data channel, as shown in fig. 2. When a user becomes active, the content of the REQ counter is transferred to the CD counter and the REQ counter is reset to zero. Although an arriving packet may contain multiple segments, only one segment at a time is admitted per node in the network. For each segment registered, the user sends out a request in the reservation channel by setting to 1 the first free request bit received. Independent from this, the CD counter is decremented by one for eachempty slot passed by. When the CD counter reaches zero, the segment is transmitted in the first free slot observed. During the time the CD counter is active, the REQ counter is incremented for each request received from the downstream stations, as shown in fig. 3. It must be noted that, since access to both buses is independent, it my happen that a segment is transmitted before the corresponding request could be sent out. In such a case, a new segment is registered immediately, if available, and the content of the REQ counter is transferred to the CD counter.

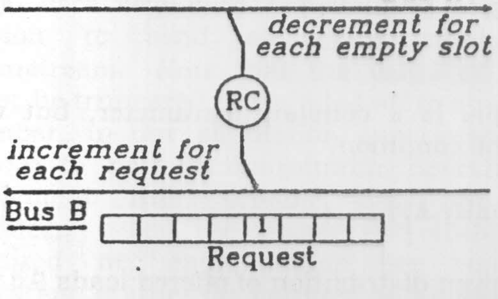


Fig. 2. Request counter operation; idle state.

Several analysis for the effect of propagation delay on fairness in DQDB [8-18] demonstrated that in some cases under overload condition the throughput of the different stations is not equal, with unfair advantage to the station that starts overloading the network. Consequently, a fair access mechanism is essentially needed to ensure equal distribution of the available bandwidth among ready stations.

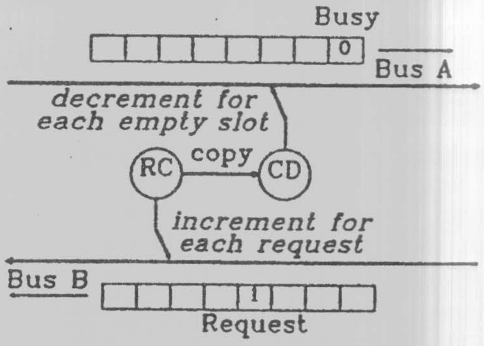


Fig. 3. Req abd CD counters operation; active state.

To solve the unfairness problem, an enhancement to DQDB protocol, the Bandwidth Balancing (BWB) mechanism was proposed in [5] and had been chosen by the IEEE 802.6 Standard Committee for incorporation into the DQDB protocol to remedy the unfairness problem. The main idea here is to perform better bandwidth allocation by allowing some bandwidth wastage. Each station is required to leave, intentionally, some empty slots into which it could have otherwise transmitted. Specifically, each station is allowed to transmit during a fraction α ($\alpha < 1$) of its normal transmission time. Let $\alpha = \beta/(\beta+1)$, where β is a positive integer. Then, each station will let go by untouched an additional empty slot after its every β^{th} transmission [5]. This scheme can be implemented by using an additional counter (called a trigger counter) per station. Where, every time a station transmits a data segment, its trigger counter is incremented by one. When the counter reaches β, it is reset to zero and the request counter is incremented by one.

The "wasted bandwidth" concept is the key principle behind why the BWB mechanism works so well. Although each station performs only a local operation (i.e., it transmits in at most α fraction of slots that is allowed to access), the "wasted bandwidth" essentially creates a covert signaling channel, with the ultimate result that the steady- state station throughputs converge to the same distribution, independent of the network's initial condition. This desirable property was not present in original DQDB.

3. Proportional bandwidth balancing mechanism

In the BWB mechanism, all the lightly loaded nodes take exactly their needed bandwidth, and all the overloaded nodes take their bandwidth equally. So the throughput achieved by each overloaded node is the same, called the control rate R. The bandwidth allocations do not change with increase or decrease of the offered loads at the nodes causing overload as long as these loads are above a certain threshold (the control rate R), which is a function of the scheme's "wasted bandwidth" parameter β and the offered loads at the various nodes. As an example, consider a network with three active nodes 1, 2 and 3. Let their offered loads be 0.24, 0.4 and 0.5 pkts/slot, respectively. If the parameter β is set to 9 (i.e., the corresponding wasted bandwidth is 0.04), then the bandwidths allocated to the stations under BWB mechanism will be 0.24, 0.36 and 0.36, respectively [5]. The allocations remain unchanged as long as the offered loads at nodes 2 and 3 are both above the value 0.36 (which is the control rate R in this case), assuming that station 1's traffic rate remains unchanged.

An alternative strategy would be to sensitize the bandwidth allocations to the actual values of the offered loads at the nodes causing overload, not just to the fact that they are above a certain threshold. This leads to our proposed scheme in which the bandwidths are allocated in proportion to the offered loads at the various nodes. Thus, in the above example, the bandwidths allocated to stations 1, 2 and 3 will now be 0.2, 0.34 and 0.42 (approximately), respectively, for the same amount of wasted bandwidth, 0.04. As another example, consider loading of 0.4, 0.6 and 1.0 at the three nodes. The bandwidths allocated by the BWB will be 0.32, 0.32 and 0.32, where as, using the proportional scheme, they will be 0.19, 0.29, and 0.48 (approximately), respectively, for wasted bandwidths of 0.04 under both schemes.

The PR- BWB scheme is motivated by the BWB mechanism. In the BWB strategy, the control rate R is the same for all the rate-controlled stations. More specifically, the control rate R is proportional to the idle bus capacity, with a proportionality constant β (β>1). That is,

$$R = \beta\left(1 - \sum_{j} \Gamma_j\right), \tag{1}$$

and

$$\Gamma_j = \min\left(R, \lambda_j\right),$$

where λ_i and Γ_i are the offered load and the carried load (throughput) *respectively at station i*, $(1-\sum_i \Gamma_i)$ is the idle channel capacity W_B (i.e., the wasted bandwidth), and β is a parameter which determines the scheme's wasted bandwidth and the threshold load at which rate control sets in.

Under PR-BWB mechanism, it is required that the rate control at Station *i* be proportional to Station *i* 's offered load (i.e., $R_i \propto \lambda_i$), and also that stations leave some spare capacity, as in BWB mechanism, for proper bandwidth sharing in a decentralized fashion. Then the rate control for station *i* is given by:

$$R_i = \beta_{PR}\lambda_i\left(1 - \sum_{j} \Gamma_j\right), \tag{2}$$

where β_{PR} is a constant parameter, but we retain the condition,

$$\Gamma_i = \min(R_i, \lambda_i) \ . \tag{3}$$

For a given distribution of offered loads $\{\lambda i\}$ so that rate control is in effect, it follows from eqs. (2) and (3) that:

$$\Gamma_i = \beta_{PR}\ \lambda_i\ W_B \ . \tag{4}$$

Thus, the bandwidth allocation is unrelated to the state of the network when overload occurs. Since the form of eq. (4) does not change if any two variables Γ_i and Γ_j are interchanged, the steady state throughput distribution is independent of the network configuration (viz. the relative positions of the stations on the network).

For implementation purposes, we note from eqs. (2) and (3) that, when rate control is in effect, the carried load of the Station *i* can be given by:

$$\Gamma_i = \alpha_i\left(1 - \sum_{\text{all } j \neq i} \Gamma_j\right) , \qquad (5)$$

where,

$$\alpha_i = \frac{\beta_{PR}\lambda_i}{1+\beta_{PR}\lambda_i} .$$

Hence, eq. (5) can be implemented by restricting the Station *i* from taking more than a fraction α_i of the spare capacity left over by the other stations.

The PR-BWB mechanism can be implemented through a minor change to the original DQDB protocol. In DQDB, as explained in Section 2, the station *i* can transmit a data segment whenever its CD-counter is zero and the data- bus empty slot is available. We propose instead that the station *i* will be permitted to transmit only a fraction α_i of that time. This is achieved by artificially increasing the REQ counter by one after every $\beta_{PR}\lambda_i$ data segments transmitted, forcing the station to send an extra empty slot downstream. Note that the value of $(\beta_{PR}\lambda_i)$ must be truncated or rounded off to an integer number. In our simulation experiments, we choose to perform the rounding operation. To implement this scheme, only one more counter, called the trigger (TR) counter, is required at each station per bus. The operation of the TR counter is explained as follows:

(I) If the parameter $\beta_{PR} = 0$, this indicates that PR-BWB is disabled, the TR counter is idle and the access function is allowed to transmit in the normal way that was explained in Section 2.

(II) If the parameter $\beta_{PR} \neq 0$, this indicates that PR- BWB is enabled and the TR counter is incremented by one every time the station *i* transmits a data-segment onto the data- bus, as long as the value of this counter is less than $(\beta_{PR}\lambda_i)$.

(III) When the value of the TR counter reaches $(\beta_{PR}\lambda_i)$, the counter is reset to zero and the REQ counter is incremented by one if no segment is queued. Otherwise, the CD counter is incremented by one. This makes it happen that the access function to the data- bus is forced to skip transmitting the segment in the next available empty slot.

In order for the scheme to respond dynamically to the changing loads, a station should estimate its own arrival rate λ_i from time to time, and calculate the value of its corresponding $(\beta_{PR}\lambda_i)$ with which to operate its trigger counter. The above estimation and calculation can be performed by the upper layers of the protocol, and the value of $(\beta_{PR}\lambda_i)$ can be placed in a register whose contents determine when the trigger counter should fire (i.e., when should the station leave an additional empty slot).

It is worthwhile to deduce the relation between the wasted bandwidth (W_B) and the scheme's parameter β_{PR}. Let γ be the total throughput of the system (i.e., the total carried load). It is known that the system wastes the minimum amount of bandwidth when all stations are rate controlled. When the rate control is not in effect, we have $\gamma = L$, where $L = \Sigma_j \lambda_j$ is the total offered load, and $W_B = 1 - L$. On the other hand, when stations are rate controlled, eqs. (2) and (3) imply that:

$$\Gamma_i = \beta_{PR}\lambda_i(1-\gamma).$$

That is,

$$(1-\gamma) = \frac{\Gamma_i}{\beta_{PR}\lambda_i} = \frac{\sum\Gamma_i}{\beta_{PR}\sum\lambda_i} = \frac{\gamma}{\beta_{PR}L} . \qquad (6)$$

Therefore, we have

$$\gamma = \frac{\beta_{PR}L}{1+\beta_{PR}L} , \qquad (7)$$

and

$$W_B = 1 - \gamma = \frac{1}{1+\beta_{PR}L}. \qquad (8)$$

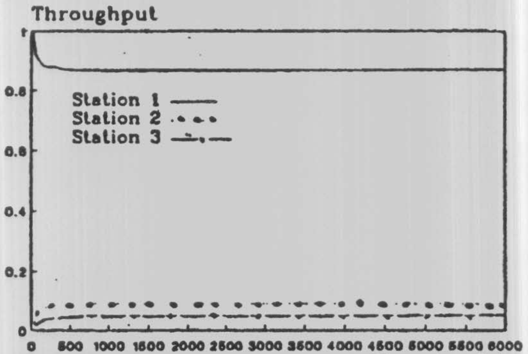
Intuitively, we observe that, for a given β_{PR}, the bandwidth wastage decreases with the increase in the total offered load when rate control is in effect. Note that this desirable property is not present in the BWB mechanism.

4. Simulation results

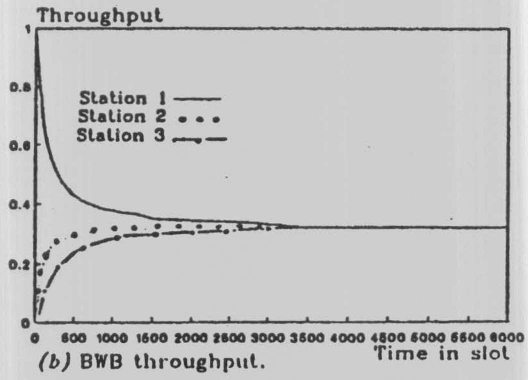
In order to compare the performance of the various schemes (normal- DQDB, BWB-DQDB, and PR-BWB- DQDB), simulation model of the network running under the above strategies is used. The analytical simulator is based on a discrete time dynamic flow model, which takes into account the distributed nature of the DQDB protocol, the network speed and size as well as propagation delay, and the various patterns of overload conditions. The simulator is characterized by low computation times, so that one can investigate the behavior of the three strategies in a network with a large number of stations. The programming language used is Pascal. For more details refer to [19].

Simulation results of the three mechanisms are obtained, based on 150 Mb/sec line capacity for each bus, slot size equal to 53 bytes, propagation speed 200 000 Km/sec and the distance between any two successive nodes is 4Km. The running time is 6000- slot.

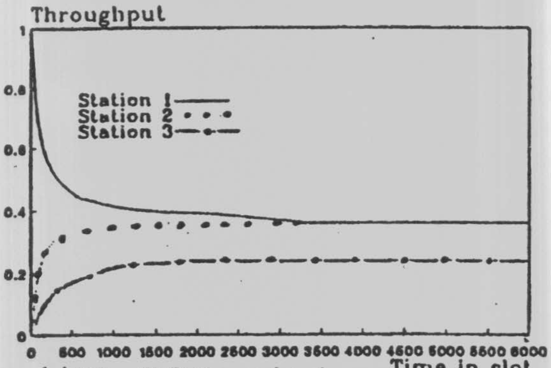
Fig. 4 depicts the throughput performance for the above three strategies in a network consisting of three stations, S_1, S_2, and S_3, with offered loads, $\lambda_1 = 1$, $\lambda_2 = 1$ and $\lambda_3 = 0.6$ pkts/slot, respectively. The system operates according to the scenario in which the most upstream station S_1 becoms active first, the middle station S_2 starts second, and the most downstream station S_3 starts third. It is obvious that, under overload condition ($\Sigma\lambda_i > 1$), the original DQDB protocol achieves unfair sharing of bandwidths allocations, fig. 4-a [7-10]. When the BWB mechanism is applied, fig. 4-b, we note that all the three stations have the same throughput of 0.32 pkts/slot, (for the system parameter $\beta = 9$, i.e., $W_B = 0.04$, [5]). Fig. 4-c represents the throughput performance of the PR-BWB mechanism, for the same $W_B = 0.04$, (where β_{PR} is calculated using eq. (8)). It is clear that the throughput performance of the PR- BWB mechanism is much better, from the fairness point of view, than that of the BWB scheme, where the bandwidth allocated to each station is proportional to its offered load.



(a) DQDB throughput.



(b) BWB throughput.



(c) PR- BWB throughput.

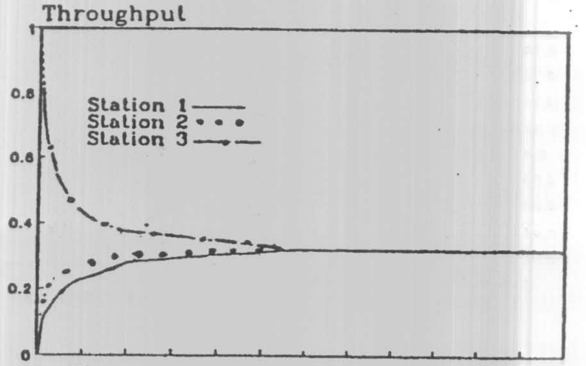
Fig. 4. Throughput comparisons of DQDB, BWB and PR-BWB; S_1, starts 1st., S_2 2nd., S_3 3rd.

In fig. 5, we compare the throughput efficiencies for the two protocols, BWB and PR- BWB, for another scenario in which the most downstream Station S_3 becomes active first, S_2 starts second and S_1 starts third. The offered loads at S_1, S_2, and S_3, are $\lambda_1 = 0.4$, $\lambda_2 = 0.6$ and $\lambda_3 = 1$ pkts/slot, respectively, and the wasted bandwidth ($W_B = 0.04$) is the same for the two schemes. The obtained results show that, under overload condition, the bandwidths allocated, by BWB mechanism, at the three stations are not sensitive to the variations of the offered loads at the various stations, (where the throughput results of figs. 4-b and 5-a are the same, although the offered load at each station for the two cases is different.) On the other hand, from figs. 4-c and 5-b, we note that the PR-BWB mechanism is very sensitive to the changes of the offered loads at the different stations, that is, the PR- BWB scheme performs bandwidth allocations to the individual stations in such a way that the assignments are in proportion to the individual offered traffic loads.

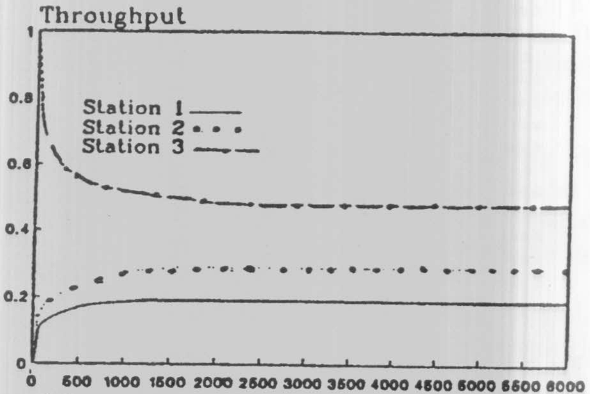
The effect of change of the total offered load on the wasted bandwidth W_B, for a given β_{PR}, is considered in fig. 6. The throughput results are based on the same number of stations, scenario and β_{PR} of fig. 5-b, but the total offered load is increased such that, $\lambda_1 = 0.5$, $\lambda_2 = 0.8$ and $\lambda_3 = 1$ pkts/slot.

We note, from fig. 6, that the corresponding steady - state throughputs, for the three stations are, $\Gamma_1 = 0.21$, $\Gamma_2 = 0.34$, and $\Gamma_3 = 0.43$, that is, the corresponding $W_B = 0.02$, ($W_B = 1 - \Sigma\Gamma_i$), while the throughputs of fig. 5(b) are based on $W_B = 0.04$. This means that, for a given β_{PR}, the bandwidth wastage decreases with the increase in the total offered load when rate control is in effect. Note that this desirable property is not present in the BWB mechanism.

Figs. 7 and 8 show the throughput performance of the BWB and PR- BWB mechanism in a network consisting of five stations, with the scenario in which all stations become active at the same time. The distribution of the offered loads for the five stations is, $\lambda_1 = 0.8$, $\lambda_2 = 0.5$, $\lambda_3 = 0.6$, $\lambda_4 = 0.7$ and $\lambda_5 = 0.9$ pkts/slot and $W_B = 0.04$. Again, the throughput performance of the PR- BWB mechanism is very sensitive to the offered loads.



(a) BWB throughput.



(b) PR- BWB throughput.

Fig. 5. Throughput comparisons of BWB abd PR-BWB; S_3 starts 1st., S_2 2nd., S_1 3rd.

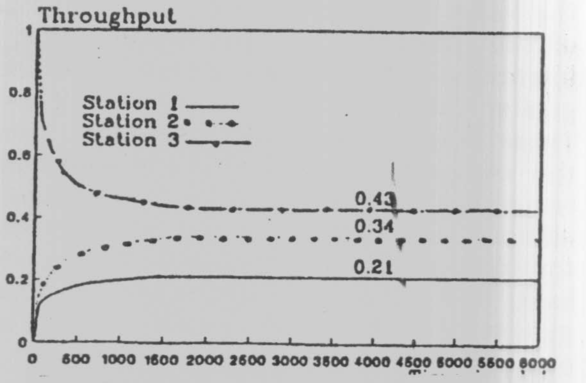


Fig. 6. PR-BWB throughput.

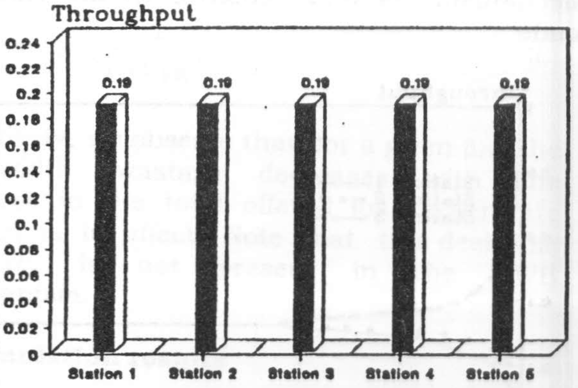


Fig. 7. BWR throughput of 5 stations.

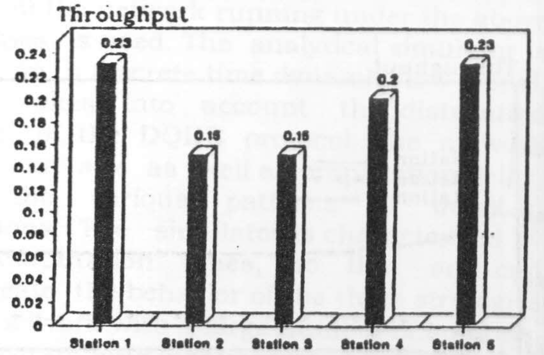


Fig. 8. PR-BWB throughput of 5 stations.

Qualitative analysis of the improved performance of the PR-BWB can be explained as follow. Under over- load conditions and when the PR- BWB mechanism is enabled, the upper limit of the station's *TR* counter is set to the value which is proportional to the station offered load, λ . This means that the intentional unused empty slots by Station *i* is greater than those by Station *j* where ($\lambda_i < \lambda_j$). These wasted bandwidth essentially permits the congestion of the network to relax and the remaining bandwidth is divided among the stations in such a way that the station throughput, Γ, is proportional to its offered load, λ. Moreover, the station throughputs are independent on the state of the network when overload occurs (refer to eq. 4), but they only depend on the number of active nodes, the system parameter β_{PR} and the offered load λ. Finally, the trigger counter *TR* which has been added in each station, neither causing drawbacks on the system performance nor overhead in the frame format [5, 6, 18, 19].

5. Conclusions

The paper has presented a new strategy, to improve the unfairness problem of DQDB network, named Proportion Bandwidth Balancing (PR-BWB) mechanism. This proposal is to employ proportional assignment so that under overload conditions the bus bandwidth can be divided among all of stations in proportion to their offered loads, independent of the network size, the relative station positions and the state of the network when overload occurs. The expressions for the throughput of PR- BWB are developed. The proposed scheme is implemented through an additional counter, called Trigger counter. Simulation examples are employed to compare the performance of the PR-BWB with those of regular DQDB, BWB- DQDB scheme. The results show that, when the PR- BWB is applied, the station throughput is independent of the state of the network when the overload occurs, but it depends on its offered load and the system parameter β_{PR}.

References

[1] R. L. Newman and J. L. Hullet, "Distributed Queueing: A Fast and Efficient Packet Access Protocol for QPSX", Proc. 8th ICCC, Munich (1986).

[2] J. W. Wong,"Throughput of DQDB Networks Under Heavy Load", Proc. EFOC/LAN' 89, Amsterdam, The Netherlands, pp. 146- 151 (1989).

[3] M. Conti, E. Gregori, and L. Enzini, "DQDB Media Access Control Protocol: Performance Evaluation and Unfairness Analysis", 3rd IEEE Workshop on MAN's, San Deigo, Calif, March, pp. 375- 408 (1989).

[4] M. Zukerman and P. Potter," The DQDB Protocol and Its Performance Under Overload Traffic Conditions", ITC Specialist Seminar, Paper No. 164, Adelaide, Australia (1989).

[5] E. L. Hahne, A. K. Choudhury and N.F. Maxemchuk,"Improving the Fairness of Distributed Queue Dual Bus Networks",

Proc. IEEE INFOCOM' 90, San Francisco, pp. 313- 320, (1990).

[6] M.Conti, E. Gregori and L. Lenzini, "Influence of BWB Mechanism on Some Performance Figures of a DQDB Subnetworks", Computer Networks and ISDN Systems, Vol. 27 (7) (1995).

[7] IEEE 802.6 Committee, IEEE 802.6 Standard:"Distributed Queue Dual Bus (DQDB) Subnetwork of A Metropolitan Area Network (MAN)", Institute of Electrical and Electronics Engineers, New York (1990).

[8] M. Zukerman and P. G. Potter,"The Effect of Eliminating the Stand By State on DQDB Performance Under Overload", International Journal of Digital and Analog Cabled Systems, (2), pp. 179- 186 (1989).

[9] Tran- gia and T. Stock, "Approximate Performance Analysis of The DQDB Access Protocol", ITC Specialist Seminar, Adelaide, Australia, Paper (16.1) (1989).

[10] V. Phung and R. Breault,"On the Unpredictable Behavior of DQDB", IEEE Contribution No. 802.6- 90117, Irvin, (1990).

[11] H. R. Van As, J. W. Wong and P. Zafiropulo,"Fairness, Priority and Predictability of The DQDB MAC Protocol Under Overload", Proc. Internal Zurich Seminar On Digital Comm., Zurich, Switzerland, pp. 410- 417 (1990).

[12] M. Conti, E. Gregori and L. Lenzini, "On the Approximation of the Slot Occupancy Pattern in A DQDB Network", Proc. IEEE INFOCOM' 92, Florence, Italy, pp. 518- 526 (1992).

[13] W. Jing and M. Paterakis, "Message Delay Analysis of the DQDB (IEEE 802.6) Network", Proc. IEEE INFOCOM' 92, Florence, Italy, pp. 527- 535 (1992).

[14] C. Y. Chen, G. Makhoul and D. Meliks,"A Queueing Approach to the Performance Evaluation of DQDB", Proc.11th Int. Phoenix Conf. On Comp. & Commun., Scottsdale, AZ (1992).

[15] I. Stavrakakis and R.Landry,"Delay Analysis of the DQDB MAN Based on A Simple Model", *Proc. ICC'92*, Chicago, IL, June 15- 18, pp. 154- 158 (1992).

[16] I. Stavrakakis and Sophia T.," A Markov service Policy with Application to the Queueing Study of A DQDB Station", Computer Networks and ISDN Systems, Vol. 26 (12) (1994).

[17] Wen J. and Michael P.,"Extending the Single- Node DQDB Analytical Model to Analyze Network- Wide Performance", Computer Networks and ISDN Systems, Vol. 27 (5) (1995).

[18] Mete K. and Kenneth S. Vastola, "A Delay Analysis of FDQ and DQDB Networks", Computer Networks and ISDN Systems, Vol. 30 (11) (1998).

[19] S. Nouh and J. Filipiak,"Discrete Time Dynamic Flow Model of DQDB Behavior", 5th IEEE MAN Workshop, Taormina, Italy (1992).

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