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# Counter Rotating Slotted Ring: A New Architecture for Ring MANs

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**Abstract.** In this paper, we describe and analyze a new architecture for ring Metropolitan Area Networks (MANs): Counter Rotating Slotted Ring (CRSR). CRSR consists of two unidirectional rings shared among the network stations. Both the rings have erasure nodes appropriately placed between each or several stations. The transmission time is slotted. Each slot has some control bits and one of the control bit indicates if the slot is busy or not. An empty slot can be marked as busy and used for transmitting data. Once a busy slot reaches its destination, the data is read and the slot is marked as "read". The erasure nodes identify the "read" slots and erase the data from these slots so that the slots can be reused. This process reduces the traffic intensity, which in turn results in less bandwidth requirements for transporting the same amount of information. The performance of CRSR is evaluated by using mathematical and simulation techniques. Several interesting results are presented in this paper in comparison with DQDB.

## 1. Introduction

Metropolitan Area Networks (MANs) represent one of an active areas of research in the field of computer communication networks. MANs are essentially high speed networks that make use of the enormous transmission capacity (more than 100 Mbps) offered by optical fiber transmission media. Due to low error rates of optical fibers, MANs can span a larger geographical area (more than 100 Kilometers) as compared to the area covered by traditional Local Area Networks (LANs). MANs are also becoming a popular choice for future applications because they have potential for integration of voice, video, data, and other services. These features of MANs are particularly of interest because of their possible coexistence with emerging Broadband Integrated Services Digital Networks (BISDNs) based on Asynchronous Transfer Mode (ATM).

MANs share some of the characteristics of LANs such as using a single transmission medium for all the stations connected to the network. However, the Medium Access Control (MAC) protocols used for LANs are not efficient enough for using in MANs and result in poor utilization. This aspect poses a challenge for researchers to develop new architectures for MANs and efficient Medium Access Control protocols.

Two MANs have been standardized: DQDB (Distributed Queue Dual Bus) and FDDI (Fiber Distributed Data Interface). DQDB uses bus architecture whereas FDDI is ring-based. Both DQDB and FDDI support a variety of services including voice and data and can efficiently utilize the network resources. There are some issues including fairness in accessing the transmission media, that are associated with these high speed networks and need to be addressed. For a detailed discussion, readers are referred to [2- 4].

In this paper, we propose, describe, and evaluate a new architecture for MANs - Counter Rotating Slotted Ring (CRSR). The performance results of CRSR are presented in comparision with the performance of DQDB. It may seem inappropriate to compare performance of a ring-based CRSR network with that of a bus-based DQDB network. However, this option was selected because the operation of CRSR is very close to the operation of DQDB and the comparison can be performed under similar loading conditions. It is observed from the comparison that the performance of CRSR, in terms of bandwidth requirement, traffic distribution, access delay, and fairness, is much better as compared to that of DQDB. A detailed description of CRSR is given in the next section. Section 3 describes the evaluation of CRSR and some analytical and simulation results are discussed. Finally, some conclusions are presented in section 4.

## 2. Counter Rotating Slotted Ring (CRSR)

CRSR consists of two unidirectional rings that are shared among all the stations connected to the network and as the name indicates, rings carry information in the opposite direction. The architecture is shown in Fig.1. All stations are connected to both of the rings. Although CRSR is a ring network, its transmission structure is similar to that of DQDB and is quite different from that of FDDI. All transmissions in CRSR are in the form of slots. A stream of slots continuously flows on each ring (in opposite directions). At the outset (i.e. at the time of initialization) a master station for each ring generates a sufficient number of transmission slots so as to fill the periphery of each ring. Each slot has a header that, among other information, keeps the information about the status of a slot. A station that has some information to transmit waits for an empty slot to arrive. As soon as an empty slot arrives, the station marks it busy (by changing its status bits) and fills it with the information to be transmitted. The slot carries the information to the destination, the destinations station copies the information into its memory and marks the slot as “read”. Please note that a ``read" slot is not empty.

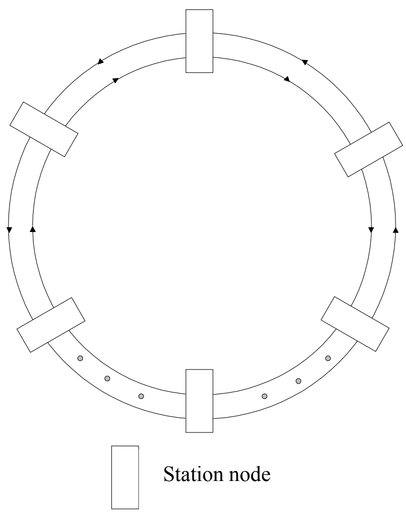



**Fig. 1. Counter rotating slotted ring (CRSR).**

CRSR architecture also has a provision for placing erasure nodes at appropriate locations on the ring [5]. The function of an erasure node is to identify the slots that have been “read”, erase the data from these slots and make them empty. Depending upon the location and/or the number of erasure nodes, a “read” slot may be made empty soon after its contents were read. As soon as the slot has been marked as empty, it can be reused by another station to transmit its data. This means, the same slot may load data from more than one station and deliver to more than one destination in a single circulation around the ring. To reiterate, an erasure node is a node that is capable of buffering up a packet and sending the same packet or replacing it with an empty one. A non-erasure node is capable of transmitting a packet but not erasing a packet.

It seems logical to conclude that if we have more erasure nodes placed around the ring, we can utilize the transmission slots in a very efficient manner. However, please note that for an erasure node to erase data from a slot and to mark it empty, the node must store the entire slot in its memory before it can be erased. This is because the information about the status of a slot i.e. whether it has been read or not is at the end of a slot. If the erasure node does not store the entire slot in its memory, it will not be able to erase its contents in case the slot is identified as “read”. This process increases delay. So, on one hand having more erasure nodes helps improve the utilization of resources and on the other hand having more erasure nodes cause more delay. Therefore, during the design process one needs to pick an appropriate number of erasure nodes to meet the needs of potential MAN applications.

The above discussion leads to two variations of CRSR: General Destination Release (GDR) CRSR as shown in Fig. 2a, and Partial Destination Release (PDR) CRSR as shown in Fig. 2b. In GDR, all stations connected to the network are also erasure nodes. This means that once a slot delivers data to its destination, that destination station removes the data from the slot and marks it as empty. In PDR, all stations are not erasure nodes. Once a slot delivers its data to its destination, the destination marks the slot as “read”. The first erasure node that receives this slot will remove its data and mark it empty. The process of erasing data from a slot and reusing it increases the utilization of the transmission media and enhances its capacity. It may seem that GDR is a special case of PDR in that the number of erasure nodes is equal to the number of nodes in the ring. However, delay in each erasure node is one slot time, whereas a non-erasure node may read the header at the beginning of a packet to determine whether the packet is addressed to it or not. If it is not the destination, it may put the packet back on the ring without reading it to minimize processing time. The advantages of PDR CRSR are thus lower cost and less delay. For performance reasons, it is worth categorizing two types of CRSRs.

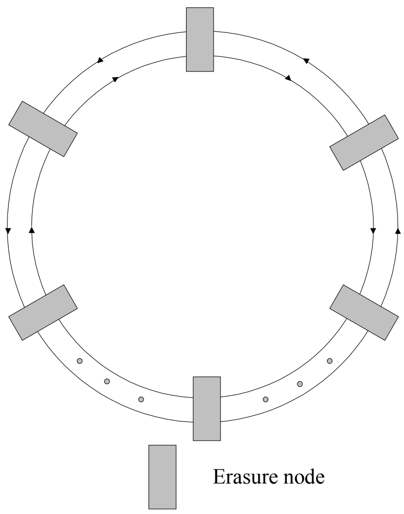



**Fig. 2a. General destination release CRSR.**

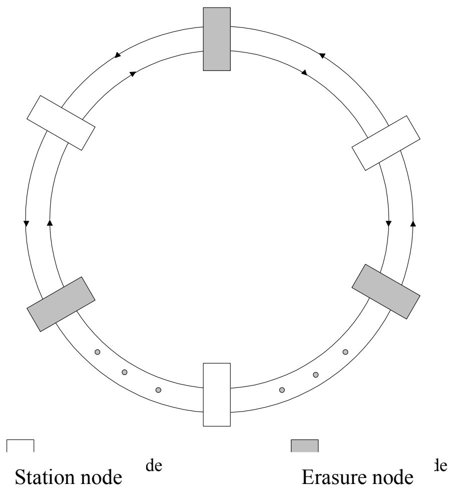



**Fig. 2b. Partial destination release CRSR.**

The routing of information in CRSR is based on minimum node count. The node count is defined as the number of nodes a slot will have to go through to reach its destination. Prior to the transmission of information, the source station will determine the node count for its destination for both rings. The ring that yields a smaller node count will be used for transmitting the information. If there are $n$ nodes (stations) connected to the network, the maximum node count from any source to any destination pair is bounded by $\lfloor n/2 \rfloor$. The use of minimum node count routing reduces traffic intensity on the transmission medium because each slot will need to traverse at the most half the ring to reach its destination.

CRSR is also fair to all stations in terms of providing access to the transmission medium. In General Destination Release CRSR with symmetric traffic conditions, all stations have the same chance of accessing the transmission medium because each station acts as an erasure node and as soon as a slot reaches its destination, its contents are erased and it is available for reuse. In Partial Destination Release CRSR, some positional unfairness may exist. However, it decreases as we increase the number of erasure nodes in the network.

As for the performance of CRSR, it turns out to be better than other equivalent networks in terms of bandwidth requirements. This can be seen in the next section, which is dedicated to the evaluation of CRSR.

## 3. Evaluation of CRSR

In this section, we present mathematical analysis of CRSR and DQDB in terms of traffic distribution, bandwidth requirement, and bandwidth compression ratio (defined as the ratio of the required bandwidth to the traffic load) and compare their performance. Although DQDB standard does not permit erasure nodes, we have evaluated performance of DQDB with erasure nodes in order to compare the performance of CRSR and DQDB under similar conditions. As the traffic conditions are assumed to be symmetric, we will only show traffic on one ring (for CRSR) and one bus for (DQDB). The following assumptions apply to the analysis:

- Total number of stations is $n$.
- Station $i$ generates the traffic at a rate of $\lambda_i$ packets per second.
- Destination nodes for each source are uniformly distributed.
- No station sends information to itself.
- There are no transmission errors.

We will first present the analysis of General Destination Release CRSR. Let us define the following notations:

$P_{ij}$ = Probability that a packet goes from station $i$ to station $j$.
$T_i$ = Total traffic at the interface of station $i$ in packets per second.
$O_i$ = Outgoing traffic from station $i$ in packets per second.
$R_i$ = Arriving traffic at station $i$ in packets per second.

If the number of stations $n$ is even, a station will see traffic from half of the stations on one ring and from the remaining half on the other ring. This is because of the Minimum Node Count Routing. Therefore, the total traffic $T_i$ at station $i$ is given by:

$$\mathrm{T_i} = \lambda_{i-1}\left[\frac{1}{2}P_{(i-1)(i+\frac{n}{2})} + \sum_{j=i}^{i+\frac{n}{2}-2} P_{(i-1)j}\right]$$

$$+ \lambda_{i-2}\left[\frac{1}{2}P_{(i-1)(i+\frac{n}{2}-2)} + \sum_{j=i}^{i+\frac{n}{2}-3} P_{(i-2)j}\right]$$

$$\vdots$$

$$+ \lambda_{i-\frac{n}{2}}\left[\frac{1}{2}P_{(i-\frac{n}{2})j}\right]$$

$$\mathrm{T_i} = \sum_{k=i-\frac{n}{2}}^{i-1} \lambda_k \left[\sum_{j=i}^{k+\frac{n}{2}-1} P_{kj} + \frac{1}{2}P_{k(k+\frac{n}{2})}\right] \tag{1}$$

Similarly, the traffic $R_i$ terminating at station $i$ is:

$$\mathrm{R_i} = \sum_{j=i-\frac{n}{2}+1}^{i-1} \lambda_j P_{ji} + \frac{1}{2}\lambda_{(i-\frac{n}{2})} P_{(i-\frac{n}{2})i} \tag{2}$$

and the traffic $O_i$ originating from station $i$ is:

$$O_i \quad = \quad \lambda i \sum_{j=i+1}^{i+\frac{n}{2}-1} P_{ij} + \frac{1}{2}\lambda_i P_{i(i+\frac{n}{2})} \tag{3}$$

Assuming uniform traffic i.e. $\lambda_i = \lambda$ for all $i$, the net traffic going towards station $i+1$ is given by:

$$T_{i+1} \quad = \quad T_i - R_i + O_i$$

$$= \sum_{k=i-\frac{n}{2}}^{i-1} \lambda \left[ \sum_{j=i}^{k+\frac{n}{2}-1} \frac{1}{n-1} + \frac{1}{2(n-1)} \right] - \lambda \left[ \sum_{j=i-\frac{n}{2}+1}^{i-1} \frac{1}{n-1} + \frac{1}{2(n-1)} \right]$$

$$+ \quad \lambda \left[ \sum_{j=i+1}^{i+\frac{n}{2}-1} \frac{1}{n-1} + \frac{1}{2(n-1)} \right]$$

$$= \quad \frac{\lambda}{(n-1)} \sum_{j=0}^{\frac{n}{2}-1} (j + \frac{1}{2})$$

$$T_{i+1} \quad = \quad \frac{\lambda n^2}{8(n-1)} \tag{4}$$

If the number of station $n$ is odd, a similar procedure yields the following result:

$$T_{i+1} \quad = \quad \frac{\lambda(n+1)}{8} \tag{5}$$

Both equations (4) and (5) are independent of $i$ and, therefore, the traffic is the same for all stations. In the case of DQDB, the contents of the slots are not erased by the destination, so the slots cannot be reused. Assuming that $\lambda_i=\lambda$, the traffic $T_i$ at station $i$ for DQDB is given by:

$$T_i \quad = \quad \sum_{k=1}^{i-1} \lambda \sum_{j=k+1}^{n} P_{ij} \tag{6}$$

In accordance with our assumption of uniform traffic, $P_{ij} = 1/(n-1)$ for all $i$ and $j$. Therefore,

$$T_i \quad = \quad \sum_{k=1}^{i-1} \lambda \sum_{j=k+1}^{n} \frac{1}{n-1} = \frac{\lambda}{2} \frac{(2n-i)(i-1)}{(n-1)} \tag{7}$$

In the absence of erasure nodes, the traffic accumulates along the bus and the last station receives all the traffic.

If slots are erased by the destination stations i.e. General Destination Release DQDB, the traffic at station $i$ is the traffic for station $i-1$ minus the incoming traffic and plus the outgoing traffic, as shown below:

$$T_i \quad = \quad T_{i-1} - R_i + O_i \tag{8}$$

In our case:

$$R_i \quad = \quad \sum_{j=1}^{i-1} \frac{\lambda}{n-1} = \frac{\lambda(i-1)}{(n-1)} \tag{9}$$

and

$$O_i \quad = \quad \sum_{j=i+1}^{n} \frac{\lambda}{n-1} = \frac{\lambda(n-i)}{(n-1)} \tag{10}$$

Therefore,

$$T_i \quad = \quad T_{i-1} - \frac{\lambda\left[(i-1)-1\right]}{n-1} + \frac{\lambda\left[n-(i-1)\right]}{n-1}$$

$$= T_{i-1} + \frac{\lambda(n+3-2i)}{(n-1)} \tag{11}$$

Now, by definition $T_i = 0$, thus

$$T_i \quad = \quad \frac{\lambda(i-1)(n-i+1)}{(n-1)} \tag{12}$$

These results are summarized in Table 1.

**Table 1. Bandwidth requirement for CRSR and DQDB**

| Network | $T_i$ = Traffic at node I |
|---|---|
| GDR CRSR (even n) | $T_i = \frac{\lambda n^2}{8(n-1)}$ |
| GDR CRSR (odd n) | $T_i = \frac{\lambda(n+1)}{8n}$ |
| GDR DQDB | $T_i = \frac{\lambda(i-1)(n-i+1)}{(n-1)}$ |
| DQDB | $T_i = \frac{\lambda(2n-i)(i-1)}{2(n-1)}$ |

To visualize the differences between the traffic distribution of DQDB and CRSR, the results of Table 1 are plotted in Fig. 3 for an even number (100) of stations. In the case of DQDB with no erasure nodes, we note from Fig. 3 that the percentage of the used transmission slots increases as the slots flow from one end to the other end of the bus. The maximum traffic of 50% is at the end of the bus. This is because we are considering only one bus. If the other bus were to be taken into consideration, this figure would have been 100%. For General Destination Release DQDB, erasure nodes (destinations in this case) remove data from the slots. Therefore, in this case, for the first half of the bus, the percentage of the used slots increases and then starts decreasing. Eventually, the traffic approaches zero (by the time a slot reaches the other end of the bus, its data must have been removed by the destination). In the case of General Destination Release CRSR, the traffic distribution is uniform for the entire network and this is due to its ring architecture and due to the fact that slots can be reused. This shows that the General Destination Release CRSR uses the least amount of the bandwidth and is more efficient than DQDB and General Destination Release DQDB. The results for an odd number of stations both in DQDB and CRSR show the same general pattern.

Keeping Fig. 3 in view, we notice that traffic distribution General Destination Release CRSR is independent of the position of a station whereas in the case of DQDB and General Destination Release DQDB, the traffic heavily depends on the position of a station. This implies that there is no positional unfairness in CRSR network given that the network is uniformly loaded. This is an understandable result due to the symmetric structure of CRSR.

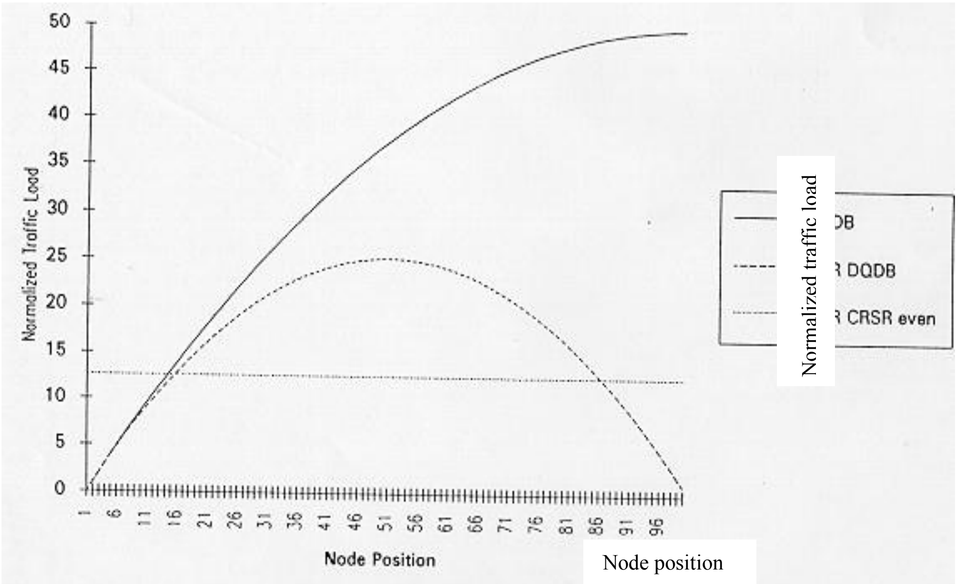



**Fig. 3. Traffic distribution for 100 nodes.**

For a given number of stations and a given value of arrival rate $\lambda$ packets per second for each station, we can define the bandwidth requirement for a network as the capacity of a bus or a ring to carry the maximum volume of traffic $T_{max}$ for DQDB and for CRCR. These are summarized in Table 2.

Due to symmetric traffic conditions, the results in Table 2 are presented for one bus in the case of DQDB and for one ring in the case of CRSR. The comparison of the results shows that the General Destination Release CRSR requires less bandwidth than DQDB and General Destination DQDB. The same results are also plotted in Fig. 4.

**Table 2. Maximum bandwidth requirement for CRSR and DQDB**

| Network | $T_{max}$ = Maximum bandwidth requirement |
|---|---|
| GDR CRSR (even n) | $T_{max} = \frac{\lambda n^2}{8(n-1)}$ |
| GDR CRSR (odd n) | $T_{max} = \frac{\lambda(n+1)}{8}$ |
| GDR DQDB (even n) | $T_{max} = \frac{\lambda n^2}{4(n-1)}$ |
| GDR DQDB (odd n) | $T_{max} = \frac{\lambda(n+1)}{4}$ |
| DQDB | $T_{max} = \frac{n\lambda}{2}$ |

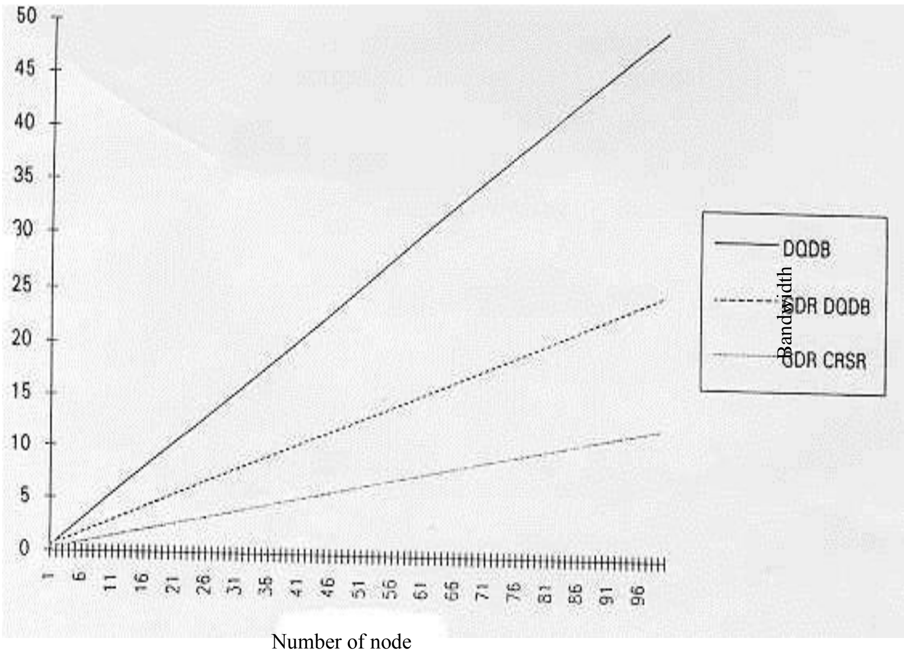



**Fig. 4. Bandwidth requirements.**

In order to compare the bandwidth of DQDB, General Destination Release CRSR, they can be normalized with respect to the total traffic in a uniformly loaded network. We call this ratio the Bandwidth Compression Ratio (BCR). BCR is a key indicator of a network's performance. As mentioned earlier, our network has $n$ stations (or nodes) and each one of them generates traffic at a rate of $\lambda$ packets per second. This gives us a total traffic of $n\lambda$ packets per second. As the traffic is uniformly distributed, each transmission medium (one bus for DQDB and one ring for CRSR) will carry $n\lambda/2$ packets per second. This value of traffic is used for computing BCR and the results are summarized in Table 3.

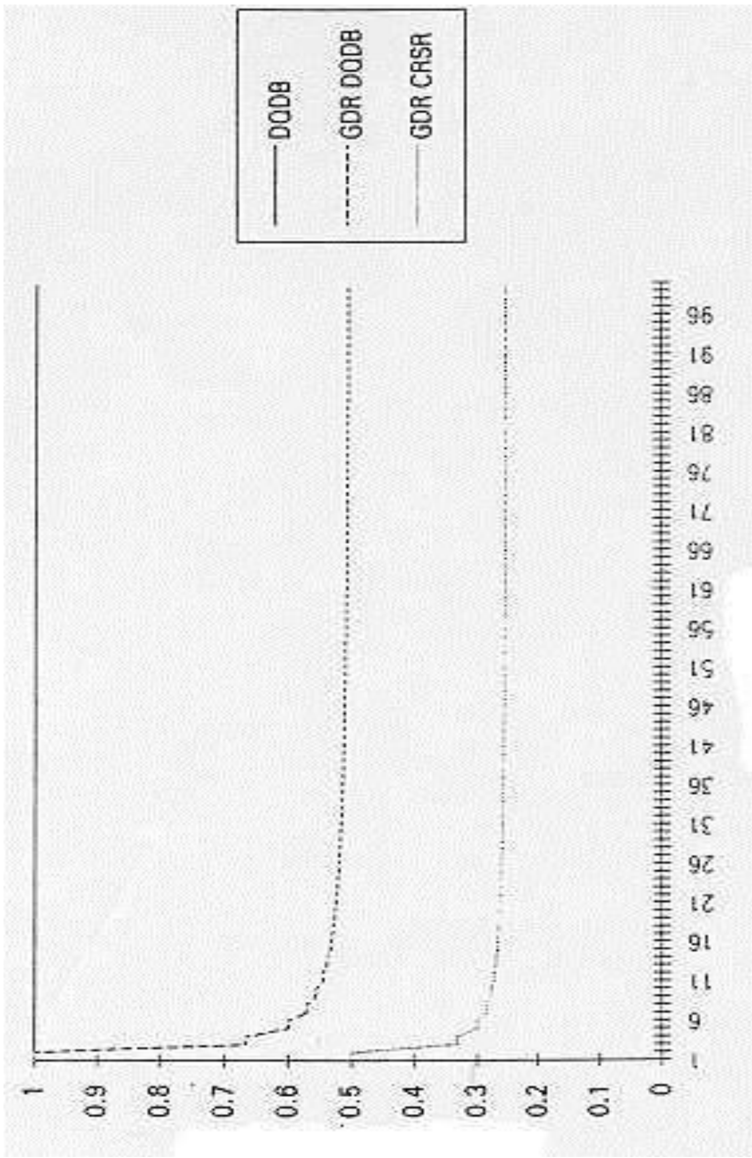
The results of Table 3 are plotted in Fig. 5. It is clear from the figure that for a large $n$, the bandwidth requirement for General Destination Release CRSR is 1/2 of an equivalent GDR DQDB. and ¼ of an equivalent DQDB network.

**Table 3. Bandwidth compression ratios**

| Network | Bandwidth compression ratio (BCR) |
|---|---|
| GDR CRSR (even n) | $BCR = \frac{n}{4(n+1)}$ |
| GDR CRSR (odd n) | $BCR = \frac{n+1}{4n}$ |
| GDR DQDB (even n) | $BCR = \frac{n}{2(n-1)}$ |
| GDR DQDB (odd n) | $BCR = \frac{n+1}{2n}$ |
| DQDB | $BCR = 1$ |

Obviously, PDR CRSR is less expensive and yields less delay than that for GDR CRSR, However, bandwidth requirement of PDR CRSR will be more than that of GDR CRSR. Under uniform loading conditions, the traffic in PDR CRSR builds up steadily until the location of an erasure node. Once an erasure node erases the contents of "read" slots, the traffic reduces and starts building again. In Fig. 6, we show the normalized traffic load for a 100 node PRD CRSR with every 25th station acting as an erasure node.

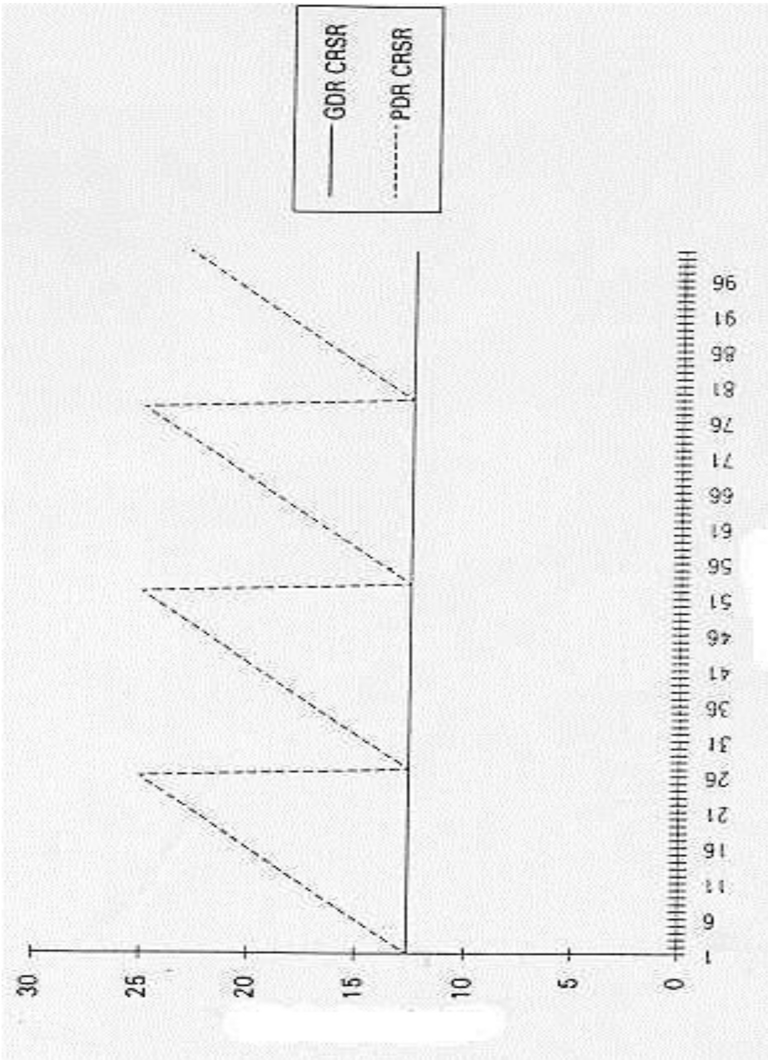
In terms of access delay versus offered load for GDR CRSR and PDR CRSR, Fig.7 shows simulation results for network with 30 stations and with a varying number of erasure nodes. It is assumed that the distance between two adjacent stations is equivalent to four slots. The delay increases as expected when the offered load is increased. Also, please note that the delay heavily depends on the number of erasure nodes.




Number of nodes

Bandwidth compression ratios

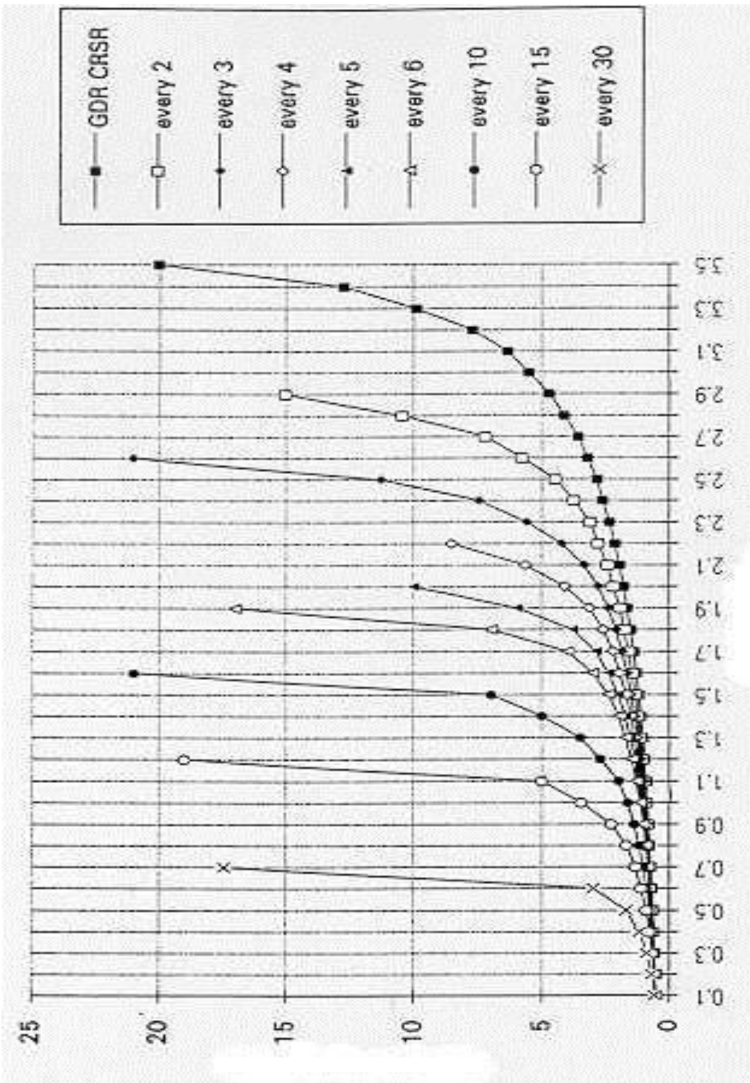
**Fig. 5. Bandwidth compression ratios.**




Node position

Normalized traffic load

**Fig. 6. Traffic distribution for 100-node PDR CRSR.**




Throughput

Normalized access delay

**Fig. 7. Access delay for a 30-node CRSR with 2 slots distance between nodes.**

As mentioned earlier, another important advantage of CRSR is its access fairness for all its users. In Fig. 8, we show simulation results indicating the probability of accessing a free slot versus the location of a station for the same offered load. As the figure shows, in the case of CRSR not only the users have less access delay, they also have a fairly good probability of accessing a free slot as compared to that in DQDB. Also, in the case of CRSR the access probability is the same for all stations irrespective of their locations which means that GDR CRSR is very fair to its users.

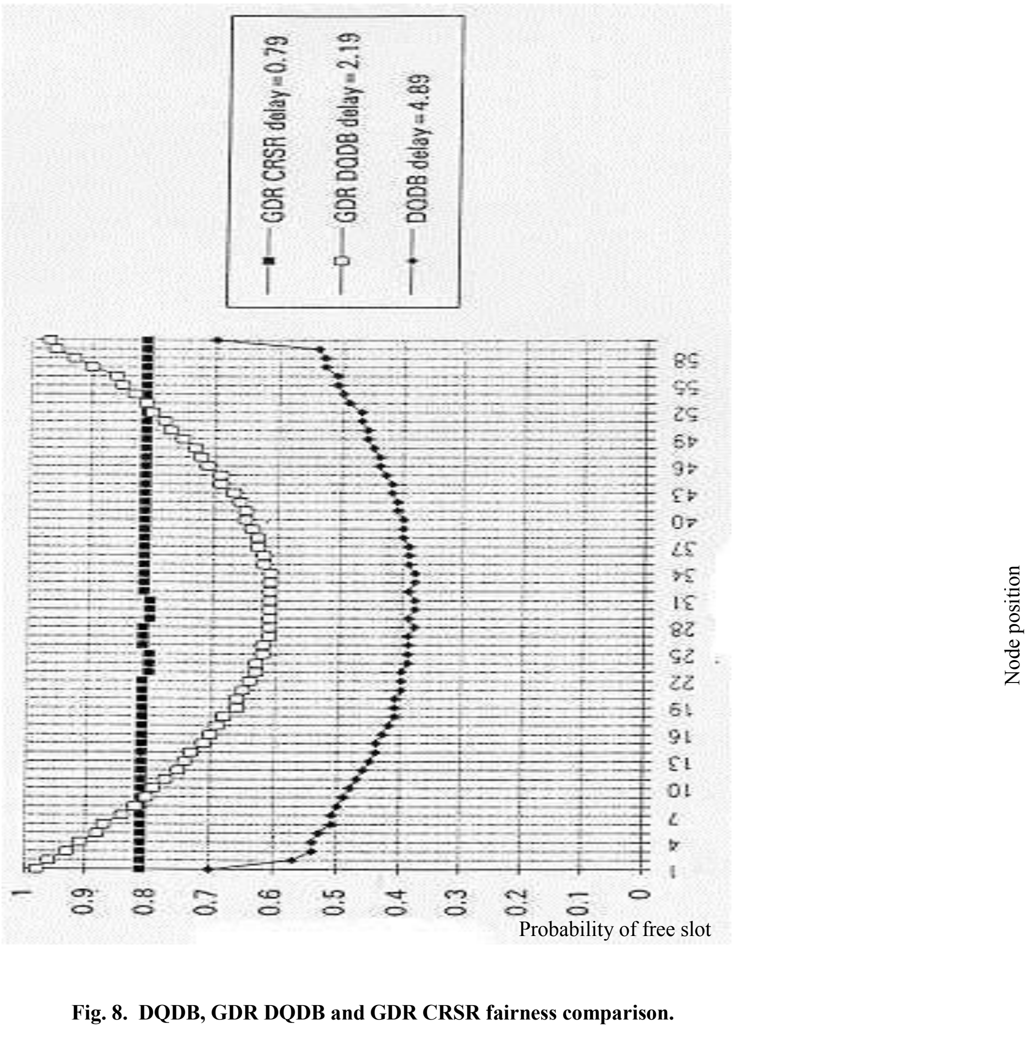



**Fig. 8. DQDB, GDR DQDB and GDR CRSR fairness comparison.**

## 4. Conclusions

In this paper, a new architecture - Couture Rotating Slotted Ring (CRSR) for metropolitan area networks has been proposed and analyzed. CRSR consists of two uni-directional rings shared among the network stations and both the rings have erasure nodes appropriately placed between each or several stations. The transmission of information is in the form of slots. The performance of CRSR is evaluated by using analytical and simulation techniques. Several interesting results are presented in this paper in comparison with DQDB. The results show that it performs significantly better than DQDB architecture and has better traffic distribution along its transmission medium. CRSR also offers better performance in terms of less bandwidth requirement and better bandwidth utilization. In addition, CRSR also is much fair to its users than DQDB.

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## الشبكة المشقبة التي تدور عكسيا: هيكل جديد للشبكات الحلقية في المناطق المدنية

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(قدّم للنشر في ١٩٩٨/٠٣/٢٧م؛ وقبل للنشر في ١٩٩٩/٠٩/١٤م)

**ملخص البحث.** في هذا البحث، وصف وتحليل لبنية هيكلية مقترحة لشبكة حلقية تصلح للمناطق المدنية: الشبكة المشقبة التي تدور عكسيا. وتتكون هذه الشبكة المقترحة من حلقتين اتجاهيتين مقتسمتين من قبل محطات الشبكة المقترحة. ويوجد بكلتا الحلقتين عقدة محو موضوعة بطريقة مناسبة بين كل محطتين أو بين كل عدة محطات. ويكون وقت الإرسال مقسما، ويجعل لكل حيز ضيق (شقب) عدة بتات تحكم، تبين إحداها ما إذا كان الحيز مشغولا أم لا. ويمكن تحديد حيز واحد على أنه "مشغول"، ويستخدم بالتالي لإرسال البيانات. وعندما تصل الرسالة المحتواة في الحيز المستخدم الآن (الشقب) تقرأ بياناتها، ثم يعاد تحديد الحيز على أنه تمت قراءته. تقوم عقد المحو بالتعرف على أي حيز تمت قراءته، ومن ثم تقوم بمحوه ليمكن استخدامه للإرسال من جديد. وتقلل هذه الطريقة من كثافة المرور في الشبكة، مما يؤدي إلى تقليل الحاجة إلى نطاقات ترددية أعرض لنقل نفس كمية البيانات.

ولقد تم اختبار أداء الشبكة المشقبة التي تدور عكسيا CRSR ، باستخدام أساليب محاكاة وتحليل رياضي، ونقدم في هذا البحث نتائج هامة لاستخدام هذه الشبكة المقترحة، بالمقارنة مع الشبكة ذات الناقلين موزعة الجودة DQDB.