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自己トークンプロトコルによる高速リング LANs の公正さの解析

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自己トークンプロトコルはマルチプル・トークンアクセス方式に基づく高速リング LANを実現する。遅延／スループットの性能は非同期モードの FDDI-I [3] の性能より優れることは既に証明された[1][2]。本文では、シミュレーションを使って均一および不均一なトラヒックバランスの下で自己トークンプロトコルにおける公正さを解析する。各ステーションの遅延／スループットの性能を比較し、それらの性能はほぼ同じであることを示す。さらに、プロトコルの公正さの特性をもっと詳しく調べるために、ステーションによって伝送およびリピートされたパケット数（つまり、バンド幅を共有する２つのステーション間の公正さ）を基に不公正さの尺度を定義し、各ステーションにおける不公正さの特性はほぼ同じであることを示す。最後には、自己トークンプロトコルとバッファ・インサーションリングにおける不公正さの特性と遅延／スループットの性能を比較する。

Analysis of Fairness on Self-Token Protocol for High Speed Ring LANs

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Self-Token protocol provides a high speed local area network (LAN) based on a multiple-token ring access scheme. Delay-throughput performances of the protocol have been proved in [1][2] to be better than that of FDDI-I[3] in asynchronous mode. In this paper, we analyse fairness of the Self-Token protocol by means of simulations. Both of symmetrical and asymmetrical traffics are investigated. First, we compare delay-throughput performances of each station and show that the performances are nearly the same overall the stations. Next, in order to investigate the fairness characteristic of the protocol more closely, we define an unfairness measure based on the number of packets transmitted and repeated by stations, i.e., fairness between any two stations that may share link bandwidth. We show that the degrees of unfairness of each station is nearly the same. Finally the degrees of unfairness and delay-throughput performance between the Self-Token protocol and the Buffer Insertion are compared.

1 Introduction

As the need of distributed computing and multimedia communications grow rapidly, research in ring LANs with smaller delay and higher throughput have received much attention lately. Spatial reuse of bandwidth has been found to be the most effective way to satisfy such LANs.

Spatial reuse which allows concurrent transmissions over distinction segment of the ring, can significantly increase the overall ring throughput and decrease the delay. The Buffer Insertion which implemented the method may suffers from well-known station starvation, because there is no traffic regulation exists. That is, in the Buffer Insertion a downstream station will starve, if its upstream stations continuously transmit packets through the station. This problem introduces fairness mechanism that regulate traffic flowing on the ring. The Metaring[4] and the Elastic Ring[5] are the examples of bidirectional ring networks that implemented a traffic regulation for achieving fairness among stations.

In the Metaring, a hardware control signal, called SAT, was introduced in order to regulate stations in accessing to each direction of the ring. The SAT signal circulates in the opposite direction to the data traffic it regulates. Starvation can be prevented by assigning a quota on the number of packets transmitted by a station between two successive SAT signal arrivals. A station will hold the SAT signal if it cannot transmit its quota, unless forward it immediately to the upstream station with no delay. The Elastic Ring uses the same type of signal, called break request, to regulate the ring traffic. A station will send a break request signal to its upstream station if it detects unfairness bandwidth usage to stop the station on sending its packets. By this dynamic unfairness detection, the Elastic Ring can achieve high degrees of fairness although network load is heavy.

On the other hand, the Self-Token protocol implements a very simple mechanism for achieving fairness among stations. By assigning private token(s), called self-token, to each station, traffic from the station can easily be regulated. A station can solely transmit its packets if the self-token (s) exists in its buffer; the heavier network load becomes, the longer stations must wait for its token(s) returns. Therefore, this protocol has an automatic traffic regulation, namely packet transmission will be delayed as the network load increases.

The basic operation of the Self-Token protocol are described in Section 2. Simulation descriptions are given in Section 3, while the fairness of delay-throughput performance and unfairness measure are described and discussed in Section 4 and Section 5 respectively. Finally, conclusions are given in Section 6.

2 The Basic Operation of the Self-Token Protocol

As mentioned earlier, in order to support multiple-token ring access scheme, we assign private token(s), called self-token, to each station — note that, the state of self token(s) which is kept in station register is free and which is attached to a transmitted packet is busy. However, this induces a conflict between packets ready to be transmitted by a station and packets which will pass the station, because all stations can transmit their packets simultaneously. Therefore, a receive register which is commonly known as the insertion register is necessary to delay the passing packets. Note that, the register is not infinitely large like the conventional Buffer Insertion operates in station priority mode, but equal to Tc * maximum packet length (Tc is the number of self-tokens on a station).

Figure 1 illustrates the structure of a Self-Token protocol station. A station can transmit its packet from transmit register if only it holds its own token in self-token register and there is no a transit packet being sent from receive register. If the station has the transit packet, it must defer its transmission until the end of the transit packet being transmitted. That is, the station priority strategy is employed.

While a station is transmitting its own packets, all packets arriving from upstream station are buffered in the receive register. The contents of the receive register are transmitted after the transmissions are completed. the destination station copies the transmission packet addressed to it and then returned the packet to its source station for removing from the ring. The source station restores the self-token in the self-token register while removing packet from the ring, so that the station can reuse the token in the next packet transmission. Therefore, in heavy traffic load, a station cannot transmit its packets continuously because the station has to wait the self-token returns. It is how the protocol regulates the traffic, so that the fairness among stations can be achieved.

Basically, the number of the self-tokens in each station are the same. However, in some system configurations, the station such as voice communication or image

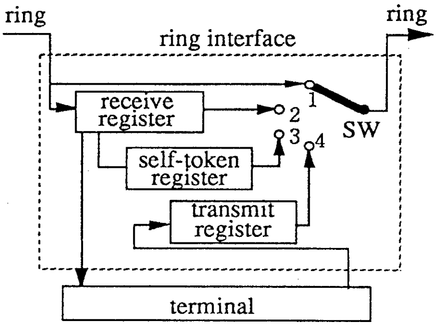

Figure 1. Structure of a Self-Token protocol station.

processing devices need to transmit a large of data in order to build a real time communication. Hence, a priority transmission is needed here to give the stations more chance to transmit their data. The priority of a station is determined by the number of the self-token assigned to the station. Stations that belong to the ordinary devices, which have the lowest priority (0 priority), are assigned only one self-token. On the other hand, stations with a higher priority p are allowed to have p+1 self-tokens, so that they can use more bandwidth than the ordinary stations. In return, the stations with p priority must provide a receive register whose length is equal to p+1 times maximum packet length. The highest priority level is 7; however, as we will show in the Section 5, stations with priority 3 can achieve total throughput performance as well as the conventional Buffer Insertion. Packet format and error recovery procedures have been described in detail in [1] [2].

3 Simulation Description

In our model, if a self-token exists in the self-token register, packet that arrives at the station is directly queued in the transmit register and wait there until the link becomes free. Otherwise the packet is queued in a waiting-buffer until the self-token returns to the station. Packets are independently generated by each station according to Poisson distribution, while its length distribution is assumed to be exponential. Average packet length is assume to be 250 bytes and the destination of the packets is uniformly distributed on the ring. Processing delay at each station is assumed to be 15 bytes, and transmission speed of the link is five nanoseconds / meter.

We consider a unidirectional ring configuration with 1 Gbps transmission rate. The ring is 10 kilometer length and has 32 stations with equal distance between them. In the fairness evaluation, mean transfer delay and throughput are considered. Mean transfer delay is define as the time interval from the generation of a packet at the source station until its reception at the destination, while throughput is the total number of data bits that has been transmitted into the ring by station in a unit time. In fairness evaluation, the mean transfer delay and the throughput were counted separately base on the station number.

4 Delay-Throughput Fairness

Figure 2 shows delay-throughput performance of every four station on the ring when all stations are assigned one and four self-tokens. The traffic condition is symmetric, i.e., all stations have the same average packet interarrival time. As shown in the figure, when Tc=1 every station has approximately the same delay-throughput performance although the network load is heavy, i.e., sta-

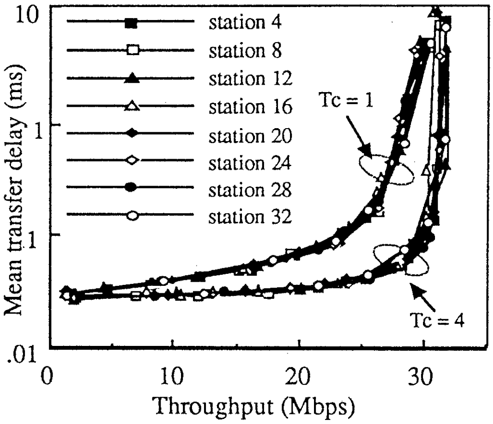

Figure 2. Delay-throughput performance for Tc=1 and 4.

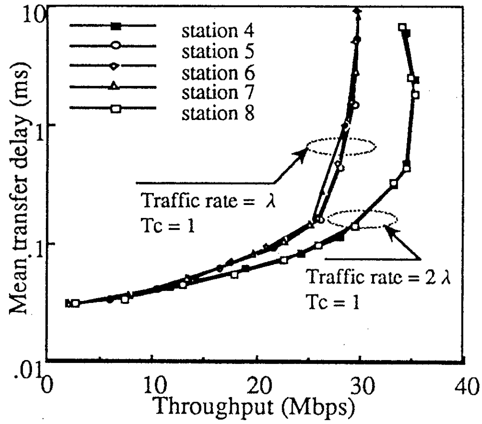

Figure 3. Delay-throughput performanceunder asymmetrical traffic condition.

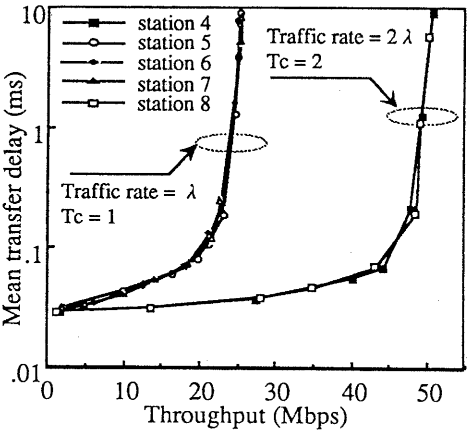

Figure 4. Delay-throughput performanceunder asymmetrical traffic condition.

tion throughput range from 25 to 30 Mbps. Furthermore, the fairness of delay-throughput performance among stations can be well achieved though self-token numbers on each station is increased to four. However, as the network load increases delay-throughput performance of each station becomes slightly different.

Logically, the fairness of delay-throughput performance among stations is easily achieved when priority of the stations are low, i.e., every station has 1 or 2 self-token. This is because the fact that a station cannot get more bandwidth as its traffic load increases so that the traffic/packet from the station does not give a special impact to the network traffic. The total throughput, however, may suffer from decrease because the ring bandwidth is not fully utilized.

Figure 3 and 4 illustrate delay-throughput performance under asymmetrical traffic condition. Every four station on the ring, which starts at station 4, is assumed to have 2λ traffic rate, i.e., station 4, 8, 12, 16, 20, 24, 28, 32 have 2λ traffic rate. And the remaining stations have λ traffic rate. For simplicity, we only consider the performance of five consecutive stations on the ring (from station 4 to station 8 ; station 4 and 8 have twice traffic rate of station 5, 6, 7).

The purpose of this traffic scenario is to reproduce an unbalanced traffic condition which commonly occurs in the high speed networks. That is, few stations, such as voice communication or image processing devices, involve in a high traffic rate while the other stations operate relatively in a low traffic rate. In this traffic scenario, we are interested in investigating the fairness among stations with the same traffic rate and impacts that may be given by the high traffic rate stations to the low traffic rate ones.

Figure 3 shows delay-throughput performance when all stations, no exception to the stations with 2λ traffic rate, are assigned one self-token. As shown in the figure, delay-throughput performance of each station with λ traffic rate as well as 2λ traffic rate is approximately the same. It is clear that the fairness of delay-throughput performance among stations with the same traffic rate is well achieved. That is, interaction between stations with 2λ traffic rate and λ traffic rate or among stations with the same traffic rate does not appear. It clearly proves that the protocol can treat fairnessly every station although stations with a high traffic rate exist on the network. However, the throughput of stations with 2λ traffic rate does not grow so highly because those stations have only one self-token for transmitting their packets.

Figure 4 shows the performance under the same traffic condition ; but each station with 2λ traffic rate is assigned two self-tokens. Again, the fairness among stations with the same traffic rate can well be achieved. It shows that increasing priority of the high traffic rate stations, i.e., increasing their self-token number, does not affect the fairness of delay-throughput performance among stations with the low traffic rate. Furthermore, the throughput of the high traffic rate stations grows 40% higher compare to the former result. This is because the fact that the stations can transmit more packets with its two self-tokens. However, the throughput of the low traffic rate stations decrease slightly because its bandwidth was taken by the high priority stations.

5 Unfairness Measure

In this Chapter we define an unfairness measure for the Self-Token protocol based on the number of packets that has been repeated and transmitted by stations. That is, traffic fairness between any two stations that may share link bandwidth is considered. We modified unfairness measure defined in [3] for the Self-Token protocol. The purpose of this measurement is to investigate more closely the fairness characteristic of the protocol. We are interested in observing the fairness of unfairness measure performance of each station and how fairnessly the protocol treats traffic that comes from stations and that flowing on the ring.

5.1 Definition of Unfairness Measure

Station *i* is said to be *ahead* of station *j* by k packets, if the number of packets that station *i* has transmitted into the ring is greater by k packets than the number of packets come from station *j* repeated by station *i* , since the receive register of station *i* is not empty.

Each packet is classified by station *i* (which transmit the packet) into the following four types :

1. *Token-idle packet* : the transmit packet is in the next two conditions,
   a. if receive register of station *i* is empty and
   b. if station *i* is removing its packet from the ring (i.e., station *i* is receiving its token) and packet from another station follows immediately after the packet.
2. *Irrelevant packet* : if receive register of station *i* is empty and it does not satisfy the second condition of the first packet type.
3. *Offending packet* : if station *i* is ahead of the source station of packet that queueing in its receive register by FT packets ($FT \geq 1$).
4. *Non-offending packet* : the packet is neither token-idle, irrelevant or offending.

Note that a transmit packet can be classified more than one times depends on the number of packets are queued in the receive register. That is, if there are n packets queueing in the receive register, the transmit packet will be classified n times into one of the above two types (offending or non-offending packet).

Let $\alpha_{j,i}^{FT}$ be the number of offending packets and $\beta_{j,i}^{FT}$ the number of non-offending packets to station *j* transmitted by station *i* when fairness threshold is FT. And let λ_{i}^{FT} be the number of token-idle packets transmitted by station *i* when fairness threshold is FT. Here we can define a local unfairness measure γ_{i}^{FT} and a global unfair-

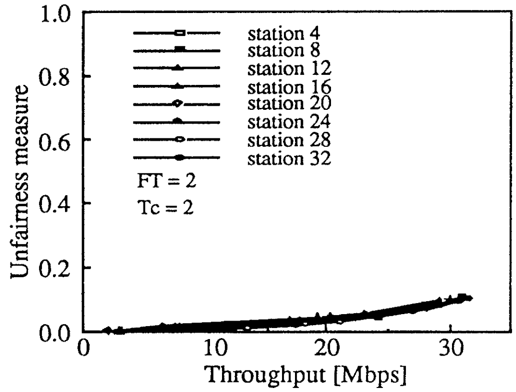

Figure 5. Degrees of unfairness under symmetrical traffic condition for Tc = 2.

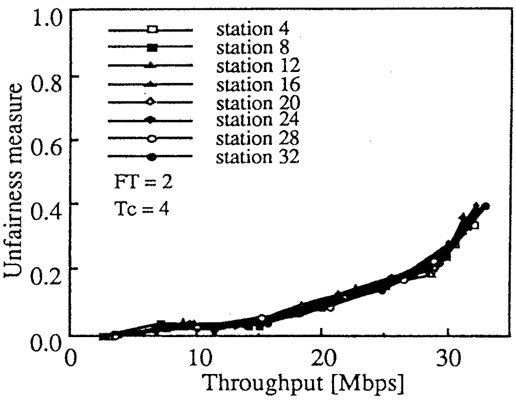

Figure 6. Degrees of unfairness under symmetrical traffic condition for Tc = 4.

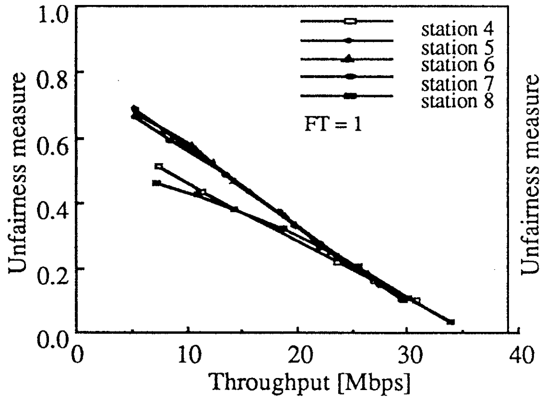

Figure 7. Degrees of unfairness under asymmetrical traffic condition when FT = 1

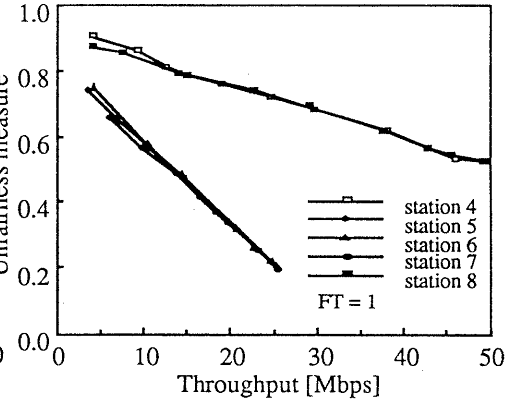

Figure 8. Degrees of unfairness under asymmetrical traffic condition when FT = 1

ness measure γ^{FT} as follows :

$$\gamma_i^{FT} = \frac{\Sigma_j\ \alpha_{j,i}^{FT}}{\Sigma_j\ \alpha_{j,i}^{FT} + \Sigma_j\ \beta_{j,i}^{FT} + \lambda_i^{FT}}$$

$$\gamma^{FT} = \frac{\Sigma_i\,\Sigma_j\ \alpha_{j,i}^{FT}}{\Sigma_i\,\Sigma_j\ \alpha_{j,i}^{FT} + \Sigma_i\,\Sigma_j\ \beta_{j,i}^{FT} + \Sigma_i\,\lambda_i^{FT}}$$

5.2 Simulation Results

Figure 5 shows the degrees of unfairness (global unfairness measure) when each station on the ring is assigned a low priority, while figure 6 shows for high priority. Note that, the fairness threshold FT is 2. It is shown that each station has the same degrees of unfairness in low and high priority level conditions. However, the degrees of unfairness becomes higher as priority of each station increases. This is because the increase of priority can relax traffic control on each station, so that the stations tend to transmit their packets than repeats queued packets from receive register.

Figure 7 shows the degrees of unfairness of five consecutive stations under asymmetrical traffic pattern when all stations are assigned just one self-token. Note that, the fairness threshold FT is 1. As fairness in delay-throughput performance, the degrees of unfairness of the same priority level stations are mostly the same. Again we find that interaction between stations with 2 λ traffic rate and λ traffic rate or among stations with the same traffic rate does not appear. The degrees of unfairness of λ traffic rate stations are higher than that of 2 λ traffic rate stations because λ traffic rate stations is many than 2 λ traffic rate stations.

Figure 8 shows the degrees of unfairness under the same traffic condition when each station with 2 λ traffic rate is assigned two self-tokens. The degrees of unfairness of 2 λ traffic rate stations grow higherly compared to the former result. However, the increase of the unfairness degrees does not give a special impact on unfairness performance of λ traffic rate stations.

Figure 9 shows the degrees of unfairness of the Self-Token protocol and the Buffer Insertion. We assume that the Buffer Insertion operates in station priority mode and packets are removed by its source station. As shown in the figure, the Buffer Insertion has the highest degrees of unfairness. Furthermore, the degrees of unfairness grows

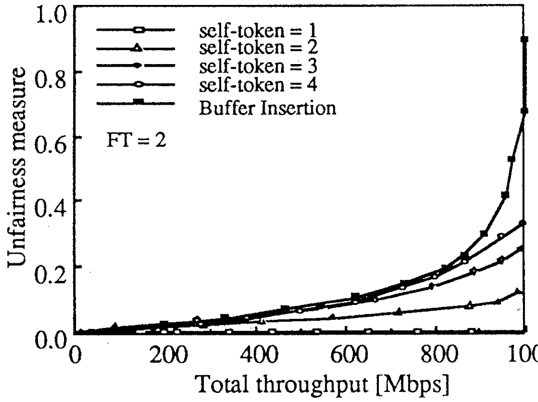

Figure 9. Degrees of unfairness of the Self-Token protocol and the Buffer Insertion when FT = 2.

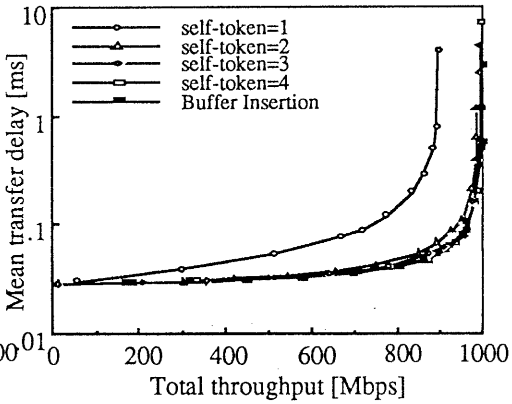

Figure 10. Delay-throughput performance of the Self-Token protocol and the Buffer Insertion.

rapidly as the total throughput reachs its limit. This is because there is no traffic regulation implemented in the Buffer Insertion.

On the other hand, figure 10 shows delay-throughput perfomance of the two access schemes. The performance of the Self-Token protocol with two self-tokens is nearly the same with that of the Buffer Insertion. Moreover, the performance becomes more nearly the same with it as the number of the self-token increases to three or four. It shows that the delay-throughput performance of the protocol can be improved by increasing the number of the self-token. However, from the degrees of unfairness point of view, it is clear that the Self-Token protocol has a better performance than the Buffer Insertion.

6 Conclusions

In this paper, we have clarified the fairness of the Self-Token protocol by means of simulations. We have shown that under symmetrical traffic as well as asymmetrical traffic condition, fairness among stations in term of delay-throughput performance and the degrees of unfairness can well be achieved by assigning private token(s), i.e., self-token(s), to each station on the ring. Under symmetrical traffic condition, the protocol still offer a better fairness performance though all stations operate in a high priority mode. Under asymmetrical traffic condition, interaction between stations with the low traffics rate and the high traffic rate does not appear, namely, stations with the same traffic rate have the same delay-throughput performance and the degrees of unfairness. Futhermore, increasing priority of the high traffic rate stations can improve delay-throughput performance of the stations without an impact to the fairness performance of the low ones. We have also shown that the Self-Token protocol can achieve the delay-throughput performance as well as the Buffer Insertion and has better fairness property than the Buffer Insertion. Our coming studies will concern a performance of the Self-Token protocol for multimedia communications.

References

[1] Toshihiro Takeda and Kuninobu Tanno, "Register Insertion/Self-Token Protocol for High Speed Ring LANs," *Proc. of 15th Conference on Local Computer Networks*, pp. 60-63, 1990.

[2] Toshihiro Takeda and Kuninobu Tanno, "Self-Token Protocol for High Speed Multi-media LANs,"*Eleventh Annual International Phoenix Conference on Computers and Transactions*", pp.604-611, 1992.

[3] John F. McCool, "FDDI: Getting to know the inside of the ring, "*Data Communication*, pp. 185-192, March 1988.

[4] Israel Cidon and Yoram Ofek, "Metaring-- A Full-Duplex Ring with Fairness and Spatial Reuse," *IEEE Transactions on Communications*, pp. 110-120, vol. 41, no.1, 1993.

[5] Jih-Shyr *et.al.*, "Network Access Fairness Control for Concurrent Traffic in Gigabit LANs," *Proc. of 18th Conference On LANs*, pp. 497-504, 1993.