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A Preemptive Local Fairness Ring Protocol for Multimedia Transmission Services

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Abstract

In this paper we propose an enhanced protocol called Preemptive Local Fairness Ring (PLFR).PLFR is a slotted counter-rotating dual-ring MAC protocol. It uses a local fairness algorithm to maintain the access control of high priority data to the ring. Local fairness that is initiated only when starvation occurs can optimize the benefits of destination stripping. In addition, local fairness should only involves segments of interfering, as opposed to global, nodes. Thus, several nodes may transmit data at the same time. This significantly improves network bandwidth utilization for high priority data transmission. To enforce prioritized transmission , PLFR uses an insertion buffer in the ring interface of each node. A node can transmit its high priority data by withholding a pass-by low priority data on the ring to reduce the access latency and cell delay variation of time sensitive data. The simulation results show that PLFR can provide better quality of service for time delay sensitive data than the existing MAC protocols for dual rings.

Keyword *:MAC Protocol , LAN , Dual-Ring , Slotted Ring , Local Fairness , Multimedia , Insertion Buffer , Prioritized transmission .*

1. Introduction

Distributed multimedia applications require transmission of data, images, voices and video on networks[13]. To support these applications, a network has to provide services for both asynchronous and synchronous traffic transmission. In the past, many different topologies have been proposed for LAN applications . However, since synchronous traffic requires bounded delay transmission services, the ring topology have received great attention .In the past, a number of high speed MAC protocols such as Orwell[1,4,5], MetaRing[3,7] and ATMR[2,11,12] have been proposed for dual-ring topology. These protocols can provide integrated services to applications and archive high efficiency in bandwidth utilization by destination stripping.

The most important topics in the MAC protocols with the dual-ring topology are the fairness control for solving a starvation problem and priority control for satisfying the QOS(Quality of Service) of delay sensitive traffic with minimal impact on a network throughput and delay. In the Orwell and ATMR, the starvation is solved by cyclic reset mechanism [9]. However their cyclic reset mechanism may result an idle time between successive cycle to detect the termination of previous cycle. This idle time is sensitive to the ring propagation delay. And the three MAC protocols above have a common problem: high priority data is not guaranteed to be transmitted ahead of low priority data when network is large and thus lead to large and unpredictable access latency in transmitting real-time data.

This paper proposes a slotted dual-ring protocol called Preemptive Local Fairness Ring(PLFR) to improve the performance of existing ring protocol. In order to optimize the benefits of destination stripping, PLFR uses a local fairness algorithm[8] to maintain the fairness access control of high priority data between nodes on the ring. To enforce prioritized transmission , each node uses an insertion buffer . A node can transmit its high priority data by withholding a pass-by low priority data on the ring . This can prevent high priority data from being delayed by low priority data .However , since each data insertion effectively increases the network length , to bound the network length PLFR uses a fixed credit-based mechanism for low priority data access control . This mechanism imposes an upper bound on the network size (length) of a PLFR network .

The paper is organized as follows. Section 2 describes the characteristics of Orwell, MetaRing and ATMR. Section 3 describes the dual-ring architecture and media access control of PLFR . Simulation results are discussed in section 4 . The contribution and conclusion are presented in section 5.

2. Related works

This section gives a brief description of the mechanisms used by different protocols. More detailed information is provided by the given references. We focus on the data integration mechanism of existing protocols and describe the restrictions for supporting delay sensitive data transmission. All discussions in this contribution are restricted to operations on a slotted dual-ring topology with destination release, where stations are allowed to access free or just released slots immediately.

2.1 Orwell

The Orwell ring, developed at the British Telecom Research Laboratories, is basically a slotted ring. There are two types traffic: Time sensitive traffic queues in service queue 1(high priority), non-time sensitive traffic in service queue 2(low priority). Fair access to the ring is guaranteed through the use of counters within the node which are allocated a *d* value for each of service queues. The value corresponds to the number of cells that can be transmitted before the next reset slot is received. The *d* value is copied to a counter and decreased by one each time a cell is transmitted from the service queue. If the counter is decremented to zero, then the node cannot transmit any more cells from that queue until a reset occurs which reloads the counter to its original value. Until then, the node sends empty slots around the ring with its own address in the destination field. If the node receives one of its slot back, then no other node has used the empty slot for its own cells, and therefore either all other nodes have no *d* allocation remaining, or the ring is lightly loaded. In either case, the node will send a reset slot which traverses the ring resetting the *d* counters to their original values.

As a cell reaches the front of its particular service queue and an empty slot arrives at the node, the protocol selects the high priority queue to check over. Two conditions must then be met: Firstly, the *d* counter of the service queue has to be greater than zero. Assuming this is true, the node then make sure that the service queue is not empty. If above conditions are compliant, then the cell of high priority queue is copied to the slot and transmitted. If the conditions are not compliant, the protocol checks to see if the low priority queue is non empty, and then goes through the same process.

In the Orwell, the starvation is solved by cyclic reset. However it may result in an idle time between successive cycle to detect the termination of previous cycle. This idle time is sensitive to the ring propagation delay. On the other hand, the protocol cannot assure that high priority data will not be delayed by low priority data.

2.2 MetaRing

The MetaRing network was prototyped at the IBM T.J. Watson Research Center. The basic MetaRing architecture is a counter rotating dual-ring providing fairness and spatial bandwidth reuse. This protocol provides service integration of synchronous and asynchronous traffic.

In this proposal fairness and non-starvation are guaranteed using a SAT-mechanism which periodically renews the transmission quota of each node. This SAT-signal is on a dual counter rotating ring and circulates in the opposite direction to the data which it controls. If a node gets the SAT-signal and it is satisfied, it sends the signal immediately to the neighboring node. Otherwise it keeps the signal until it becomes satisfied. When sending the signal to the neighboring node, the value of counter is updated.

The integration protocol uses three different control signals: GREEN, YELLOW and RED to periodically halt the asynchronous traffic, if necessary. Under normal condition, the GREEN rotates around the ring freely, i.e., each node will forward the GREEN immediately after receiving it. After the GREEN has completed at least r rounds a node that has a back-log of high priority traffic, can change the control signal from GREEN to YELLOW. When nodes see the YELLOW signal they cannot start to transmit new low priority data to the ring. The YELLOW signal is transferred unconditionally until it reaches its origin node which then changes the signal from YELLOW to RED. The RED signal is transferred once around the ring. A node forwards the RED signal to its up-stream neighbor if it has no back-log of high priority traffic, otherwise it holds the RED signal until it has no back-log of high priority traffic. When the RED signal returns to its origin node it will change the signal back to GREEN.

In MetaRing, the back-log high priority data will still be delayed by the low priority data of up-stream nodes. And the global fairness algorithm regulates the access to a network by viewing the whole network as a single resources. Because of this, it has the following two basic characteristics that become drawbacks in networks with spatial bandwidth reuse. First drawback is that every node sees the same transmission constraints. And the second drawback is that it operates even if there is no starvation.

2.3 ATMR

ATM-based high-speed slotted dual-ring (ATMR) protocol is proposed as a technique to construct multi-service networks. It provides fairness control with a cyclic reset mechanism, with many similarities to the Orwell protocol. ATMR proposes a transmission-level reset mechanism for priority control in multi-service environments. The ATMR network is initially in transmission-level_1 as the primary state. That is, all nodes in the network recognize that they are allowed to send the high class (i.e. service-class_1) only. When all nodes become inactive for service-class_1, the node which detects this inactive state issues a Reset_2 slot. The Reset_2 slot by going around all nodes, changes the network state to transmission-level_2, in which both service-class_1 and 2 cells can be transmitted. When all nodes become inactive for both service classes, the node that detects this state issues Reset_3. This changes all nodes to be in transmission-level_1 again, and the counters for both service classes are reset to the initial value. If time D1(corresponding to the delay variation condition for service-class_1) expires while the network is in transmission-level_2 it is necessary for service-class_1 to have access priority over the lower class_2. For this purpose, an interruptive reset is defined as Reset_1 which changes the state of all nodes into transmission-level_1 and updates only counter_1 for service-class_1.

As the Orwell, ATMR uses cyclic reset to solve the starvation problem. Therefore it may result in an idle time between successive cycle to detect the termination of previous cycle. This idle time is sensitive to the ring propagation delay. Furthermore, the protocol cannot assure that high priority data will not be delayed by low priority data.

3. PLFR MAC Protocol

PLFR(Preemptive Local Fairness Ring) protocol is developed based on the counters mechanism of Orwell and Local Fairness concept. We propose an insertion buffer[14] in the ring interface of each node to preempt low priority data. This significantly reduces the access latency and cell delay variation (CDV) of delay sensitive data. Under multimedia transmission environment, CDV is an important performance parameter. A protocol can provide better QOS (Quality of Service) to meet the requirement of real-time traffic if it can guarantee smaller CDV for data transmission. PLFR uses destination stripping mechanism to effectively improve system throughput. Additionally, PLFR uses local fairness[8] algorithm to maintain the fairness control of high priority data between nodes on the ring. Local fairness can improve network bandwidth utilization and is a good method for distributed system. In the rest of this section, we will describe local fairness algorithm at first, then describe the operation mechanism and the architecture of PLFR.

3.1 Local Fairness Algorithm

All global fairness algorithms regulate the access to the network by considering the network as a single communication resource. Therefore, they cannot fully utilize the throughput advantages offered by spatial bandwidth reuse. A local fairness mechanism views the network as a distributed collection of communication resources and not as a single resource. The local fairness mechanism is triggered locally, at an arbitrary time, only if potential starvation exists. It regulates the transmission of the interfering nodes without affecting others.

Local fairness algorithm distinguishes between two basic modes of operation: nonrestricted mode and restricted mode. Under nonrestricted mode, nodes can transmit at any time as long as the protocol permits it without any quota restriction. This mode is identified by a single Free Access(FA) state. Under restricted mode, nodes can transmit only a predefined quota of data units before they transmit back to the nonrestricted mode. The algorithm uses two types of control signals to facilitate the transition between these two operation modes, and they are:

- REQ: This signal initiates the restricted period of operation and is forwarded upstream over the congested segment of the ring.
- GNT: This signal is used, when the node is satisfied, to terminate the local fairness cycle.

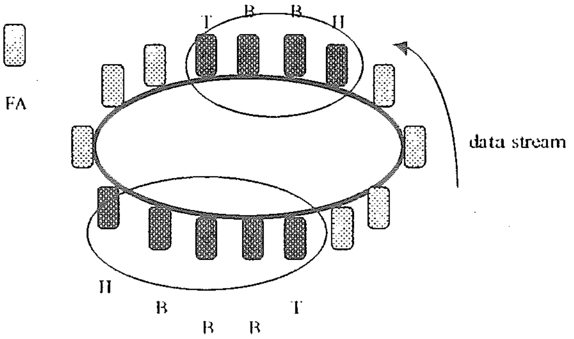

Fig. 3.1 The local fairness operation and state diagram

Fig. 3.1 demonstrates the basic operation of the algorithm and state diagram of nodes. A starved node triggers the operation by sending the REQ signal upstream and entering the tail (T) state. Upon reception of such a signal, a node enters the restricted mode of operation and, if its upstream is idle, it will enter the head (H) state. If this node cannot provide silence (it senses traffic from upstream), it will forward the REQ upstream and enter the body (B) state. Upon satisfaction, i.e., transmission of a certain predefined quota, the tail node sends a GNT signal upstream and transits back to the nonrestricted free access (FA) state. Upon receiving this GNT, the node upstream follows similar rules: If it is in the body state, it transits to a tail (T) state and will similarly forward GNT upon satisfaction. If it is in the head state, the local cycle on this segment is terminated. Even though the segment covers the whole ring and no head is present, the tail node transits to the combined head-tail (HT) state.

3.2 The PLFR Protocol

PLFR uses a slotted counter rotating dual-ring architecture as shown in Fig. 3.2, where one ring for data transmission and another ring for, signal transmission. Destination stripping mechanism is used to fully exploit network bandwidth. PLFR supports both synchronous and asynchronous traffic. Synchronous traffic is high priority data and its access to the slots on the ring is controlled by local fairness algorithm. Asynchronous traffic is low priority data and uses a simple cyclic reset mechanism to maintain the fairness between nodes.

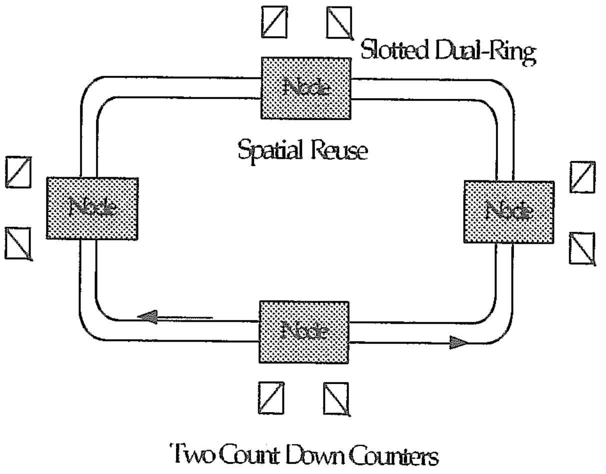

Fig. 3.2 The topology architecture of PLFR

When an empty slot arrives, a node will first send traffic from high priority queue if the queue is active. A node can transmit its high priority data by withholding a pass-by low priority data on the ring. To preempt low priority data, PLFR uses an swapping buffer in the ring interface of each node. The pass-by low priority data will be inserted into the first-in-first-out swapping buffer. When high priority data is transmitted, a node whose high priority data is starved by continuous high priority data from upstream triggers local fairness algorithm, forces interfering nodes into restricted mode, and accesses the slots on the ring.

If the high priority queue is inactive, PLFR demands that data of low priority queue can be transmitted only after the swapping buffer is empty. Otherwise, the backlog low priority data of swapping buffer must be transferred at first. This assures that the low priority data can be delivered in sequence. We define that low priority counters resetting process can be initiated only after the swapping buffers of all nodes have been cleared. Therefore, when an empty slot arrives, if high priority queue is inactive and the swapping buffer is cleared, then the node which still has unused quota can transmit data from low priority queue.

In PLFR, there are two data types (high priority and low priority) on the data ring and four signal types (chk_swapQ, reset, REQ and GNT) on the signal ring. And we use two counters for high priority queue and low priority queue. The initial values of counters are predefined as the maximum data quota which can be transmitted in one cycle. The value of the counter will be decremented by one while sending one slot from the corresponding queue. If the value of the counter becomes zero, then the node must wait until the beginning of next cycle.

The main function of chk_swapQ signal is to check and assure that the low priority data of swapping buffer in all nodes have been cleared. Upon reception of such a signal, a node checks the swapping buffer of itself. If the buffer is empty now, a node will forward the chk_swapQ upstream. Otherwise, a node must hold this signal until its swapping buffer is empty. Reset signal is used, after the chk_swapQ signal has rotated around the ring for one round, to update the low priority counters of all the nodes on the ring. A node whose high priority data is starved triggers local fairness by sending the REQ signal upstream and enforces the interfering nodes into restricted mode. Upon satisfaction, i.e., transmission of a certain predefined quota, the tail node sends a GNT signal upstream and transits back to the nonrestricted free access (FA) state.

3.3 The Resetting Mechanism of Counters

We have mentioned that in PLFR the counter of high priority queue will be initiated only when the node is entering restricted mode (H,B,T,HT). Therefore a node will trigger the resetting mechanism of high priority counter immediate after it sends out REQ signal due to starvation.

Besides, PLFR uses two control signals, chk_swapQ and reset, to maintain the low priority counter resetting mechanism. When the value of low priority counter becomes zero and swapping buffer of node *i* is cleared, node *i* can send chk_swapQ signal on the signal ring and reset its own low priority counter to initial quota. After the chk_swapQ signal has rotated around the ring and come back, node *i* will send reset signal on the signal ring. The reset signal will be cleared by any reset signal issuers on the ring to prevent unnecessary excessive resetting.

If more than one node issues chk_swapQ signals, PLFR will take some actions to prevent the waste of bandwidth. Upon reception of a chk_swapQ signal, a node which is also a chk_swapQ issuer will compare the source of the signal and its own identity(ID) and use the following rules :

1. If ID > source, the node clears the signal slot and release an empty slot for use.
2. If ID = source, the node converts the signal type to reset signal.
3. If ID < source, the node forwards the signal upstream.

One example is presented in Fig. 3.3. Node 1 and node 5 are both chk_swapQ issuers. Upon reception of a chk_swapQ signal from node 1, node 5 will take rule 1 to clear the signal slot and release an empty slot for use. And upon reception of a chk_swapQ signal from node 5, node 1 will take rule 3 to forward the signal upstream. Only when the signal from node 5 rotates around the ring and come back to the original issuer, will node 5 take rule 2. As mentioned above, the mechanism can prevent many signals that have the same type from rotating on the ring. Therefore PLFR can optimize the utilization of bandwidth.

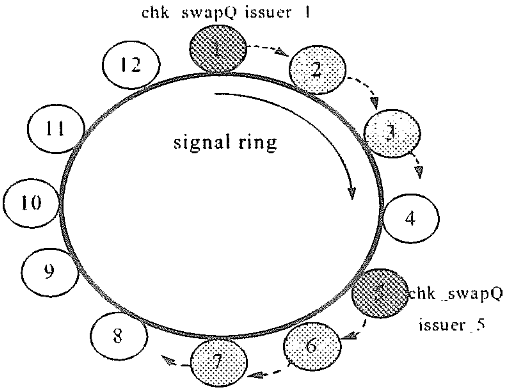

Fig. 3.3 The operation of chk_swapQ signal

3.4 Properties of the PLFR

In this section, we present the properties of PLFR. Because using preempting mechanism, each node insertion effectively extends the ring size of PLFR. The properties below will show that PLFR can control the length of swapping buffers and ensures that the low priority data is delivered in sequence.

Lemma 1 : The low priority data of the same data stream, i.e., from the same source to the same destination, will be delivered in the correct sequence.

Proof : In PLFR, the low priority data of the same data stream will form a long first-in-first-out Tandem Queue on the ring. Therefore PLFR can ensure the correct sequences of low priority data.

Lemma 2 : For a ring with N-slots, the maximum length of swapping buffer in node *i* is $\sum_{j=1,j\neq i}^{N} low\_cnt_j$ (slot)。

Proof : Consider the situation that only node *i* has back-log high priority data and the other N-1 nodes have only back-log low priority data. If all the permitted quota of low priority data in one cycle are preempted by node *i* , then the length of swapping buffer in node *i* is $\sum_{j=1,j\neq i}^{N} low\_cnt_j$ (slot). In PLFR, a node can update its low priority counter only after the swapping buffers of all nodes on the ring have been cleared. Therefore the maximum length of swapping buffer in node *i* is $\sum_{j=1,j\neq i}^{N} low\_cnt_j$ (slot)。

Theory 1 : The sum of maximum length of swapping buffers in all nodes on the ring is $\sum_{j=1}^{N} low\_cnt_j$ (slot), therefore the average length of PLFR network will be limited.

Proof : In lemma 2 we have proved that for a ring with N-slots, the maximum length of swapping buffer in any one node *i* is $\sum_{j=1,j\neq i}^{N} low\_cnt_j$ (slot). If there are more than one high priority data sources on the ring, then all the permitted quota of low priority data in one cycle are preempted by more than one nodes. Because the sum of all the permitted quota of low priority data in one cycle is $\sum_{j=1}^{N} low\_cnt_j$ (slot), the maximum length of swapping buffer in all node on the ring.

From theory 1 , we know that network size of PLFR is at most $\sum_{j=1}^{N} low\_cnt_j$ (slot).

4. Simulation Result

In this section, we study the performance and the average network length of PLFR. We only compare the performance of PLFR with that of Orwell and MetaRing because Orwell is the base of all the slotted ring protocol and the performance of MetaRing has been showed to be better than other ring protocols in access latency [6]. To investigate the performance of the three protocols, several performance parameters such as mean queuing delay, cell delay variation (CDV) of high priority data and mean end-to-end delay of low priority data are evaluated by simulations. Furthermore, we calculate the 95% confidence interval of mean queuing delay to validate the simulation results.

In the simulation model, messages arrive in poisson process and message length is normal distributed. The destination of a message is uniformly distributed to any other nodes. PLFR will divide one message into many fixed size slots [10] with the same destination. In each node, the traffic load of high priority data is four times larger than low priority data as in reference [10]. The simulation environment assumes a ring of 20 nodes, and the number of time slots on the ring is 10. Each data slot is 53 octets. The network capacity is 100 Mbps, and the distance between two adjacent nodes is half an slot transmission time.

4.1 Performance in different protocols

In the simulation, we define two scenarios. Firstly, we consider the situation in which the sources of high priority data are tightly clustered and node 1,2,3,4 and 5 generate high priority data. Secondly, we consider the situation in which the sources of high priority data are distributed around the ring, and node 0,5,10,15 and 19 generate high priority data. In both scenarios, all nodes generate low priority data. By these two scenarios, we can investigate the impact of clustering on the performance of the local fairness algorithm.

Fig. 4.1 and 4.4 show the curves of mean queuing delay of high priority data versus throughput for scenario 1 and 2 respectively. From the figures, PLFR has the lowest mean queuing delay for all network load. On the other hand, Orwell has the highest mean queuing delay as predicted. Fig. 4.2 and 4.5 show the CDV of high priority data under different network load for scenario 1 and 2 respectively. PLFR again has the lowest CDV at all different network load. The simulation results shown above demonstrate that PLFR can effectively solve the problem of latency for high priority data. Also, PLFR can effectively control the CDV of high priority data and hence can maintain the best quality of services for high priority data transmission.

Fig. 4.3 and 4.6 shows the mean end-to-end delay of low priority data versus throughput. As we have expected, the low priority data of PLFR may be delayed by the preempting and swapping mechanisms. However, even under heavy load, PLFR does better than MetaRing. This is due to the high bandwidth utilization obtained by the local fairness algorithm.

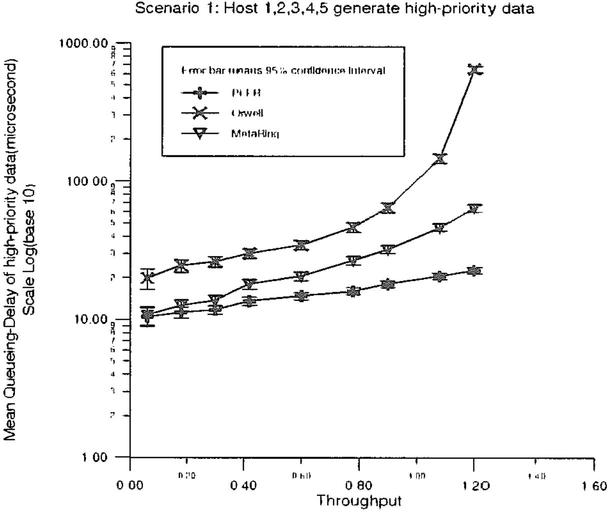

Fig. 4.1 Mean queuing delay of high priority data of three protocols under Scenario 1

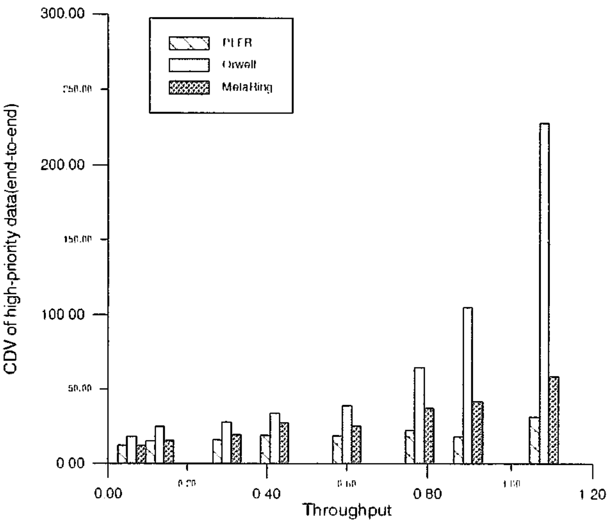

Fig. 4.2 CDV of high priority data under Scenario

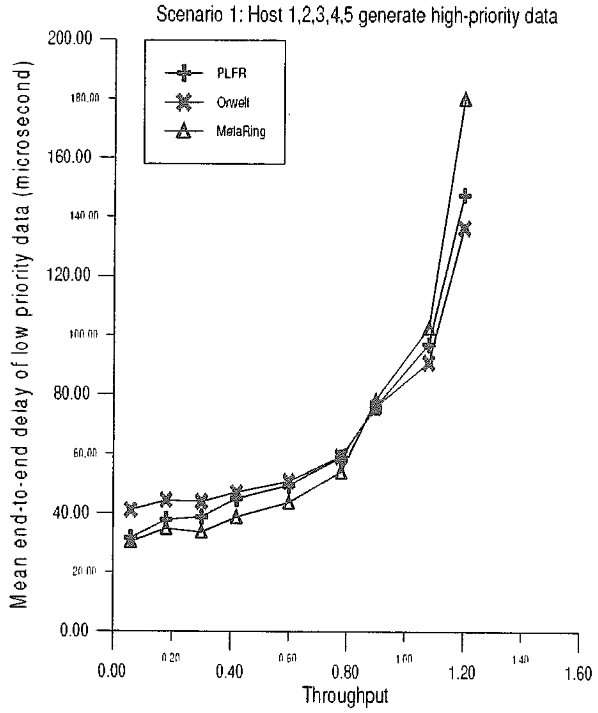

Fig. 4.3 Mean end-to-end delay of low priority data under Scenario 1

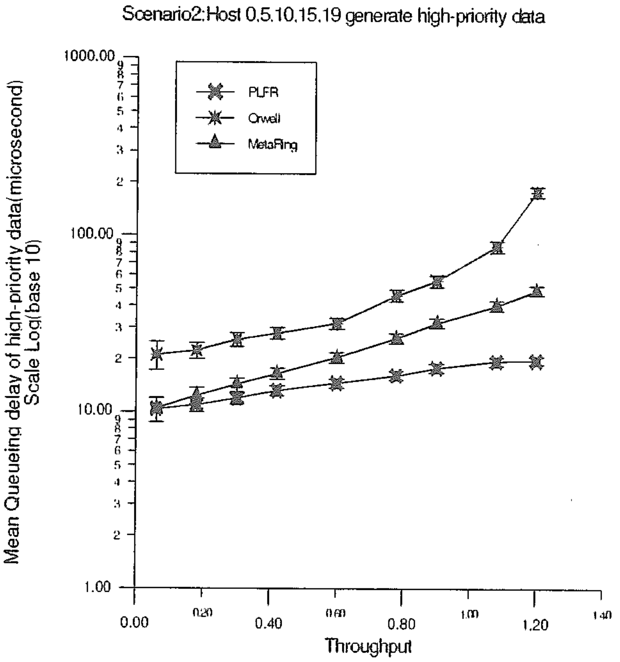

Fig. 4.4 Mean queuing delay of high priority data of three protocols under Scenario 2

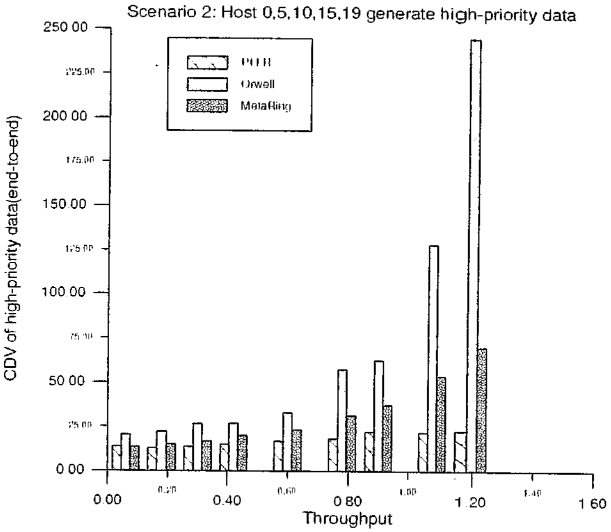

Fig. 4.5 CDV of high priority data under Scenario 2

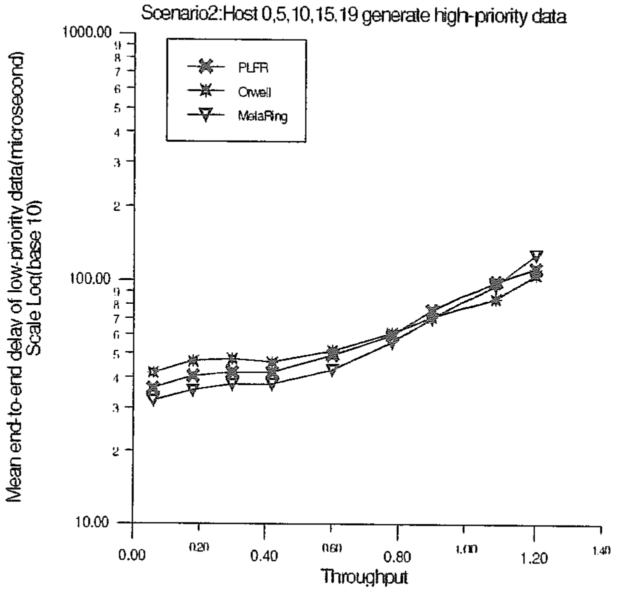

Fig. 4.6 Mean end-to-end delay of low priority data under Scenario 2

4.2 Performance in Network Length of PLFR

To preempt low priority data on the ring, PLFR uses an insertion buffer in the ring interface of each node. Each data insertion effectively extends the ring size of PLFR. Therefore there is additional network length in every node on the ring. We must control the length of the swapping buffers to bound the average network length, i.e., the length of the whole ring. Fig. 4.7 shows the average network length of PLFR versus throughput by simulations. The minimum ring size 10 is as specified in the simulation environment. The simulation results show that the average ring size is smaller than 13 slots under different network load. It means that there are few slots in swapping buffers at most of the time.

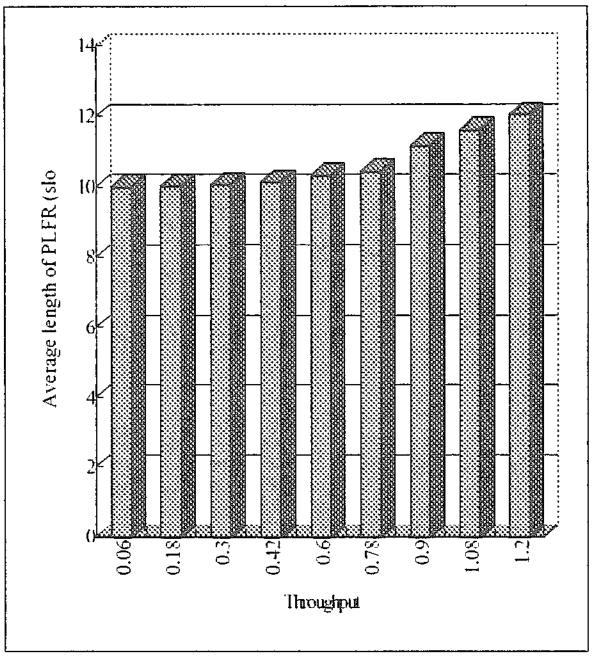

Fig. 4.7 The average network length of PLFR

5. Conclusion

In this paper, a slotted dual-ring MAC protocol called PLFR is proposed and its performance is simulated. The dual-ring architecture consisting of two separate rings, a ring for information packet transmission and another ring for signal transmission. PLFR can support real-time synchronous voice and video traffic and asynchronous data traffic. It uses a local fairness algorithm for high priority data access control and a fix credit-based mechanism for low priority data access control. To perform effective priority control, PLFR allows a node to transmit its high priority data by preempting low priority data on the ring. This significantly reduces the access latency and cell delay variation of delay sensitive data. The simulation results show that PLFR can meet with the requirement of low latency and low cell delay variation for multimedia data transmission.

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