CSMA with Reservations by Interruptions (CSMA/RI): A Novel Approach to Reduce Collisions in CSMA/CD

Chuan Heng Foh, *Student Member, IEEE,* and Moshe Zukerman, *Senior Member, IEEE*

***Abstract*—This paper proposes an enhancement for the carrier sense multiple access with collision detection (CSMA/CD) protocol, called CSMA with reservations by interruptions (CSMA/RI). This new protocol uses a novel approach to reserve capacity by interrupting an ongoing packet transmission. The performance of the protocol is studied by simulations under realistic (long range dependent) traffic conditions and compared to the CSMA/CD, token ring protocols, as well as with the work conserving G/D/1 queue. It is demonstrated that CSMA/RI always offers better performance than CSMA/CD, and under certain realistic assumptions regarding packet size, the performance of CSMA/RI can be very close to that of token-ring and G/D/1.**

***Index Terms*—Computer networks, local area networks (LAN), LRD traffic, multiaccess communication.**

I. Introduction

THE CHALLENGE of developing an efficient yet reliable medium access protocol (MAC) has been an important research topic for over 30 years. Due to spatial distribution of the stations, and the bursty nature of the traffic, it has been considered impossible to achieve a reliable, simple, work conserving and a perfect scheduler MAC protocol.

In principle, there are many MAC approaches: collision based versus collision free, those based on distributed control versus those based on central control, and "circuit switched" types (TDMA FDMA etc.) versus demand assigned. The reader is referred to [1], [2], [3, Ch. 4], and references therein for a comprehensive review and insightful analyzes of MAC protocols. These MAC ideas have contributed over the years to developments of data networks such as Ethernet, Token Ring, FDDI, and DQDB, and others which are still in operation.

Recently, we have experienced significant growth in research, development, and deployment of multimedia multiservice access networks. Such recent developments include MAC protocols for broadband wireless and wireline networks. With the advent of technology came the need for new MAC protocols to meet Quality of Service (QoS) demands for different services (see [4]–[6] and references therein).

In many of these new developments, old ideas are being recycled. For example: ideas based on the Aloha protocol [7] and tree algorithms [8], [9] are now reused in MAC proposals for modern multi service wireless and wireline networks [6]. Many of these new proposals employ a central controller which receives reservations from the stations that wish to transmit and allocate bandwidth dynamically. Stations contending for access to the network must compete with each other to inform the controller of their need for a share of the available bandwidth. This leads to an access protocol which is based on two phases: 1) a collision based access protocol (e.g., Aloha or tree algorithm) for the signals sent by the stations to the central controller, and 2) a collision free transmission which follows bandwidth allocation by the central controller to the stations in accordance with a certain scheduling algorithm.

As the access part of the network is the most costly, and since old ideas related to collision based MAC protocols are still—and will be for the foreseeable future—in extensive use, it is still important to review those old fundamental concepts and ideas and make an effort to improve on them perhaps **by breaking the most sacred rules**. In this paper we improve the carrier sense multiple access with collision detection (CSMA/CD) protocol [10] by allowing stations to interrupt a successful transmission, and in this way to make a reservation. We call our protocol CSMA with reservations by interruptions, or CSMA/RI in short.

The CSMA/CD protocol is a collision-based protocol—an extension of the Aloha protocol. While in Aloha, stations transmit and, if they collide, they transmit later randomly, under CSMA/CD, stations listen to the channel and try to transmit when the channel is idle. This way, collisions can be reduced. We propose a further improvement by allowing a station, which has data to transmit, to interrupt a successful transmission, just for a short while, to notify all other stations that it would like to reserve capacity for transmission. The small interrupted portion of the ongoing transmission is immediately retransmitted by the sender as it can also detect the interruption. The overhead is thus minimized and a fair order of transmissions can be maintained. If several stations interrupt a transmission (to make reservations) at the same time, collisions may occur since any of these stations is not aware of others making reservations. In this case, as in CSMA/CD, the stations may use any known conflict resolution algorithm to resolve their collisions. In this paper, we use the *Truncated Binary Exponential Backoff* (BEB) method used in the Ethernet protocol [10]. This method is chosen because of its wide acceptance in the "real" world. However, this choice is not obligatory and, as mentioned above, any other collision resolution algorithm could be used.

There have been several attempts to improve Aloha using reservation techniques. In R-ALOHA [11] and PRMA [12], a

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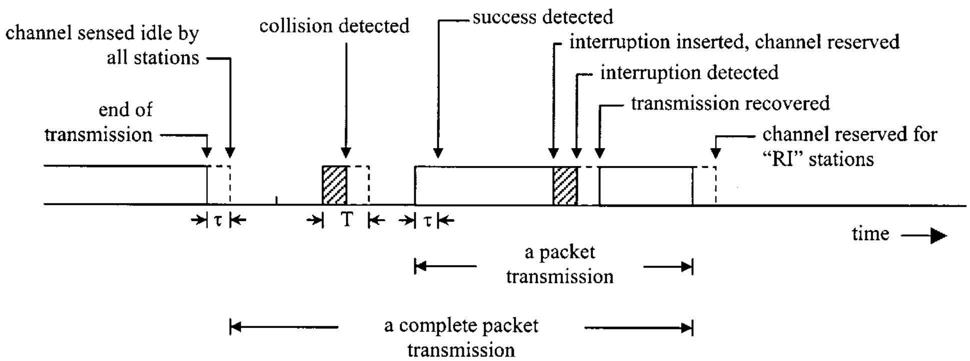

Fig. 1. A snapshot of the broadcast channel of CSMA/RI.

fixed bandwidth is reserved for reservations which introduces wastage of transmission resources. Also in these two protocols, only the active stations can make further reservations but not the others. In CSMA/CA [13], ready stations go through a period of reservations before one of them gets the right to access the channel. During that period of contention for reservations, collisions are possible. This contention period also causes loss of bandwidth. On the other hand, in CSMA/RI, reservations are made during an ongoing packet transmission, and therefore it leads to a better channel utilization.

In [3, Section 4.5], the authors classify a set of access protocols under the category of multiple access reservations. Protocols belonging to this category send short packets either in contention based, or contention free, mode to reserve bandwidth for the actual data. CSMA/CD is considered a contention based reservation protocol since fundamentally the first few bits that may be subjected to a collision can be viewed as a reservation for the rest of the packet. On the other hand, the token-ring protocol is a contention free reservation protocol because under the token ring protocol, a token is passed around the ring between the stations and only the station holding the token has exclusive right to transmit.

Although CSMA/RI is a contention based protocol, the proposed interruption mechanism reduces the number of stations competing for the channel and hence the collision probability is reduced. Therefore, it performs better than CSMA/CD and almost as good as the token-ring protocol, in many cases.

At this point in time, the CSMA/RI concept is mainly applicable to wireline networks. According to the current state of the art, collision detection cannot be achieved in wireless networks using the same channel that is used for packet transmissions. Nevertheless, recent developments [14], [15] propose a means for collision detection in wireless networks in certain circumstances using a separate channel for that purpose. As soon as collision detection becomes applicable to wireless network, so will CSMA/RI.

The remainder of the paper is organized as follows. In Section II, we describe the mechanism of the CSMA/RI protocol. In Section III, we focus on implementation issues. In Section IV, we provide insight into the performance of CSMA/RI supported by extensive quantitative simulation results based on a wide range of traffic models and a comparison with its close relative, CSMA/CD, and the token-ring protocol. The conclusions are finally drawn in Section V.

II. The CSMA/RI Protocol

Consider a slotted system whereby time is divided into fixed length intervals. Each of these time intervals will be called a *slot*. The purpose of the slotted system assumption is to simplify the explanation and simulation of this new protocol. Nevertheless, CSMA/RI can be implemented as a nonslotted system.

Let T be the duration of a slot. All stations in the network are synchronized so that a packet transmission is always commenced at the beginning of a slot. Henceforth, we shall use the concept of slot to refer also to the amount of data [bits] which can be transmitted within a time slot. Packet length may be variable, but it must be padded as in Ethernet [10] so that it is equal to an integer number of slots.

Let τ denote the maximum propagation delay between any two stations in the network. As in [16], in order to use common mechanisms for detecting collisions and aborting collided transmissions in a slotted channel, the minimum duration of a slot is $T = 2\tau$. In addition, the channel is sensed idle by all stations τ units of time after the end of a successful transmission, and a successful transmission is detected τ units of time after it is started. Fig. 1 represents a snapshot of the CSMA/RI channel. Notice the analogy between this figure and [16, Fig. 1] which describes CSMA/CD.

We introduce the concept of a *ready station* to refer to a station that has a packet or more waiting for transmission. Our proposed CSMA/RI protocol is an extension of the 1-persistent CSMA/CD protocol version [17] described by the following rules.

- (R1) If the channel is sensed idle, a ready station transmits its packet immediately. It is required to monitor the channel status in case of a collision.
- (R2) If the channel is sensed busy, a ready station keeps monitoring the channel status. As soon as the channel becomes idle, the ready station transmits its packet into the next slot with probability one.
- (R3) Upon detection of a successful transmission, each station reads the data from the ongoing packet transmission into its local buffer. Only the station to which the packet is addressed to may use the data, others should discard the data.
- (R4) If a collision is detected, each ready station reschedules the retransmission individually to some later time based on a certain collision resolution algorithm. As

mentioned in the Introduction, in this paper we choose the BEB algorithm.

CSMA/RI enhances CSMA/CD by adding reservations by interruptions. The reservation is performed during an ongoing packet transmission. It is done by interrupting the ongoing packet transmission with a short period of pseudo-noise broadcast to all stations. The ongoing packet transmission is then resumed right after the interruption recovering the interrupted slot. Upon the completion of that ongoing packet transmission, only the stations that have performed the reservation (by interruption), henceforth called *RI stations*, are allowed to access the channel. The rules respectively corresponding to the above CSMA/CD rules are described as follows.

(R1*) is the same as (R1).

(R2*) If the channel is sensed busy, in the case where a successful transmission is detected earlier, i.e., the channel is carrying a packet, (R2a*) applies to a ready station, otherwise the channel is busy due to a collision, and then (R2b*) applies.

(R2a*) A ready station may interrupt the packet transmission to make a reservation and to become an RI station only if no reservation has already been performed during that ongoing packet transmission. Otherwise, it becomes a backlogged station. Upon the completion of the successful packet transmission, only an RI station is allowed to transmit into the next slot. A backlogged station remains silent and continues to monitor the channel.

(R2b*) In this case, if a ready station becomes ready during a collision, it transmits into the next slot as soon as the channel becomes idle as in (R2).

(R3*) Upon detection of a successful transmission, in addition to following rule (R3), each station, either an RI which failed to obtain a channel or a backlogged station, waits for a randomly chosen waiting time that is not longer than the packet transmission time. During the waiting time, the station is required to monitor the channel to detect if other stations make reservations. If such reservation is made by other stations, the station aborts its reservation attempt and becomes a backlogged station. On the other hand, if no one else has made a reservation during the station's waiting time, then by the time its waiting time expires, the station performs the reservation (by interruption).

(R4*) is the same as (R4).

(R5*) For a backlogged station, following the completion of a successful transmission, if the channel remains idle for at least a slot, it becomes a ready station and transmits its packet into the idle channel immediately as in (R1*).

We choose the 1-persistent version because for CSMA/RI it is more efficient than the p-persistent or the nonpersistent version. Due to the reservations made, the likelihood of collision is significantly reduced and therefore the more aggressive 1-persistent version will be more efficient. As discussed earlier, several stations may interrupt a successful transmission at the same time slot. Nevertheless, the likelihood of such *interruption collision* is small, thus the resulting *packet collisions* are infrequent.

Notice that in (R2a*), a station that becomes ready during a packet transmission does not go through the process of choosing a random waiting time to perform the reservation. Instead, it makes the reservation immediately if no reservation has already been carried out by the time it is ready. This way, it is making the random choice by the statistical nature of its arrival so that a statistically similar access right can be maintained among all the stations.

By (R3*), the reservation operation is carried out immediately after detecting a successful packet transmission. Then, each station waits for a random number of slots to initiate the reservation procedure. This random number has a discrete uniform distribution based on the packet size. For example, if the packet size is equal to 11 slots, the waiting time in number of slots will be equal to any of the following: 2, 3, ..., 11, each with probability 1/10. Recall that the first slot in a packet transmission cannot be used due to the detection time requirement. If two or more stations pick the same waiting time, this leads to an interruption collision which in turn leads to a packet collision. In this case, the packet collisions will be resolved as in CSMA/CD (e.g., by BEB algorithm).

The reservation procedure is performed by interrupting the ongoing transmission with pseudo-noise for a duration of τ. This pseudo-noise is broadcast to all stations in the network. Upon detecting the pseudo-noise, the sender ceases the packet transmission, all other stations abort their reservation procedures and mark themselves as backlogged stations. Because the pseudo-noise only lasts for τ, it will vanish within the same slot which ends the reservation procedure. The sender then continues the packet transmission of the same packet from the point where it was interrupted by the pseudo-noise. Since we assume that the channel is slotted, the fragmented packets can be recovered if the receiver is equipped with memory to buffer the receiving packet slot by slot. In practice, the recovery can be achieved by adding necessary information in the beginning of the *pasted part* of the packet so that the receiver can paste the fragmented packet back together. This will be discussed in more details in Section III-A.

After the completion of the packet transmission, only RI stations can participate in the next packet transmission. Backlogged stations remain silent until the next successful transmission is detected. This way, CSMA/RI divides the ready stations into two groups: RI stations and backlogged stations. This division reduces the number of stations participating in the contention.

Notice that the duration of a packet transmission is an important factor which affects the performance of CSMA/RI. Let n be the packet size in slots. Since reservations are based on randomly choosing a number among the numbers: 2, 3, ..., n, each with probability $1/(n-1)$, the larger the n, the lower the interruption collision probability, and hence the better the performance. This will be demonstrated in Section IV.

In a noisy channel environment, it is not critical to distinguish between pseudo-noise and real noise. If noise occurred during an ongoing packet transmission, in CSMA/CD, the sender will abort the transmission and schedule the retransmission of the entire packet which is inefficient. By comparison, in CSMA/RI, the sender will correct it and save the retransmission overhead

[18]. This is an additional benefit of CSMA/RI. Since real noise is treated as pseudo-noise that represents a reservation, RI stations may not exist in this case. However, the absence of RI stations will not lead to a deadlock because an idle period on the channel leads to normal CSMA/CD collision resolutions as described in (R5*).

III. Implementation Issues

In this section, we address several ideas related to the CSMA/RI implementation and operation under special situations.

A. Pasting Fragmented Packets

An interrupted packet is fragmented into two parts.

1) The first part—this is the part of the packet that was transmitted before the interruption.
2) The pasted part—the remainder of the packet.

If perfect synchronization can be achieved, then the interruption will occur at the slot boundary, and the pasted part can begin exactly at that slot boundary. However, to improve CSMA/RI robustness in case of imperfect synchronization, some data that were transmitted in the first part should be repeated. In this case, the pasted part of the packet will also need to include a header which specifies the exact position of the beginning of the pasted part in the packet as shown in Fig. 2.

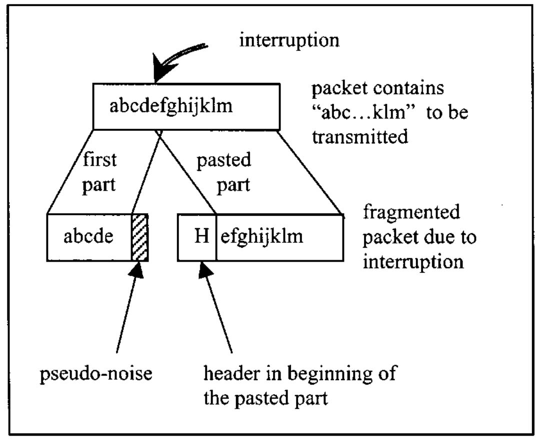

Fig. 2. The fragmented packet presented to the receiver.

B. The Packet Size

CSMA/RI allows variable packet size; however, in this case, the following must be implemented.

1) The packet size should be specified in the header of the packet so that ready stations know how to choose their random waiting time to initiate the reservation procedure.
2) There must be a minimum packet size to limit the interruption collision probability, and to guarantee the required performance level.

C. Power Up

A station which is powered up in the middle of an ongoing packet transmission is not allowed to interrupt that packet transmission. This rule is for the following reasons.

1) It may not be aware of any already existing reservation made during the ongoing transmission.
2) It does not know the remainder length of the packet currently being transmitted.

The CSMA/RI power up rule improves its efficiency when many stations power up at once. This is an important scenario which often occurs following a network failure. This scenario is termed the disaster scenario in [19]. We do not allow powered up stations to make reservations by interruptions immediately because in the case of a disaster scenario, there will be a large batch of stations colliding which means a large number of RI stations and a long wasted resolution time. We prefer that they make the reservation within the next packet transmission so that only some of them may experience packet collision. In the case of no prior reservation occurring in that ongoing packet, the channel will be sensed idle after the completion of that packet transmission. In this case, all ready stations should wait a minimum of one slot before they can transmit into the idle channel as in (R5*).

D. Power Down

It is possible that a station makes a reservation to become an RI station and shuts down due to an internal failure. In this case, (R5*) will apply to all backlogged stations after the channel is sensed idle for a minimum of one slot, so that they are allowed to transmit into an idle channel.

IV. Performance

In this section, we evaluate the performance of CSMA/RI by simulations. We first explain why CSMA/RI performs better than CSMA/CD using concepts such as: delay performance, *Channel Assignment Delay* [16] as well as *the packet collision probability*. Next, we study the delay performance of CSMA/CD and CSMA/RI in a disaster scenario [20]. Afterward, we investigate the stability of CSMA/RI based on the study in [21]. Two cases of load conditions are used to demonstrate the stability of CSMA/RI. Then, we present performance comparison between CSMA/CD, CSMA/RI and the token ring protocol. This comparison is based on realistic network parameters and a dual packet size assumption [22]. Finally, we evaluate the performance under LRD traffic.

For all simulations in this section, we assume the following: 1) a noise-free channel is assumed, and 2) it is possible to achieve perfect synchronization among all stations so that the overhead required in the pasted part of an interrupted packet described in Section III-A is excluded.

For all CSMA/CD and CSMA/RI simulations, we further assume that all stations are arranged in a star topology so that the propagation delay between any two stations is always τ. The duration of a slot is assumed to be 2τ.

In addition to these general assumptions, there will be other specific assumptions which will described in the relevant subsections.

A. Why CSMA/RI Performs Better than CSMA/CD

In Fig. 3, we demonstrate the improvement of CSMA/RI over CSMA/CD. The results in Fig. 3 are based on the assumptions

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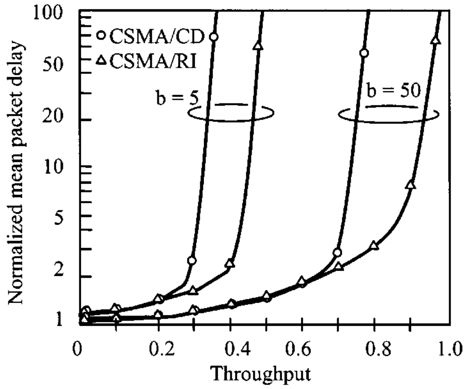

Fig. 3. CSMA/CD and CSMA/RI: normalized mean packet delay versus throughput.

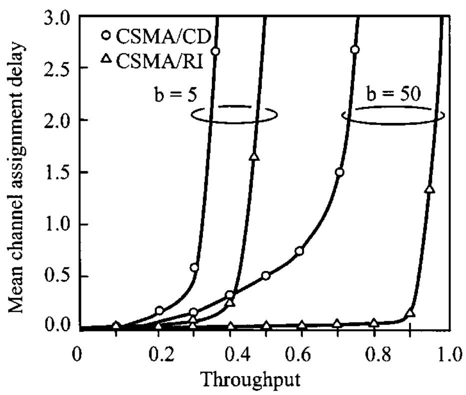

Fig. 4. CSMA/CD and CSMA/RI: MCAD versus throughput.

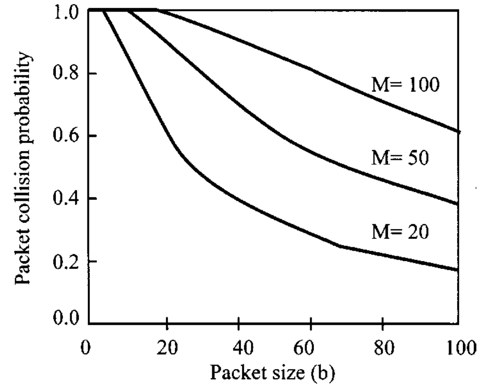

Fig. 5. Packet collision probability versus packet size for CSMA/RI.

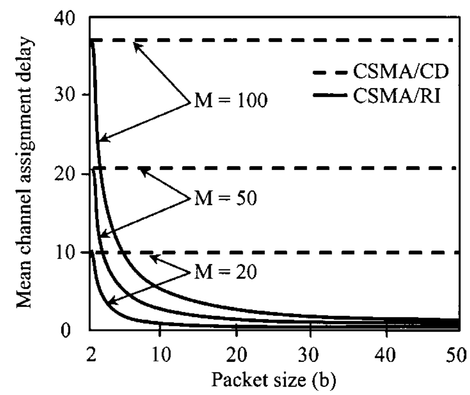

Fig. 6. MCAD versus packet size for CSMA/CD and CSMA/RI.

that the number of stations is infinite, the arrival process is a Poisson process, and each arrival carries a packet of constant size b. All these assumptions are consistent with those of [16] except that we assume that both CSMA/CD and CSMA/RI implement BEB instead of an adaptive retransmission algorithm used in [16].

Two cases of packet sizes—1) 5 slots, and 2) 50 slots of the delay performance of CSMA/CD and CSMA/RI—are presented in Fig. 3. The normalized mean packet delay is defined as the ratio between the mean packet delay and the packet transmission time. As demonstrated in Fig. 3, CSMA/RI achieves higher throughput than CSMA/CD in both cases.

In Fig. 4, we focus on the mean channel assignment delay (MCAD) of CSMA/CD and CSMA/RI. It is the number of wasted slots due to packet collisions before a successful packet transmission is obtained. As presented in Fig. 4, CSMA/RI has significantly lower MCAD value than CSMA/CD. In particular, for the case of 50 slot packets, CSMA/RI has negligible MCAD for throughput level of up to 80%. **This lower MCAD value is the main reason that CSMA/RI performs better than CSMA/CD.**

We also observe in Fig. 3 that the improvement in performance obtained by CSMA/RI over CSMA/CD is greater for the case of larger packets. Clearly, in general, for both CSMA/CD and CSMA/RI, for a given load, if the size of the packet increases, the rate of the packet arrival process is reduced, this in turn reduces both the packet collision probability and the MCAD value. This generic effect is evident in Figs. 3 and 4 where the performance of both CSMA/RI and CSMA/CD is improved for larger packets. Our main interest here is the further improvement in performance achieved by CSMA/RI as the packet size increases. As mentioned earlier in Section II, the packet collision probability will be further reduced as the packet size increases. It is because the mechanism of reservations by interruptions in CSMA/RI is based on randomly choosing a slot in a packet. With a larger packet, the probability of interruption collisions is lower and hence the MCAD value is reduced.

Figs. 5 and 6 provide insight into this further performance improvement of CSMA/RI. In these two figures, we exclude the arrival process and instead, we consider a batch of backlogged stations waiting in the beginning of an ongoing packet transmission. This way, we exclude the generic effect of the packet size and focus only on the further performance improvement of CSMA/RI.

Clearly, in CSMA/CD, if there are two or more backlogged stations waiting in the beginning of an ongoing packet transmission, the packet collision probability immediately after the completion of that packet transmission is equal to one since all stations are expected to transmit upon the completion of that ongoing packet transmission. By comparison, in CSMA/RI, backlogged stations are allowed to make reservations (by interruptions) by randomly choosing a slot from the ongoing packet transmission, and only those stations that performed the reservations can access the channel, therefore the packet collisions probability will drop below one. The larger the ongoing packet, the less likely it is for two or more backlogged stations to choose the same slot for reservations and hence the smaller the packet collision probability. Fig. 5 shows the packet collision probability as a function of the number of backlogged stations M and the packet size b. As expected, we see a reduction in the packet collision probability in CSMA/RI as packet size increases.

In Fig. 6, we further investigate MCAD in CSMA/CD and CSMA/RI due to packet collisions. In the case of CSMA/CD, the MCAD values that are shown in the dashed lines do not change for different packet sizes. In fact, for a given M, CSMA/CD MCAD is equal to CSMA/RI MCAD when $b = 2$. It is because when the packet size is two, all backlogged stations in CSMA/RI will interrupt the second slot of the packet transmission as that is their only choice, therefore they will all transmit and collide after that ongoing packet transmission as in CSMA/CD.

However in CSMA/RI, as the packet size increases, the choice of slots for reservations by interruptions becomes larger, the number of RI stations is reduced and so is the MCAD value. Notice that the MCAD value drops quickly in the range between two and ten slots of the packet size, and it decreases slowly as the packet size grows longer. This result indicates that a reasonable packet size is enough for CSMA/RI to achieve a low MCAD value.

B. The Disaster Scenario

In this traffic model [20], we assume a power up situation whereby M stations transmit simultaneously during a slot at a particular instant. A burst of size M therefore collides and has to be resolved. With no additional arrival, we evaluate the delay performance for a constant packet size of 50 and 10 slots in CSMA/CD, CSMA/RI, and G/D/1. The work conserving G/D/1 is used as a benchmark to represent the best delay performance possible to be achieved by a MAC protocol. In this case, it is important to know how close CSMA/CD and CSMA/RI are to this benchmark.

Notice the difference in the performance measures used here and in the previous subsection. Here we consider the mean packet delay through the entire period required until the entire batch is successfully transmitted. There we were interested only in MCAD until one packet is transmitted to explain the advantage of CSMA/RI.

In Fig. 7, it is demonstrated that for $b = 50$, the normalized mean delay in CSMA/CD increases at a much higher rate than that of CSMA/RI as the burst size M increases, while CSMA/RI performs very close to the work conserving G/D/1 benchmark.

In Fig. 8, the packet size is reduced to 10 slots. We see that both CSMA/CD and CSMA/RI have higher normalized mean delay due to the shorter packet size, however, CSMA/RI still performs better than CSMA/CD.

C. A Stability Study of CSMA/RI

It is well known that certain Aloha-type random access protocols may be unstable. As the instability of BEB has been established [23], it is important to evaluate the stability of CSMA/RI when it is implemented with the BEB algorithm.

In line with the channel stability study of Aloha protocols in [21], we present the system throughput of CSMA/CD and CSMA/RI as a function of the number of backlogged stations in

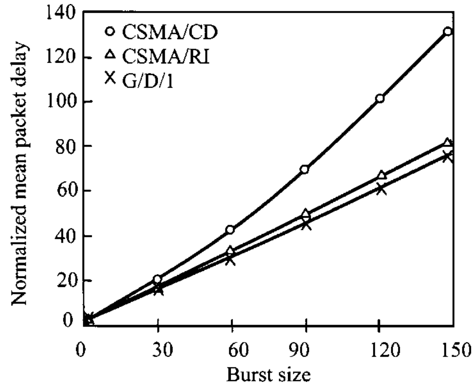

Fig. 7. Normalized mean delay versus burst size for $b = 50$.

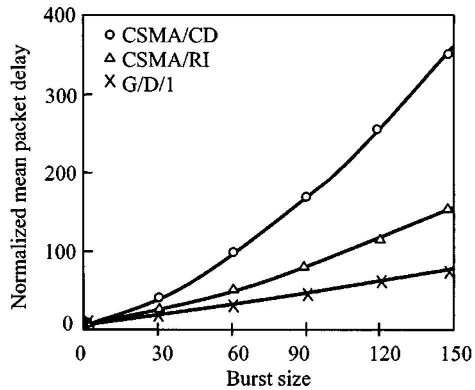

Fig. 8. Normalized mean delay versus burst size for $b = 10$.

Fig. 9. A Poisson arrival process and a constant packet size of 50 slots are assumed here.

Let M be the total number of stations. A station is either idle or backlogged. If a station is idle, it generates a new packet with probability σ within a time slot. If the packet is successfully transmitted, the station returns to the idle state, otherwise it stays backlogged until the packet is transmitted. Let the number of backlogged stations be n, and S be defined as $S = (M - n)\sigma$, the curve of S as a function of n is known as the *Channel Load Line* [21]. Fig. 9 also includes the two load lines S_1 and S_2 related to the case $M = 100$.

The load line S_1 represents a busy environment where stations are saturated. A station is defined as saturated if it always has a packet to transmit. In other words, as soon as it has completed its packet transmission, it immediately generates a new packet. In this case, $\sigma = 1$. Whereas in the case of the load line S_2, all stations equally share the total bandwidth. In this case, $\sigma = 1/M$ or 0.01.

We first observe that both load lines S_1 and S_2 intersect with the throughput curve of CSMA/RI at around 0.9, which is its maximum throughput. This high throughput level together with the long distance between the intersections signifies efficiency and stability. This result suggests that if the network consists of 100 stations, CSMA/RI can achieve high throughput even under very heavy load conditions (e.g., S_1). The wide operation range of CSMA/RI between the intersections means that it can achieve its maximum throughput for a wide range of traffic conditions. On the other hand, CSMA/CD has a narrow peak. In both S_1

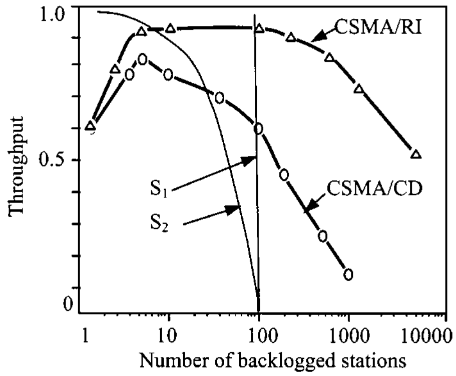

Fig. 9. Throughput versus number of backlogged stations for CSMA/CD and CSMA/RI.

and S_2 load conditions, CSMA/CD operates at relatively low throughput, especially for S_1.

D. Comparison to CSMA/CD and Token Ring Under Dual Packet Size

As mentioned earlier, in addition to the comparison between CSMA/RI and CSMA/CD, it is also of interest to compare CSMA/RI with a contention-free reservation protocol such as the token-ring protocol.

As in [24], we assume that packets are generated from 100 identical stations according to a Poisson process. The propagation delay in all cases is assumed to be 10 μs. The ring latency of the token ring network is assumed to be 1 bit/station. We further assume that the *limited-1* service discipline is used for the token-ring protocol to achieve a fair comparison to CSMA/CD and CSMA/RI as the stations transmit no more than one packet when they seize the channel. As in [17], we adopt the realistic scenario of a dual packet size [22], that is the traffic consists of long and short packets. Let b_1 (b_2) be the size of short (long) packets. The proportion of the short (long) packets is 70% (30%). We consider two cases for b_1 and b_2 values. In the first case, we consider a 10 Mbit/s bit rate (corresponding to Ethernet), and 16 Mbit/s bit rate (corresponding to the token ring) in the second case. The value for b_1 in both cases is set to be equal to 10 slots. Recall that a slot is assumed to represent twice the propagation delay, thus it is equal to the bit rate times twice the propagation delay. The value of b_2 in both cases, however, is different. It is related to the standard maximum Ethernet packet size ($b_2 = 50$ slots or 1.25 kbytes) in the first case and to the standard maximum token ring packet size ($b_2 = 200$ slots or 8 kbytes) in the latter case.

In both cases, we see a clear benefit of using CSMA/RI over CSMA/CD as presented in Figs. 10 and 11. Observe that under CSMA/RI, following a long packet transmission, it is likely to achieve a successful packet transmission due to the reservations by interruptions while in such a case under CSMA/CD, many backlogged stations, including those accumulated during the long packet transmission will collide immediately following that long packet transmission.

On the other hand, the token-ring protocol which behaves almost like a perfect scheduler performs better than CSMA/RI. As the average packet size increases in the second case, we observe that the performance of CSMA/RI comes closer to that of the token-ring protocol.

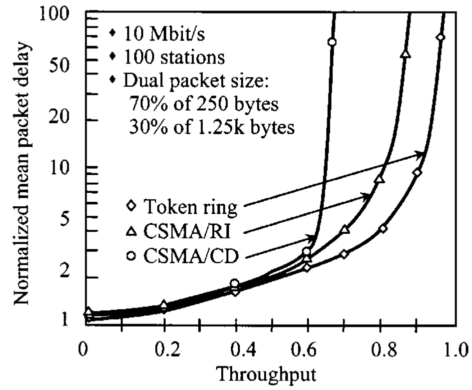

Fig. 10. Normalized mean packet delay versus throughput for the three protocols at bit rate 10 Mbit/s.

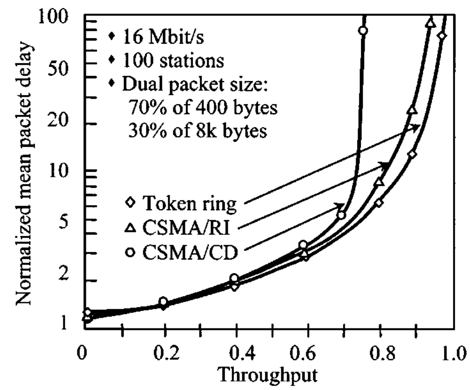

Fig. 11. Normalized mean packet delay versus throughput for the three protocols at bit rate 16 Mbit/s.

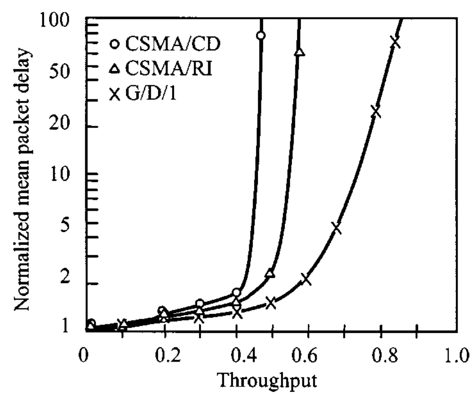

Fig. 12. CSMA/CD and CSMA/RI: normalized mean packet delay versus throughput for $b = 50$ and traffic burstiness $= 0.2$.

E. The LRD Traffic Model

It was well verified in [25] and [26] that Poisson traffic assumption is inadequate to model Ethernet traffic. Reference [27] shows that the M/Pareto can be used as a realistic traffic model for packet data traffic. M/Pareto traffic is a process composed of a number of overlapping bursts. Bursts arrive according to a Poisson process and have a Pareto distributed duration. It is characterized by four parameters which allow fitting of mean, variance, Hurst parameter H, and the level of aggregation. For

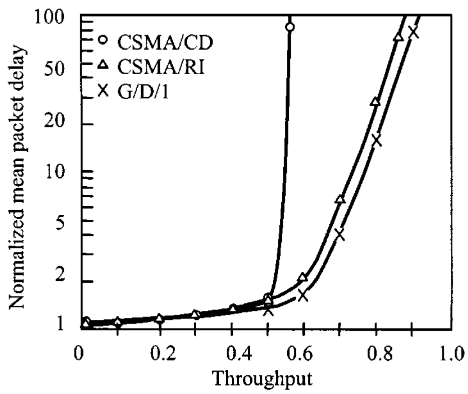

Fig. 13. CSMA/CD and CSMA/RI: normalized mean packet delay versus throughput for $b = 50$ and traffic burstiness $= 0.5$.

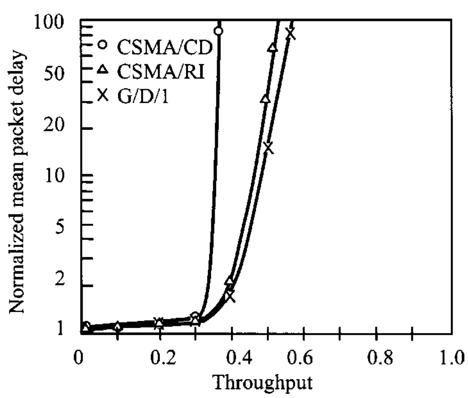

Fig. 14. CSMA/CD and CSMA/RI: normalized mean packet delay versus throughput for $b = 50$ and traffic burstiness $= 0.8$.

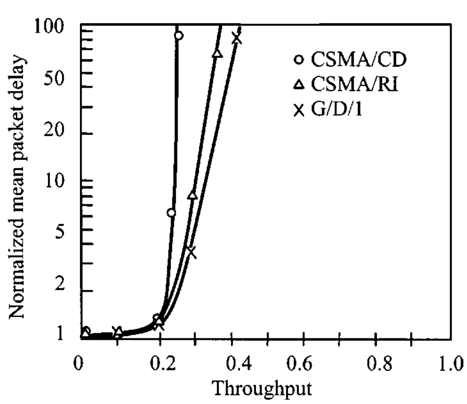

Fig. 15. CSMA/CD and CSMA/RI: normalized mean packet delay versus throughput for $b = 10$ and traffic burstiness $= 0.2$.

simplicity, we fix the mean of the Pareto distributed burst size to one, so that the process can be characterized by its mean, variance and Hurst parameter.

Assume an infinite number of stations and constant packet size. Define the *burstiness* of an LRD traffic process as the ratio of the standard deviation to the mean. In Figs. 12–14, we provide the delay performance for the case $b = 50$, $H = 0.9$, and for different burstiness levels. The choice of $H = 0.9$ is based on the study of [25]. To obtain a fair comparison, CSMA/CD and CSMA/RI were fed by the same LRD traffic generated by the M/Pareto model. We also compare its performance with its work conserving G/D/1 benchmark. As demonstrated in Figs. 12–14, CSMA/RI performs very close to this benchmark for $b = 50$.

Notice that these almost-perfect performance results have been achieved for the case of 50 slot packets. We know that the performance of CSMA/RI degrades if the packet size is reduced. This is demonstrated in Fig. 15, where the delay performance of CSMA/RI backs off from its G/D/1 benchmark, and approaches that of CSMA/CD when $b = 10$.

V. Conclusion

We have presented an enhancement of the CSMA/CD protocol called CSMA/RI. Under CSMA/RI, ready stations interrupt an ongoing packet transmission to reserve capacity. We have demonstrated by simulations, which were based on realistic traffic models and scenarios, that CSMA/RI performs better than CSMA/CD. For realistically long packets, it performs almost as well as token-ring and G/D/1.

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