Back to the Packet Radio with MACA

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1 Introduction

Karn introduced MACA (Multiple Access with Collision Avoid-ancd) in [4] which was designed for packet radio network. It was used as the basis for the IEEE802.11 LAN standard. Thereafter, based on simulation studies of MACA, Bharghavan et al. fine tuned MACA to improve its performance and renamed their new protocol MACAW in [7].

In this paper, we first investigate the performance of MACA under the no hidden terminal situation. By an analytic way, we will compare the throughputs of MACA and CSMA[1]. We then review CSMA and some kind of protocols cosidered as extended versions of CSMA, and point out that MACA has an ability to get the throughput exceeding one. A suggestion in Conclusion in this paper will remind us that we are people who love amateur radio and have some interests in computers.

2 CSMA and Hidden Terminal

It is well-known that in Ethernet, CSMA/CD (Carrier Sense Multiple Access with Collision Detection) is used as a MAC protocol. When a packet to be transmitted by a station is occur, the station firstly sense the medium, then (1) if the medium is idle, it transmit the packet immediately or in accordance with some rule, (2) if the media is busy, it postpone the transmission. During the transmission, when the station detects a collision, it aborts its transmission, waits a random period of time, and then tries again. CSMA/CD is considered as an extended version of CSMA which was proposed by Kleirock and Tobagi [1] as a protocol on PRNs.

Figure 1 indicates the connection among terminals on packet radio network.

Teminals connected by a line in Figure 1 can comminucate with each other. Consider the case that the terminal B is transmitting a packet to the terminal D. In this situation, even if the terminal A tries to transmit a packet, it can stop to do that, bacause A can detect the packet from B. We should note **that** there is no line between the terminals B and C. Thus, in spite of transmitting packet from B to D, C falsely conclude that it can transmit a packet. The packet cause collision at D with the packet from B to D. We call the terminals B and C "hidden terminal" each other. The existance of hidden terminal makes the throughput of PRN seriously decrease.

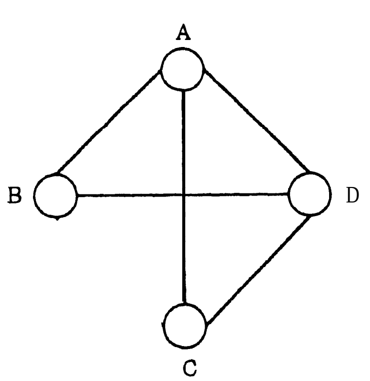

Figure 1: Connection among terminals

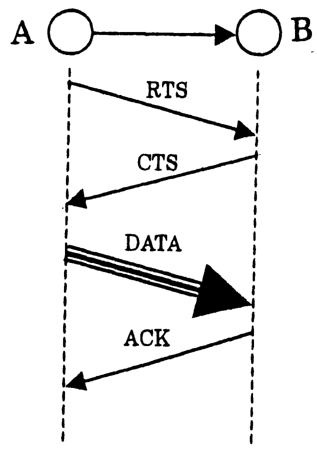

Figure 2: Sequence Diagram of MACA

3 MACA

Karn proposed a new MAC protocol, Multiple Access with Collision Avoidance (MACA) as an alternative to the traditional CSMA protocol in [4]. One of the purposes of introducing MACA to a PRN is to eliminate the hidden terminal problem. Let us consider how the terminal A sends a packet to the terminal B in Figure 2. A starts the action by sending a short packet called RTS (Request To Send) packet to B. The RTS contains the length of the data frame that will eventually follow. Then B replies with a CTS (Clear To Send) packet which contains the data length (copied from the RTS frame). Upon receipt of the CTS frame, A begins to transmit a data. If B has received the data successfully, it sends the ACK [1] packet to A. The diagram of this sequences is shown in Figure 2.

Any station overhearing an RTS defers all transmissions by the time after the associated CTS packet would have finished. Any station overhearing a CTS packet defers for the length of the expected data transmission which was contained in the RTS and was copied to CTS.

Figure 3 shows the state diagram for MACA. A total of 8 states IDLE, CONTEND, WFCTS, WFACK, WFDATA,

[1] The ACK packet is introduced in [7] as one of the extended function of MACA.

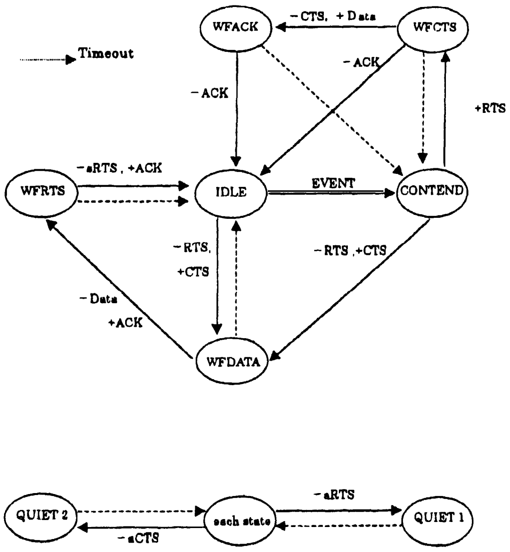

Figure 3: State Diagram of MACA

WFRTS, QUIET1, and QUIET2 exists, these states except WFRTS, QUIET1, and QUIET2 were presented in [7] in order to explain the transition rules in a concrete example.

We must need the state WFRTS since we have been considered the extended MACA by the ACK packet. In [7], the state QUIET was used in order to indicate the deferral rules on both of RTS and CTS. Recall that deferral times by RTS and CTS are different. In [7], the difference was realized by setting one of two values to a timer. Instead of using these two values, we adopt the two types of states QUIET1 and QUIET2 which corresponds to the deferral times by RTS and CTS.

When an event occurs (EVENT), the transition is done from the state IDLE to the state CONTEND. After the timer for contention is expired (dot-dash-line), a source terminal called A transmits an RTS (+RTS) and enters the state WFCTS. If a destination terminal called B accepts the RTS correctly, it responds to A by CTS after a time x. If A accepts the CTS correctly (-CTS), it transmits a data packet (+Data) after a time c, and then enters WFACK immediately. After a time d from when B recognizes the data packet was successfully accepted, it transmit ACK to A. Thereafter, if A receives ACK (-ACK) correctly, it enters IDLE immediately. It is a cycle in the case that the transmission is succeeded.

Note that the parameters x, c, and d which represent the times between RTS and CTS, CTS and Data, and Data and ACK, respectively, reflect the performance of a network node controller (NNC) .

In one case when, in spite of sending RTS from the source terminal A, the destination terminal B can not send CTS, or the other case when B can not send ACK to A, A backs to the state CONTEND after the corresponding timer is expired (dot-dash-line).

Suppose that a terminal called C receives RTS from a terminal called D (-RTS) in a state IDLE. Then C transmits CTS after a time x (+CTS) and enters WFDATA state. After a time c from when D have received the CTS successfully, C begins to receive a data packet, from C (-Data). If it is successfully received, C sends ACK to D (+ACK) after a time d and enters WFRTS state. In the WFRTS state, if C receives the same RTS (-sRTS) as the one received before, then it transmits ACK (+ACK) and enters IDLE state. If C expires the timer for the RTS it simply enters IDLE state (dot-dash-line).

In each state, if a terminal overhears RTS (CTS) to be used for cornmunicat ions among anot her terminals (-aRTS (-aCTS)) , it enters QUIET1 (QUIET2) and then keep quiet until the timer is expired.

We must note that because MACA does not perform carrier senses, we can neglect any hidden terminal situation in this protocol.

4 MACA in No Hidden Terminal Situation

It is interesting to compare the performances of MACA and CSMA. Because the CSMA is supposed to work on the situation with no hiddern terminals, considerations should be made on no hidden terminal situation.

We will now derive the throughput equation for the MACA. Since the technique for the derivation is similar to the one in [1], we only give sketches of that.

Let the "frame time" denote the amount of time needed to transmit the standard, fixed-length frame. Let us assume that the probability of transmission attempts per frame time is Poisson with mean G per frame time. The transmission attempts consists of newly generated frames and retransmitted frames that previously suffered collisions. We denote the ratio of maximum propagation delay to packet transmission time by $a > 0$. Further, in the following argument, we assume that the frame time is 1.

The expected value of the time needed to transmit a packet is simply the probability that no terminal transmit a packet during the time x between the arrival of an RTS and the departure of a CTS, it was noted in the previous section. Therefore,

$$\bar{U} = e^{-xG}$$

Define a *busy* period to be the time during at least one station is not in an IDLE state and an idle ***period*** to be the time during all stations are in idle state. Let $\bar{B}$ be the expected duration of the busy period and $\bar{I}$ be the expected duration of the idle period. Then, the throughput is given by

$$S = \frac{U}{\bar{B} + \bar{I}}$$

Let P_{RTS0} denote the probability to be succeeded in transmitting a packet. It is easy to see that the probability P_{RTS0} is equal to the probability that during the time x no terminal transmits an RTS. Thus,

$$P_{RTS0} = e^{-xG}$$

And the period of time in which a cycle of transmission is completed is

$$B_{RTS0} = 4a + c + d + x + 1$$

, where c (d) is the time between the arrival of a CTS (a data packet) and the departure of a data packet (an ACK), it was noted in the perivious section.

On the other hand, the probability P_{RTS1} to be the packet is reserved is given by,

$$P_{RTS1} = 1 - P_{RTS0}.$$

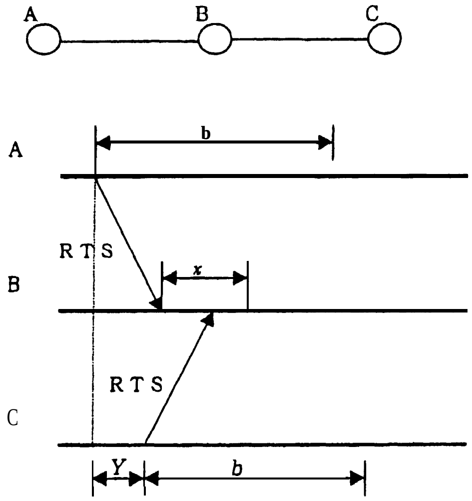

Figure 4: Contention of RTS

We consider the case the number of stations transmit RTSs during the time x. Let $Y(< x)$ denote the time between the first station transmits an RTS and the last station transmit an RTS and let $\bar{Y}$ denote the expected value of Y. See Figure 4. Let b be the time needed to expire a timer for the state WFCTS.

In this case, the expected value of the busy period of time is given by

$$B_{RTS1} = \bar{Y} + b$$

The distribution function for Y is

$$\begin{aligned} F_Y(y) &\triangleq Pr\{Y < y\} \\ &= Pr\{\text{no arrival occurs in an interval a} - y\} \\ &= e^{-G(x-y)}, (y \geq x) \end{aligned}$$

The average of Y is therefore given by

$$Y = x - \frac{1}{G}(1 - e^{-xG})$$

Thus, we have

$$B_{RTS1} = b + x - \frac{1}{G}(1 - e^{-xG})$$

Then, the expected duration of the busy period is obtained as follows.

$$\begin{aligned} B &= P_{RTS0}B_{RTS0} + P_{RTS1}B_{RTS1} \\ &= (4a + c + d - b + 1)e^{-xG} + b + x \\ &\quad - \frac{1}{G}(1 - e^{xG})^2. \end{aligned}$$

From the argument above and the average duration of an idle period is simply representable as $\bar{I} = \frac{1}{G}$, we can get the throughput equation as follows.

$$S = \frac{Ge^{-xG}}{G\{(4a + c + d - 6 + 1)e^{-xG} + b + x\} - (1 - e^{-xG})^2 + 1}$$

We must note that ail of a, c, and d in the above fomura are constants, because of the no hidden terminal condition. Then, we will later observe the behavior of the throughput with respect to only the variable x.

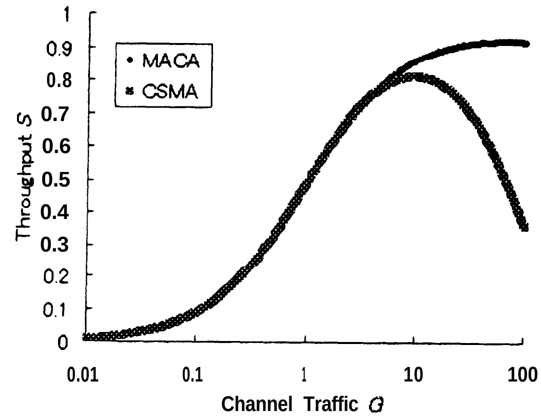

Figure 5: a = 0.01, x = 0,005

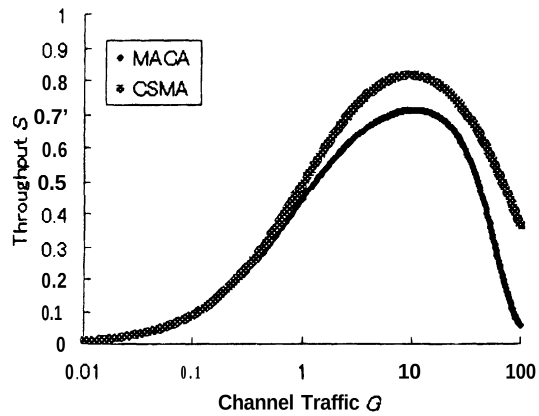

Figure 6: a = 0.01, x = 0.01

On the no hidden terminal condition, if the performance of MACA is better than that of CSMA, we can conclude that MACA has an inherently good performance than CSMA. The throughput equation of CSMA was given in [1] as follows:

$$S = \frac{Ge^{-aG}}{G(1 + 2a) + e^{-aG}}.$$

We will investigate the difference between the throughputs of MACA and CSMA by changing conditions of the delay time a and the time between RTS and CTS. Figure 5 to 8 show the results.

It is well-known that the throughput of CSMA decreases according to the increase of the channel traffic. On the other hand, it is clealy evident from Figure 5 that even in high channel traffic, the throughput of MACA does not decrease. The reason to be the phenomenon occured is that although when a collison occurs, the time between one frame time and two frame time is lost in the CSMA environment, in the MACA environment the time to be lost is only the short frame times to be used by RTS and CTS.

We will compare Figure 5 and Figure 6. It is no wonder but, while the throughput of CSMA does not depend on the parameter x, the throughput of MACA does. It follows that in no hidden terminal and low propargation delay environment, in order to overcome the CSMA, the performance of RTS and CTS interchange at MACA should have excellent efficiency.

By comparing Figure 5 and Figure 7, we can find that the MACA is less sensitive to increases in the delay a, as compared to the CSMA.

Figure 8 indicates that in the low channel traffic the through-

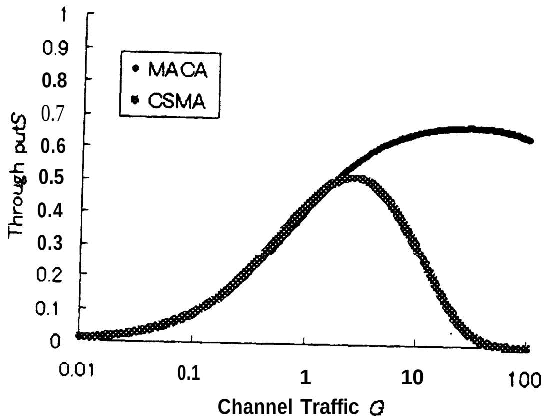

Figure 7: a = 0.1, $x = 0.005$

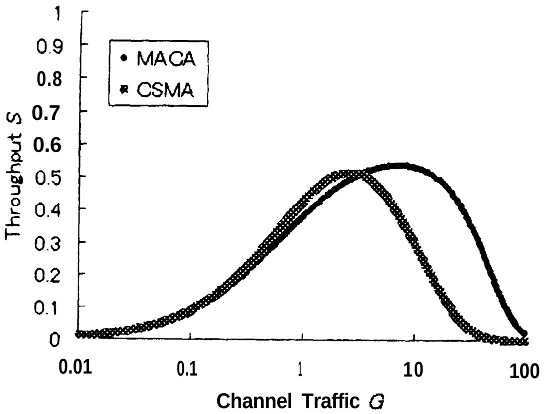

Figure 8: a = $0.1, x$ = 0.01

put of CSMA is better than that of MACA, but in high traffic the positions of these protocol are reversed.

5 MACA and Other Protocols

Karn also pointed out in [4] that less well-known than hidden terminal but a serious problem for CSMA protocol is the problem of exposed terminal. Let us consider the situation that the terminal B is transmitting to the terminal A as shown in Figure 1. If the terminal C senses the medium, it will hear an ongoing transmission and falsely conclude that it may not send to the terminal D. But, in fact, the packet transmitting from C to D gives no conflict at A. We can find that the existance of exposed terminal should lose the chance to transmit more than two packets simultaneously.

It is noted that if the whole period of time is completely occupied by packets, then the throughput is defined to be one which is the upper bound of the range.

Many investigations about the MAC protocols each of which can be considered as an extended version of CSMA are performed [2, 3, 6, 11, 9]. The concepts of all of these protocols are "How do we overcome hidden terminals on the protocol with carrier sense ?". We call these protocols "carrier sense type protocols". The key of carrier sense type protocols is to locate a central station on a PRN which informs the presences of transmitting terminal to all terminals by a tone signal. Thus, if a terminal having a packet to be transmitted receives the tone signal, it is going to postpone the transmission. This mechanism leads the terminals to preserve collisions, but for even faraway terminals from the transmitting terminal (above two

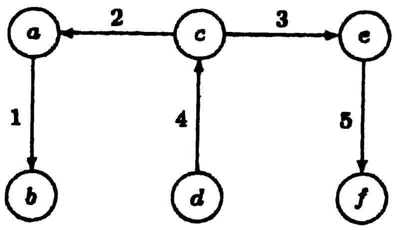

Figure 9: A scene on a PRN

hops), the transmission is going to be reserved. In other words, if we use the carrier sense type protocol, all terminals in a PRN necessarily should be exposed terminals. This is stupid, because, obviously, these above-two-hops-away-terminals can transmit data independently.

On the other hand, MACA uses RTS and CTS as a mechanism to aviod collisions of packets. Moreover, MACA is worked on a basis of connecting information up to two hops around some fixed node. It is intersting to compare the fact above and the fact that in order to work carrier sense type protocol in a PRN well, any terminal must care all terminals in the PRN. Then, by introducing MACA to PRN, we can get efficient throughput exceeding one. As concerning to carrier sense type protocols, we never get the performance as the throughput is exceeding one, because the protocol has no ability to achive the simultaneous transmission.

We should note that there are some cases that some terminals within two hops can transmit data simultaneously. The PRN in Figure 9 has six terminals a,b,c,d,e, and f. An arrow between two terminals indicates the flow of data. Each of these six arrows is labeled by an integer. We can easily find that the following conbinations of arrow are available for simultaneous transmission.

$$(1,3),(1,4),(1,5),(2,5),(4,5),(1,4,5)$$

Note that the origins of arrows of each of conbinations above are within two hops. An algorithm to get simultaneous transmission is presented in [10].

Another Protocols to be enabled simultaneous transmissions had already introduced in [5, 8]. It is similar to MACA that both of the protocol STS[5] and STMA/DA[8] use two types of short frames or tones such as RTS and CTS of MACA to be simultaneous transmission available. In addition to this, STMA/DA uses special tones for avoiding collisions. Moreover, at both of STS and STMA/DA, directional antennas are used to increase the throughput by spatially reusing the channel.

In order to show efficiency of the proposed protocol, the comparison of throughput between that and carrier sense type protocol was performed in each of [5] and [8]. According to expectation, the proposed protocol has more efficient performance than the carrier sense type protocol. But it is a natural result, because the comparisons between the protocols which can simultaneous transmissions and can not are made. It is our present interest to compare the performances among these protocols to be able to simultaneous transmission such as MACA, STS, STMA/DA, and others.

6 Conclusion

CSMA, which is the origin of CSMA/CD, had been proposed by Kleinrock and Tobagi as a MAC protocol on Packet Radio Network (PRN) in 1975 [1]. They had noticed that the serious problem of CSMA is the existence of hidden terminal, and had shown a way of'solution to the problem in the paper [2] just followd by [l].

Nowadays, CSMA/CD is a famous protocol on a bus network such as Ethernet. Needless to say, since there is no hidden terminals in a bus network, CSMA/CD works well. But, actually, in a PRN, it is reasonable to consider that no hidden terminal situation is a special case.

Karn had, proposed in [4] that "Let's ignore data carrier detect (i.e., carrier sense)" . This suggestion is not only eliminate a bad effect of hidden terminal, but also leads to the efficient communication way in a PRN, that is, "simultanious transmission'.

Recall that, CSMA had been originally arised as a protocol for Packet Radio. Now, our turn has come again. Let's "Back to Packet Radio with MACA" for more excellent communications.

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