Performance Analysis of a CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) Protocol in a Wireless LAN system

Jae Hyun Kim and Jong Kyu Lee
Dept. of Computer Science and Engineering, HanYang University
396 Dae-Hak Dong, Ansan, Kyung-Gi Do, 425-791, Korea
Email : jhkim@commlab.hanyang.ac.kr

ABSTRACT

In this paper, we have analyzed the performance of a BRAM (The Broadcasting Recognizing Access Method) protocol, as a CSMA/CA (Carrier Sense Multiple Access/ Collision Avoidance) scheme, which is widely used in wireless LAN systems. We have selected a fair BRAM protocol among CSMA/CA schemes, considering the fairness of channel usage and the simplicity of the protocol and analyzed the throughput of BRAM scheme. First, we have set up an imbedded Markov chain and calculated state transition probabilities. Then, we have calculated steady state probabilities and finally derived the throughput of a fair BRAM model. To verify our analysis, we have simulated practical models. As a result, we have found that analytic results are very close to simulation ones. Our analysis of the BRAM protocol will be expected to be very helpful to design and evaluate a MAC (Media Access Control) protocol in wireless LAN systems.

I. Introduction

In recent years, there has been an increasing need for Local Area Networks(LAN) in commercial and military applications. More and more personal computers are connected through LAN to share data and expensive peripherals such as massive storage device and laser printers [1]. Then, the costs for installation and relocation have been increased. For an example, Motorola estimated that the total cost of U.S. industry to relocate LAN terminals reached $ 5.6 billion in a year [2]. From the economic and efficient points of view, wireless LAN systems have many merits in installation and relocation. Nowadays some commercial products have been shown such as NCR WaveLAN, Telesystem ARLAN and Motorola ALTAIR [3][4].

One of important considerations in wireless LAN implementation is the selection of a MAC protocol. There are some protocols which can be applied to wireless LAN systems, such as IEEE 802.3 CSMA/CD, IEEE 802.4 token bus, IEEE 802.5 token ring, CSMA/CA protocol which will be adopted as 802.11 by IEEE [5],[6].

The token ring scheme is a point to point mode, so it is not appropriate to wireless LAN. The token bus protocol is a broadcasting mode and has high reliability, priority functions, and no limitation of packet length. It has advantages of low packet delay and high throughput, when the traffic is heavy. But, it has some defects of complicated protocol and high price. Also, it shows large overhead because of token passing time, when the traffic is scarce. CSMA/CD protocol is a very simple one which uses a high speed channel and it is a broadcasting mode. It shows relatively good performance for packet delays when the volume of traffic is low. But, if the volume of traffic increases above the specific level, packet delay is abruptly increased and it is not easy to implement priority function in CSMA/CD scheme [7],[8]. CSMA/CA protocol not only senses a channel status, but also reserves a channel before using it, so it prevents packet conflicts. Though it requires scheduling periods for channel reservation, it can avoid the loss of conflict time and doesn't need retransmission management.

In this paper, we have selected a BRAM (The Broadcast Recognizing Access Method), as a CSMA/CA protocol, to consider the fairness of channel usage and the simplicity of the protocol. And, we have evaluated performance of CSMA/CA scheme by a mathmetical analysis and simulations. In section II, we have described the characteristics of BRAM in wireless LAN and set up an imbedded Markov model in section III. And, we have analyzed the performance of a fair BRAM and verified mathmetical analysis in section IV. Finally, section V derives some conclusions.

II. Broadcast Recognizing Access Method

The BRAM protocol is a random access protocol which is operated by decentralized control. There are four variants such as Fair BRAM(FB), Prioritized BRAM(PB), Parametric Fair BRAM(PFB), Parametric Prioritized BRAM(PPB). The former two schemes avoid packet collisions, the latter two schemes limit the probabilities of collisions [9].

The fair BRAM scheme has a scheduling period before a transmission period and a transmission sequence is determined during the scheduling period which is produced by a following scheduling function $H(n_1,n_2)$.

$$H(n_1,\ n_2)=\begin{cases} (n_1-n_2+K)\ modular\ K & ;\quad n_1 \neq n_2 \\ K & ;\quad n_1 = n_2 \end{cases} \tag{1}$$

- n_1 : the index of a station which wants to transmit.
- n_2 : the index of a station which has transmitted just before.
- K : the number of stations in a LAN system.

It is obvious that a H(*,*) is an integer valued from 1 to K. If a station i wants to transmit, the station waits an $H(i,n_2)\times\tau$ (propagation delay) time, then it senses the channel. If the channel is idle, a transmission is started, otherwise it is busy, station i waits for the channel to become idle and then reschedules another transmission point by function H(i,*). A station, which has the smallest H(*,*) value starts a transmission first, and gets a largest H(*,*) value after the transmission is completed. So, the channel access discipline is fair for all stations.

The PB method is similar to that of the FB scheme, but $H(n_1,n_2)=0$, if $n_1=n_2$, which gives access priority to the station which has transmitted just before. If the station, which has transmitted just before, wants to transmit again, it can transmit at once. But, other stations must wait to the end of its continuous transmissions.

In PFB, all stations in a LAN system is divided into some groups, and stations in the same group contend transmission at the same transmission point. A scheduling function $R(n_1,n_2)$ is as follow,

$$R(n_{1,}\ n_2) = \begin{cases} (n_1 - n_2 + G)\ modular\ G & ;\quad n_1 \neq n_2 \\ G & ;\quad n_1 = n_2 \end{cases} \qquad (2)$$

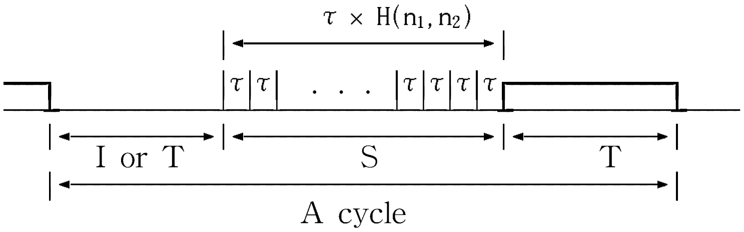
- n_1 : the index of a station which wants to transmit.
- n_2 : the index of a station which has transmitted just before.
- G : the number of groups in a LAN system.

When more than two stations in the same group try to transmit packets, a collision can occurs. So, G value affects system performance. Small G values tend to reduce the length of scheduling periods, but increase the probability of collisions, while large G values tend to increase the length of scheduling period, but reduce the probability of intragroup collisions.

Finally, PPB is similar to PFB, but gives a priority to the group which includes the station which has successfully transmitted just before. When the number of stations in a LAN system and a propagation delay is small, FB and PFB offer fair channel allocation and PFB provides good performance measures for small channel throughput values. While PPB shows better performance measures than those of others, independent of value of parameters. But, in PFB and PPB method, collision can occur and it is difficult to determine optimum G value. Considering the fairness and simplicity of protocol, we have selected a fair BRAM scheme as a CSMA/CA protocol.

III. Imbedded Markov Chain Model

In the fair BRAM method, channel state consists of a sequence of cycles composed of idle, scheduling and transmission periods. An idle period occurs when no station attempts to access channel. A scheduling period occurs when one or more station attempts to obtain the control of the channel for a transmission. A transmission period occurs when a station transmits a packet. The longest scheduling period is determined by the number of stations and propagation delay, and a scheduling period in a cycle is determined by the index of a station which has transmitted just before, and the index of a station which ready to transmit. A cycle with three periods is shown in Fig.1.



- I : idle period
- S : scheduling period
- T : transmission period
- τ : end-to-end propagation delay
- $H(n_1,n_2)$: scheduling function

Fig.1 Channel states for a fair BRAM model

We have set up a following model to analyze a fair BRAM scheme. A wireless LAN system is composed of N stations and each station generates a new packet by Poisson process with a mean of g. The time axis is slotted as the size of a slot time τ, the end-to-end propagation delay. All stations are synchronized and packets are transmitted only at the beginning of each slot. For the simple analysis, we have assumed that all packets are of the same length, F slots. In the following analysis, we have considered the imbedded Markov chain at the system transition points. If we consider the number of ready packets in the system, the system can be in the one of following set of states,

$$(I, S_0, S_1, S_2, \cdots, S_N, T_1, T_2, T_3, \cdots, T_N)$$

where, state I denotes that there is no ready packet in the system. State S_i means that the system is in the scheduling state, and there are i ready packets State T_i denotes the system is in the transmission state, and there are i ready packets. N denotes the number of stations in the system.

Fig 2. State transition diagram for BRAM model

IV. Performance Analysis

First, let P(τ) be the the probability which a station generates a packet during τ. P (τ) can be find easy because packets are generated by Poisson process.

$$\mathrm{P}(\tau) = (\tau g) \cdot e^{(-\tau g)} \tag{3}$$

Then, we have to find the state transition probabilities for all states. Let Pr(i,j) be the transition probability from a state i to a state j. P(τ) and state transition probabilities are as follow.

$$\begin{aligned} \Pr(I,I) &= \Pr[\,\textit{no station becomes ready during a slot}] \\ &= \binom{N}{0} \cdot [P(\tau)]^0 \cdot [1-P(\tau)]^N \qquad (4) \\ &= [1-P(\tau)]^N \end{aligned}$$

$$\begin{aligned}\Pr(I, S_i) &= \Pr[\ \textit{i stations become ready during a slot}\ ] \\ &= \binom{N}{i} \cdot [P(\tau)]^i \cdot [1-P(\tau)]^{N-i}\ ;\ 1 \leq i \leq N\end{aligned} \tag{5}$$

$$\begin{aligned}\Pr(T_i, S_j) &= \Pr[\ (j-i+1)\ \textit{stations become ready during}\ (F+1)\ \textit{slots}\ ] \\ &= \binom{N-i}{j+i+1} \cdot [1-\{1-P(\tau)\}^{F+1}]^{j-i+1} \cdot [\{1-P(\tau)\}^{F+1}]^{N-j-1} \\ &\qquad ;\ 0 \leq i-1 \leq j \leq N-1\end{aligned} \tag{6}$$

where, the transmission period is fixed at (F+1) slot, since one slot is included as a propagation delay.

We have to consider more rigorously for $\Pr(S_i,T_j)$, because the duration of state S_i is not constant. Let n_2 denote the index of the station which has transmitted just before, k denote the difference between the index of a station, which has transmitted just before, and the index of a arbitrary station. Let $\{(n_2+k) \bmod N\}$ denote the station whose transmission sequence number is k. Let D denote the set of ready stations in state S_i, $L(S_i)$ denote the number of slots in a scheduling period. N denotes the number of stations. We can find $\Pr(S_i,T_j)$ as following.

$$\begin{aligned}\Pr\ (S_i, T_j) &= \Pr[\ (j-i)\ \textit{stations become ready during a state}\ S_i\ ] \\ &= \begin{cases} \sum_{k=1}^{N-i}\big(\Pr(j-i, k) \cdot \Pr[L(S_i)=k,\ \{(n_2+k) \bmod N\} \in D] \\ \quad + \Pr(j-i-1, k) \cdot \Pr[L(S_i)=k,\ \{(n_2+k) \bmod N\} \notin D]\big) \\ \qquad\qquad ;\ 0 \leq i \leq j \leq N,\ \ 0 \langle\ j \\ 1 \qquad\qquad ;\ i = N,\ j = N \end{cases}\end{aligned} \tag{7}$$

$\Pr(S_i,T_j)$ is composed of two term, the first term means that k scheduling slot is fixed and (j-i) stations which are not in D generate packets to transmit, and the other term means that $\{(n_2+k) \bmod N\}$ station is detemined during this scheduling period and then (j-i-1) stations which are not in D generate packets. Let Pr(j-i, k) be the probability that (j-i) station generate packet during k scheduling slot, and Pr(j-i-1, k) means same manner. Then, Pr(j-i, k)b, Pr(j-i-1, k) can be calculated as follow,

$$\begin{aligned}\Pr(j-i,k) &= \Pr[\ (j-i)\ \textit{stations not in D become ready} \\ &\qquad\qquad \textit{during k scheduring slots}\ ] \\ &= \binom{N-i}{j-i}\cdot[1-\{1-P(\tau)\}^{k}]^{j-i}\cdot[\{1-P(\tau)\}^{k}]^{N-j}\end{aligned} \tag{8}$$

$$\begin{aligned}\Pr(j-i-1,\ k) &= \Pr[(j-i-1)\ \textit{stations not in D}\ ,\ \{(n_2+k)\ \mathrm{mod}\ N\}\ \textit{become} \\ &\qquad \textit{ready during k scheduling slots}\ ] \\ &= \begin{cases}\binom{N-i-1}{j-i-1}\cdot[1-\{1-P(\tau)\}^{k}]^{j-i-1}\cdot[\{1-P(\tau)\}^{k}]^{N-j} & ;\ i\neq j \\ 0 & ;\ i=j \\ 1 & ;\ i+1=j\end{cases}\end{aligned} \tag{9}$$

Pr[L(S_i) = k, {(n_2+k) mod n} ∈ D] in the right-side of (7) is the probability that {(n_2+k) mod n } station is already determined and k scheduling slot is fixed in previous state. And, Pr[L(S_i) = k, {(n_2+k) mod n} ∉ D] is the probability that {(n_2+k) mod n } station is not determined and k scheduling slot is fixed in this state. So, Pr[L(S_i) = k, {(n_2+k) mod n} ∈ D] and Pr[L(S_i) = k, {(n_2+k) mod n} ∉ D] are drived as follow,

$$\begin{aligned}&\Pr[\ L(S_i)\ =\ k,\ \{(n_2+k)\ \mathrm{mod}\ N\}\in D\ ] \\ &\quad= [\prod_{m=1}^{k}\{1-P_x(m)\}]\cdot\frac{{}_{(N-k-1)}C_{(i-1)}}{{}_{(N-k)}C_{i}} \\ &\quad= [\prod_{m=1}^{k}\{1-P_x(m)\}]\cdot\frac{i}{N-k}\end{aligned} \tag{10}$$

$$\begin{aligned}&\Pr[\ L(S_i)\ =\ k,\ \{(n_2+k)\ \mathrm{mod}\ N\}\notin D\ ] \\ &\quad= [\prod_{m=1}^{k}\{1-P_x(m)\}]\cdot[1-\frac{i}{N-k}]\cdot[1-\{1-P(\tau)\}^{k}]\end{aligned} \tag{11}$$

where, P_x(m) is the probability that {(n_2+k) mod n} station is ready upon its scheduled transmission point. it means that k scheduling slots are detemined this scheduling.

We have

$$
\begin{aligned}
P_x(m) &= \Pr[\{(n_2+m) \bmod N\} \textit{ is ready upon its scheduled transmission point }] \\
&= 1 - [1 - \frac{i}{N-m}]^{m-1}
\end{aligned}
\tag{12}
$$

And, the $\Pr(S_0,I)$ means that packet is not generated in this system during a scheduling slot(S_0). We have

$$
\begin{aligned}
\Pr(S_0, I) &= \Pr[\textit{ no station becomes ready during a slot}] \\
&= \binom{N}{0} \cdot [P(\tau)]^0 \cdot [1-P(\tau)]^N \\
&= [1-P(\tau)]^N
\end{aligned}
\tag{13}
$$

We have found all state taransition probabilities. Now, we have to find the duration for each state. The duration for idle state is a slot time, and for state T_i is fixed at F. But, duration for station S_i is not constant. Let $T(S_i)$ be the duration for state S_i. To simplify the analysis, we have assumed that $T(S_i)$ is fixed, and it is computed as follows.

$$
\begin{aligned}
T(S_i) &= \sum_{k=1}^{N-i} k \cdot \Pr[L(S_i) = k] \\
&= \begin{cases} \displaystyle\sum_{k=1}^{N-i} k \cdot \Pr[L(S_i)=k, ((n_2+k) \bmod N) \in D \\ \quad + \Pr[L(S_i)=k, ((n_2+k) \bmod N) \notin D] & ; k \neq N \\ N & ; k = N \end{cases}
\end{aligned}
\tag{14}
$$

where, Prob[$L(S_i)$ = k] can be calculated by the same way of $\Pr(S_i,T_j)$ case. Let Π = [Π(I), Π(S0), ･･･] be the vector of steady state probabilities, and P be the transition probability matrix. We can solve the equation $\Pi = \Pi P$ to get all steady state probabilities. So, we can derive the throughput S as follow [10][11].

$$
S = \frac{\sum_{i=1}^{N} \Pi(T_i) \cdot F}{\Pi(I) + \sum_{i=1}^{N} \Pi(T_i) \cdot (F+1) + \sum_{i=1}^{N} \Pi(S_i) \cdot T(S_i)}
\tag{15}
$$

- $\Pi(i)$: steady state probability for state i
- S : throughput

We have used computer simulation techniques to verify mathematical analysis. In simulation model, a LAN system is composed of 20 or 40 stations, and packet size is fixed at 1024 or 2048 bytes. The total offered load(G) is in the range from 0.1 to 10, and the transmission speed is fixed at 2 Mbps, since the transmission rate of wireless LAN systems is slower than that of cable LAN's [12]. Also, we have assumed that ratio of propagation to transmission rate is 0.05. The software tool used for simulations is SIMSCRIPT II.5 which supports event driven and process oriented approach [13].

When the number of stations is 20, a throughput performance is shown in Fig. 5. The throughput curve is continuously increased when the G value is less than 1, while it is saturated at specific level, as the G value is above 1. And, the variation of packet size is less effective to the throughput of this practical model. In Fig.6, the throughput performance is presented, when the number of stations is increased at 40. This graph shows similar results to Fig. 5, throughput of BRAM is saturated, when the G is above 1. Though traffic is increased above specific level, throughput of BRAM is garanteed, since packet collisions are avoided in this protocol. In the two graphs, the results of mathematical analysis are very close to the simulation ones.

Fig. 5 Throughput characteristics when the station number is 20

Fig. 6 Throughput characteristics when the station number is 40

V. Conclusions

In this paper, we have analyzed the performance of a fair BRAM scheme as a CSMA/CA protocol. Considering the fairness and simplicity of protocol, we have selected a fair BRAM scheme as a CSMA/CA protocol. In a fair BRAM protocol, all stations sense a channel status and reserve a channel before using it, so packet collisions are avoided.

Wireless LAN has many defects such as multipath fading and shadow fading, etc. Therefore, the volume of traffic is relatively increased by packet retransmission caused by transmission error, which is the disadvantage of radio communication. Usually, the transmission speed of wireless LAN is slower than that of cable LAN. It causes a high channel utilization and increase traffic.

In order to compare the performance of a fair BRAM scheme with a CSMA/CD scheme, we have simulated two protocols in the throughput point of view. As simulation results, we have found that fair BRAM show better performance than the CSMA/ CD scheme. Considering performance comparison results of a fair BRAM and increasing traffic factors, we have found that CSMA/CA (BRAM) scheme is more appropriate than CSMA/CD in a wireless LAN system.

We have analyzed the performance of a fair BRAM using imbedded Markov chain, then verified this analysis by simulation technique. As results, analytic results are very close to the simulation ones, so our mathematical analysis is neatly verified. Therefore, our analysis for a fair BRAM scheme will be expected to be helpful to design and evaluate a MAC protocol in the wireless LAN system.

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