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Conflict Resolution Algorithm for Local Computer Networks

Jong Soo Kim
Dept. of Electrical and Electronic Engineering
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〈Abstract〉

In this paper, conflict resolution protocols in Carrier Sense Multiple Access Networks with Collision Detection (CSMA-CD) are considered.

Non-binary search schemes are developed from the binary scheme to resolve the window access.

Two protocols, one nonadaptive and the other adaptive protocols are described based on the binary search method.

To evaluate the manimum throughput easily, an analytical method is presented.

컴퓨터 네트워크의 중복된 데이타해석 알고리즘

김 종 수
전 기 및 전 자 공 학 과
(1983. 4. 30 접수)

〈요 약〉

동시에 여러 사용자가 단일 채널을 사용하는 컴퓨터 네트워크에서, 채널까지 도달되는 정보의 지연시간으로, 정보들이 중첩 될 수가 있다.

따라서 데이타를 송신하기 위해 채널의 상태를 검출하는 window 시간에 n개의 데이타가 도달되는 경우 이를 해결하는 알고리즘을 제시하고 해석하였다.

첫째, window를 2개로 나누어 해석하고 이를 확장하여 f개로 분할한 경우에 효율을 구하였다.

둘째, adaptive인 경우, 즉 충돌된 정보의 수를 정확히 알수 있다는 가정하에 처음 방법을 도입 해석하였다.

이 결과 종래의 방법보다 향상된 효율을 얻었으나 adaptive의 경우 non-adaptive 방식보다 상대적으로 큰 효율을 얻을 수 없음을 확인하였다.

I. Introduction

Computing effectiveness have been increased by providing both users and systems with access to other systems through a circuit connecting user to system, or system to system.

In order to connect the computers, there has been a need to multiplex transmission facilities.

Some of the earliest multiplexing techniques were frequency division and time division multiplexing.

However, old multiplexing techniques are not adequate because of its bursty nature.

Fixed subchannel allocation schemes have low utilization to meet peak transmission rates.

Just as in any field, the development of local computer network is subject to some constraints; simplicity, flexibility and reliability.

We consider the radio channel as a wide band channel.

This suggests another approach for using the channel; namely, the Carrier Sense Multiple Access (1), (7).

The earlist and simplest such schemes are ALOHA and CSMA.

The CSMA has been shown to be highly efficient in enviroment with propagation delays which are short compared to the packet transmission time (1).

This CSMA-CD reduces the level of interference caused by overlapping packets in the random multiaccess channel by allowing devices to sense carrier due to other users' transmission, and inhibit transmission when the channel is in use.

An important problem in the development of a local computer network (LCN) is the design of an efficient control structure governing access to the bus (coaxial cable or channel). (8)

Therefore, in this paper we consider a carrier sensing enviroment as found in an LCN and develop efficient conflict resolution algorithms for accessing the networks. (4—6)

In Section Ⅲ. we analyze the nonadaptive protocal.

Based on the nonadaptive protocal in section Ⅲ, adaptive protocal is considered in Section Ⅳ (4).

In a slotted system, users can begin transmitting a message only at the start of a slot.

Ⅱ. Preliminaries

Based on the information of the channel state, various action can be taken by the user.

Ethernet is a local communication network which uses CSMA on a tapped coaxial cable to which all the communicating devices are connected. (2)

The use of a single coaxial cable naturally achieves broadcast communication.

Ethernet is a variation of CSMA which we refer to as Carrier Sense Multiple Access with Collision Detection (CSMA-CD)

Due to the finite end to end propagation delay, it is possible to sense the channel state idle, even though it is not.

CSMA-CD has been analyzed and its performance derived. (9)

Once a collision occurs, Ethernet can abort the transmission because it can still sense the presence of other carriers after transmitting.

This is a unique feature of Ethernet.

In developing the conflict resolution protocol, We make the following assumptions.

1) The user population is very large and effectively infinite.
2) Message arrivals are governed by Poisson process with arrival rate λ
3) If only one message is transmitted, it is received without error, whereas if two or more messages conflict, no information is received.
4) A user can sense the channel and determine which of the following occurs:
   a) No transmission (idle period),
   b) A single transmission (success), or
   c) Two or more message (busy or unsuccessful).
5) The end to end propogation delay is α
6) In the case of adaptive protocol, users know the number of message involved in a collision.

Ⅲ. Non-adaptive Protocols

Non-adaptive protocols do not know the number of message involved in a collision. Hence, it need not have the stack.

In developing the non-adaptive conflict resolution protocols, we consider two kinds of protocols; those are Ethernet and simple CSMA.

Simple CSMA can not abort transmission after a collision.

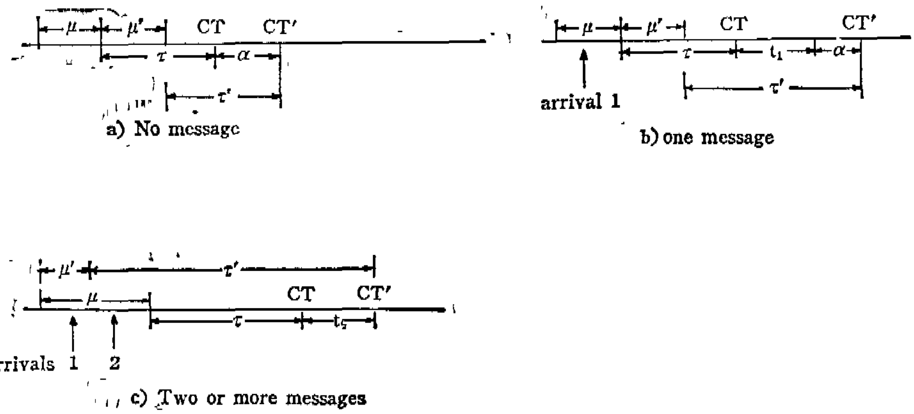


Fig. 1. Events on the time axis

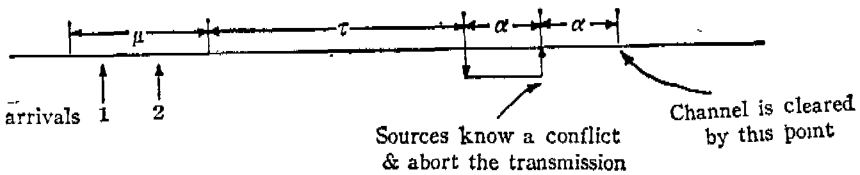


Fig. 2. A collision on the Ethernet

1. Binary Algorithm.

Each terminal satisfies the assumptions specified in previous section and keeps track of two common parameters, μ and τ.

μ is a window in the past which each user examines to see if there is any messages to transmit. τ is the length of time preceding the present time, at which each terminal examines the window. μ and τ are parameters that vary in time at the beginning of each algorithm.

User transmit messages which arrived during the window and which had not been transmitted previously; the feature of first come first service. These actions are described in Fig. 1 and CT refers to current time.

The length of time t_1 is 1 if we use the normalized expression. The t_c transmission period is $1+\alpha$ long in the case of the simple CSMA networks. Fig. 2 is the case of the Ethernet which has the capability of aborting the transmission.

Thus, the idle time when there is no message in window is $t_0 = \alpha$.

If there is a single message, $t_1 = 1+\alpha$.

The time taken when there are two or more messages is

$$t_c \fallingdotseq 1+\alpha \cdots \text{CSMA}$$
$$2\alpha \cdots \text{Ethernet}$$

The algorithm can be found in Fig. 3

(1) If there is a message whose arrival occurred in the interval (CT-τ-μ, CT-τ) and delay is between τ and $\tau+\mu$, transmit it;

Sense the channel;

if a conflict has occurred
$\tau \leftarrow \tau + t_c + \mu/2$
$\mu \leftarrow \mu/2$
go to step 2
else
if channel is idle
$\mu \leftarrow \min.(\mu_0, \tau+\bar{t}_0)$
$\tau \leftarrow \max.(0, \tau+\bar{t}_0-\mu_0)$
else
$\mu \leftarrow \min.(\mu_0, \tau+\bar{t}_1)$
$\tau \leftarrow \max.(0, \tau+\bar{t}_1-\mu_0)$
go to step 1.

(2) If there is a message whose arrival occurred in the interval (CT-τ-μ, CT-τ) and delay is between τ and $\tau+\mu$, transmit it;

Sense the channel;

if a conflict has occurred

$\tau \leftarrow \tau + t_c + \mu/2$

$\mu \leftarrow \mu/2$

go to step 2.

else

if channel is idle

$\mu \leftarrow \mu/2$

$\tau \leftarrow \tau + \bar{t}_0 - \mu/2$

go to step 2.

else

$\tau \leftarrow \tau + \bar{t}_1 - \mu$

go to step 2.

Fig. 3. Non-adaptive binary algorithm.

If there is a collision while users are in state 1, all users transit to state 2 and reduce their windows $\mu=\mu/2$ in an attempt to resolve the collision.

At the end of algorithm, the window is set to $\mu=\mu_0$ whose value is system constant chosen to obtain maximum throughput.

2. Binary Algorithm Analysis

We define some terms used in analysis and present following notation.

1) $P(n)$: Probability that messages arrive during a window of length

$P(n)$ is given by the Poisson distribution

$P(n)=\frac{(\lambda\mu)^n e^{-\lambda\mu}}{n\,!}$

2) t: A random variable which denotes the time required to complete an epoch

3) S_n: A random variable which denotes the fraction of a window resolved during an epoch.

4) $\bar{t}_n$: The expected value of t_n

5) $\bar{S}_n$: The expected value of s_n

6) $\bar{t}_A{}^0$: The average value of t under steady state condition

$$\bar{t}_A{}^0=\sum_{n=0}^{\infty}\bar{t}_n p_{(n)} \qquad (1)$$

7) $\bar{S}_A{}^0$: The average value of s under steady state condition

$$\bar{S}_A{}^0=\mu_0\sum_{n=0}^{\infty}\bar{S}_n p_{(n)} \qquad (2)$$

The system is saturated when $\bar{t}$ is greater than S, namely that the time taken to resolve the conflict is greater than the period being resolved.

Therefore, we can conclude that the maximum throughput is that value of at $t=s$. An epoch of conflict resolution is completed whenever two successful transmission of a single message each followed a conflict.

Due to the property of the Poisson Process, the length of epochs are statistically independent and identically distributed.

If we split the window μ as binary group like Fig. 4, we can calculate the expected value of t:

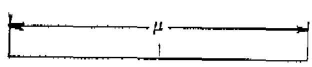
$$\bar{t}_0=\alpha, \quad (n=0) \qquad (3)$$

$$\bar{t}_1=1+\alpha, \quad (n=1) \qquad (4)$$

$$\bar{t}_2=t_c+\frac{\binom{2}{0}}{2^2}[\bar{t}_0+\bar{t}_2-t_c]+\frac{\binom{2}{1}}{2^2}[\bar{t}_1+t_1]+\frac{\binom{2}{2}}{2^2}\bar{t}_2, \quad (n=2) \qquad (5)$$

For $n=3$,

$$\bar{t}_3=t_c+\frac{\binom{3}{0}}{2^3}[\bar{t}_0+\bar{t}_3-t_c]+\frac{\binom{3}{1}}{2^3}[\bar{t}_1+\bar{t}_2]+\frac{\binom{3}{2}}{2^3}\bar{t}_2+\frac{\binom{3}{3}}{2^3}\bar{t}_3, \quad (n=3) \qquad (6)$$



arrivals		Probability
0	3	$\frac{\binom{3}{0}}{2^3}$
1	2	$\frac{\binom{3}{1}}{2^3}$
2	1	$\frac{\binom{3}{2}}{2^3}$
3	0	$\frac{\binom{3}{3}}{2^3}$

Fig. 4. Distribution of 3 arrivals on binary splitted axis

In general for n arrivals,

$$\bar t_n\left[1-\frac{\binom{n}{0}+\binom{n}{n}}{2^n}\right]=\frac{\binom{n}{0}}{2^n}\bar t_c+t_c\left[1-\frac{\binom{n}{0}}{2^n}\right]+\frac{\binom{n}{1}}{2^n}\bar t_{n-1}'+\sum_{i=1}^{n-1}\frac{\binom{n}{i}}{2^n}\bar t_i \qquad (7)$$

Now we can obtain a similar expression to S_n

$\bar S_0=1$

$\bar S_1=1$

In general for n arrivals

$$\bar S_n\left[1-\frac{\binom{n}{0}+\binom{n}{n}}{2^{n+1}}\right]=\frac{\binom{n}{0}}{2^{n+1}}+\frac{\binom{n}{1}}{2^{n+1}}[1+\bar S_n-1]+\sum_{i=2}^{n-1}\frac{\binom{n}{i}}{2^{n+1}}\bar S_i \quad (n\geq 2) \qquad (8)$$

We can calculate $\bar t_n$ and S_n, for $n=0, 1, \cdots k$.

Based on the real enviroments, we can decide the value of k such that

$|\bar t_A(K)-\bar t_A(K+1)|\leq\varepsilon$ and

$|S_A(K)-S_A(K+1)|\leq\varepsilon$,

where ε is allowable tolerance.

The value of λ gives maximum throughput at $\bar t_A(K)=S_A(K)$

In Fig. 5, We can note that the throughput is insensitive to the window size μ_0.

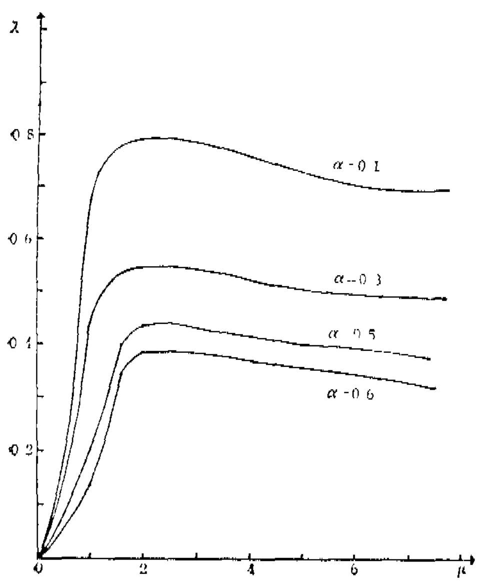


Fig. 5. Window size vs throughput

3. Non-binary Algorithm Analysis

Based on the previous section,

We consider a non-binary approach protocol. We devide the interval into f unit of time and examine to resolve a collision. Binary scheme is a special case of non-binary for $f=2$. Splitting the window in the ratio $1:(f-1)$ as in Fig. 6, we can write the equations for $\bar t_c$, $\bar t_1$ and t_c. In general for n arrivals (seen Fig. 6.), we have

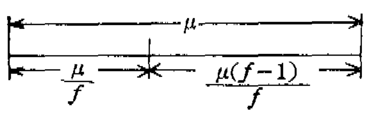
$$\bar t_n=\frac{\binom{n}{0}(f-1)^{n-1}}{f^n}\bar t_0+t_c\left[1-\frac{\binom{n}{0}(f-1)^n}{f^n}\right]+\frac{\binom{n}{0}(f-1)^n}{f^n}\bar t_n+\frac{\binom{n}{1}(f-1)^{n-1}}{f^n}\bar t_{n-1}+\sum_{i=1}^{n}\frac{\binom{n}{i}(f-1)^{n-i}}{f^n}\bar t_i, \quad (n\geq 2) \qquad (9)$$

we can obtain S_n in a similar manner.

$$\bar S_n=\frac{\binom{n}{0}(f-1)^n}{f^n}\left[\frac{1}{f}+\frac{(f-1)\bar S_n}{f}\right]+\frac{\binom{n}{1}(f-1)^{n-1}}{f^n}\left[\frac{1}{f}+\frac{(f-1)}{f}\bar S_{n-1}\right]+\sum_{i=2}^{n}\frac{\binom{n}{i}(f-1)^{n-i}}{f^n}\frac{\bar S_i}{f} \quad (n\geq 2) \qquad (10)$$

We calculated the maximum throughput by solving $\bar t$ - $\bar s$ and fraction f which optimize throughput in Fig. 7.

Binary splitted algorithm can be equally applied to the non-binary algorithm except



arrivals		Probability
0	2	$\frac{\binom{2}{0}(f-1)^2}{f^2}$
1	1	$\frac{\binom{2}{1}(f-1)^1}{f^2}$
2	0	$\frac{\binom{2}{2}(f-1)^0}{f^2}$

Fig. 6. Distribution of 2 arrivals on non-binary splitted axis

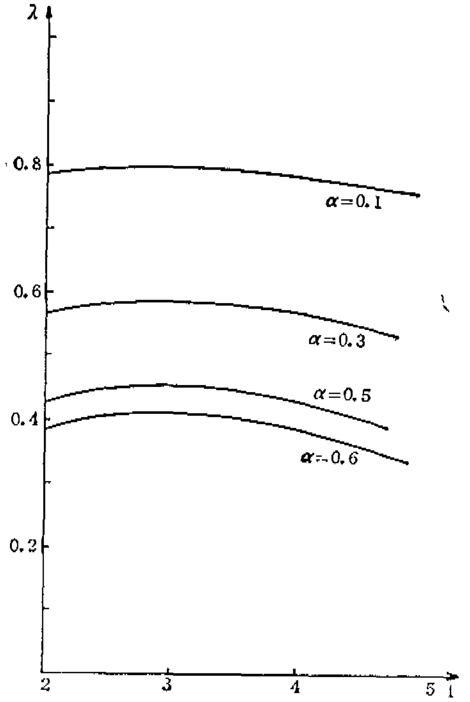


Fig. 7. Splited ratio vs throughput

splitting ratio $\mu/2$ to μ/f and $\frac{f-1}{f}\mu$.

Ⅳ. Adaptive Algorithm

We presume that each user has the additional knowledge of how many messages are involved in a collision. Since we know the number of messages that tried to be transmitted in a collision, an epoch is completed when all messages involved in a collision are resolved.

Thus we redifine an epoch to be completed when all messages are resolved. Due to this adaptive nature, the algorithm becomes more complex; namely, while users are in state 2, further collisions may occur.

Therefore, users require the use of stack to resolve these collisions (10).

1. Algorithm Description

Before we present the algorithm, we define stack operations, push n, r, pull n, r. Here r is the absolute value of the right boundary of the window being examined ($r \leftarrow$CT-τ). n is the number involved in a collision when a collisin occurs. The current time is updated at the end of a transmission. The users move into state 2 if a collision occurs and reside there until all the messages are resolved while the window is reduced to a fraction of the previous window.

(1) If there is a message whose arrival occurred in the interval (CT-τ-μ, CT-τ) and delay is between τ and $\tau+\mu$ transmit it;

Sense the channel;

if n conflicts have occurred.

$r \leftarrow$CT-τ

push n, r

$\tau \leftarrow \tau + t_c + \frac{(f_n - 1]}{f_n}\mu$

$\mu \leftarrow \mu / f_n$

go to step 2.

else

if channel is idle

$\mu \leftarrow$min. $(\mu_0, \tau + \bar{t}_0)$

$\tau \leftarrow$max. $(0, \tau + \bar{t}_0 - \mu_0)$

go to step 1.

else

$\mu \leftarrow$min. $(\mu_0, \tau + \bar{t}_1)$

$\tau \leftarrow$max. $(0, \tau + \bar{t}_1 - \mu_0)$

go to step 1.

(2) If there is a message whose arrival occurred in the intrerval (CT-τ-μ, CT-τ) and delay is between τ and $\tau+\mu$ transmit it;

Sense the channel;

if n conflict hake occurred push n, r

$\tau \leftarrow \tau + t_c + \frac{[f_{n-1}]}{f^n}\mu$,

$\mu \leftarrow \mu / f_n$

go to step 2.

else

if channel is idle

$\tau \leftarrow \tau + \bar{t}_0 - \frac{[f_{n-1}]}{f^n}\mu$

$\mu \leftarrow \frac{[f_{n-1}]}{f^n}\mu$

go to step 2.

else

decrement stack while stack is not empty

pull n, r
if $n=1$.
$r' \leftarrow \mathrm{CT}-(\tau+\bar{t}_1)$
$\mu \leftarrow r-r'$
$\tau \leftarrow \mathrm{CT}-r$
go to step 2.
else if $n>1$
$r \leftarrow \mathrm{CT}-(\tau+\bar{t}_1)$
$\mu \leftarrow \frac{r-r'}{f^n}$
$\tau \leftarrow \mathrm{CT}-r+\frac{(f_{n-1})}{f_n}$
go to step 2.
else
continue
$\mu \leftarrow$ min. (μ_0, $\mathrm{CT}-r$)
$\tau \leftarrow$ max. (0, $\mathrm{CT}-r+\mu_0$)
go to step 1.

Fig.8. Adaptive non-binary algorithm

The users transit to state 1, when the stack is emptied, and a new window of length μ_0 is chosen.

2. Algorithm Analysis

Based on the previous section, we can analyze the adaptive protocol in general splitted window scheme. The length of an epoch is one algorithm step if no transmission or successful transmission occurs.

If a collision occurs, the length of an epoch is lasted until all messages involved in the collision are transmitted.

Using the same notation as in the previous section, we have

$$\bar{t}_0=\alpha$$
$$\bar{t}_1=1+\alpha$$

$$\bar{t}_n\Big[1-\frac{\binom{n}{0}+\binom{n}{n}}{f_n^{\,n}}\Big]=\frac{\binom{n}{0}(f_{n-1})^n}{f_n^{\,n}} +t_c\Big[1-\sum_{i=0}^{n-2}\frac{\binom{n}{i}(f_{n-1})^{n-i}}{f_n^{\,n}}\Big] +\sum_{i=1}^{n-1}\frac{2\binom{n}{i}(f_{n-1})^{n-i}}{f_n^{\,n}}\;\bar{t}_i \quad (n\geq 0) \qquad (11)$$

Since the interval should be resolved, we have

$$\bar{S}_n=1 \qquad \text{for all } n$$

$$\bar{S}=\mu_0\sum_{n=0}^{\infty}{}' \bar{S}_n p_n=\mu_0 \qquad (12)$$

We can solve the equation 11 to obtain optimum value of f

For $n=2$, we have

$$\bar{t}_2=\frac{t_c}{2}\Big[\frac{2f-1}{f-1}\Big]+\frac{t_0}{2}[f-1]+2\bar{t}_1 \qquad (13)$$

In order to minimize the value of $\bar{t}_2$,
We differentiate the equation 13 with the f.
Thus we have

$$-t_c+\bar{t}_0[f^2-2f+1]=c \text{ or}$$

$$f^2-2f+\Big(1+\frac{t_c}{t_c}\Big)=c$$

In case of Ethernet, $t_0=\alpha$, $t_c=2\alpha$.
Therefore $f=1\pm\sqrt{2}$
Now the value of equation 13 at $f=1\pm\sqrt{2}$.
$t_2\min=2+5.414\,\alpha$

If we use the same theory to the binary split scheme, we have $t_2=2+5.5\,\alpha$

From the above analysis, we should consider the computation time of table look up to obtain maximum throughput.

V. Conclusion

In this paper we presented and analyzed the adaptive and nonadaptive conflict resolution protocols according to the effect of the window size μ, window splitting ratio f.

We presumed the adaptive algorithm had the knowledge of the exact number of the messages involved in a collision. By this nature of adaptive algorithm, this scheme showed the throughput slightly better but not simple as the nonadaptive protocol. Non-binary splitting scheme was more efficient than the binary splitting. In case of finite user population, another approch study was required to obtain high performance.

We did not address delay trade-off and variable message length problem which is easily shown. The user synchronization established in slotted or unslotted mode. (10)

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