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Wireless Access Method and Physical Layer

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TITLE: Comments on CSMA

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ABSTRACT

This contribution comments on the peformance aspects of CSMA protocols. Some of the information is based on information found in *Performance Analysis of Local Computer Networks* by Hammond and O'Reilly. Other comments are based on experience with existing commercial products.

CSMA as an access methods works well under light loads, either when the number of users is small or the applications being used generate little traffic. While this may be typical of the "quickly-created-and-disbanded" work group, it is not typical of some of the loads generated by some desktop applications that run on fixed or portable computers. Our recommendation is that the 802.11 defer any decision on access technique until other methods have been explored enough to provide performance contrasts.

1. INTRODUCTION

Recently there have been contributions [1,2,3] to the 802.11 committee suggesting that CSMA be used as an access technique. These contributions have tended to emphasize the desirable aspects of using CSMA, such as simplicity, well-known art, etc., and de-emphasize the negative. In addition, most of the "facts" thus far have been presented qualitatively rather than quantitatively. The intent of this contribution is to present some quantitative material about CSMA and point out some important points based on prior experiences with commercial products.

2. PERFORMANCE -- THROUGHPUT & DELAY

Figure 9.21 [4] shows throughput vs. offered load for a set of typical radio access methods. These results were generated by computer simualtion and represent upper bounds on throughput. There are instances where the throughput of CSMA approaches 80%. This occurs when the offered load, i.e., new packets plus retransmissions due to collisions, is relatively high.

Figure 9.23 [4] shows a comparison of delay vs. throughput. This graph reflects the results of computer simulation using fairly elaborate mechanisms for determining the arrival process for new packets and for determining the retransmission times (i.e., backoff interval). The trend is rather apparent: *as the throughput for a particular CSMA technique increases toward maximum for that method, the delay increases exponentially toward infinity.* The simulation model was created to generate the best-case delay numbers, i.e., real systems exhibit worse delay.

3. THE IMPORTANCE OF THE PARAMETER A

The parameter *a* is the normalized propagation delay and can be defined by the following equation:

$a = t_d / t_p$; where t_d is the propagation delay and t_p is the packet length in time.

Figure 9.22 [4] provides an indication of the maximum throughput vs. *a* for different CSMA protocols. A suggested candidate access method for 802.11 is nonpersistent CSMA [3], so let's probe a bit further along those lines.

The throughput curves of Figure 9.21 were derived for $a = 0.01$. Figure 9.18 [4] shows the effect of varying *a* on the throughput of nonpersistent CSMA. The graph points out two things: (1) high throughput is achievable with low values of *a*, and (2) as *a* increases, the theoretical throughput decreases logarithmically. The question that begs answering is how to design a system to provide a certain value of *a*.

The propagation delay consists of the time for a radio signal to propagate between two physically distinct points, the time to sense the channel, and the time to switch the radio from receive to transmit and begin transmitting. The packet length in units of time is just the packet size in bits divided by the bit rate of the channel. Table 1 and its associated graph in Figure 1 provide values of t_d for differing values of *a* and t_d. The packet length is chosen as 4000 bits since it is evenly divisible by 1000 and it is the number closest to the 512-byte packets specified in the 802.11 PAR.

The carrier sense and radio turnaround circuitry account for most of the delay in t_d. Radio turnaround times of less than 10 μsec are commercially unacceptable with today's technology, so a system that achieves 80% throughput at greater than 4 Mbps is largely a fantasy. Radio turnaround times of less than 100 μsec are possible, but costly. The additional cost for short turnarounds may be palatable in systems with higher bit rates (> 4 Mbps), but would probably not be tolerable in systems with lower bit rates. This leads to the belief that systems with *a* >= 0.1 would likely be the outcome of the 802.11 work.

Based on this assumption, Figure 9.18 shows that the throughput will be less than 50% and only for fairly light loads. In addition, there are three other factors that may contribute to a further reduction in throughput: (1) the use of forward error correction (FEC) techniques, (2) the use of a retransmission scheme, and (3) the choice of backoff algorithm. (1) and (2) are optional in a CSMA system, but (3) is not.

The 802.11 PAR specifies a 10^{-8} delivered bit error rate to the LLC layer. At the very least, a retransmission scheme is needed in order to compensate for the difference between the error rate in the PAR and the probable radio channel bit error rate of 10^{-5}. Given the 512-byte packet length specified in the 802.11 PAR, successful transmission of a packet will occur approximately 96% of the time. This means that the effective throughput of the system may be reduced by 4% on the average because of bit errors.

The figures from [4] presented in this paper have shown results where the backoff algorithm is optimal. This is rarely, if ever, achieved in practice. Today's backoff algorithms are only crude approximations of the optimal case resulting in further reduction of throughput.

Taking all these factors (achievable turnaround times, error compensation, and non-optimal backoff strategies) into consideration, the likely region of operation for a CSMA system as defined by 802.11 would have a throughput less than 30% at an offered load of less than 1. The cost of the turnaround will probably limit the channel bit rate to 4 Mbps or less, yielding throughputs of 1.2 Mbps or less. This is unsatisfactory for most office applications of tomorrow.

4. CONCLUSIONS

CSMA has been offered as a candidate for access method. The above discussion has shown that it works well when the offered load is light, via either a limited number of users or low-traffic applications. While these characteristics may be the case in quickly created and disbanded workgroups, they are not the case in the typical office environment. Today's desktop applications, whether accomplished by using a fixed or portable terminal, often generate higher offered loads than can be supported by simple CSMA techniques. The committee would do well to consider other access methods before making a decision since migrating from a CSMA-based standard to something that is more efficient will likely be impossible.

5. REFERENCES

[1] *Petition for Rulemaking: Data-PCS*, submitted to the FCC by Apple Computer, Inc., January 28, 1991

[2] IEEE P802.11/91-25, *A Modest Proposal for a Asynchronous, Data Intensive, Wireless Local Area Network*

[3] IEEE P802.11/91-HH17, *802.11 MAC Layer — Some Proposed Characteristics*

[4] *Performance Analysis of Local Computer Networks*, J.L. Hammond and P.J.P. O'Reilly, Section 9.4: Protocols that Use Carrier Sensing, pp. 304-320

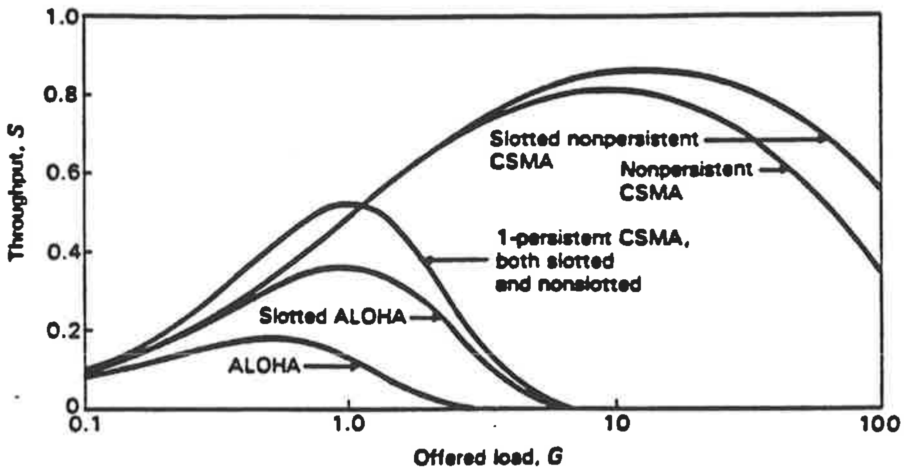

Figure 9.21 **Comparison of the *S* versus *G* Characteristics of ALOHA, Slotted ALOHA, and Nonpersistent, Slotted Nonpersistent, and 1-persistent CSMA, both Slotted and Nonslotted, all for *a* = 0.01**

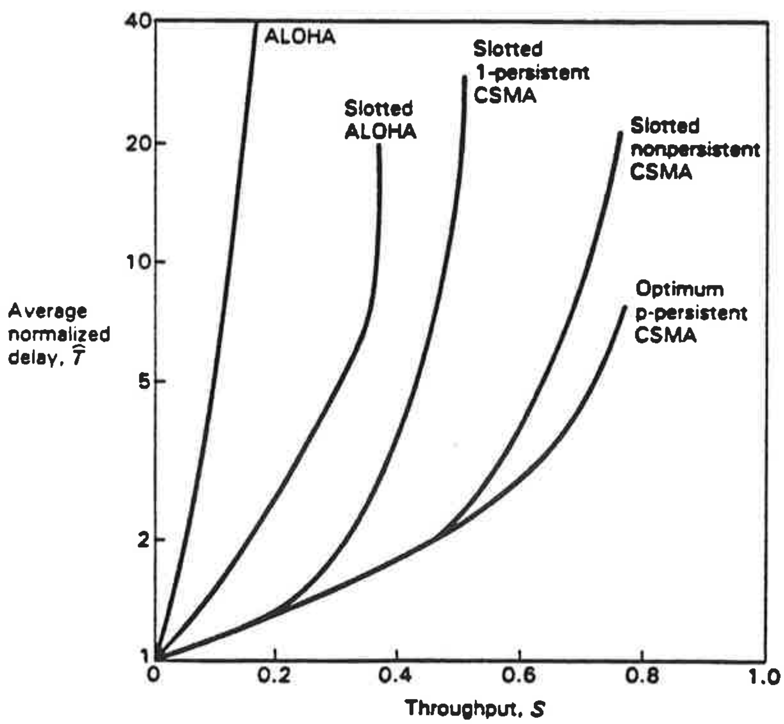

Figure 9.23 **Average Normalized Delay versus Throughput for Different Random Access Protocols (From simulation studies by Kleinrock and Tobagi [5])**

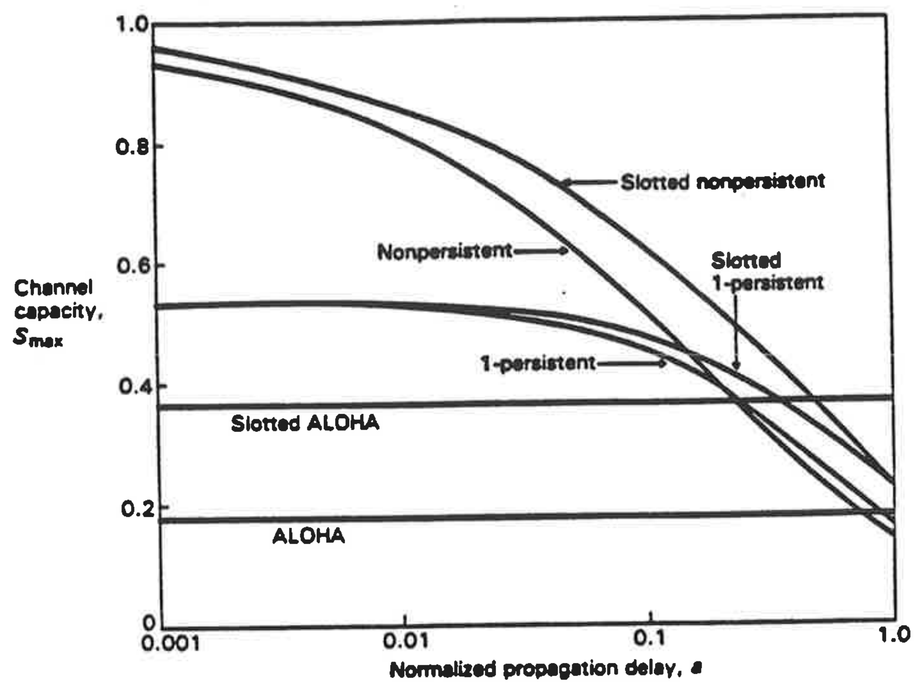

Figure 9.22 Maximum Throughput or Capacity versus Normalized Propagation Delay for Different CSMA Protocols

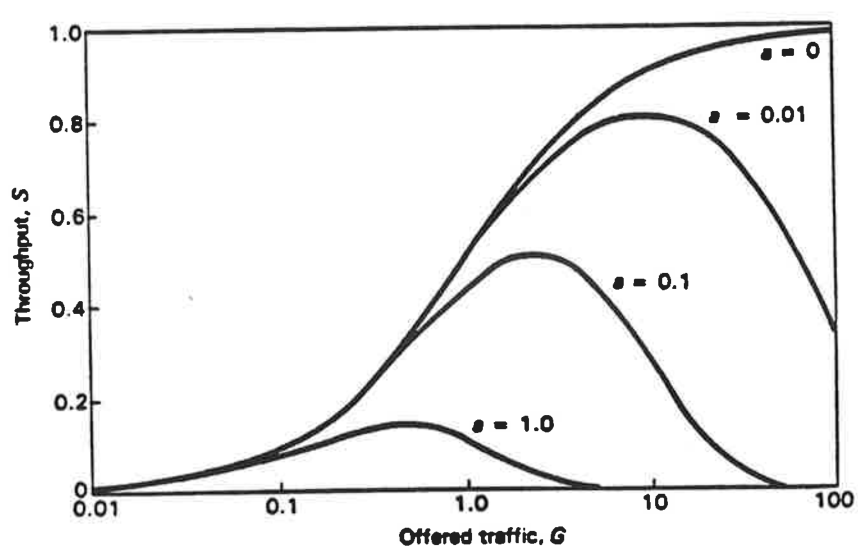

Figure 9.18 Throughput, S, versus Offered Load, G, for Nonpersistent CSMA

bit rate (in Mbps)	t_p (in µsec)	t_d (in µsec) a = .1	a = .01
1	4000	400	40
2	2000	200	20
4	1000	100	10
10	400	40	4
16	250	25	2.5

Table 1. Values of t_d for packet length of 4000 bits

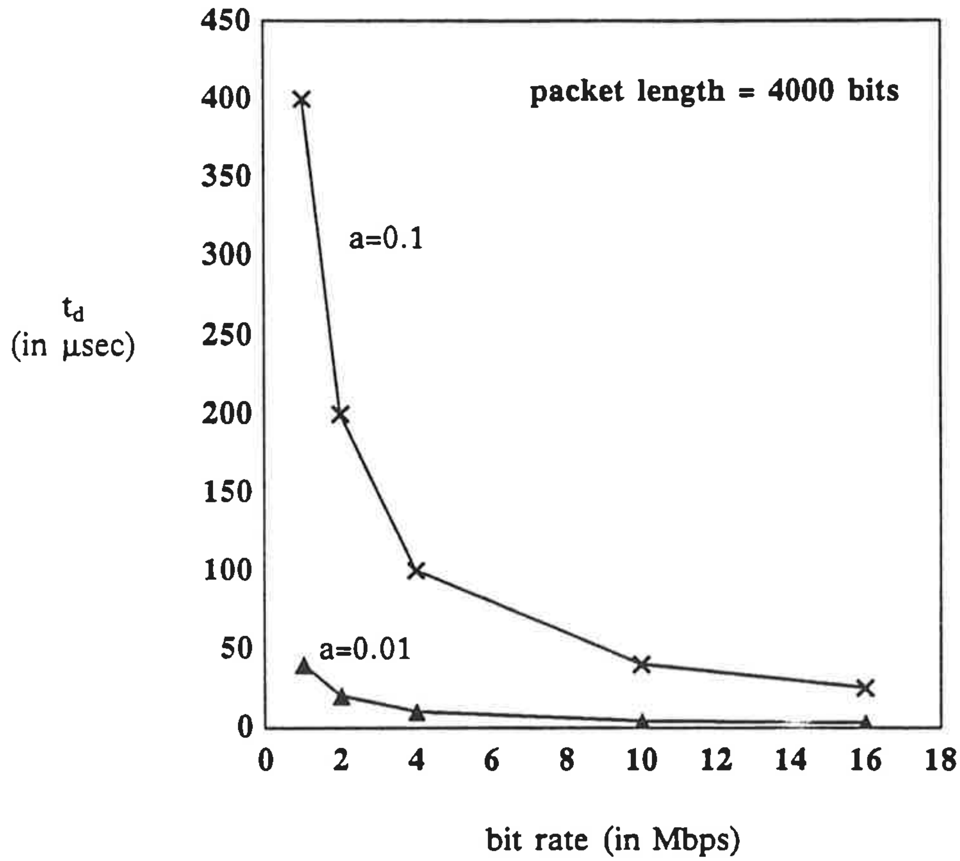

Figure 1. Propagation Delay vs. Bit Rate