Multiple Access Methods: Delay and Throughput

By JONATHON Y.C. CHEAH

The push to adopt a suitable overlaying access protocol for the Indoor Wireless LAN has seen an increase in effort to examine other similar access protocols in use in the cable LAN networks. The analyses presented so far ignore the detail intricacies of communications in a radio medium to a large extent. In addition, these analyses borrow tailor-made results available in the open literature that are mainly pertaining to benign and easily isolated media such as a cable based environment, or a tame Gaussian noise channel such as a satellite link. It is still early to predict whether there is a possibility to transplant one of these existing methods directly into the Indoor LAN environment, however, it is necessary to examine the properties of these access methods in relation to meeting the promulgated IEEE802.11 requirement specifications. In this note, the distinctive parameters such as access delay and throughput are highlighted.

1. Introduction:

Scanning the recent progress in the IEEE802.11 standard committee proceedings, there is an obvious interest in the application of CSMA access method with its derivatives of /CA ,/CD in the Indoor Wireless LAN environment. The presentation of these methods demonstrates its superiority in performance by means of the well known Traffic vs Throughput curves. The aim of this note is to examine the fundamental premises behind these results and their relevance to the communications channel characteristics observed in the Indoor Wireless LAN environment. Three classes of the access methods will be reviewed. They are Slotted ALOHA, CSMA, and SALOHADAMA . The aim of this note has the hope to solicit interests from expert access method analysts to participate in this endeavor.

2. Slotted ALOHA:

The channel throughput is not the sole parameter that is an important indicator of the suitability of the access method. The mean packet delay is equally important. It is obvious that there is an optimal trade-off between the two. In the ALOHA scheme, the delay incurred is a consequence of the collision occurrence. Indeed, the wait between a collision and a receipt of a request for retransmissions, can be considerable without some delay minimizing protocol overlays.

The throughput and the access delay analyses are briefly outlined below, the intention to present these well known analyses is to empathize the particular transmission nature of the access method. Thus it can be used to compare and contrast other access methods that have been presented in the IEEE802.11 group in the past. For the Slotted ALOHA case, a simplistic but detail derivation is provided so that the inherent assumptions are clear, and the tedium of listing the obvious can be avoided.

Let ,

n= number of users
g_i=the probability of $user_i$ sending a packet
s_i=the probability of $packet_i$ sent is successful.,

At the beginning of a time slot, the probability function of s_i must be when no other users except $user_i$ transmits.
Thus,

$$s_i=\frac{g_i}{(1-g_i)}\prod_{i=1}^{n}(1-g_i)$$

Given the fairness criterion for all users, then if the eventual throughput is S and all traffic is G, it can be seen that,

$$s_i=\frac{S}{n}$$

$$g_i=\frac{G}{n}$$

Thus,

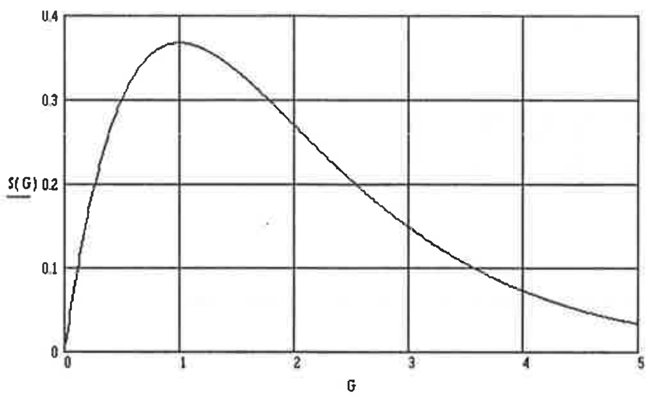
$$\frac{S}{n}=\frac{G}{n}\left(\frac{1}{(1-\frac{G}{n})}\right)\prod_{i=1}^{n}\left(1-\frac{G}{n}\right)$$

The well known Slotted ALOHA formula then follows,

$$S=Ge^{-G}$$

Figure 1 shows a plot of this throughput equation. As it is apparent that the curve shows the well known Slotted ALOHA response. It is important in this exercise to review the above derivations for the implicit conditions under which the derivation is valid.

Figure 1. The throughput plot of S versus G



It is necessary to state the transmission delay performance. The delay performance is important as it can be traded for throughput if the systems can tolerate it.

Let,

m=the number of users who will transmit in a particular slot.
W_i=the delay between the arrival of i^{th} packet and its eventual successful transmission
R_i=the residual time left in the present slot.
t_j= the duration of the successful transmission of j^{th} packets during the meantime.
y_i=the intermediate time between successful transmissions.
λ_i=total fractions of slots with successful transmission.

Then,

$$W_i=R_i+\sum_{j=1}^{m} t_j+y_i$$

and here the expectation solutions are stated without proofs,

$$E[R_i]=\frac{1}{2}$$

$$E\left(\sum_{j=1}^{m} t_j\right)=\lambda eW$$

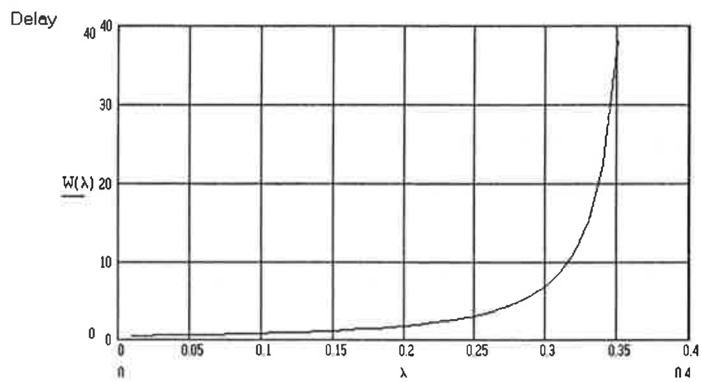
$$E[y_i]=\frac{(e-1)}{\lambda}\left[\lambda-\left[\frac{(1-\lambda e)(e^{\lambda}-1)}{(1-(e-1)(e^{\lambda}-1))}\right]\right]$$

Then, the delay W can be written as.

$$W=\frac{1}{2}\left[\frac{(\lambda e^{\lambda+1}+\lambda e-\lambda e^{\lambda}-2e^{\lambda+1}+2e+2e^{\lambda}-2)}{(\lambda(e^{\lambda+1}-e-e^{\lambda})(\lambda e-1))}\right]$$

Figure 2 shows this relationship. The delay's equation does not hold after the virtual asymptote at about 0.35 .

Figure 2. The plot of delay W versus λ



3. Carrier Sense Multiple Access :

The analytical results for CSMA that are commonly known are related to that given by Kleinrock and Tobagi [1975]. In this analysis, a number of assumptions are implicit. They are:

a) There are no errors, except those caused by collisions.
b) There is no capture effect.
c) Sensing the state of the channel can be done instantaneously.
d) Each station can sense the transmissions of all other stations.
e) The propagation delay is small compared to the packet transmission time and identical for all stations.
f) All packets are of the same length.

g) A station may not transmit and receive at the same time.
h) Packet generation attempts form a Poisson process.
i) The random delay after a collision is uniformly distributed and large compared to the packet transmission time.

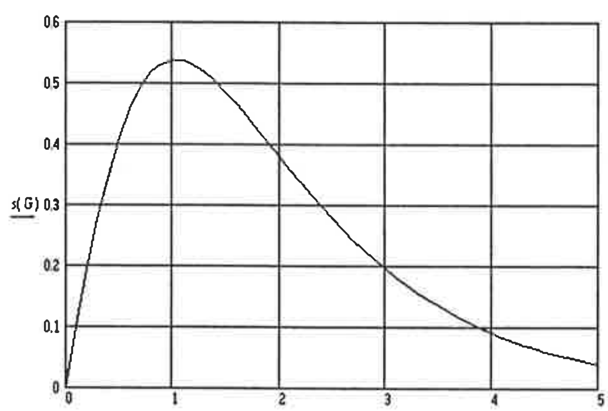
The abundance of theoretical and practical endeavors reported in regards to this access method in turn fueled its popularity. This is because the common IEEE802.3 LAN is using one of its derivatives by providing collision detection. However, it should be clear that the above listed assumptions are by and large true in the cable environment which it works so well. One has perhaps experienced an unterminated node in IEEE802.3 LAN, and the outcomes are well known. In the radio environment, one can image a totally unterminated cable in a distributive sense. It is straightforward though tedious to eliminate the above assumptions one at the time to visualize the eventual performance, and form an opinion if CSMA derivatives are suitable in its rudimentary form for indoor radio environments

With the above assumptions, the governing throughput equation for CSMA can be shown to be:

$$S=\left(\frac{1}{G+e^{-G}}\right)\left(Ge^{-G}\left(1+pG\sum_{k=0}^{\infty}\left(\frac{((1-p)G)^k}{(1-(1-p)^{k+1})k!}\right)\right)\right)$$

For p=1 , that is 1 persistent CSMA, a plot is shown in Figure 3. This is an important equation because we should use it to compare with other access method, bearing in mind of all the assumptions it needs and that the throughput is impaired by any violations to the assumptions.

Figure 3: CSMA throughput with persistent = 1



Slotted ALOHA access with Demand Assigned Multiple Access:

(Pseudo-infra-structure-less access method)

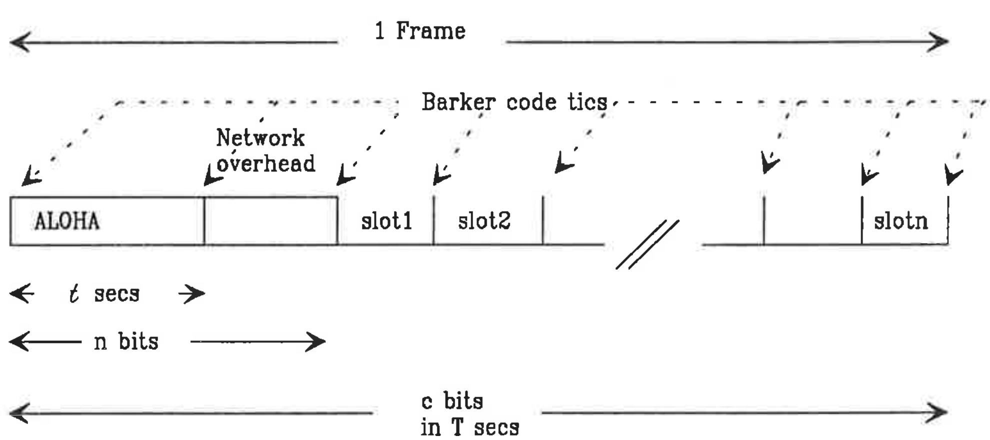
This access method was proposed sometime ago to the IEEE802.11 standard working group. The intent was to allow a flexible access system that is configurable. This is taking into account that the radio propagation medium is neither a temporal nor a spatial invariant system. However, it mimics to a limited extent the slotted structure for contention access, and a guaranteed contentionless transmission channel assigned as required. It can be shown that such a system has imbedded in it a controllable throughput and access delay structure to suit individual LAN needs.

The conceptual origin for this access configuration lies in the exploitation of the limit of minimum persistent slotted CSMA performance. It is well known that this is the only condition where near perfect throughput efficiency is possible. However, one pays the penalty of near infinite access delay. Like-wise in the SALOHADAMA access method, the delay problem is extenuated by a slotted Aloha time slot for the demand requests. The aim is to reduce access overhead and maintain the throughput efficiency.

This is necessary to point out that the original SALOHADAMA proposal assumed a larger coverage area where peer to peer propagation within the communications distance of the two stations is not possible, and thus a repeating attribute is inherent. Using CSMA case as a reference, which assumes that no propagation problems exist among peers as being a mandatory property then by the same inference, the SALOHADAMA repeating function would not be necessary.

On the subject of the propagation, which may be best to solicit a full expert thesis, it remains a great unknown how CSMA can sustain its proclaimed performance when the population of independent LAN operators are in close proximity. This is obvious that the neighbor's traffic will be accumulative to the throughput equation unless code-division is used. On other hand, if code division plays a part to this solution, then effective code such as Barker Code cannot be used for preamble purposes. Less effective code would have to be used, and thus the spurious cross-correlation problem has to be resolved. This has a direct probabilistic impairment to throughput parameter. Another subsequent problem that cascaded from the uncertain correlation properties will be synchronization delay to detect the presence of carrier.

Figure 4 shows a simplified access temporal flow structure for analysis purposes of the SALOHADAMA access method.



In Figure 4, all the time tics are raw Barker code of a suitable length (For example 13). The time tic structure is common to all systems. A particular LAN will insert all the necessary supervisory messages in a code division manner. The time tics serve two major purposes:

a) To maintain maximum throughput efficiency possible.
b) To render the system synchronous in nature.

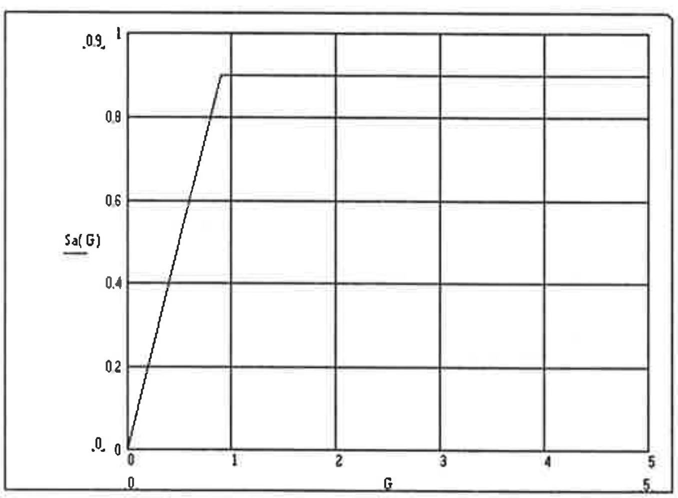
First, we can examine the throughput. Here, throughput is defined as the successful transfer the number of bits S versus the available traffic G.

Assuming the ideal case, where all the CSMA assumptions applied, and the demand assignment has a perfect slot assignment placement algorithm then it can be seen that the demand assigned access can be written as,

S=min(G,(c-n))

Where c is the available number of bits to fill all the slots and n the control overhead.

Figure 5: SALOHADAMA throughput analysis with 0.9 traffic slot capacity.



It can be seen in the later section that though this is an intuitive inference, however it conforms to the prediction of well established analysis. At this point, the task that remains is to estimate the expected access delay. This can also be done by borrowing the established analysis on Slotted Aloha with fixed time overhead. A heuristic estimate is that the slotted ALOHA delay relationship shown above has in it a fixed delay approximately equal to the frame time T. A frame time is defined as the length of time from one ALOHA slot to the next. Thus, if the ALOHA slot length is τ secs, then the total access delay W is:

$$W=\frac{1}{2}\left\{\frac{(\lambda e^{\lambda+1}+\lambda e-\lambda e^{\lambda}-2e^{\lambda+1}+2e+2e^{\lambda}-2)}{(\lambda(e^{\lambda+1}-e-e^{\lambda})(\lambda e-1))}\right\}+(T-\tau)$$

Here, the access delay can be configured by adjusting τ. The trade-off with throughput can also be easily discerned by examining the throughput equation.

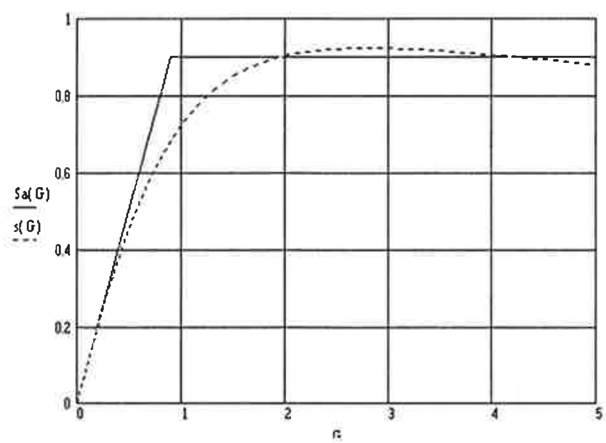
Let the bit rate be R, then,

S=min(G,(c-Rt))

Obviously, if τ approaches T, the demand assigned throughput = 0, and if the input requests carry any useful data at all then the access method degenerates to a purely Slotted ALOHA in nature.

Another intuitive conclusion is that if a minimum persistent CSMA access method is used, then at some point its throughput will be similar to SALOHADAMA, since this is basically where SALOHADAMA originated in part. Figure 6 shows this interesting comparison. A 0.9 channel SALOHADAMA is plotted against a CSMA with persistent= 0.06.

Figure 6: Comparison of CSMA with persistent=0.06 with SALOHADAMA of a 0.9 channel.



5. Discussions

There is no clear interest in the adaptation of the basic slotted ALOHA access method within the IEEE802.11 Working group, and thus only CSMA and SALOHADAMA need be compared here. It is easier to list some of the real time environment constraints:

a) Transmission errors caused by the channel is inevitable.
b) Capture exists and may not be correlated strongly with distance.
c) Sensing of the channel cannot be done instantaneously. Minimum delay is the time required for successful synchronization and decoding and false detection control.
d) The propagation delay is small.
e) Each station can only sense a sub-group of the wanted stations, and it can also sense other unwanted stations.
f) All packets can be made the same length.
g) Half duplex is acceptable.
h) Packet generation is not a Poison process.
i) Delay after collision is controllable.
j) The channel may not be reciprocal in all directions.

Item (j) is not normally associated with communications environments commonly understood. In a fading environment, it is no unusual that a station A 's transmission to a station B can be heard by another station C, but station C may not necessary hear station B's transmission to station A. In CSMA this phenomenon is fatal. In SALOHADAMA, if station A bears the heart beats, and if station C or B cannot hear station A, then they are simply is out of communication. The question is then would this access method has smaller or larger coverage area. The answer is uncertain, however what is certain is that SALOHAMA would support heavier user density within a faded area. Again, the configurable nature of SALOHAMA can be configured for a repeating mode, which would reduce the throughput by 50% but then the coverage area will be greatly extended. More importantly, this change of configuration can be done without co-ordination with the nodes, and is tranparent to the nodes. The DAMA portion of the access control has this very unique advantage.

Table 1: This comparison is done in a very arbitrarily manner. For accurate insight in a qualitative manner, each item can assume a suitable probability density function whereby the throughput and the delay equation can be re-computed. This is a very interesting exercise for the readers copious leisure time.

Assumptions	CSMA	SALOHADAMA
a) Transmission error	affects throughput severely	affects throughput minimally
b) Capture effects	affects throughput	affects access delay
c) Sense delay	affects throughput and access delay severely	no effect
d) prop delay	dont care	dont care
e) sub-group sense	affects throughput severely	helps in coverage
f) equal packet length	affects throughput severely	affects throughput minimally
g) half duplex	necessary	necessary
h) Poisson process	needed	dont care
i) Delay after collision	needed	needed
j) Reciprocity	affects throughput totally.	affects throughput minimally

For SALOHADAMA to be as flexible as presented and allows pseudo-infrastructure-less peer to peer communications, how much more complicated will the design be? Figure 6 shows a simple conceptual block diagram of this design. It is easy to discover that the additional hardware overhead is very minimal.

Figure 6: The block diagram for decoding the Barker code time tics and frame synchronization while maintaining code division communications channels.