Analysis of Slotted Nonpersistent CDMA

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***Abstract*—Radio channel has been a precious resource to manage since the take off of the mobile communications in late 70s. Several techniques have proposed over the years trying maximize utilization while allowing a number of users to share the channel. Among those techniques, CDMA has arisen as one of the most popular ones, and several approaches have been taken following the concept of carrier sensing before transmission. In this paper we analyze one of the CDMA variants called nonpersistent slotted CDMA, where the popular nonpersisten CDMA is modified dividing the time axis into time slots.**

I. Introduction

The critical shortage of the RF spectrum raised a number of new problems in the first part of the 70s decade. For the first time in history of telecommunications, broadcast radio transmissions where beginning to be used by the general public attracted for the many advantages of wireless access to networks. However, immature research on wireless shared medium techniques made the existing protocols [2] inefficient and virtually unfeasible at short-mid term.

Was at that moment that researches began to imagine solutions that could deal with many users trying to access the same channel at the same time. First systems to focus on wireless communications [2] appeared to be too simple and too wasteful; pure ALOHA, for example, barely utilizes a 20 percent of the maximum throughput in optimum conditions, while its slotted version, although able to achieve double throughput due to the slotting characteristics, still appear too wasteful and unable to achieve better performances.

It was around mid 70s when a natural evolution of access to the shared medium was published [1]. If one of the important limitations of the previous protocols was that they tried to transmit whenever the sender was ready (without caring if the medium was busy or not), why not sensing the channel for other user's transmissions before attempting to transmit? CSMA (Carrier Sense Multiple Access) was born as an alternate approach in an attempt for maximizing the traditionally wasted throughput in shared channel transmissions, characterized for a number of users attempting to use the channel and eventually causing collisions that need to be handled.

Several protocols following the concept of channel sensing where developed depending on the actions taken by the terminals when the channel is sensed busy. First the nonpersistent CSMA, where the sender reschedules the packet transmission when the channel is sensed busy. Second, the p-persistent, where the sender keeps on sensing the channel until it becomes idle, transmitting then with a probability p.

As a particular version of the nonpersistent CSMA, the slotted nonpersisten CSMA was also developed. In this paper we will describe the slotted version of the nonpersisten CSMA and will show its throughput analysis.

The rest of the paper is organized as follows. Section II describes the model used, while section III develops the throughput analysis. Section IV provides an evaluation of the results of the analysis, and finally section V concludes de paper.

II. Description and Model

As explained before, in the nonpersistent versions of CSMA, the sending terminal senses the channel before transmitting. If the channel is sensed busy, the sender behaves as if the packet had collided and reschedules its transmission after a (random) period of time. In general, the only vulnerable period in CSMA for a collision to occur is the propagation delay, as otherwise the channel will be sensed busy and a potentially colliding transmission will never happen. In the slotted version of the nonpersistent CSMA, the time axis is partitioned in slots of *transmission time*. Ready to transmit terminals will wait for the beginning of the next slot to transmit, and then they will sense the channel and will transmit depending on the nonpersistent CSMA algorithm stated above. This means that any transmission starting at the beginning of a slot can be sensed by any other listening terminal by the end of that slot.

The model used for the nonpersistent CSMA is the following (note that this model and the one for p-persistent CSMA are the same). First, we assume that traffic coming from a infinite number of competing users is an independent Poisson source with a mean packet generation rate of λ packets/s. Every packet is of constant length T seconds, and so S = λ T is defined as the input rate normalized with respect to T, or throughput. Note that the maximum value of S is 1, reflecting a situation with no collision or idle period between packet transmissions.

It is assumed that the users always receives an acknowledgement after a the packet has been sent successfully (i.e. no channel interference for ack packets). As a result, if the sender doesn't receive an acknowledgement after a certain time-out, its assumed that the packet has collided and so its rescheduled for later transmission. The random time taken by a terminal for retransmission has mean $\overline{X}$, which can be normalized to

$$\delta = \frac{\overline{X}}{T}$$

The traffic *offered* to the channel by the users (new packets plus rescheduled ones) is denoted by G where G $\geq$ S. We also define τ as the propagation delay, which can be aslo normalized to

$$a = \frac{\tau}{T}$$

and T $_a$ as the ack packet transmission time, normalized to

$$\alpha = \frac{T_a}{T}$$

Finally we define to assumptions. First, the average retransmission time $\overline{X}$ is large compared to T. Second, the interarrival times of the point process defined by the start times of all packets plus retransmission are independent and exponentially distributed.

Table I shows a summary of all definitions of the model.

Notation	**Definition**
λ	Packet generation rate
T	Packet length
S	Throughput
$\overline{X}$	Random retransmission time
δ	Normalized $\overline{X}$ to T
G	Traffic offered
τ	Propagation delay
a	Normalized τ to T
T $_a$	Ack packet transmission time
α	Normalized T $_a$ to T

TABLE I

Model Definitions

III. Throughput Analysis

As exposed before, a collision will only occur if a transmitter sense the channel during the propagation delay of another user's packet transmission. Let t be the time a sender starts to transmit a packet when the channel is actually idle. According to the definitions given (see I), if the general CSMA any other terminal attempts to transmit between t and t+a, a collision will occur. In the slotted version, as the terminals must wait until the begining of the next slot to transmit, a collision will occur when 2 or more terminal attempt to transmit during the same slot. Equally, the *vulnerable* period is still τ, that is the slot time. The period between the start of a tranmission and the end of the propagation delay of that transmission we call it *transmission period* (TP) or *busy period* (B), which will be the number of transmission slots plust the propagation time (T+τ or, normalizing T=1, 1+a) The *idle period* (I) will be thus the time between two consecutive TPs, and B+I will be a *cycle* . If we note $\overline{B}$ and $\overline{I}$ as the

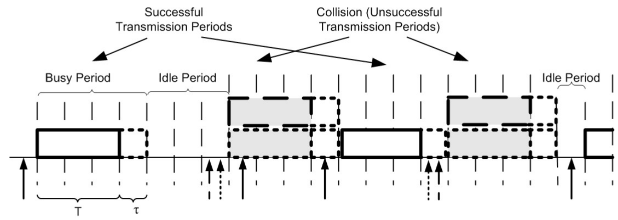

Fig. 1. Slotted Nonpersistent CSMA timings and Busy and Idle periods. Arrows represent terminal attempting to transmit.

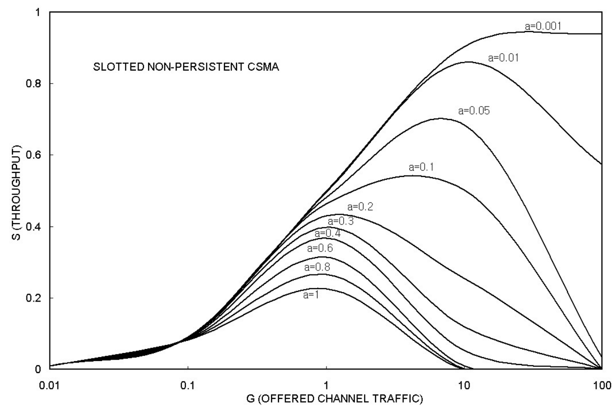

Fig. 2. Throughput in slotted nonpersistent CSMA

expected values of B and I respectively, and U the time during a cycle that the channel is used without conflicts, we can define S as the average channel utilization period by

$$S = \frac{\overline{U}}{\overline{B} + \overline{I}} \tag{1}$$

Returning to our definition of slotted nonpersistent CSMA, we can derive that the length of an idle period is at least one slot. For the idle period to be n slots, no attempt of transmission should exist in the first n-1 slots, while at least 1 attempt should exist in the last slot (A graphical representation with the busy and idle periods and timing considerations is depicted in figure 1). As we are considering independent Poisson arrivals, we can thus write

$$P[\overline{I} = n \cdot a] = (e^{-aG})^{n-1}(1 - e^{-aG}) \ \forall n \in {}^{+}R$$

so,

$$I = \frac{a}{1 - e^{-aG}} \tag{2}$$

Following a similar reasoning, a busy period will last n TP if there is at least one attempt of transmission in the last slot of each one of the first n-1 TP and no attempt in the last slot of the last TP. So we can write:

$$P[\overline{B} = n(a+1)] = (1 - e^{-aG})^{n-1} e^{-aG} \ \forall n \in {}^{+}R$$

so,

$$B = \frac{a+1}{e^{-aG}} \tag{3}$$

For the probability of a successful transmission period (P_S) we have that

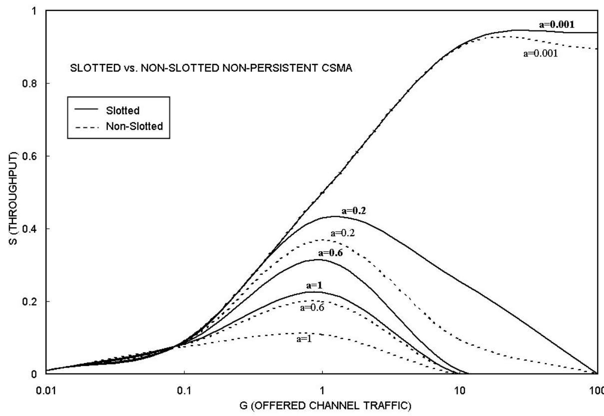

Fig. 3. Slotted vs. Non-Slotted Nonpersistent CSMA

$$P_S = [Successful\ TP]$$

$$P_S = \frac{P[One\ arrival\ in\ the\ slot\ previous\ to\ the\ TP]}{P[At\ least\ one\ arrival]}$$

$$P_S = \frac{Gae^{-aG}}{1 - e^{-aG}} \tag{4}$$

Since the number of transmission periods during $\overline{B}$ is

$$\frac{\overline{B}}{1+a}$$

then,

$$U = \frac{B}{1+a} P_S \tag{5}$$

To get the throughput S, we just need to substitute in (1)

$$S = \frac{U}{B+I} = \frac{\frac{B}{1+a} P_S}{\frac{a+1}{e^{-aG}} + \frac{a}{1-e^{-aG}}} = \frac{aGe^{-aG}}{1-e^{-aG}+a} \tag{6}$$

IV. Evaluation

Following the results obtained for the ALOHA protocol (figure 4, [2]) we expect a relative improvement in the throughput result in slotted nonpersistent CSMA in comparison with the non-slotted version. Figure 3 plots both slotted and non-slotted versions of the nonpersistent CSMA for several values of a, using the following equation for the non-slotted version

$$S = \frac{Ge^{-aG}}{G(a+2a) + e^{-aG}} \tag{7}$$

As it can be observed, improvement of throughput is higher for bigger values of *a*. For values of a tending to *0*, both protocols would show identical throughput

$$S_{a \to 0} = \frac{G}{G+1} \tag{8}$$

For both (6) and (7).

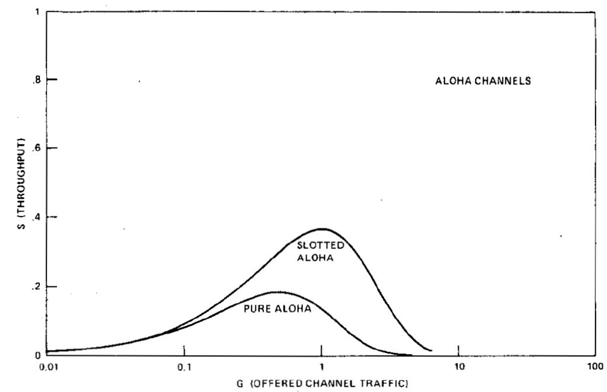

Fig. 4. Throughput in ALOHA channels

V. Conclusions

In this paper we have introduced the slotted nonpersistent CSMA protocol. We have developed the analysis of its throughput, stating the model and showing a graphical representation for several values of the transmission delay a. Moreover, we have compared both slotted and non-slotted versions of the protocol and concluded that the slotted version offers best results for bigger transmission delays in comparison for the same values in the non-slotted version.

References

[1] Leonard Kleinrock, Fouad A. Tobagi, *Packet Swithching in Radio Channels: Part I-Carrier Sense Multiple-Access Modes and Their Throughput-Delay Characteristics*, Computer Science Department, Univeristy of California, Los Angeles, Calif. 90024.

[2] N. Abramson, *The ALOHA System-Another alternative for computer communications*, in 1970 Fall Joint Comput. Conf., AFIPS Conf. Proc., vol. 37. Montvale, N. J.: AFIPS Press, 1970, pp. 281-285.