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On Simulating MAC Protocols

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Abstract – A simulation environment for analyzing MAC protocols for wireless LANs is discussed. Results of simulating some of the proposed protocols are presented. We conclude with an analysis of our approach, and suggestions for future work.

1. Introduction

Recent papers [2, 3] on simulations of various MAC protocols have underscored the need for a common simulation environment. We discuss a framework for modeling the physical environment, as well as the various applications in which wireless networks are expected to be used. The various network parameters that need to be characterized are discussed, including the physical environment, the layout of the networks, the performance characteristics of the receiving and transmitting stations, traffic statistics, and defining the protocol to be used.

This paper also presents results of simulating network protocols, including the ALOHA and LBT (with and without Handshake/Acknowledge [1]). The results in this paper have been produced by a home-grown simulator running on a SparcStation. Most of the network parameters discussed in the following section can be specified in considerable detail to the simulator, thereby allowing a range of applications and environments to be simulated. The outputs of the simulator include the throughput of the system, the backlog and mean delay suffered by the packets, and various other packet statistics such as the number of collisions, unsuccessful deferrals (timeouts), lost acknowledgements, etc.

2. Network Parameters

The parameters which characterize the network include the physical layout of the networks, the transmitter/receiver characteristics, the traffic characteristics, and the MAC protocol. In the simulator that we employed, each of these can be specified in considerable detail. In this section, various aspects of these parameters will be discussed.

Physical Characteristics of the Networks

These include

- the number of nodes, and the separation between the nodes
- the number of networks,
- the separation and fading margin between networks (in a multi-network system),
- the attenuation of the medium, and
- roaming and hidden stations

Each of these can be set, with the exception of the separation between the nodes – they are uniformly distributed. There is no limit on the number of networks that constitute the system. The only restriction that we set is that the total number of stations in all the networks does not exceed 100.

For the results in this paper, networks were assumed to be thirty meter squares, with ten stations uniformly distributed in each network. The separation, fading margin, etc. were varied: two networks separated on the XY plane as well as on the XYZ plane were simulated.

Transmitter/Receiver Characteristics

- the transmit power level,
- the carrier sense threshold
- the decoding capability of a receiver
- the statistics of the station turnaround delay

Traffic Characteristics

- the offered load,
- the packet distribution (size and probability), and
- the distribution of the incoming request times.

The offered load is varied between 0.01 and 5.0 of the bandwidth of the network. This allows an analysis of various protocols at low to medium loads – in this interval, the throughput should maintain a roughly linear relationship to the offered load. When the network is overloaded, the degradation of the network performance should be as low as possible. The robustness of a protocol is indicated by the throughput of the network traffic under heavy load conditions.

In a multi-network system, the offered loads of all but one network are held constant. Packet-types are specified by three-tuples – (size, overhead, probability of occurrence). The overhead associated with each packet is used to synchronize the clock, phase, etc. of the receiver, and does not take any prior handshake mechanism (Request to Send, Clear to Send, etc.) into account – RTS and CTS are themselves packets which require their own overheads.

Protocol Implementation

The protocols which have been simulated are ALOHA, Slotted ALOHA, Carrier Sense, Carrier Sense with Acknowledge, and Carrier Sense with Handshake and Acknowledge.

The changes to the handshake/acknowledge protocol proposed in [1] are:

(1) All packets have destination and source addresses

(2) A failure is noted when an RTS or DATA packet is sent and no activity is sensed for a predetermined timeout period, or if activity is sensed but is not appropriate (i.e., if it is not a CTS or ACK packet with the correct Destination/Source addresses)

(3) The deferral mechanism used (either upon sensing energy on the carrier, or upon noting a failure) is the Binary Exponential Backoff algorithm [4], an adaptive randomization strategy. It minimizes delay under light loads, and is stable under heavy loads.

Packet Generation

The mechanics of generating packets is done as follows: the entire system of networks is regarded as one large segmented network. The nodes (stations) of each segment are restricted to communicate only with each other, but this of course does not apply to interference between networks. Given an offered load, requests are generated and appended to a queue. The queue is a linked list, updated to keep track of the order in which requests need to be serviced. Overlapping requests are dealt with in the obvious fashion: sensing activity on the medium would cause a would-be transmitter to defer its request; collisions would result in deferrals (if the Acknowledge feature is present in the protocol) or in lost packets; transmissions that began during the turnaround time of a would-be transmitter would result in a collision, etc.

The strength of a transmitted signal at the receiver and all would-be transmitters is computed, to allow for carrier sensing and flagging collisions and any capture effects.

Each request in the queue is a structure with the following components:

From & To	Linked list predecessor and successor
Xmt & Rec	Identity of transmitter and receiver
Ntk	Network
Start & End	Time request starts and ends
Length	of request, in octets
Dly	Total delay accumulated by request
Status	of request

The status of the request can change many times before it is finally removed from the list: it can either be waiting to transmit a Request to Send or Data, receive CTS or ACK, or finally times out. The status item in the list keeps track what stage the request is in.

3. Simulation Results

This section deals with some simulation runs that were carried out using different physical configurations of the networks and different MAC protocols. Only peer-to-peer communication was investigated – services such as a server-based system, isochronous data transfer, etc. all depend on the contention-based foundation of a protocol, and this serves as a good starting point.

In all the simulations, the maximum bit rate was assumed to be 2 M bits/s, the expected packet payload was about 420 octets (64 octets with probability 0.2, 512 octets with probability 0.8), and each packet had an overhead of 30 octets, resulting in a total expected packet length of about 3600 bits: consequently, one slot is about 1.8 μs.

Single Network Performance

Figure 1 show the results of simulating a single network using three protocols, ALOHA, LBT, and LBT with Handshake and Acknowledge.

The results of the ALOHA protocol simulation are in agreement with the predicted (theoretical) results. The throughput seems slightly degraded because we do not count the overhead as part of the payload. The same technique is used in evaluating other protocols.

All the networks that we consider consist of 10 stations uniformly distributed in a 30 meter × 30 meter area. The transmitter/receiver characteristics and the packet distribution

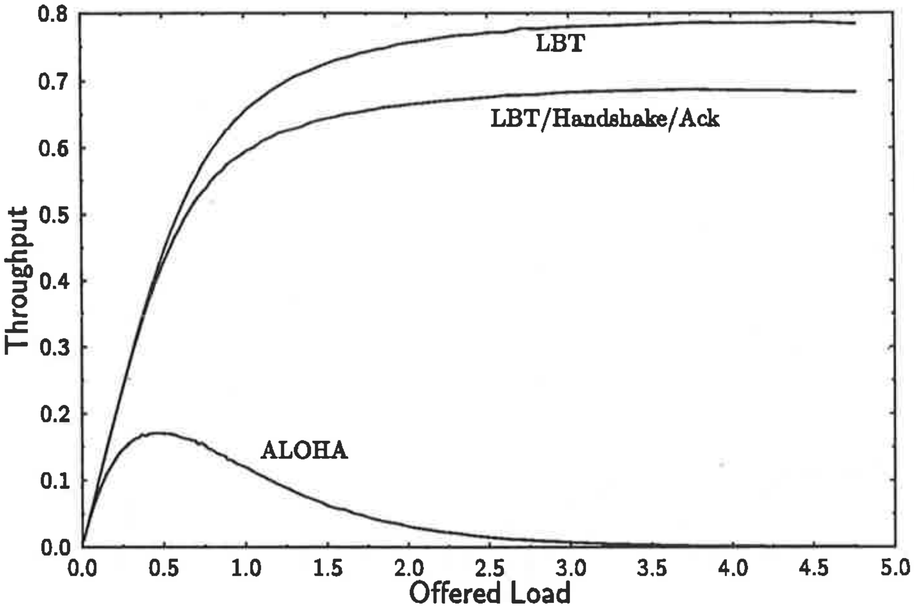

Figure 1. Single Network Configuration

and size are those specified in the example in Table 1. The decoding capability of the receiver (that is, the signal-to-interference ratio at which the receiver can correctly decode the received packet) is set at 15 dB.

Colocated Networks

We now analyze multiple-network systems. In order to avoid crowding the graphs, we will restrict ourselves to two colocated networks. In the next three examples, the configuration that we use is two networks, each constructed as above (10 stations uniformly distributed in a 30 meter × 30 meter area). The centers of the two networks are 60 meters apart.

Figure 2 graphs the performance of the two networks located as above. The offered load of Network 2 is held constant at 0.3 (that is, 30% of the network bandwidth), and the offered load of Network 1 is varied from 0.01 to 5.0. As we would expect, the throughput of Network 2 rapidly drops from a high of almost 16% (where it is behaving as a one-network system) as the offered load of Network 1 increases. Comparing Network 1's throughput with Figure 1, we see that the shape of the curve is roughly the same, but the performance degrades by about 50%.

Next, we look at carrier-sense type networks. As in the case in which the ALOHA

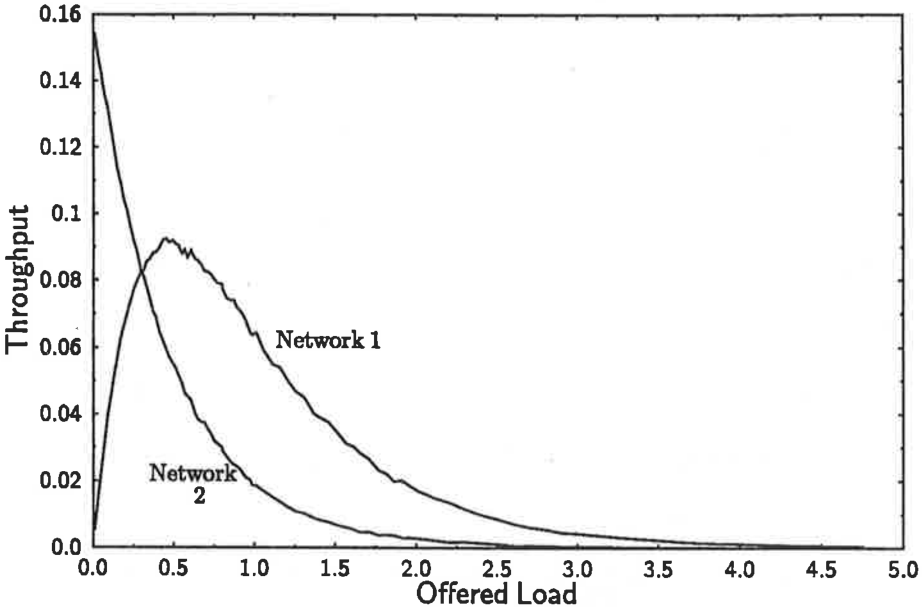

Figure 2. Two Networks using ALOHA

protocol was simulated with two networks, we hold one of the networks to a constant offered load, and vary the other network.

Simulations were performed holding the constant load to low (20%), medium (70%), and overload (120%). We see, as in the case of the two-network ALOHA system, that the shape of the performance remains about the same, but is shifted downward as there is increased degradation.

The peak performance of the simple Carrier-Sense system (see Figure 1) is about 80%. The theoretical asymptotic limit for this system is, of course, 100%, but that does not take into account real-life details like the overhead, the turnaround time, etc. Our throughput is computed on the volume of the payload successfully transmitted.

Next we look at the LBT system with handshake and acknowledge. The basic premise of this protocol is that a station may not be able to hear an ongoing transmission, but that its intended receiver can, and so rather than transmitting data when the medium seems to be inactive, the transmitter first transmits a Request to Send (RTS). If it hears a Clear to Send (CTS) from the correct station, then it proceeds to transmit a frame with the payload. Optionally, the receiver transmits an Acknowledge (ACK) if the checksum of the received frame is deemed to be correct.

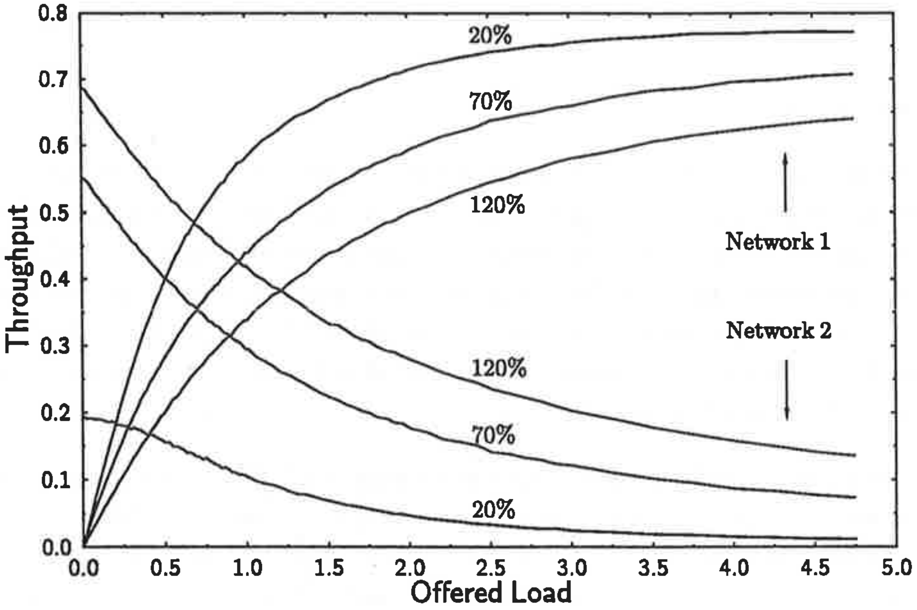

Figure 3. Two Networks using LBT

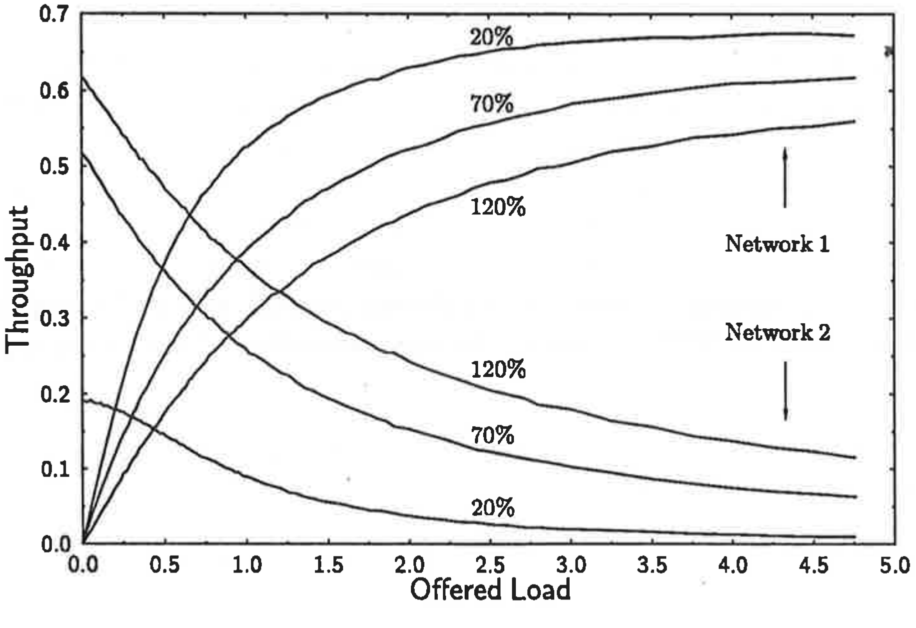

Figure 4. Two Networks using LBT/Handshake/Acknowledge

Assuming that the RTS and CTS are each 30-octet packets (and this is the very minimum since the overhead for a packet is 30 octets), and the turnaround time is normally distributed with mean = $20\mu s$, $\sigma^2 = 5(\mu s)^2$ (which is the same as for regular packet transmission) the throughput for two colocated networks using the same parameters as the (previous) Carrier-Sense case are shown in Figure 4.

Comparing Figures 3 and 4, we see that using a handshake mechanism seems to degrade performance. There are physical configurations in which a handshake would improve performance, but it would appear that having an adaptive handshake mechanism would be better – using this strategy, terminals initiate data transfers without requests, but can optionally transmit requests if the intended receiver is having trouble with receptions. This can occur when one of two conditions is true: (1) there is a colocated network that is partially jamming some nodes, and (2) if there are hidden stations.

Condition (1) does not usually seem to warrant using RTS-CTS either, because if the interfering signal is attenuated to the extent that it escapes detection, then the signal-to-interference ratio will be large enough for error-free decoding by the receiver. Consequently, it would seem that the presence of hidden stations is the only rationale for using a handshake mechanism. If the stations of a network are capable of learning (through the lack of an ACK in previous transmissions) that some nodes are being interfered with in ways that cannot be detected by other nodes, then the handshake mechanism can be used.

The Timeout/Mean Delay tradeoff

The notation *k defers* is used to indicate that a transmitter makes a total of k attempts to transmit before it gives up. The length between each of the attempts does not remain constant – each deferral increases the expected length of time before the succeeding attempt is made: for example, timing out after four defers implies that the expected delay is roughly double that of the expected delay for three defers. This depends on other factor, however, such as the amount of traffic on the network. The manner in which this backoff algorithm was implemented in the simulator caused the maximum possible delay (for the case of k attempts before timeout) to be $2^{k+1} - 2$ slots. The exponentially increasing delay is shown in Figure 6.

Figures 5 shows the relationship between the throughput and the maximum number of defers that a transmitting station is permitted before it times out.

We see that as the maximum number of defers is increased, the throughput increases, but with diminishing returns. The results seem to indicate that timing out sometime between 2-4 defers offers a good tradeoff between throughput and mean delay. This contains the mean delay to acceptable limits, while the increased throughput for anything beyond this is negligible.

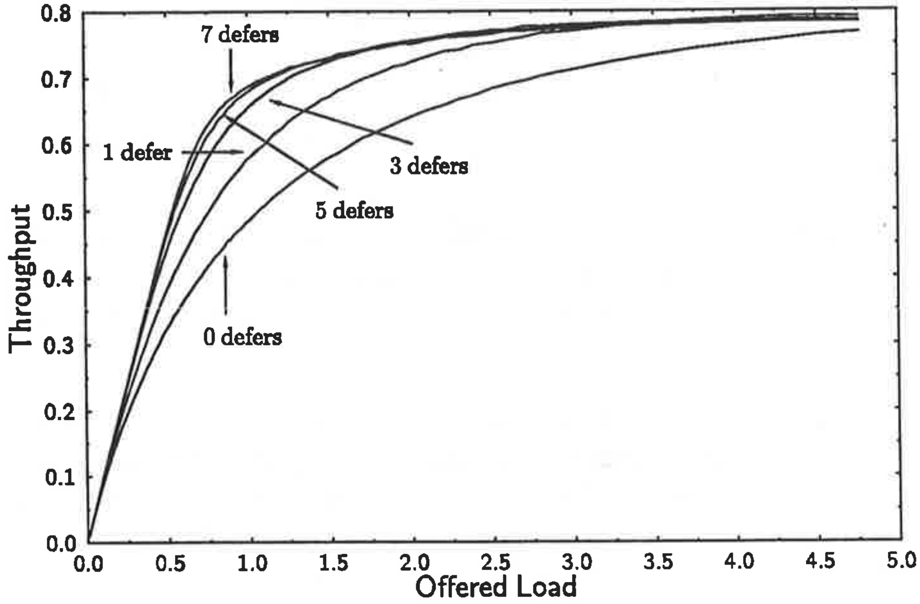

Figure 5. One Network (Carrier Sense): Throughput as a function of the number of defers before timeout

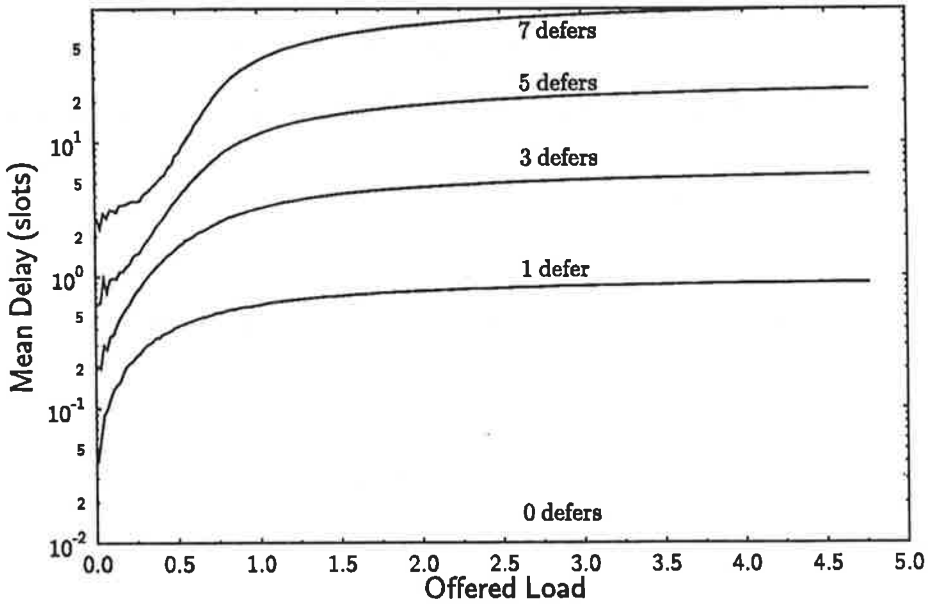

Figure 6. One Network (Carrier Sense): Mean Delay as a function of the number of defers before timeout

4. Conclusions

This contribution was motivated by the need for comparing proposed protocols using a common set of definitions, topology, and physical environment. The sections on Network Parameters and Simulation Results contain details on specific parameters that were chosen, and on decisions made on modifications to the protocol, backoff mechanism, etc.

The simulator was designed to measure the performance of MAC protocols not only on the basis of throughput vs. offered load, but a host of other statistics including the backlog, average delay, number of collisions, unsuccessful deferrals (timeouts), lost acknowledgements, etc.

The performance and stability of protocols must be compared by taking all these factors into account. Previous contributions have also referred to many of these parameters – they need to be taken as a starting point to formulate a framework for evaluating competing protocols.

References

[1] Ken Biba, "A Hybrid Wireless MAC Protocol Supporting Asynchronous and Synchronous MSDU Delivery Services," *IEEE 802.11/91-92, September, 1991.*

[2] Wim Diepstraten, "Wireless Network Performance Modeling Approach," *IEEE 802.11/92-26, May, 1992.*

[3] Mike Smith, "Further Simulations of the Hybrid MAC Protocol," *IEEE 802.11/92-37, February, 1992.*

[4] A. S. Tanenbaum, *Computer Networks,* Prentice-Hall, Inc., Englewood Cliffs, NJ, 1981.