ACKNOWLEDGING DSMA WITH PRIORITY SCHEDULING FOR LOCAL AREA NETWORKS*

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ABSTRACT

A mini-slot, appended to the data slot in the distributed scheduling multiple access (DSMA) protocol described in [1], for the transmission of acknowledgement packets is described and analyzed. The resulting DSMA with fixed slot acknowledgement (DSMA/FSA) presents a better alternative to sending a separate acknowledgement packet for each received data packet. With priority requests, DSMA/FSA appears to be a viable media access protocol for integrated voice and data services in a local area network.

1. INTRODUCTION

DSMA (Distributed Scheduling Multiple Access) is an asynchronous time-division multiple access scheme where the channel time is divided into contiguous slots of duration sufficiently long to transmit one packet of data [1]. If the packet length is variable then the slot length is also variable. This paper is concerned only with fixed packet size.

With base band signaling, two channels are required for the DSMA protocol, i.e., a main channel for data transmission and a subchannel to request data slot assignment. (If broadband signaling is employed, then data and slot request transmissions can be frequency multiplexed and transmitted over the same physical channel). Each transceiver (TCVR) in the local area network is assigned an n -bit address a priori, and each has access to both of the channels as shown in Fig. 1.

To request a data slot allocation each active TCVR transmits its address bits serially with the most significant bit first into the common request channel. An active TCVR with an address lower than another active TCVR in the same request cycle drops off from contention temporarily until a slot has been assigned to the active TCVR with the highest address. Each TCVR is allowed access to only one data slot during a cycle; this ensures fairness for all TCVRs. A request cycle terminates when each active TCVR has been assigned a data slot. Fig. 2 illustrates the slot request cycle.

A reservation period takes h slots, which is the time required to transmit the n -bit address serially on the reservation channel. The end of a request cycle is indicated by imposing an h -slot silent period on the request channel [1]. Thus, if there are to be no gaps between consecutive DSMA cycles during a busy period, then the constraint $2h < 1$ must be satisfied [1].

Although the DSMA protocol is capable of multi-priority requests the analysis given in [1] has been concerned only with a single class message transmission without acknowledgement. A more complete model, which includes a protocol for transmitting multi-priority messages with acknowledgement for each packet, is described in this paper. In addition, the possibility of integrating voice packet transmission is discussed. In the modified protocol the basic two channel configuration and the slot request rule of the original DSMA model remain essentially unaltered.

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The paper is organized as follows. Section 2 explains the details of the modified protocol. Section 3 analyzes the delay-throughput characteristics. Analytical results are compared with simulation results in section 4.

2. ACKNOWLEDGING DSMA

The frame format of DSMA is modified to permit the incorporation of fixed slot acknowledgement (FSA). The modified DSMA with fixed slot acknowledgement protocol will be referred to as DSMA/FSA.

2.1 Acknowledgement Scheme

The two channel timing diagram for the acknowledgement scheme is shown in Fig. 3. A b -bit slot is reserved after every data slot for the transmission of an acknowledgement (ACK) packet. Takoro et al [2] have shown that it is not unreasonable for an ACK packet to be generated almost immediately upon reception of a data packet. (Acknowledging Ethernet is a modification of the Ethernet protocol [3], one that includes transmission of ACK packets for each packet.)

Acknowledgement for any given data packet should be transmitted $(1+a)$ slots ($a=b/P$, where P is the length of one data packet in bits.) after the reception of a data packet. Since there is a fixed delay in the transmission of the ACK packet, it is apparent that every time an ACK packet is transmitted there is only one TCVR that has had the opportunity to create the packet, and there is only one TCVR in the entire network expecting acknowledgement. (If the source has multiple destinations, the b -bit acknowledgement mini slot may include a control field so that the source can designate which destination should acknowledge a given packet.) Thus, the size of the b -bit mini-slot can be made quite short; in fact, ideally only one bit ("yes" or "no") need be transmitted. All addressing information may be removed from the normal packet format. In practice, however, the "yes" or "no" signal consists of $b > 1$ bits to enhance protection against channel noise, processing delay and other errors. For example, if $b = 7$, we may use a (7,4) Hamming code to protect the integrity of the ACK bits.

The fixed slot acknowledgement scheme (DSMA/FSA) possesses several advantages. Firstly, the length of the ACK packet can be made quite short relative to a data packet. Consequently, a very small proportion of the channel capacity is occupied by the ACK packets. Secondly, the format, and hence the generation of

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the ACK packets, is simple, consisting of a few ones or zeroes. Finally, the TCVR design is not complicated by the inclusion of high priority ACK packets that are of a different length and format from data packets.

The one major disadvantage of the DSMA/FSA scheme is the wastage of data slots under certain conditions. For example, (see Fig. 3) if after the end of a cycle, a packet arrives during the period B, then it cannot be transmitted until after the following ACK slot (marked "A" in Fig. 3). Thus, the arrival of a data packet under this condition results in the wastage of a data slot and represents a penalty in delay due to the DSMA/FSA scheme. A second more minor disadvantage of the DSMA/FSA scheme is that the first b -bit slot after an idle period is always wasted.

2.2 Priority Scheme

Priority scheduling is accommodated in DSMA and DSMA/FSA by reserving the k most significant bits of the n -bit TCVR address to indicate $K=2^k$ levels of priority [1]. The priority scheme will be described for two level ($k=1$) priority. Extrapolation to K -level priority will then be straightforward.

Any TCVR wishing to transmit a priority packet contends on the reservation bus by transmitting its address bits, with the most significant bit of its n -bit address set to "1". This effectively makes the priority TCVR the highest address TCVR, thus ensuring transmission of the priority packet ahead of any non-priority packets with which it contends. If two or more TCVRs have priority packet to be transmitted in the same cycle, the slot request rule applies within each level of priority. It should be noted that a priority packet arriving after the start of a scheduling interval must wait till the next scheduling interval before it can contend for access to the data bus.

The operation of the two-level priority scheme described above is easily extended to K -level priority, where the highest priority TCVR would have all k -bits set to "1". As described above, the highest priority class packets would gain access to the data channel ahead of all lower priority class packets with which they contend.

2.3 Voice Traffic Consideration

Voice traffic characteristics are significantly different from those of data traffic. Voice traffic consists of talkspurts and silent periods. During talkspurts, packets are generated periodically; during silences, no packet occur. The statistics of the duration of talkspurts and silences in conversational speech are given by Brady [4], [5]. The mean talkspurt length and the mean pause length are 1.366s and 1.802s, respectively. The call arrival distribution can be assumed to be Poisson [6], with the average duration of a call taken to be approximately 100s. Also, approximately 40% of the time a call is in talkspurt, with the talkspurt and silence lengths modeled using a geometric distribution [7].

There are two basic requirements for voice traffic: to maintain high quality speech the end-to-end network delays must be held to small fractions of a second and a nearly synchronous output must be maintained at the receiver output. Network delay is comprised of three components: terminal delays, nodal (TCVR) delays and propagation delay. Terminal and propagation delay will be ignored here and only the TCVR to TCVR protocol delay will be studied. (It should be noted, however, that in any real implementation, the terminal to TCVR protocol will incur some delay that will have to be considered.) It has been determined that a typical end-to-end delay of 150 ms - 350 ms is satisfactory for delivering voice packets [8]. As well, gaps in conversations (interpacket delays) exceeding 50 ms should not occur for more than 1% of the packets [9].

To ensure that the criteria specified above are satisfied, the highest priority must be reserved for voice packets, i.e., voice packets will all be of higher priority than data packets. This means that amongst voice packets, the priority due to TCVR addresses will prevail. This inherent ordering of voice packets will have to be considered when determining whether the above criteria will be

satisfied. (Actually, almost all systems, where channel access by users is position-dependent, are "unfair", unless a priority swapping policy is incorporated.)

No acknowledgement is necessary for voice packets since comprehension of speech is quite tolerant of bit (packet) errors. It should, therefore, be possible to remove the b -bit acknowledgement mini slot described for the FSA scheme and utilize this bandwidth for voice packet transmission. This would, however, involve the adoption of a more complicated protocol (and hence more complex TCVR design), one that would have to be able to adapt between interspersed data transmission (with acknowledgement) periods and voice transmission (without acknowledgement) periods. It appears that the advantage of a simpler TCVR and protocol may outweigh the marginal gain in bandwidth achievable by utilizing the b -bit acknowledgement slot (b in the order of 10 bits) for voice packet transmission. Voice packet transmission will, therefore, be integrated into the DSMA/FSA scheme where the acknowledgement slot corresponding to voice packets may or may not be used.

3. DELAY ANALYSIS FOR DATA

3.1 DSMA/FSA Without Priority

The analysis of the DSMA/FSA scheme follows closely the analysis of the DSMA protocol [1]. Assumptions made in the derivation of an expression for packet delay of DSMA apply as well to the analysis below. Furthermore, all remarks and interpretations of the delay equation for DSMA hold for DSMA/FSA.

To obtain an expression for the packet delay, we consider a packet in the entire system and obtain a delay expression for any packet in the network. Following the arguments given in [1], the mean delay $\bar{d}$ may be expressed as:

$$\bar{d} = \text{propagation delay} + \text{service time} \\ + \text{acknowledgement time} + \text{queuing delay.}$$

The mean service time of a data packet equals 1 slot and the acknowledgement time = "a" slot. The mean queuing delay is given by the following:

$$\bar{W} = \text{mean delay for packet to join the queue} \\ + \text{average remaining service time of packet} \\ \text{in service} + \text{waiting time of } N \text{ packets who are} \\ \text{ahead of the packet in question.}$$

The mean delay for a packet to join the queue for service is given by:

$$\bar{H} = h(1 - \rho(1 + \frac{a}{\bar{x}}))e^{-\rho(1 + \frac{a}{\bar{x}})} \\ + \left[1 - \rho(1 + \frac{a}{\bar{x}})\right] \left[h + \frac{a + \bar{x}}{2}\right] \left[1 - e^{-\rho(1 + \frac{a}{\bar{x}})}\right], \quad (1)$$

where h in slots is the overhead due to reservation, $\bar{x}$ is the mean service time of a data packet, "a" in slots is the length of an ACK packet, and $\rho = \lambda \bar{x}$ is the traffic intensity and λ is the mean aggregate arrival rate. The first term on the right-hand-side of (1) is the delay penalty when the system is idle and no packets arrive during the next $(1+a)$ slots. If at least one packet arrives during the next $(1+a)$ slots, a data slot is wasted and the delay penalty is given by the second term on the right-hand-side of (1). Bearing in mind that the derivation of the delay equation follows the arguments given in [1], without presenting details, the mean queuing delay $\bar{W}$ is given by

$$\bar{W} = h + \left(\frac{1+a}{2}\right)(1 - e^{-\rho}) + \frac{\rho(1+a)}{2(1-\rho)}, \quad (2)$$

where we have let $\bar{x} = 1$ and $\rho' = \rho(1+a)$. The mean packet delay $\bar{d}$ is now given by

$$\bar{d} = \alpha + 1 + a + h + \left(\frac{1+a}{2}\right)(1-e^{-\rho}) + \frac{\rho'(1+a)}{2(1-\rho')}, \quad (3)$$

where α is the propagation delay in slots. Equation (3) only represents the delay to transmit a packet. The delay associated with reception of the acknowledgement packet has not been included. since acknowledgement for each data packet arrives exactly $(1+a)$ slots after it has been transmitted, we may write the mean delay as:

$$\bar{d} = 2\alpha + 2(1+a) + h + \left(\frac{1+a}{2}\right)(1-e^{-\rho}) + \frac{\rho'(1+a)}{2(1-\rho')}. \quad (4)$$

3.2 DSMA/FSA with Priority

The priority scheme implemented within DSMA/FSA may be modeled as a head-of-the-line (HOL) queueing system without preemption [11]. Thus, the derivation of an expression for a packet delay will follow the arguments outlined in [5, Chap. 3]. In what follows, we derive the delay expression for a two level priority system.

The mean queueing delay $\bar{W}$ may be expressed as:

$$\bar{W} = \beta \bar{W}_1 + (1-\beta) \bar{W}_2 \quad (5)$$

where

$\bar{W}_1$ = mean queueing delay for priority packets,

$\bar{W}_2$ = mean queueing delay for non-priority packets,

and

β = fraction of total traffic that is priority.

The traffic into a two-level priority HOL system may be taken as two independent Poisson streams with intensity $\rho'_1 = \rho_1(1+a)$ and $\rho'_2 = \rho_2(1+a)$ such that $\rho' = \rho'_1 + \rho'_2$, where ρ'_1 = traffic intensity of priority packets and ρ'_2 = traffic intensity of non-priority packets. The same result may be achieved by considering the input traffic stream, with intensity ρ' , where a fraction β of the packets are randomly and independently tagged to be priority and the remainder are tagged to be non-priority packets. Therefore, we get $\beta = \rho'_1/\rho'$ and $(1-\beta) = \rho'_2/\rho'$ and equation (5) may be written as:

$$\bar{W} = \frac{\rho'_1}{\rho'} \bar{W}_1 + \frac{\rho'_2}{\rho'} \bar{W}_2 \quad (6)$$

Following the arguments in the derivation of the expression for $\bar{W}$ in the single class commodity case, we obtain

$$\bar{W}_1 = \left[\frac{1-\rho'_1}{1-\rho'_1} \right] \left[h + \left(\frac{1+a}{2}\right)(1-e^{-\rho'}) \right] + \frac{\rho'(1+a)}{2(1-\rho'_1)} + (1+a) \left[1 - (1-\rho')e^{-\rho} \right] \rho'_1. \quad (7)$$

Now, using the relationship for $\bar{W}$ given by (6), we may solve for $\bar{W}$ to obtain:

$$\bar{W}_2 = \left[h + \left(\frac{1+a}{2}\right)(1-e^{-\rho'}) + \frac{\rho'(1+a)}{2(1-\rho')} \right] \left[\frac{1}{1-\rho'_1} \right] - (1+a) \left[1 - (1-\rho')e^{-\rho} \right] \rho'_1, \quad (8)$$

where

$$\bar{W} = h + \left(\frac{1+a}{2}\right)(1-e^{-\rho}) + \frac{\rho'}{2(1-\rho')}. \quad (2)$$

Finally, the equations for packet delay may be obtained from (4) by substituting the appropriate expression for mean queueing delay. The mean delay for the transmission of a priority packet is given by

$$\bar{d}_1 = \alpha + 1 + a + \left[\frac{1-\rho'_1}{1-\rho'_1} \right] \left[h + \left(\frac{1+a}{2}\right)(1-e^{-\rho'}) \right] + \frac{\rho'(1+a)}{2(1-\rho'_1)} + (1+a) \left[1 - (1-\rho')e^{-\rho} \right] \rho'_2 \quad (9)$$

and that for a non-priority packet is given by

$$\bar{d}_2 = \alpha + 1 + a + \left[h + \left(\frac{1+a}{2}\right)(1-e^{-\rho}) + \frac{\rho'(1+a)}{2(1-\rho')} \right] \left[\frac{1}{1-\rho'_1} \right] - (1+a) \left[1 - (1-\rho')e^{-\rho} \right] \rho'_1. \quad (10)$$

When the delay for reception of acknowledgement is taken into account, equations (9) and (10) become, respectively,

$$\bar{d}_1 = 2(\alpha + 1 + a) + \left[\frac{1-\rho'_1}{1-\rho'_1} \right] \left[h + \left(\frac{1+a}{2}\right)(1-e^{-\rho'}) \right] + \frac{\rho'(1+a)}{2(1-\rho'_1)} + (1+a) \left[1 - (1-\rho')e^{-\rho} \right] \rho'_2 \quad (11)$$

and

$$\bar{d}_2 = 2(\alpha + 1 + a) + \left[h + \left(\frac{1+a}{2}\right)(1-e^{-\rho}) + \frac{\rho'(1+a)}{2(1-\rho')} \right] \left[\frac{1}{1-\rho'_1} \right] - (1+a) \left[1 - (1-\rho')e^{-\rho} \right] \rho'_1. \quad (12)$$

4. NUMERICAL RESULTS

Voice is synchronous traffic. The delay-throughput performance for data can be studied under a reduced channel capacity model, where the capacity reduction is the portion of the total capacity captured by voice, plus any overhead due to boundary switching between voice and data transmissions. The numerical results presented in this section is restricted to Poisson input traffic only.

Analytical and simulation results of delay-throughput performance for DSMA/FSA are plotted in Fig. 4. The results were obtained for a slot length equal to the length of a 256 bit data packet and an ACK packet length of $b = 10$ bits. Transceiver address length of $n = 8$ bits, giving a request overhead of $h = 0.3164$ slot, was used. Using the same parameters, analytical and simulation results for a two level priority system are plotted in Fig. 5.

The analytical results are in close agreement with the simulation results. Only for the case of 85% priority traffic is there any disagreement between simulation and analysis. Even in this case, there is still "good" agreement between simulation and analysis at low to medium throughput ranges, i.e., at throughput rates < 0.7 .

Suppose the priority commodity is voice and the transmission rate is 2 Mbps. Consider the case that 50% of the total traffic is priority traffic. At $\rho = 0.80$, we obtain from Fig. 5 that the mean packet delay for the priority (voice) traffic is approximately 3.5 slots, which corresponds to approximately 0.5 ms.

5. CONCLUSIONS

In this paper we have described a fixed slot acknowledgement scheme for the distributed scheduling multiple access (DSMA) protocol described in [1]. Although there is a wastage of data slot when packets arrive within one slot after the system becomes idle, the proposed DSMA/FSA scheme is more efficient in terms of delay-throughput compared to the case in which a separate acknowledgement packet is sent for each data packet.

Since DSMA offers multi-priority requests, the TCVRs in the local area network are coordinated so that priority scheduling can be imposed at the communications subnetwork level, i.e., not just at an individual TCVR. With integrated voice and data services, voice traffic can be treated as a high priority network commodity. It is conjectured that DSMA/FSA is capable of supporting integrated voice-data services which meet the end-to-end mean packet delay and mean interpacket delay requirements for voice.

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Figure 1 Dual Channel Access by iTH Transceiver

Figure 4 DSMA/FSA Delay-Throughput Characteristics

Figure 5 Delay-Throughput Characteristics of DSMA/FSA With Priority