On a Mixed Mode Multiple Access Scheme for Packet-Switched Radio Channels

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Abstract—We extend the study of access schemes for packet-switched radio channels as an alternative to conventional wire communications for data transmission among users. Among the various multiple access schemes previously implemented or proposed, ALOHA presents many advantages, especially for a large population of bursty users. However, more than 60% of the ALOHA channel capacity is wasted. In this paper we introduce a separate large carrier-sensing user who "steals" slots which remain unused by the background of ALOHA users. This leads to a new multiple-access scheme: the Mixed ALOHA Carrier Sense (MACS) access scheme, whose performance we analyze. The total channel utilization is significantly increased with MACS, and the delay-throughput performance of both the large user and the background of ALOHA users is shown to be better with MACS than with a "split channel" mode in which the large user and the ALOHA users are each permanently assigned a portion of the channel.

I. INTRODUCTION

Numerous papers have already appeared in the literature which discuss the constantly growing need for data communication channels and the problem of allocating these expensive resources among an ever increasing number of bursty users [1, 2]. In this paper, we focus attention on data communication over packet-switched radio channels. These broadcast radio channels are effective alternatives to conventional wire communications [3, 4].

A large number of methods have previously been implemented or proposed which attempt to resolve the following problem: how to share a single broadcast channel and how to control access to that channel in some multi-access fashion at an acceptable level of performance. These methods fall into the following categories: Fixed Assignment—Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) [5]; Roll Call Polling [5, 6]; Random Access Schemes—ALOHA [3, 7, 8, 9] and Carrier Sense Multiple Access (CSMA) [4]; and more recently, reservation [10] and conflict-free dynamic techniques [11, 12]. The use of packet radio communication has been experimented with in the ALOHA System [7] and in the packet radio network being developed by the Advanced Research Projects Agency [13].

The ranking of the multiple access schemes presented above will often depend upon the specific environment in which they operate. Nonetheless, ALOHA provides a small delay and an efficient channel utilization at low traffic and does not require that users be in line-of-sight (LOS) and within range of each other. This is an important consideration. However, we are dismayed that the maximal channel efficiency is only $1/e \cong .37$ and therefore a large part of the channel capacity is wasted with ALOHA. In order to increase the channel utilization, we introduce traffic from a separate source (if there is any), referred to as *large user*, on the same channel being used by the large population of bursty ALOHA users, referred to as *small users*. As an example, we might consider a background of bursty interactive small users, together with a large user transmitting a large amount of data (e.g., a file transmission) which need not be characterized by short service times. Several papers have already suggested the use of a radio channel in an environment including small users and a large user [9, 14, 15, 16].

In the following, we introduce and analyze the Mixed ALOHA Carrier Sense (MACS) mode. In such a multiple access scheme, we use the carrier sensing capability of the large user, i.e., his capability of listening to the carrier of the small user transmissions. By sensing the carrier (i.e., listening to activity in the channel), the large user "steals" slots which remain unused by the background of small slotted-ALOHA users. We give priority to the small users, and since they are controlling the entire bandwidth, they perform better than if they were dedicated only a part of the available bandwidth. However, since the large user has lower priority (he will not transmit a packet unless all small users are quiet, i.e., carrier absent), he may incur higher delays and achieve less throughput than if he were dedicated a portion of the available bandwidth.

Not only is the throughput-delay performance of the small users improved with MACS (as opposed to the "split-channel" assignment), but the total channel utilization is shown to be significantly increased with MACS. In addition, for all (given) values of the small users' traffic, we show that a higher throughput is achieved by the large user with MACS than with a split channel mode in which the large user and the small users are dedicated two separate channels.

In Section II we list our assumptions, characterize the traffic model and present the operational features of the MACS protocol. The large user's throughput-delay performance and the total channel utilization are analyzed in Section III. Finally, MACS is compared to a split channel mode in Section IV and some concluding remarks are made in Section V.

II. TRAFFIC MODEL, PROTOCOL AND SYSTEM ASSUMPTIONS

We consider a single *high-speed* broadcast radio channel which is shared among users in a packet-switched mode. All packets are of constant length requiring P seconds for transmission [for both the small and large users] and are transmitted over an assumed noiseless channel. The system assumes no multipath effect. (The effect of multipath is to introduce a time-spread on the signal.) We assume a non-capture system, i.e., the overlap of any fraction of two packets results in destruction of both. In addition, acknowledgment traffic is assumed to be carried over a separate channel.

This single channel carries traffic from a large number of *small users* as well as the traffic from a single *large user*. The small users contend for the channel in a slotted ALOHA fashion [3] and collectively form an independent Poisson source with an aggregate mean packet generation rate of λ_1 packet/s. We assume an infinite number of small users.

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This is an approximation to a large (but finite) number of small users who generate packets infrequently and whose packets can be successfully transmitted in a time interval much less than the time between successive packet generations at a given user. Each small user is assumed to have at most one packet requiring transmission at any time (including any previously collided packet) [3]. The large user is buffered with an infinite buffer size. Packets are generated at the large user according to a Poisson point process with intensity λ_2 packet/s, independent of the small users' arrival process; this is the meaning of a "large" user, namely, he has a significant packet generation rate by himself and he is buffered. Packets generated at the large user are served on a first-come-first served (FCFS) basis. The large user is assumed to be in line-of-sight and within range of all small users. Therefore, we assume that the large user has the ability to *sense the carrier* of any small user's transmission on the channel. In the context of packet radio channels, sensing carrier prior to transmission was originally suggested by D. Wax of the University of Hawaii in a memorandum dated March 4, 1971. This concept has been applied to carrier sense multiple-access (CSMA) modes by Kleinrock and Tobagi [4]. Furthermore, the time required to detect the carrier due to a packet transmission is considered to be negligible. The maximum propagation delay τ between any small user and the large user is considered to be only a small fraction a of the packet transmission time P. a is chosen to be equal to .01 in the numerical calculations throughout this paper.

The time axis is slotted as in Fig. 1. All users are forced to start their transmissions only at the beginning of a slot and are synchronized as follows: When a small user has a packet ready for transmission (a newly generated or previously collided packet [3]), he transmits the carrier (without data modulation) for the first τ seconds of the slot and then transmits the (information) packet over the next P seconds.

When the large user has a packet ready for transmission, he senses the carrier at the beginning of the slot. After a maximum of τ seconds, the large user is able to detect the presence or absence of the carrier. If the carrier is present (one or more small users are transmitting in the current slot) the large user remains quiet until the beginning of the following slot and then operates as above.

The last τ seconds of a slot in Fig. 1 account for the maximum delay between the end of a packet transmission and the end of its reception (by the large user). The practical problems involved in synchronizing users are not addressed in this paper.

Finally, we characterize the traffic as follows. Let $S_1 = \lambda_1 P$ and $S_2 = \lambda_2 P$. S_1 and S_2 are the average number of packets generated per transmission time, i.e., they are the input rates normalized with respect to P respectively for the small users and for the large user. Let $S = S_1 + S_2$ be the total normalized input rate. In equilibrium, S_1, S_2, and S can also be referred to as the small user, large user and total channel throughput rates (also referred to as channel utilizations [3]). If we were able to perfectly schedule the packets into the available channel space with no overlap and no gaps between packets, we could achieve a maximum throughput equal to 1. The maximum achievable throughput for an access scheme is called the *channel capacity* of the scheme and is denoted by $C = \max S$.

In addition, let $\Lambda_1 = \lambda_1 P[1 + 2a]$ and $\Lambda_2 = \lambda_2 P[1 + 2a]$. Λ_1 and Λ_2 are the small user and large user input rates normalized with respect to one slot.

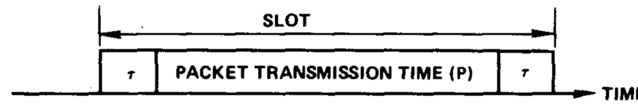

Figure 1. MACS Slot Configuration (τ = propagation delay).

Below, we solve for the channel capacity C and the delay-throughput performance of the small users and the large user.

III. THROUGHPUT AND DELAY ANALYSIS

The delay-throughput performance of the ALOHA population (small users) is not affected by the presence of the large user (except that the slot size is $P(1 + 2a)$ instead of P when there is no large user). An analysis of the small user performance in a ground radio environment can be found in [4] which is similar to the satellite treatment in [3, 9]. In particular, the small user load (number of packets per slot) is given by

$$\Lambda_1 = Ge^{-G} \tag{1}$$

where G (average number of packets transmitted per slot) is the offered traffic rate (newly generated and previously collided packets) of the ALOHA population.

On the other hand, the large user's transmission is sensitive to the ALOHA traffic: the higher is the ALOHA traffic, the lower will be the large user's throughput.

III.I Large User's Throughput Analysis and Total Channel Capacity

Three kinds of slots can be identified in a slotted ALOHA mode:

i) *"Successful"* slots in which one packet is successfully transmitted (one and only one user is transmitting).

ii) *"Collision"* slots in which more than one small user is transmitting. Packets "collide" and must be retransmitted.

iii) *"Idle" slots* in which no small user is transmitting (each small user either has no packet to transmit or has rescheduled the transmission of a previously collided packet for some later time).

In the first two cases, the channel is sensed busy by the large user. In the third case (idle slot), the channel is sensed idle by the large user who may "steal" these idle slots for transmitting his own packets; this significantly increases the total channel utilization. For a given ALOHA traffic rate G, the maximum achievable throughput rate Λ_2 at the large user is given through the Poisson formula by:

$$\Lambda_2 = e^{-G}. \tag{2}$$

Indeed Λ_2 may be defined as the expected value of the random variable (r.v.) $\tilde{S}$, the number of packets generated at the large user that are allowed to get "through" the channel in a given slot. Then

$$\Lambda_2 = E(\tilde{S}) = 1 \times P\{\tilde{S} = 1\} + 0 \times P\{\tilde{S} = 0\}.$$

Observing that $P\{\tilde{S} = 1\} = P\{\text{idle slot}\} = e^{-G}$, we get [1]

[1] The ALOHA channel traffic is an r.v. (with mean G) representing the total number of packets transmitted by all ALOHA users in a slot. The ALOHA channel traffic is assumed to be Poisson distributed. The accuracy of this assumption has been examined in [9] through simulation and has been shown to be quite good. The smaller is the throughput, the better is the Poisson approximation.

Eq. (2). Note that under steady state conditions, this maximum throughput Λ_2 is achieved with infinite delay at the large user. From Eqs. (1) and (2) and observing that $\Lambda_1 = S_1(1 + 2a)$ and $\Lambda_2 = S_2(1 + 2a)$, we obtain the total channel throughput rate (normalized with respect to P):

$$S = \frac{(G + 1)e^{-G}}{1 + 2a}. \tag{3}$$

The maximum value of S is achieved when $G = 0$ (no traffic from the ALOHA background):

$$C = \max S = \frac{1}{1 + 2a}. \tag{4}$$

Eq. (4) illustrates the fact that when the small users are quiet, a maximum throughput of 1 packet/slot may be achieved at the large user (with infinite delay) and also that for each packet transmitted, a portion of the channel is wasted (2τ seconds are wasted for control in each slot).

In Fig. 2 we plot the total channel throughput $\Lambda = S(1 + 2a) = (1 + G)e^{-G}$ and the ALOHA (small user) throughput Λ_1 normalized with respect to a slot versus the ALOHA traffic rate G. Λ decreases with increasing values of G from $1 (G = 0)$ to $0 \; (G = \infty)$.

Because of the ALOHA population, the channel eventually drifts into saturation (unstable channel), i.e., the throughputs (Λ_1 and Λ) will go to zero while the channel load will increase without bound [3]. However, by applying dynamic control policies [17], we can get a stable channel with a bounded ALOHA traffic. Therefore, the probability of an "idle" slot is greater than zero and we can achieve a throughput for the large user Λ_2 which is greater than zero. Since the performance obtained for slotted ALOHA by applying stabilizing control policies has been shown [9, 17] to be close to the quasi-stationary performance (for an unstable channel), clearly the same will be true when we include the large user as well as the ALOHA background which controls the channel. Throughout this paper, we use the ALOHA results achievable only over a finite time horizon (unstable channel) as approximate results for a stable channel and assume $G \leqslant 1$.

When $G = 1$ (Fig. 2), the ALOHA background achieves a maximum throughput (see Eq. (1))

$$\Lambda_1 = 1/e.$$

It is interesting to note that at this value the large user's throughput is also $\Lambda_2 = 1/e$ and so $\Lambda = 2/e$. When G goes to zero, so does Λ_1, but Λ_2 (which is also the probability of an idle slot) increases to 1. The probability of a conflict in a given slot between more than one (small) user (equal to $1 - \Lambda$) decreases as G goes to zero, from $1 - 2/e$ (at $G = 1$) to zero (at $G = 0$).

It can easily be shown [18] that the performance predicted from our model (Eqs. (1) to (4)) is much greater than the performance predicted by the large user model [9, 14]. In that model, first studied by L. Roberts in an unpublished note, one considers a large buffered user and a population of small users (modeled by an infinite population as described above). The large user and the small users compete on the same channel and *both* groups use slotted ALOHA.

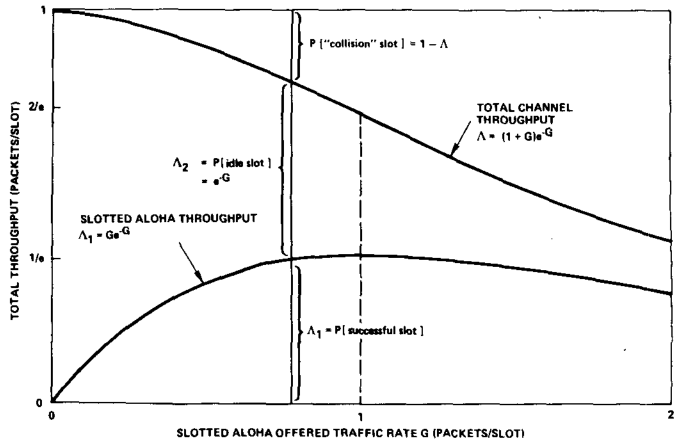

Figure 2. MACS: Total Channel and Aloha Throughputs versus G.

III.2 Delay Analysis for the Large User

In this section, we solve for the expected packet delay T at the large user normalized with respect to the packet transmission time P. The packet delay is defined as the time period elapsing from its instant of generation to the end of its successful transmission.

Let us define the "service time" $\tilde{x}$ of a packet at the large user as the number of slots it takes to transmit the packet from the first time the carrier is sensed at the large user for this packet, until the end of the transmission of this packet. Since the ALOHA channel traffic is Poisson distributed (see footnote 1), we have

$$P[\tilde{x} = k] = (1 - e^{-G})^{k-1} e^{-G} \qquad k \geqslant 1 \tag{5}$$

and so the service time $\tilde{x}$ is geometrically distributed with mean $E[\tilde{x}] = \bar{x} = e^G$.

A packet which is generated when the large user is idle must wait during a "rest period" until the beginning of the next slot before sensing the carrier, i.e., before its "service" starts. Therefore, we can model the large user as an $M/G/1$ queue with rest period [19], FCFS order of service, (Poisson) arrival process with intensity λ_2, geometric service time (with parameter e^{-G}) and deterministic rest period with length one slot. It is shown in [19] that the expected time in system (delay) in an $M/G/1$ queue with rest period is given by:

$$T = \bar{x} + \frac{\lambda \overline{x^2}}{2(1 - \lambda \bar{x})} + \frac{\overline{T_0^2}}{2\overline{T_0}} \tag{6}$$

where $\bar{x}$ and $\overline{x^2}$ are the first and second moments of service time, $\overline{T_0}$ and $\overline{T_0^2}$ are the first and second moments of the rest period and λ is the intensity of the Poisson arrival process.

In our model these quantities become

$$\left.\begin{aligned} \bar{x} &= e^G \text{ (slots)} \\ \overline{x^2} &= (2 - e^{-G}) e^{2G} \text{ ([slots]}^2) \\ \overline{T_0^2}/2\overline{T_0} &= \tfrac{1}{2} \text{ (slots).} \end{aligned}\right\} \tag{7}$$

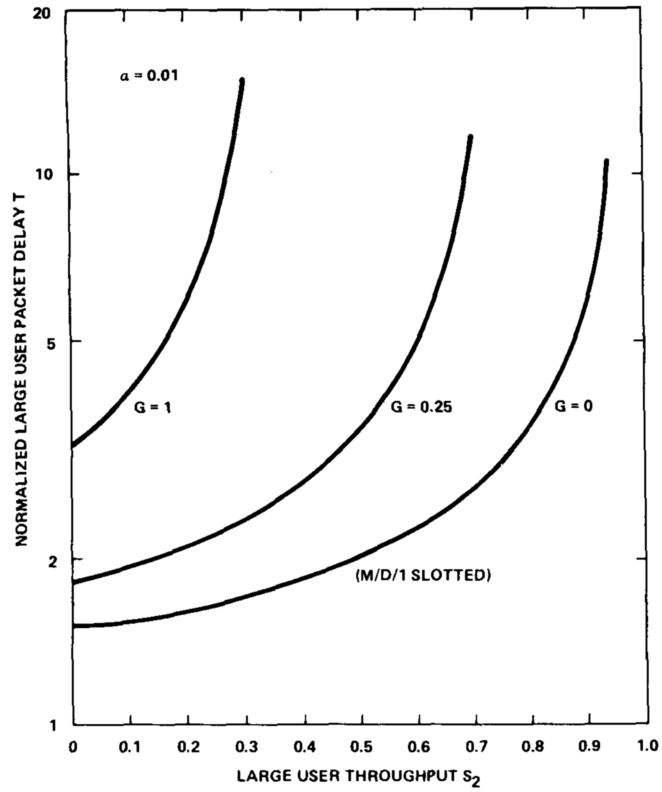

Figure 3. Effect of Small User Traffic on Large User Throughput-Delay Performance T versus S_2.

Recalling that the slot size is equal to $P(1 + 2a)$ and substituting Eq. (7) into Eq. (6), we finally have T expressed in units of P seconds as

$$T = \left[\frac{2 - \Lambda_2}{2(e^{-G} - \Lambda_2)} + \frac{1}{2}\right](1 + 2a) \tag{8}$$

where $\Lambda = \lambda_2(1 + 2a)P$ is the input rate at the large user normalized with respect to one slot.

III.3 Large User's Delay-Throughput Characteristic

From Eq. (8) it is clear that the limiting throughput at the large user is e^{-G} (with infinite delay) and that the expected packet delay increases as the small user traffic rate G increases. When $G = 0$, Eq. (8) reduces to the expression of the expected packet delay in an $M/D/1$ slotted system where the "service time" of each packet of the large user is exactly one slot.

This is illustrated in Fig. 3 where T is plotted versus the input rate S_2 at the large user normalized with respect to a packet transmission time P for various values of G.

The large user's throughput Λ_2 (packets/slot) and the small users' throughput Λ_1 (packets/slot) are compared in Fig. 4 for various values of D, the delay at the large user (expressed in slots: $D = T/(1 + 2a)$. The shaded region identifies the feasible region. The limiting contour Λ_1 versus Λ_2 (Eqs. (1) and (2)) for $G < 1$ corresponds to infinite delay at the large user. The region inside the boundary delimited by the axes $\Lambda_1 = 0$, $\Lambda_2 = 0$ and the contour Λ_1 versus Λ_2 for a given finite value of D (e.g., $D = 5$) represents the set of feasible achievable throughputs at the large user and the small users with the

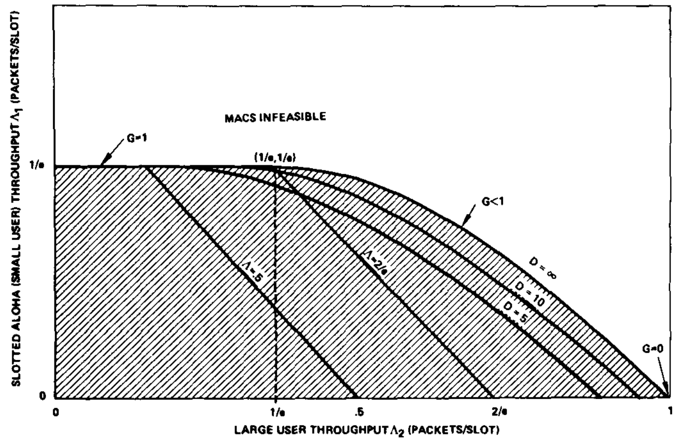

Figure 4. MACS: Λ_1 versus Λ_2 ($G \leqslant 1$).

constraint of a maximum average delay at the large user equal to D slots. Clearly with a maximum delay $D = 5$, the maximum achievable throughput at the large user is close to the limiting throughput (infinite delay) for all values of the ALOHA throughput.

IV. MACS VERSUS SPLIT CHANNEL MODE

The results of Section III justify the inclusion of traffic from the two different sources on the same channel since we may then achieve a very large total channel utilization. For example, if we ask that the ALOHA user population with MACS receive the same maximum throughput ($1/e$) as they could with slotted ALOHA, then, in addition, the large user can also receive $1/e$, thus doubling the channel throughput.

Here we approach the problem from a synthesis viewpoint. That is, given the traffic from source 1 (the small ALOHA users) and source 2 (the large user), the question is whether one should split the channel (of bandwidth W) so that a portion, αW of the bandwidth ($\alpha < 1$), is assigned to the large user and the rest, $(1 - \alpha)W$, to the small users; this we call the "α-split." The α-split will be compared to the case when we mix the two traffic sources according to the MACS mode studied above. We already know that for the small users, the best performance is obtained when they are provided the entire bandwidth. By splitting the channel, we increase the small users' delay and reduce their throughput. However, we inquire as to whether the large user gains by this split.

Assume an α-split of the channel. For all values of G (small users' traffic), since the slotted ALOHA throughput is equal to or less than $1/e$, we have the following constraint:

$$\frac{1 - \alpha}{e} \geqslant S_1 \text{ (packets/}P\text{)}. \tag{9}$$

From Eq. (1), we then have

$$\frac{1 - \alpha}{e} \geqslant \frac{Ge^{-G/(1+2a)}}{1 + 2a}. \tag{10}$$

Observing that α represents the maximum throughput achievable at the large user, the upper bound on throughput at the large user for a given value of G with an α-split is simply

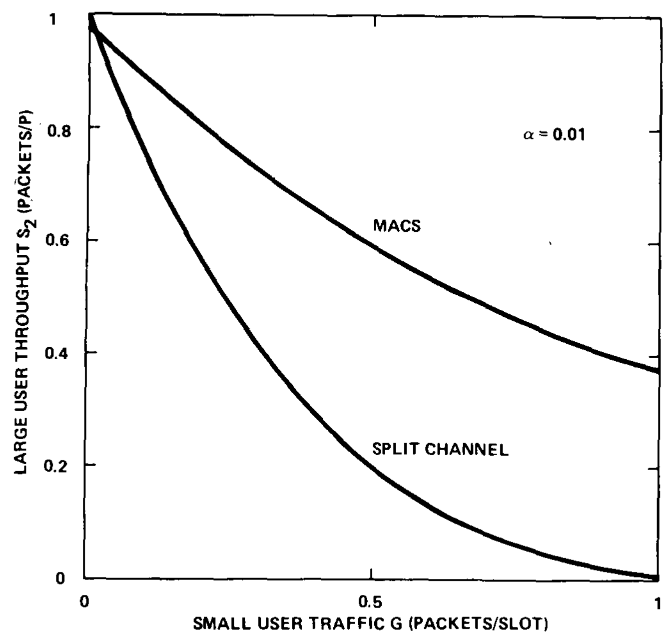

Figure 5. MACS and Split Channel: Effect of Small User Traffic on Limiting Large User Throughput Rate.

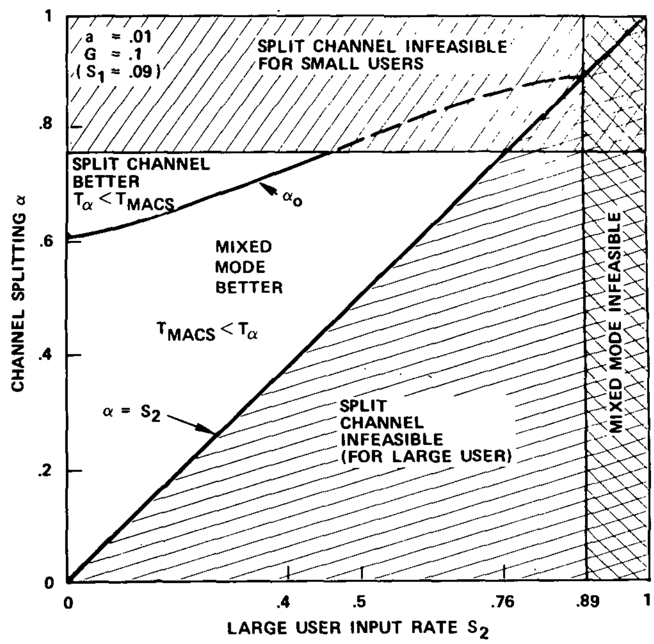

Figure 6. MACS and Split Channel: α versus S_2.

obtained from Eq. (10) as

$$\alpha \leqslant 1 - \frac{eGe^{-G/(1+2a)}}{1+2a} \triangleq S_{02}. \tag{11}$$

From Eq. (2) the maximum achievable throughput (in packets/P) at the large user with MACS for a given value of S is:

$$S_2 = \frac{e^{-G}}{1+2a}. \tag{12}$$

S_2 is plotted versus G for both systems (Eq. (11) and (12) in Fig. 5). It is clear from this figure that a larger limiting throughput is achieved at the large user with MACS than with an α-split (except when the small users' traffic is very low[2]). The larger G is, the more dramatic is the increase in throughput obtained with MACS: when $G = 1$, $S_2 = 1/e(1 + 2a)$ with MACS (Eq. (12)), while at $G = 1 + 2a$, $S_2 = 0$ with an α-split ($\alpha = 0$: the total bandwidth is required for handling the traffic of the small users who achieve a limiting throughput equal to $1/e$).

Both systems (MACS and α-split) may thus achieve a given large user throughput S_2 provided that the latter is not too large (from Eq. (11), $S_2 < S_{02}$). One wonders if for given values of G and S_2 ($< S_{02}$) there exists an α-split such that the expected large user's packet *delay* denoted by T_α is significantly lower than that obtained (for the same values of G and S_2) with MACS, previously denoted by T (Eq. (8)).

Modeling the large user by an $M/D/1$ queue, we have the Pollaczek-Khintchine formula [20]:

$$T_\alpha = \frac{1}{\alpha}\left[1 + \frac{S_2/\alpha}{2(1 - S_2/\alpha)}\right]. \tag{13}$$

[2] If $G \cong 0$, a throughput $S_2 = 1$ packet/packet transmission time is achieved with an α-split ($\alpha = 1$), while with MACS, $S_2 = 1/(1 + 2a)$; a small part $2a \ll 1$ of the channel capacity is lost for control. The case $G \cong 0$ is of little interest and will be omitted in the following discussion.

We wish to solve for α_0, such that:

$$T_{\alpha_0} = T$$

$$T_\alpha \leqslant T \qquad \text{for all } \alpha \geqslant \alpha_0. \tag{14}$$

Observe from Eq. (10) that we must have:

$$\alpha \leqslant 1 - \frac{eGe^{-G/(1+2a)}}{1+2a} \tag{15}$$

and obviously

$$\alpha \geqslant S_2.$$

Eq. (14) and (15) ensure us that an α-split is feasible for a given (G, S_2) pair.

Equating the right-hand sides of Eq. (13) and Eq. (8), we obtain a second degree equation in α, for which there is at most one solution α_0 which satisfies the constraints (14) and (15).

It turns out that for $G > .2$, the solution α_0 of Eq. (14) does not satisfy Eq. (15). In other words, when $G > .2$, to get a delay lower with an α-split than with MACS, one must dedicate a portion $\alpha W (> \alpha_0 W)$ of the bandwidth to the larger user, such that the remaining portion $(1 - \alpha)W$ is not sufficient to achieve the small users' throughput $S_1 = [Ge^{-G/(1+2a)}]/(1 + 2a)$; this, of course, is unacceptable. However, for $0 \leqslant G < .2$ and for a given value of $S_2 (\leqslant S_{02})$ the system of Eqs. (14) and (15) has exactly one solution, i.e., there is a range of possible values of α such that a split-channel provides lower delays at the large user than does MACS.

Five regions appear in Fig. 6 where α is plotted versus S_2 for $G = .1$, $a = .01$ and $S_1 = .09$.

In the first (doubly shaded) region for which $S_2 \geqslant .89$, MACS is not feasible. Because of the presence of the small users, one cannot achieve a throughput at the large user greater than .89.

In two regions we observe that the split-channel mode is not feasible. One or both among the constraints ($\alpha \leqslant 1 - eS_1$) and ($\alpha \geqslant S_2$) are not satisfied in these regions. As we already know (see Fig. 5), it is clear from Fig. 6 that the limiting throughput S_2 is lower with a split-channel mode (.76) than with MACS (.89).

In the two remaining regions, both the split-channel mode and MACS are feasible and comparable. The contour $\alpha_0(S_2)$ delimits the tradeoff. Above this contour ($\alpha \geqslant \alpha_0$), the delay at the large user is lower with the split-channel mode than with MACS ($T_\alpha < T$). Below this contour ($\alpha < \alpha_0$), $T_\alpha > T$.

Clearly, for $S_2 > .46$, there is no α-split providing a lower delay at the large user than MACS. In addition, even at very small values of the large user's throughput rate, in order to have $T_\alpha < T$, α must be greater than .6 (see Fig. 6). But with such an α-split (say $\alpha = 2/3$, the small users incur a significantly higher delay than they do when they share the entire bandwidth with MACS (this delay is approximately multiplied by three). Thus when the throughput rate S_2 is very small, a split-channel mode may provide lower delays than MACS at the larger user. But this implies a very significant degradation of the small user's delay (compared to that provided by MACS). And when S_2 is not too small, MACS definitely provides a better delay performance at the large user than does a split-channel mode.

In summary, MACS is not only justified in terms of the small users' performance, but it also improves the large user's performance. By sharing the entire bandwidth, the large user achieves more throughput with delays (under heavy traffic conditions) lower than those incurred when he is dedicated a fraction of the channel.

V. CONCLUSION

In this paper, we addressed the problem of allocating a communication radio channel to two independent sources of traffic: a large buffered user and a large population of (small) bursty users. The study of such a problem is motivated by the increasing need in communications between data terminals and computers[3] [2]. The simplest solution is to assign a dedicated channel to each source, the small users sharing their dedicated channel in a slotted ALOHA fashion which has been shown to be efficient and simple to implement [3]. As an alternative to this "split-channel" solution, we introduced and analyzed MACS by dynamically sharing the channel among the two sources; with MACS it is possible to save a large part of the channel capacity (wasted under slotted ALOHA) and, therefore, to very significantly increase the total channel utilization (see Section III). By providing the total available bandwidth under the control of the small (ALOHA) users, we increase their achievable throughput and decrease their packet delay. We have shown that not only is the small user performance improved, but also the performance of the large user is better with MACS than it is when dedicated channels are assigned to the large user and the small users [Section IV].

[3] The computer-to-terminal traffic (large buffered user's traffic) is assumed to be independent of the terminal-to-computer traffic (small user traffic). This is not a strong assumption if we consider for example that the computer is a part of a wire point-to-point network of computers: the terminals access any resource of the network of computers and the traffic addressed to the terminals is initiated anywhere in the network (and not only at the terminals themselves or at their "host" computer).

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