On the Performance of the Dynamic Packet Reservation Multiple Access Scheme

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Abstract

The performance of the Dynamic Packet Reservation Multiple Access (DPRMA) protocol over a Gilbert-Elliott fading channel is investigated in this work. The DPRMA protocol is designed for use in a wireless ATM system. A primary feature of DPRMA is the intelligent allocation of resources based on the requests submitted by each active mobile and on the Quality of Service (QoS) requirements of each type of user. The ability of a mobile to dynamically change its bandwidth reservation request is another feature of the system. The system investigated in this work contains voice, video conferencing, and data traffic. We demonstrate that DPRMA performs well in a harsh wireless environment.

1 An Overview of DPRMA

The Dynamic Packet Reservation Multiple Access (DPRMA) protocol, which was first proposed in [1], was inspired by the Packet Reservation Multiple Access (PRMA) protocol proposed by Goodman et al. in [2]. The DPRMA protocol assumes that system resources are divided into uplink and downlink channels and that the channels are divided into time slots. The DRPMA protocol specifies that the uplink allocation of resources is the responsibility of the base station. To accomplish this, each mobile is responsible for making a reasonable estimate of its bandwidth requirements and submitting a request for resource allocation to the base station. In the DPRMA scheme, the mobile's requirements are conveyed to the base station through several Reservation Request (RR) bits that are part of the header of each uplink time slot. The objective is to closely match each user's transmission rate with its packet generation rate.

It is assumed in this work that the packets that are being transmitted are ATM-sized cells (53 bytes, 5 of which are for the header). It is further assumed that the RR bits can replace some of the ATM header fields, and, thus will not add any additional overhead to the cells.

Since there will be a limited number of bits in the RR field, it therefore becomes necessary to restrict users to requesting only certain transmission rates, c_i. These rates are defined as:

$$c_i = 2^i \times C/n \qquad i_{min} \leq i \leq \log_2 n \tag{1}$$

where C is the data rate of the channel in bits per second, n is the number of slots in a frame, and i is an integer. The value for i_{min} dictates the smallest possible bandwidth allocation and can be set to any value that is appropriate for the system in question. For this study i_{min} was set to -3.

When a user has a new burst of information to transmit, it must first attempt to obtain a reservation. It sets the appropriate RR bits to indicate its rate request, contends for an empty slot, and monitors the downlink channel to determine its success or failure status from the base station. Success or failure is indicated via several Reservation Acknowledge (RA) bits in the headers of the downlink messages. The RA bits are accommodated within the downlink message in much the same way as the RR bits are in the uplink message. When a successful transmission has occurred, the base station immediately attempts to accommodate as much of the rate requested as is possible. If the total request cannot be fully accommodated, then a partial allocation is made. The base station keeps a record of any partial allocations so that the remaining request can be accommodated whenever the bandwidth later becomes available.

For further description of the DPRMA operation and performance evaluation on lossless channel, the reader is referred to [3].

2 Simulation Parameters

The three traffic types used in this work are: voice, video conferencing and data. Due to space limita-

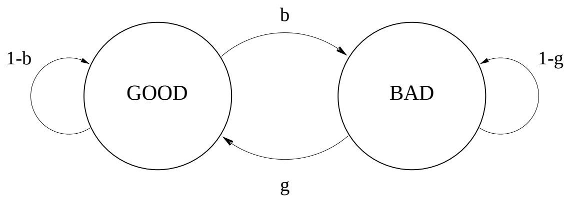

Figure 1: Markov chain of the Gilbert-Elliott model

tions, we will omit here the precise definitions of the three traffic types models; the reader is referred again to [3] for detailed description.

The channel we selected for this study has a capacity, C, of 9.045 Mbps and, therefore, can accommodate several video conferencing users, several hundred voice or data users, or some combination of the three. As we will describe shortly, the channel is characterized by a fading process, which may result in a temporary loss of communication between the mobile and the base station. For simplicity we assume that signal propagation delays are negligible.

The channel is divided into ATM-sized slots of 53 bytes each. The 48 bytes of payload remain unchanged from a standard ATM network. The 5 bytes of header, however, are modified to include all of the overhead associated with the MAC protocols. Any additional channel overhead is not accounted for in this study. The frame size was selected so that a reservation of one slot in a frame provides 35.333 kbps. This corresponds to a data rate for the payload of 32 kbps, which is the same as the transmission rate for voice traffic. Therefore, a voice user requires a reservation of one slot per frame. In order to accomplish this, the channel is divided into frames consisting of 256 slots. The frame length, T, is 12 msec, which results in slots that are 46.88 μsec long. The system parameters are summarized in Table 2.

Unless otherwise stated, all results are obtained by testing the performance of the protocol for 400 simulated seconds. All users initiate calls at randomly spaced intervals prior to the beginning of the timed simulation. All connections are maintained for the duration of the test.

The channel model selected for use in the simulations is a Gilbert-Elliott model [4] [5]. This model specifies that the channel is binary symmetric. It can be described via the two-state discrete-time Markov chain, shown in Figure 2. Here the channel alternates between a GOOD state and a BAD state with transition probabilities g and b. Probabilities of bit error are p_g and p_b in each state, respectively. The Gilbert-Elliott channel model is a very popular fading model and has been used in other works (e.g., [6] and [7]).

We define the parameter $\Gamma = \tau_t/\tau_0$, where τ_t is a threshold Signal to Noise Ratio (SNR) and τ_0 is the

Channel Capacity (Mbps)	C	9.045
Frame Length (msec)	T	12
Slots per Frame	N	256
Slot Length (μsec)	T/N	46.88
Slot Size (bytes)	D	53
Average time spent in ON state for voice (sec)	β^{-1}	1.0
Average time spent in OFF state for voice (sec)	α^{-1}	1.35
Video Frame length (msec)	F	40
Peak cell generation rate for video (cells/VF)		220
Average cell generation rate for video (cells/VF)		104.8
Average arrival rate for data (cells/sec)	λ	94.34
Max allowed transmission delay for voice (msec)	D_v	40
Max allowed transmission delay for video (msec)	D_{vc}	40
Max transmission buffer size for data (kBytes)	B	10
Max allowed cell dropping probability for voice	P_{vdrop}	10^{-2}
Max allowed cell dropping probability for video	P_{vcdrop}	10^{-4}
Max allowed cell dropping probability for data	P_{ddrop}	0.0

Table 1: Values of the basic system parameters

average SNR that a users encounters in the system. A transition from a GOOD to a BAD state corresponds to a user's SNR falling below τ_t. Likewise, a return back to the GOOD state coincides with the SNR rising above τ_t.

If we assume that there is Rayleigh fading and that the channel is slow fading with respect to bit intervals, then the state transition probabilities can be expressed as (see [8] and [9]):

$$g = \frac{f_d T_s \sqrt{2\pi\Gamma}}{\exp(\Gamma) - 1}, \quad b = f_d T_s \sqrt{2\pi\Gamma}, \tag{2}$$

where T_s is the symbol interval. The maximum Doppler frequency, f_d, is given by:

$$f_d = \frac{v f_c}{c} \quad , \tag{3}$$

where v is the velocity of the user, f_c is the carrier frequency, and c is the speed of light. By carefully selecting appropriate values for these fading parameters, we can assess the performance of the DPRMA system on this fading channel.

In order to further simplify the analysis, we assumed that the system uses Forward Error Correction (FEC). The probability of a bit error in the GOOD state is on the order of 1×10^{-6}, which implies an extremely low probability of uncorrectable error. Therefore, we approximate that in the GOOD state, no packets are transmitted with errors.

When a user is operating in a BAD state, the probability of bit error is quite high, typically on the order of 0.2 to 0.5, and the probability of uncorrectable errors is consequently high as well. We will consider the worst case scenario; i.e., in the BAD state, all packets have uncorrectable errors.

One additional approximation was made to simplify the simulation. Although transitions from GOOD to BAD states can occur at each symbol interval, the results of the transition are not considered until the beginning of the next slot. In this manner, it is assumed that no transitions will occur in the middle of a packet transmission. For the range of fading parameters considered, this was found to be a reasonable approximation.

2.1 Protocol Modifications

In order to facilitate the use of DPRMA in this fading environment, a few changes to the protocol were required. First, in our original work, we have specified in the QOS requirements for data that no packets can be lost. However, in the fading channel packets are often lost when in the BAD state. We must, therefore, allow retransmissions to take place in order to meet the QOS requirements of the data users. No retransmissions will be allowed for real-time traffic, since some packet loss is permitted, and we assume that the delay constraints are too tight to allow for successful retransmissions. In order to accommodate the data retransmissions, sequence numbers and an Automatic Repeat reQuest (ARQ) protocol were implemented for this traffic type. Since the base station can acknowledge packets in the next slot of the downlink channel, there is never a significant wait for feedback about a user's transmission. The most appropriate ARQ protocol was found to be Go-Back-N. Since the response from the base station arrives within one slot time, we require a send window of only two and, consequently, a two-bit sequence number suffices and corresponds to very little overhead in the protocol.

The second change to the DPRMA protocol is brought about in order to reestablish reservations that have been lost due to fading conditions. From the user's perspective, when a BAD fading state is entered, the user is unable to determine which slots are reserved for which users. In the absence of this information, the user refrains from transmitting until conditions improve. While the user is in the BAD fading state, it has no way of knowing if it has missed a slot reservation or not. If it has, then its reservation has been forfeited. Otherwise, transmission can continue as it did before. To compensate for this problem, video and data users must set a timer whenever they determine that they have passed through a BAD fading state. This timer is set upon exiting from the state. If the user detects a reserved slot with its own ID number in it before the timer expires, then it knows that the base station has not removed

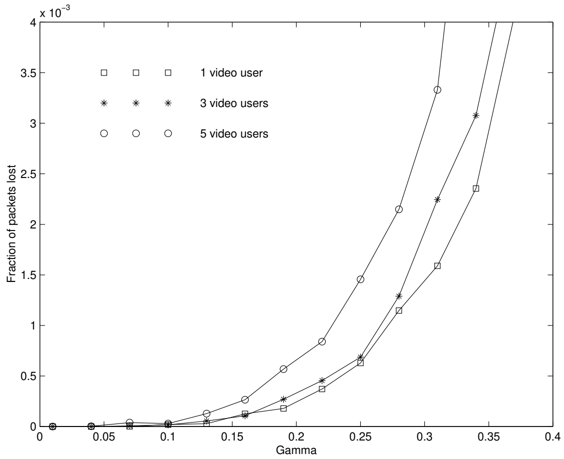

Figure 2: Fraction of video packets lost vs. Γ

the reservation. The timer can then be ignored. If the timer expires, however, then the user will assume that the reservation has been lost and will attempt to reestablish it. In this scenario, the base station must always check new reservation requests to ensure that the user does not already have an established reservation.

This approach was tested for video and data users and produced very good results. The voice users also implemented the timers, but a different approach was considered in this case. Voice users are always assigned the same slot in every frame. Therefore, it is known exactly how much time will elapse before the next reserved slot arrives. The voice users set their timers immediately after they transmit. If one frame time passes without a reserved slot arriving, the user knows with complete certainty that its reservation has been lost and it should begin contending again.

The selection of appropriate timer settings is clearly important in ensuring that the system performs efficiently and is discussed further in the next section.

2.2 Fading Simulations

In order to optimize the system performance, the optimal transmission probabilities for each user type needs to be determined. A system with all types of users present was simulated and the transmission probability for each user type was varied in order to determine the optimal values. A transmission probability for video of 0.4 was found to provide the best service for the video users. For voice users, the appropriate transmission probability was found to be 0.1 and for data users, 0.007.

In the first part of this study, the effect of the transition probabilities on the system performance was

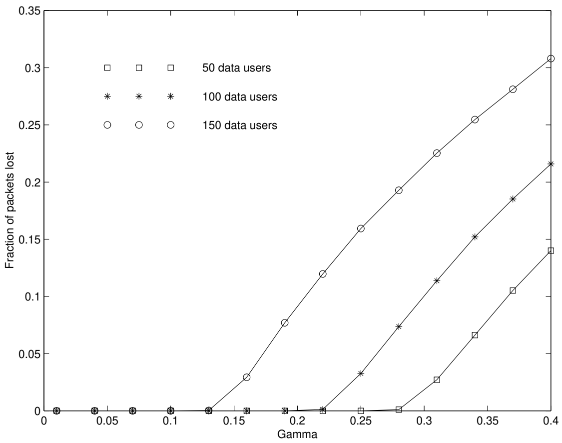

Figure 3: Fraction of data packets lost vs. Γ

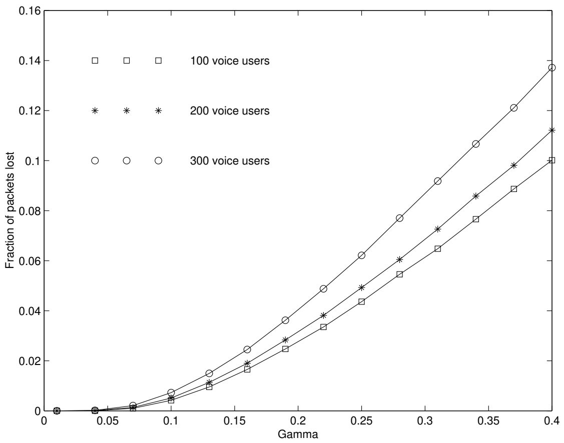

Figure 4: Fraction of voice packets lost vs. Γ

analyzed. Equation 2 were calculated with Γ ranging from 0.01 to 0.4, with $v = 60$ mph, with $c = 3 \times 10^8$ m/s, and with $f_c = 800$MHz. With Binary Phase Shift Keying (BPSK) as the modulation scheme and the parameters from Table 2:

$$T_s = \frac{T}{8ND} = 1.106 \times 10^{-7}. \qquad (4)$$

Each user in the system makes transitions between GOOD and BAD fading states independently of all other users.

Simulations were run while varying Γ values in a single user-type system. The number of users was fixed, and the fraction of packets that were lost during the simulation was plotted as a function of Γ. Acceptable time-out values were determined for each user type prior to the simulation. Different timer values were tested in a single-user system and the value that produced the lowest packet loss was selected. For the video-conferencing traffic this value was determined for $\Gamma = 0.1$ and $N_{vc} = 5$, and it was found to be $T/32$. For the data users, this value was determined for $\Gamma = 0.1$ and $N_d = 100$, and it was found to be T.

The results of the simulation of DPRMA for video conferencing users can be seen in Figure 2.2. Here simulations were run separately for $N_{vc} = 1$, $N_{vc} = 3$, and $N_{vc} = 5$. In all three cases, the protocol is able to support the QOS requirements of the video users for a certain range of Γ values. With $N_{vc} = 1$ and $N_{vc} = 3$ this range is $\Gamma < 0.16$, and with $N_{vc} = 5$ this range is $\Gamma < 0.13$.

For data users, the results produced by DPRMA can be seen in Figure 2.2. In this case simulations were run with N_d values of 50, 100, and 150. With 50 users present, QOS requirements could be maintained as long as Γ was below 0.28. When this number was increased to 150, the value for Γ could not exceed 0.13 without affecting the QOS guarantees.

The results of a system with only voice users present are shown in Figure 2.2. This system was tested with the number of voice users present set at 100, 200, and 300. A system with 400 users was tested as well but with this many users present, the contention in the system is too great to be handled for $\Gamma \geq 0.04$. Above this value, the system throughput approaches zero due to an excessive number of collisions. When 100 users are present, the system performs within the QOS requirements for $\Gamma < 0.16$, and when 200 or 300 users are present the performance is acceptable for $\Gamma < 0.13$.

In all of the cases considered here, reasonable results are provided if Γ is set sufficiently low. Since Γ is the ratio of average SNR to threshold SNR, we consider a value around 0.1 to be a reasonable choice for Γ [10]. In all of the cases considered here, this value of Γ provides each user-type with an acceptable level of QOS. Thus, we will use this value for all subsequent simulations.

The next step in our study is to test the functionality of DPRMA in a fading environment when all three traffic types are present. Our objective is to determine the maximum number of users that the system can accommodate. The results for the DPRMA simulation can be seen in Figure 2.2. Here we note that we are able to accommodate a significant number of users into the system despite the implementation of the fading model. The throughput values associated with these results can be seen in Figure 3. These values range from 0.62 down to 0.48.

When the fading model results are compared to the results from the non-fading channel (see [3]), there is a drop in performance. For example, the number of data users that can be admitted decreases by 60 to 85 users. Throughput decreases by about 30%. With the fading model, users very frequently lose

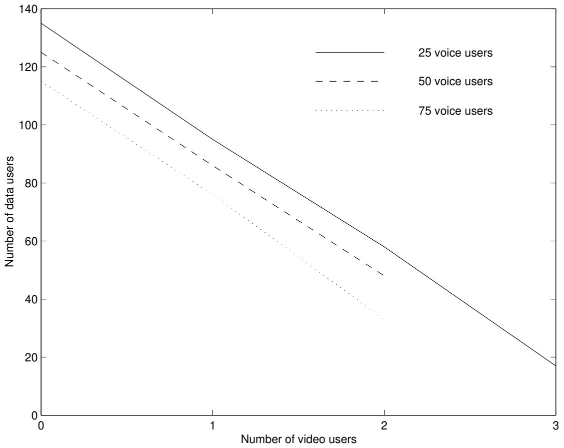

Figure 5: Maximum number of data users vs. number of video users

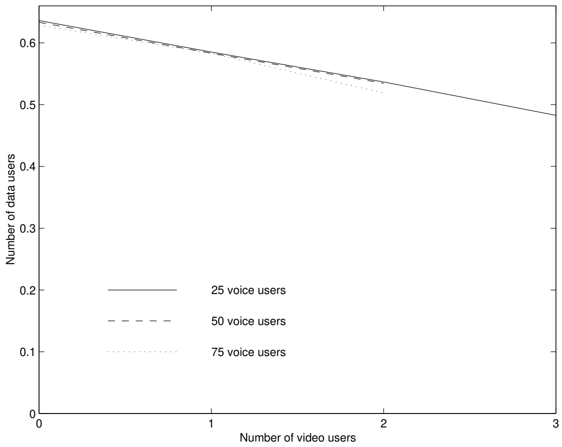

Figure 6: Maximum throughput vs. number of video users

their reservations and must re-acquire them, thereby causing packet transmission delay and packet loss. Despite this degradation of performance, the results that are shown for DPRMA are very encouraging, when we consider the fraction of time that the users remain in the BAD fading state for $\Gamma = 1.0$, which is nearly 10%; $\frac{b}{g+b} = \cdots = 0.095$. As this portion of time is quite significant, we conclude that the performance achievable by DPRMA is very reasonable.

3 Conclusion

We have demonstrated that the Dynamic Packet Reservation Multiple Access protocol performs well in the fading wireless channel with multiple traffic types present. There are several major advantages that DPRMA offers. First, the designation of the base station as the resource allocator allows intelligent allocation of bandwidth based on all users' requirements. Thus, the delay constraints of real-time traffic can be easily met. This improvement comes at the expense of increased queueing delay for the non real-time traffic users. However, this additional delay is with the QoS requirements specified by these users. An additional feature of DPRMA is the ability of reservation updates to be submitted in a contention-free manner. This decreases the contention in the system and increases throughput. We envision that schemes such as DRPMA will play a central role in the implementation of the third generation wireless data systems.

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