The Dynamic Packet Reservation Multiple Access Scheme

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Abstract

The performance of the Dynamic Packet Reservation Multiple Access (DPRMA) protocol for Medium Access Control (MAC) is investigated in this work. This MAC protocol is designed for use in a wireless ATM system. A primary feature of DPRMA is the centralized controller, a base station in a cellular system, whose responsibility is to allocate resources on the uplink channel. The base station does this in an intelligent fashion based on the resource demands submitted by each active mobile and the Quality of Service (QoS) requirements of each type of user. Each user is responsible for providing updated information about its immediate bandwidth needs. The ability of the mobile to dynamically change its bandwidth reservation request is another primary feature of the system. The system investigated in this work contains voice, video conferencing, and data traffic.

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 DPRMA 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, which includes 5 byte 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 becomes available later.

For further description of the DPRMA operation the reader is referred to [3].

2 Simulation Results

The three traffic types used in this work are: voice, video conferencing, and data. Due to space limitations, we will omit here the precise definitions of the three traffic types models; see [3] for detailed description.

Queue Length	Transition from	Transition to
6	70.667 kbps	141.333 kbps
11	141.333 kbps	282.667 kbps
16	282.667 kbps	565.333 kbps
21	565.333 kbps	1.131 Mbps
26	1.131 Mbps	2.261 Mbps
31	2.261 Mbps	4.523 Mbps
26	4.523 Mbps	2.261 Mbps
21	2.261 Mbps	1.131 Mbps
16	1.131 Mbps	565.333 kbps
11	565.333 kbps	282.667 kbps
6	282.667 kbps	141.333 kbps
1	141.333 kbps	70.667 kbps

Table 1: Threshold levels for video conferencing sources

Queue Length	Transition from	Transition to
10	70.667 kbps	35.333 kbps
30	35.555 kbps	70.667 kbps

Table 2: Threshold levels for data sources

In addition to our general performance analysis of DPRMA, we desire to demonstrate the areas where this protocol offers an improvement over PRMA. We do this by comparing it to a multimedia PRMA protocol, which we shall refer to as PRMA*.

2.1 PRMA* Description

The adaptation to PRMA that permits it to accept VBR users simply involves allowing a user to reserve multiple slots in each frame. The user must monitor both the number of slots it needs and the number of slots it currently has reserved. The users must contend for each slot individually, and there is no communication between the mobile and the base station to indicate how many slots are available and how many the user will attempt to acquire. Each time the user successfully contends for and gains a slot reservation, it is allocated the same slot in subsequent frames. In addition, the user continues to maintain a reservation in all the slots it had previously reserved in past frames. Whenever a user wishes to decrease the number of slots it has reserved, it leaves the appropriate number of slots empty. The presence of an empty slot does not imply that the user's entire reservation is being released, but rather that a single slot reservation is being given up. When the user needs to release all of its reserved slots, the base station will not be aware of this fact until it observes that all slots have been left empty by that user.

This modified PRMA protocol (PRMA*) requires that the mobiles are able to determine their own reservation requirements, which is done in the same manner as in DPRMA. The PRMA* users will be allowed to attempt to obtain reservations for the bit rate intervals specified in equation 1. When a rate increase is required, the user will contend for new slots until it has successfully obtained reservations in the appropriate number of slots. When a decrease is required, the user will cease transmission until the appropriate number of its reserved slots have been released.

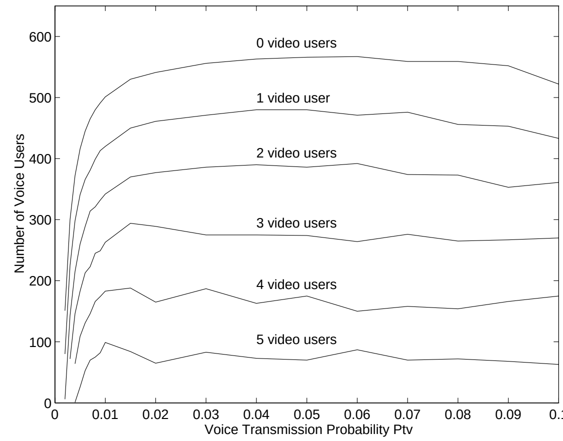

Figure 1: Maximum number of voice users allowed into the DPRMA system vs. P_{tv} with $P_{tvc} = 0.3$, $P_{vdrop} = 0.01$, and $P_{vcdrop} = 0.0001$

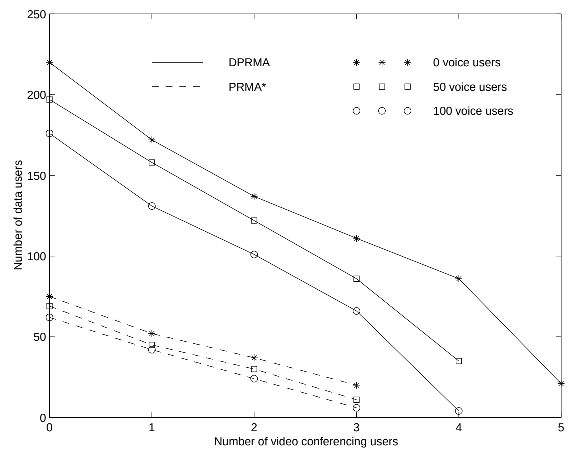

Figure 2: Maximum number of data users vs. number of video users in a voice, video and data system at maximum capacity; $P_{vdrop} < 0.01$, $P_{vcdrop} < 0.001$, and $P_{ddrop} = 0.0$

2.2 Parameter Optimization

Several system parameters must be optimized to ensure the maximal capacity of the DPRMA scheme. In particular, the appropriate transmission probabilities and threshold level pairs must be determined for each user type. Since for the voice users the packet generation rate exactly matches one of the possible transmission rates in the system, no threshold levels are need. Threshold levels were required for data and video traffic and were determined based on an analysis of each traffic type. The threshold levels used for video and data traffic are shown in Tables 1 and 2.

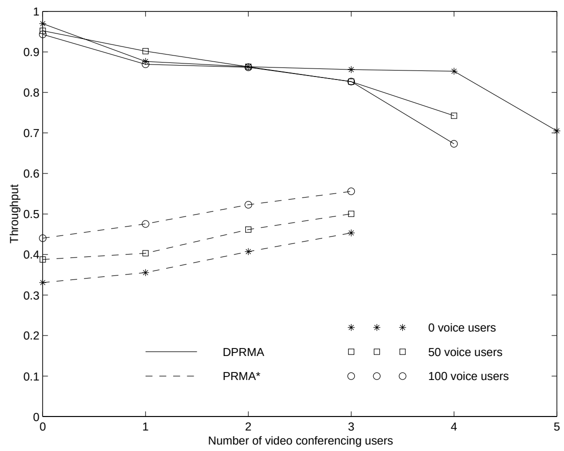

Figure 3: Maximum throughput vs. number of video users in a voice, video and data system at maximum capacity

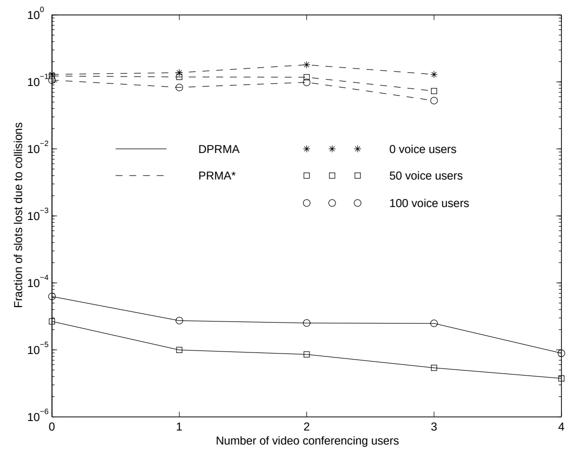

Figure 4: Fraction of slots lost due to collisions vs. number of video users in a voice, video and data system at maximum capacity

These threshold levels are selected such that users very infrequently lose reservations once they have been obtained. In our simulations we assumed that connections are maintained for the entire duration of the simulation. Therefore, the selection of transmission probabilities for video and data traffic in the DPRMA system is not a significant problem. The transmission probability for video, P_{tvc}, was set to 0.3 and the transmission probability for data, P_d was set to 0.007.

The selection of an appropriate transmission probability for the voice users is of greater consequence to the DPRMA system. Since voice users are frequently alternating between ON and OFF states they will often lost their reservations. This introduces significant contention into the system and, therefore, the transition probability, P_{tv}, must be selected with care. Fig. 1 shows the effect that different values of P_{tv} have on the maximum capacity of a voice and video system. This figure was generated by varying P_{tv} and then increasing the number of voice users present, N_v, until the QoS requirements for one of the user types was violated. These results show that with different numbers of video users present, N_{vc}, the value of P_{tv} that produces the maximum system capacity is between 0.05 and 0.06. Since we are studying an ALOHA-based protocol, the issue of a bistable system must be considered. To help avoid operating in this type of a system, we choose the lower value for P_{tv}, 0.05.

In the PRMA* system the same transmission probability parameter optimization was required. The approach taken was identical to that in Fig. 1. The transmission probabilities for the different user types were varied and simulations were run in a multi-user system. The values that produced the highest system capacity were selected for the appropriate user types. These values are: $P_{tvc} = 0.3$, $P_{tv} = 0.05$, and $P_{td} = 0.003$.

2.3 Voice, Video and Data System

For the simulations, we consider a system that has all three user types present, and we compare the performance of the DPRMA and PRMA* protocols. The results can be seen in Figs. 2 and 3. Fig. 2 shows the maximum number of data users that can be admitted into the system for varying values of N_v and N_{vc}. In all cases DPRMA outperforms PRMA*. The DPRMA protocol admits between 70 and 140 more data users than does PRMA*, while still maintaining QoS requirements.

The system throughput that results when the maximum system capacity is achieved is shown in Fig. 3. Here it is shown that DPRMA produces very high system throughput, ranging from 0.66 up to 0.97. The throughput in the PRMA* system ranges from 0.33 to 0.59. It is interesting to note that the throughput in the DPMRA system decreases as the number of video conferencing users increase, but in the PRMA* system the opposite is true. In the DPRMA system this decrease is due to the high bandwidth and degree of statistical variation in the video traffic. When more video users are present, more bandwidth must be set aside to ensure that these users will be able to get the resources they need in periods of heavy load. In the PRMA* system, however, it is the presence of data users that presents a serious impact on the throughput. Data users in this system are not permitted to make reservations. Therefore, a significant amount of bandwidth is lost due to the contention that these users introduce. When more video users are added to the system, fewer data users can be accommodated. However, the resulting combination of users has a higher throughput since the contention has been reduced. This indicates that the DPRMA feature of allowing data users to obtain bandwidth reservations improves the system performance over PRMA*.

The reason for the lower throughput that results in

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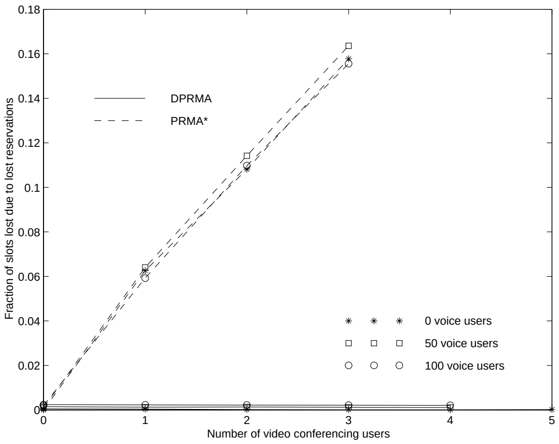

Figure 5: Fraction of slots lost due to lost reservations vs. number of video users in a voice, video and data system at maximum capacity

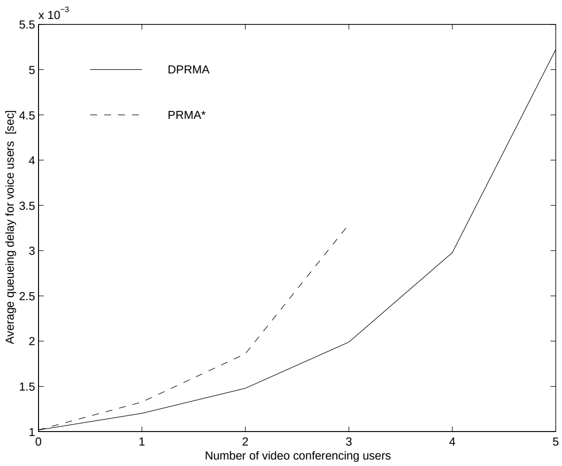

Figure 6: Average queueing delay for voice users in a voice/video/data system; $N_d = 25$ and $N_v = 25$

the PRMA* system can be seen clearly in Figs. 4 and 5. The first figure shows the fraction of slots that are left empty in the system because a user has no more packets to transmit. These results were obtained in conjunction with those in Figs. 2 and 3. Consequently, they indicate the fraction of slots left empty when the system is operating at full capacity. In the PRMA* protocol, a slot is left empty each time the user wishes to reserve one fewer slot. Therefore, each time rate requirements decrease, the user could leave multiple slots empty within the frame. Users in the DPRMA system, on the other hand, provide the base station with this rate information in advance. This allows the base station to reallocate the unneeded slots to other users or to declare that they are available for access by new users. Fig. 5 indicates that many slots are wasted in this manner in the PRMA* system.

Another source of loss in throughput is due to the

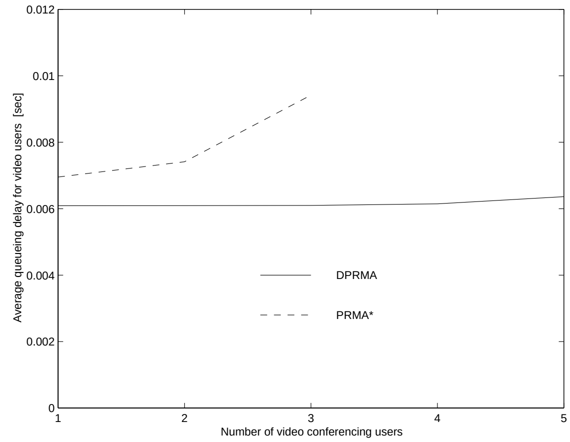

Figure 7: Average queueing delay for video users in a voice/video/data system; $N_d = 25$ and $N_v = 25$

number of slots that are wasted when collisions occur in the system. Fig. 5 shows how the two protocols compare in this performance measure. In PRMA* 6% to 18% of the slots are wasted due to collisions, compared to DPRMA where a maximum of 0.006% are lost. The increase in collisions in the former system is due in part to the process by which video users must contend for slots to increase their transmission rate. The presence of the data users introduces significant contention as well, since data users cannot reserve slots. This is a serious drawback to the PRMA* system. The only major source for collisions in the DPRMA system is from the voice users.

These results show that the improvements offered by DPRMA are due to the fact that we have removed much of the throughput loss associated with collisions and empty slots in PRMA*. The contention-free reservation update mechanism of DPRMA is, therefore, a major advantage in the MAC protocol issue.

2.4 Average Queuing Time

The next set of simulations were run to measure queueing delays that were produced for the two protocols. A voice, video, and data system was investigated, where the number of voice and data users was fixed at 25 users apiece. The number of video users was incremented and queueing delays for all user types were measured. The results can be seen in Figs. 6 and 8. These results demonstrate the improvement in queueing delay that DPRMA offers for voice and video users.

Fig. 6 shows the queueing time for the voice users in the simulation. In all cases, DPRMA outperforms PRMA* by producing delays that are 0.01 to 1.4 msec less than those produced by the latter protocol.

The corresponding delay results for video users can be seen in Fig. 7. In this case again, DPRMA clearly performs better. The average queueing times for DPRMA are 0.8 to 3.3 msec less than those for PRMA*. For both protocols, the delays are several msec greater than those suffered by the voice users. Since the transmission rate of this traffic type can change throughout the transmission, the delays are dependent upon several factors. These factors include the initial access delay, the number of packets in the queue, and the threshold level parameters. For PRMA*, the increase in the number of users in the system effects the delay in a manner that is similar to the effect for voice. The presence of more users produces greater average queueing time due to a higher slot occupancy and an increase in collisions. For DPRMA however, the video packets suffer a fairly uniform amount of delay regardless of the number of users in the system. An increase in users only produces a slight change in the results. Since the DPRMA protocol does not generally lose reservations during a simulation, the effect of the access delay on the traffic is no longer significant. The main cause of the small increase in the queueing time is due to the delay that the video users suffer when they update their reservation requests. Having more users present in the system decreases the availability of slots. Therefore, when a video user wishes to increase its rate request, often there may be no channel capacity immediately available to accommodate it. An increase to the average queueing time results. Fig. 7 indicates that this effect is very small for DPRMA.

Fig. 8 shows the average queueing delay experienced by data packets in the same system. For DPRMA, data users experience up to 170 msec more queueing delay than do those in PRMA*. The data users in PRMA* are permitted to attempt transmission of new packets as soon as they are generated. The delay is then only dependent upon the current system utilization and the number of users simultaneously contending for slots. If these values are low enough, the user will be able to transmit its packet very quickly. Indeed, Figure 2.4 shows that for low system load the delay seen by the data packets is less than 10 msec.

3 Conclusion

The suitability of the Dynamic Packet Reservation Multiple Access protocol for a wireless system is clearly demonstrated in this work. In particular, it has been shown how well the protocol performs with multiple traffic types present. The improvements that DPRMA offers over the PRMA family of protocols is quite significant. 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

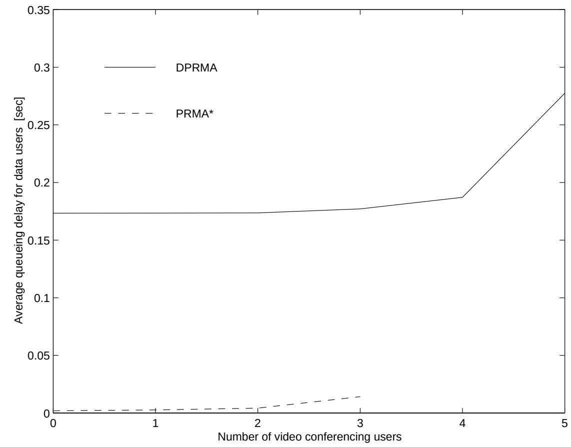

Figure 8: Average queueing delay for data users in a voice/video/data system; $N_d = 25$ and $N_v = 25$

queueing delay for the non real-time traffic users. However, this additional delay is within 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. Finally, although the system performance is degraded in a fading environment, the results that are obtained are considered acceptable given the amount of time the users spend in a bad fading state.

References

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