# MULTI-FRAME PACKET RESERVATION MULTIPLE ACCESS FOR VARIABLE-RATE MULTIMEDIA USERS

*J. Brecht, L. Hanzo, M. Del Buono*

Dept. of Electr. and Comp. Sc., Univ. of Southampton, SO17 1BJ, UK.
Tel: +44-703-593 125, Fax: +44-703-593 045
Email: lh@ecs.soton.ac.uk
http://www-mobile.ecs.soton.ac.uk

## ABSTRACT

**Multi-frame Packet Reservation Multiple Access or MF-PRMA is proposed for supporting multi-rate, multi-media users in high-rate systems employing time-division multiframes. PRMA and MF-PRMA are compared for a variety of traffic scenarios using optimised system parameters.**

## 1. INTRODUCTION

A possible approach to supporting multi-rate users in Packet Reservation Multiple Access (PRMA) is the introduction of a hierarchical structure of PRMA multiframes, which comprise a certain number of frames. This protocol will be referred to as MF-PRMA. In a TDMA system a terminal can only reserve one slot per frame. Namely, if $M$ is the number of frames per multiframe, a reservation of $n_R < M$ slots per multiframe corresponds to a reservation rate lower than that of one slot per frame. The reservation rate can be reduced down to $(1/M)^{th}$ of the reservation rate of the original structure. Initially, we assume that a certain reservation rate is associated to each column in Figure 1. This will be referred to as the reservation level of the column. Figure 1 displays an example for two columns, where a high-rate video user would choose the column with a high reservation rate, one slot per frame, while a speech user only needs one slot every fourth frame and is transmitting in slots of the appropriate column. A terminal seeking to transmit packets for a certain service will thus contend in a column with the reservation level that is most suitable for the required service.

The introduction of a reservation expiry time, which allows a delayed reservation cancellation, reduces the number of contentions and improves the performance of a MF-PRMA system.

## 2. MULTI-RATE PERFORMANCE OF STANDARD PRMA

In order to pinpoint the deficiencies of standard PRMA in supporting multi-rate users, below we characterise its performance as a function of reservation rate, using the parameters of Table 2[1] [2]. We adopted a variable frame size in the range of 10 ... 30 slots per frame and a reservation expiry time of zero or one slots. We also limited the maximum number of reserved sots per frame per terminal. With 30 simultaneous conversations, the system throughput is $Z_{max} = 0.63$. Simulations were carried out transmitting 500000 slots, equal to 400 seconds of speech.

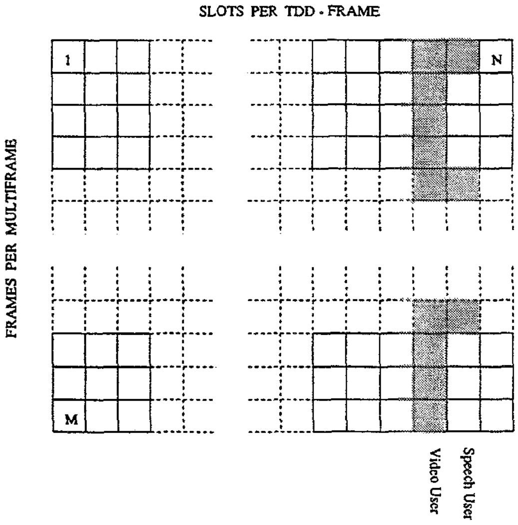

Figure 1: Multiframe comprising $M$ frames - example for slots occupied by a speech and a video user

Initially we examined the influence of the number of generated packets (cells) per frame ratio $C_F$ on PRMA efficiency. In most of the former studies on PRMA, $C_F = 1$ was assumed [1] [2], and the performance was then measured as a function of the other parameters of Table 1. The results represented in Figure 2 show the effect of varying $C_F$. Explicitly, by changing the number of slots per frame, we can vary $C_F$ without affecting the channel rate, source rate or slot size. In view of the fact that a terminal loses its reservation, if it cannot provide a ready-to-send packet in each frame, $C_F < 1$ leads to an increased number of contentions and thus to an increased number of collisions. It is obvious that for $C_F < 1$, i.e. a reservation rate higher than the source rate, PRMA efficiency is decreasing. On the other hand, for $C_F > 1$, delay problems occur, if each terminal is only allowed to reserve one slot per frame, since the reservation rate is lower than the source rate. If a terminal may reserve more than one slot per frame and $C_F$ is smaller than this integer number, the number of collisions is increasing

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| Definition | Notation | Unit | Value |
|---|---|---|---|
| Channel Rate | $R_C$ | kbps | 720.0 |
| Source Rate | $R_S$ | kbps | 32.0 |
| Gross Slot Size | $S_G$ | bit | 576 |
| Net Slot Size | $S_N$ | bit | 512 |
| Header Size | $H$ | bit | 64 |
| Number of Conversations | $U$ | | 30 |
| Permission Probability | $p$ | | 0.3 |
| Maximum Delay | $D_{max}$ | sec. | 0.03 |
| Max. No. of Reserved Slots/Frame/Terminal | $n_R$ | | 1 or 2 |
| Reservation Expiry Time | $T_{exp}$ | slots | 0 or 1 |
| Slots per Frame | $N$ | | 10 to 30 |

Table 1: PRMA parameters for initial simulations

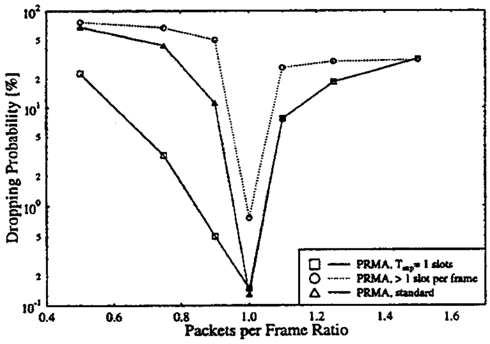

Figure 2: Initial simulation on a 720 kbps channel using the parameters displayed in Table 2

for the reasons mentioned in the $C_F < 1$ case. Namely, the terminal cannot provide a sufficiently large number of ready-to-send packets in each frame in order to keep the reservations. Hence reservations are cancelled and new contentions are needed to transmit the forthcoming packets. Figure 2 shows clearly, that for $C_F \neq 1$, only the approach in which a reservation expiry time of $T_{exp} = 1$ slot is used seems promising for multi-rate systems. In addition, the constraint $0.5 < C_F < 1$ must be fulfilled.

Figure 2 shows that slight changes in $C_F$ lead to enormous variations in PRMA performance. This very high susceptibility to non-optimum sets of PRMA parameters was also shown with regard to the permission probability in Reference [1]. It has to be considered as one of the major drawbacks of any PRMA system.

## 3. MULTI-RATE PERFORMANCE OF MF-PRMA FOR ON-OFF TYPE SERVICES

Let us now consider multiframe PRMA. We assume a MF-PRMA architecture similar to that described in Section 1.

As an outlook towards wireless ATM, a high rate system will be investigated. Table 2 shows the system variables used for our simulations, where the net and gross slot size as well as the number of slots per frame represent parameters chosen for the MEDIAN wireless ATM Pan-European project [3]. Since simulations for the 155 Mbps WATM rate are extremly time consuming, we used a reduced channel rate of 50 Mbps. This could be considered as a lower bound for wireless interactive multimedia systems. As in the MEDIAN system, the first two slots of each frame are used for physical layer synchronisation information and broadcast information, respectively [3]. Simulation were carried out for 32,000,000 slots, equal to 655 seconds of speech.

| Definition | Notation | Unit | Value |
|---|---|---|---|
| Channel Rate | $R_C$ | Mbps | 50.0 |
| Source Rate | $R_S$ | kbps | 16.0 |
| Gross Slot Size | $S_G$ | bit | 1024 |
| Net Slot Size | $S_N$ | bit | 424 |
| Slots per Frame | $N$ | | 64 |
| Maximum Delay | $D_{max}$ | sec. | 0.03 |
| Max. No. of Reserved Slots/Frame/Terminal | $n_R$ | | 1 |
| Frames per Multiframe | $M$ | | 16 |
| Reservation Expiry Time | $T_{exp}$ | slots | 0 or 1 |
| Permission Probability | $p$ | | variable |
| Number of Conversations | U | | variable |

Table 2: PRMA Parameters for a high rate system

Initially we compared standard PRMA, MF-PRMA and MF-PRMA with an optimized reservation expiry time for 16 kbps speech services. Since in MF-PRMA a certain service is only allowed to use certain colums in the multiframe, we can separate simulations for different reservation levels and evaluate the throughput for this specific 'reservation level' without taking into account any other services requiring a different 'reservation rate'. We assume that only one slot per frame can be used for the speech service's reservation level, i.e. one column of the multiframe shown in Figure 1. For on-off type speech services in MF-PRMA, we now have to find the appropriate reservation rate which is i) possible for the parameters in Table 2 and ii) is closest to the required speech rate from the set of all possible 'reservation rates' not lower than the speech rate. For the reservation of one slot in each of the 16 frames of a multiframe, i.e. for $n_R = M = 16$, we obtain the following reservation rate:

$$R_{n_R} = R_{16} = R_{max} = \frac{S_N}{T_F} = \frac{S_N\, R_C}{N\, S_G}, \qquad (1)$$

where $T_F$ is the frame duration. For the parameters of Table 2, we obtain

$$R_{16} = \frac{424\; 50\, Mbps}{64\; 1024} = 323.486\, kbps. \qquad (2)$$

Other possible reservation rates are $R_8$, $R_4$, $R_2$ and $R_1$, where $R_8 = R_{16}/2$, $R_4 = R_{16}/4$ etc, corresponding to reserving slots in 8, 4, 2 or 1 of the frames of a multiframe.

Consequently, $R_1 = R_{16}/16 = 20.218$ kbps for the parameters in Table 2 and is thus the rate we choose for our 16 kbps speech codec. In Figure 3 the packet-dropping probability versus throughput performance of our three schemes is compared, where the *throughput* $Z$ is defined as the fraction of slots $Z$ that carry application level information:

$$Z = U \frac{R_{S,av}}{R_C} \frac{S_G}{S_N}, \tag{3}$$

with $R_C$ being the channel rate, $U$ the number of users transmitting at an average source rate of $R_{S,av}$, while $S_G$ and $S_N$ are the gross and net slot size, respectively.

Standard PRMA implies that a terminal can contend for a slot and, in case the contention was successful, acquires a reservation for this slot in subsequent frames until it has no more ready-to-send packets in its buffer. In order to obtain comparable results with respect to the two MF-PRMA simulations, only one slot per frame can be contended for. In the MF-PRMA simulation, the above reservation rate of $R_1 = 20.218$ kbps is associated with the last slot of each frame, hence a successful contention leads to the reservation of one slot every 16 frames. Once again, the reservation is cancelled as soon as a terminal does not use a reserved slot. The third simulation, optimized MF-PRMA, corresponds to the MF-PRMA simulation except for a reservation expiry time of $T_{exp} = 1$ slot. Hence a reservation is cancelled only after two unsused slots. We call this case optimized MF-PRMA. According to this scheme, for on-off type speech services, a minimum number of contentions, i.e. one per talkspurt, is guaranteed, unless there was an initial collision. In comparison to the voice-activity-limited TDMA throughput of 0.42, a higher throughput can be achieved for the optimized MF-PRMA.

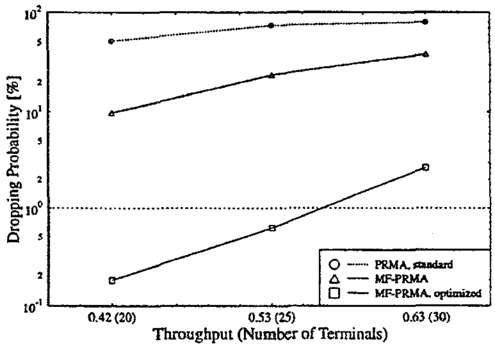

Figure 3: Speech service in a 50 Mbps system. The parameters are shown in Table 2.

Given the parameters in Table 2 for standard PRMA and non-optimized MF-PRMA, a terminal cannot hold a reservation for the duration of a whole talkspurt, resulting in an unacceptable performance for the examined range of throughputs shown in Figure 3. Note that in case of standard PRMA, a reservation rate of $R_{16} = 323.486$ kbps is available for a speech service of 16 kbps. The terminals thus stay in contend-and-send pattern, rather than holding a reservation. Figure 4 displays the throughput of optimised MF-PRMA for permission probabilities between 0.1 and 0.75, exhibiting a surprisingly rigorous symmetry to the permission probability of 0.5.

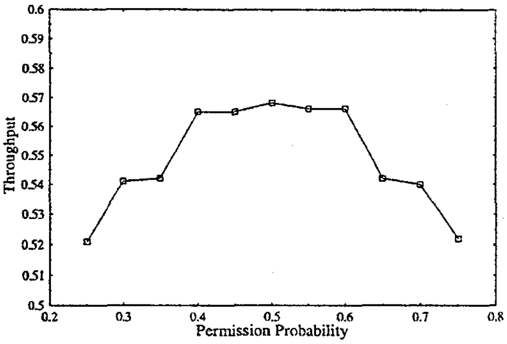

Figure 4: Effect of the permission probability on the throughput of optimized MF-PRMA using the parameters from Table 2.

| Definition | Notation | Unit | Value |
|---|---|---|---|
| Channel Rate | $R_C$ | Mbps | 50.0 |
| Source Target Rate | $R_S$ | Mbps | 1.0 |
| Gross Slot Size | $S_G$ | bit | 1024 |
| Net Slot Size | $S_N$ | bit | 424 |
| Slots per Frame | $N$ |  | 64 |
| Slots per Uplink Partition | $N_U$ |  | 29 |
| Maximum Delay | $D_{max}$ | sec. | 0.03 |
| Max. Number of Reserved Slots/Frame/Terminal | $n_R$ |  | 10 |
| Frames per Multiframe | $M$ |  | 16 |
| Reservation Expiry Time | $T_{exp}$ | slots | 0 |
| Permission Probability | $p$ |  | 0.1 .. 0.4 |
| Number of Video Terminals | U |  | 7 |

Table 3: MF-PRMA Parameters for a 1 Mbps video service

## 4. SIMULATION OF MF-PRMA FOR VIDEO SERVICES

In this section, video services of different rates are examined in the environment of the proposed MF-PRMA protocol. We investigated medium access for mean video target rates of 64 kbps and 1 Mbps. Video sequences are generated using the video source model described in Reference [5]. Assuming that the considered services are interactive, delay contraints of 30 ms for high quality video are imposed. For calculating the average delay, only the successfully arrived packets are taken into account. The delay curves must thus always be considered in conjunction with the dropping probability performance. In order to avoid the unrealistic situation that all terminals start contending at the same

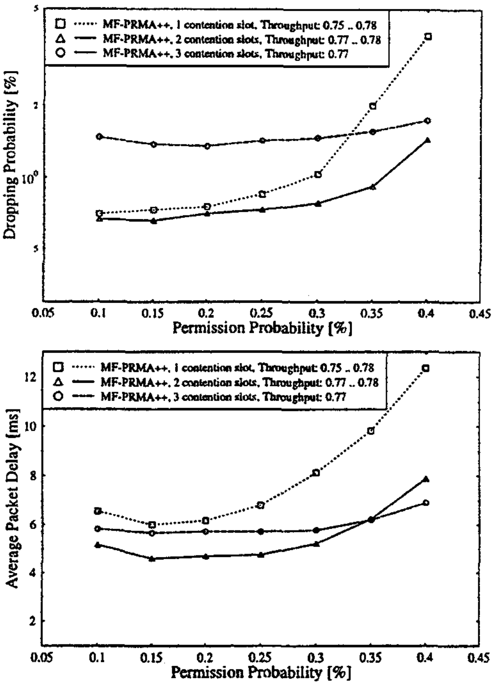

Figure 5: MF-PRMA++ simulations for 1 Mbps video service. Examination for different numbers of contention slots.

time, i.e at the beginning of the simulation, the packet generation in a terminal starts randomly in one of the first 120 frames. All simulations correspond to 260 seconds of video transmission.

Table 3 summarises the parameters for our 1 Mbps, 30ms-latency, 50 Mbps carrier-rate video service. In order to derive the maximum system throughput as a reference, it is assumed that 29 slots are available for the uplink partition. This allows 7 video users to transmit with a packet dropping probability smaller than 0.2%, if the optimum set of parameters is taken into account. Results for all other parameter configurations then show the deviations from the optimum case. Considering the MF-PRMA protocol, the average rate of 1 Mbps is higher than the 323 kbps reservation rate of one slot per frame, requiring on average of 3-4 slots per frame. As the bitrate fluctuates, additional slots must be assigned and released sufficiently quickly and hence no reservation expiry time is imposed.

For the video simulations, three different types of PRMA protocols were examined. Namely, the proposed MF-PRMA scheme, MF-PRMA++ and MF-PRMA++ with adaptive permission probability. In MF-PRMA++, a certain number of slots per frame is used only for contentions, as in the PRMA++ protocol. The remaining slots of the uplink partition carry non-contending packets. Apart from this, the MF-PRMA++ structure is equivalent to the MF-PRMA scheme. In an extended MF-PRMA++ protocol, the permission probability decreases with an increasing number of reserved slots, as we will explain later.

In order to characterize MF-PRMA++, simulations were carried out for reserving 1, 2 and 3 contention slots, considering 7 users and an overall uplink partition of 29 slots. Figure 5 displays the associated dropping probability and average packet delay versus permission probability performances.

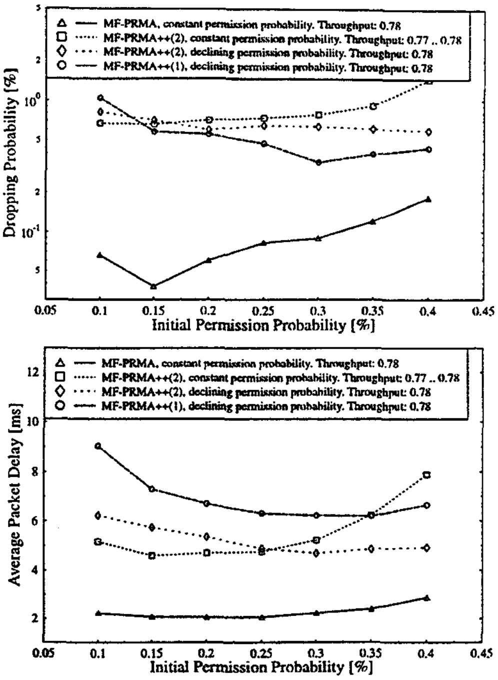

Figure 6: MF-PRMA and MF-PRMA++ simulations for 1 Mbps video service. The figure in brackets indicates the number of contention slots.

The system with two contention slots, that is $2/29 * 100\% = 6.9\%$ contention bandwidth, gives the best performance for both packet dropping and average packet delay. Due to an increased number of collisions for high permission probabilities $p$ and low contention bandwidth, the delay and dropping probability performances decrease significantly for $p > 0.3$ in the case of two or less contention slots. For values of $p$ between 0.1 and 0.3, the protocols performance is remarkably constant.

In the next series of simulations, the MF-PRMA++ performance described above will be compared to that of a MF-PRMA system. In addition, a novel variant of MF-PRMA++ is examined, which involves a decreasing permission probability for an increasing number of reserved slots. This approach, which does not require any additional signalling, is chosen due to the following observations: Initial simulations showed that although only 3-4 slots are needed on average by each terminal for the 1 Mbps video service, the system performance increased significantly if the terminal was allowed to reserve more slots when its buffer queue was much longer than that of other terminals. For this reason, each terminal was allowed to reserve up to 10 slots per frame. With acknowledgements for successful contentions only being given in the broadcast cell once a frame, however, a terminal keeps contending until the next broadcast cell arrives, even if contentions earlier in the same frame were successful and it does not have any more packets to transmit. In order to lessen this effect without reducing the maximum number of reserved slots per frame, above we proposed a decreasing permission probability. Initial simulations showed that a slower than linear decline with an exponent of about 0.7 yielded a good performance. Results for the MF-PRMA++ approach with declining permission probability are presented in Figure 6, along with results for the MF-PRMA system without contention slots.

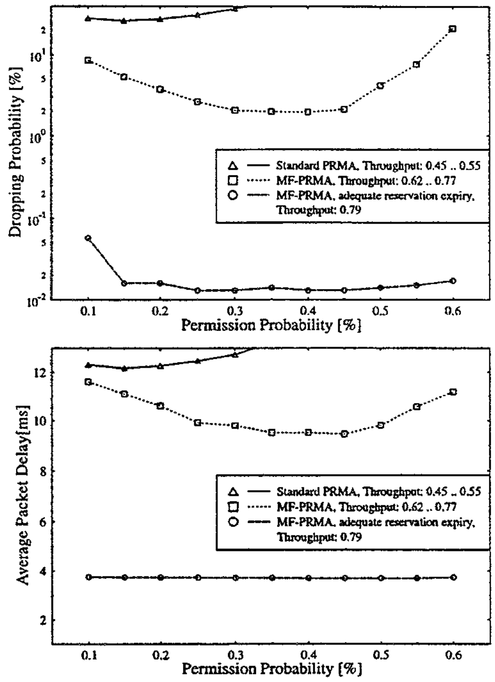

Figure 7: PRMA and MF-PRMA simulations for a 64 kbps video service. A reservation expiry time of 1 slot is adequate in these simulations. Table 4 shows the system parameters.

Figure 6 shows that in terms of both delay and dropping probability performance, the MF-PRMA++ approach is inferior to the MF-PRMA scheme. Whereas the average packet delay for this MF-PRMA protocol is nearly independent of the permission probability in the simulated range $0.10 < p < 0.45$, the packet dropping probability is clearly minimized for $p = 0.15$. In comparison of MF-PRMA++ and MF-PRMA++ with reducing permission probability, the latter scheme yields a slightly better performance. However, further work is needed to exploit the potential of this idea, which was also investigated in [4] using explicit signalling.

For the next set of simulations, a 64 kbps video service, the parameters are displayed in Table 4. Again, a 30 frames-per-second video service is considered and packets are discarded after 30 ms. Assuming a high load scenario, eight video users share two columns of the multiframe, all contending for the reservation rate associated with reserving one slot every fourth frame, which is the optimal choice. In our simulations, we compared standard PRMA, MF-PRMA and MF-PRMA with an optimized reservation expiry time. In both MF-PRMA schemes, a reservation rate of $R_4 = 80.87$ kbps is derived from Equation 1. With a target source rate of 64 kbps, the adequate reservation expiry time is 1 slot. Figure 7 shows clearly the superiority of our proposed MF-PRMA with optimized reservation expiry for both packet delay and dropping probability, especially in comparison to the standard PRMA scheme. Note that for the proposed scheme, the dropping probability and the average delay are nearly independent of the permission probability in the interval $0.15 < p < 0.60$.

In conclusion, as seen in Figures 3 and 7, the performance of standard PRMA can be improved by the introduction of a hierarchical multiframe structure and by the application of a reservation expiry time for a variety of teletraffic scenarios in wireless ATM systems.

| Definition | Notation | Unit | Value |
|---|---|---|---|
| Channel Rate | $R_C$ | Mbps | 50.0 |
| Source Target Rate | $R_S$ | kbps | 64.0 |
| Gross Slot Size | $S_G$ | bit | 1024 |
| Net Slot Size | $S_N$ | bit | 424 |
| Slots per Frame | $N$ | | 64 |
| Maximum Delay | $D_{max}$ | sec. | 0.03 |
| Max. No. of Reserved Slots/Frame/Terminal | $n_R$ | | 1 |
| No. of Considered Upl. Slots | $N_U$ | | 2 |
| Frames per Multiframe | $M$ | | 16 |
| Reservation Expiry Time | $T_{exp}$ | slots | 0 or 1 |
| Permission Probability | $p$ | | 0.1 .. 0.6 |
| Number of Video Terminals | U | | 8 |

Table 4: Parameters for the simulation with a 64 kbps video service

## 5. ACKNOWLEDGEMENT

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