Performance of Packet Reservation Frame-based MAC Protocols for Wireless ATM Networks

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Abstract

In this paper we study the performance of packet reservation frame-based MAC protocols for wireless ATM networks. We evaluate the impact on the protocol performance of the frame size, the ratio between the request and data periods, the buffering capacity of the mobiles and the transmission errors due to a non-ideal channel. We consider a two-state Markov model for the non-ideal channel. Results suggest that performance optimization requires dynamic adaptation of the protocol parameters to the QoS requirements, and to the traffic load and wireless channel conditions.

1. Introduction

The design of an efficient medium access control (MAC) protocol is a relevant issue in the context of wireless ATM networks (WATM). Several MAC protocols have already been proposed in the literature for WATM [1-5]. They are all centralized and they all integrate both random and contention free medium access control mechanisms. Also, a large number of them are frame-based [1-3,5]. The performance of frame-based protocols may depend on parameters like the frame size, the ratio between the request and data periods and the buffering capacity of the mobiles. In this paper we evaluate the performance of a frame-based protocol considering the parameters mentioned above, assuming an ideal wireless channel. Performance metrics presented are the throughput, the average packet delay and the packet loss rate.

An ideal wireless channel may be adequate to capture the general behaviour of the protocol. However, a more realistic performance evaluation requires the consideration of the non-ideal nature of the wireless channel. Markov models have been widely used to describe the bursty behaviour of error streams. These models try to capture the combined effect of multi-user interference, noise multi-path interference and propagation losses. The parameters of a Markov model can be estimated from experimental data or from simulated data using a channel model that considers the impairments mentioned above [6]. The number of states of a Markov model is a trade-off between accuracy and computational efficiency. In this paper we study the effect of a non-ideal channel using the 2-state Markov model proposed by Chen et al. [7].

The paper is organised as follows. In the next section we provide a description of a generic frame-based protocol. Section 3 presents the model used to simulate the protocol. Section 4 describes the wireless channel. Section 5 presents the simulation results for different scenarios considering both ideal and non-ideal wireless channels. Section 6 concludes the paper.

2. MAC protocol description

In TDMA frame-based MAC protocols the time axis is slotted and slots are tied together to form a frame. The uplink and downlink frames are illustrated in figure 1.

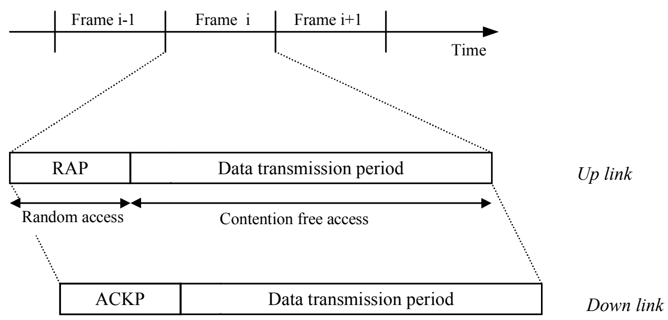

Figure 1: Protocol timing diagram

Different upstream and downstream links were considered. Both frames have two parts: one is reserved to control messages and the other to data messages. The uplink frame has a Request Access Period (RAP) and a Data Transmission Period (DTP). The downlink frame has an Acknowledgement Period (ACKP) and a Data Transmission Period. Medium access is random during RAP and contention free during ACKP and DTP. DATA slots are ATM cell sized. The size of request slots is smaller and depends on the information it carries: it may enclose only the mobile terminal identification or, in addition, the number of buffered packets or its QoS requirements. Whenever a new packet arrives at a mobile that has its buffer empty the mobile inquires the base station for data slots. This is done by sending a REQUEST message during RAP, using a random medium access protocol. By listening to the channel during RAP, the base station updates its Request Map according to the error free REQUEST messages received. The Request Map has an entry for each mobile associated to the base station, which allows the base station to keep track of the mobiles status. The base station acknowledges the reception of each REQUEST by broadcasting an ACKNOWLEDGE during ACKP. Base station serves waiting mobiles according to a specific packet scheduling transmission policy. After receiving the ACKNOWLEDGE the mobile accesses the channel in the assigned data slots. Mobiles with non-empty buffers continue requesting medium access through piggybacking, by setting a (piggyback) flag in DATA packets. Using piggybacking improves the protocol performance as it reduces the contention between mobiles associated to the same base station.

Different random access mechanisms and scheduling strategies may be chosen for TDMA frame-based MAC protocols. Slotted-ALOHA is used in [1,3,4]. Petras [2] proposes random access, but also polling when the number of active mobiles is small. Frigon [5] proposes a modified ALOHA algorithm, the frame pseudo-bayesian priority ALOHA. The scheduling strategies found in WATM literature includes first come first served [1], priority regulated allocation delay oriented with leaky bucket [3], time of expiry [1,5] and round robin [3]. DTP may also be split in different parts, each one for a specific QoS class [1].

In this paper we use slotted-ALOHA during RAP and an harmonic backoff algorithm with attempt probabilities 1, 1/2, 1/3,…, to resolve collisions. The scheduling transmission policy considered is round robin since all mobiles have identical service requirements.

3. Wireless channel model

Sivaprakam derived a six-state discrete time Markov chain for a wireless indoor channel from experimental data [7]. Chen et al. [8] derived an equivalent 2-state model that still captures the original behaviour of the channel. Under Chen's model, the channel alternates between a *good* state with no errors and a *bad* state with an error probability of one. The transition probability matrix of the underlying Markov chain is

$$P = \begin{pmatrix} p_{gg} & p_{gb} \\ p_{bg} & p_{bb} \end{pmatrix}$$

where p_{gb} is the transition probability from the good state to the bad state and p_{bg} is the transition probability from the bad state to the good state. Table 1 presents the channel parameters and the corresponding average error probability considered in our studies. The parameters in the first line of the table were reused from [8]. Two other channels with higher average error probabilities were also considered.

Table 1: Wireless channel parameters

	Channel (BSP)	p_{bg}	p_{gb}
Channel 1	1,26x10^{-3}	0,7953	0,001
Channel 2	3,64x10^{-2}	0,7953	0,030
Channel 3	1,12x10^{-1}	0,7953	0,100

5. Simulation results

The block diagram of the simulation model is depicted in figure 2. The model was created using SIMAN simulation language [9] and run in the simulation

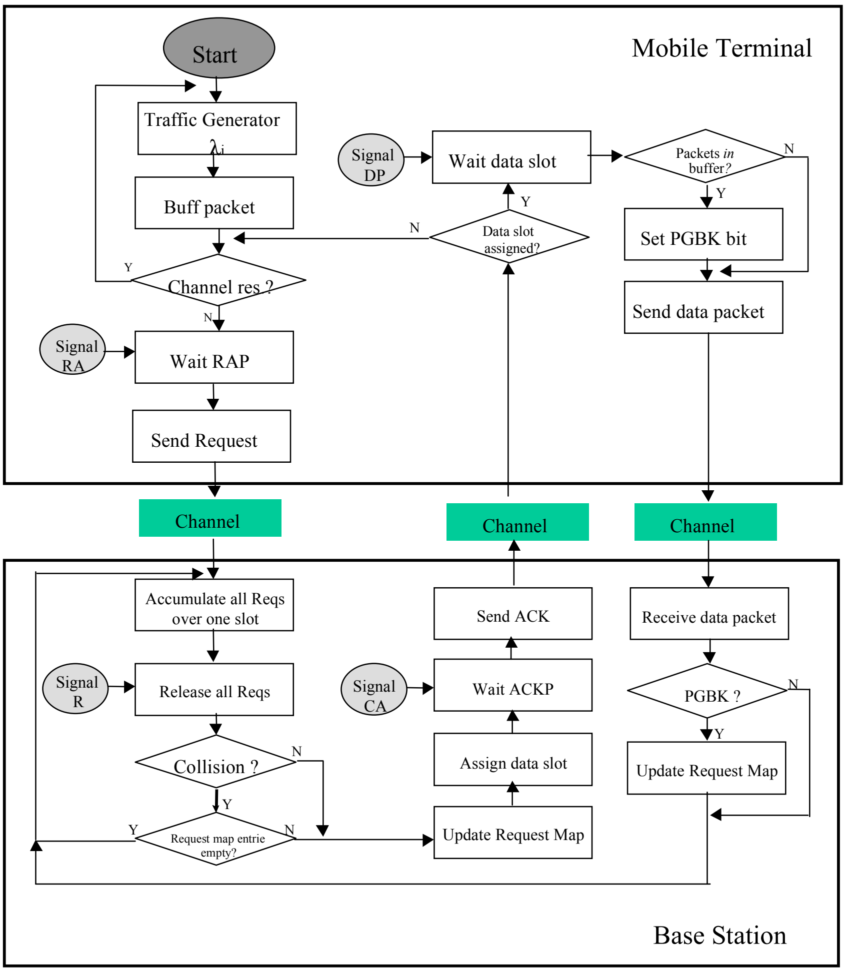

Figure 2: Simulation model

package ARENA [10]. The performance metrics considered are the channel throughput, the average packet delay and the packet loss rate. We define throughput as the ratio between the average number of successful DATA packets received at base station per frame period (FP) and the channel capacity. The average packet delay is defined as the average number of time units spent since a DATA packet is buffered at the mobile until it is successfully received at the base station. The packet loss rate is defined as the average number of lost packets per DATA slot. We consider that REQUEST slots have 1:9 the duration of DATA slots.

We consider a default simulation scenario with the following characteristics: (i) a population of 100 mobiles, (ii) a channel capacity of 1000 Kb/s, (iii) a frame with 25 RAP slots and 25 DTP slots and (iv) a maximum of 16 retransmission attempts. For each simulation scenario, we made 10 replications, each with 10^6 generated packets, and computed the 95% confidence interval.

Figures 3 to 5 depict simulation results of the protocol performance as a function of the duration of the frame period (FP), measured in number of data slots.

Figure 3 shows that for low traffic loads (≤ 0.25) the throughput is almost constant and independent of the frame length. As the load increases optimal throughput is achieved for FPs duration above 30 data slots (DS). Increasing FP duration increases the average packet delay, as illustrated in figure 4. For low traffic loads the behaviour is almost linear. However, linearity is lost as the traffic load increases. For loads above 0.8 and FP sizes up to 60 DS, the average packet delay increases rapidly due to collisions during RAP. This effect is slightly compensated for FPs between 60 DS and 90 DS due to piggybacking. Note that piggybacking is more active for high traffic loads because the probability of the mobile's queue being not empty increases.

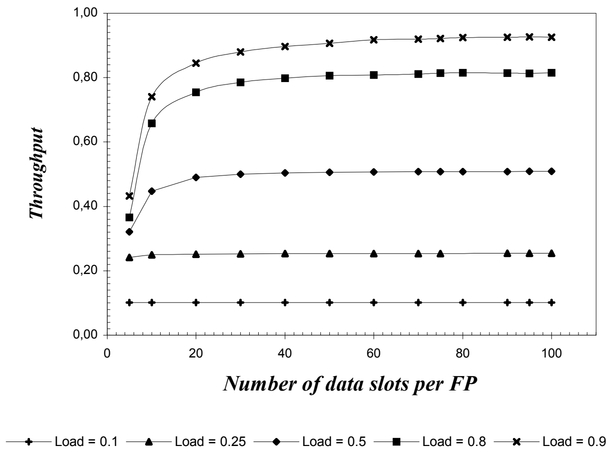

Figure 3: Throughput versus number of data slots per frame period

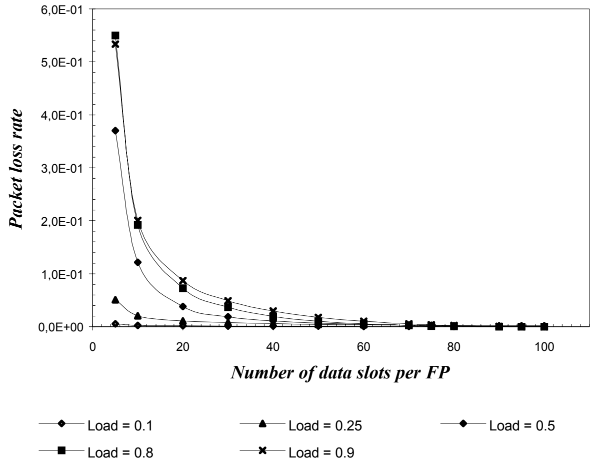

Figure 5: Packet loss rate versus number of data slots per frame period

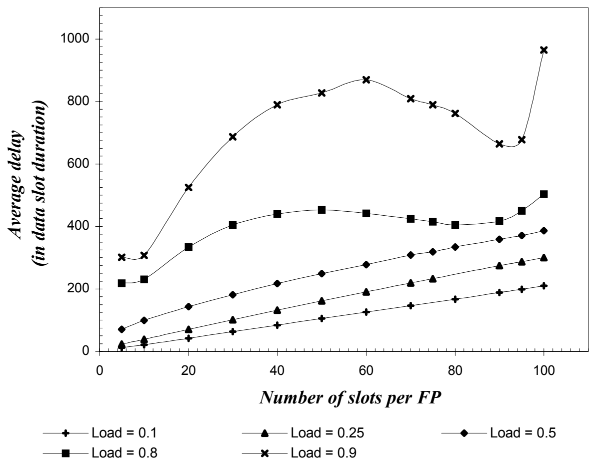

Figure 4: Average packet delay versus number of data slots per frame period

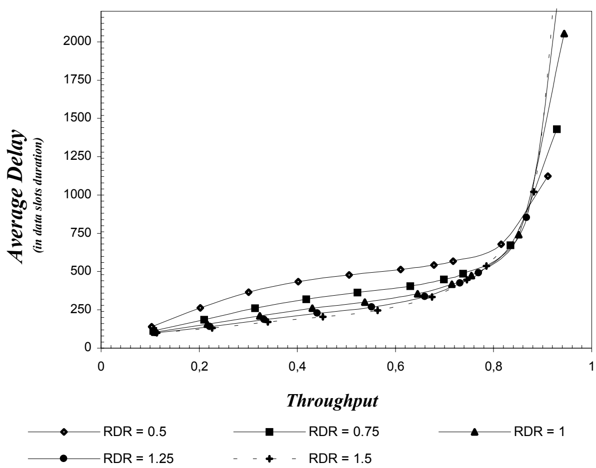

Figure 6:Average packet delay versus throughput for different RAP to DTP ratios

Figure 5 shows that for FPs above 20 DS the packet loss rate increases rapidly as the load increases due to the raising collision probability. Note that the backoff algorithm has a limited number of retransmission attempts. From these results we conclude that a tradeoff between the three metrics must be done to select the frame period size. For the scenarios considered best results are obtained for the interval 20 to 40 DS.

Figure 6 depicts the protocol performance for different values of the ratio between the number of slots in RAP and the number of slots in DTP (RDR). We consider five scenarios, with ratios 0.5, 0.75, 1, 1.25 and 1.5. The number of slots in DTP was fixed at 25 in all scenarios. For loads below 0.8 the average delay decreases as RDR increases. This is due to the decrease of the collision probability during RAP and also to the significantly small request slot size as compared to the data slot size. For higher loads the behaviour is opposite. In this case the average delay increases as RDR increases, because of the combined effect of a longer FP and a higher average number of retransmissions. Only ratios equal or below 1 have reasonable average packet delays. It may be concluded that an equal number of slots in RAP and DTP allows reasonable results for all loads.

Figures 7 and 8 illustrate the effect of the buffering capacity and maximum number of allowed retransmissions on the protocol performance. We considered queues of infinite length and with capacities of 100, 10 and 5 packets. For traffics loads below 0.2 the protocol performance is independent of the queue length. As expected, for higher traffic loads, as the

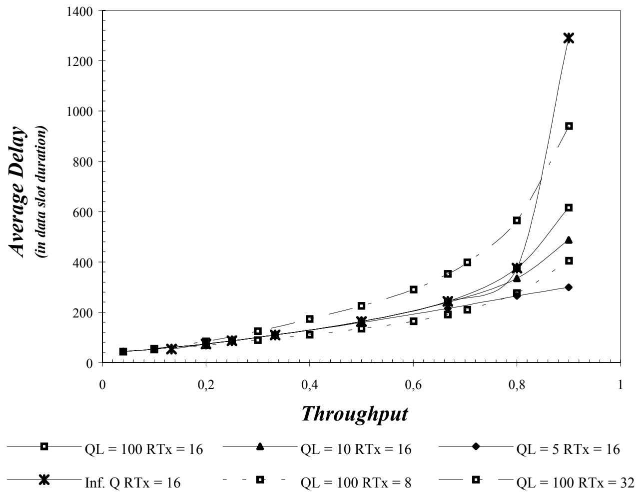

Figure 7: Average packet delay versus throughput for different mobile's buffer length

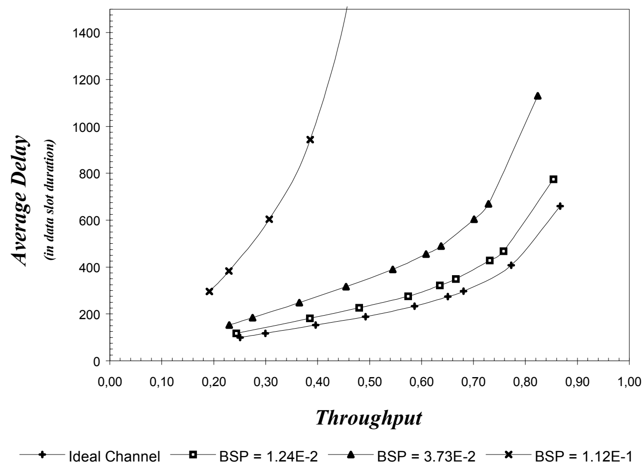

Figure 9: Average packet delay versus throughput for different wireless channels

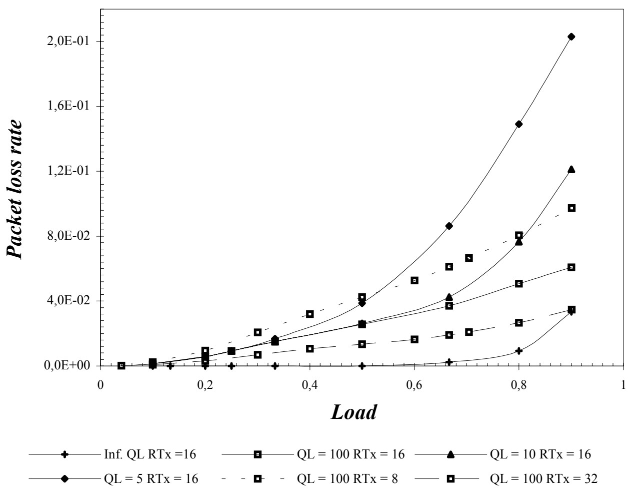

Figure 8: Packet loss rate versus load for different mobile's buffer length

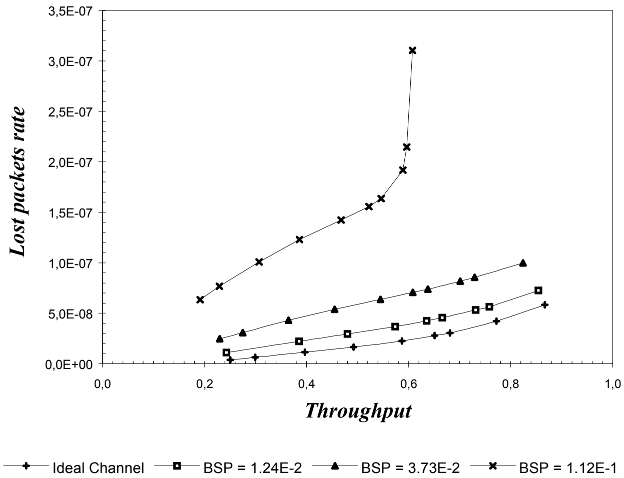

Figure 10: Packet loss rate versus throughput for different wireless channels

queue size decreases the overall packet loss rate increases and the average packet delay decreases due to the limited buffer size. Performance also depends on the maximum number of retransmission attempts. Simulation results for a queue length of 100 and three different values of the maximum number of retransmission attempts (8, 16, 32) shows that this parameter is effective in controlling the trade-off between the average packet delay and the packet loss rate. The value of the queue size and the maximum retransmission attempts value to be adopted depend on the relative importance of each QoS parameter.

Figures 9 to 11 depict protocol performance results for the three non-ideal wireless channels of table 1. Results are compared to the ideal channel scenario. From these results we verify the protocol tolerance to noisy channels. Performance is only significantly affected if the channel is deeply bad. In figure 11 we present curves for each contribution to the packet loss rate, for the worst case channel under consideration. Packets can be lost due to finding a full buffer on a mobile station (Rejected), achieving the maximum number of retransmissions (Max RTx) and corrupted DATA packets (In Channel). The figure suggests that contention impairments overcomes channel impairments, since the contribution of the maximum number of retransmissions is greater than the contribution due to the wireless channel considered.

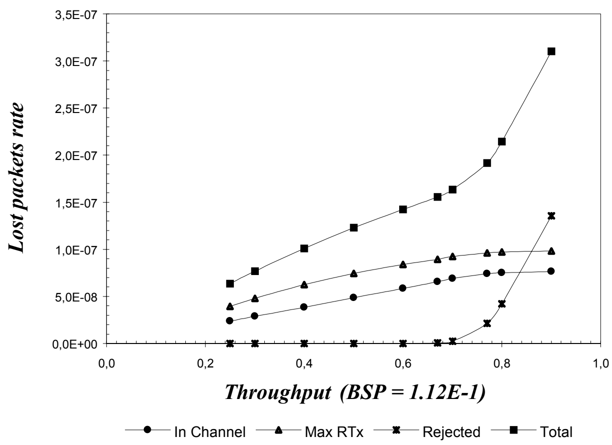

Figure 11: The different contributions to the packet loss rate for channel 3

However, it should be noted that achieving the maximum number of retransmissions is not only due to collisions but also to corruption of REQUEST and DATA packets in the channel

6. Conclusion

In this paper we investigated how the performance of a frame-based MAC protocol for wireless ATM networks may be affected by the frame characteristics and by the combined effect of the buffering capacity at the mobiles and the maximum number of retransmission attempts. We also study the impact of a non-ideal wireless channel on the protocol performance. Results suggest that performance optimization requires dynamic adaptation of the protocol parameters to the QoS requirements, and the traffic load and wireless channel conditions. This work will proceed by investigating adaptation strategies and support of multiple QoS classes.

Acknowledgments

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