MRAP : A Multiservices Resource Allocation Policy for Wireless ATM Network

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In this paper we investigate the integration of both CBR (Constant Bit Rate) and ABR (Available Bit Rate) services in a wireless personal communication network. MRAP is a proposed Multiservices Resource Allocation Policy which intends to share efficiently slot times of the TDMA frame between two classes of traffic while satisfying the quality of service requirements of both. By means of performance modeling, and especially the Stochastic Automata Networks model, we demonstrate that ABR traffic is transparent to CBR traffic while loss rate is kept under reasonable values. By computing both blocking and dropping handover probabilities, we show also that offered QoS to CBR service is also satisfactory.

Key words: Wireless ATM Networks. Services integration. Resource Allocation. Performance Evaluation. Stochastic Automata Networks.

1 Introduction

Due to the growing success of Personal Communication Systems (PCS), the next generation of wireless networks intends to offer more services than the classical pagers, cordless phone, fax or wireless local phone system. Before allowing advanced information transfer like video, data transfer services must be first provided on existing systems. Now, GSM (Global System for Mobile Communication) [13] operators offer some data and fax transfer services but in fact, current data services simply transfer data in a voice channel by means of a modem at a rate of 9,6 Kbps.

As future wireless networks will use BISDN (Broadband Integrated Services Digital Network) as the backbone network [10] [4],and consequently, the Asynchronous Transfer Mode (ATM), it will be convenient for the wireless part to be compatible with the ATM part of the network. Compatibility can be provided in various ways, for instance, by identical information units or, by the same protocols or, by the same offered services [17]. Such a wireless network is generally called a Wireless ATM network [2].

Integrating BISDN services is an interesting challenge in the wireless environment. However, the limited bandwidth of radio channels and the users' mobility during communication introduce new problems dealing with call request transfer [1], error recovery control [20] and, radio resource allocation.

In this paper, we discuss a proposed *Multiservices Resource Allocation Policy (MRAP)* which aims at sharing efficiently network resources between multiple classes of traffic while satisfying both QoS requirements. Among the five service classes defined either by the ATM Forum [5] or by ITU, two services are considered as having most stable specifications: CBR, or *Constant Bit Rate*, and non real-time ABR, or *Available Bit Rate*. CBR services consist of circuit switching emulation with a constant cell rate like in telephone systems. The class of ABR services includes normal data traffic such as file transfer and e-mail. Such services are loss sensitive and a maximum Cell Loss Ratio is specified for them. A Minimum Cell Rate is also guaranteed for this class whereas neither cell transfer delay nor cell delay variation are guaranteed. These source rates could be controlled in order to react to the state of congestion on the network.

After reviewing the main characteristics of some existing allocation mechanisms integrating both voice and data traffic in a TDMA (Time Division Multiple Access) environment, we introduce the MRAP in section 2.3. In order to prove the effectiveness of MRAP, we use a new modeling methodology: *Stochastic Automata Networks (SAN)*. This methodology has recently received attention in the literature as a means of modeling complex systems of interacting components when the systems are not amenable to analytical solutions by queuing network analysis. They appear to be particularly useful when modeling parallel architectures, distributed systems and protocols, either in discrete or continuous time [16], as they allow an easy representation of synchronization mechanisms and some efficient numerical algorithms. We present the SAN methodology in section 3. Then, in the fourth section, we investigate the modeling process of MRAP using SAN. Numerical results are presented in section 5.

2 Resource allocation for both voice and data traffic

In this study, we consider a wireless cellular network where radio resource is shared between users of a particular cell within TDMA-based medium access control. Schematically, the TDMA technique lets time be discretized into frames periodically transmitted. The TDMA frames are also partitioned into a fixed number of time slots. For voice calls, a time slot acts as a virtual channel since it is allocated to a connection at connection set-up and freed at its termination. Obviously, time slots constitute the critical resource in such systems.

We assume that the base station is a kind of gateway between the wireless network and the ATM-based switching network, as it is stated in [17]. We consider that an ATM cell fits with the size of the TDMA slot. The ATM cell header is compressed and a specific wireless part is added to it.

Whereas a lot of papers proposed and studied the Multiple Access Control of call requests, only a few considered Resource Allocation Control because existing PCS do not often deal with multi-service integration. Before describing our own Resource Allocation Mechanism, MRAP, we introduce some of these references.

2.1 Combination of both reservation and random access

Without speaking of wireless ATM networks, [11] proposes and analyzes a multi-access protocol for integrating transparently data traffic in a TDMA digital voice system. They justified their work by stating that a substantial fraction of the channel capacity is not used by voice: from 20% for a poor number of time slots up to 60% for a larger number.

It is assumed that voice terminals use the access protocol in the E-TDMA (Enhanced-TDMA) standard. The data multi-access protocol combines random access with slot reservation to statistically multiplex data packets transmitted by data terminals with speech spurt packets transmitted over the shared reverse air channel. Random access is used when traffic is light, whereas slot reservation access operates when load is heavy, even allowing multi-slot assignments per TDMA frame. To keep compatibility within the E-TDMA standards, the voice terminal access mechanism is used without modifications. The reverse slot allocation to data requests is based on allocation requests transmitted by data terminals via the reservation sub-slots which are stored in a round-robin served queue. When a slot is assigned to a data terminal, it keeps it in subsequent frames until its packet queue is empty. In order to not interfere with voice call requests, the Base Station assigns reverse slots with priority to voice request over data requests. The mechanism allows one to allocate various priority levels to various data service types (high throughput, real time or not) and multi-slot assignments per frame in order to increase the data rate.

Furthermore, at any time, data terminals sense which slots are free on the forward channel. They can access these free slots in a contention mode: in case of collision, they attempt to retransmit the same packet. The data access protocol is then simulated.

The major drawback of this scheme is that when a slot is allocated to a data terminal it occupies it for one or more subsequent frames. Even if phone calls have priority for allocation, they can be rejected if all slots are occupied either by voice calls or data traffic. Data traffic is not transparent to voice traffic as this scheme increases the voice calls blocking probability.

2.2 Boundary Schemes

This set of schemes proposes to partition resources into the two traffic classes by defining a boundary between both parts.

In [19], the TDMA frame is partitioned into two compartments, one for voice circuits and the other for data packets. The boundary between the two compartments can be either fixed or movable. Movable boundaries are better because data traffic has the capability to use any idle slots of the voice compartment resulting in higher bandwidth utilization. As each data packet occupies only one slot, data traffic does not interfere with voice traffic. No preempting mechanism of data slots by voice calls has to be supported. In contrast, if a voice call were permitted to use a slot from the data compartment, this slot would be unavailable to data traffic for the entire duration of the call. Voice slots are allocated with previous reservation whereas data slots are allocated with contention.

[17] proposes a MAC (Media Access Control) protocol called MDR-TDMA (Multiservices Dynamic Reservation) in order to provide bandwidth sharing to various multimedia services with high channel utilization, while maintaining a reasonable QoS level on each service. In this mechanism, the TDMA frame is subdivided into N_r request slots and N_t message slots; a message slot contains exactly one basic data link unit. Request slots are used for initial access in slotted Aloha mode. Of the N_t message slots, a maximum of $N_v < N_t$ slots in each frame can be assigned for voice traffic. Packet data messages are dynamically assigned to one or more other message slots. The dynamic allocation is based on a statistical algorithm in which available capacity is prorated among demands based on Usage Parameter Control (UPC). It allows one also to take into account a real-time data traffic by using a time-of-expiry based queue service scheme. In the paper, a numerical evaluation of this protocol is presented.

The advantage of these mechanisms is that a guaranteed amount of bandwidth is always provided to voice traffic while a minimal amount of resources is also guaranteed to data traffic with the possibility of using all slots in the absence of voice calls. Furthermore, resource allocation to data traffic is really adapted to the available resource. The major drawback is the difficulty to determine the boundary to have a good compromise between data-packet delay and voice-call blocking.

2.3 Multiservices Resource Allocation Policy: MRAP

From the characteristics of other proposed mechanisms, we have derived our own Multiservices Resource Allocation Policy which allows ABR service transfer (also simply called data transfer) in a transparent way for CBR service traffic (also called voice service).

To achieve the constant bit rate requirement for the CBR service, we always allocate a time slot to a call request for the duration of the communication; it is equivalent to a circuit. As the telephone is a real-time service, if every time slot is busy, new requests are not queued but rejected. We distinguish two types of requests: new call requests and handover requests. New call requests come from users who want to initiate a communication whereas handover requests come from users who have moved from a neighbour cell to the considered one. As it is better to continue a communication in progress than to initiate a new one, a priority is given to handover requests over new call requests. As has been said above, ABR service is neither delay-sensitive nor real time. Moreover, we assume it is connectionless: an ABR request is constituted by the data packet itself. As a consequence, a lower priority is assigned to ABR requests. Data packets are queued in a buffer when waiting for available slots in a next TDMA frame. As the data packet buffer has a finite size, it could be saturated if packets are arriving and all slots are used by CBR connections. To avoid packet losses, both mechanisms could be provided in MRAP:

- a flow control mechanism regulates the source rate in case of buffer congestion; it enforces rate reducing on ABR sources.
- a part of bandwidth is reserved for ABR traffic, allowing the guaranteed Minimal Cell Rate of such service specification; we reserve one specific time slot of the TDMA frame for data transfer.

Our policy allows ABR service to use the fraction of bandwidth unused by CBR service in a *transparent* way for CBR services with *provisioning QoS* for ABR services.

Transparent means that sharing resources with data packets does not change the offered QoS to CBR service i.e. the new call blocking probabilities and dropping handover probabilities. Our solution proposes that resource allocation for ABR services will be done slot by slot. Actually, it means that data packets are transferred when time slots are available and when all received call requests have been served; in contrast, data packets are stored in the buffer whenever all slots are busy with call requests. As there is no priority among data services, the buffer scheduling is first-in, first-out. Obviously, when the buffer is full, new arriving data packets are lost. A flow control mechanism and reserved bandwidth are provided to avoid this problem even in a large buffer.

In the next sections, we introduce the SAN modeling technique and the model we have developed in order to evaluate the effectiveness of this allocation mechanism.

3 Discrete-time Stochastic Automata Networks

Stochastic Automata Networks (SAN) have been introduced to represent complex systems with interacting components such as parallel systems, distributed algorithms and protocols [15]. SAN is a Markov chain model. Compared to queuing networks, it has the advantage of facilitating the representation of complex synchronization constraints. The key idea in SAN is to describe the states and the transitions of the Markov chain in a compact formulation and to avoid generation of the whole transition matrix (or generator). Unlike Stochastic Petri Nets [12], the SAN approach does not build the state space and computation of the steady-state probabilities may be reduced. Furthermore, many software tools implementing current algorithms have been recently developed [3]. In [14] and [16] , it is showed how to build the transition matrix or the generator of the Markov chain by applying tensor operations on the matrix representations of these automata. We solve numerically the steady-state distribution and, we compute the rewards defined by the user on this probability vector. The complexity of the numerical computations is weakened when we take into account the generator description with tensor product. These operations have been implemented in a package called PEPS [16,15,8].

At the present time, few SAN models have been developed. In [6], SAN is studied a resequencing system. In [18], [7] and [9], many buffer management policies which have been proposed for ATM switching node were investigated. To develop a SAN model, the system must be first decomposed into semantically independent components. Then, each system component is represented by an automaton. Like in Stochastic Petri Nets, the arcs are labeled with a transition rate or a probability; this label can be governed by a function. Furthermore, specific types of labels may be used to describe the dependencies between the components.

Stochastic Automata Networks may be used either in discrete-time or continuous-time. However, in this paper, we only introduce the discrete-time analysis [15] (see [14,16] for continuous-time SAN). An automaton itself is not Markovian, but the whole automata network is associated to a multidimensional discrete-time Markov chain. To insure the Markovian framework, transitions in the SAN models must have one of the following:

- Fixed rate (just like for ordinary Markov processes or chains).
- Network dependent rate: the transition rate is a function of the states of the other automata.
- Synchronization: several transitions occur at the same time. The rates of transitions may be either fixed or state dependent. All of the automata must be in a suitable state for firing the synchronization. In the literature, this type of synchronization is denoted as a Rendez-vous.

Definition 1 (Tensor Product) *Let A be a matrix of order $n \times n$, and B a matrix of order $p \times p$. The tensor product of A and B is a matrix C of order $np \times np$ such that C may be decomposed into n^2 blocks of size p.*

$$C = A \bigotimes B = \begin{bmatrix} a_{11}B & \dots\dots & a_{1n}B \\ . & . \quad . & . \\ . & . \quad . & . \\ . & . \quad . & . \\ a_{n1}B & \dots\dots & a_{nn}B \end{bmatrix}$$

Assume that the states are in lexicographic order, the transition matrix P of the Markov chain associated to a discrete time Stochastic Automata Network is obtained using the following relation [15]:

$$P = \bigotimes_{i=1}^{n} P_l^{(i)} + \sum_{s \in \mathcal{S}} \left(\bigotimes_{i=1}^{n} P_{(s)}^{(i)} - \bigotimes_{i=1}^{n} P_{n(s)}^{(i)} \right)$$

where

- n is the number of automata in the network.
- $\mathcal{S}$ is the set of synchronizations.
- $P_l^{(i)}$ is the matrix describing the local transitions of automaton i.
- $P_{(s)}^{(i)}$ is the matrix describing the effect of synchronization s on automaton i.
- $P_{n(s)}^{(i)}$ is the normalization matrix associated to $P_{(s)}^{(i)}$.

This equation is used in the iterative computation of the steady state distribution to obtain a smaller complexity of the product vector-matrix [16]. The generator of a Markov chain associated to a continuous time Stochastic Automata Network is obtained using a similar construction, applying tensor product and sum on local contributions.

4 Modeling MRAP with SAN

As seen before, MRAP aims at sharing network resources i.e. the time slots of the TDMA frame between call requests and packet transfer requests. Due to the constant duration of a time slot and the periodic transmission of the TDMA frame, it seems natural to use a discrete-time model where the time-slot duration acts as the system unit. We focus on a particular cell and consider only one carrier and one TDMA frame of C slots.

For CBR services, we are interested in two QoS parameters: the blocking probability for new voice calls and, the dropping handover probability for calls from neighbour cells. For ABR services, only a packet loss rate is guaranteed and computed in this evaluation. From the modeling point of view, we consider three classes of requests:

- the *new call requests* are real time and intend to set up connection. This class of traffic keeps the allocated slot through the call termination or through the user moves to another cell. The probability of one arrival of a new call is denoted P_c.
- the *handover requests* are connections coming from a neighbour cell because of the user's mobility during the communication. Once they are accepted, they have the same characteristics as new call requests. The probability of one arrival of a handover request is denoted P_h.
- the *packet transfer requests* come from connectionless ABR services. It is supposed that the packet transfer delay fits with the time slot duration. Then each time a packet is transferred, it frees the allocated slot and the probability of service completion is equal to 1.0. Data packets come most of the time from a fragmented message; then more than one data packet can arrive during the same slot. Packets arrivals are geometrically distributed with probability P_{nc}. The probability of packets arrival is denoted P_{nci} where i represents the number of packets to be transferred. We consider by hypothesis, $i \leq 3$.

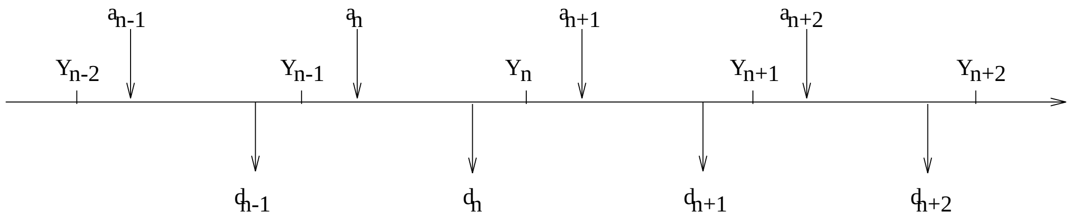

Fig. 1. Automaton for CBR traffic (new connection and handoff)

4.1 Early Arrivals

The Discrete Time Model considers early arrivals as depicted in Fig. 1; in a time slot $[Y_n, Y_{n+1}]$, arrivals happen just after the beginning of a slot and service completion (and departure) takes place just before the end of the slot. This assumption has a great impact on the modeling process because it implies that data packets begin and complete their service during the same time slot. Consequently, when observing the state of the system, we never see any data packet being served.

All these events are defined as Bernouilli processes. As we take very low values for the probability of call arrival, we have neglected the probability of more than one arrival in a single time slot. We make the same simplification for the probability of having more than one service completion in a single time slot. The probability of service completion for CBR traffic is denoted P_s.

4.2 Modeling Process

To evaluate the QoS described before, we need to represent the dynamics of the slot allocation policy for both CBR and ABR services. The first automaton represents CBR requests of both classes during their service. In order to compute the data loss rate, the second automaton represents the number of data packets in the buffer. The third automaton acts as the flow enforcement mechanism in case of buffer congestion. As has been said before, we can not represent the data packets being served.

4.2.1 Automaton for CBR traffic

Figure 2 depicts the number of CBR connections using the C slots of a particular TDMA frame. To keep the figure readable, C is taken to be equal to 3 and the automaton has 4 states.

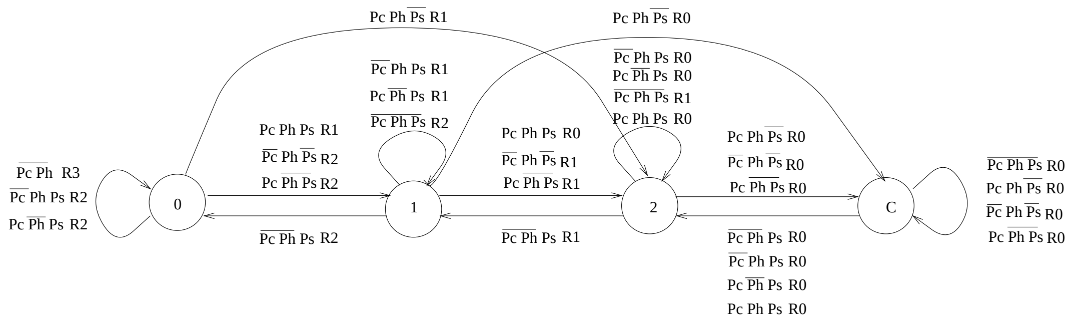

Fig. 2. Automaton for CBR traffic (new connection and handoff)

From state i, transitions to the next state are one of the following :

- to state i, when no arrival and no departure ($\overline{P_c P_h P_s}$) occurs or for both one arrival and one departure ($\overline{P_c} P_h P_s + P_c \overline{P_h} P_s$).
- to state $i+1$ or at most C, when an extra connection has arrived ($\overline{P_c} P_h \overline{P_s} + P_c \overline{P_h P_s} + P_c P_h P_s$).
- to state $i+2$ or at most C, when both a new connection and an handover request have arrived with no departure ($P_c P_h \overline{P_s}$)
- to state $i-1$ or at least 0, when a departure occurs but no arrival ($\overline{P_c P_h} P_s$).

We note that when there are no customers in the system, only new arrivals can occur.

Depending on the state of the automaton, each transition triggers additionally a synchronization with the other automaton. The semantic of a synchronization, denoted R_j, is that j represents the number of slots which are not used by CBR traffic and which can be used to transfer ABR packets. As an example, the transition from state 0 to 1 labeled by $P_c P_h P_s R_1$ means that consequently to this double arrival, only one time slot is available for an ABR packet. We define $C+1$ synchronizations at all (in Fig. 2, there are 4 synchronizations).

A blocking state is defined as a state where it is not possible to accept a new call, typically the state where the C slots are busy. Consequently, blocking states are states C and $C-1$ for new voice calls and only state C for handover as handoffs have priority over new calls. From this model, we compute the new call blocking probability as the sum of probabilities of states from which a call is refused (equation 1). In the same way, we deduce the dropping handover probability as the probability of state from which a call handover is refused (equation 2).

$$Blocking = \Pi_{C-1} + \Pi_C \tag{1}$$

$$Dropping = \Pi_C \tag{2}$$

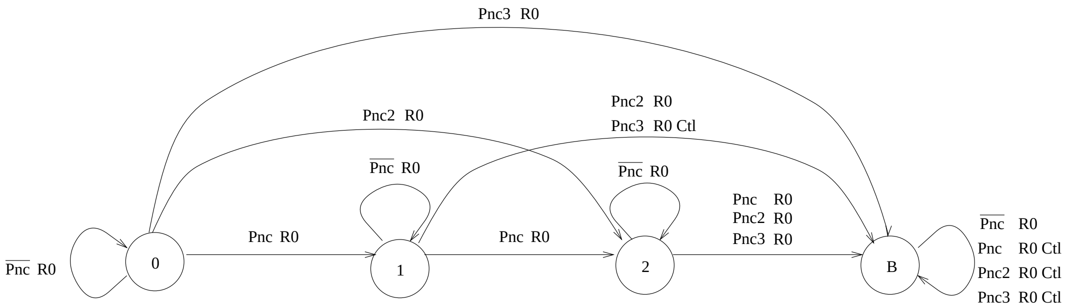

Fig. 3. Automaton for the buffer: synchronization R0

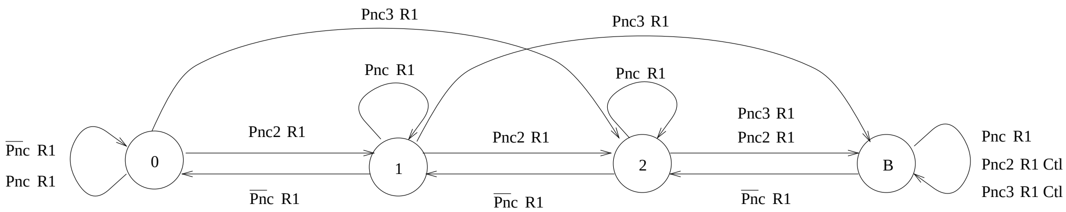

Fig. 4. Automaton for the buffer: synchronization R1

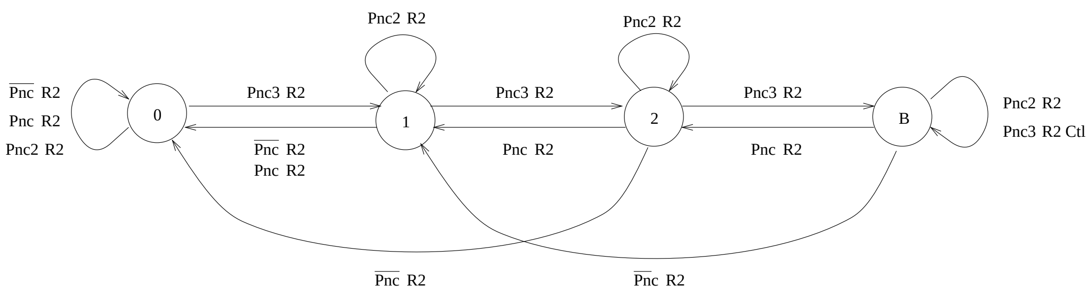

Fig. 5. Automaton for the buffer: synchronization R2

4.2.2 Automata for the buffer

We have divided the buffer model into four automata according to the four synchronizations R_j defined before. These automata describe how the number of packets stored in the buffer increases or decreases depending on the available slots in the frame and of the number of new requested packets. The arcs are then labeled with a particular synchronization associated to the probability P_{nci} that i packets arrive during a time slot. On the following four figures, we present automata with a buffer capacity of $B = 3$ data packets. We can see that the buffer size only increases when there is no available slot in the frame (Fig. 3 and synchronization R_0). We can see also how the number of packets increases or decreases when only one slot (Fig. 4), two slots (Fig. 5) and three slots (Fig. 6) are available.

Loss of data packets occurs when the buffer overflows i.e. when the number of packet arrivals exceeds the number of available time slots added to the number of free places in the buffer. In state B, these losing transitions triggers then another synchronization denoted *Ctl* which synchronizes the buffer automaton

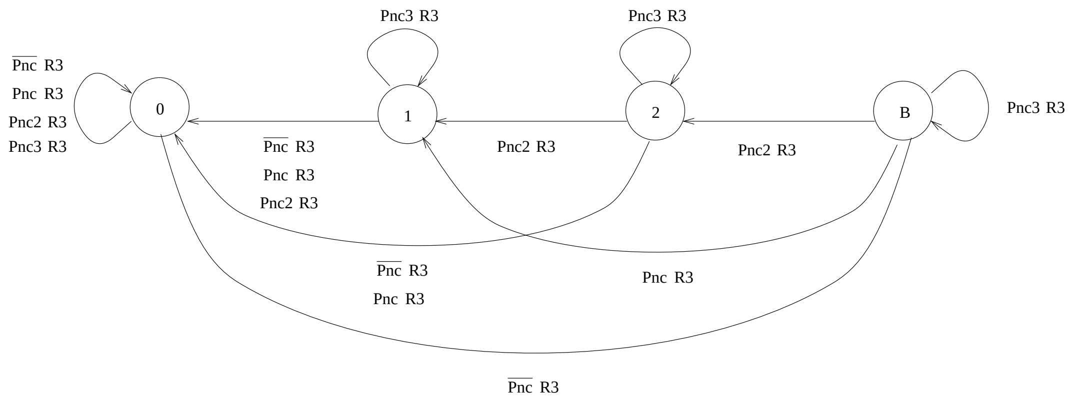

Fig. 6. Automaton for the buffer: synchronization R3

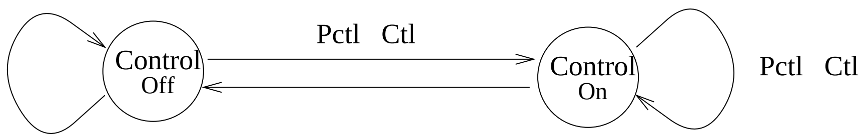

Fig. 7. Automaton for the flow control

with the flow control automaton. It means that as soon as the buffer overflows, the ABR source must reduce its rate. For example, the first automaton triggers the synchronization $R0$ and the second automaton is in state B with more than one arrival of data packets, P_{nc2} (Fig. 3).

4.3 Automaton for the flow control

The third automaton has only two states to represent if the flow control is enabled or not (Fig. 7). Flow enforcement is triggered by the synchronization Ctl when the buffer overflows as seen before. When the control is on, the probability of packet arrivals is multiplied by P_{ctl}, the reducing rate.

5 Numerical Example

5.1 Input parameters

We perform several experiments and present here only the most representative ones. We have fixed some parameters while we vary the others. Table 1 presents the exact or minimal value of the parameters. The time slot is the time unit of the model. The primary data rate is fixed to 1 Mbps. Consecutively to a flow enforcement , the data rate is multiplied by P_{ctl} which is equal here to 10 % of the primary rate. In all experiments, we vary the load of CBR traffic by increasing the probability of a new call arrival, P_c. We study also two different buffer sizes of 30 and 60 data packets and two TDMA frame sizes of 10 and 30 time slots.

Table 1
Parameters

Parameter	Actual Duration	Notation	Model Value
time unit	576.10^{-6} s	-	-
primary data rate	1 Mbps	P_{nc}	0.45
reducing rate	10 %	P_{ctl}	0.1
voice call inter-arrival	7..600 s	P_c	$8.10^{-6}..1.10^{-6}$
mean voice call duration	120 s	P_s	5.10^{-6}
buffer sizes	30, 60	B	-
TDMA frame	10, 30	C	-

5.2 Providing QoS to CBR service

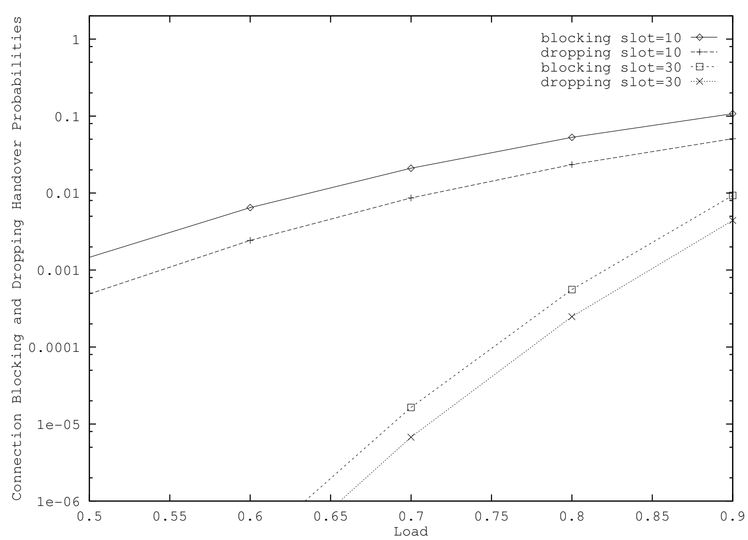

Fig. 8. Blocking and dropping handover probabilities for various TDMA frame sizes

Let us now describe the results concerning the two QoS parameters of CBR traffic. In Fig. 8, blocking and dropping handover probabilities versus load are compared for both numbers of slots. For the same proportion of new connection and handover requests, we can clearly see the effect of the priority policy on both QoS parameters. The dropping handover probabilities are always lower than the blocking probabilities.

Obviously, when the number of slots decreases, the blocking probabilities increase. For a TDMA frame of 10 slots, blocking probabilities are kept under 1% until the load reaches 60%. They exceed 10% for a very high load of more than 80%. For a TDMA frame of 30 slots, they are kept under 1% for a load until 90%. These performance parameters are those usually specified for such a wireless network.

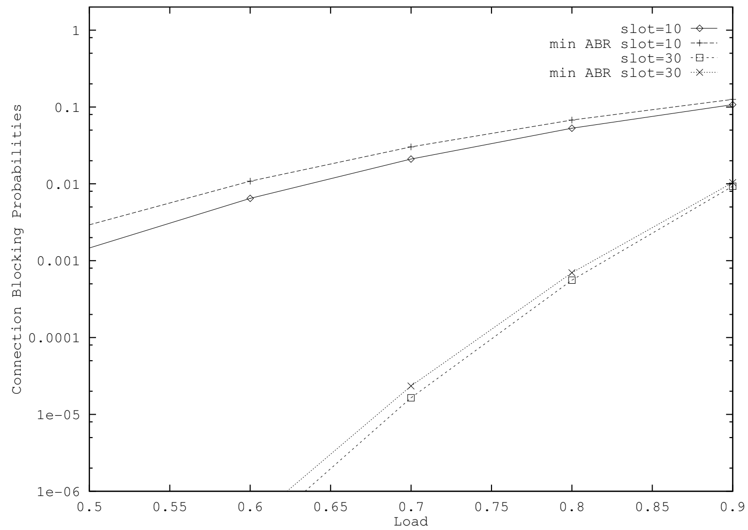

Fig. 9. Blocking probabilities when bandwidth is reserved to data traffic

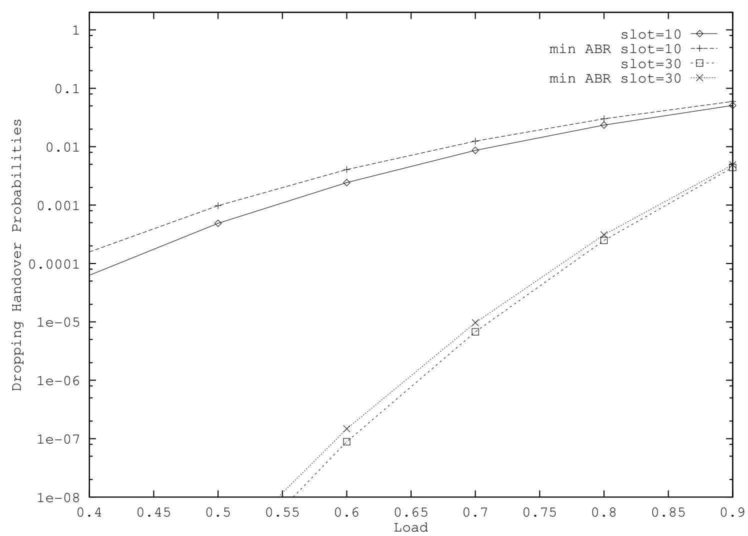

Fig. 10. Dropping probabilities when bandwidth is reserved to data traffic

Logically, neither the flow control mechanism nor the buffer size have any impact on the QoS of CBR traffic. However, to guarantee a minimal amount of bandwidth to ABR service (one time slot in the scenario) increases both the performance parameters for CBR service (Figs. 9 and 10). In this case, CBR requests have only access to $C-1$ slots. We observe however, that the blocking probabilities with less available bandwidth are just slightly higher than the blocking probabilities with all of the bandwidth available. Same remark for the dropping probabilities. In conclusion, MRAP allows standard values for blocking and dropping probabilities even with a little part of bandwidth reserved to ABR service. In the following section, we will show that this short reserved bandwidth is enough to reduce significantly data packet losses.

5.3 Providing QoS to ABR service

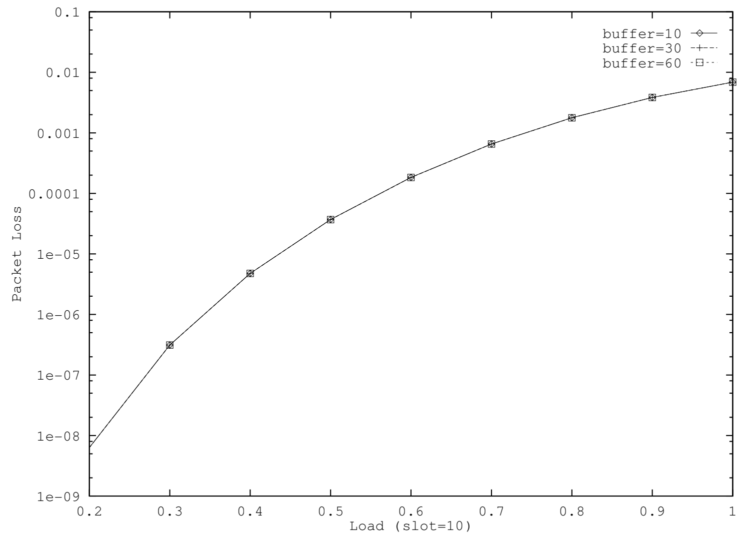

Fig. 11. Packet Loss probabilities for three buffer sizes

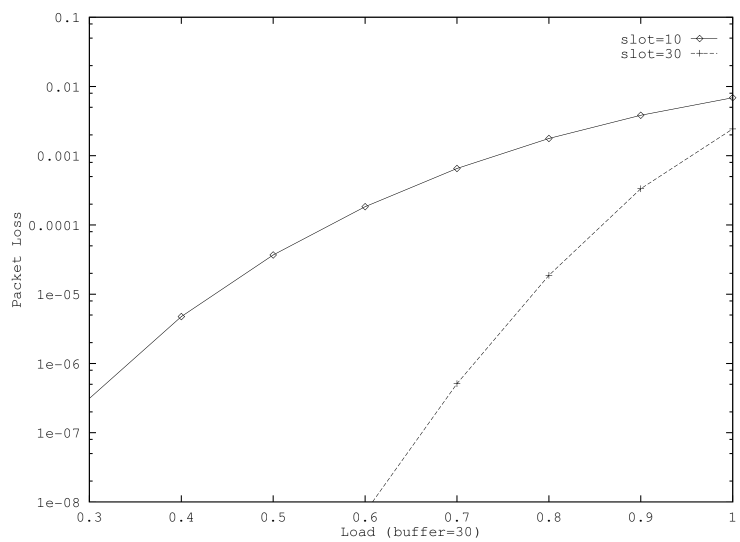

Fig. 12. Packet Loss probabilities for two frame sizes

In order to reduce data packets losses, we can perform four actions:

(i) increase the buffer size.
(ii) increase the number of slots in the frame.
(iii) control the source rate.

(iv) reserve a part of bandwidth to ABR service.

As shown in Fig. 11, when the number of slots is reduced (10 slots), too many packets need to be stored in the buffer and it is always full, whatever its size. On the other hand, when the size of the TDMA frame increases, the loss probabilities decrease (Fig. 12). However, the size of the TDMA frame is a fixed parameter of the Personal Communication System and is difficult to modify in an existing network.

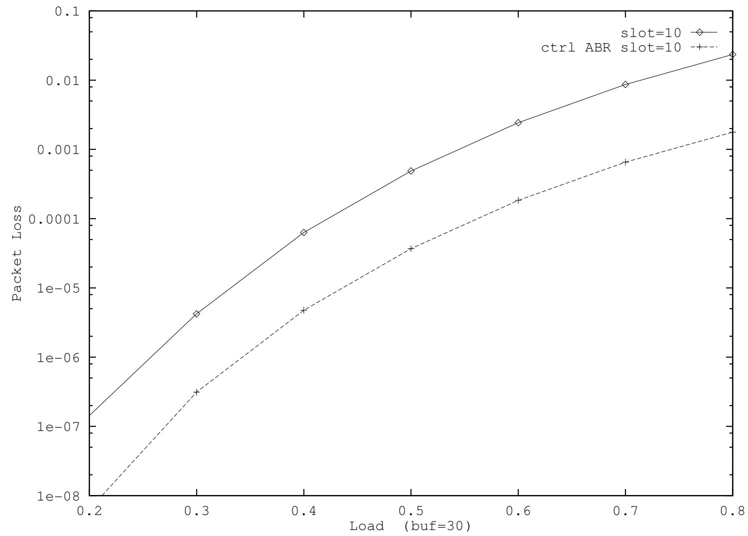

Fig. 13. Packet Loss probabilities with Flow Control

The next enhancement is to control the source rate each time the buffer overflows. It consists of sending 10 times less data during a time unit. Figure 13 exhibits the obtained results. This action has little impact on the loss rate as it increases rapidly with load, even when data throughput is low.

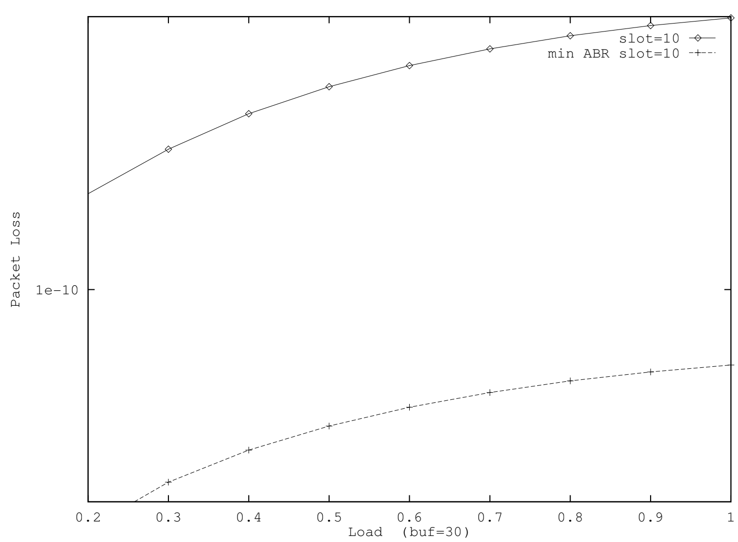

Fig. 14. Packet Loss probabilities with Minimal Guaranteed Bandwidth

The last solution is to always reserve one time slot for ABR traffic. As it is shown in Fig. 14, this solution gives the best results in terms of reducing losses, whereas, as seen before, bandwidth reservation does not affect the QoS for CBR traffic. The results are similar when we perform only bandwidth reservation as when we perform both bandwidth reservation and flow control.

6 Conclusion

We have investigated the integration of both ABR and CBR services in a Wireless ATM network by means of a proposed mechanism called MRAP. MRAP allows the sharing time slots of the TDMA frame efficiently between two classes of traffic, while satisfying the QoS requirements of both.

MRAP consists of giving priority to handover over new call requests, which have in turn, priority over data requests. As data packets use the allocated resource for a single time slot, data traffic is completely transparent to the voice traffic.

We use a new modeling methodology, the Stochastic Automata Networks which allows us to develop a readable model and to compute the steady-state probabilities without building the entire state space.

To obtain low data packet losses, we compare the impact of four actions. Most of the time, it is not possible to increase the size of the TDMA frame which is part of the wireless communication system. Then, we can act on the buffer size, the source rate control and, the slot allocation policy. Our experiments show that the last action gives the best performance. It consists of reserving a minimal bandwidth amount to the ABR service. We have shown furthermore that it does not affect the blocking or dropping probabilities of the CBR service, and that it considerably reduces the packet loss probabilities for the ABR service. It is possible to have no flow control unless the mechanism is implemented in conjunction with error control. As it is very simple, MRAP seems to be very promising.

Future investigations will take into account not only ABR service classes but also real-time VBR service classes. In contrast with CBR ones, VBR connections are not active all the time but only during short period called *bursts*. It is then possible to increase the effective data rate by using the VBR slots during their inactive periods. This system keeps the transparency property as VBR connections recapture their slots as soon as they become active again. However, the slot activity management seems to be complicated significantly and the associated model

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