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Introduction of a new polling strategy for a wireless LAN at an ATM radio interface

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***Abstract* -- The transmission of capacity requests is one major problem in wireless LAN at an ATM radio interface. Random access on the one hand is efficient but cannot guarantee a certain access delay. Polling on the other hand maintains a short access delay while introducing a high signalling overhead. We propose a polling scheme based on the nominal cell rate (NCR) to reduce the signalling overhead. Our simulations show that our new polling strategy maintains a low access delay while reducing the overhead significantly. The polling scheme can be adapted to all kinds of traffic.**

I. Introduction

Medium Access Protocols (MAC) are a key issue for wireless ATM systems and are characterised by a frame based organisation of a TDMA channel. A lot of proposals have been made proposing a frame structure as shown in Figure 1 [4], [5], [6], [7], [9]. This type of frame based MAC protocol is the basis for the HIPERLAN Type 2 standardisation within ETSI BRAN [15].

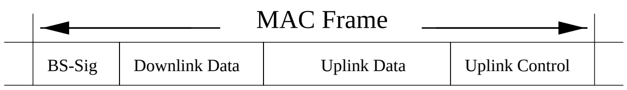


Figure 1: MAC Frame structure

In [6], a reservation-based medium access control (MAC) protocol for wireless-ATM networks has been proposed which can, in some ways, guarantee the quality of service in terms of allocated bandwidth by first reserving and then scheduling the required resources via a control channel. In that protocol, a registered wireless terminal (WT), that wants to set up a connection, can send a request via an ATM signalling cell to the ATM layer of the base station (BS) or central controller (CC). When the ATM layer of the BS/CC receives this request cell, it will determine the nominal number of slots and the buffer space required, based on the traffic descriptor in that signalling cell and the available buffer space in the MAC of the WT. If the available buffer space is sufficient for the required one and the nominal number of slots required can be covered by the available bandwidth, then the connection is accepted and the calculated nominal number of slots will be reserved for that connection for subsequent slot allocation (see [6] for details of the slot allocation). An ATM signalling packet is then sent back to the ATM layer of the WT to confirm the connection. Clearly, all the connection setup management is done via ATM signalling cells.

Besides the scheduling algorithm, which has been well addressed in literature, the transmission of capacity requests is one of the major problems in this kind of systems [7]. Mainly three options have been identified so far:

1. Piggybacking of capacity requests on uplink data packets
2. Random Access
3. Polling

The first option has been proved to be most efficient, but it is limited at least to terminals, which have been assigned capacity in the previous frame. The second and third option is used, if piggybacking is not possible, because a terminal just changes its state from idle to active.

In [8] a splitting algorithm is described, which combines random access and polling in an elegant way. One of the key factors for the efficiency of this algorithm as well as for a pure polling scheme is the estimation of the next arrival of a data packet within a terminal. This estimation and its application is the main focus of this paper.

The paper is organized as follows: Section II. describes the determination of the *Nominal Cell Rate* (NCR), which can be used for scheduling as well as for polling. Polling strategies to serve CBR and VBR traffic are discussed in Section III. An introduction to a novel combination of random access and polling using Energy Bursts [3] is given in Section IV. Simulation results to confirm the effectiveness of our proposal are summarized in Section V. Finally, conclusions are drawn in Section VI.

II. Determination of Nominal Cell Rate

The *Nominal Cell Rate* (NCR) is the minimum cell rate which is necessary to meet the quality-of-service requirements of an established VC. The NCR is calculated during connection setup time using the parameters given in the traffic descriptor. The NCR does not change over the whole duration of a connection.

A. *Traffic Descriptor*

Generally, the ATM traffic can be categorized into five types:
(1) constant bit rate (CBR),
(2) real-time variable bit rate (rt-VBR),
(3) non-real-time variable bit rate (nrt-VBR),
(4) unspecified bit rate (UBR), and
(5) available bit rate (ABR).

Each of these traffic types can be described by a traffic descriptor that consists of some traffic parameters and some QoS parameters.

The traffic parameters in an ATM service may include:

Table 1: ATM Service Category Attributes

Attribute	ATM Traffic Types				
	CBR	**rt-VBR**	**nrt-VBR**	**UBR**	**ABR**
Traffic Parameters:					
PCR and CDVT	specified			optional	specified
SCR, MBS, CDVT	n/a	specified		n/a	
MCR	n/a			n/a	specified
QoS Parameters:					
peak-to-peak CDV	specified		unspecified		
maxCTD	specified		unspecified		
CLR	specified			unspecified	optional
Others:					
feedback	unspecified				specified

- Peak Cell Rate (PCR)
- Cell Delay Variation Tolerance (CDVT)
- Sustainable Cell Rate (SCR)
- Maximum Burst Size (MBS)
- Minimum Cell Rate (MCR)

The QoS parameters in an ATM service may include:

- Peak-to-peak Cell Delay Variation (peak-to-peak CDV)
- Maximum Cell Transfer Delay (maxCTD)
- Cell Loss Ratio (CLR)

Details of parameters specified in a traffic descriptor for a particular traffic type can be found in Table 2-1 of [2]. For ease of reference, it is reproduced in Table 1.

B. *Problem Formulation*

Given a traffic descriptor (*D*) of a real-time VBR connection requested by a WT and the available buffer space (avB) at the WT,
(a) determine its *Nominal Cell Rate* (NCR) and its required buffer space (reqB),
(b) check if the connection can be accepted or rejected, using the calculated NCR and reqB only.[1,2]

C. *Calculation of NCR and reqB for rt-VBR*

From Table 1, the traffic descriptor for real-time VBR traffic is given by
D={PCR, CDVT, SCR, MBS, peak-to-peak CDV, maxCTD, CLR}.
In the following, we will consider a rt-VBR connection setup request and use some of the above parameters and the available buffer space, avB, to determine its NCR and buffer space required, reqB.

There are several limiting factors for determining NCR. So far, we have identified three of them, namely,
(a) the maximum cell transfer delay (maxCTD),
(b) available MAC buffer space (avB), and
(c) the sustainable cell rate (SCR).

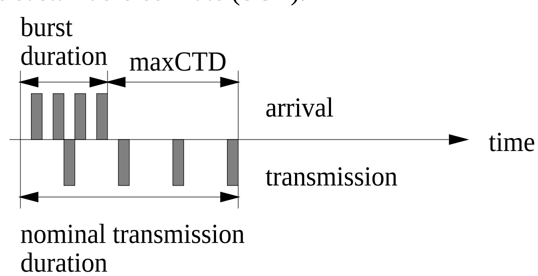


Figure 2: Definition of parameters for the nominal cell rate calculation

Limiting factor A: maximum cell transfer delay (maxCTD)
In order to serve a burst of length MBS without violating the maxCTD constraint, the NCR must be sufficient high such that difference between the departure time and the arrival time of the last cell is less than maxCTD as shown in Figure 2.
In the upper part of Figure 2, a burst of length MBS arrives at PCR. So, the burst duration τ_B is given by:

$$\tau_B = \frac{MBS}{PCR} \qquad \text{(EQ 1)}$$

The transmission of a burst is performed at NCR. Hence, the nominal transmission duration τ_N is given by:

$$\tau_N = \frac{MBS}{NCR} \qquad \text{(EQ 2)}$$

Since the nominal transmission duration must be less than the sum of the burst duration and the maxCTD, this implies

1. This task is done at the BS.
2. The bottleneck is considered to be the availability of bandwidth in the air.

$$\tau_N \le \tau_B + maxCTD \qquad \text{(EQ 3)}$$

Combining EQ 1, EQ 2 and EQ 3, the nominal cell rate will be given by:

$$NCR \ge \frac{MBS}{PCR \cdot maxCTD + MBS} \cdot PCR \qquad \text{(EQ 4)}$$

Limiting factor B: available MAC buffer space (avB)
In order to serve a burst of length MBS without overflowing the MAC buffer, avB must be sufficient large such that

$$avB \ge (PCR - NCR) \cdot \frac{MBS}{PCR} \qquad \text{(EQ 5)}$$

This implies

$$NCR \ge \left(1 - \frac{avB}{MBS}\right) \cdot PCR \qquad \text{(EQ 6)}$$

Of course, EQ 5 is useful only when $avB < MBS$.
Limiting factor C: Sustainable cell rate (SCR)
In order to ensure the performance of an ATM connection,

$$NCR \ge SCR \qquad \text{(EQ 7)}$$

By taking all three limiting factors into account, we have

$$NCR \ge max\left\{\begin{array}{c} SCR \\ \left(1 - \frac{avB}{MBS}\right) \cdot PCR \\ \frac{MBS \cdot PCR}{PCR \cdot maxCTD + MBS} \end{array}\right\} \qquad \text{(EQ 8)}$$

and the MAC buffer space required (reqB) could be obtained from EQ 5 as follows:

$$reqB = max\left\{0, (PCR - NCR) \cdot \frac{MBS}{PCR}\right\} \qquad \text{(EQ 9)}$$

Remark: the cell delay variation has not been considered in our calculation yet.

D. NCR and reqB for other traffic types

So far, we have only considered the calculation of NCR and reqB for rt-VBR traffic. The NCR for other traffic types is more easy to obtain, which are summarized in Table 2.

III. Polling strategies

The most simple polling strategy in a frame based MAC protocol using a combination of piggyback and polling for the transmission of capacity requests is to poll all inactive terminals in every frame. This scheme is very simple and leads to a very low signalling delay, but on the other hand is paid by a high signalling overhead (cp. Figure 3 (1)). As long as the number of inactive terminals is around ten, the signalling overhead is acceptable but increases linear with the number of inactive terminals.

Table 2: NCR and reqB for various ATM Services

	ATM Traffic Types				
	CBR	**rt-VBR**	**nrt-VBR**	**UBR**	**ABR**
NCR	PCR	See algorithm	SCR	0	MCR
reqB	0	See algorithm	[a]	TBD	TBD

a. reqB for nrt-VBR is given by the same formula as in EQ 9

In order to reduce the signalling overhead that arises from polling all inactive terminals, it is essential to estimate the arrival time of new cells in the terminals. The knowledge of the arrival time of new cells is necessary to reach the goal of transmitting capacity requests only, if they have been recently changed (cp. Figure 3 (2)).

A. Characteristics of the ATM traffic types

The describing attribute of CBR type traffic is the deterministic inter-arrival time of ATM cells. But taking into account the cell delay variation, which arises from different delays in the switches of the ATM core network, only statistical values can describe the inter-arrival time.

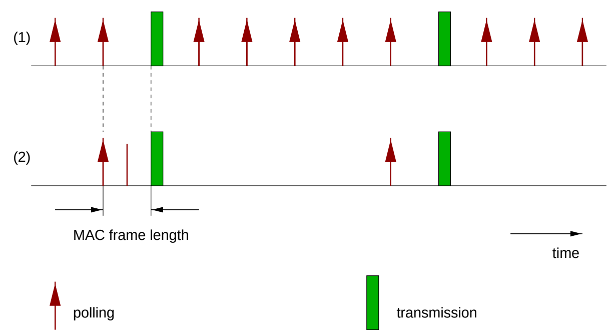


Figure 3: Reducing the signalling overhead by estimating the arrival of a new cell

VBR type traffic is bursty in nature. Unfortunately the inter-arrival time of burst is in most cases non-deterministic and cannot be derived from the parameters given in the traffic descriptor. So the NCR is used to estimate the inter-arrival time of bursts.
ABR services are not time-critical and therefore the access delay for transmitting the capacity requests is not time-critical as well. The NCR for ABR is based on the minimum cell rate (MCR), if specified in the traffic contract (see Table 2). Because of the fact that no quality of service parameters are guaranteed to UBR services, no NCR can be computed. Terminals that run connections with ABR or UBR services only, can be polled in a cyclic manner with quite long time intervals because they are not time-critical. The limiting factor is the buff-

er space here. Further research will show a required buffer size for ABR and UBR and based on it a suitable polling cycle. Additionally, random access can be used for these kinds of traffic types.

B. Priority based Polling Algorithm

Figure 4 depicts the polling algorithm that calculates a priority P(k, j) for each VC j to determine, whether the VC is polled or not. The calculation is done at the beginning of a new MAC frame after the scheduling is performed. The algorithm uses the number of assigned slots S(k, j) in the current MAC frame k and the *Minimum Poll Rate* MPR(k, j).

At connection setup, the priority P(k, j) is initialized with the *Minimum Poll Rate* (in slots per MAC frame). MPR(k, j) depends on the MAC frame length as well as on the traffic characteristics of the VC.

The computation and evaluation of the priorities is done one after the other. So, it is done for VC 0 first.

If there has been a poll slot assigned to VC j in the last MAC frame and VC j used this poll slot, the priority P(k, j) is reset to MPR(k, j) to synchronise the computation of the priority with the arrival process in the terminal.

The VC used the first assigned poll slot, if no poll slot has been assigned to VC j in MAC frame k-2 and Poll Slot (k-1, j) has been used. The P(k, j) is increased by MPR(k, j) and decreased by the number of assigned slots in the current MAC frame S(k, j).

If the priority exceeds the threshold T, the terminal will be polled in the current MAC frame.

After the evaluation is done, the calculation of the priority of VC j+1 is performed until every VC is processed.

In case the number of terminal that can be polled per MAC frame is limited, the polling strategy has to determine which terminal is polled and which is not. Because the priorities are calculated using the MPR, terminals with high requirements for time-critical handling have high priorities. This makes it easy to decide which terminal to poll because the terminals with the top priorities will be chosen first. In the following MAC frame these top prioritised terminals are ignored and less prioritised terminals are polled.

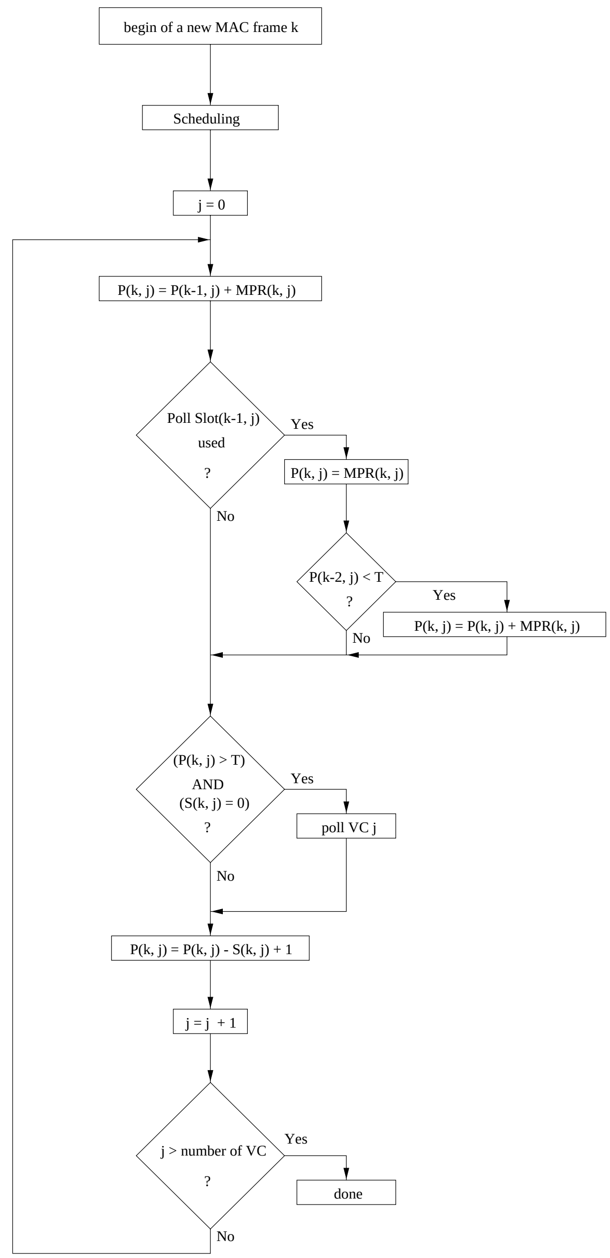
C. Parameters for the Polling Algorithm

The priority based polling algorithm, as described above, is characterized by the *Minimum Poll Rates* (MPR) and a threshold T. Both parameters influence each other.

We propose the following two ways to determine the *Minimum Poll Rate*. Both, the SCR and the NCR, have been used as parameters in our simulations (see Section V.).

C.1 SCR as Minimum Poll Rate

In [2], the *Generic Cell Rate Algorithm* (GCRA) has been proposed to control the traffic of each VC. The GCRA calculates a theoretical arrival time of a new cell using the *Sustainable Cell Rate* (SCR). So, the SCR can be used to set the *Minimum Poll Rate* (MPR).



P(k, j): Priority of VC j in MAC frame k
S(k, j): Number of assigned slots in MAC frame k for VC j
MPR(k, j): Minimum Poll Rate for VC j in MAC frame k
T: Threshold

Figure 4: Priority based Polling Algorithm

C.2 NCR as Minimum Poll Rate

The *Nominal Cell Rate (NCR)*, as described in Section II., takes the traffic and QoS parameters into account. The NCR is greater than or equal to the SCR and so, in some cases, the access delay can be reduced when using the NCR to set the *Min-*

imum Poll Rate (MPR).

IV. Combination of Polling and Random Access using Energy Bursts

Energy Bursts has been introduced in [6] as a simple and efficient way to poll terminals. An *Energy Burst* (EB) is energy detected by the receiver in a certain time slot. An EB does not contain any data and is as short as the time to reliably detect energy on the channel.
So far, random access has been always based on at least the transmission of *Short Bursts* (SB) which are characterised by a address and some byte of information. SB are longer than EB as it takes more time to decode a signal than to detect one.
The most important difference is that with Energy Bursts the transmission of one or more terminals cannot be distinguished and thus results in the same state ENERGY.
The principle of *Random Access* (RA) is that more than 1 terminal is allowed to access one slot. The result of possible transmissions is summarised in Table 3.

Table 3: Transmission results for Energy and Short Bursts

WTs transmitting	0	1	> 1
EB	IDLE	ENERGY	ENERGY
SB	IDLE	SUCCESS	COLLISION

If no terminals are transmitting, the result is the same for EB and SB. If 1 terminal is transmitting, with SB the transmission is successful, but with EB it is not clear whether 1 or more terminals have been transmitting. In case of RA with EB a transmission of 1 terminal is logically a collision and results in the state ENERGY.
If more than 1 terminal is transmitting a collision resolution algorithm is necessary. The goal is to minimise the probability of a collision. This is done by limiting the number of terminals which are allowed to access a specific slot. If only one terminal is allowed to access a specific slot, this terminal is polled. Basically, collision resolution can be done for both, SB and EB. The difference is that for a successful transmission with EB polling must be performed, with SB not (remember, if 1 terminal is transmitting it is fine with SB, but not with EB in case of RA).

A. *Implementation considerations*

In theory it is simple to detect the correct state of a transmission, but in practice it is not.
The following effects have to be considered while judging random access techniques: fading, co-channel interference and capture effect.
These effects have to be considered while determining the result of a transmission.

A.1 Fading

Fading here is seen as the effect that the path loss of a transmission is higher than before on a short term basis resulting in a low power level for the expected signal at the receiver. With fading the results of a transmission may change as listed in Table 4 (compared to Table 3).

Table 4: Transmission results for Energy and Short Bursts considering fading

WTs transmitting	0	1	> 1
EB	IDLE	IDLE or ENERGY instead of ENERGY	IDLE or ENERGY instead of ENERGY
SB	IDLE	IDLE or COLLISON instead of SUCCESS	IDLE or COLLISION instead of COLLISION

With fading both EB and SB are effected in the same way for more than 1 terminal transmitting. For 1 terminal transmitting there is a significant difference between EB and SB. As the signal power level for energy detection is lower than for signal decoding the probability for a misdetection using EB is lower than for a faulty reception using SB.

A.2 Interference

With interference an effect is described which results from the transmission in neighbouring or adjacent systems or cells. This leads to an interference level which does not allow the decoding at the receiver. With interference the results of a transmission may change as listed in Table 5 (compared to Table 3).

Table 5: Transmission results for Energy and Short Bursts considering co-channel interference

WTs transmitting	0	1	> 1
EB	ENERGY instead of IDLE	ENERGY	ENERGY
SB	COLLISION instead of IDLE	COLLISION instead of SUCCESS	COLLISION

With interference ENERGY is detected even if no terminal is transmitting. This is termed as FALSE ALARM. The same applies for SB where the result is COLLISION.
With more than 1 terminal transmitting the result is not affected by co-channel interference.

Note that a transmission of 1 terminal leads to a correct transmission result for EB (ENERGY) but not for SB.

A.3 Capture effect

Capture describes an effect that it is sometimes possible to decode a transmission although other terminals are transmitting in the same radio cell as well. The reasons for capture may be the near-far effect (one terminal close to the receiver the other one far away) or even fading. With capture the results of a transmission may change as listed in Table 6 (compared to Table 3).

Table 6: Transmission results for Energy and Short Bursts considering capture effect

WTs transmitting	0	1	> 1
EB	IDLE	ENERGY	ENERGY
SB	IDLE	SUCCESS	SUCCESS instead of COLLISION

Capture does not affect the transmission results with EB.
With SB a successful transmission may occur even if more than 1 terminal is transmitting. This is a positive effect for the terminal whose transmission has been captured but may be negative for the other terminals, because no collision resolution takes place in case of a successful transmission. It may happen that a terminal far away but still in range of the receiver does not have any chance to get through because each time it access the channel a terminal close to the receiver does so as well and the transmission of the later one will be captured. With EB the terminal far away from the receiver will get a dedicated EB (polling) because of the collision resolution initiated by the transmission result ENERGY.
The probability for a wrong detection of the outcome of a transmission is lower for Energy Bursts than for Short Bursts. Furthermore, with Energy Bursts the probability of a FALSE ALARM is much higher than for a SILENT ALARM so that Energy Burst detection is very robust especially for delay and loss sensitive messages like alarms.
For the modem design it is very simple to reliably detect energy by exploiting the properties of an OFDM receiver [13], [14], but it is not an easy task to detect collisions.

B. Collision resolution algorithms for Energy Bursts

As an example one collision resolution algorithm is presented here for EB and SB. There are other possibilities and optimization. Here, we use a non-blocking identifier splitting algorithm. For details please refer to [11],[8].
Figure 5 shows an example for a splitting algorithm. Every box represents an EB or SB, the numbers above the boxes determine the terminals allowed to access this slot and the numbers

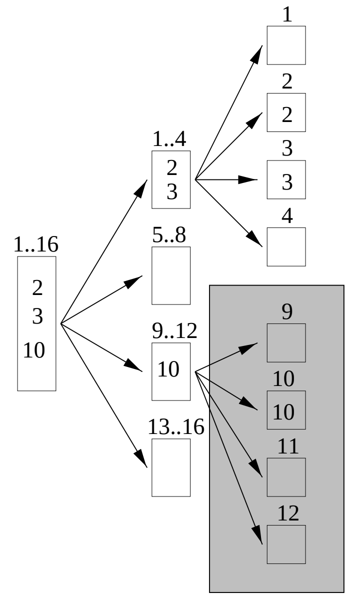


Figure 5: Basic splitting algorithm

within the boxes represent the terminals which actually used this slot. Three MAC frames are shown starting on the left hand with one slot.
In the first MAC frame all 16 terminals are allowed to access the single slot. Three terminals do so (2, 3, 10). In case of SB a COLLISION is detected, in case of EB ENERGY. In the next MAC frame the 16 terminals are split into 4 sub-sets in order to lower the probability of a collision, this is termed as a splitting order of 4.
In the second MAC frame 4 slots are available and the results of the access are IDLE for slot 2 and 4, COLLISION/ENERGY for slot 1 and SUCCESS/ENERGY for slot 3. For slot 1 another splitting is necessary, for slot 3 another splitting is necessary for EB but not for SB, so the grey box is needed for EB only.
A first impression of the performance of RA with EB is given in Figure 6. Here the ratio of the length (in time) of EB to SB is the parameter varied. Two scenarios have been considered, with 100 and 1000 terminals per radio cell. The maximum access delay is shown in Figure 6 measured in number of MAC frames (=1ms). The start set is 1 for SB and EB/SB for EB. The splitting order is 4 for SB and EB/SB for EB. With these parameter settings the overhead for RA per MAC frame is nearly the same for SB and EB.
The higher the number EB/SB the lower the maximum access delay and the better the performance for EB. Further investigations will show reasonable numbers for EB/SB.
Instead of using one slot in the first MAC frame, it is possible to use several sub-groups right from the beginning. The size of the groups as well as the WTs belonging to the group can be optimized by using the knowledge about the access probability. In case of MAC signalling, this probability is given by the algorithm described in Section III.B. The performance of such

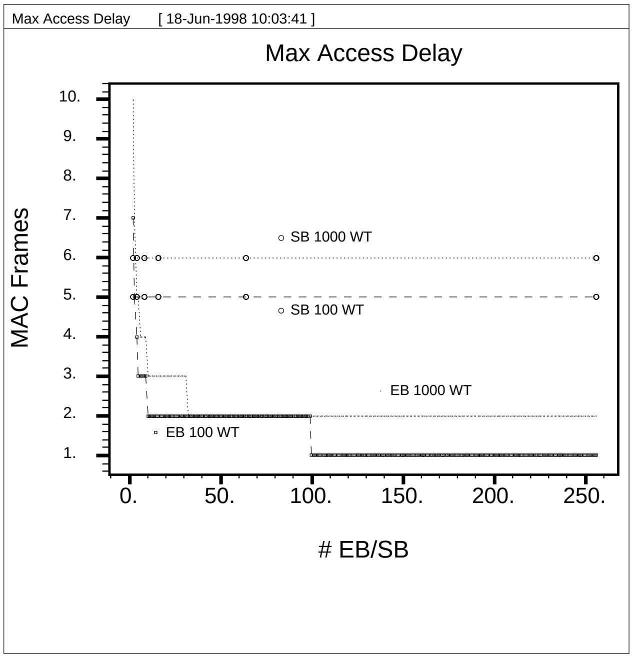


Figure 6: Maximum Access Delay for Random Access with SB and EB

a scheme is for further study.

V. Performance Evaluation by Simulation

The performance of the new polling method has been evaluated by computer simulation using the BONeS Designer simulation tool [10].

The three parameters which have been evaluated by simulation runs are

1. the number of poll tries per successful access,
2. the saving of signalling overhead with the new scheme compared with the simple one (polling every MAC frame), and
3. the average access delay.

As only these parameters are of interest in this investigation not a whole wireless ATM system has to be modelled.

A. Scenario Description

A system with one base station serving one mobile station running one connection has been considered. If multiple mobiles have to be served, the amount of capacity used for signalling purposes can be multiplied by the number of mobiles. Therefore, it is reasonable to concentrate on the results with one mobile only.

Transmission errors have been neglected as they affect both signalling techniques in the same way.

The MAC frame has a constant length of 1 ms and a maximum of 50 ATM cells can be transmitted within one MAC frame. Whenever an ATM cell is transmitted, piggybacked signalling is used instead of polling. In order to investigate the effect of polling without having too much piggyback signalling the system load has to be below 1% which equals 0.5 ATM cells every MAC frame on average. The simulated SCR varies from 0.15 to 0.5 ATM cells per MAC frame.

CBR type traffic has been modelled by a constant inter-arrival time of ATM cells which vary with the peak-to-peak cell delay variance.

For the modelling of VBR sources three types of traffic models have been used.

1. *Bursty CBR*: Bursts with a constant number of ATM cells are generated at constant inter-arrival times.
2. *Video*: This type of source describes the cell stream that is generated by a high quality video codec. The number of pictures per second is constant and the number of pixels per pictures is determined by an first order auto-regressive process [16].
3. *Geo*: This type of source is a quite general model for VBR traffic. It is an *On-Off* source with negative exponential distributed inter-arrival times of bursts and geometrical distribution of the number of ATM cells per burst.

B. Interpretation of Simulation Results

Figure 7, Figure 8 and Figure 9 show the simulation results for the two different polling schemes using NCR and SCR respectively. The results using all four source models are given.

Figure 7 shows the average access delay. For the simple scheme it is 0.5 MAC frames and not plotted in Figure 7. The access delay for the *CBR*, *Bursty CBR* and *Video* sources is ideal, whereas the delay for the *Geo* source while using the SCR is not acceptable. Using NCR for polling *Geo* sources the delays are still moderate.

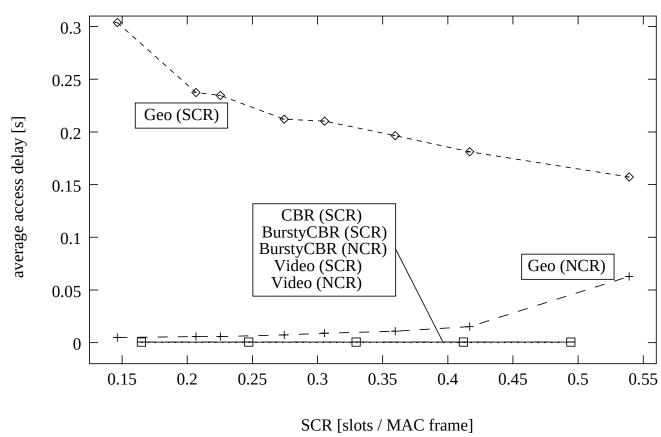


Figure 7: Average access delay

Low delays are paid by a high number of poll tries per burst. Figure 8 shows the average number of poll tries per burst. For *CBR* type services both polling schemes (for CBR both schemes are the same as PCR=SCR=NCR) lead to low delays and only little more than 1 poll try per ATM cell. It is close to the optimum.

The results for VBR strongly depend on the polling scheme as well as the source characteristics. For *Bursty CBR* type traffic

SCR outperforms NCR by factor of up to 7. For the *Video* model the performance of NCR and SCR is nearly the same with advantages for SCR with a factor of around 1.5. *Geo* type traffic is best polled with NCR as it leads to low delays and a moderate amount of poll tries per burst.

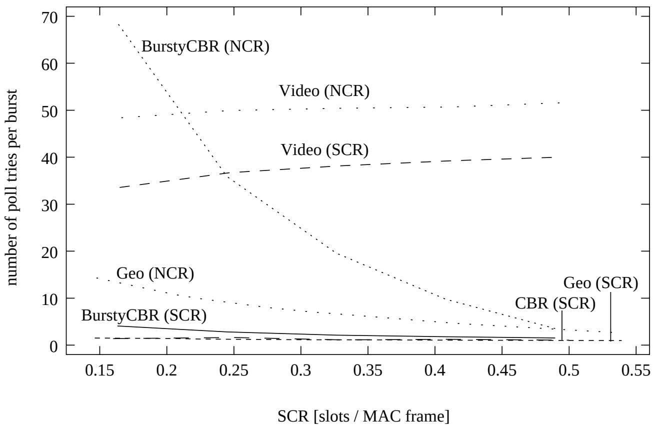


Figure 8: Number of poll tries per burst

Figure 9 shows the saving of signalling compared with the simple scheme. For both types of polling and all types of sources the savings are significant and in a range between 20% and 95%.

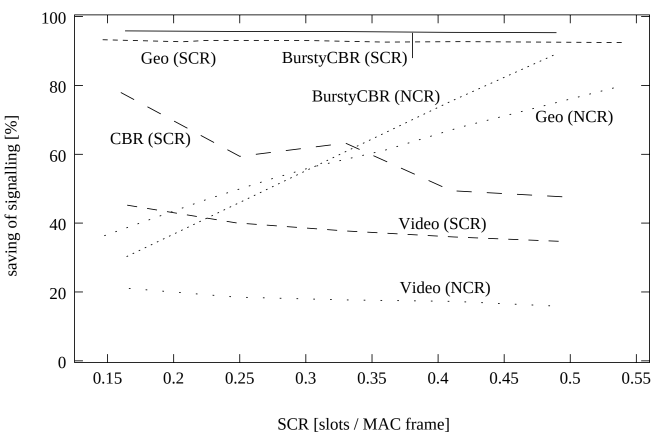


Figure 9: Saving of signalling

VI. Conclusions

Signalling techniques are one of the important issues influencing the efficiency of frame based MAC scheme as proposed for wireless ATM standardisation in ETSI Project BRAN. In order to improve the efficiency of polling and random access techniques, a method to estimate the arrivals of ATM cells has been introduced. This is based on the SCR or on the NCR which in turn is based on the ATM Traffic Contract of each individual VC. This method is both simple and flexible enough to cover a whole range of applications such as CBR and real-time VBR type traffic.

Computer simulations show that the performance of the algorithm strongly depends on the characteristics of the ATM sources, but still is better than using no prediction algorithm at all. A combination of polling and random access is promising and for further study.

VII. Acknowledgements

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VIII. References

[1] K. Chen: "Medium Access Control of Wireless LANs for Mobile Computing", IEEE Network, vol. 8, no. 5, Sept./Oct, 1994, pp 50-63.

[2] "Traffic Management Specification (Version 4.0)," ATM Forum, April 1996.

[3] Y. Du, S. N. Hulyalkar, D. Evans, et al., "System Architecture of A Home Wireless ATM Network," Proc ICUPC´96, Sept. 1996, Cambridge, Massachusetts, pp. 477-481.

[4] Bauchot, F. et al, "MASCARA, a MAC Protocol for Wireless ATM," ACTS Mobile Communications Summit, Granada, Spain, November 1996, pp. 647 - 651.

[5] Delli Priscoli, F., "Medium Access Control for the MEDIAN System," ACTS Mobile Communications Summit, Granada, Spain, November 1996, pp. 631 - 638.

[6] S. Hulyalkar, C. Ngo, Y. Du, A. Hettich, "Contention-free MAC Protocol for Wireless ATM LAN," ACTS Mobile Communications Summit, Aalborg, Denmark, October 1997, pp. 728-733.

[7] J. Sanchez, R. Martinez, M. Marcellin, "A Survey of MAC Protocols Proposed for Wireless ATM," IEEE Network, November 1997, pp. 52 - 62.

[8] D. Petras, A. Krämling, "Fast Collision Resolution in Wireless ATM Networks," 2nd MATHMOD, Vienna, Austria, February 1997, pp. 517-524.

[9] D. Petras, A. Krämling, "Wireless ATM: Performance Evaluation of a DSA++ MAC Protocol with Fast Collision Resolution by a Probing Algorithm," Int. J. of Wireless Information Networks, October 1997, Vol. 4, pp. 215-223.

[10] BONeS Designer (Version 3.6), Alta Group, 1996.

[11] D. Bertsekas and R. Gallager, "Data Networks," Englewood Cliffs, NJ, Prentice Hall, 1987.

[12] Y. Du, D. Evans, R. Fifield, C. Herrmann, A. Hettich, M. Lott, P. May and C. Ngo, "Adhoc wireless LAN based upon cellular ATM air interface," submitted to IEEE Journal on Selected Areas of Communications, Special issue on Wireless Ad Hoc Networks.

[13] S. Boyd, "Multitone Signals with Low Crest Factor," IEEE Trans. Circuits and Systems, Vol. CAS-33, No. 10, October 1986, pp. 1018-1022.

[14] C. Tellambura, "Use of m-sequences for OFDM peak-to-mean average power reduction ratio," Electronics Letters, Vol. 33, No. 15, 17 July 1997, pp. 1300-1301.

[15] ETSI TR 101 031, "Requirements and Architectures for Wireless ATM Access and Interconnection," Sophia Antipolis, France, 1997.

[16] E.-P. Rathgeb, "Modeling and Performance Comparison of Policing Mechanisms for ATM Networks," IEEE J. Select. Areas in Commun., Vol. 9, No. 3, pp. 325-333, April 1991.