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Philippe Jacquet, Paul Mühlethaler, Philippe Robert. A Slotted Medium Access Control Scheme Designed for CATV Network. [Research Report] RR-4106, INRIA. 2001. inria-00072525

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

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No 4106

Janvier 2001

THÈME 1

Rapport de recherche

ISSN 0249-6399 ISRN INRIA/RR--4106--FR+ENG

A slotted Medium Access Control Scheme designed for CATV Network

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Thème 1 — Réseaux et systèmes
Projet HIPERCOM

Rapport de recherche n ° 4106 — Janvier 2001 — 17 pages

Abstract: In this paper, we propose for Cable TV Networks (CATV Networks) designs of a slotted medium access scheme with collision detection. These designs are very simple; the used operations are as simple as the ones used in Ethernet. We analyze performance of these medium access schemes and show that easy optimizations of the collision resolution scheme can provide performance close to optimal. We discuss in detail synchronization issues. In the framework of our proposed protocol design,we describe a scheme to handle medium access priority. Our approach allows to handle various applications (ATM, CBR, VBR, ABR) and remains extremely simple.

Key-words: Medium Access Control scheme, Cable TV network (CATV network), Ethernet, performance evaluation, access priority.

(Résumé : tsvp)

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Accès multiple slotté dédiés pour des réseaux câblés de télévision

Résumé : Dans ce papier, nous proposons une classe de protocoles d'accès multiple slotté avec résolution de collision dédié aux réseaux câblés de télévision. Ces protocoles sont très simples et utilisent des opérations aussi simples que celles utilisées dans Ethernet. Nous étudions les performances de cette classe de protocole et montrons qu'une simple optimisation du système de résolution de collision permet d'obtenir des performances proches de l'optimal. Par ailleurs nous discutons en détail des problèmes de synchronisation. Nous montrons également que la classe de protocoles décrite permet de gérer des priorités d'accès MAC. Notre approche qui permet de gérer plusieurs applications (ATM, CBR, VBR, ABR) reste extrémement simple.

Mots-clé : Protocoles d'accès multiple, réseau câblé de télévision, Ethernet, évaluation de performance, priorité d'acc'es.

1 Introduction

Cable TV networks are now existing for more than thirty years. These large networks were used in towns to distribute television. In the early 90s the technology started works to use Cable TV to transmit interactive data. Obviously in such networks design for Tv broadcast, broadcast of data is much easier than returning data from a terminal. First the transmission on the return channel is more difficult due to noise problems, this explains why the return channel generally offers a significantly smaller throughput than the broadcast channel. Secondly the return channel is, of course, a shared medium. Sharing efficiently this medium will be our main interest in this paper. This paper has been presented as a contribution to the IEEE 802.14 commity. This paper is organized as follow. The next section provides a short intoduction to CATV network and a brief remainder on the usual MAC parameter in a packet switching network. Section 3 deals with the CATV physical layer requirement to handle our proposed access scheme. Section 4 deals with synchronization issues. Section 5 describes our Medium Access Scheme proposal. In section 6 we describe a simple way to handle MAC priority above our proposed access scheme and we show how to use this priority scheme to handle quality of service requirements.

2 Description of the architecture

2.1 Topology of a CATV network

Cable TV networks are metropolitan networks. The topology of a Cable TV network (CATV network) is a tree. At the root one can find the cable TV headend and one finds the user nodes at the leaves of the tree. The headend is an active part of the system which concentrates and redistributes data sent by the nodes. Cable TV networks have a large geographical extension, the headend may be up to 100 km or more far from a user node in the larger networks. See figure 1. The nodes transmit their packets towards the headend on the return channel. The headend concentrates the packets and broadcasts the packets to the nodes. In the following, we suppose the simplest architecture: the headend station uses a dedicated forward channel on which it echoes all signals received from the node on the return channel. See figure 1.

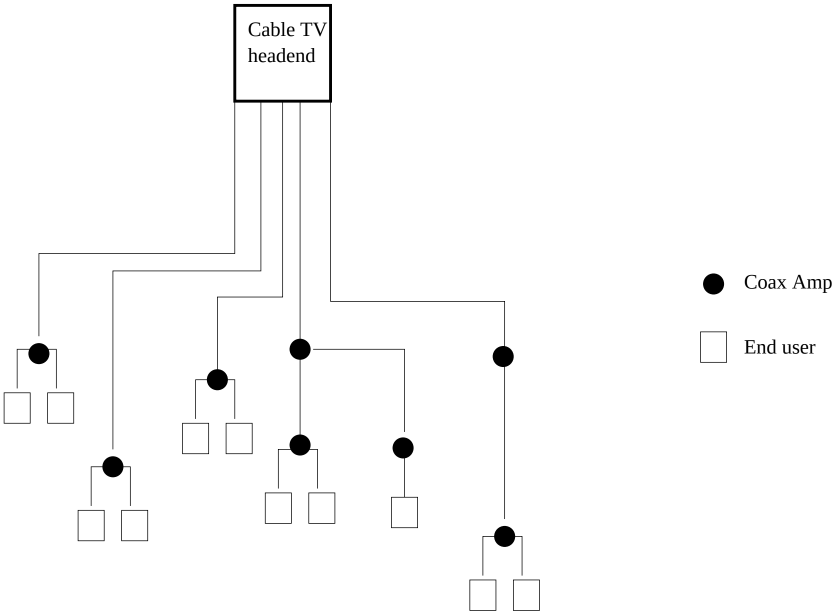

Figure 1: General architecture for CATV.

2.2 The MAC parameters

In packet switched systems when a packet is given by upper layers to the MAC layer the only mandatory information is the destination address. This is the most simple case. If one wishes to handle applications with special requirements, the use of additional control information is requested. Roughly speeking, one can distinguish two ways to handle special application requirements on a packet switched system. The first idea is to organize a reservation for applications. The nodes will therefore use a reserved part of the bandwidth to send their data. This approach is, for instance, the one which is used in RVSP. The second approach is to classify packets, a hierarchy is created between packets of different applications and packets are supposed to be handle in the network considering this hierarchy. This approach has been popularized by the IETF's DiffServ protocol. Hierarchy between packet is generally created with QoS parameters. These parameters allow upper layers to describe to the MAC the quality their requesting for their packets. One can find a lot of QoS parameters sets. One of the simplest QoS parameters set consists into a packet deadline. This QoS parameter is for instance used in [1]. With such QoS parameters system, packet for interactive voice will be assigned a deadline in the order 10-30 ms. The video packet deadline will be in the order 50-100 ms. File transfer packet deadline will, for instance, be set by default to 500 ms[1]). A packet which overcome its deadline shall be discarded. Before deciding of transmission attempts packets shall be stored in local queues according to their QoS parameters.

3 Considerations about CATV physical layer

3.1 Feedback durations

The nodes in active mode are supposed to permanently listen on this forward channel. The elapsed time between transmission and feedback is called feedback duration of the node. Each node can determine its feedback duration Δ as soon it can transmit a packet without interference. On existing CATV networks the maximum feedback duration Δ_m is 800 μsec. This value gives a network extension of 240 km (including return path) by also includes electronic durations and detection delays.

3.2 Alignment of feedback durations

Discrepancies between nodes' feedback durations may lead to "physical" unfairness. Indeed a node with a short feedback will receive feedback of successful transmission or failure faster than a node with larger feedback duration; therefore the former node has the possibility to retry or to submit new packets faster than the latter node, leading to what we can call physical unfairness.

The MAC must cope with this source of unfairness which may favor nodes as soon they are closer to the headend. To this end each node MAC will "simulate" a feedback duration identical for all nodes and set to its maximum value Δ_m. The general method to do will be to defer each retransmission decision of $\Delta_m - \Delta$ as it will be mentioned several times in the paper. The consequence of this operation is that all feedback durations will be set to the longest feedback duration. See figure 2.

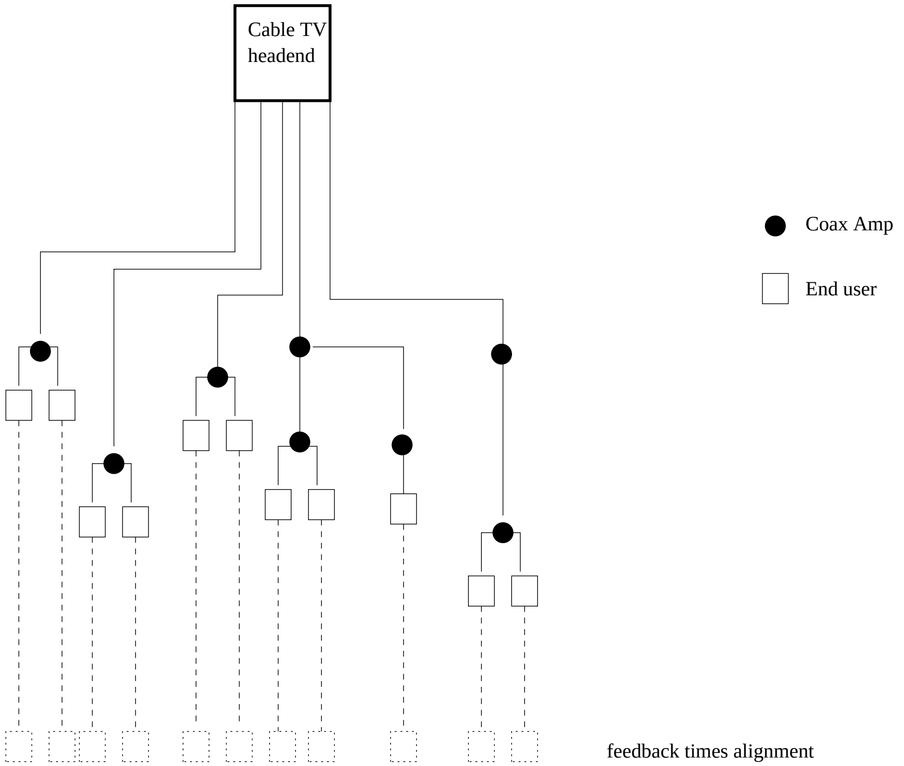

Figure 2: Feedback durations alignment to cope with PHY unfairness.

3.3 Slotted MAC

With usual figures $\Delta_m = 800\mu$sec and channel capacity 10 Mbps, the feedback duration corresponds to 8,000 bits which is several times the expected average packet size. With such large feedback durations, a CSMA scheme would not be efficient. Non slotted Aloha provides too poor throughput (upper bounded by 18% channel capacity) to be considered in this proposal, without speaking of classical Aloha collapse which may deadlocks any communication with zero throughput [2]. Actually we have in CATV network the same situation as in high speed network, the propagation delay is large related to the transmission delay of a packet. Surprisingly the kind of algorithms that will be suited for high speed network will therefore be possible candidate for CATV network [9]. A wise approach would be to choose a slotted scheme. Slot synchronization and distributed management will be discussed later and shall not pose serious problems. Slot size will be the maximum packet size, slot size S can be 64 bytes as in Ethernet or 53 bytes as in ATM, or something bigger.

3.4 Intra packet block reservation, virtual CSMA

If slot size is relatively small, long packets will need to be fragmented in several blocks. In order to avoid repeated collisions on blocks one can introduce a reservation bit in each block. The reservation bit basically tells:

- either the block is the last one in the packet (terminal block);
- or the block will be followed by another block (reserving block) in the same packet, consequently other stations should avoid transmission on slot $\Delta_m - \Delta$ later.

Notice that the process operates like a virtual CSMA: if the head block of a packet is successful, the other blocks on the packet should be safe from collision. In order to keep fair access to channel, one must fix a maximal packet size in blocks. See figure 3.

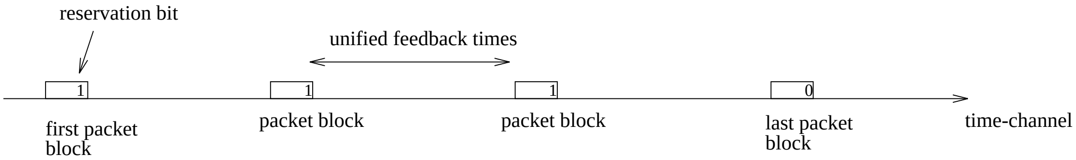

Figure 3: Reservation blocks and virtual CSMA.

4 Synchronization issues

4.1 Feedback durations

A node can compute its feedback durations via simple means. In insertion phase or refreshing phase, the node can send probe packets of one block each, from time to time. It will stop transmitting such probe packets when it will have a successful transmission of its own probe detected on the feedback channel. The gap between two consecutive probes from the same node shall be greater than Δ_m. The feedback duration will be computed in a straightforward manner by the difference of time between the last probe transmission and its successful reception on the feedback channel. A probe transmission can be unsuccessful because of collision with other packets (maybe within two blocks because of lack of slot synchronization of probe packet). Preferably transmission of probe packets should be done in low channel utilization period. A dedicated protocol for probe insertion could be defined.

4.2 Slot synchronization

It is not necessary to have a periodic signal which indicates each beginning of the slot on the channel (slot beaconing). In fact it should play against the feedback probing above described. Nevertheless the slot is needed for performance reasons, but in case of sustained traffic on the network, the slot synchronization would naturally self maintain via simple channel tracking. Of course one supposes that the nodes have already estimated their feedback durations. Consequently probe packets shall be omitted in channel tracking in slot synchronization.

In case of too long idle channel periods, the slot synchronization can be refreshed by the headend station via transmission of simple synchronization packets of one block each. Another solution shall be that the node users take care of refreshing synchronization via a distributed manner. For example the nodes can maintain an artificial flow of synchro packet at low input, and such a flow would disappear during real traffic occurrences. A last solution should be that after a long period of idle channel, the first packet transmitted on the channel plays the role of slot synchronizer.

5 Collision Resolution Protocol

In Ethernet, the collision resolution algorithm is precisely the Binary Exponential Backoff algorithm. This protocol is subject to unfairness and unstabilities under some range of use but its robustness makes it attractive. Here we present the basic backoff protocols.

In the present proposal we also introduce the tree algorithms [3, 5, 4] which are known in the literature as a fundamental improvement over any backoff algorithm. The tree needs to detect collisions on the feedback channel, which could be done by integrity check on block (local CRC).

In fact if one uses reservation bit, the receiver must detects whether a block is really a reserving block or if the reservation bit is set at "1" by accident (collision or noise). Therefore an integrity check shall be mandatory and collision detection be straightforward.

5.1 The Backoff protocol

When a packet is submitted to channel access and if the channel access control is available, the node tries to transmit the packet on the next available slot (available means not been reserved $\Delta_m - \Delta$ before by a reserving block).

The node detects the success or the failure of its transmission within its feedback duration plus one slot. In case of failure it runs the basic backoff algorithm as follow:

- set a counter B to a random integer value between 1 and N;

- remove 1 from B after each slot on the feedback channel except when the slot carries a reserving block;
- when $B = 0$, schedule packet transmission for $\Delta_m - \Delta$.

The quantity N is called the "backoff" parameter. Typical $N = 8$ or $N = 32$.

5.2 The tree algorithm

The tree algorithm can be seen like a stabilized version of the backoff protocol.

- after each failure, the node sets a counter C to a random integer value, between 1 and M.
- remove 1 from C after each slot on feedback channel except when the slot carries a reserving block;
- add M each time a collision is detected on the feedback channel
- when $C = 0$, schedule packet transmission for $\Delta_m - \Delta$.

Quantity M is known as the "branching" parameter. Typical $M = 2$ or $M = 4$ [6].

5.3 Performance of protocols

The Backoff algorithm is sensitive to burst and overload conditions and the performance may be affected as we will see below. In general the performance of the algorithms are expected to be good, but the top will be reached with the tree algorithms. Tree algorithms provide access delay distribution which in statistic does not depend on the number of users on the network and only depends on the cumulated input. This property, called the *channel transparency*, is very attractive if it is put in perspective with the expected big size of CATV local networks (within 1,000 users). Protocols based on round robin TDMA are not channel transparent because the token must visit all nodes one by one during each cycle. Backoff protocols are also non channel transparent but for less obvious reasons. Channel transparency drastically reduces access delays and consequently limits queueing in nodes and improve network behavior in case of bursts of traffic.

Throughput equals input as long the cumulated offered load stay below a certain limit $C_{\max}$ which depends on the channel capacity, the type of collision algorithm and the average packet length. When the load is below threshold $C_{\max}$, one has channel transparency with tree algorithms. When the offered load is above $C_{\max}$, some packet are indefinitely delayed (to be finally discarded in MAC layer). However with tree algorithm the throughput remains stable and the protocol remains quite fair (excepted about the indefinitely delayed packets). Meanwhile the backoff performance slightly degrades when the load increases, and unfairness may appear (for example with binary exponential backoff) or throughput may degrade (Aloha collapse).
We have the formula:

$$C_{\max} = \frac{c\mathcal{L}}{1 - c + c\mathcal{L}} \tag{1}$$

where $\mathcal{L}$ is the average packet length in blocks, and c is a scalar which depends on the algorithm itself. In general $c \approx 1/e$, for example $c = 0.4$ for the tree algorithm.

M	c	$C_{\max}$: $\mathcal{L} = 8$	$C_{\max}$: $\mathcal{L} = 16$
2	0.360177	0.818296	0.900069
3	0.401599	0.842988	0.914806
4	0.399293	0.841713	0.914054
5	0.387241	0.834866	0.910002
6	0.373354	0.826580	0.905058
7	0.359731	0.818008	0.899894

Table 1: maximum stable throughput for tree algorithms

There are also versions of the tree algorithm with deterministic collision resolution, thus such protocols provide strict upper bounds on access delays. Higher values of c can also be reached with little more sophisticated versions [7, 8]. These versions are not described in this paper in order to keep the length reasonable.

The throughput per node and per packet is limited to S/Δ_m of channel due to reservation chaining. But the channel access control can manage several packets simultaneously, and the local throughput per user will be raised in consequence. One shall notice that the size of the batch handled by each node is naturally limited to Δ_m/S.

6 Handling QoS with an access priority

In section 3, we have described MAC protocols for CATV network. In the following section, we will explain how we can build above these protocols an architecture to handle QoS requirements. We will use a priority based approach and we will show that it is possible to handle at least two QoS parameters set:

1. static access priority;
2. deadline.

We will first handle the case of static access priority and we will then show that the deadline case can be handle roughly as the static access priority.

6.1 Handling QoS with an access priority

Handling access priority at the MAC level on a collision resolution protocol is not an easy task. For instance, it is well known that such a facility does not exist on Ethernet. Of course it is rather simple to locally handle, in network nodes, various access priority. What is remaining difficult is to offer the property of hierarchical independence [10]. This property requires that the performance of high priority packets shall not depend on the offered load of low priority traffics. This property actually implies that priorities must rule access in whole network and not only locally. In other words that means that high priority traffic in a node must not be delayed by overload due to low priority packets in other nodes. We propose a simple mechanism to achieve this priority and to simplify the presentation we will describe it with two access priorities (*high* and *low*). We call this scheme Medium Access Soft priority.

6.2 Medium Access Soft Priority scheme

The medium access soft Priority scheme is a new technique to handle priority at the MAC level. It can work on any collision resolution MAC protocol and relies only on usual behaviour of such schemes. The Medium Access Soft priority scheme relies on the following ideas

- when you have a good collision resolution algorithm it is not in most load cases useful to add an extra priority mechanism ;
- as long as the offered load is below $C_{\max} - \varepsilon$, the access delays are satisfactory and match most QoS requirements.

The quantity $C_{\max} - \varepsilon$ will be called the critical load. Therefore it suffices that the priority management strives to keep the load on the channel below $C_{\max} - \varepsilon$ by granting access to high priority packets and denying access to some low priority packets. Provided that this later property is achieved, we meet the hierarchical independence property. To this end each node will use a tracking parameter $p(t)$ to rule the access. $p(t)$ will be the transmission probability of low priority packets.

When a high priority packet is sent to the MAC for transmission, the MAC tries to send it without doing any control. When a low priority packet is sent to the MAC for transmission, the transmission is attempted with probability $p(t)$. Otherwise the packet returns in the waiting queue for a certain time T_{hold}, predetermined to be same for all the nodes.

The tracking parameter $p(t)$ evolves according the activity measured on the channel. $p(t)$ will tends to decrease as long channel load is above $C_{\max} - \varepsilon$ and to increase if the channel load is above $C_{\max} - \varepsilon$. Note that that a node does not need to track the priority of transmitted packets. We will give an example of tracking in the next section. Consequently if λ_{high} is the load of high priority traffic on the channel, the tracking parameter will refrain low priority packets so that their load on the channel λ_{low} satisfies:

$$\lambda_{\text{high}} + \lambda_{\text{low}} = C_{\max} - \varepsilon \tag{2}$$

If the bandwidth request of low priority packets is smaller $C_{\max} - \varepsilon - \lambda_{\text{high}}$ the tracking parameter will be close to 1 and admission control of low priority packets will not operate. If the high priority demand exceeds $C_{\max}$ the low priority packet load will be reduced to a minimum determined by the minimal value of $p(t)$ (which can be very small).

6.2.1 Example of tracking algorithm

This following algorithm is adapted from the basic tree algorithm with $M = 4$. Fix maximal value of $p(t)$ at 1, and minimal value to 10^{-4} for example. Set scalars $\alpha > 1$ and $\beta = \alpha^{-4-\varepsilon'}$.

- At each slot multiply $p(t)$ by α
- At each collision reported by the feedback channel, multiply $p(t)$ by β.

The quantity $p(t)$ stabilizes when the collision rate is exactly $1/(4 + \varepsilon')$ which correspond to a critical load of the form $C_{\max} - \varepsilon$ with $\varepsilon \to 0$ when $\varepsilon' \to 0$.

When α is close to 1 the network reacts slowly to traffic changes. On the other side, when α is larger, the parameter $p(t)$ may oscillate in a way which may prevent load stabilization.

6.2.2 Several priority levels

The soft priorities scheme can be extended to an arbitrary number of priority levels. The concept of hierarchical independence can be extended to more than two priority levels. A multilevel hierarchically independent MAC priority scheme shall stisfy the following property performance at a priority level will remain satisfactory whatever is the offered load in the lower priorities.

If $n + 1$ is the total number of priority levels one must consider n tracking parameters: $p_1(t), \ldots, p_n(t)$. To this end we define a decreasing sequence of critical loads defined by an increasing sequence ε_i.

Therefore cumulated load of priority lower than i will tune itself to be smaller than $C_{\max} - \varepsilon_i$ minus the offered load of higher priorities.

6.2.3 Handling deadline based QoS parameters

One of the idea to handle deadline based QoS parameters is to translate a deadline into a MAC priority parameter. Of course, it is possible to do it statically. However, if the deadline of packet can updated during the lifetime of the packet in the network, it can be shown that that a dynamic mapping of priority offers superior performances [11]. The performance improvement of the scheme with dynamic mapping is quite natural. It can also be seen as the consequence of optimal behaviour of the EDF (Earliest Deadline First) algorithm. See figure 4 for a tentative mapping of the lifetime with MAC priorities. In this figure we have shown four priority levels, priority 1 denotes the highest priority and priority 4 denotes the lowest priority.

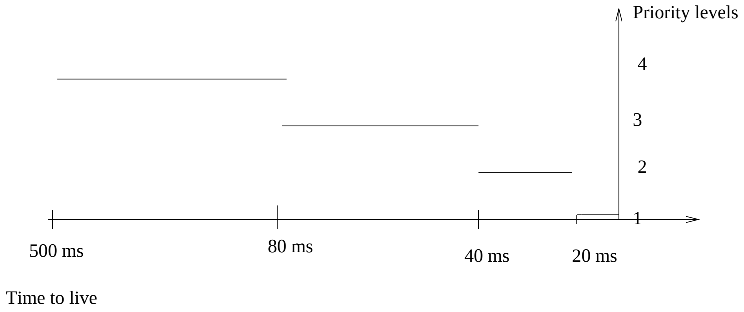

Figure 4: Mapping between residual lifetime and MAC priorities.

7 Conclusion

We have presented access schemes based slotted access and collision resolution designed to CATV networks. Except that the feedback delay is much larger that on usual LANs, the access mechanisms are similar to those that are used in LANs. We have discussed in details a few technical issues that are peculiar to CATV networks and we have shown that these problems can solved rather easily. We have presented a simple performance evaluation. As a the result of this evaluation we have shown that our proposed access protocols can offer high throughput. In order to support the various qualities of services of the expected applications on CATV (CBR, VBR, ATM, ABR), we have proposed a simple MAC priority scheme. This scheme will be able to handle priority based QoS requirement but also the more realistic deadline base QoS requirement.

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Éditeur
INRIA, Domaine de Voluceau, Rocquencourt, BP 105, 78153 LE CHESNAY Cedex (France)
http://www.inria.fr
ISSN 0249-6399