A NEW DYNAMIC RESERVATION MULTIPLE ACCESS PROTOCOL FOR SUPPORTING MULTIMEDIA TRAFFIC IN THIRD GENERATION CELLULAR SYSTEM

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ABSTRACT In this paper a Dynamic Reservation Multiple Access (D-RMA) protocol for future third generation cellular mobile radio systems, which is explicitly designed for supporting multimedia traffic, is proposed and its behavior is investigated under variable traffic conditions. Its structure is based on traditional PRMA++ protocol. In addition to PRMA++, a dynamic adaptation of percentage of bandwidth to use for reservation within a frame to traffic condition, is permitted, this having the main goal to guarantee the required GoS to multimedia services. The goal is also achieved by providing for a suitable bandwidth allocation strategy, which assigns to different broadband services a different amount of frequency resource, and by coupling it with a suitable management scheme for the base station reservation buffer. Obtained results shows that performance of D-RMA protocols are superior when compared with a traditional "non-dynamic" protocol, both in terms of offered GoS to carried services and number of activable connections in a microcell at the same time.

1. INTRODUCTION

In the near future, wireless communication is supposed to experience enormous growth. In fact Personal Communication Systems (PCS), based on wireless technologies, will have to evolve toward supporting a wider range of applications including voice, video, data and multimedia [13]. The ideal future scenario in the field of telecommunications will be characterized by several Mobile Audio Visual Terminals by which users, via a base station connecting wired and wireless networks, access to multimedia services scattered all over a high speed communication backbone [10]. To this aim, in last years, researchers attention has focused on the integration between personal communication systems and broadband networks, such as B-ISDN using ATM protocol. Such integration requires third generation wireless information systems, based on the following characteristics: (1) massive radio coverage in densely populated urban areas, meaning high transmission and near-ubiquity (reaching them almost wherever they are) [17]; (2) packet transmission and switching, as outlined in [1], for integration with MAN; (3) multiple access protocol having high flexibility and efficiency in supporting future integrated services; (4) simple bandwidth management strategies to perform statistical multiplexing of many users on a common channel inside each cell.

In this paper all listed items are addressed, even if attention is mainly focused on the design of a new flexible Multiple Access Protocol coupled with an efficient bandwidth management strategy.

The coverage of a densely populated geographic area, can be assured by an arrangement of hexagonal microcells having the radius not greater than few hundred meters. At the center of each microcell there is a base station with an omnidirectional antenna, serving all mobile users within that cell. Dispersed Portable Multimedia Terminals (PMT), like those described in [10], share, in the microcell, a common channel (up-link) for transmitting their information streams towards the base station. The delivery of information from Base-Station towards PMT is supported by a TDM broadcast transmission on the down-link. Two frequency channels within available spectrum, managed in a Time Division Multiplexing (TDM) manner, are assigned to each microcell. Transmission time on each channel is split in a sequence of frames, made up of a fixed number of time slots.

Early PCS proposals have been driven by the idea that voice services would dominate future communication scenario. Thus the frame structure has been designed in such a manner that one time slot in the frame can support a stable voice channel. Thereby proposed Access Protocols provide only for the assignment of single slots to each connection. On the contrary, in order to support a multimedia connection, a greater amount of bandwidth than that used by a voice connection needs to be allocated. A new access protocol, providing for multiple slots assignment can resolve this problem. According to this protocol, different broadband services can be assigned a different amount of bandwidth (groups of slots) in order to better fit their QoS requirements.A further purpose of the proposed protocol must be also to obtain a good multiplexing gain. This can be obtained by providing for a burst level rather than call level channel reservation in such a way that, during inactivity periods of a transmitting PMT, released channels can be used by other cellular network users. The MAC (Medium Access Control) layer of the protocol has to permit the transmission, of reservation packets which inform base-station about requested bandwidth on high-protection control channels. Conversely, information can be transmitted over channels which require lower Signal-to-Interference (S/I) ratio compared with reservation channels.

A first goal of this paper is to propose a protocol, called Dynamic Reservation Multiple Access (D-RMA) protocol, suitable for a multimedia, which couples: (1) the advantage deriving from a complete separation between Reservation channels and Information channels; (2) the flexibility of a

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dynamic approach in the choice of the percentage of bandwidth to be used for reservation.

A second goal is to model several bandwidth allocation strategies, suitable for cellular environments and to investigate the respective performance (in terms of access delay and packets dropping) under different multimedia traffic conditions. The rest of the paper is organized as follows. A brief overview on Multiple Access Protocols described in the literatureand, D-RMA protocol description are presented in Section 2. Simulation results are shown in Section 3 under either voice-only traffic or multimedia traffic. Conclusions and future works are the subjects of Section 4.

2. "D-RMA" PROTOCOL DESCRIPTION.

In the early period a lot of Multiple Access Protocols were proposed and analyzed [2, 3] in the field of satellite communication networks and wireless LAN's. Later, above mentioned protocols (for instance *R-ALOHA* protocol proposed by Crowther [4]) have been reconsidered for Cellular Mobile Radio Systems. An example of such protocols is represented by well-known *Packet Reservation Multiple Access* (PRMA) [5, 6]. In PRMA, within the frame, an active terminal detects "available" or "reserved" slot according to the feedback information broadcasted on down-link from the base station and contends for channel access (as in S-ALOHA) on the "available" slots. When successful, it begin to transmit speech packets and holds a reservation for a slot in subsequent frames until the end of its talkspurt. Every up-link slot, according to PRMA protocol, can be used for reservation, thus an acknowledgment at the end of each slot is required on down-link. With the PRMA, as the traffic increases, the probability of finding free slots in the frame decreases and the access delay would increase without limit.

An adaptive protocol, named Multiple Access (MA) protocol, which attempts to solve the above mentioned problem, was carried out by Mitrou et al. [7]. This protocol permits to make reservation only on some slots, called *R-slots,* and to carry an information stream on other slots, called *I-slots*. In the MA protocol, a minimum number of R-slots is fixed to obtain a good performance in a high load condition and free I-slots can be all used, in the presence of a low load, as reservation slots. The presence of a partial separation between control channel and information channel is the main inconvenience of MA protocol. In fact, when reservation packets are transmitted through R-slots, they have a greater protection against interference; conversely this protection is absent on I-slots and the reservation packets can be corrupted by channel impairments.

Recently, a new version of PRMA, named PRMA++, has been proposed and analyzed [8]. In PRMA++, according to [9], the separation between control and information slots permits to establish different degrees of quality between control and information channel. Moreover, in PRMA++ a few number of acknowledgment slots, unlike PRMA, are required on the down-link in correspondence with the R-slot on the up-link. In PRMA++, the number of R-slots as well as their positions within the frame are fixed. This has the effect of causing mobile terminals to experience access delay even at low load [8]. Moreover, in presence of multiple slot assignment (i. e. multimedia traffic), access delay may become a critical factor. The D-RMA protocol can be regarded as a dynamic adaptation of traditional Reservation Multiple Access Protocols to future multimedia traffic needs. The choice of maintaining a complete separation between Reservation and Information Slots and dynamically adapting the percentage of reservation bandwidth within a frame to traffic conditions, coupled with a suitable bandwidth allocation strategy, has the main goal to guarantee required QoS to multimedia (integrated video/voice) services.

The design of its up-link frame format (illustrated in fig. 1), is mainly based on the structure PRMA++, thus constituted by a sequence of *I-slot* and *R-slot*.

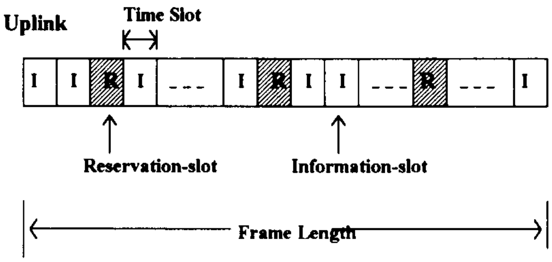

Fig. 1. Transmission Frame Format.

The total number of slots in a frame is set to N. In D-RMA frame structure a maximum and a minimum number of R-slots, $Nr_{\max}$ and $Nr_{\min}$ respectively, are established. At each instant of time the actual number of activated (thus available for reservation) *R-slots* in the frame is Nr, with $(Nr_{\min} \le Nr \le Nr_{\max} < N)$. All "non-activated" R-slots are used for transporting information, like I-slots. The $Nr_{\max}$ positions of R-slot within the frame are fixed. They are scattered in a homogeneous manner along the frame, so that new burst likely have not to wait a long time for intercepting an available R-slot [7]. The model of the system under study is sketched in fig. 2.

Described contention mechanism is similar to other reservation protocols. What really makes D-RMA protocol different from previous proposals, is the dynamic management of reservation bandwidth. In fact upon traffic load variations (in terms of number of transmitting terminals variation), due to either originating/terminating calls or handovers, the base station is allowed to modify the number of active R-slots within the transmission frame.

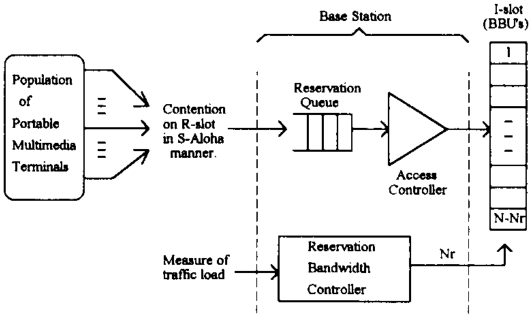

Fig. 2. Block diagram for D-RMA protocol.

As will be demonstrated in section 3, better performances, compared with *Nr* fixed, can be obtained by properly varying the number of "active R-slots" (*Nr*). It will be also shown that a reduction of *Nr* is preferred when load increases and vice versa upon traffic load decreasing. The optimum number of active R-slots related to a specific channel load value has to be chosen according to a quality index. The proposed protocol is able to dynamically adapt itself, on frame basis, when traffic variations occur. Particularly, at the end of each frame, the base station runs an algorithm which examines channel load (i.e. controls the number of terminals within the microcell which have a connection established) and determines a suitable *Nr* value. This algorithm is computed by Reservation Bandwidth Controller, shown in fig. 2. The active R-slot number is a function of input channel load and, as demonstrated in section 3, *Nr* versus load is constant in some ranges. An efficient and simple technique to manage the variation of *Nr* by tracking traffic load fluctuations, is represented by a "threshold-based policy".

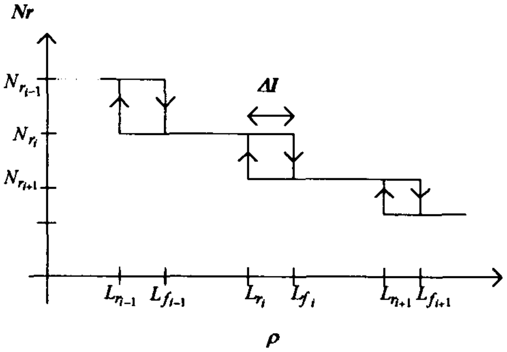

Fig. 3. Optimum number of R-slot (Nr) versus channel load r.

According to this strategy, a base station decides to change the number of active R-slots when traffic load exceeds one of a set of fixed threshold values. By adopting this policy, a problem that can arise, when many variations of traffic load around a threshold value occurs, is the persistent need for a variation of active R-slot number in subsequent frames. This phenomenon would provoke an undesired overload of signaling traffic on down-link. In order to overcome this problem, in D-RMA, an hysteresis control mechanism is introduced. Precisely, each threshold value is provided of an *hysteresis margin*, as illustrated in figure 3, which permits a change in *Nr* only when offered load shows an actual trend of rising (when crossing L_r) or falling (when crossing L_f).

If the base station, at the end of a frame, perceives a need for an increase in active R-slot number, it controls the number of idle non-active (used for carrying information) R-slots. This number could be equal to zero, then it has to procrastinate frame redefinition and to wait for any R-slot to become free. Time spent before that frame is updated, depends on traffic statistics, particularly on mean burst duration. The dynamic protocol will suffer from a decrease in performance if during that time another change in the number of transmitting terminals occurs. However, since it has been assumed a microcellular environment, variations in the number of active terminals (and consequently of traffic load), within one microcell, are substantially caused by handovers rather than by originating or terminating calls. Anyway, handovers don't occur frequently, compared with a burst mean duration. A vehicular terminal crossing at velocity of *50 Km/h* a microcell with radius of *500m* spends a time of *72 s* within that cell. This time is quite large when compared with actual bursty traffic statistics. Consequently, the probability that a new change in the number of transmitting terminals will occur, before the update of a frame is performed, is negligible.

3. SIMULATION STUDY.

A flexible discrete event simulator has been implemented and used in order to study D-RMA protocol. Protocol performance have been analyzed by considering the following variables:

D_{vo}: average access delay for voice terminals; it represents the average time spent from the instant in which a talkspurt is generated until its first packet is transmitted on the channel (an upper bound of *32 ms* is in [6]);

D_{vi}: average access delay suffered by video terminals (an upper bound of *300 ms* is in [7]);

$Pdrop_{vo}$: average packet dropping probability for voice terminal, computed as $\frac{\text{dropped packets}}{\text{arrived packets}}$ (an upper bound of *1E-2* is in [6]);

$Pdrop_{vi}$: average packet dropping probability for video terminal (an upper bound of *1E-3* is in [13]).

The speech traffic model used in simulation is Brady's model [12] which considers a voice source as a sequence of talkspurts and gaps. All talkspurts and silence periods have an exponentially distributed duration with means T_{on} for talkspurt and T_{off} for gaps, respectively. If a packet is queued into terminal buffer for a time longer than $D_{\max_{vo}}$ it is dropped. Video or data terminals generate bursts with variable length (exponentially distributed with mean *L* Kb/s), as in [13]. Arrival rate of a new message is assumed equal to λ_m. Since a video service can be considered a "time critical service" like voice, it is also assumed that packets are dropped if their waiting time within terminal's queue exceeds the maximum delay value $D_{\max_{vi}}$.

Simulation were run under conditions listed in Tab. 1.

Definition	Symbol	Value
Channel bit rate (Kb/s)	*Rc*	500
Frame length (ms)	*F*	6
Number of slot within frame	*N*	50
Num. of "active R-slot"	*Nr*	variable
Acknowledgment delay [ms]	*Da*	1
Voice stream rate (Kb/s)	*Rvo*	8
Low res. video rate (Kb/s)	*Rvi*	32;64
new msg arrival rate (msg/s/user)	λ_m	1
Average message lenght (Kb)	*L*	5.12; 10.24
Average talkspurt duration (s)	*Ton*	1.41
Average silent period (s)	*Toff*	1.78

Tab. 1. List of nominal values utilized in simulations.

First we present the D-RMA performance results in the presence of voice traffic only; subsequently protocol behaviour analysis is extended to voice-video traffic case.

Voice traffic performance.

Fig. 4 shows that the optimum number of active R-slots is inversely proportional to channel load (and consequently to active terminals number).

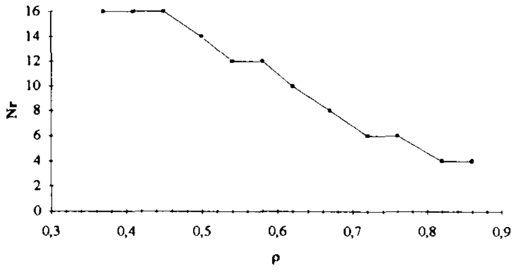

Fig. 4. Optimum Nr versus Voice channel load ρ, under nominal conditions .

This phenomenon can be explained as follows. In Reservation Multiple Access protocols two contributions affect access delay: the first is due to the contention access process (S-ALOHA), while the second is due to the waiting time of reservation packet within base station reservation queue.

$D_{tot} = D_{con} + D_{que}$ where

D_{con} = contention delay D_{que} = queue delay

When traffic is low, contention access delay dominates. In such a situation, the presence in the frame of a greater number of available R-slots contributes to a decrease in access delay. Conversely, under high load conditions the delay accumulated within reservation queue dominates. Thus, it is better to reduce the number of active R-slots in order to increase information channel bandwidth.

The optimum number of R-slots that must be activated is chosen using the following quality index:

$$Q = \frac{1 - Pdrop_{vo}}{\frac{1}{T_{on}}\left(T_{on} + D_{vo}\right)}$$

and, for a given load, the simple criterion:

optimum Nr is the one which maximizes Q.

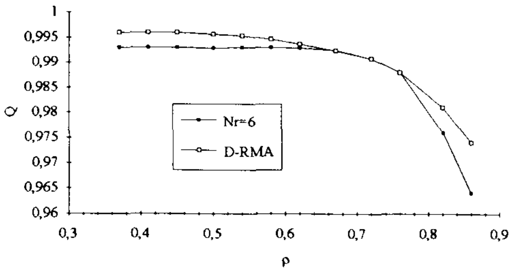

Fig. 5. Quality Index Q versus voice channel load ρ, under nominal condition showed in table 1, when adopting D-RMA protocol and Nr=6.

Fig. 5 shows that better performances are obtained by using the optimum *Nr* for each load value, when compared with the case in which a fixed *Nr* is adopted under both low and high load. Improvements in the value of quality index correspond to an increase in the maximum number of terminals that can be simultaneously activated. In order to quantify this augmentation, different curves of packet drop and access delay, under vary load and system conditions, have been calculated. This curves show that the gain obtained with D-RMA protocol with respect to "Nr fixed" protocol is approximately of *5%*.

This percentage refers to one carrier only. As each microcell contains a set of carriers, a considerable increment in the number of simultaneously active terminals can be obtained.

Multimedia traffic performance.

It is supposed that future mobile terminals will require both narrow-band channels for supporting voice connections and wide-band channels for multimedia connections. This means that classes of traffic with different needs had to share up-link bandwidth resource. Thereby, there is the need for a flexible bandwidth allocation mechanism which is able to guarantee required Grade of Service (GoS) to every connection. Several bandwidth allocation strategies, as Complete Sharing, Complete Partitioning, Mutually Restricted Access, for broadband telecommunication network, have been proposed and analyzed [14, 15, 16]. Particularly, in these schemes, transport capacity at network nodes is splitted in Basic Bandwidth Units (BBU's), that can be allocated to an integrated narrowband-connection and wideband-connection traffic flow. The up-link TDMA frame can also be seen as a channel in which each slot represents exactly one BBU. The basic idea is that in order to satisfy a transmission request of a narrow-band service, like voice, one slot is sufficient; on the contrary, if a multimedia terminal needs a wide-band transmission connection, multiple slots assignment is necessary. Therefore, concepts and schemes already utilized in B-ISDN can be conformed to wireless access systems too. According to Complete Sharing (CS) all slots in the frame are shared by every kind of terminals; on the contrary, in Complete Partitioning (CP) slots are partitioned into distinct groups, so that a particular type of service can occupy only the slots within its group. The main disadvantage of CS policy is that, if a traffic type experiments a temporary overload (i.e. the number of terminals of a particular type increases), the absence of available bandwidth can provoke a degradation in the performance of other traffic types. Mutually Restricted Access (MRA) technique offers itself as a solution to this problem. This policy imposes that the number of type i connections which can simultaneously transmit information on the up-link, is limited by a cut-off value c_i. The main disadvantage of this technique is the waste of those slots reserved to a type of traffic which offer a load under its estimated value. In B-ISDN environments this problem can be overcome by permitting a type of traffic to overflow its reserved bandwidth and use a bandwidth belonging to another connection type. There is the risk however, for this type of traffic to be preempted when arriving a call which "stolen" bandwidth was reserved for [16]. Anyway, preemption strategy is not convenient for a Radio Multiple Access Protocol, since this operation require too much control overload on down-link for informing the terminals of occurred changes.

Thereby, in this paper, behaviors of CS strategy and simple MRA policy , which seem to be promising strategies for a multimedia cellular environment, have been simulated and compared when low resolution video traffic at 32Kb/s and 64Kb/s is added to voice traffic.

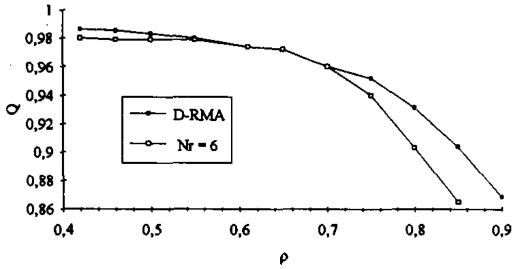

Fig. 6. Quality Index Q vs total channel load ρ (75%voice, 25% video), when using D-RMA and Nr=6, Bvi=32 Kb/s, L=5.12, bandw. alloc. strategy= CS.

Fig. 6 show the improvement in the quality index Q when utilizing "optimum *Nr* based" instead of "fixed *Nr* based" strategy. Nominal conditions (see tab. 1) and heterogeneous traffic nature (75% voice and 25% video [13]) are assumed. The increase in the maximum number of simultaneously activable terminals with respect to "*Nr* fixed" algorithm is about *10%*. This is greater than only-voice traffic case, thus showing that D-RMA is more adequate for supporting multimedia application traffic in a mobile environment.

Access delay, *Pdrop* and percentage of traffic type are the variables which have been considered for the definition of a new quality index:

$$Q = \%voice\left(\frac{1-Pdrop_{vo}}{\frac{1}{T_{on}}\left(T_{on}+D_{vo}\right)}\right)+\%video\left(\frac{1-Pdrop_{vi}}{\frac{1}{T_{on}}\left(T_{on}+D_{vi}\right)}\right)$$

Results depicted in fig. 6 are found when Complete Sharing strategy is adopted for bandwidth allocation.

In order to sketch similar curves when adopting D-RMA protocol, preliminary studies have to be carried on. Simulations must be performed in order to evaluate the optimum set of restriction parameters for bandwidth management.

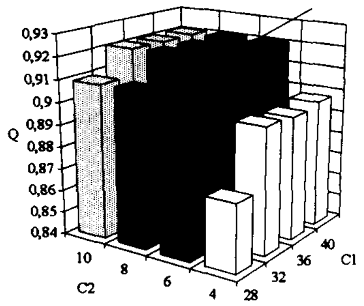

Fig. 7. Quality index Q versus cutoff values c_1 and c_2 for M=83, Nr=4.

Fig. 7, shows that the best couple of cutoff values, which can be adopted under "75% voice and 25% video" load conditions, are $c_1 = 32$ and $c_2 = 6$. This means that the best choice is to allow only 32 voice connections to be simultaneously active on a frame. In similar manner six 32 Kb/s video connections (each asking base station for groups of 4 slots) are allowed to transmit at the same time. Terminals, of type i, which exceeds cutoff value c_i are queued and wait until the number of connections already active on the frame becomes less than c_i.

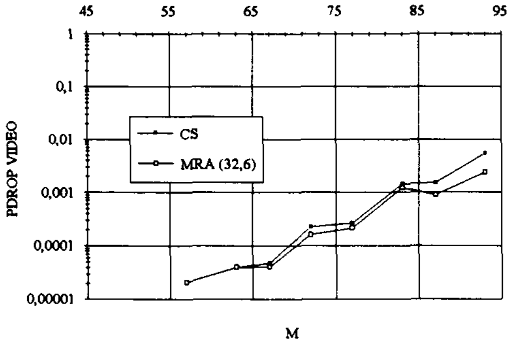

Fig. 8. Avg. packet dropping probability for video terminal vs total active terminal number M, when using Nr optimum, for different bandwidth alloc. strategies: Bvi=32 Kb/s, L=5.12, (total channel load=75% voice, 25% video).

As expected, Fig. 8 shows that, by utilizing MRA policy, better performance of $Pdrop_{vi}$ compared with CS strategy can be obtained. In fact, video terminals are reserved an amount of bandwidth that cannot be occupied by voice terminal traffic. Fig. 9 shows that Q values for CS and MRA are about the same in the whole load variation range. As a consequence, it is preferable to adopt the MRA strategy since it protects a type of traffic from overload of the others. The only disadvantage of MRA strategy is that voice performance is lightly worse compared with CS strategy (see figure 10).

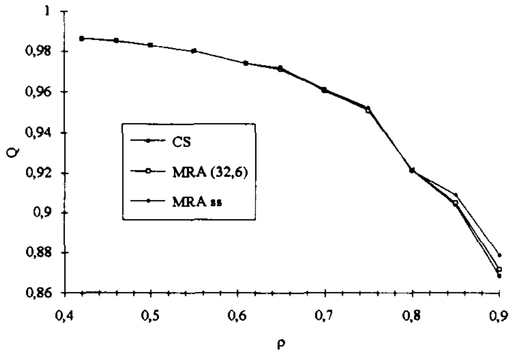

Fig. 9. Quality index Q vs total channel load ρ for different bandwidth alloc. strategies: Bvi=32 Kb/s, L=5.12, (total channel load=75% voice, 25% video).

With CS strategy voice terminals can transmit over all I-slot within the frame (and also on inactive R-slot). On the contrary, with the MRA strategy their bandwidth is restricted. Thus, under high load conditions their traffics experience a higher access delay as compared to CS.

In order to overcome this problem a most efficient reservation queue management strategy has been provided.

By making use of a FIFO scheme, a video terminal reservation request which occupies the head of the queue could block following voice traffic reservation requests when few slots than needed are available (HOL problem). This difficulty is overcome by scanning subsequent queue positions until voice requests, which can use available slots, are found (Scan and Serve policy [14]). The curves of voice access delay in fig. 10 show the better performance achieved by utilizing MRAss (MRA scan and serve) strategy compared with both MRA and CS strategy.

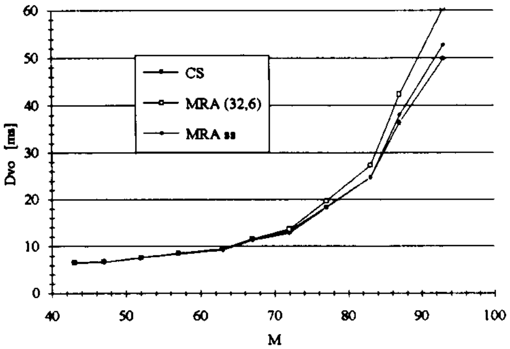

Fig. 10. Avg. voice access delay vs total active terminal number M, for different band. alloc. strategies: Bvi=32Kb/s, L=5.12, 75% voice, 25% video.

It might be assumed that MRAss brings quite a light increase in delay for those video terminals requests which frequently will be by-passed. Simulation have shown that actually video terminals are not excessively delayed since simultaneously transmitting voice connections cannot exceed the cutoff value c_1. As illustrated in figure 9, by utilizing both the MRA policy for bandwidth allocation and "Scan and Serve" for the reservation queue management, the best performances are obtained when compared to simple CS strategy or MRA with FIFO queue management.

Furthers studies have been carried out when 64 Kb/s channels (groups of 8 slots) requests and allocations are considered for low resolution video terminals. Simulation shows that MRA coupled with "Scan and Serve" results to be the best choice also in this case

4. CONCLUSIONS.

A dynamic reservation protocol, called D-RMA, has been proposed, which both permits wireless networks to embrace a wider range of capabilities and represents the first step towards the integration between Personal Communication Systems and broadband packet-networks. Its behavior has been observed under both voice and low resolution video traffic conditions. In order to compare D-RMA and other traditional access protocol performances, new quality indexes have been defined. By adopting those indexes, better performances resulted from the adoption of the dynamic protocol when compared with a "Nr fixed" protocol. Moreover, bandwidth allocation policies for the management of the analyzed types of traffic have been investigated. Good results have been obtained when MRA Strategy is coupled with Scan and Serve management for the reservation queue.

At the moment, studies on D-RMA extensions, aiming at differently treating handover calls compared with originating ones, are being carried on.

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