Pr-PRMA: A PRMA-based Protocol for Third Generation Communication Systems

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Abstract— Traditional MAC protocols for mobile communication systems were originally designed to deal only with voice and rudimentary data services. With the advent of third generation communication systems, new services are being designed and offered to the communication system community. These new services, like e.g. Web browsing and real time VOD, impose different packet traffic patterns on the existent MAC protocols when compared with traditional personal communication services. This work analyzes the behavior of one of the most well-known MAC protocols, the PRMA protocol, when submitted to a packet traffic pattern generated by Web browsing services. A series of analyses is presented, where the impact of the presence of Web packets (packets generated by Web browsing services) is discussed. In addition, the Pr-PRMA protocol, a new variant for the PRMA protocol, is presented and analyzed. This new protocol contains a set of improvements on the original protocol, aiming to increase its performance when dealing with Web packet traffic. Finally, a description of the MacSim environment, a simulation environment created to support the MAC and LAC protocol analysis process, is also provided.

Index terms—Third Generation Communication Systems, MAC Protocol, PRMA protocol, Performance Evaluation, Modeling and Evaluation of MAC and LAC protocols

A. INTRODUCTION

Third generation mobile communication systems (3G systems) for personal communication are becoming a reality faster than expected. Nowadays more and more features envisaged for these new communication systems are being incorporated in the existent second generation mobile communication systems (2G systems). Actions for the development of the IMT-2000 [1], a framework proposed by the ITU (International Telecommunication Union) for worldwide wireless access for personal communications, are under way, aiming to fulfill one's dream of a real anywhere, anytime communication system.

Along with these new 3G systems, new services will also be offered to their user community. These new services include traditional services (e.g. voice and data access), network services (e.g. Web browsing and email), multimedia services (e.g. real time VOD) and new services yet to be defined. All these services must be supplied with ubiquitous access, high performance and quality standards, competitive prices, and must be able to run in a great variety of terminal types.

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The presence of such a diversity of service types has a great impact on the protocols used to transmit data information between mobile users and the radio base station on a communication cell. Each layer of the protocol stack has to deal with different packet traffic patterns, generated by distinct services with different QoS requisites. Furthermore, even services with similar packet traffic patterns can have different QoS requisites.

The MAC (Medium Layer Access) layer is one of protocol stack layer whose operation will be affected by this new service profusion. Most MAC protocols for personal communication systems were designed to support mainly voice and traditional data services [2] [3] [4] [5] [6]. The inclusion of services with packet traffic patterns much different from the originally expected ones can have a great impact on the MAC protocol operation and performance.

Among the new services offered by 3G systems, there are services that are based on the Internet use, e.g. FTP and Web browsing (Web navigation). Although these services can be classified as data services, they generate a packet traffic on the lower levels of the protocol stack that presents a traffic pattern completely different from the traffic pattern generated by conventional data services [7] [8] [9] [10]. On [9] and [10], the authors have presented evidences that the packet traffic pattern generated by the Web navigation service on the lower layers of the protocol stack has characteristics that are consistent with the self-similarity phenomena. This means that its packet traffic pattern has properties completely different when compared with the packet traffic pattern generated by traditional data services.

The reason for this behavior is that the transmission of Web objects (HTML pages, icons, images, etc.) is not completely initiated by the service user. Almost every Web page (even pages adapted for small telephone handsets) contains a set of embedded objects and, when a user requests a Web page, the browser automatically initiates a series of additional requests to load its embedded objects. Models to represent the packet traffic pattern generated by a Web browsing service on fixed links are presented on [11] and [12]. Both models represent this packet traffic pattern as a multiplexing of a great number of ON/OFF processes, whose period duration for both ON and OFF states follows a heavy tail distribution model.

On this paper, the impact of the Web packet traffic (traffic generated by a Web browsing service) on the PRMA protocol (Packet Reservation Multiple Access Protocol [6]) is analyzed and the Pr-PRMA protocol, a new protocol derived from the PRMA protocol, is proposed. This new protocol aims to adjust the PRMA protocol to handle not only Web packet traffic, but also all kind of periodic packet traffic.

This paper is organized as follows. In Section B, the environment created to give support to the MAC protocol analyses is briefly described, along with the models used to represent each packet source used on the analyses. In Section C, the PRMA protocol is analyzed. The main objective of these analyses is to verify the protocol behavior under the presence of Web packet traffic. In section D, the new Pr-PRMA protocol is presented and analyzed. Concluding remarks are made in Section E.

B. THE MACSIM ENVIRONMENT

The principal objective of the MacSim environment is to provide the necessary framework to support analyses of MAC and LAC protocols running over wireless links. Although this environment has been originally conceived to support analyses of MAC and LAC protocols designed for personal mobile communication, there is no restriction for its use on the study of generic MAC and LAC protocols.

The MacSim (MAC Simulator) environment was developed to support MAC and LAC protocols designed for communication systems based on the TDMA and CDMA/TDMA radio transmission technologies in a single-cell system. The environment mimics the presence of a set of mobile users (or mobile terminals) in a cell covered by a single radio base station, where each user runs an instance of the MAC and LAC protocols under analysis. The channels are organized according to the radio transmission technology and the MAC protocol. For both CDMA/TDMA and TDMA based systems, the transmission time scale of each uplink and downlink channel is organized in frames, each one containing a fixed number of time slots. The MacSim environment was designed to be platform independent: it is written using ANSI C and all its inputs come from text files.

The MAC and LAC protocol analyses are based on simulation. The pseudorandom number generator used by MacSim is based on the Mersenne Twister algorithm [13]. To permit more accuracy on the simulation process, the MacSim user can specify how many times each input scenario will be simulated, each time with a different number generator seed.

On the MacSim environment, the capacity of each time slot depends on the used radio transmission technology. For TDMA based systems, each time slot has the capacity to transmit just one packet at a time. If two or more packets are transmitted on the same time slot in a channel, all packets are consider corrupted and are discarded. For CDMA/TDMA based systems, the capacity of each time slot is limited by the total interference (sum of the interference generated by a destructive background noise and generated by the transmitted packets) present on the channel. If the total interference in a time slot surpasses a certain threshold, all packets transmitted on that time slot are consider corrupted and are discarded. If necessary, a grateful channel degradation scheme can be used. The MacSim environment also permits to simulate the existence of noisy channels. More information about the MacSim environment can be found at [14].

Each available service on a mobile communication system can be described as a combination of one or more independent packet source, where each packet source has its own packet generation pattern. For example, the packet stream generated by a real time conference terminal can be viewed as a combination of a voice packet source and a real time video packet source. On the MacSim environment, we implemented a series of packet generation models, which represents the packet generation patterns, and map the communication system services on these models. The already implemented packet source models are slow voice user, data user, Web user and WebLight user. New packet generation models can be easily integrated in the environment if necessary.

Table 1 - Generic Input Parameters

Packet Sources Parameters	
Slow Voice User Parameters	
ON state mean duration (1/μ) = 1.0 s	OFF state mean duration (1/μ) = 1.35 s
Data User Parameters	
σ = 0.2	
Web User Parameters	
Minimum file size = 75 bytes	Maximum file size = ∞
Loner file probability = 0.32	Loner file cutoff = 0.66
Base file probability = 0.30	Base file cutoff = 0.93
Embedded file probability = 0.38	Maximum number of embedded files = 150
Loner file size distribution function 1→ Log-normal (mean = 7.101, standard deviation = 1.2)	
Loner file size distribution function 2→ Log-normal (mean = 11.151, standard deviation = 1.143)	
Base file size distribution function 1→ Log-normal (mean = 7.630, standard deviation = 1.001)	
Base file size distribution function 2→ Pareto (K = 10000, alpha = 1.0)	
Embedded file size distribution function → Log-normal (mean = 8.215, standard deviation = 1.460)	
Number of embedded file distribution function → Pareto (K = 2, alpha = 1.245)	
Inactive OFF period length distribution function → Pareto (K = 1, alpha = 1.4)	
Active OFF period length distribution function → Weibull (shape = 1.46, scale = 0.382)	
WebLight User Parameters	
Minimum file size = 60 bytes	Maximum file size = 10 MBytes
Loner file probability = 0.32	Loner file cutoff = 0.66
Base file probability = 0.30	Base file cutoff = 0.93
Embedded file probability = 0.38	Maximum number of embedded files = 50
Loner file size distribution function 1→ Log-normal (mean = 5.932, standard deviation = 1.002)	
Loner file size distribution function 2→ Log-normal (mean = 9.903, standard deviation = 1.015)	
Base file size distribution function 1→ Log-normal (mean = 6.393, standard deviation = 0.839)	
Base file size distribution function 2→ Pareto (K = 2500, alpha = 1.0)	
Embedded file size distribution function → Log-normal (mean = 7.099, standard deviation = 1.261)	
Number of embedded file distribution function → Pareto (K = 2, alpha = 2.441)	
Inactive OFF period length distribution function → Pareto (K = 1, alpha = 2.333)	
Active OFF period length distribution function → Weibull (shape = 1.46, scale = 0.191)	
QoS Requisites	
Voice Packets	
Maximum transmission delay = 40 ms	Input buffer length = 500 packets
Maximum outage probability = 0.01	
Data and Web packets	
Maximum transmission delay = ∞	Input buffer length = 500 packets
Maximum outage probability = 0.02	

1st. Slow Voice User Model

A voice user creates a pattern of talkspurts and gaps, which are classified by a voice activity detection (VAD) mechanism. The slow voice user model simulates this voice user using a "slow" voice activity detection mechanism. This VAD mechanism can identify only the principal talkspurts and gaps. The slow voice user activity is modeled as a two-state Markov process with transition at the end of each time slot [4]. The ON state is associated with the talkspurts and the OFF state is associated with the gaps. Voice packets are generated only on the ON state, with a rate of one packet per frame. Both states have exponentially distributed duration, with the ON state having a mean duration of $1/\mu$ and the OFF state a mean duration of $1/\lambda$. The flow rate from the ON state to the OFF state is μ and from the OFF state to the ON state is λ. The two-state Markov model and the transition probabilities between the states can be found at [4].

2nd. Data User Model

The data user model represents random data traffic generated by data users, like e.g. a data terminal. In this model, each data user transmits a new data packet in every frame according to a Bernoulli experiment with parameter σ [5]. If necessary, more complex models for data users (like, for example, models for video streams) can be easily integrated on the MacSim environment.

3rd. Web User Model

The Web user model represents the behavior of packet traffic generated by a Web browsing service. The Web user model implemented on the MacSim environment is based the Web traffic model used on the SURGE package [11]. Although this model was primely designed for fixed links, it can be used to represent the Web packet traffic over a wireless link, because the generated traffic pattern does not depend on the media used to transmit the packets, but on the events that cause the packet generation.

In this model, the traffic of Web packets is modeled as a result of an ON/OFF process, where the ON state corresponds to the periods when the Web objects are being transmitted and the OFF state corresponds to the idle time ("think time" or "Inactive OFF"). The ON periods also can be seen as a second ON/OFF process. In this case, the ON state represents the actual transmissions of the Web objects and the OFF state ("Active OFF") represents the gap between the transmission of two consecutive Web objects. This "Active OFF" period corresponds to the processing time spent by the browser parsing the already loaded Web object, looking for loading instructions of new Web objects, and preparing to start new TCP connections. Web packets are generated only on the ON state. It is assumed that the Web browsing service is able to send one Web packet per frame to the MAC layer when sending a Web object. A description of the Web user model used on the MacSim environment, along with the description of the probability functions used in this model, can be found at [11].

4th. WebLight User Model

The WebLight user model represents the behavior of packet traffic generated by a Web browsing service running on a small mobile handset. The WebLight user model implemented on the MacSim environment is the same of the Web user model, except for the values of the parameters.

The expected mean value for file size is reduced to 25% of the original value for all three file types. The file size is also limited to 10 Mbytes. The expected number of embedded file is also reduced to 50% of the original value, with its maximum being set in 50 embedded files. Both "Inactive OFF" and "Active OFF" time means are reduced in 50%.

C. WEB TRAFFIC INFLUENCE ON PRMA PROTOCOL

In this section, we will present the analyses of the PRMA protocol [6] when handling with Web packet traffic. This packet traffic is a result of Web browsing services. All analyses were made using the MacSim environment described on the previous section. All scenarios were simulated at least three times with different number generator seeds and the arithmetic average of the collected values in each simulation is taken as the final result for each scenario. Table 1 contains the common input values used for all simulated scenarios. Any change in the values listed on Table 1 necessary for a specific test will be outlined in the text.

In all simulated scenarios, the frame length is assumed to have a 20 ms length and it is divided in 10 time slots. This makes the length of each time slot equals to 2 ms. It is considered that the voice transmission rate is 13 kb/s and that each voice packet has a capacity of 640 information bits and a 64-bit header. The data and Web packet capacity depends on the analysis made. As a default value, both packet types also have a 640-information bit capacity with a 64-bit header. For simplicity, it is assumed that each packet source is assigned for just one uplink channel. In this case, it is not permitted that a packet source tries to send its packets at two or more uplink channels at the same time. Although MacSim can also analyze LAC protocols, it is assumed in the PRMA analysis that a non-contentious LAC protocol is present. In another words, all access requests for the LAC protocol is granted at once.

The PRMA protocol [6] was designed for 2G systems based on the TDMA technology. It was conceived to support only two packet types in wireless links: voice packets and data packets. On the PRMA protocol, voice packets have priority over data packets, because their QoS requisites are more restrictives (see Table 1 and [6]). The PRMA protocol was developed aiming to take advantage of the fact that voice sources have a periodic behavior. In other words, if a voice packet is generated by a voice source in frame t, there is a high probability that a new voice packet will be generated by the same voice source in frame $t + 1$.

If the original PRMA protocol is intended to support Web packet traffic over a wireless link, in conjunction with voice and data packet traffic, the following question must be answered: Web packets must be transmitted as voice packets or as data packets? The natural answer is to transmit Web packets as data packets, because of their non-real time nature.

On the other hand, Web sources also have a periodic behavior like the voice sources, which signalize that transmitting its packets as voice packets shall be a better choice. The problem of mapping Web packets as voice packets is that Web packets are much more tolerant in terms of transmission delay than voice packets. Voice packets have to be transmitted almost as soon as they have arrived at the MAC layer, while Web packets can be stored in a waiting queue to be transmitted later. In this case, the main restriction for Web packets is the waiting queue capacity.

As 2G systems were designed to support mainly voice services, the first analysis made was to verify the influence of Web packet traffic presence on the total capacity of the PRMA protocol. In this case, the MAC protocol capacity is defined as the maximum numbers of active voice packet sources simultaneously supported by the MAC protocol.

Figure 1 shows this influence. On it, the two curves represent the transmission of Web packets as voice packets and as data packets, respectively. On both curves, the abscissa axis represents the number of active Web source instances, and the ordinate axis shows the maximum number of active voice source instances that simultaneously can still use the communication channel, meeting the QoS requisites of all packet sources. These curves were obtained using a permission probability equal to 0.30 for both voice and data packets, and data packets with a 640-information bit capacity.

The results presented in Figure 1 indicate that transmitting Web packets as voice packets is more efficient than transmitting them as data packets. There are two reasons for this. The first reason is that PRMA protocol takes into account the periodic behavior of the Web sources when transmitting Web packets as voice packets. The second reason is that, when transmitting Web packets as data packets, the PRMA agent (PRMA protocol instance running on a mobile terminal) associated with a Web source has to fight for a permission to use a time slot for each Web packet through a contention mechanism, because there is no time slot reservation for it. In this case, as the number of active Web users increases, the number of Web packets that must wait in the input queue for permission increases as the chance to have permission to transmit decreases. With this scenario, the input queue length tends to increase, as well as the overflow probability on these input queues, limiting the channel capacity.

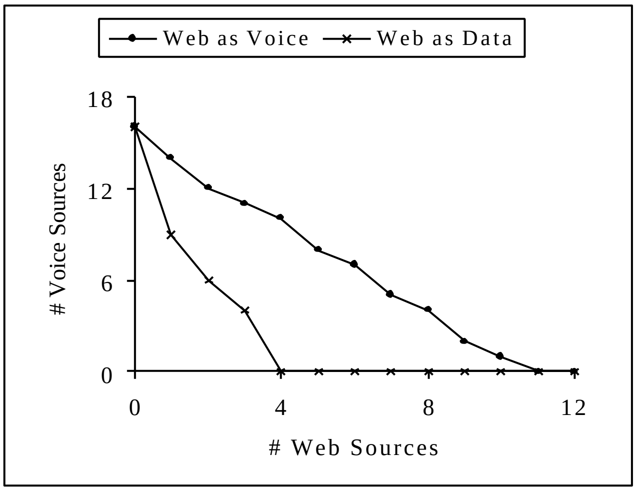

Figure 1 - Web packet traffic influence on PRMA protocol

Many scenarios were created to study the PRMA protocol behavior when dealing with the Web packet traffic, changing some parameters of the original protocol. Tests were done replacing Web sources for WebLight sources. In all cases, the observed behavior were analogous to the one depicted on Figure 1, with the transmission of Web packets as voice packets presenting a better performance. In the case of WebLight sources, the PRMA protocol capacity is always larger than the protocol capacity for same scenario with Web sources, with the shape of curves remaining similar.

Another analyzed aspect is the influence of the Web packet capacity, in terms of information bits, on the overall PRMA protocol capacity. As stated before, a Web browsing service can be modeled as a combination of two ON/OFF processes. The ON state length is directly influenced by the Web packet capacity. Large capacity means that fewer packets must be transmitted (as long as the upper layers of the protocol stack can supply enough information to fill in the packets).

Figure 2 shows the influence of the Web packet capacity on the total capacity of the PRMA protocol. It shows that the PRMA protocol reacts in different ways for each scenario. In the first scenario (Web packets transmitted as data packets), the PRMA protocol capacity augments sensibly as the packet capacity increases. The explanation for this behavior is that, as the packet capacity increases, fewer packets are necessary to transmit the Web objects. Consequently, the mean input queue length decreases, as well as the overflow probability. In the second scenario (Web packets transmitted as voice packets), there is only a small augment in the protocol capacity, because this capacity is limited almost exclusively by the time slot occupation rate. In this scenario, the mean lengths of the input queues are not very high and are under control. For each Web object transmitted, a time slot reservation is granted after its first packet has been transmitted and all subsequent packets is transmitted with a fixed delay, limiting the overflow probability. Therefore, a reduction on the Web packet quantity is the only way for a PRMA protocol capacity augment. A reduction on the number of packets necessary to transfer a Web object decreases the ON state mean length. But, as the OFF states mean lengths stay the same (a small change on the “think time” mean length can occur, but this change can be disregarded), the number of ON state increases, diminishing the expected impact on the time slot occupation rate. This behavior explains the small augment on the protocol capacity. The same results were obtained replacing Web sources for WebLight sources.

At the first moment, mapping the Web packets as voice packets seems to be a good solution to transmit Web packets over wireless links running the PRMA protocol. However, there are two points that must be considered. The first one is that Web packets do not have a so tight delay restriction as voice packets. A Web packet discarded by the MAC protocol obliges the upper layers of the protocol stack to retransmit the lost packet. This is an unnecessary penalty as the Web packets do not a delay restriction (or, if they have, this restriction is looser). The second point is that voice packets must have a higher priority than Web packets, because they are associated to real time processes. Trying to handle these points, the Pr-PRMA protocol, a new variant for the PRMA protocol, has been developed. In the next section, this new protocol is presented, along with its performance analysis.

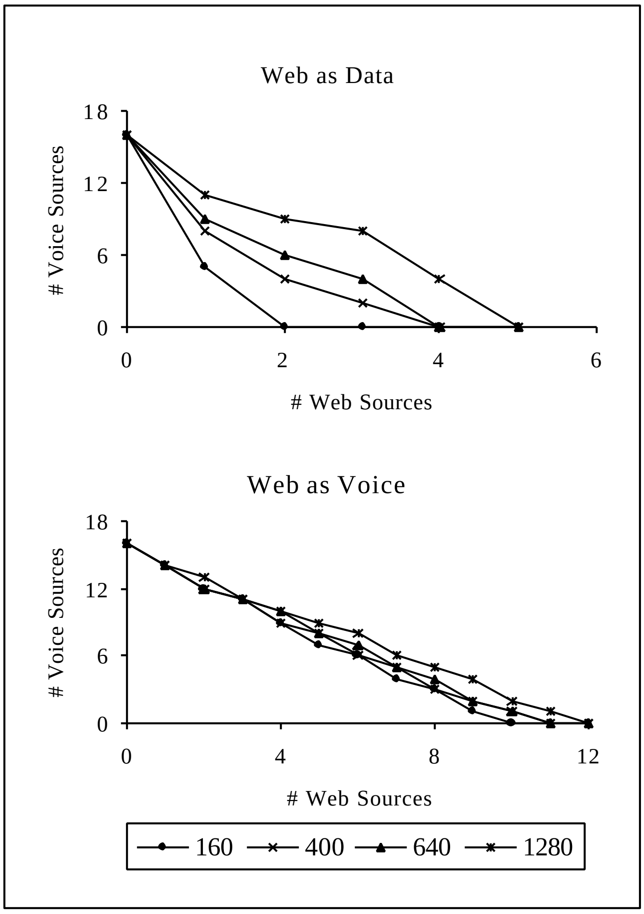

Figure 2 – Web packet capacity influence

D. THE PR-PRMA PROTOCOL

As stated before, the main idea of the PRMA protocol is to take advantage of the periodic behavior of the voice sources, giving them the ability to lock a free time slot on the transmission frame to transmit their packets. This artifice gives them a higher priority over data sources.

This periodic behavior is not restricted to voice sources. Many other packet source types also have this behavior, like e.g., Web and video sources. The difference between these packet streams is their transmission requisites. For example, voice packets have a very tight delay constraint and a low outage probability. On the other hand, real time video packets also have a tight delay constraint but accept a higher outage probability, while Web packets have looser restrictions. Packet sources that present this periodic behavior will be named as *periodic* packet sources, while packets sources, like for example a data terminal, will be named as *sporadic* packet sources.

The first idea that comes into someone's mind is to treat all periodic packet sources in the same way, except for the transmission requisites: maximum allowed delay and maximum outage probability. In this case, the modified PRMA protocol would not make any distinction between any periodic source. All periodic sources would have the right to lock a free time slot to transmit their packets during a packet burst, using the same contention algorithm of the original PRMA protocol. The sporadic packet sources would be treated in the same way of the original protocol.

The difference between periodic packet sources would be how the protocol handles the delay requisite of each one. For each periodic packet source, the protocol would store the delayed packets in an internal waiting queue and would discard enqueued packets each time they wait in the queue longer than their delay tolerance. For periodic packet sources with no delay constraint, the protocol would store the packets as long as there is room on the queue; otherwise, the packets would be discarded as a result of an overflow event.

This simple artifice deals with the first weak point of the original PRMA protocol regarding the Web packet transmission, but the second point (voice packets with a higher priority over Web packets) is not taken into account.

In the original PRMA protocol, when a periodic packet source obtain a time slot reservation, it grants the right to use this time slot to transmit its packets on subsequent frames. The reservation ends only when the periodic packet source fails to supply a packet to send on the reserved time slot. So, as long as a periodic packet source with a time slot reservation is able to provide new packets, the reserved time slot cannot be used by any other packet source, even periodic ones with a higher priority.

To favor periodic packet sources with higher priority (higher priority sources), the reservation concept in the PRMA protocol must be reviewed. The idea is to weaken the reservation concept for periodic packet sources with lower priority (lower priority sources).

Many strategies can be envisaged to weaken the reservation concept. For example, the reservation grant mechanism can be modify for lower priority sources, defining that a successful packet transmission does not guarantee a time slot reservation. In this case, the radio base station is the entity that decides if a reservation should be grant or not. Another strategy would be to permit the radio base station to free time slot reservations at its will. To make these decisions, the radio base station could use a random experiment or any deterministic process based on the current load of the transmission channel or of the transmission system as a whole.

The aim of both strategies is to diminish the average number of reserved time slots in a frame, trying to create more room for higher priority sources. However, both strategies have a conception problem: the weakening of the time slot reservation of lower priority sources is controlled by the radio base station, not by higher priority sources that long for a time slot reservation. Therefore, the reservation loss (or its grant delay) is not linked with a room necessity in the transmission frame. To be successful, the reservation loss must be an answer to a room demand of a higher priority source in the transmission frame.

Conceptually, the PRMA protocol is a decentralized protocol, where each PRMA agent decides which action to take based on some parameters sent by the radio base station and on some random experiments. As neither a dedicated control channel between the PRMA agent and the radio base station nor a common control channel exists, an agent associated with a higher priority source has no way to inform the radio base station or lower priority sources with a time slot reservation that it needs a time slot to transmit its packets. Therefore, an artifice that permits higher priority packet sources to inform its demand to lower priority sources must be created.

In wireless communication systems, the rate of packet loss caused by electromagnetic interference over wireless links normally can be considered very small. This is a consequence of the employment of mechanisms like transmission power control and error recovering schemes. Initially, lets assume that the packet loss rate caused by electromagnetic interference is zero. If so, a packet loss can only occur when two or more packet sources transmit their packet on the same time slot. On the PRMA protocol, when a time slot is reserved, only packets that belong to the packet source that holds the reservation for this time slot are allowed to use this time slot.

Now suppose that a higher priority source transmits a packet on a time slot reserved to a lower priority source. As both packet sources transmit one packet (supposing the reservation holder still has a packet do deliver), a collision on the time slot will certainly occur and both packets will be lost. As there is no packet loss caused by electromagnetic interference, the reservation holder can infer that another packet source has sent a packet on its reserved time slot. This can be interpreted as a signal that there is a higher priority packet source demanding a time slot reservation.

That is the main idea of the Pr-PRMA protocol (Priority Packet Reservation Multiple Access Protocol). On this protocol, the time slot reserve procedure is the same used on the PRMA protocol, but associated with each time slot reservation there is a priority. The reservation priority is an integer number (0 represents the higher priority) and is determined according to the packet source priority. This reservation priority can be fixed or variable during a time slot reservation, depending on the communication system parameters.

For simplicity, lets assume that a packet source with priority P always obtains a P-priority reservation and that the reservation priority is fixed during all the reservation period. So, higher priority sources obtain stronger reservations than lower priority sources and can “stolen” reservations held by lower priority packets. A 0-priority reservation cannot be stolen by any other packet source: it only ends when the packet source that holds it ceases to transmit packets.

In the Pr-PRMA protocol, when a periodic packet source S with a reservation priority P wants to start transmitting its packets, it initially follows the original reserve procedure, trying to grant a time slot reservation. After K frames, if the periodic packet source S still has not been able to transmit a packet, obtaining with it a time slot reservation, it starts signaling to periodic packet sources, which holds a R-priority time slot reservation, $R > P$, that it needs a time slot. In each time slot reserved to a periodic packet source with priority less than P, the packet source S tries to send a probe packet on this reserved time slot. This probe packet is the next-to-send packet on the input queue associated with packet source S. The packet transmission authorization for a reserved time slot is obtained through a random experiment, which is controlled by a protocol parameter called collision probability C. The radio base station is responsible to adjust this parameter, based on the actual network load.

After packet source S has sent its probe packet on a reserved time slot, two situations can occur. On the first situation, no other packet source has sent a packet on this time slot (even the packet source that holds the reservation). In this case, the periodic packet source S obtains a P-priority reservation for this time slot on subsequent frames. On the second situation, one (or even more than one) packet source sends a packet on the reserved time slot. These sources can be the lower priority source that holds the reservation and/or others higher packet sources that also need a time slot reservation. Due to channel characteristics, all packets sent on this time slot are corrupted and are discarded by the radio base station, preventing the recognition of the time slot reservation claimant (or claimants). So, the radio base station cannot immediately transfer the reservation to a higher priority source, needing a mechanism to grant the reservation.

Lets suppose that the lower priority source L that holds the time slot reservation has not ended its transmission cycle yet and that its reservation is a Q-priority reservation, $Q > P$. In this case,

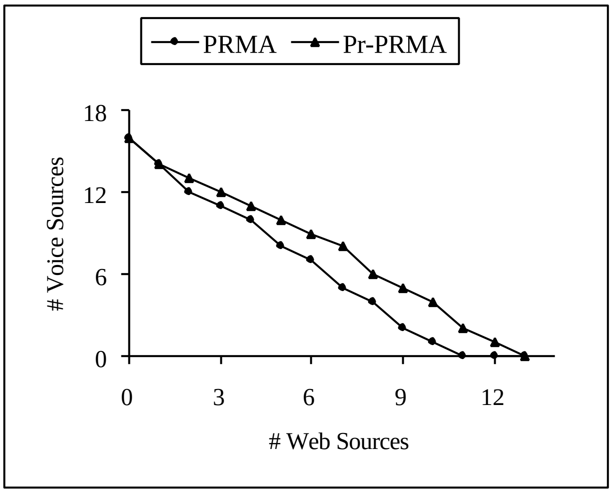

Figure 3 – Pr-PRMA Protocol

when its time slot arrives on the next frame, this packet source L does not transmit a packet, leaving the time slot temporally free. This temporally free time slot is called a blocked *Q*-priority time slot.

Before the next instance of the blocked time slot, the radio base station informs all Pr-PRMA agents that there is a blocked *Q*-priority time slot available. This means that all periodic packet sources with priority greater than *Q* that are trying to steal a time slot are candidate to occupy this blocked time slot.

These candidate packet sources try to steal this blocked time slot reservation, sending a packet on the time slot, following the conventional contention procedure. If a packet source T managed to transmit a packet, without colliding with others competing packets, then the radio base station reverts the time slot reservation to this voice source T and the packet source L starts competing for a new time slot reservation. If any of the candidate packet sources managed to successfully transmit a packet, then the time slot reservation continues with the packet source L and it restarts sending its packet on the next frame. If the packet source L has finished its transmission cycle, it leaves the time slot free signaling that it no longer needs the reservation.

Figure 3 compares the capacity of the PRMA and Pr-PRMA protocols. In this scenario, we consider that there are only two types of periodic packet sources: voice packet sources, with priority 0, and Web packet sources, with priority 1. As it can be seen, the capacity of the Pr-PRMA protocol is superior to the capacity of the original PRMA. A similar result has been obtained replacing Web sources for WebLight sources.

The Pr-PRMA protocol imposes a very low overhead when compared with the original PRMA protocol. The additional information that must be informed to the Pr-PRMA agents is the collision probability and, for each time slot, its status (free, reserved or blocked) and its priority reservation (for reserved and blocked time slots). All this additional information can be efficiently sent to the Pr-PRMA agents, slightly increasing the amount of data sent by the radio base station to the Pr-PRMA agents on its cell. The number of bits necessary to code the priority reservation depends on the number of priority levels.

The question now is how great is the Pr-PRMA protocol impact on the transmission of the packets associated with lower priority sources. A clear consequence of the Pr-PRMA protocol is an increase on the delay

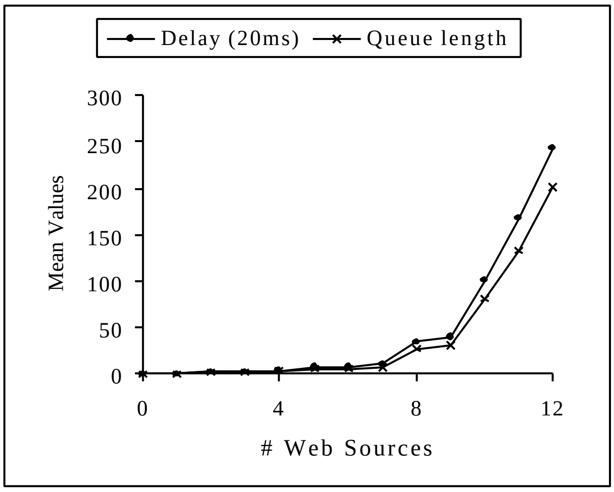

Figure 4 – Queue and delay transmission on the Pr-PRMA protocol (K = 1, *C* = 0.4)

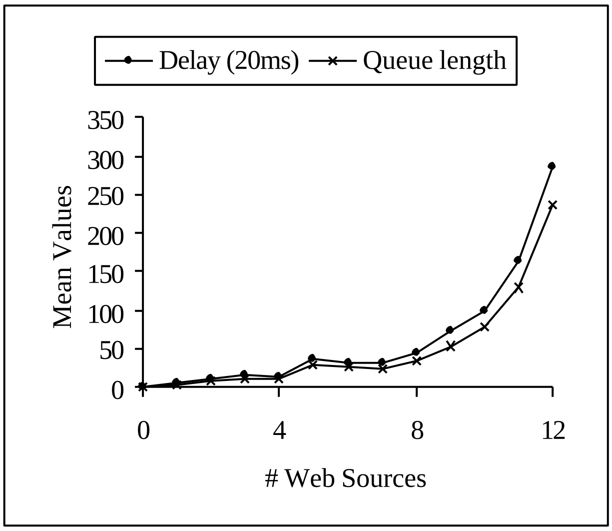

Figure 5 – Queue and delay transmission on the Pr-PRMA protocol (*K* = 0, *C* = 0.25)

transmission of packets associated with lower priority sources, as well as on the input queues related with these sources.

Figure 4 shows how the mean value of the delay transmission and input queue length associated with Web packet sources behave as the number of Web packet sources increases. Again, we consider that there are two types of periodic packet sources: voice packet sources, with priority 0, and Web packet sources, with priority 1. In this scenario, the number of active voice packet sources is kept constant, equal to four. It can be noted that the mean values of the delay transmission as well as the input queue length remain low, till the number of active Web packet sources reach 6 (approximately 5 units occupied on the input queue and a 140-ms delay transmission). After this point, the input queue length and delay transmission mean values increase smoothly, until 8 active Web packet sources, when the curves slopes become deep. It is important to mention that packet loss due to input queue overflow (only way to drop Web packet packets on the protocol) just start to happen when the number of active Web packet sources reaches 8.

On the Pr-PRMA protocol scenarios presented before, voice packets sources just start trying to steal Web packets source reserves after one frame (K = 1). In this case, the best value found for the collision probability *C* is 0.4. If the K value is changed to zero (which means that voice packet sources start trying to steal a time slot reservation at the very beginning of its transmission cycle), the best value found for the collision probability *C* is 0.25. A lower value for the collision probability is necessary because Web packet sources need more protection against eager voice packet sources.

Figure 5 shows the same scenario presented on Figure 4, but now with K = 0 and *C* = 0.25. It can be see that presented values are greater than obtained values for K = 1. They remain stable (approximately 30 units occupied on the input queue and a 300-ms delay transmission) until a 5-active Web packet sources mark. Until this point, there is no packet loss due to overflow. After this point, the protocol starts losing packets due to overflow. This coincides with the mean value augment for the delay transmission and queue input length.

The results presented in Figure 4 and 5 show that the Pr-PRMA protocol is very stable. Until the saturation point, when packet

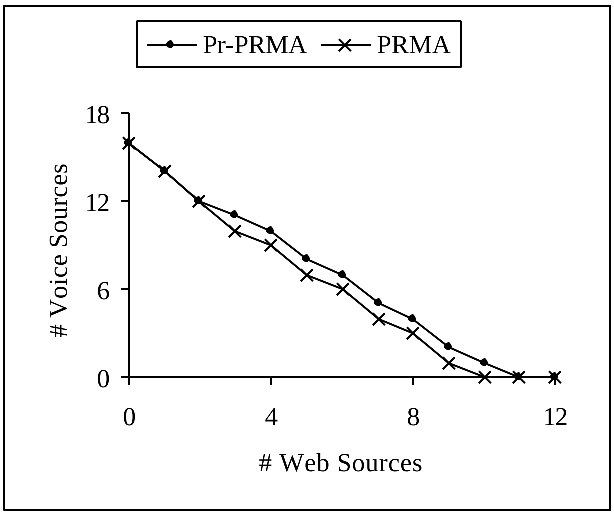

Figure 6 – Pr-PRMA Protocol, on noisy communication channels (0.5%)

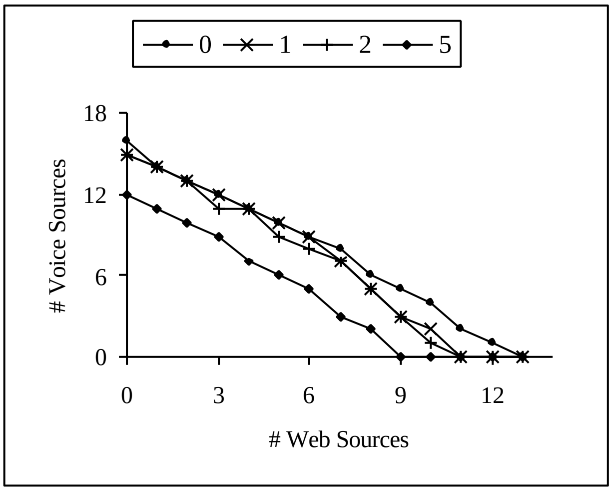

Figure 7 – Data packet source influence on Pr-PRMA protocol

loss due to input queue overflow starts, the mean values for delay transmission and input queue length remain under control, approximately constant.

All results presented until now is based on the premise that no packet is lost due to electromagnetic interference. Figure 6 shows the capacity of the original PRMA protocol and the Pr-PRMA protocol over a noisy communication channel. These curves were obtained simulating a wireless channel with 0.5 % of its time slots destroyed by electromagnetic interference. Both protocols were simulated using the two interference models implemented on the MacSim environment. On the first interference model, for each time slot, there is a probability of 0.5% that the time slot is corrupted by electromagnetic interference. On the second interference model, many scenarios was defined, creating different burst patterns of electromagnetic interference on the channel, but in all simulated scenarios the mean value of corrupted time slot is 0.5% of the total. The obtained results for all scenarios were the same as depicted in Figure 6. Other protocol parameters, like input queue lengths and delay transmission, were also analyzed and all parameters have presented satisfactory mean values. The same results were obtained when replacing Web sources with WebLight sources.

Figure 7 shows the behavior of the Pr-PRMA protocol capacity, in the presence of data packet sources (sporadic packet sources), along with voice and Web packet sources. The data sources were supposed to have a $\sigma = 0.2$. As expected, as the number of active data packet sources grows, the protocol capacity decreases. Analyses made on other protocol parameters have shown that the presence of data packet sources has not cause any disturbance on the Pr-PRMA protocol.

Finally, Figure 8 shows the Pr-PRMA protocol behavior when submitted to 3 different periodic packet source types: voice packet sources, with priority 0, Web packet sources, with priority 1, and low priority Web packet sources, with priority 2. In this Figure, each curve represents the Pr-PRMA protocol capacity with a fixed number of low priority Web packet sources. As can be seen, the presence of low priority Web sources affects the protocol capacity in a straight way, without creating a disturbance on the protocol capacity. In other words, the Pr-PRMA protocol remains stable even in the presence of many periodic packet types. Analyses made on other protocol performance indicators, like e.g. mean transmission delay, waiting queue behavior and outage probability

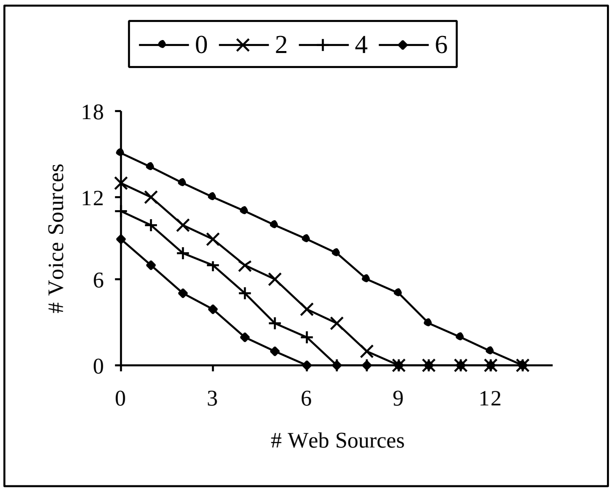

Figure 8 –Pr-PRMA protocol capacity with 3 different periodic packet source type

behavior, have shown that the Pr-PRMA protocol is suitable to deal with the packet traffic generated by periodic packets sources.

E. CONCLUDING REMARKS

The impact of the Web packet traffic on the PRMA protocol is analyzed on this paper. The obtained results have shown that transmitting Web packets as voice packets has a better performance than transmitting them as data packets. The reason is that the PRMA protocol is able to take advantage of the periodic characteristic of the Web packets. However, when transmitting Web packets as voice packets, the original protocol unnecessarily discard Web packets and does not give a higher priority to voice packets over Web packets.

To suppress these weaknesses, the Pr-PRMA protocol, a new variant of the PRMA protocol, is proposed and analyzed on this paper. It deals with both weaknesses of the original PRMA protocol and has a better performance than the original protocol in terms of the maximum numbers of voice packet sources simultaneously supported, with a slightly superior overhead. Although this variant uses a subterfuge based on intentional packet destruction to work, analyses made have shown, that even when used in noisy channels, the Pr-PRMA protocol has a good performance, making the protocol suitable to deal with new 3G system services. Although Web and WebLight sources have different mean values for file size and other parameters, their results are very similar. This shows that the performance of both PRMA protocols is more related with the packet traffic pattern than with the load of the sources.

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