Performance of CDMA/PRMA as an Access Technique for Integrated Services in a UMTS High Altitude Platform System

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Abstract. High Altitude platforms (HAPs) have gained a great interest in recent years. HAP systems will be globally in nature but nationally in service provision. They will deliver IMT-2000 mobile and fixed wireless access using the proposed IMT-2000 terrestrial component radio transmission technologies and protocols. Under the above considerations, in this paper the performance of a MAC protocol based on the combination of the well-known Packet Reservation Multiple Access (PRMA) scheme with Code Division Multiple Access (CDMA) technologies in a Frequency Division Duplex (FDD) mode is studied, for a HAP operating at the 2GHz frequency band at an altitude of 22Km. The impact of acknowledgement delay has been examined through computer simulations, along with the selection of suitable channel access functions (CAFs) to control the access of mobile users. Moreover the protocol performance is investigated in a cellular HAP environment and compared to that of a Ground Based System. Finally, different traffic scenarios have been considered in order to investigate the access delay for non-real time traffic and the packet dropping performance for real time traffic.

Keywords: CDMA/PRMA, medium access, HAPs, UMTS

1. Introduction

The employment of High Altitude Platforms (HAPs) has been recently proposed as an alternative to traditional terrestrial and satellite-based infrastructure for the design of future communication systems [1, 2]. The cost-effective coverage of rural low population density areas, the capability to upgrade their telecommunication payload periodically in order to fulfill future demands, are some advantages of HAP based systems. The International Telecommunication Union (ITU) has granted spectrum for HAPs in IMT-2000 frequency bands [3, 4].

A HAP station can centrally manage the available resources. From a Medium Access Control (MAC) layer point of view these resources may be allocated using either circuit or packet switching. This paper examines a MAC protocol based on the well-known Packet Reservation Multiple Access (PRMA) operating in a Direct Sequence Code Division Multiple Access (DS-CDMA) environment in order to support bursty traffic characteristics, such as packetized voice when applying voice activity detection. The PRMA scheme is based on Time Division Multiple Access (TDMA) and combines random access with slot reservation. In the case of voice traffic each user that holds a reservation of a slot, sends every packet of the current spurt in that specific slot. Similarly, for non-real time traffic each user can reserve a slot for the transmission of data and holds the reservation according to an allocation cycle (section 4). Combining it with the characteristics of CDMA more efficient radio packet communication systems can be achieved, since each slot can support more than one simultaneously transmitted packets, limited by multiple access interference (MAI) [5–8]. Multiple access is handled by suitable channel access functions (CAFs). These functions determine access permission probabilities varying slot by slot, depending on the number of users that hold a reservation, the number of contending users and the maximum number of simultaneous transmitted packets that the channel can correctly receive.

An important issue when designing a cellular system is the propagation delay. In the case of Ground-Based system, a mobile user promptly receives the outcome of an attempt, whilst in a HAP system the impact of acknowledgement delay is significant (eg. macrocell service areas). For instance as it was shown in [2] the maximum propagation delay for elevation angles less than 10^o is about 3 ms, meaning that a contending user re-attempts for transmission after at least 3 ms. The impact of acknowledgement delay is studied through computer simulation in this paper.

Similarly to a terrestrial system, in a HAP constellation operating in a cellular CDMA environment the other-cell to same-cell interference is an important parameter. Some studies have dealt with the estimation of the interference factor in a HAP system [9, 10]. In this paper the impact of interference in a CDMA/PRMA access scheme for a stand-alone and a cellular configuration is examined.

The paper is organized as follows. Section 2 presents some important characteristics of a HAP system serving a single macrocell and a multi-cellular area. Section 3 describes the traffic characteristics considered in this paper. In section 4 the CDMA/PRMA protocol description is presented along with the selection of a suitable Channel Access Function, and further different scenarios of reservation phase duration for Web users are examined. Simulation results are presented in section 5. Finally, section 6 concludes the paper.

2. HAP System Definition

Each High Altitude Platform Base Station (HAPBS) uses a phase array antenna to project hundreds of spot beams to provide telecommunication services. The coverage area ranges in size from metropolitan to wider areas, in a pattern similar to that created by a traditional cellular system. In our case a HAPBS carrying a CDMA payload is considered, at an altitude of 22 Km above the service area. Stability issues have been ignored meaning that the HAPBS is kept stationary with regard to the ground surface. The effect of the earth's curvature is neglected due to the low altitude and the service area is further consisted of equally sized circular cells of radius r [9], or a single macrocell. Assuming an area served by a single macrocell, the maximum distance traversed by a signal is 517 Km for an aerial base station at 21 Km [2]. In such scenarios, propagation delay plays a significant role. A mobile user, which has sent a packet in contention mode in a particular time slot will not be allowed to contend again in the next s slots (s denotes the time period that a mobile user waits in the downlink the result of its packet transmission), regardless of whether there are time slots for contention available in this period.

Mobile users are uniformly distributed and perfect power control is employed, ensuring that signals from all mobile users in a given cell arrive at the HAPBS with the same power. Two different scenarios have been studied. A stand alone configuration where a HAPBS can serve a single macrocell (Figure 1b), and a cellular configuration with more than one cell rings (Figure 1a).

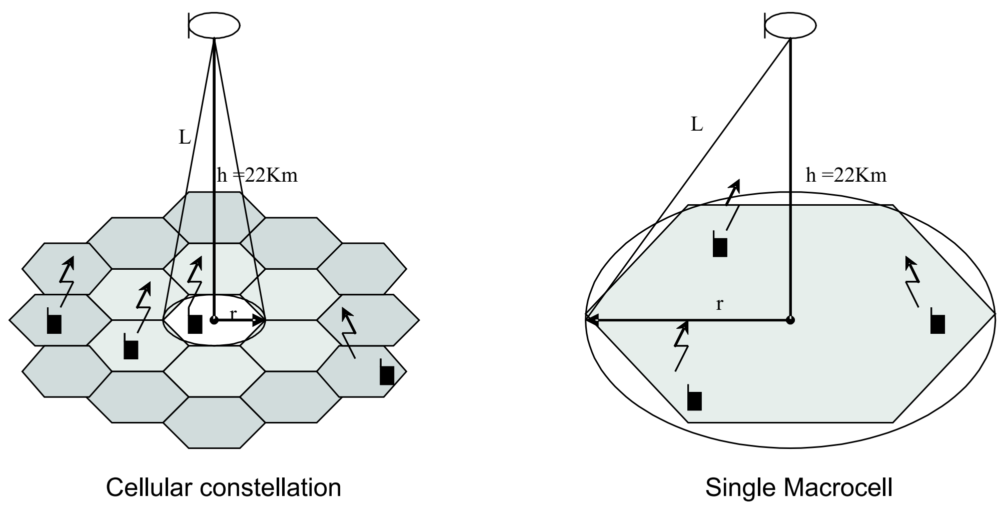

Figure 1. System configuration

2.1. HAPs - Single Macro-Cell

In this simple scenario the aim is to determine the BER of the channel. For DS/CDMA environment the Standard Gaussian Approximation has been widely used. Assuming that the dominant interference contribution is Multiple Access Interference (MAI), and AWGN is ignored, the average BER or the probability of bit error P_e, can be calculated using

$$P_e = Q(\overline{SNR}) \tag{1}$$

where $Q(x)$ is equal to

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{\frac{-u^2}{2}} du \tag{2}$$

and

$$\overline{SNR} = \sqrt{\frac{3G_p}{2(K-1)}} \tag{3}$$

where G_p denotes the processing gain or the spreading factor for a CDMA channel, and K is the number of simultaneous transmitted packets in a specific time slot (equals to the number of users). Perfect power control and QPSK modulation have been assumed. When packets of length L are transmitted over such a radio channel the probability of a packet success Q_{pe} is obtained from

$$Q_{pe} = \sum_{i=0}^{e} \binom{L}{1} (1 - Q_e)^i (Q_e)^{L-i} \tag{4}$$

where $Q_e = 1 - P_e$ is the average probability of data bit success. For a spreading factor $G_p = 15$, a packet length $L = 255$ and a (255, 107, 22) BCH code, the packet success probability is depicted in Figure 2. It is obvious that in a stand-alone scenario where a HAPBS serves a single cell, the maximum number of correctly received packets in a time slot should not be greater than 10, since dropping probability $P_{pe}[K > 10]$ falls below 2%. For $K = 10$ packet success probability is almost 1, meaning that all transmitted packets will be received correctly.

2.2. HAPs - Cellular Environment

In the case of a cellular environment, users located in neighboring cells, also generate interference, yielding in an increased BER. The average signal to noise ratio with perfect power control and QPSK modulation is given by

$$\overline{SNR} = \sqrt{\frac{3G_p}{2(K-1) + 2(K_{aver}f)}} \tag{5}$$

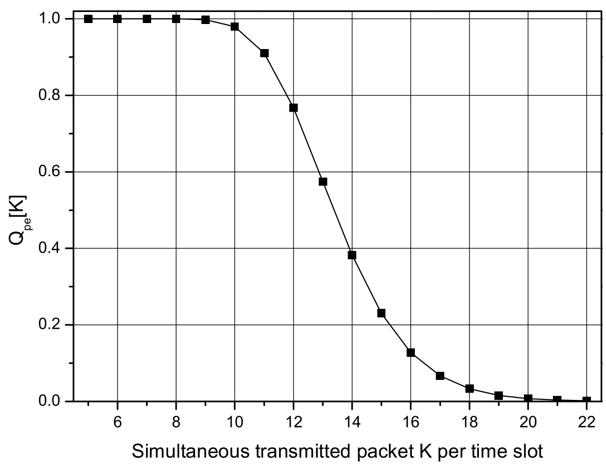

Figure 2. $Q_{pe}[K]$ for $G_p = 15$ and a (255, 107, 22) BCH code

In equation (5) K_{aver} is the average number of users per time slot (in other words this number denotes also the average number of simultaneous transmitted packets since each user can transmit only one packet per slot). In the case where each cell is equally loaded with M mobile voice users K_{aver} is equal to

$$K_{aver} = \frac{M a_u}{N} \tag{6}$$

In equation (6) N is the number of slots per frame and a_u is the voice activity factor. It is further assumed that K_{aver} denotes the number of users (packets) per time slot in the test cell.

Another important parameter in equation (5) is the factor f, which denotes the other-cell to same-cell interference factor. The f factor further represents the normalized level of intercell interference (normalized to the total received power of all mobile users served by the aerial base station), which does not depend on the cell radius [7]. As it was shown in [10], it is a good approximation to consider 4 tiers of interfering cells and $f = 0.155$ for a cellular HAP environment.

From equation (4) the packet success probability can be derived. Since the average SNR in a cellular environment is strongly related to the number of users M, an increase in the load will result in a reduction in the number of simultaneous transmitted packets in a time slot that the aerial base station can correctly receive. This effect is depicted in Figure 3. From the above figure when $M = 100$ and $K_{max} = 9$ we

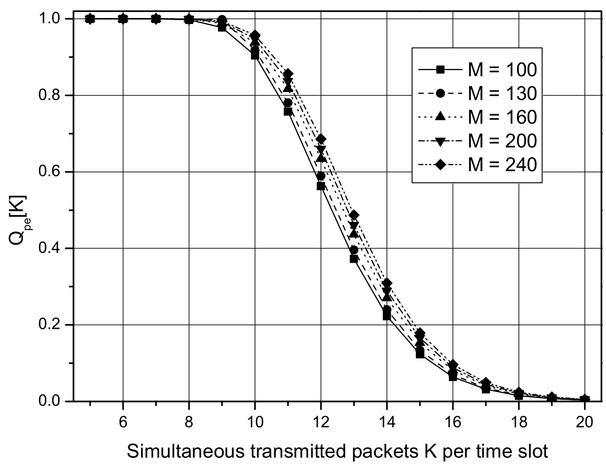

Figure 3. $Q_{pe}[K]$ for $G_p = 15$ and a (255, 107, 22) BCH code and different values of users M

can achieve a packet success probability equal to 0.9937, whilst for $K_{max} = 10$ the average packet success probability falls below 96%. By increasing the number of users M we observe that for $M = 240$ no more than 8 packets can be correctly received at the HAPBS ($Q_{pe}[9] < 0.98$).

2.3. Terrestrial - Cellular Environment

Similar results can be derived in the case of a terrestrial cellular environment. In Figure 4 the packet success probability in different loads is shown for a ground-based CDMA system without shadowing, for other cell interference factor $f = 0.33$ and pathloss coefficient $\gamma_{pl} = 4$. No more than 7 packets can be correctly received when M is greater than 260 as $Q_{pe}[8] < 0.96$. In Figure 5 $Q_{pe}[K]$ is derived for a ground based CDMA cellular system with $f = 0.55$, lognormal shadowing, $\gamma_{pl} = 4$ and standard deviation $8dB$. In this case, $K_{max} = 6$ is a reasonable value for 180 active mobile users, since $Q_{pe}[7]$ is less that 0.99. From the above figures it is obvious that as the number of active mobile users increases someone will expect a degradation of the protocol's performance, since it is strongly related to the maximum number of correctly received packets K_{max} at the aerial base station.

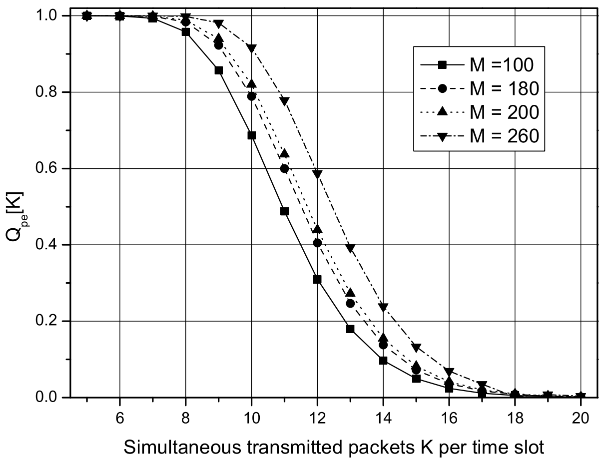

Figure 4. $Q_{pe}[K]$ in a Ground Based CDMA system ($f = 0.33$) for $G_p = 15$ a (255, 107, 22) BCH code and different values of users M

3. Traffic Sources

3.1. Voice Traffic Model

Each voice terminal uses a slow speech activity detector so the speech source can be modeled as a two state Markov chain. The two statuses are talkspurts and silentgaps. The lengths of both are assumed to be exponentially distributed. The Markov chain is assumed to be of discrete time with transition on slot boundaries. Voice packets are generated only during talkspurts, at the rate of one per frame. The mean duration of talkspurts is $D_{talkspurt} = 1sec$ and for silentgaps $D_{silentgap} = 1.35sec$, yielding to a voice activity factor of 0.426. A finite number of voice terminals M is considered, which are all involved in a conversation and this number remains fixed per simulation run.

3.2. Web Browsing Traffic Model

A model for Web browsing was proposed in [12]. This model was suggested for both link directions, and will therefore be used for the uplink direction in this paper. A graphical representation of this model is depicted in Figure 6. According to this model a session is made up of several packet calls that in turn contain multiple packet datagrams. Each datagram consists of a number of packet bursts. The number of packet calls per session N_{pc} is a geometrically distributed random

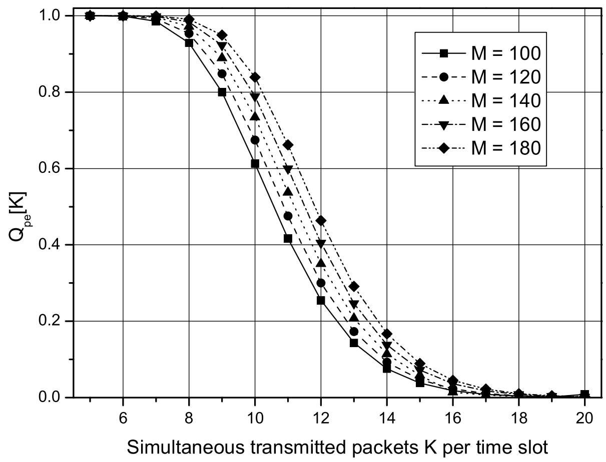

Figure 5. $Q_{pe}[K]$ in a Ground Based CDMA system ($f = 0.55$) for $G_p = 15$ a (255, 107, 22) BCH code and different values of users M

variable with a mean number of packet calls $\mu_{N_{pc}} = 5$. The reading time, D_r, between two consecutive packet calls follows a geometrical distribution with $\mu_{D_r} = 4sec$ (for simulation purposes). Since the slot duration is much smaller that the mean reading time an exponential distribution has been used instead. The reading time starts when the last burst of the previous packet call has been successfully transmitted. The number of datagrams, N_d in a packet call is also distributed according to a geometrical distribution and has a $\mu_{N_d} = 25$ datagrams. The time interval between two consecutive datagrams inside a packet call, D_{id} is again a geometrically distributed random variable with a mean μ_{inter}. For the same reason as for the reading time an exponential distribution has been used instead of a geometrical one. The inter-arrival time corresponds to average data rates. The mean inter-arrival time can be calculated from the average bit rate as:

$$\mu_{inter} = \frac{0.426 \cdot 8kbit}{R_{UDD}} \tag{7}$$

where R_{UDD} is the average data bit rate (in Kbit/s). In Table I μ_{inter} is calculated for different values of R_{UDD}.

Finally the datagram size S_d in bytes is modeled using a Pareto distribution. The normal Pareto distribution (without cut-off) is defined by:

$$f(x) = \frac{ak^a}{x^{a+1}}, \qquad x \geq k \tag{8.1}$$

Table I. Average Interarrival time in different UDD bit rate

Packet Based information types	N_{pc}	D_r (sec)	N_d	D_{id} (sec)
WWW - UDD 8Kbps	5	4	25	0.426
WWW - UDD 64Kbps	5	4	25	0.05325
WWW - UDD 144Kbps	5	4	25	0.023666
WWW - UDD 384Kbps	5	4	25	0.008875

$$F(x) = 1 - \left(\frac{k}{x}\right)^a, \quad x \geq k \tag{8.2}$$

$$\mu = \frac{ka}{a-1}, \qquad a > 1 \tag{8.3}$$

$$\sigma^2 = \frac{k^2 a}{(a-2)(a-1)^2}, \quad a > 2 \tag{8.4}$$

The packet size is defined with the following formula (with cut-off):

$$PacketSize = min(P, m) \tag{9}$$

where P is a normal Pareto distributed random variable with $\alpha = 1.1$ and $k = 81.5$ (bytes). The value of the parameters α and k is proposed in the ETSI model for packet traffic [12]. The parameter m is the maximum allowed packet size, $m = 66666$ (bytes). The probability density function (pdf) of the packet size becomes:

$$f(x) = \begin{cases} \frac{ak^a}{x^{a+1}}, & k \leq x < m \\ \\ \beta\delta(x-m), & x = m \end{cases} \tag{10}$$

where β is the probability that x $\geq$ m. It can easily be calculated as:

$$\beta = \int_m^\infty f(x)dx \left(\frac{k}{m}\right)^a, a > 1 \tag{11}$$

The average packet size can be calculated as:

$$\mu_{sd} = \int_{-\infty}^{\infty} xf(x)dx = \frac{ak - m\left(\frac{k}{m}\right)^a}{a-1} \tag{12}$$

with the parameters of α and k the average packet size is then: $_{sd} =$ 480 bytes. Assuming that each user cannot transmit more than one burst per frame a datagram of 66666 bytes will require more than 66 seconds for transfer. This means that queues of significant size have to be introduced. In this paper it is assumed a negligible dropping probability, in other words no www bursts are being dropped.

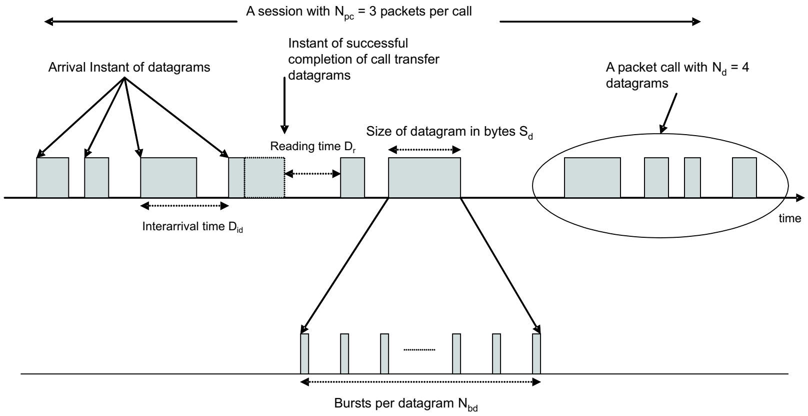

Figure 6. Web Browsing Model

4. Protocol Description

CDMA/PRMA protocol is an extension of the conventional PRMA in order to operate in a DS/CDMA environment [6–8]. The time axis is divided into time slots where a fixed number of them consists a TDMA frame. The TDMA frame rate is equal to the basic source frame rate. Each voice source generates one packet per TDMA frame. For higher bit rate services such as WWW traffic, multiple slots per frame should be allocated in order to reduce transmission delay. If this strategy would be used the HAPBS should keep control about the type of the user in each slot, thus assigning to it the requested resource, if there are any available. This would require a more complex scheme of acknowledgments. Since PRMA was first design to serve real time traffic such as voice in order to avoid deterioration of quality, in this paper we assume that each WWW user cannot make use of multiple slots for packets transmission in a frame.

In an uplink information channel, each time slot can support more than one simultaneous transmitted packet. The maximum number of correctly received packets at the HAPBS is limited by the MAI (section 2). These time slots are either available for contention or reserved for the information transfer of a particular mobile user. The HAPBS informs all mobile users in the downlink about the status of each time slot (reserved or available).

When a packet arrives at a mobile user it will switch from idle mode to contention mode, trying to perform a transmission at the first contending slot (S_c). The mobile user has first to perform a Bernoulli experiment with some permission probability (P_v for voice users and P_w for WWW users) in order to gain access to the channel.

In the case of a positive outcome (the output of the experiment is less than P_v or P_w) the user transmits the first packet. If this packet is received correctly by the HAPBS, it will send an acknowledgment, which implies a reservation of the same slot (which is now characterized as a reserved slot, S_r) in subsequent frames. As far as voice traffic is concerned, the reservation phase will be kept until the transmission of all packets in a current talkspurt. For WWW users an allocation cycle is important to be introduced [13] in order to reduce the duration of reservation phase and protect by this way the delay sensitive voice traffic transmission. Upon positive acknowledgment the reservation of the particular slot will be kept until the transmission of the remaining bursts in the allocation cycle.

In the case of a negative outcome or corruption of the packet due to excessive MAI the contention procedure is repeated. Voice packets are dropped when a delay threshold value D_{max} elapses and contention is repeated with the next packet of the talkspurt. For WWW bursts each burst is retransmitted until it gains a reservation.

HAPBS broadcasts permission probabilities to all mobile users before the beginning of the next slot. Permission probabilities are variable changing slot by slot according to the channel load and the selected channel access function.

Unlike conventional CDMA/PRMA the introduction of end-of-use flags prevent [11] reservation cancellation due to excessive MAI, yielding an increased protocol efficiency. Mobile users transmit packets, which include end-of-use flags and the HAPBS will release reservations only by recognizing these flags.

4.1. Access Control (Voice Users)

As it has been mentioned above, the introduction of end-of-use flags at the end of a spurt transmission will prevent reservation cancellation. Furthermore the excessive MAI generated by contending users (U_c) accessing the same time slot with reservation mode users (U_r) must be restricted. In this case, the access of contending users is controlled by suitable channel access functions (CAFs) [7]. The permission probability for the same slot in a subsequent frame is related to the estimated number of users with reservation (U_{er}) and the number of contending users U_c in the current slot. For example to calculate P_v for frame n_f and slot $n_s = 2$ the following simple calculations must be made

$$U_{er}[n_f + 1, n_s = 2] = U_r[n_f, n_s = 2] + U_c[n_f, n_s = 2] \tag{13}$$

$$P_v(n_f + 1, n_s = 2) = CAF(U_{er}[n_f + 1, n_s = 2]) \tag{14}$$

where CAF stands for the selected channel access function. The choice of an appropriate CAF allows the variance of MAI to be reduced slot by slot yielding a decreased packet loss. From Figure 2 in a stand-alone HAP system configuration, it is obvious that access should be denied for U_c, if U_{er} is greater than 10. On the other hand, if U_{er} is very short, then a high permission probability or even $P_v = 1.0$ must be broadcasted to all users. An example of different CAF curves is depicted in Figure 7. Determining suitable channel access functions, several iterations depending on system characteristics are involved. Many simulation runs have been made observing the number of users holding a reservation and the number of contending users in order to estimate suitable CAFs. As it is shown in Figure 7 an average CAF has also been calculated and it is used for our simulation results. Another

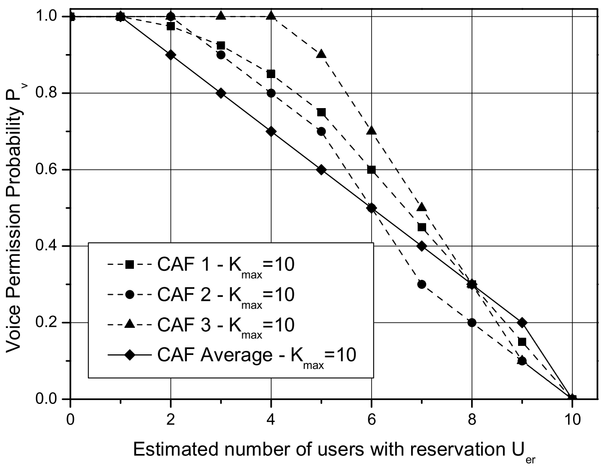

Figure 7. Example of channel access functions for $K_{max} = 10$ and single cell

characteristic of these CAFs is that they are very generous in low load or in small number of contending users. This will cause some slots to be heavily overloaded with packets that hold a reservation. As a consequence the delay of contending users will increase resulting in an increased packet loss. Furthermore, by ignoring the introduction of end-of-use flags, which prevent reservation cancellation, in such slots, both reserved and contending packets will be erased yielding an increased packet loss probability. From equations (13, 14) and Figure 7 someone could claim that if the sum of U_c and U_r is greater than K_{max} then access in a subsequent frame in the same slot is prevented ($P_v = 0.0$).

This means that packets have to re-contend after at least one frame resulting in an increased access delay. In a HAP system this delay could be crucial due to the fact that propagation delay in some cases (aerial macrocell) cannot be ignored, thus P_{loss} will be increased. In order to give the opportunity to contending users to try again for transmission in such slots with heavy load, we calculate P_v in a slightly different way according to the following simple algorithm. This algorithm (Figure 8) is also very useful in the case where reservation cancellations do not occur. As an example we assume that the system is in slot $n_s = 2$ and frame n_f. In the above algorithm we examine if the number of

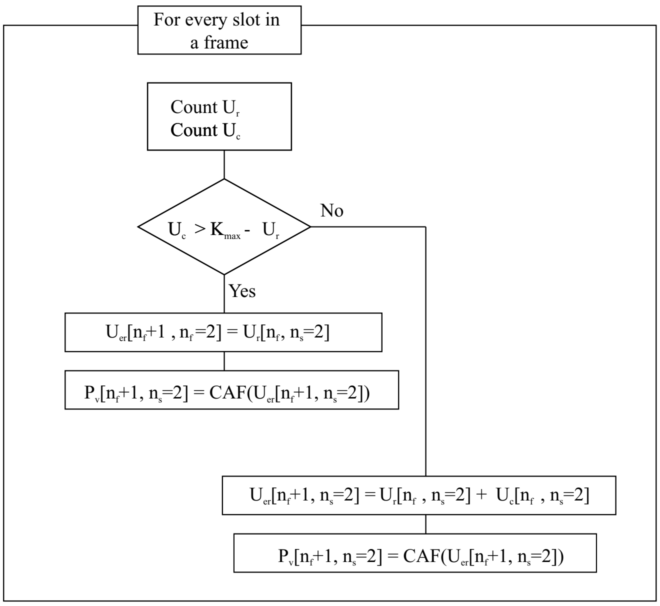

Figure 8. Algorithm to calculate permission probabilities

contending users in a current slot is greater than the available resources. If so, permission probability is calculated according only to the number of users with reservation. By this way we ensure that permission probability in the same slot in a subsequent frame will not be zero, giving the opportunity to some possible contending users to try again for a slot reservation reducing dropping probability. In a cellular environment where the number of active mobile users M affects K_{max}, as it was shown in section 2.2, different CAFs have to be determined. An example of used CAFs is depicted in Figure 9.

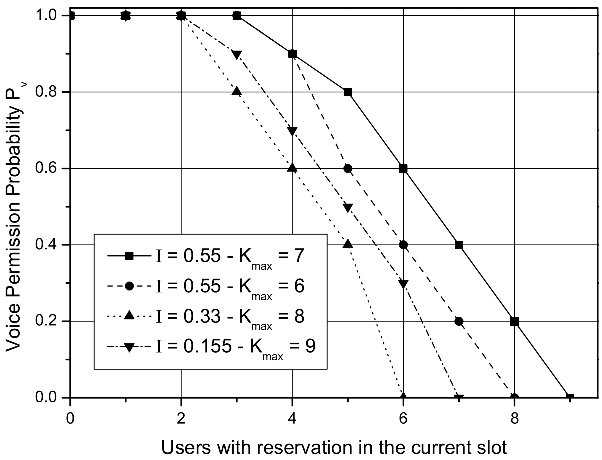

Figure 9. Example of channel access functions in a cellular environment

4.2. Allocation Cycle (WWW Users)

As it has been mentioned above a mobile user that produces voice traffic can hold the reservation of a slot until it transmits all the packets of the current talkspurt. Then it releases the reserved slot while it is in an idle period (during a silentgap) and re-contend again at the beginning of the next talkspurt. For a WWW user the reservation is necessary to be limited according to an allocation cycle. It is assumed that WWW mobile users have to re-contend after the expiration of a cycle. Upon successful transmission of the last burst in a cycle the user returns to an idle state and re-contend in order to gain a reservation for the next cycle. Two different scenarios have been simulated in order to estimate a reasonable value for the allocation cycle (see section 5). In the first dynamic approach, a percentage of the current buffer status of a user has been assigned as an allocation cycle, whilst in the second scenario the allocation cycle has been taken equal to a fixed number of bursts (packets). The aim was to reduce the mean time that WWW users spent in queue in order to obtain a reservation of a slot and further to reduce the number of dropped packets for voice mobile users when a mixed traffic scenario is implemented.

5. Simulation Results

In this section simulation results of CDMA/PRMA performance in a HAP system are presented. For voice traffic permission probabilities are controlled through suitable CAFs. The overall performance is measured by the packet loss probability P_{loss}, which is composed of the packet dropping ratio due to excessive delay and the packet erasure rate due to excessive MAI. The number of simultaneous supported conversation M at a tolerable maximum P_{loss} of 1% is of interest here. M remains fixed over a simulation run. For WWW users the duration of the reservation time is controlled according to the allocation cycle. Each datagram is segmented into packets and only one packet is transmitted in every frame. Fixed permission probabilities have been considered. The performance is measured by the mean access delay, which equals to the time interval between a new transmission request (a new datagram arrival with an empty buffer, or an expiration of an allocation cycle) and the time when a reservation is obtained. A simulation tool was developed in Python (an OSI certified open source) [14] and the simulation time in every run was 333sec. For voice users each simulation run was conversation time (subsequently talkspurts and silentgaps), whereas for WWW users it is assumed that a new session arrival happens immediately after the end of the previous one thus reducing the time spent in an idle state. Several simulation runs have been performed in order to take an average of the packet loss probability (voice users) and the mean access delay (WWW users).

5.1. Design Parameters

The frame length has been taken equal to $D_{frame} = 10ms$, which is further consisted of $N_{slots} = 15$ slots of $D_{slot} = 0.666ms$ duration. With a voice source rate R_s of 8 Kbps, a packet is consisted of 80 information bits, to which a header of 27 bits is added. Assuming a FEC code rate equal to 0.42 a suitable BCH code is (255, 107, 22). With this choice the channel rate before coding R_{ch} of 107 Kbps increases to a channel rate R_{ec} of 255 Kbps after error coding. With a spreading factor equal to G_p of 15 the resulting chip rate of R_c of 3.8250 Mcps is very close to that proposed for UTRA FDD mode. Interleaving is not applied thus every packet has the same format and is separately error-coded. In the case of WWW traffic a packet burst of 80 information bits is assumed. Thus every datagram is segmented in a number of equal sized packets. Simulation parameters are depicted in Tables II and III.

Table II. Traffic parameters

Traffic	Variable	Symbol	Value
	Voice Source-Rate	R_s	8 Kbps
Voice:	Mean talkspurt duration	$D_{talkspurt}$	1 sec
	Mean silentgap duration	$D_{silentgap}$	1.35 sec
	Reading time	D_r	4 sec
	Calls per session	N_{pc}	5
WWW:	Datagrams per call	N_d	25
	Pareto parameters	a	1.1
		k	81.5
	Average bit rate	R_{UDD}	(8, 64, 144, 384) Kbps

Table III. System parameters

Variable	Symbol	Value
Frame duration	D_{frame}	10 msec
Slot duration	D_{slot}	666 μsec
Slots per frame	N_{slots}	15
BCH code		(255, 107, 27)
Channel Rate before Error coding	R_{ch}	107 Kbps
Channel Rate after Error coding	R_{ec}	255 Kbps
Chip Rate	R_c	3.825 Mcps
Dropping Delay Threshold	D_{max}	20 msec

5.2. HAPs - Single MacroCell-Voice Users

In Figure 10 P_{loss} values are reported as a function of M for different channel access functions (CAF1, CAF2, CAF3) as they are depicted in Figure 7. A single macrocell HAP system is assumed. According to section 2.1 the maximum number of simultaneous transmitted packets K_{max} has been taken equal to 10. For all these cases the system cannot support more than 320 simultaneous conversations for a P_{loss} of 1%. As it is shown in Figure 7 the average of all CAFs has also been calculated. For the next results this averaged CAF is used to calculate voice permission probabilities. The impact of acknowledgement delay plays an important role when designing a HAP single macrocell system.

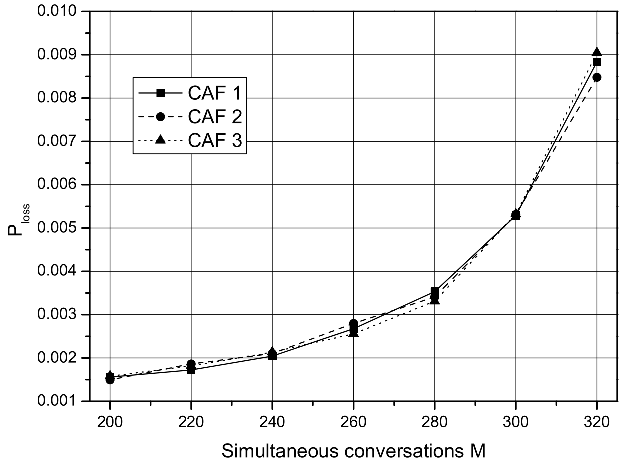

Figure 10. P_{loss} as a function of M for different channel access function in a single cell environment

In [2] it was shown that the maximum distance traversed by a signal is 517 Km (one way) for a platform at 21 Km. This means that a user will be informed about the outcome of a packet transmission after 3.5 ms or after almost 6 slots. Thus a mobile user, which has sent a packet in contention mode in a particular time slot, will not be allowed to contend again in the next s time slot (6 slots for the worst case where a mobile users is located at the maximum distance from the HAP), regardless if there are available slots in this time period. In Figure 11 the impact of acknowledgement delay s, is studied. While s increases, voice-dropping probability also increases. A mobile user waits the outcome of the transmission for s slots. In a negative response it must re-transmit the packet, thus increasing the possibility to discard it due to delay constraints for voice traffic (refer to section 4). For the results in Figure 11 it was further assumed the use of end-of-use flags, to prevent reservation cancellations. Figure 12 indicates the performance of CDMA/PRMA protocol using CAFs with and without end-of-use flags and furthermore immediate acknowledgement has been assumed ($s = 0$). In the first case where reservation cancellations are avoided (with end-of-use flags) P_{loss} is much lower even in heavy loads whilst when reservation cancellation occurs (no end-of-use flags), the maximum number of M with a tolerable P_{loss} is much lower compared to the first case.

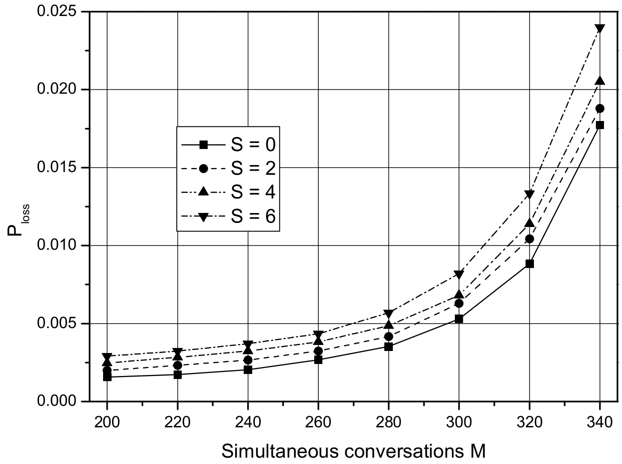

Figure 11. Impact of acknowledgement delay in a HAP system

5.3. HAPs - Multiple Cell-Voice Users

Figure 13 shows P_{loss} as a function of simultaneous conversations for four different cases. A single cell HAP system, a cellular HAP system with 4 tiers and $f = 0.155$, and two terrestrial systems with $f = 0.33$ (without shadowing) and $f = 0.55$ (with shadowing). For all simulation results it was assumed that no reservation cancellation occurs (end-of-use flags). Furthermore the acknowledgement delay was taken equal to zero ($s = 0$). The reduced performance is obvious in cellular cases, since the number of simultaneous transmitted packets in a time slot decreases as M increases. The performance in ground-based CDMA systems is even worst due to a higher other-cell interference factor.

5.4. HAPs - WWW Users

A fixed permission probability equal to 0.4 has been assumed for WWW users in the following results, since the aim was to examine the effect of the allocation cycle in WWW users performance. Figure 14 presents the variance of mean access delay for different number of WWW users. The first approach for simulation cycle has been implemented where a percentage of buffer status controls the reservation phase. A single HAP cell environment is considered, with immediate acknowledgement and no reservation cancellation. It is obvious that by increasing the percent of the allocation cycle, an increased access delay is obtained. This is reasonable since an increased reservation phase do not let contending

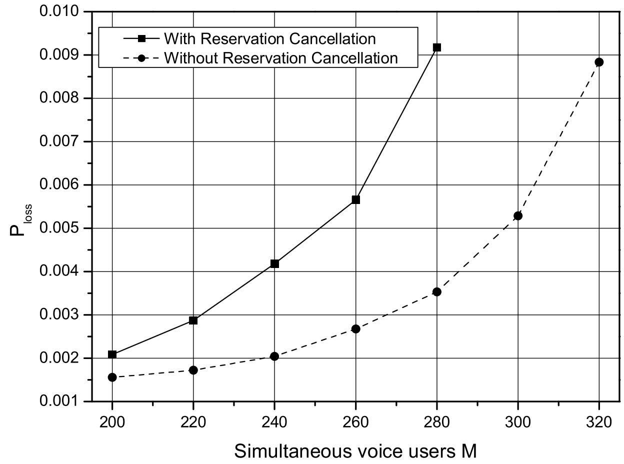

Figure 12. Impact of end-of-use flags in P_{loss}

users gain a reservation of a slot. In low load traffic we take quasi-similar results since the channel can serve many users in the same slot (max = 10 for a single cell constellation) and secondly the high value of the permission probability smooth the contention mechanism. In Figure 15 simulation results are presented with an allocation cycle equal to a fixed number of bursts. As it was mentioned in section 3 the mean datagram size is equal to 480 bytes corresponding to 48 bursts of 80 bits. Taking an allocation cycle greater than 48 bursts we expect that the reservation phase for a datagram size close to the mean will last for the whole transmission of the datagram. Thus, such users do not have to re-contend to gain a reservation resulting in a reduced access delay. When the allocation cycle is increased the mean access delay is also increased since the reservation phase is too long and in heavy load it is difficult to find an idle slot. On the other hand, as it was shown in Figure 14 even in small datagrams only a percent of the buffer will be transmitted increasing the access delay since many attempts during the transmission of the datagram will occur. This first approach is more suitable in a mixed traffic, where voice packet loss is of greater importance than mean access delay for WWW traffic. Finally, Figure 16 present results for different average WWW bit rate (RUDD). As it was shown in equation (7), the average bit rate affects the interarrival time between datagrams. Increasing RUDD results in a decrease in the interarrival time. As a result datagrams arrive and are stored in buffer more frequently. This means that the buffer has almost always bursts

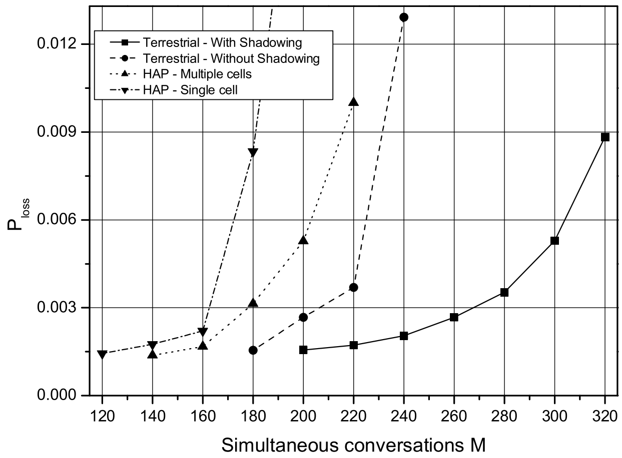

Figure 13. P_{loss} for different configuration as a function of M

for transmission. Applying an allocation cycle of 20% the re-contention attempts will be increased as the bit rate increases, resulting in larger mean access delay as it is shown below.

5.5. HAPS - Mixed Traffic Scenario

For the mixed voice-WWW traffic scenario fixed permission probabilities have been assumed equal to 0.6 and 0.2 for voice and WWW users respectively, with immediate acknowledgment and no reservation cancellation. The aim was to study the effect of WWW users in packet loss probability. In Figure 17 results are presented for different number of WWW users. For WWW users it is assumed an allocation cycle equal to 20% of the buffer status when a new trial for contention begins. Furthermore a single cell HAP constellation is assumed meaning that a single slot cannot support more than 10 simultaneous transmitted packets/bursts (Figure 2). It is obvious that by increasing the number of WWW users a deterioration in packet loss probability is obtained since a harder contention mechanism takes place. The channel cannot support more than 250 simultaneous conversations for all cases. Comparing the results with those from Figure 10 there is a significant degradation in the protocol's performance. Finally, in Figure 18 we examine the effect of allocation cycle for WWW users in P_{loss} under a fixed number of WWW users equal to 50. The first approach has been considered where a percent of buffer status implements the allocation cycle. From

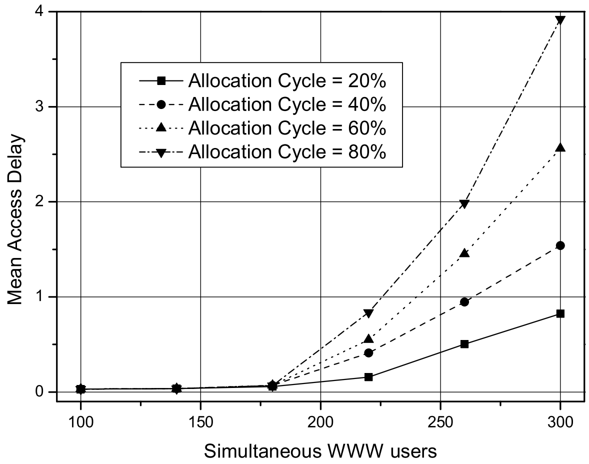

Figure 14. Mean access delay as a function of simultaneous WWW Users and different percentage of the allocation cycle

the results it is observed that as the allocation cycle increases, thus the reservation phase for WWW users also increases, P_{loss} decreases. Voice users cannot be served since there are no idle slots and the number of dropped packets increases due to delay constraints.

6. Conclusions

In this work the performance of a CDMA/PRMA access protocol was studied for a IMT-2000 HAP system. For simulation results two different traffic scenarios, voice and web browsing, have been taken into consideration. For voice traffic the impact of acknowledgement delay that is of much more interest due to delay constraints has been studied. Furthermore, the performance of the protocol is examined in both cellular and single cell environments and it is compared to a that of a ground based system. Due to a lower interference factor compared to a terrestrial system, in a HAP system an increased capacity has been observed. Assuming that users with reservation do not suffer from excess interference it was shown that the protocol has a good performance even in heavy loads. For WWW users different scenarios of allocation cycle have been studied since its value affects the reservation phase, which in turn in a mixed traffic scenario affects the delay sensitive voice traffic. Furthermore the impact on the mean access delay for WWW users of higher bit rate has been examined as well. Finally the performance of the protocol in a mixed traffic scenario has been studied through simulation and especially the variance of packet loss probability for voice traffic when the number of web users and the allocation cycle is increased.

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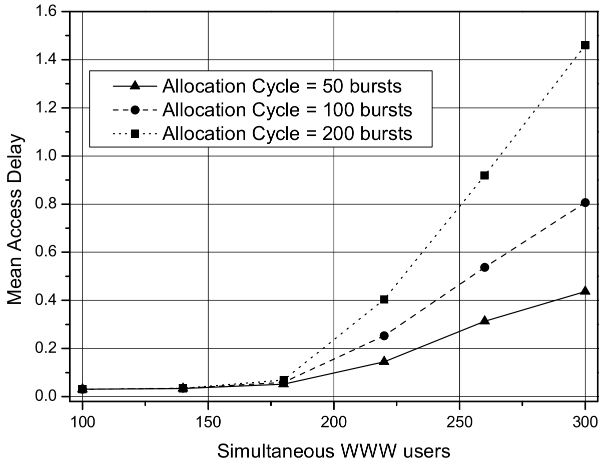

Figure 15. Mean access delay as a function of simultaneous WWW Users and fixed allocation cycle

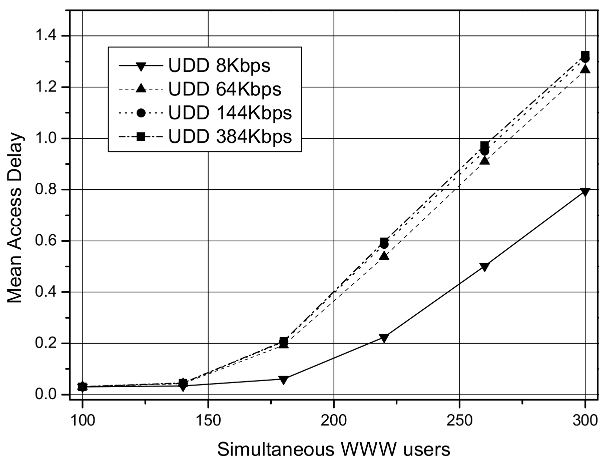

Figure 16. Mean access delay as a function of simultaneous WWW Users in different average bit rates

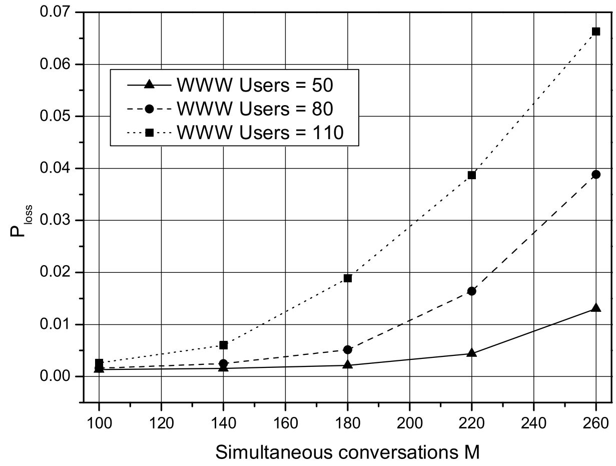

Figure 17. P_{loss} as a function of simultaneous conversations M with different number of web users

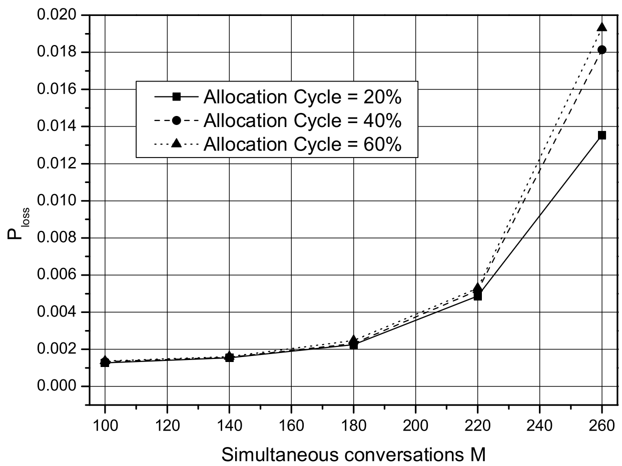

Figure 18. P_{loss} as a function of simultaneous conversations M with fixed number of web users and varying allocation cycle