CDMA and PRMA Analytical Models for Voice Users in Satellite-UMTS Systems

Abbas Ibrahim and Samir Tohme
Ecole Nationale Supérieure des Télécommunications, Department: InjRes,
46 Rue Barrault 75013 Paris France,

abbas.ibrahim@enst.fr Tel: 01 45 81 75 52, samir.tohme@enst.fr Tel: 01 45 81 78 61

Key words: satellite-UMTS, LEO, MAC, PRMA, CDMA

Abstract: The third generation UMTS (Universal Mobile Telecommunication System) provides worldwide multimedia wireless services in a host of environments encompassing indoor picocells to satellite megacells. The UMTS and Satellite-UMTS consists of two modes, a frequency division duplex (FDD) mode and a time division duplex (TDD) mode. The agreement recommends the use of Wideband Code Division Multiple access (WCDMA) for FDD and Time Division-Code Division Multiple Access (TD-CDMA) for TDD mode. In this article two MAC (Medium Access Control) protocols are compared analytically and by simulation for LEO (Low Earth Orbit) satellite used in UMTS. The goal of this comparison is to choose the protocol that benefits from efficient statistical multiplexing on the large common pool of available resources.

1. INTRODUCTION

Over the last decade digital cellular networks made mobile voice communication accessible to almost anyone. This has been possible thanks to early agreement on a common standard. To complement current terrestrial cellular networks, several systems based on low/mid earth orbit (LEO/MEO) constellations operating at the LIS-band have or are being deployed to provide global mobile satellite personal communications (GMPS or S-PCN).

Mobile multimedia services are therefore expected to be in high demand by mobile wireless users on a global scale. While second generation digital cellular networks can already cope with a large variety of requirements, the inherent bandwidth limitations make these networks less suitable for high speed applications [2]. One of the major service objectives set by European Telecommunications Standards Institute (ETSI) and International Telecommunication Union (ITU) is Integration with the satellite component. The S-UMTS component will make outdoor coverage globally seamless while maintaining terminal compatibility and service portability. More specifically, the S-UMTS component's major objectives are:

- To enable global roaming of UMTS users.
- To provide quality of service (QoS) commensurate with that of terrestrial at an affordable cost.
- To provide rapid and cost-effective deployment of UMTS services over large geographical regions and to augment the development of telecommunication services in developing countries.

Comparison among possible orbital solutions (GEO, HEO, MEO, and LEO) has been presented and discussed in the framework of many studies dealing with terrestrial and satellite integration [4]. Most studies opted for a LEO or MEO satellites configuration.

This paper is concerned with some medium access control (MAC) strategies suitable for multimedia packet type traffic. These MAC strategies are CDMA [5] and PRMA [9]. So we define first PRMA and CDMA and we describe how these protocols can be used in satellite-UMTS systems. We compare then these methods in the case of voice sources with voice activity detection (VAD) and we choose parameters by analytical calculation and then by simulation.

2. S-UMTS NETWORK AND TERMINAL

Satellite is integrated in UMTS system by means of a special access network and special terminals like in Figure 1. The terminals may connect to both terrestrial and satellite access networks and perform handover between the two. The terminal must also have the capability to support more than one radio interface. The GRAN approach followed by ITU and ETSI separates the terminal into a radio technology independent part and a radio technology dependent part, the later giving the flexibility to adapt to different air interfaces as the radio interface technology evolves [12].

The complete integration of a satellite network with terrestrial cellular network is a system architecture challenge that requires solving problems at both the transmission and network levels. In [14], several levels of integration are presented; geographical integration, services integration, network integration, technique integration and system integration. In UMTS the system integration is used and the satellite is not seen as alternative routing able to support communications in areas not covered by the terrestrial system, but as a part of unique really integrated system. According to this solution, handover of calls in progress between terrestrial and satellite cells could be realized each time it becomes necessary due to partial channel occupancy, degradation of some links, and so on. Such an integrated system should have the same access technique for both satellite and terrestrial networks. The MAC protocol has to use this technique in each network and use the channel as efficiently as possible taking into account that a UMTS user will not accept to receive lower QoS in S-UMTS than in T-UMTS

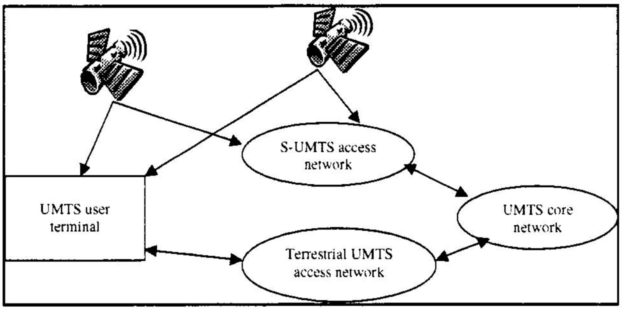

Figure 1. Terrestrial and satellite UMTS system

Two possible architecture scenarios can be imagined to integrate the satellite component in the UMTS access network. The first scenario sees the satellite acting as node B in the USRAN (UMTS Satellite Radio Access Network) [16] [17], while in the second, the space segment. consisting of one or more satellites, supports the dual functionality node B and RNC (Radio Network Controller) [15].

3. MAC PROTOCOLS

From a MAC layer point of view, resources may be allocated using circuit switching or packet switching. Packet switching allows for statistical multiplexing of bursty sources such as multimedia traffic sources and packetized voice when applying voice activity detection (VAD). The amount of bursty multimedia traffic is expected to increase significantly in the near future. Therefore, packet switching appears to be the access strategy of choice of third generation systems, with circuit switching to be supported optionally for the provision of some constant bit rate services or very high-quality voice transmission.

In this paper speech sources with voice activity detection are used. The source is constituted of two phases; a talkspurt phase where it sends with constant rate and a silent phase where it stops sending. The terminal transits from one phase to another following a Markov process.

However, it is important to note that mobility management does not pose significant problems with the MAC layer. As soon as UT with call in progress in cell *A* enters an adjacent cell *B,* a handoff procedure is started. This situation may be considered as a UT starting a talkspurt in cell *B*.
The MAC protocols to be compared use packet switching access strategy, these protocols are CDMA and PRMA.

3.1 CDMA

The CDMA access protocol, presented in the end of this paragraph, is a basic one that uses the CDMA technique. In this work, the CDMA/DS (Code Division Multiple Access / Direct Sequence) technique is used with different frequencies in the neighboring cells (spot beams) [10]. A direct sequence code with a very high rate will be added to the original signal as a signature of the transmitter. The receiver will be able to decode this signature and understand the message. By using different frequency bands in neighboring cells the inter-cell interference problem [5] is resolved.

In [11], it is assumed that the performance of a CDMA system is dominated by the bit error ratio (BER) performance and problems related to packet acquisition are ignored. A widely used approximation to determine the BER performance on the CDMA channel is the standard Gaussian approximation (SGA). Assuming that the MAI (Multiple Access Interference) is Gaussian and using simple correlation receivers, the BER or probability of bit error Pe can be obtained from

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

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

We consider random direct sequences ($\Pr\{x_j = 1\} = \Pr\{x_j = -1\} = 0.5$) where, x_j is a chip of direct sequence with an arbitrary odd codelength (or preading factor) *sf.* The average signal to noise ratio (SNR) for the ith packet in the case of unequal power reception can be written as

$$\overline{SNR} = \sqrt{\frac{P_i}{(3\times sf)^{-1}\sum_{\substack{k=1\\k\neq i}}^{K} P_k + \frac{N_0}{2T}}} \tag{3}$$

A system with K simultaneous transmitters is considered with received power levels P_j where (j = 1, 2, ..,k), data bit duration T and two-sided spectral density of additive white Gaussian noise $N_0/2$.

In our system no intercell interference will exist because different frequencies are used in neighboring cells. Supposing a perfect power control in the cell, the signal emitted by every transmitter is received by the satellite with P_0 power level, if we neglect N_0 [5]

$$\overline{SNR} = \sqrt{\frac{P_0}{\frac{(K-1)P_0}{3\times sf}}} = \sqrt{\frac{3\times sf}{K-1}}\,. \tag{4}$$

Assuming that packets with length L bits are transmitted over a memory-less binary symmetric communication channel with average probability of data bit success $(Q_e = 1 - P_e)$ and employing a block code, which can correct up to t errors, the packet success probability Q_E can be derived from

$$Q_E(K) = \sum_{i=0}^{t} C_L^i (1-Q_e)^i (Q_e)^{L-i} \tag{5}$$

And by defining a minor limit of the probability of success we can deduce the maximum number of codes that can be used simultaneously nc, (simultaneous users that can use the channel). Notice that a code is assigned to each user accepted by the CAC function (the number of available codes is higher than the number of codes that can be used simultaneously).

The access protocol is then as follows. When a talkspurt begins, the terminal contends by sending a packet on his assigned code and continues sending during the talkspurt.

3.2 PRMA

In conventional PRMA [9], U time slots of fixed length are grouped into frames. These slots are either available for contention (C slots) or reserved for information transfer of a particular terminal (I slots), as indicated by the base station BS. When a packet spurt arrives at a terminal, it will switch from idle to contention mode, try to obtain permission to send a packet on the next available C slot by carrying out a Bernoulli experiment with some permission probability P_x, and in the case of positive outcome, transmit the first packet of the spurt. If this packet is received correctly by the BS, it will send an acknowledgement, which implies a reservation of the same slot in the subsequent frames for the remainder of the spurt. In the case of negative outcome of the random experiment or a collision on the channel with another contending terminal, the contention procedure is repeated with the next packet in the spurt. As packet dropping will cause deterioration of the perceived quality of voice, some maximum admissible packet dropping will normally have to be specified.

In order to use the PRMA protocol, we must consider the time needed to know the outcome of a reservation attempt during the contention phase (round trip delay RTD). In MSS (Mobile Satellite System) this time is much greater than in terrestrial cellular systems. And it is not negligible with respect to the frame duration. The UT stops contending when it is waiting for the result of transmission attempt; this information is received from the satellite after an RTD time. This fact will make the use of PRMA in LEO systems unpractical because RTD is in the order of 20ms as will be demonstrated in 4.2.

4. ANALYTICAL MODELS FOR MAC PROTOCOLS

This paper uses an *on-off* speech model. A speech source creates patterns of talkspurts and gaps, as classified by speech activity detector. There are spurts and gaps related to the talking, pausing and listening patterns of a conversation. The speech activity detector is modeled as a two-state Markov process (Figure 2). The probability that a talkspurt with mean duration t_{on} *s* ends on a time τ is:

$$\sigma = 1-\exp(-\tau/t_{on}) \tag{6}$$

This is the probability of a transition from the talking state to the silent state. Corresponding, the probability that a silent gap, of mean duration t_{off} *s* ends during a τ *s* time is:

$$\gamma = 1-\exp(-\tau/t_{off}) \tag{7}$$

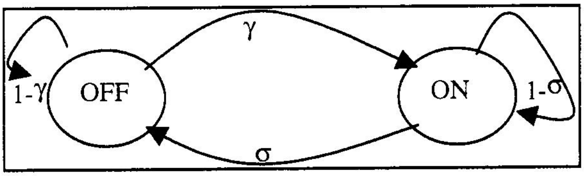

Figure 2 The speech model

We define the probability that a user is in the *on* state as follows:

$$\pi_{\mathrm{on}} = t_{\mathrm{on}} / (t_{\mathrm{on}} + t_{\mathrm{off}}) \tag{8}$$

The probability that a user is in the *off* state is:

$$\pi_{\mathrm{off}} = t_{\mathrm{off}} / (t_{\mathrm{on}} + t_{\mathrm{off}}) \tag{9}$$

4.1 CDMA

Let m be the total number of sources. Y_n the number of codes used in frame n (it is also the state of a user sending with $Y_n - 1$ others), Y_{n+1} the number of codes used in frame $n + 1$. We have then $Y_{n+1} = Y_n +$ (input users from m-Y_n *off* users) - (output users from Y_n *on* users).

The number of input users is independent of the number of codes before Y_n and so of the number of output users. This is due also to the fact that the *on-off* is exponential distributed without memory. Y_n is then a Markov chain, supposed homogeneous.

The transition matrix is defined by probabilities that the number of codes used simultaneously pass from x to y, this probability can be calculated like this:

$$\begin{aligned} P_{xy} &= \Pr\{Y_{n+1} = y | Y_n = x\} = \Pr\{Y_n + NI_i - NI_o = y | Y_n = x\} = \\ &\Pr\{x + NI_i - NI_o = y | Y_n = x\} = \\ &\sum_a \Pr\{(NI_i = a | Y_n = x) \quad \cap \quad (NI_o = a - y + x | Y_n = x)\} \end{aligned} \tag{10}$$

Nl_i and NI_o are the number of input and output users during the frame *n,* respectively.

$$
\begin{aligned}
x \geq y \qquad & P_{xy} = \sum_{a=0}^{y} \Pr\{NI_i = a | Y_n = x\} \times \Pr\{NI_o = a - y + x | Y_n = x\} \\
x < y \qquad & P_{xy} = \sum_{a=y-x}^{y} \Pr\{NI_i = a | Y_n = x\} \times \Pr\{NI_o = a - y + x | Y_n = x\}
\end{aligned}
\qquad (11)
$$

If τ used in (6) and (7) is the frame time ($\tau = T_f$) we have:

$$\Pr\{NI_i = a | Y_n = x\} = C_{m-x}^{a} \gamma^{a} \times (1-\gamma)^{m-x-a} \qquad (12)$$

$$\Pr\{NI_o = a - y + x | Y_n = x\} = C_{x}^{a-y=x} \sigma^{a-y+x} \times (1-\sigma)^{y-a} \qquad (13)$$

Where C_x^y is the binomial distribution of y on x

By this calculation we obtain the matrix $P = \lfloor P_{xy} \rfloor_{\substack{0 \leq x \leq m \\ 0 \leq y \leq m}}$ (14)

$$\pi \times P = \pi$$

And we calculate the steady state π by the system: $\sum_{k} \pi_k = 1$ (15)

π_k is the probability that there is *k on* voice users in the steady state (the probability that a user is in state *k* where it sends with *k* -1 others). We have then to calculate the error probability in the steady state. From equation (5) we obtain the probability of success, the error probability when *k* users are *on* is given by ($1-Q_E(k)$). The loss probability in the steady state is:

$$P_{loss} = \sum_{k=0}^{m} \pi_k \times (1 - Q_E(k)) \qquad (16)$$

P_{loss} is the significant QoS parameter, it depends on *m* which is the number of users accepted by the CAC (Connection Admission Control) function.

4.2 PRMA

The PRMA analytical model is studied in [13] for terrestrial system. The Markov chain described in [13] is not valid for the satellite system. The reason is the increased response waiting time due to RTD which is comparable to the maximum packet voice waiting time D. If n is the number of slots in a frame, m is the number of accepted users by the CAC function and p is the permission probability. Let R_i be the user reservation of the ith slot state. C the user contention state. A_i the state where a user succeeded a contention and will receive a positive response in i slots (positive wait state). A'_i the state where a user did not succeed in his contention and will receive a negative response in i slots (negative wait state). Suppose that RTD = $T_f - T_s$, the Markov chain is as follows:

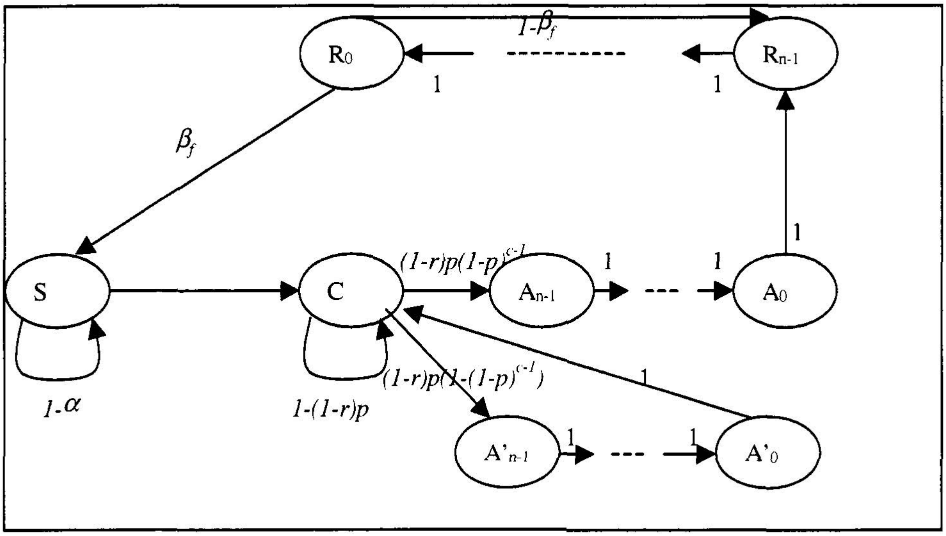

Figure 3. PRMA satellite Markov chain

if X is a defined state (X is also the number of users in this state), x represents its equilibrium value (see [13] for details about equilibrium values).

$$\beta = 1 - \exp(-T_s / t_{on}) \qquad (17),$$

$$\alpha = 1 - \exp(-T_s / t_{off}) \qquad (18)$$

β_f is the probability that after n slots a user finish a talspurt;

$$\beta_f = 1 - (1 - \beta)^n \approx n\,\beta. \qquad (19)$$

Equilibrium values can be calculated by equations system derived from Figure 3:

$$r_0 = r_1 = \dots\dots\dots\dots = r_{n-1} = r. \tag{20}$$

$$a_0 = a_1 = \dots\dots\dots\dots = a_{n-1} = a. \tag{21}$$

$$a'_0 = a'_1 = \dots\dots\dots\dots = a'_{n-1} = a'. \tag{22}$$

$$r\,\beta_f = s\,\alpha. \tag{23}$$

$$r(1-\beta_f) + a = r. \tag{24}$$

$$c\,(1-r)\,p\,(1-u) = a'. \tag{25}$$

$$c\,(1-r)\,p\,u = a. \tag{26}$$

$$s + c + n\,a + n\,a' + n\,r = m. \tag{27}$$

Let *R* represents the number of users in reservation state and *C* the number of users in contention state
The probability that a terminal in contention gains a reservation in the current slot is

$$v = (1 - R/n)\,p\,(1-p)^{c}, \tag{28}$$

the probability that it does not contend in the current slot is:

$$\mu = 1 - (1 - R/n)\,p, \tag{29}$$

the probability that it contends but a collision occurs is

$$\theta = (1 - R/n)\,p\,(1 - (1-p)^{c}). \tag{30}$$

An arriving packet waits in the buffer until the user succeed in sending it, the packet wait time probability is more complicated in satellite system than

in terrestrial PRMA. A user in contention state can pass to positive wait state (equivalent to reservation), negative wait state or stay in contention state. When a user transits to negative wait state, he has to wait n time slots before returning to contention. This fact increases the wait time considerably.
The probability of waiting one time slot is v (user transits directly to A_i state = transmission successfully).
The probability of waiting two time slots is $v\ \mu$ (user waits in contention for one time slot then transmits successfully)
The probability of waiting n time slots is: $v\ \mu^{n-1}$ (stay $n-1$ time slots in contention state then transmits successfully).
The probability of waiting $n + 1$ time slots is: $v\ \mu^{n} + v\ \theta$ (stay n time slots in contention then transmits successfully or contends unsuccessfully then transmits successfully).
The probability of waiting $n + 2$ time slots is: $v\ \mu^{n+1} + 2\ \mu\ v\ \theta$ (stay $n + 1$ time slots in contention then transmits successfully or contends unsuccessfully then wait in contention one time slot then transmits successfully or wait in contention one time slot then contends unsuccessfully then transmits successfully). The factor 2 is due to the fact that the two events (contend unsuccessfully) and (wait in contention) can be ranged in two different manners.
The probability of waiting $2\ n + 2$ time slots is: $v\mu^{2\,n+1} + \mathrm{fa}(n+1,2)\ \mu^{n+1}\ v\ \theta + fa(1,3)\ \mu\ v\ \theta^2$ (stay $2\ n + 1$ time slots in contention then transmits successfully or contends unsuccessfully and wait in contention $n + 1$ time slot then transmits successfully or wait in contention one time slot and contends unsuccessfully twice then transmits successfully). The factor $\mathrm{fa}(x,y)$ is due to the fact that the events (contend unsuccessfully $y-1$ time) and (wait in contention x time) can be ranged in $fa(x,y)$ different manners.
We define $fa(x,y)$ as the number of possible fashions to range x white balls and $y-1$ red balls $\Rightarrow fa(x,y) = C_{x+y-1}^{x}$
The probability that a user waits $k\ n + j$ ($k \geq 0$ and $j > 0$) slots before transition to reservation state is

$$
\begin{aligned}
p_{w}(k \times n + j) &= \upsilon \times \sum_{i=0}^{k} fa\left[(k-i) \times n + j - 1, i + 1\right] \times \mu^{(k-i)\times n + j - 1} \times \theta^{i} \\
p_{w}(k \times n + j) &= \upsilon \times \sum_{i=0}^{k} C_{(k-i)\times n + j + i - 1}^{(k-i)\times n + j - 1} \times \mu^{(k-i)\times n + j - 1} \times \theta^{i}
\end{aligned}
\qquad (31)
$$

The probability that k packets are dropped when the talkspurt contains L packets is:

$$\Pr(n_{drop} = k|L) = \begin{cases} \sum_{x=D+(L-1)\times n+1}^{\infty} p_w(x), & k = L \\ \sum_{x=D+(k-1)\times n+1}^{D+k\times n} p_w(x), & k \neq 0, L \\ \sum_{x=1}^{D} p_w(x), & k = 0 \end{cases} \tag{32}$$

And using the equation: Pr (talksurt = L) = $\beta_f (1- \beta_f)^{L-1}$ (33)

The drop probability due to a collision or to unacceptable waiting time is:

$$p_{drop}(\upsilon,\theta,\mu) = \beta_f \times E(n_{drop}), \quad 1/\beta_f = \overline{talkspurt}$$
$$where \quad E(n_{drop}) = \sum_{L=0}^{\infty} \Pr(L) \times E(n_{drop}|L) \quad and \tag{34}$$
$$E(n_{drop}|L) = \sum_{k=0}^{L} k \times \Pr(n_{drop} = k|L)$$

We have then to calculate the distribution of users in reservation and in contention states:

$$\theta_R(R) = C_n^R r^R (1-r)^{n-R}$$
$$\theta_C(C|R) = \begin{cases} p_0(1-p_0)^C, & C < m-R \\ (1-p_0)^{m-R}, & C = m-R \\ 0, & otherwise \end{cases} \quad , \quad p_0 = \frac{1}{c+1} \tag{35}$$

The loss probability is:

$$= \sum_{R=0}^{n-1} \sum_{C=0}^{m-R} \theta_R(R)\theta_C(C|R)P_{drop}(\upsilon,\theta,\mu). \tag{36}$$

5. ANALYTICAL AND SIMULATION RESULTS

In this section analytical results derived from equations are computed using Matlab. We first draw the probability of the number of active users for three cases of CAC accepted users in CDMA. When the number is 140, the probability that active users are close to the threshold, calculated from equation 5 and equal to 80, is very low. On the contrary this probability is high when *m= 180.* The best choice is when *m=160.* This result can be seen clearly in Figure 7. In fact this leads to the choice of the maximal number of users accepted by the CAC function. This number describes the system capacity.

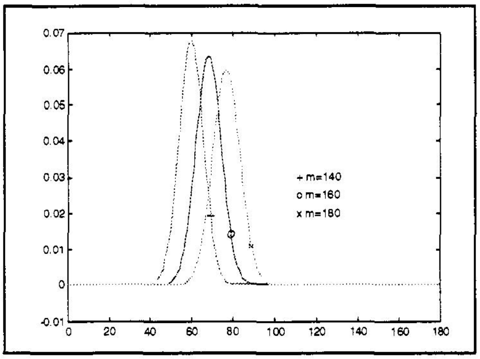

Figure 4. Probability of active users (CDMA)

We then study PRMA protocol in the LEO system. The frame contains 24 slots, so the voice rate is 8 Kbits/s and the channel bandwidth is 192 Kbits/s. We demonstrate by Figures 5 and 6 how PRMA loses its performance in satellite context. In Figure 5 when contentions take place the non-drop probability can be very high and unacceptable. This is the reason why in Figure 6 the loss probability is greater in satellite context and the multiplexing efficiency decreases considerably. PRMA protocol can work for satellite system but with decreasing efficiency. We can understand a reason for introducing a code factor (CDMA) in LEO systems and more generally in UMTS.

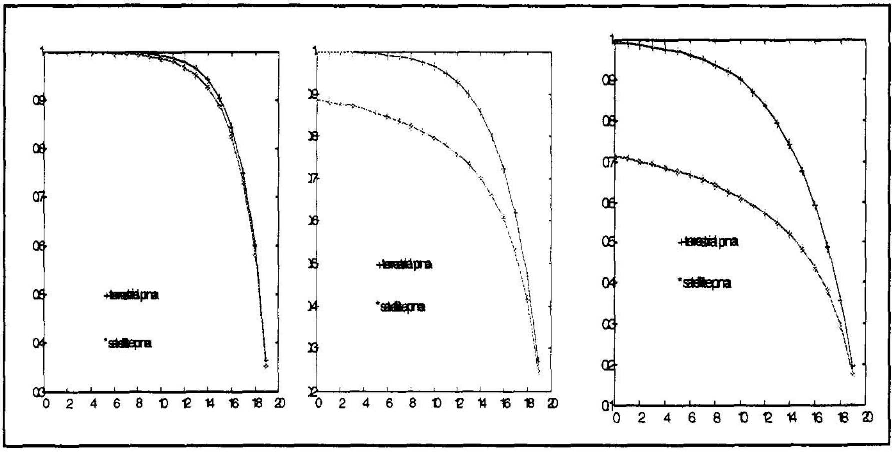

Figure 5. Terrestrial and satellite drop probability comparison in PRMA

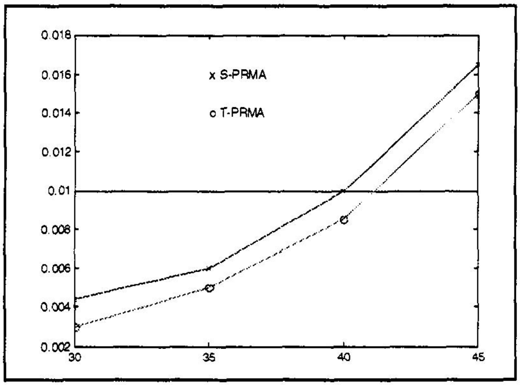

Figure 6. T-PRMA and S-PRMA loss probability comparison

In Figure 7 CDMA and PRMA protocols are compared analytically and by simulation. The simulation is done using NS (Network Simulator) with same parameters of analytical calculation. It is seen that PRMA has a very bad performance in LEO context. An important performance issue is the multiplexing efficiency relative to perfect statistical multiplexing. We define the multiplexing efficiency factor as: $\mu = M_{0.01} \times \delta / M$.

Where $M_{0.01}$ is the number of simultaneous conversations supported with a loss probability less than 0.01. δ is the voice activity factor given by $\delta = T_{ON} / (T_{ON} + T_{OFF}.)$ and M represents the maximum number of users in TD/CDMA case.

The multiplexing efficiency factor for PRMA is 130 / (2.35 * 80) = 0.7 and for CDMA 170 / (80 * 2.35) = 0.9.

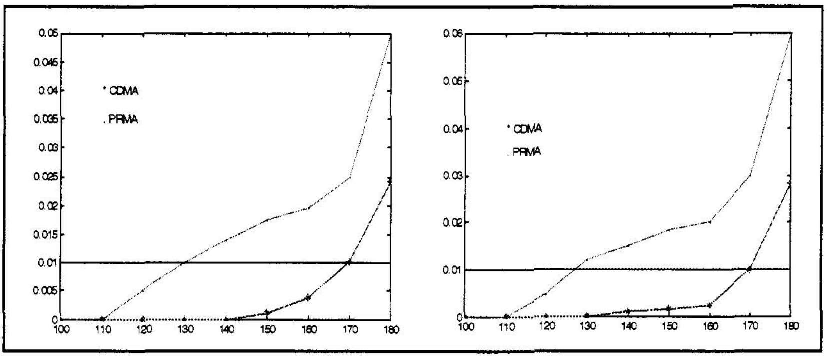

Figure 7. Protocols multiplexing efficiency comparison (analytical and simulation results, simultaneously)

6. CONCLUSIONS AND FUTURE WORK

In this paper we studied two access protocols in the context of S-UMTS where a LEO (Low Earth Orbit) satellite network will probably be used. These protocols are CDMA and PRMA. An analytical model and computation is presented for each one in order to compare these protocols and to determine the parameters that influence the efficiency of each one. It is shown that CDMA has the maximum multiplexing efficiency and so maximizes the capacity of the system. Notice that the study is for one type of traffic source and integrating services in CDMA is not evident and can degrade the total capacity of the channel [7]. On the contrary in PRMA integrating services is on the time scale to separate the influence of one class on the other. Finally simulations are done using NS, these simulations give results close to analytical computations, and this demonstrates the validity of the proposed models. By simulation we can next study integrated services in each case with more complicated traffic sources

REFERENCES

[1] Alex E. Brand and Hamid Aghvami, “Multidimensional PRMA with Prioritized Bayesian Broadcast – A MAC strategy for Multiservice traffic over UMTS,” IEEE trans. On Vehicular Technologies, November 1998.

[2] Payam Taaghol, Enrico Burachini, Riccardo De Gaudenzi, Gennaro Gallinaro, Joon Ho Lee, Chung Gu Kang "Satellite UMTS/IMT2000 W-CDMA Air Interfaces," IEEE Communications Magazine, september 1999.

[3] Philippe Godlewski, Xavier Lagrange and Sami Tabbane "Réseaux GSM-DCS" HERMES 1997.

[4] Integrated Satellite-UMTS Real Environment Demonstrator. final reports of the project http://www.infowin.org/ACTS/RUS/PROJECTS/FINAL-REPORTS/fr-229

[5] Andrew J. Viterbi "Principles of Spread Spectrum Communication" Addison-Wesley Wireless Communications Series 1995.

[6] Abbas Ibrahim and Samir Tohme, "A Modified CDMA/PRMA Medium Access Control Protocol for Voice Users in LEO Systems,'' in PWC2000 Gdansk Poland.

[7] Abbas Ibrahim and Samir Tohme, " A Modified CDMA/PRMA Medium Access Control Protocol for Integrated Services in LEO Satellite Systems" Mobicom2000 August 6-1 1, 2000 Boston, Massachusetts.

[8] Alexander Guntsch, Mohamed Ibnkala, Giacinto Losquadro, Michel Mazzella, Daniel Roviras, Andreas Timm, "EU's R&D Activities on Third Generation Mobile Satellite Systems (S-UMTS)" IEEE Communications Magazine. February 1998.

[9] D. J. Goodman, R. A. Valenzuela, K. T. Gayliard and B. Ramamurth "Packet Reservation Multiple Access for Local Wireless Communications," IEEE Trans. On Communications, August 1989.

[10] Fulvio Ananasso and Francesco Delli Priscolli, "The Role of Satellites in Personnal Communication Services" IEEE Journal on Selected Areas in Communications, February 1995.

[11] Alex E. Brand and A. Hamid Aghvami "Performance of a Joint CDMA/PRMA Protocol for Mixed Voice/Data Transmission for Third Generation Mobile Communication," IEEE Journal on Selected Areas in Communications, December 1996.

[12] Lars Lundheim, Erik Olsen, Isabel1 Buret "Reconfigurable Hardware for UMTS Prototypes and Terminals," SINUS (Satellite Integration Into Network UMTS System) project http://www.infowin.org/ACTS/RUS/PROJECTS/ac2 12.htm

[13] Sanjiv Nanda, David J. Goodman, Uzi Timor, "Performance of PRMA: A Packet Voice Protocol for Cellular Systems," IEEE Transactions On Vehicular Technology, August 1991.

[14] Enrico Del Re, "A Coordination Effort for The Definition of a Satellite Integrated Environment for Future Mobile Communications" IEEE Communications Magazine, February 1996.

[15] Heba Koraitim, Gunter Schafer, Samir Tohme. "Quality of Service Aspects of Transport Technologies for UMTS Radio Access Network" PWC2000 Gdansk, Poland.

[16] UMTS technical Specification 3G TS 25.21 1 V3.3.0 (2000-06).

[17] UMTS technical Specification 3G TS 23.002 V3.3.0 (2000-03).