Call Admission Control in Multiservice High Altitude Platform (HAP) W-CDMA Cellular Systems

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Abstract

Of the various radio resource management functions, in this paper we focus on call admission control (CAC). We propose a CAC scheme for multiservice High Altitude Platform (HAP) wideband code division multiple access (W-CDMA) cellular systems that caters for multimedia services. HAPs have known increasing popularity during the past few years and are expected to play a pivotal role in the telecommunications arena by virtue of their appealing features. We first study the uplink capacity of a multiservice HAP W-CDMA cellular system taking into consideration power control imperfections and evaluate the degradation that a new call induces in the quality of service of ongoing calls. Based on the obtained statistics, we then develop a CAC scheme that takes account of power control imperfections and user mobility and compare it to a CAC scheme that is based on instantaneous energy per bit to noise power spectral density ratio (E_b/N_0) measurements. Additionally, we examine these algorithms for two different criteria that apply to both new and handoff call requests. The first criterion is based on the minimum E_b/N_0 of the first tier cells, while the second bases its decision upon the mean E_b/N_0 of the cells of the first tier. Simulation studies further document and confirm the positive characteristics of the proposed CAC scheme.

Key words: Call admission control, W-CDMA, imperfect power control, HAP systems

1. Introduction

Within the past few years, a great deal of attention has been drawn towards platforms positioned in the stratosphere, often aptly dubbed High Altitude Platforms (HAPs). HAPs can be either airships or aircraft soaring in the stratosphere at an altitude between 17 and 22 km above the Earth's surface. With some of their outstanding features such as wide coverage area, low propagation delay and very favorable path-loss characteristics HAPs will indisputably be instrumental in future communications networks, providing a compelling spectrum of applications. For more details on HAPS, the reader is referred to [1], which provides a thorough survey on communications via HAPs.

HAPs constitute a real asset to wireless infrastructure operators to provide telecommunication services in rural, remote and impervious areas since it is rather difficult and economically inefficient to cover these areas with terrestrial cellular networks. Furthermore, the cost for the development of satellite systems is much greater and it may be economically more efficient to cover a large area with many HAPs rather than with a satellite system. HAPs are also tailored to applications limited in scope, for instance, they can be summoned to cover an one-time event like Olympic Games or to satisfy augmented seasonal

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communication demands as is the case with islands that are deluged with tourists in summer. Moreover, HAPs can also be integrated with terrestrial and satellite systems. The amalgamation of heterogeneous access networks can lead to a powerful hybrid network infrastructure that can make up for the weaknesses of each other.

In this paper we consider a stand alone HAP W-CDMA cellular system. Wideband code division multiple access (W-CDMA) has emerged as the mainstream air interface solution for the third generation (3G) networks and several treatises have addressed the merits of W-CDMA systems [2]. Its employment in HAP systems holds considerable appeal for 3G and beyond networks and ITU has specifically authorized the use of some IMT-2000 (3G) frequency bands by HAPs [3]. However, despite the vast literature on terrestrial CDMA cellular systems, there exists only a handful of studies on HAP CDMA systems.

Of the various radio resource management functions of a HAP W-CDMA system, in this paper we focus on call admission control (CAC). In this type of systems, the network capacity is limited by the uplink since the transmission onto this is asynchronous [4], [5], [6], [7]. Thus, in this work we restrict ourselves to CAC for the uplink of HAP W-CDMA systems, which is common practice for CDMA systems [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16]. The aim of CAC is to decide whether to accept or reject a new call. The call is admitted into the network provided that the QoS (quality of service) requirements of the new call are met and the QoS guarantees made upon the establishment of the existing calls are not breached.

In contrast to TDMA/FDMA systems, users in a CDMA system share the same portion of bandwidth at the same time and multiple access is achieved by assigning each user a pseudo-random code. In this respect, a new user can be admitted into the network as long as the signal-to-interference ratio (SIR) is adequate for processing at the receiver. Many studies have grappled with the critical issue of CAC, mainly for terrestrial networks. Notwithstanding, all of them were based on the assumption of perfect power control. In the uplink, power control is required to compensate for channel fading and eliminate the near-far problem by equalizing the powers of all users in a cell. Nonetheless, perfect power control is beyond the realms of possibility, and in real systems, power control errors cause variations in the power received by a base station, which in turn results in variations in the received energy per bit to noise power spectral density ratio (E_b/N_0) [17], [18], [19].

In this paper we propose and evaluate an SIR-based CAC scheme, tailored for the uplink of a HAP W-CDMA cellular system, that takes account of power control imperfections and user mobility. The proposed scheme can also be used in terrestrial W-CDMA cellular systems with slight modifications. The call admission decision is based on E_b/N_0 measurements. Our approach relies on the averaging of E_b/N_0 measurements over a period of time in order to eliminate the impact of errors due to power control impairments on the estimation of the system state and enhance network performance. In addition, the proposed algorithm caters for multimedia services by setting appropriate E_b/N_0 thresholds for both new and handoff calls of each service class. Moreover, we compare it to a scheme that is based on instantaneous E_b/N_0 measurements.

The rest of the paper is structured as follows. A succinct review on CAC schemes for CDMA cellular systems is given in section 2. Section 3 contains the delineation of the proposed scheme, dealing also with implementation issues. In section 4 simulation results are presented and discussed, while concluding remarks are drawn in section 5.

2. Review of CAC schemes

As befits such an important issue, CAC algorithms have been the subject of extensive research. This section constitutes a concise review on CAC schemes for CDMA cellular systems, highlighting their salient features. Most of these schemes have been proposed for terrestrial systems, however, they can be applied to HAP systems as well. The studies are referenced on a time-line basis, identifying seminal works on the one hand, and works that primarily extended previous works on the other hand.

In [5], two SIR-based CAC algorithms were proposed for networks that support only voice service. Both techniques were predicated upon the notion of residual capacity. The residual capacity is derived from SIR measurements and is defined as the additional number of new calls that the base station can accept so that the outage probability of ongoing calls is still below a predefined threshold. The CAC decision of the first algorithm is based only on the SIR measurement of the candidate base station for serving the call. The second algorithm differs from the first one in the sense that, except for the SIR measurement at the local base station, the CAC algorithm also takes into account the SIR measurements of adjacent cells. In order to estimate the impact of a new call on ongoing calls in adjacent cells the adjacent cell interference coupling coefficient β was introduced, which is the normalized interference that a new call causes to an adjacent base station. Kim *et al* extended the previous work and proposed a new algorithm that aims to predict the additional intercell interference that a new call will induce in adjacent base stations [8]. All the aforementioned techniques were examined for both homogeneous cell loading and hot spot loading under the assumption of perfect power control. It must also be noted that the mobility of users and call handover were not modeled.

In [6], [7], an adaptive channel assignment scheme was proposed, based on interference measurements rather than SIR measurements. The algorithm was evaluated for a fixed number of users in neighboring cells, while the impact of a new call on ongoing calls in adjacent cells was not considered. Tugcu *et al* extended that scheme and proposed a scheme that adaptively adjusts the number of guard channels in each cell [9]. This scheme requires the location, the speed and the direction of the user to be known. Both algorithms were evaluated only for voice service and under the assumption of perfect power control.

The effect of power control imperfections on outage probability was investigated in [10]. It was shown that imperfect power control significantly degrades system performance. Furthermore, two CAC schemes were proposed which constitute extensions of the ones described in [5], [6]. These schemes were evaluated in a multiservice cellular CDMA system. However, in that set of experiments ideal power control was assumed.

In [20], a CAC technique tailored for CDMA systems that support multimedia services was proposed. The scheme is based on SIR measurements and gives priority to handoff calls over new calls. Additionally, it takes into account the traffic asymmetry between the uplink and the downlink. Upon the arrival of a new or a handoff call request, the base station estimates the mean E_b/N_0 for each service class if the call is accepted, and checks if it is over a predefined threshold (which is different for new and handoff calls). This scheme does not take into account the impact of admitting a new call on the QoS of ongoing calls in adjacent cells. Furthermore, the estimation of the resultant E_b/N_0 in a real system might be inaccurate due to power control imperfections.

An intelligent call admission control scheme was proposed in [11]. This scheme makes use of a fuzzy logic control and pipeline recurrent neural network techniques in order to decide on whether to accept or reject a call request. This scheme caters for different service classes.

A reservation-based CAC technique was proposed in [12]. According to this technique some portion of the system resources is reserved to cope with the intercell unbalanced traffic problem. This scheme was evaluated for fixed users, hence results regarding dropping probability were not provided. Methods for calculating the Erlang capacity of the uplink of a CDMA system were presented in [13]. The system was considered to serve both voice and data users. An adaptive power control scheme was employed for data users. According to this scheme, transmission from data users is suspended when these are in a bad channel condition.

A CAC scheme with an emphasis on reducing dropped calls was proposed in [21]. In order to prioritize handoff calls the concept of soft guard channel was introduced. The authors of that work considered a system that supports one type of service. Upon the arrival of a request, the effective load was calculated and compared to a fixed threshold which indicated the number of users that a cell can serve.

The study in [22] focused on a CAC scheme for both the uplink and downlink. The scheme takes account of the effect of mobility, coverage and wired link capacity for the uplink. However, it does not take into consideration power control imperfections. Regarding downlink, the main constraint is posed by the maximum power that a base station can emit.

A CAC algorithm that incorporates a bandwidth degradation scheme was described in [23]. The authors of that paper considered a UMTS network that serves constant bit rate video users. Two user profiles were assumed. According to the proposed technique, the bandwidth of low profile users is temporarily reduced in order to admit more high priority calls. The technique was assessed under the assumption of perfect power control.

Foo *et al* proposed CAC schemes for HAP UMTS networks in [16] and [24]. In [16], uplink CAC schemes were proposed. The proposed schemes aimed to predict the increase that a new call will induce in the total received power of every base station. Nonetheless, the way that the increase in power was estimated accounts only for fixed users. The proposed schemes were also assumed to process sequentially calls originated in different cells. In [24] a downlink CAC scheme was proposed. The proposed scheme capitalizes upon the unique position of the HAP station in order to dynamically allocate power to each base station.

Interactive CAC methods represent another category of CAC techniques. Although these schemes have been initially proposed for TDMA and FDMA systems, they are also suitable for cellular CDMA systems. In these schemes a user is permitted to interact with the network before the final decision is taken. Interactive power-controlled admission algorithms were proposed in [14] and [15]. In [14] the transmission power of each terminal is controlled by a distributed constrained power control algorithm. When a new call arrives, active transmitters adjust their power in order to maintain their Carrier to Interference ratio. The call is accepted as long as a new effective power vector is obtained. The shortcomings of this technique are the increased signaling overhead and the relatively high convergence time which render it impractical. Two algorithms that aim to improve the admission time and curtail the network coordination cost were proposed in [15]. The first one is a coordinated method that requires measurements to be exchanged among base stations, while the second one is a distributed method that diminishes signaling overhead.

3. Proposed CAC scheme

3.1. *Motivation*

As mentioned in the previous section, all the CAC schemes that have been proposed in the literature do not take account of power control imperfections. According to those studies, the power received by the base station from a user is constant and equal to the one from any other user. Nevertheless, in practice, impairments in the power control loop result in variations in the received power, which in turn lead to variations in the received E_b/N_0, and exacerbate network performance [4], [10], [25].

Due to the fact that CDMA systems are interference limited rather than capacity limited, the bulk of the proposed uplink CAC schemes is based on instantaneous SIR measurements (which also refer to E_b/N_0 measurements). SIR is one of the most crucial QoS parameters in any communications system. Concerning CDMA cellular systems, SIR measurements can enhance the performance of CAC algorithms by predicting the impact of a new call on the QoS of ongoing calls in either the same cell or adjacent cells. However, instantaneous SIR measurements cannot always reflect the current system state owing to power control errors. In the literature all the CAC schemes that are based on SIR measurements are evaluated under the assumption of perfect power control. Nonetheless, in a real system power control imperfections will beyond doubt aggravate the performance of these schemes.

Based on the above, it becomes evident that a CAC scheme that will take power control errors into account will provide significant gains; this has been the main drive behind this work. In this paper we propose a CAC scheme that is predicated upon the concept of averaging SIR measurements over a short time interval in order to diminish errors in the estimation of the mean SIR of ongoing calls. We assess this scheme in a multiservice HAP W-CDMA cellular system because this kind of systems are expected to play a multifaceted role in future telecommunications networks by virtue of their outstanding features. The most important advantages that HAP systems are endowed with are their easy and incremental deployment, flexibility/reconfigurability, low-cost operation, low propagation delay, high elevation angles, broad coverage area, broadcast/multicast capability, broadband capability and their ability to move around in emergency situations. However, it is also worth mentioning that the proposed scheme can also be employed in terrestrial CDMA systems with slight modifications.

3.2. *Design Parameters*

Before describing the CAC scheme in detail, we shall investigate the impact of a new call on E_b/N_0 and outage probability of ongoing calls. The obtained results will help us later to design the CAC scheme. Throughout in this study we consider a HAP located at an altitude of $20\,km$, using a multibeam phased array antenna whose pattern conforms to ITU recommendations [3] and is given by

$$G(\vartheta) = \begin{cases} 34.8 - 3\left(\dfrac{\vartheta}{1.57}\right)^2, & \text{for } 0^o \le \vartheta \le 4.53^o \\ 9.8, & \text{for } 4.53^o < \vartheta \le 5.87^o \\ 55.95 - 60\log(\vartheta), & \text{for } 5.87^o < \vartheta \le 37^o \\ -38.2, & \text{for } 37^o < \vartheta \le 90^o \end{cases} \quad (1)$$

while the radius of the cell is such that the gain at the edge of the cell be 10 dB below the maximum gain. In our study we examine two service classes which are presented in Table 1. These service classes have been specified by 3GPP (3^{rd} Generation Partnership Project) in [26],[27] and are considered as two of the service classes that HAPs are suitable for [4].Voice and data activity factors have not been modeled. Moreover, as far as the nominal received power of each type of service is concerned, i.e.,c the received power with ideal power control, it was obtained in a similar way to the one presented in [10], according to

Table 1
Service classes

	Class-1	*Class-2*
Information bitrate	12.2 kbps	64 kbps
Minimum required E_b/N_0	5 dB	2 dB
Power Factor	0 dB	4.2 dB
Typical applications	voice	interactive-data interactive-audio interactive-video

which the Power Factor, that is, the ratio of the nominal received power of a service class to the nominal received power of the lowest bitrate service class (namely *class-1*) is equal to

$$PowerFactor = \frac{E_{b_i} R_{b_i}}{E_{b_1} R_{b_1}} \tag{2}$$

where E_{b_i} and R_{b_i} are the energy per bit and bitrate of the i^{th} service class, whilst E_{b_1} and R_{b_1} are the energy per bit and bitrate of the *class-1* type of service.

First, the capacity of a HAP W-CDMA cellular system will be estimated with respect to outage probability both for perfect and for imperfect power control. In this study, the outage probability is defined as the probability that E_b/N_0 is smaller than the minimum required $(E_b/N_0)_{min}$. The latter values were taken from [28]. It should be pointed out that the minimum required energy per bit E_b for each service class is obtained by dividing the signal power by the service bitrate. Thereby, the minimum required $(E_b/N_0)_{min}$ of *class-2* type of service is smaller than the one of *class-1* type of service. Ample Monte Carlo simulations (the number of iterations was 2^{20}) proved that intercell interference stems from the first three tiers. Hence, in our study we simulated a reference cell located directly below the HAP and surrounded by three tiers of interfering cells. Albeit as the distance from the HAP increases the shape of the cells turns from circular into elliptical, in all our simulations we considered a hexagonal cellular layout, which constitutes a valid approximation for distances up to the fourth tier.

E_b/N_0 represents the quality of the uplink and is given by

$$\frac{E_b}{N_0} = \frac{W}{R_b} \frac{P_{c_i} e^{\alpha\theta_k}}{(1-\beta) I_{intra} + I_{inter} + n_{th}} \tag{3}$$

The nominator of the right-hand fraction expresses the power from a user that is received by a base station when power control impairments are taken into account. Power control imperfections have been reckoned to be log-normally distributed [17], [18], [19], [29], [30], therefore, the power received by a base station can be expressed as $P_{c_i} e^{\alpha\theta_k}$, where P_{c_i} denotes the nominal received power for a *class-i* user with ideal power control, α is equal to $ln(10)/10$ and θ_k is a zero-mean gaussian random variable with standard deviation σ_p, which accounts for variations of the received power in dB owing to power control imperfections. Furthermore, R_b is the information bitrate, W is the transmission bandwidth and is equal to 5 MHz in our study, I_{intra} is the intracell interference, that is, the interfering power stemming from users located in the same cell, I_{inter} is the intercell interference, namely the interfering power stemming from users located in neighboring cells, β denotes the efficiency of the base station Multiuser Detection (MUD) technique and n_{th} is the thermal noise power. The efficiency of MUD is defined as the percentage of I_{intra} that can be canceled by means of the MUD technique (in our study $\beta = 0$). In the rest of the paper we set $P_{c_1}/n_{th} = -1$ dB. It must also be noted that all interfering signals are affected with power control impairments with the same statistics as the desired signal.

I_{intra} can be expressed as

$$I_{intra} = \sum_{i=1}^{M_{1_0}} P_{c_1} e^{\alpha\theta_{k_i}} + \sum_{j=1}^{M_{2_0}} P_{c_2} e^{\alpha\theta_{k_j}} \tag{4}$$

where M_{1_0} is the number of *class-1* users in the reference cell, whereas M_{2_0} is the number of *class-2* users in the reference cell. Apparently, the power received from the desired user is not taken into account in this sum.

Before setting out the way I_{inter} is calculated, we should highlight a unique feature that HAP systems are endowed with. This is the very favorable path-loss characteristics. It can be said that HAP links undergo free space propagation at distances comparable to the ones of a terrestrial wireless system. Concerning a HAP cellular system, all base stations are located on the HAP within a distance of a few meters; therefore, the signal from a user traverses the same path toward all base stations. Thus, in contrast to terrestrial cellular systems where a user is connected to the base station toward which the radio path loss is minimum, which may not be the closest one owing to log-normal shadowing, in a HAP system a user is connected to the base station that illuminates the cell in which the user is located.

Hereinafter, when a parameter is expressed in dB, it will be in parentheses with a subscript dB appended. The signal power $(P_{R_{ji}})_{dB}$ received by the j^{th} base station BS_j from the i^{th} user within its coverage area can be expressed as

$$(P_{R_{ji}})_{dB} = (P_{T_i})_{dB} - (L_{ji})_{dB} + (G_{R_{ji}})_{dB} + (G_{T_{ji}})_{dB} \quad (5)$$

where $(P_{T_i})_{dB}$ is the user's transmission power, $(L_{ji})_{dB}$ denotes the losses due to free space attenuation and shadowing, while $(G_{R_{ji}})_{dB}$ and $(G_{T_{ji}})_{dB}$ are the gains of the receiving and transmitting antennas respectively, evaluated at the angle under which the i^{th} user is viewed from BS_j. The interfering power $(P_{R_{0i}})_{dB}$ that this user induces in base station BS_0 that illuminates the reference cell is

$$(P_{R_{0i}})_{dB} = (P_{T_i})_{dB} - (L_{0i})_{dB} + (G_{R_{0i}})_{dB} + (G_{T_{0i}})_{dB} \quad (6)$$

where $(L_{0i})_{dB}$ indicates the losses due to free space attenuation and shadowing, while $(G_{R_{0i}})_{dB}$ and $(G_{T_{0i}})_{dB}$ are the gains of the receiving and the transmitting antennas respectively, evaluated at the angle under which the i^{th} user is viewed from BS_0. However, the signal traverses the same path to both base stations, therefore, $(L_{ji})_{dB} = (L_{0i})_{dB}$ and $(G_{T_{ji}})_{dB} = (G_{T_{0i}})_{dB}$. By replacing $(G_{T_{0i}})_{dB}$ in eq. (6) with eq. (5) we result in

$$(P_{R_{0i}})_{dB} = (G_{R_{0i}})_{dB} - (G_{R_{ji}})_{dB} + (P_{R_{ji}})_{dB} \quad (7)$$

Considering that the power received by BS_j is $P_{c_i} e^{\alpha\theta_k}$, we obtain

$$P_{R_{0i}} = \frac{G_{R_{0i}}}{G_{R_{ji}}} P_{c_i} e^{\alpha\theta_{k_i}} \quad (8)$$

and therefore, concerning I_{inter} the following equation holds

$$I_{inter} = \sum_{j=1}^{K} \left\{ \sum_{i=1}^{M_{1_j}} \frac{G_{R_{0i}}}{G_{R_{ji}}} P_{c_1} e^{\alpha\theta_{k_{ji}}} + \sum_{l=1}^{M_{2_j}} \frac{G_{R_{0l}}}{G_{R_{jl}}} P_{c_2} e^{\alpha\theta_{k_{jl}}} \right\} \quad (9)$$

where K is the number of surrounding cells, M_{1_j} is the number of *class-1* users in the j^{th} cell and M_{2_j} is the number of *class-2* users in the j^{th} cell.

As regards the distribution of users, we assume that they are uniformly distributed inside each cell. Additionally, the number of users in each cell is Poisson distributed

$$p_n(n) = e^{-\lambda} \frac{\lambda^n}{n!} \quad (10)$$

where λ is the average number of users per cell [30]. According to this model, the number of users in a cell is statistically independent of the number of users in any other cell. This model is more realistic than the one that considers a fixed number of users per cell, since it accounts for instantaneous unequal cell loading while the average load is the same in each cell.

In Fig. 1 we present the admissible combinations of users for different thresholds of the outage probability (P_o) and for both perfect and imperfect power control. As far as imperfect power control is concerned, the standard deviation of the received power was set to $\sigma_{p_1} = 1$ dB for *class-1* users and $\sigma_{p_2} = 0.5$ dB for *class-2* users [4]. A greater value of σ_p was given to *class-1* users on the grounds that these users are characterized by higher mobility than *class-2* users. It should also be stressed that the axes represent the average number of users per cell. Apparently, there exist specific limits on the maximum number of users per service class that can exist in the system at the same time. The number of users of a service class changes linearly with respect to variations in the number of users of the other service class. Moreover, it is evident that the capacity is profoundly affected by impairments in the power control loop.

Fig. 2 depicts E_b/N_0 and P_o as a function of the average number of *class-1* users per cell, while the average number of *class-2* users per cell remains constant. In addition to Fig. 2, Fig. 3 illustrates E_b/N_0 and P_o as a function of the average number of *class-2* users per cell, while this time the average number of *class-1* users remains fixed. As it can be seen in the graphs that present P_o, albeit *class-2* users bring about a greater reduction in the mean E_b/N_0 of both service classes, the uplink capacity is limited by the QoS requirements of *class-1* users and not by those of *class-2* users. In other words, the outage probability of *class-1* users is always greater than the outage probability of *class-2* users.

In order to gain a deeper insight into the impact that a new call has on ongoing calls, in Fig. 4 we provide graphs that illustrate the effect of a new call on E_b/N_0 and P_o of ongoing calls when this call is admitted either into the same cell or into a neighboring cell of the first tier. In this set of experiments, the average number of users per cell was the same for all cells, whereas new users were added only to a specific cell. The outage probability of *class-2* users in adjacent cells is not depicted in this figure due to the fact that it is very low, on the order of 10^{-5}. It should be mentioned that the results presented in figures 1-4 were obtained through Monte Carlo simulations in order to eliminate statistical errors (the number of iterations was 2^{20} and different initial seeds were used in each iteration).

It can be perceived from Fig. 4 that among all the possible types of new calls, the impact of *class-2* new calls on ongoing calls in the same cell is preponderant. Specifically, a careful look at Fig. 4 manifests that a *class-2* new call brings about a reduction of about 0.20 dB in the mean E_b/N_0 of ongoing calls of both service classes in the same cell, while a *class-1* new call causes a reduction of roughly 0.08 dB. Moreover, it is worth noting that the effect of a new call on ongoing calls in a neighboring cell is fractional. In particular, it appears that both the mean E_b/N_0 and outage probability are hardly affected by the admission of new users into an adjacent cell. With this information at hand, we will now proceed to formulate a CAC scheme that will cater for both of these services and prioritize handoff calls requests over new call requests, since the dropping of a handoff call is generally considered more irksome than the blocking of a new call.

3.3. *Description of the scheme*

In this subsection we spell out the details of the proposed CAC scheme which capitalizes upon E_b/N_0 measurements. The proposed CAC scheme aims at taking into account both power control imperfections and user mobility. Additionally, it caters for multimedia services by setting appropriate E_b/N_0 thresholds both for new and for handoff calls of different service classes.

In the bulk of SIR-based CAC schemes, upon the arrival of a new call, the algorithm decides whether to accept or reject the call based on instantaneous SIR measurements. However, due to power control errors instantaneous measurements do not always accurately reflect the system state. Our approach consists in averaging E_b/N_0 measurements over time. E_b/N_0 measurements are taken in every frame for each user. However, consecutive measurements do hardly differ. In our algorithm mean values of the E_b/N_0 per service class and per cell, which are obtained by averaging the individual E_b/N_0 measurements out, are stored only every 0.25 *sec*. Therefore, for each cell two values are stored every 0.25 *sec*; one which represents the mean E_b/N_0 of *class-1* calls and another that is equal to the mean E_b/N_0 of *class-2* calls. Upon the arrival of a new or handoff call request these stored values are averaged out and compared to predefined thresholds. We also had to decide on the time interval over which these stored E_b/N_0 values would be averaged.

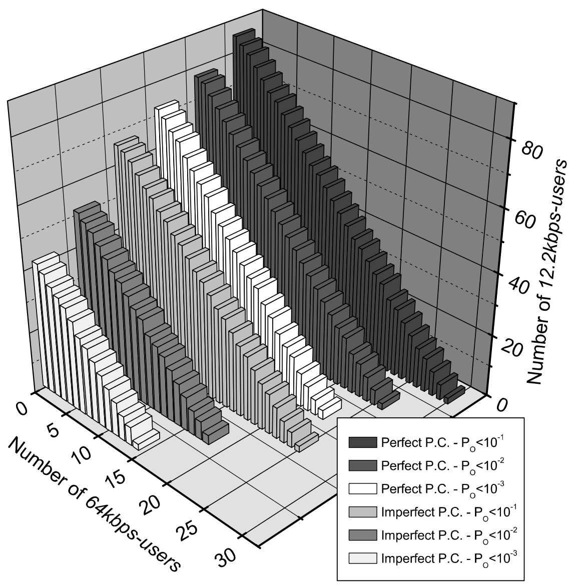

Fig. 1. Uplink capacity for both perfect and imperfect power control ($\sigma_{p_1} = 1$ dB, $\sigma_{p_2} = 0.5$ dB) and for different outage probabilities

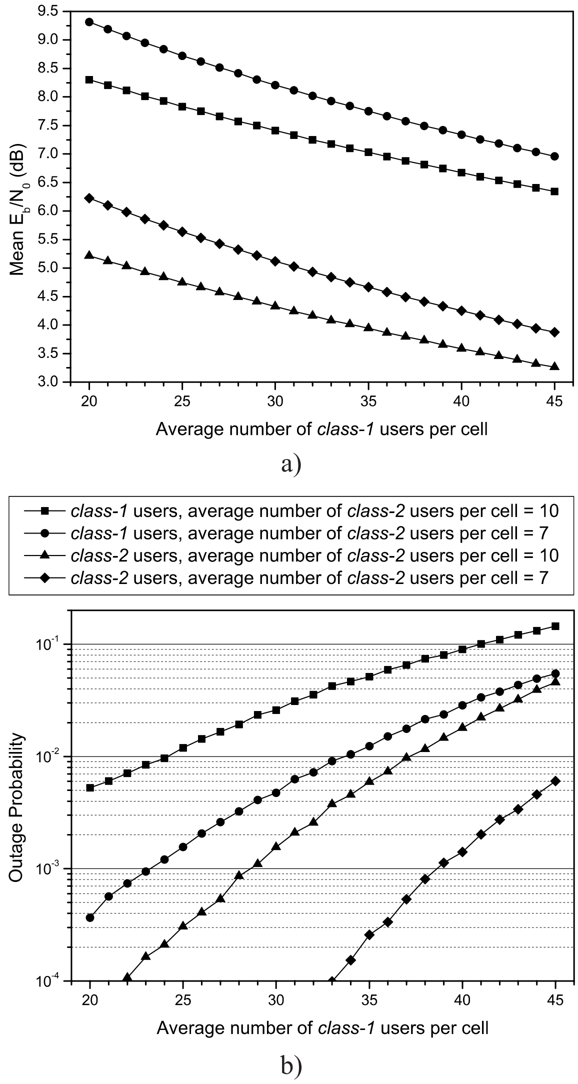

Fig. 2. Mean E_b/N_0 and outage probability vs average number of *class-1* users per cell ($\sigma_{p_1} = 1$ dB, $\sigma_{p_2} = 0.5$ dB)

On the one hand, a short time interval cannot account for variations in the received mean E_b/N_0. On the other hand, a long time interval can lead to the miscalculation of the current system state since new calls may be initiated or ongoing call may be terminated in the meanwhile. Intuitively, one should opt for a time interval which will not be too short, but shorter than the mean inter-arrival time of new calls. We ran simulations for two different values of this time interval, namely for 1 *sec* and 2 *sec*, which correspond to the last 4 and 8 stored measurements respectively. Furthermore, as far as the 2 *sec* time interval is concerned, we evaluated also another version in which different weighting factors were given to different stored E_b/N_0 values. More precisely, the weighting factor for the last four values was 0.15, whereas the weighting factor given to the remaining four values was 0.1. The rationale behind this decision was based on the fact that the more far off the measurements are, the less they reflect the current system state. Simulation experiments showed that the scheme based on averaging without weighting factors over a 2 *sec* time interval performs slightly better than the other two schemes, and therefore, we focus on this scheme in the rest of the paper. The model used in these simulation runs is delineated in section 4.

Upon the arrival of a new or handoff call request, the mean E_b/N_0 for each service class is calculated by averaging the corresponding 8 stored measurements. This procedure is performed both for the candidate cell for serving the call, as well as for the first tier cells. As regards the mean E_b/N_0 of first tier cells, this should be such that guarantees the QoS of ongoing calls and assures that the new call will not be dropped at its first handoff attempt. One approach that has been employed in other studies (e.g. [10]) is that all the first tier cells should satisfy all the admission criteria, hereinafter referred to as the *Minimum criterion* since it is equivalent to a scheme that computes the minimum of the mean E_b/N_0 values of first tier cells for each service class and then compares it to the corresponding predefined threshold. In other words, the algorithm calculates the mean E_b/N_0 for each service class in each cell and then selects the

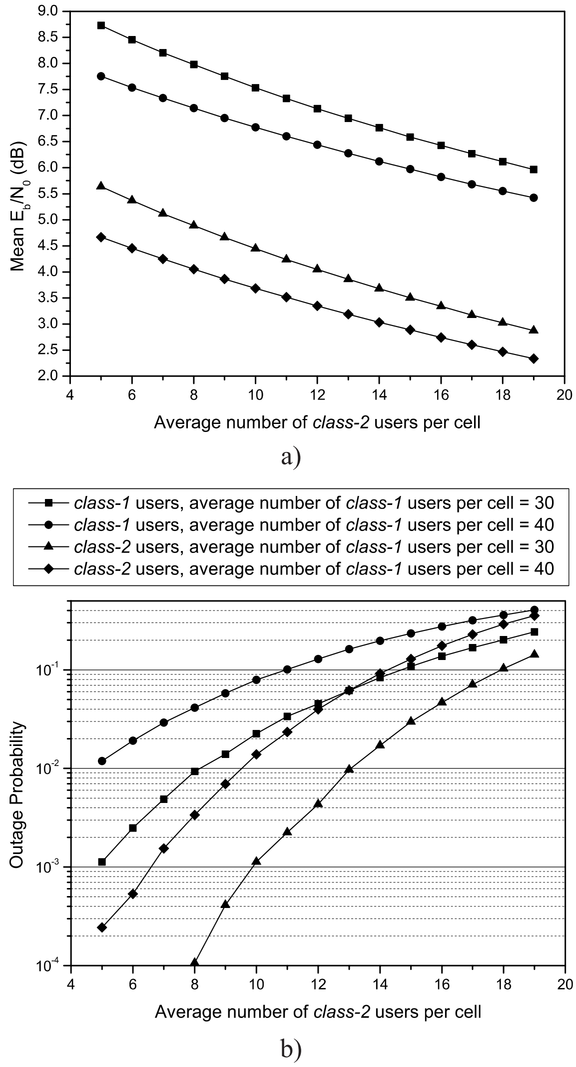

Fig. 3. Mean E_b/N_0 and outage probability vs average number of *class-2* -users per cell ($\sigma_{p_1} = 1$ dB, $\sigma_{p_2} = 0.5$ dB)

smaller of these values. However, if we take into account the mobility of users, then we are led to the conclusion that the interference that a new call will induce in other base stations will vary over time, and what is more, it may diminish over time. In this paper we also evaluate a scheme that is based on a different approach. Specifically, instead of computing the minimum E_b/N_0 for each service class, the new scheme first estimates the average E_b/N_0 of the first tier cells that corresponds to each service class every $0.25\,sec$ (that is, it averages out the stored measurements of E_b/N_0 of the first tier cells that correspond to a particular time instant). Upon a new call or handoff call request, the last 8 of these average values are averaged out for each service class and the obtained value is then compared to the corresponding predefined threshold. This scheme is hereinafter referred to as the *Average criterion.*

Last but not least, we also had to decide on the values of the predefined E_b/N_0 thresholds. These values should be appropriately selected so that can guarantee the QoS requirements of both ongoing and new calls. In wireless telecommunications systems, the outage probability represents one of the most meaningful performance metrics. The proposed CAC algorithm aims at keeping it below or on the order of 10^{-2} for all service classes, even for high traffic loads. As it can be perceived in Fig. 2, 3 and 4, the outage probability of *class-2* is always far below the outage probability of *class-1*. Therefore, it is the outage probability of *class-1* users that determines whether a new or handoff call can be admitted into the network or not. It becomes evident from these figures that the decrease in the mean E_b/N_0 is greater when a *class-2* call is accepted into the same cell rather than when a *class-1* call is admitted into the same cell. Hence, we define different thresholds for each service class. In particular, greater values have been given to the thresholds for new and handoff *class-2* calls owing to the profound effect of these calls on the QoS of ongoing calls. Recall that the mean E_b/N_0 decreases by 0.20 dB in the case of a new *class-2* call, while it decreases only by 0.08 dB in the case of a new *class-1* call. In addition, the impact of a new call on the QoS of calls in adjacent cells is negligible. Therefore, the thresholds that apply to first tier

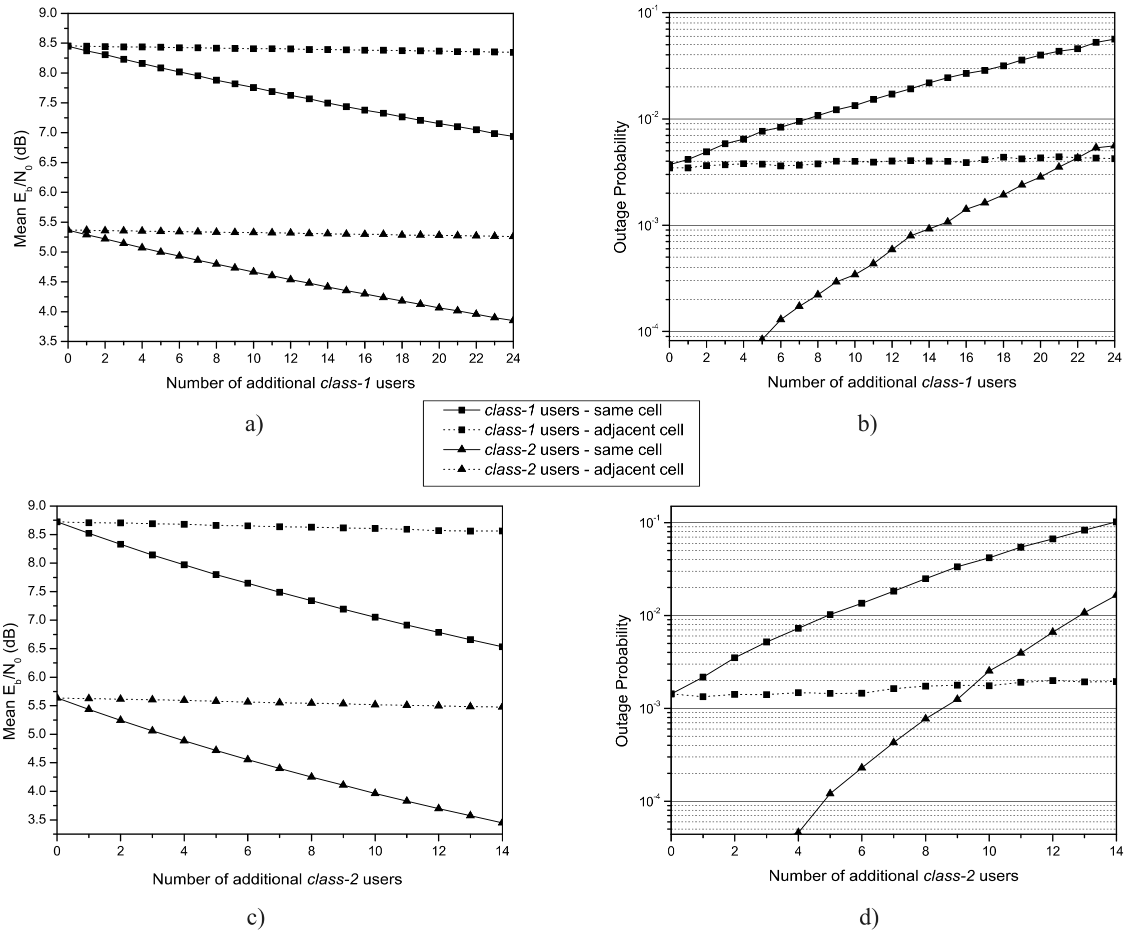

Fig. 4. The impact of new added users on mean E_b/N_0 and outage probability (in graphs a) and b) the average number of *class-1* users per cell is 20 and the average number of *class-2* users per cell is 10, in graphs c) and d) the average number of *class-1* users per cell is 30 and the average number of *class-2* users per cell is 5, $\sigma_{p_1} = 1dB$, $\sigma_{p_2} = 0.5dB$)

cells are smaller. Further, the proposed algorithm aims to prioritize handoff calls over new calls. To this end, smaller thresholds are employed for handoff call requests than for new call requests [20].

Table 2 presents the CAC parameters. The objective was to select appropriate values for these thresholds in order for the outage probability of each service class to be acceptable. The values of these thresholds are much larger than the corresponding minimum required $(E_b/N_0)_{min}$ in order to assure that outage probability is below 10^{-2} for most of the time. It should be noted that the parameters listed in table 2 have been selected taking into account the results presented in section 3.2. Moreover, since these parameters are computed for a HAP W-CDMA system, they should be recalculated for the case of a terrestrial CDMA cellular system. This is the only modification that should be made in order for the CAC scheme to be functional in terrestrial CDMA cellular systems.

In conclusion, the proposed technique can be summarized as follows. E_b/N_0 measurements are taken every $0.25\,sec$. Upon the arrival of a new or handoff call request the last 8 measurements are averaged out both for the candidate serving cell and for the first tier cells. This averaging procedure results in four values. Two that represent the mean E_b/N_0 of both service classes in the candidate cell for serving the call and other two which correspond to the average E_b/N_0 of both service classes in the first tier cells. Note that concerning the way that the latter two values are calculated, two different approaches can be applied, namely the *Minimum criterion* or the *Average criterion*. These four values are then compared to four different predefined thresholds. Only upon a successful outcome will the call be served by the corresponding cell. In other words, the request will be accepted only if each one of these four values is greater than the corresponding threshold.

In the following section the proposed algorithm is compared to another SIR-based CAC scheme, which can be viewed as an extension of the CAC uplink scheme that was proposed in [20]. According to that scheme, the decision is based on instantaneous E_b/N_0 measurements. The same thresholds were applied to this scheme as well. Therefore, we assessed four different CAC schemes which, for the sake of clarity, are described below:

Table 2
CAC parameters

Threshold for	E_b/N_0 *class-1*	E_b/N_0 *class-2*
new *class-1* calls - same cell	7.00 dB	2.80 dB
new *class-2* calls - same cell	7.10 dB	2.90 dB
new *class-1* calls - 1^{st} tier cells	6.70 dB	2.60 dB
new *class-2* calls - 1^{st} tier cells	6.80 dB	2.70 dB
handoff *class-1* calls - same cell	6.65 dB	2.60 dB
handoff *class-2* calls - same cell	6.80 dB	2.70 dB
handoff *class-1* calls - 1^{st} tier cells	6.60 dB	2.55 dB
handoff *class-2* calls - 1^{st} tier cells	6.65 dB	2.55 dB

– ***AM scheme:*** Based on Average E_b/N_0 measurements and on the *Minimum criterion.*
– ***IM scheme:*** Based on Instantaneous E_b/N_0 measurements and on the *Minimum criterion.*
– ***AA scheme:*** Based on Average E_b/N_0 measurements and on the *Average criterion.*
– ***IA scheme:*** Based on Instantaneous E_b/N_0 measurements and on the *Average criterion.*

3.4. *Implementation issues*

When a new CAC scheme is presented, a major design issue is to ensure its tractability and its easy implementation. E_b/N_0 measurements, which are required by the proposed algorithm, already form part of the operational mechanism of DS-CDMA cellular systems, as is the case with UMTS networks, and hence, their implementation will not add any additional overhead to the system. Concerning the monitoring of the mean E_b/N_0 of each cell and its neighboring cells by the Radio Network Controller (RNC), this does not bring about high additional signaling overhead and computational cost. Moreover, for terrestrial systems, this additional signaling overhead is considered acceptable since it can result in great benefits [10]. Finally, our scheme requires the storage of all the measurements of the past 2 seconds at the RNC. Nevertheless, the additional cost that this requirement induces is negligible.

4. Performance evaluation

4.1. *Modeling power variations*

In the uplink of a W-CDMA system, the requirement for power control arises because of the multiple access interference. Power control aims at achieving a constant received power for each user in order to eliminate the near-far effect. However, in practice it cannot eliminate the near-far effect completely due to imperfections in the power control loop. Power control errors cause variations in the received power. Empirical evidence from terrestrial cellular systems suggests that the received power is log-normally distributed [17], [18], [19], [30] and since HAP cellular systems share many commonalities with terrestrial cellular systems, we base our study on this presumption.

To account for uplink fading, the base station measures the received E_b/N_0 for each active call in every frame and decides whether the terminal's transmission power needs to be increased or decreased. Power control errors in dB can be modeled as a Gaussian random variable. Equivalently, we may express the error in dB at the time instant of a measurement as the sum of a component which accounts for the error at the moment of the previous measurement, and a component which pertains solely to the current measurement and is independent of the error of the previous measurement. Thus, the error in dB at any time instant can be expressed as

$$\theta_k = a\theta_{kprev} + b\theta_{knew} \tag{11}$$

where

$$a^2 + b^2 = 1$$

with

$$E(\theta_k) = E(\theta_{kprev}) = E(\theta_{knew}) = 0,$$
$$Var(\theta_k) = Var(\theta_{kprev}) = Var(\theta_{knew}) = \sigma^2,$$

$$E(\theta_{kprev}\theta_{knew}) = 0,$$

where θ_k denotes the current error in dB, θ_{kprev} is the error in dB at the instant of the previous measurement and θ_{knew} is a Gaussian random variable which accounts for variations in the received power over time. The parameter θ_k is computed independently for each user according to eq. (11). Its value is then replaced in eq. (3) so that the current E_b/N_0 can be calculated. This model includes the limiting cases of measurements taken consecutively at time instants that are very close to each other ($a \approx 1$) and of measurements taken consecutively at time instants that are far off between each other ($a \approx 0$). In our algorithm, E_b/N_0 measurements are required every 0.25 *sec*. Due to the fact that simulations were extremely time-consuming, for the sake of simplicity, in our simulations we generated a new value for the received power every 0.25 *sec*, and a reasonable set of values for a and b is $a^2 = b^2 = 0.5$ for both class-1 and class-2 calls. It is recognized that there has been no experimental verification of the aforementioned model for HAP systems. It is, nevertheless, a reasonable supposition based on the well accepted model for terrestrial CDMA systems.

4.2. *Simulation environment*

The experiments conducted in this work aim at evaluating the performance of the proposed scheme, as well as comparing it with a scheme that is based on instantaneous E_b/N_0 measurements. The tool that was used for these experiments was custom coded by the authors in C++. The unique position of a HAP provides some outstanding features which have been taken into account in our simulation tool. The most appealing one is the very favorable path-loss characteristics. As mentioned in subsection 3.2, contrary to terrestrial cellular systems where a user is connected to the base station toward which the radio path loss is minimum, which may not be the closest one, in a HAP system a user is connected to the base station that illuminates the cell in which the user is located. This fact also alleviates the need for soft handoff. Even though we shall not dwell upon this issue in this work, we will describe briefly the concept of soft handover.

Soft handoff is the technique whereby mobile users in transition between one cell and its neighbor transmit to and receive from two or more base stations simultaneously. This technique proved to improve system performance of terrestrial CDMA cellular networks at the expense of increased backhaul connections [31], [32]. Moreover, it ameliorates the undesirable "ping-pong"effect where a user is handed back and forth several times from one base station to the other as he/she hovers around the cell boundary. Notwithstanding, in a practical system this can be avoided by handing over the user only when the base station power is sufficiently below its value at the theoretical cell boundary. Moreover, the very sharp antenna radiation pattern of a HAP base station makes soft handoff easier said than done since the soft handoff zone would be rather small. In this study, for the sake of brevity we shall not accentuate the performance disparity between hard and soft handoff. Due to the aforementioned reasons, in the simulation experiments a hard handoff scheme was employed. An active user was dropped either due to an unsuccessful handoff or on account of being continuously in outage for more than 5*sec* for *class-1* users and more than 26*sec* for *class-2* users [10].

In order to evaluate the performance of the algorithms, a 4×4 cellular system was used, illustrated by the hatched area in Fig. 5. The HAP was considered to be located directly above cell 6. However, we

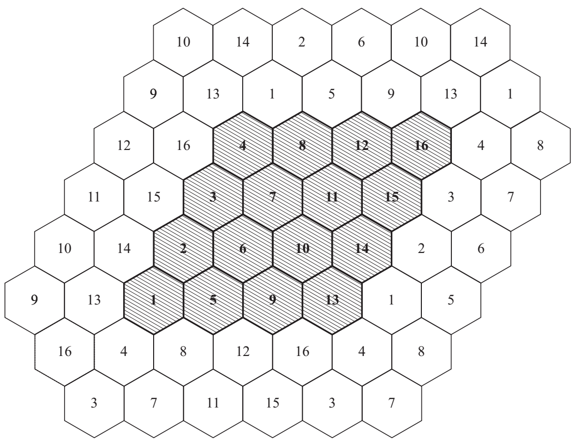

Fig. 5. The simulated cell layout

also had to approximate an infinite network, so that each cell has neighboring cells in all directions, and therefore: i) a mobile user remains in the network as he/she crosses the boundary of the hatched area; and ii) interference is experienced from all directions. To this end, the hatched cell layout was wrapped around into a torus-shape [33]. Thus, the (hatched) reference cells were repeated in a regular manner, as it can be seen in Fig. 5.

Call arrivals were generated according to a Poisson distribution. Once a call is admitted into the network, its duration is generated according to an exponential distribution. At the start of a call, the terminal's position is uniformly generated over the simulation area and its direction is randomly set at a value between 0^o and 360^o. The time between two consecutive changes in the user's direction is exponentially distributed with a mean value of $40sec$ for *class-1* calls and $80sec$ for *class-2* calls (due to the lower maximum speed of *class-2* users). The new direction is generated according to a uniform distribution over $[-45^o, 45^o]$ in reference to the previous direction. Additionally, the user's velocity is uniformly generated over $[Min.\ user\ velocity,\ Max.\ user\ velocity]$ at the start of the call and remains constant throughout the duration of the call. In addition to the parameters that were described in the previous section and presented in Tables 1 and 2, and which were also used in this set of experiments, Table 3 provides a tabulation of the rest of the simulation parameters. Recall that $P_{c_1}/n_{th} = -1$ dB, $P_{c_2}/P_{c_1} = 4.2$ dB, $W = 5$ MHz, $\beta = 0$, whereas the radius of the cell is such that the gain at the edge of the cell is 10 dB below the maximum gain, that is 1 km. Moreover, the antenna radiation pattern that is given in eq. (1) was applied. Last but not least, it should also be pointed out that the presented results represent average values over 3 independent simulation runs, while in each run a time interval equal to $80000sec$ was simulated.

Table 3
Simulation Parameters

	class-1 calls	*class-2* calls
Portion of new call arrivals	75%	25%
Mean call duration	180 sec	500 sec
Minimum user velocity	0 m/sec	0 m/sec
Maximum user velocity	20 m/sec	5 m/sec
σ_p	1 dB	0.5 dB

4.3. *Simulation results*

In Fig. 6 and 7 the blocking probability versus the total call arrival rate (in the whole system) is depicted for *class-1* and *class-2* calls respectively. Recall that 75% of the total call arrival rate corresponds to new *class-1* calls, while only 25% refers to new *class-2* calls. It becomes evident from Fig. 6 that when the same method of averaging is employed, i.e. the *Average criterion* or the *Minimum criterion*, the proposed CAC scheme (that is, either the AM or AA scheme) performs slightly better than the scheme that relies upon instantaneous E_b/N_0 measurements (that is, either the IM or IA scheme), though the gains are not significant. In the case of *class-2* calls, the performance disparities between the two algorithms are even less noticeable. Furthermore, it is evident that the *Average criterion* outperforms the *Minimum criterion*, which is more obvious in Fig. 7.

Our next objective is to examine the ability of the examined CAC algorithms to assure service continuity. To this end, the schemes are assessed in terms of dropping probability. Dropping a call is generally considered much more disruptive and irksome than blocking a new call since it involves breaching QoS guarantees made upon the call establishment. Therefore, the primary aim of any CAC technique should be the minimization of this probability. Nevertheless, this should not come at the expense of excessive blocking probability. Fig. 8 and 9 illustrate the dropping probability versus the total call arrival rate for *class-1* and *class-2* calls respectively. In these figures an impressive amelioration can be perceived when the proposed CAC scheme is employed. In essence, regarding *class-1* type of service, the dropping probability is dropped down by half. Significant gains are obtained for *class-2* type of service as well and the corresponding decrease in dropping probability is more than 30% for both the *Average criterion* and the *Minimum criterion.* One can expect that for greater values of σ_p the proposed scheme will perform even better. It is also evident that the *Average criterion* considerably enhances network performance.

So far it is evident that the proposed CAC scheme outperforms the scheme that is based on instantaneous E_b/N_0 measurements in terms of both blocking and dropping probabilities. The positive characteristics of the proposed technique are attributed to the more accurate estimation of the system state that

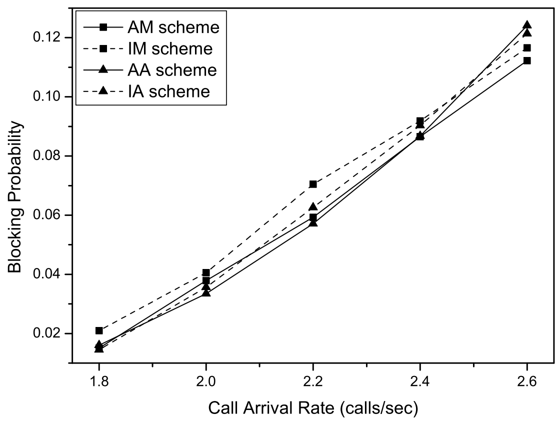

Fig. 6. *Class-1* Blocking Probability vs total call arrival rate

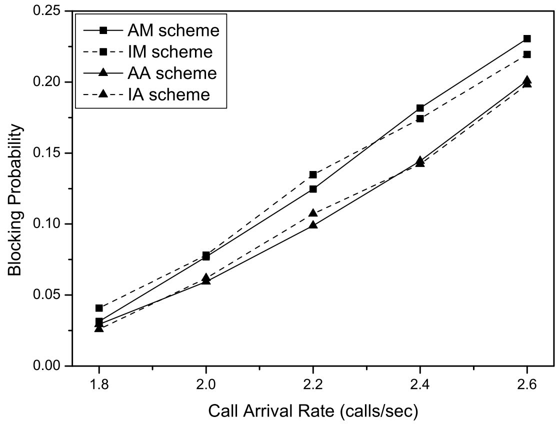

Fig. 7. *Class-2* Blocking Probability vs total call arrival rate

the scheme attains by averaging E_b/N_0 measurements. Moreover, when it is combined with the *Average criterion* it achieves some striking results. However, in order for our study to be complete, we should also evaluate the outage probability that each scheme accomplishes. As previously stated, the outage probability is defined as the probability that E_b/N_0 is smaller than the minimum required $(E_b/N_0)_{min}$. In the previous section, where the proposed scheme was delineated, it was mentioned that it is the outage probability of *class-1* calls that limits the capacity of the system. Our efforts were concentrated on finding a trade-off among blocking, dropping and outage probabilities. Usually, for voice users, as is the case with *class-1* users, outage probability is acceptable as long as it is below 5% [10].

Fig. 10 and 11 present the outage probability versus the total call arrival rate for *class-1* and *class-2* calls respectively. On a first observation, the *class-1* outage probability of the proposed CAC scheme is slightly higher than the one achieved by the scheme that is based on instantaneous measurements, irrespective of the method of averaging used. However, under further scrutiny, it becomes evident that it is in any case acceptable and in addition, the impressive decrease in dropping probability that this scheme achieves makes this increase in outage probability seem negligible. Besides, for low and moderate traffic loads, the outage probability remains below 10^{-2}. Concerning the outage probability of *class-2* calls, it is extremely low, on the order of 10^{-5} for all the schemes, and it is not worth considering it in the comparison. Therefore, on the whole, the proposed CAC algorithm which is based on averaged E_b/N_0 measurements outperforms the algorithm which bases its decision upon instantaneous measurements for both the *Average criterion* and the *Minimum criterion.*

Additionally, as noted above, the *Average criterion* outperforms the *Minimum criterion* in terms of blocking and dropping probability. As regards outage probability, the *Minimum criterion* gets the upper hand. Notwithstanding, if we take into account blocking, dropping and outage probabilities we reach the conclusion that the *Average criterion* is more efficacious. When this criterion is combined with the proposed CAC scheme it further enhances the positive characteristics of the latter.

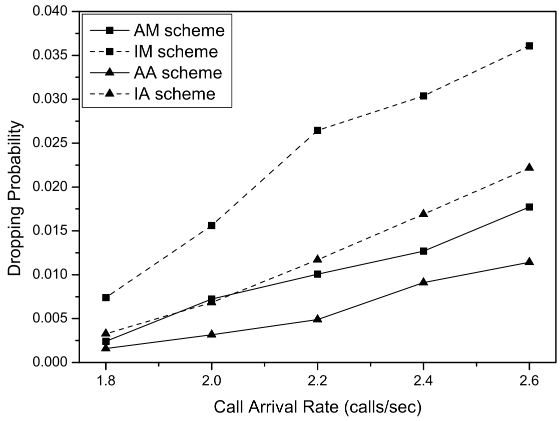

Fig. 8. *Class-1* Dropping Probability vs total call arrival rate

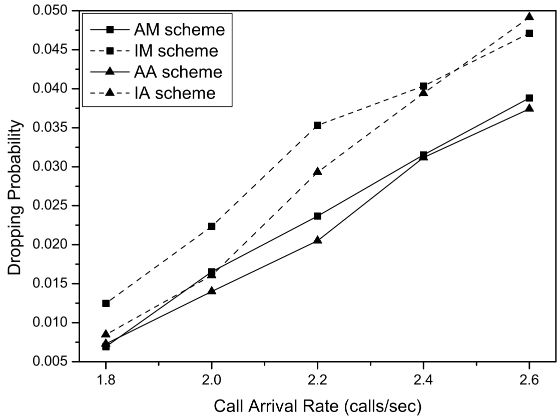

Fig. 9. *Class-2* Dropping Probability vs total call arrival rate

5. Conclusions

In this work, we proposed and evaluated a call admission control scheme for the uplink of a HAP W-CDMA cellular system which capitalizes upon E_b/N_0 measurements. The mechanism behind the proposed scheme that allows it to attain a better performance relies on the estimation of the system state by averaging E_b/N_0 measurements over a specific time interval. Averaged E_b/N_0 measurements can account for variations in the received E_b/N_0 due to power control imperfections. The CAC parameters were appropriately selected via simulation. Moreover, we combined the proposed scheme with a criterion according to which the decision of the algorithm is based upon the mean E_b/N_0 rather than the minimum E_b/N_0 of the cells of the first tier. Albeit the combined scheme was evaluated in a HAP W-CDMA cellular system, it can be used in terrestrial CDMA systems as well. The good characteristics of the proposed scheme were confirmed by ample simulation experiments and significant gains in performance were witnessed, especially with regard to dropping probability.

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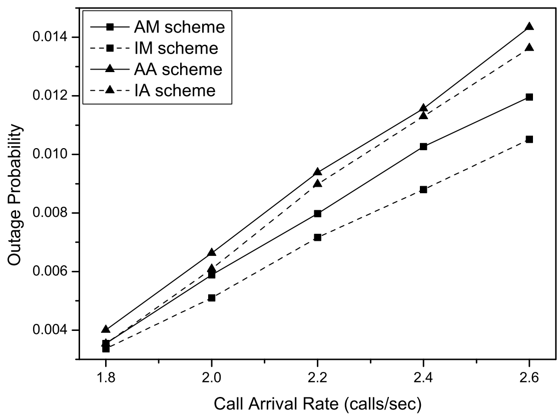

Fig. 10. *Class-1* Outage Probability vs total call arrival rate

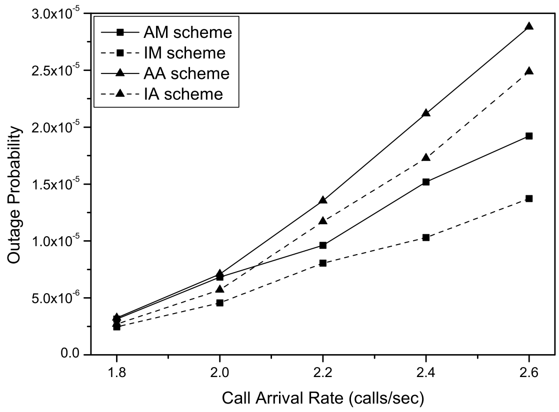

Fig. 11. *Class-2* Outage Probability vs total call arrival rate

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