ON CALL ADMISSION CONTROL IN W-CDMA NETWORKS SUPPORTING HANDOFF TRAFFIC

Vassilios G. Vassilakis, Georgios A. Kallos, Ioannis D. Moscholios, and Michael D. Logothetis
WCL, Dept. of Electrical & Computer Engineering, University of Patras, Patras, Greece
e-mails: {vasilak, kallos, moscholios, m-logo}@wcl.ee.upatras.gr

ABSTRACT
In this paper, we evaluate a Call Admission Control (CAC) scheme suitable for W-CDMA networks accommodating multiple service-classes. In such networks, the distinction between new and handoff traffic is very important. A simple CAC scheme can distinguish calls between the two traffic types by setting different thresholds for call admission. This simple CAC scheme is evaluated in respect of blocking probabilities of both new and handoff calls. To this end, we formulate aggregated Markov chains, which describe both new-call and handoff-call arrival processes, under the assumption that they are Poisson or quasi-random. Based on these Markov chains we derive recurrent and computationally efficient formulas for the calculation of the system state probabilities. Consequently, we calculate new-call and handoff-call blocking probabilities. The analytical results are verified through simulation and found to be quite satisfactory.

Keywords: W-CDMA, handoff traffic, blocking probability, call admission control, QoS.

1 INTRODUCTION

Wideband Code Division Multiple Access (W-CDMA) networks support applications with different Quality-of-Service (QoS) requirements, while offering wide range of voice and data services [1]. In such networks, the call-level performance modelling and QoS assessment is complicated, not only because of the so-called soft blocking, the inter- and intra-cell interference, but also due to the existence of *new* and *handoff traffic* which are the components of total traffic in a cell.

New traffic is generated by new calls within a cell, while *handoff traffic* is transferred to this cell from neighboring cells by ongoing calls, due to the user's mobility. The amount of *handoff traffic* is heavy enough, especially when it is seen as a percentage of the total traffic. This is especially true in the case of micro-cells and pico-cells (small sized cells), where *handoff traffic* is significant [1]. Furthermore, it is generally accepted that in the case where there is limited availability of cell resources, *handoff traffic* must be coped with a higher priority than *new traffic*, in respect of resource allocation. Therefore, it is apparent that a CAC scheme in a mobile network must treat these two different types of traffic individually [2].

In [3] a simple CAC scheme is proposed and evaluated when the W-CDMA network accommodates high speed calls of the same service-class. According to this CAC scheme, when a *new call* originates in the cell, the *cell load* is determined as if the call was admitted. If the calculated *cell load* exceeds a certain predefined value (threshold), the *new call* is blocked, otherwise it is accepted. The same CAC criterion is applied to *handoff calls* but with a higher value of threshold in order to treat them with higher servicing priority compared to *new-calls). New-call* and *handoff-call* blocking probabilities are calculated by a recurrent formula, based on the Kaufman-Roberts (K-R) recursion, for Poisson arrivals [4], [5]. The term *new-call* blocking refers to the failure of the initial call establishment inside the reference cell, whereas the term *handoff-call* blocking refers to the blocking of in-service calls when they move from one cell to another. The K-R recursion was initially proposed in for the calculation of call blocking probabilities in the classical Erlang Multirate Loss Model (EMLM) and has been extensively used in wired or mobile networks (e.g. [6]-[11]).

Several teletraffic models have been proposed for the call-level performance evaluation of cellular networks, either CDMA or W-CDMA [12]-[15], [17], [18]. In all these references *handoff traffic* is considered aggregated to *new traffic*. In [12], [13] a CDMA network is considered accommodating a single service-class only. In [14], the *new-call* blocking calculation in the uplink of a W-CDMA cell is based on the K-R recursion while incorporating local blockings. Multiple service-classes with infinite number of traffic sources (Poisson traffic) are assumed. This work is extended in [15] where a more realistic, finite number of traffic sources, is assumed for each service-class, so that a quasi-random call arrival process [19] is formulated. The model of [15] is based on the Engset Multirate Loss Model (EnMLM) (which is used in connection-oriented wired networks [16]) and is named Wireless EnMLM (W-EnMLM) to reveal its applicability to wireless networks. In [17], although quasi-random traffic is assumed, the calculation of call blocking probabilities is based on the K-R recursion; this is achieved by considering a reduced load approximation method. In [18], another teletraffic model is presented for CDMA cellular networks supporting elastic traffic. Poisson arriving calls are accepted for service with the required bandwidth, which, however, can be modified during their service time. Although this is a realistic consideration, the proposed model is not computationally efficient. Similar teletraffic models for other types of wireless networks, as WLAN (IEEE 802.11) and WMAN (IEEE 802.16) are proposed in [20] and [21].

In this paper, we generalize the work of [3] and [15] by considering that in W-CDMA networks calls may originate from different service-classes of either infinite or finite number of sources (i.e. Poisson or quasi-random traffic). The simple CAC scheme of [3] is considered so that each service-class has its own thresholds individualized for the *new* and *handoff calls*. To analyze the system, we formulate an aggregate one-dimensional Markov chain, which describes both *new-call* and *handoff-call* arrival processes, under the assumption that they are either Poisson or quasi-random. We determine the system state probabilities by efficient recurrent formulas. Consequently, we determine *new–call* and *handoff-call* blocking probabilities for each service-class. These probabilities correspond to time congestion probabilities when quasi-random traffic is assumed [19]. We evaluate the proposed models through simulation and we find that they are quite satisfactory. Furthermore, we show that it is easy to treat *handoff calls* with a higher priority by selecting a higher threshold for them than for *new calls*.

This paper is organized as follows. In section 2 we present the multi-service W-CDMA system under Poisson traffic. In subsection 2.1 we describe the interference and CAC. In subsection 2.2 we determine the *load factors* of the service-classes and the *cell load*, while in subsection 2.3 we define the CAC according to the *cell load*. In subsection 2.4 we calculate the system state probabilities and consequently the *new-call* and *handoff-call* blocking probabilities. In section 3 we extend the results of section 2 (specifically of subsection 2.4) in the case of quasi-random traffic. In section 4 we present application examples for both Poisson and quasi-random traffic cases. For evaluation we provide both analytical and simulation results. We conclude in section 5.

2 MULTI-SERVICE SYSTEM – POISSON TRAFFIC

Consider a multi-service W-CDMA cellular system that supports K independent service-classes. The system consists of a reference cell controlled by a *Node B* and surrounded by neighboring cells. We focus our study on the uplink only – i.e. calls from the mobile users (MUs) to the *Node B*. A MU can be seen as a traffic source that generates calls. For simplicity reasons we assume that each traffic source generates calls of only one particular service-class. The traffic offered to the reference cell can be either *new* or *handoff*. *New traffic* is generated by MUs within the reference cell. On the other hand, *handoff traffic* is generated by MUs that move to the reference cell from neighboring cells.

The main parameters of a service-class k (k=1,…,K) call (either a *new* or a *handoff call*) are the following:

- R_k: Transmission bit rate.
- $(E_b/N_0)_k$: Signal energy per bit divided by noise spectral density, required to meet a predefined Block Error Rate.
- v_k: Activity factor at physical layer. This factor represents the alteration of a service-class k call between transmitting (active) and silent (passive) periods and is defined by the percentage of the duration of the active periods over the total call duration. MUs that at a time instant occupy system resources are referred to as active users. The rest of the users (passive users) are in silent period and do not occupy any system resources. The user activity can be modeled by a Bernoulli random variable with probability of success equal to the activity factor [22]. Typical values of the activity factor are 0.67 for voice services and 1.0 for data services [23].

In this section, we assume Poisson call arrival processes for each service-class k. The *new-call* arrival rate is denoted by $\lambda_{N,k}$, whereas the *handoff-call* arrival rate is denoted by $\lambda_{H,k}$. The service-class k *new-call* holding time is exponentially distributed with mean $\mu_{N,k}^{-1}$. Similarly, the service-class k *handoff-call* holding time is also exponentially distributed, but with mean $\mu_{H,k}^{-1}$. A reasonable assumption is that $\mu_{N,k}^{-1} > \mu_{H,k}^{-1}$. The service-class k *new-calls* offered traffic-load is defined as $a_{N,k} = \lambda_{N,k} \mu_{N,k}^{-1}$, whereas the service-class k *handoff-calls* offered traffic-load is defined as $a_{H,k} = \lambda_{H,k}\mu_{H,k}^{-1}$.

2.1 Interference and Call Admission Control

The capacity of *Node Bs* in W-CDMA networks is interference limited. In the uplink, the capacity of a *Node B* is limited by the multiple access interference (MAI) [2]. This type of interference is caused by both the MUs of the reference cell and the MUs of the neighbouring cells. Because of the stochastic nature of the MAI, in W-CDMA networks we talk about soft capacity. Hence, it is apparent that the inclusion of all types of interferences in the performance modelling is necessary. The MAI basically consists of two types of interference: a) the *intra-cell interference*, I_{intra}, caused by MUs of the reference cell, b) the *inter-cell interference*, I_{inter}, caused by MUs of the neighbouring cells. We also take into account the thermal noise, P_{noise}, which corresponds to the interference of an empty system. A typical value of the thermal noise power density is -174dBm/Hz [2]. Throughout the paper we assume perfect power control – i.e. we assume that the received power at the *Node B* from each call is the same [2].

From the above discussion it is apparent that the CAC in W-CDMA systems must be based on the measured interference. More precisely, the CAC in the W-CDMA system under consideration is performed by measuring the *noise rise*, *NR,* which is defined as the ratio of the total received power at the *Node B*, I_{total}, to the thermal noise power, P_N:

$$NR = \frac{I_{total}}{P_N} = \frac{I_{intra} + I_{inter} + P_N}{P_N} \qquad (1)$$

When a call arrives to the cell, the *noise rise* is estimated and if it exceeds a maximum predefined threshold, the call is blocked and lost. These thresholds can be individualized among different service-classes. Furthermore, one may choose different thresholds for *new* and *handoff calls*. By choosing a higher threshold for *handoff calls*, the blocking probabilities of *handoff calls* will be decreased, whereas the blocking probabilities of *new* calls will be increased.

2.2 Load Factor and Cell Load

The *cell load, n*, is defined as the ratio of the received power from all *active users* to the total received power [2]:

$$n = \frac{I_{intra} + I_{inter}}{I_{intra} + I_{inter} + P_N} \qquad (2)$$

From (1) and (2) we can derive the relation between the *noise rise* and the *cell load*:

$$n = \frac{NR - 1}{NR} \qquad (3)$$

Hence, instead of using the *noise rise* for CAC, we can use the *cell load*. The *cell load* thresholds for service-class *k new* and *handoff calls* are denoted by $n_{N,k}$ and $n_{H,k}$, respectively. Typically the thresholds $n_{N,k}$ and $n_{H,k}$ must be lower than or equal to a maximum value, n_{max}= 0.8, which can be considered as the shared system resource.

The *load factor*, L_k, of (4) can be considered as the resource requirement of a service-class *k* call [14]:

$$L_k = \frac{(E_b / N_0)_k R_k}{W + (E_b / N_0)_k R_k} \qquad (4)$$

where W=3.84Mcps is the chip rate of the W-CDMA carrier.

Note that the cell load, *n,* can be written as the sum of the *intra-cell load*, n_{intra} and the *inter-cell load*, n_{inter}. The first term is the *cell load* derived from MUs of the reference cell while the second one is the *cell load* derived from MUs of the neighbouring cells [14].

2.3 Call Admission Control Based on the Cell Load

Due to (2) we can define the CAC thresholds, $n_{N,k}$ and $n_{H,k}$, for *new* and *handoff calls*, respectively. Therefore, with the aid of (1) and (2) the following CAC conditions can be used at the Node B in order to decide whether to accept or not a service-class *k new call*:

$$n + L_k \le n_{N,k} \qquad (5)$$

Similarly, the condition of acceptance of a *handoff call* is given by:

$$n + L_k \le n_{H,k} \qquad (6)$$

2.4 Blocking Probabilities Calculation

2.4.1 Local blocking probabilities

The probability that a call is blocked when arriving at an instant with *intra-cell load*, n_{intra}, is called *local blocking probability* (LBP) [14]. According to the conditions (5) and (6) we define LBPs for service-class *k new calls* and *handoff calls* in (7) and (8), respectively.

$$\beta_{N,k}(n_{intra}) = P(n_{intra} + n_{inter} + L_k > n_{N,k}) \qquad (7)$$

$$\beta_{H,k}(n_{intra}) = P(n_{intra} + n_{inter} + L_k > n_{H,k}) \qquad (8)$$

In order to calculate the LBPs, $\beta_{N,k}$ and $\beta_{H,k}$, we can follow a procedure similar to [3]. Hence, the *inter-cell interference*, I_{inter}, is modelled as a lognormal random variable with mean $E[I_{inter}]$ and variance $Var[I_{inter}]$. Consequently, the *inter-cell load*, n_{inter}, will also be a lognormal random variable with cumulative distribution function given by:

$$F_n(x) = \frac{1}{2}[1 + erf(\frac{\ln x - \mu_n}{\sigma_n \sqrt{2}})] \qquad (9)$$

where $erf(\bullet)$ is the well-known *error function* and the parameters μ_n and σ_n are given by:

$$\mu_n = \ln(E[I_{inter}]) - \frac{\ln(1+\frac{Var[I_{inter}]}{E[I_{inter}]^2})}{2} + \ln(1-n_{max}) - \ln(P_N) \quad (10)$$

$$\sigma_n = \sqrt{\ln(1+\frac{Var[I_{inter}]}{E[I_{inter}]^2})} \quad (11)$$

Hence, if we substitute $x = n_{N,k} - n_{intra} - L_k$ into (9), from (7) we obtain:

$$\beta_{N,k}(n_{intra}) = \begin{cases} 1 - \mathrm{F}_n(n_{N,k} - n_{intra} - L_k), & x \geq 0 \\ 1, & x < 0 \end{cases} \quad (12)$$

Similarly, if we substitute $x = n_{H,k} - n_{intra} - L_k$ into (9), from (8) we obtain:

$$\beta_{H,k}(n_{intra}) = \begin{cases} 1 - \mathrm{F}_n(n_{H,k} - n_{intra} - L_k), & x \geq 0 \\ 1, & x < 0 \end{cases} \quad (13)$$

2.4.2 System state probabilities

The multi-service system of section II can be described as a Discrete Time Markov Chan (DTMC). We discretize the parameters n, n_{intra} and L_k, by the use of a basic unit, g:

$$j = \frac{n}{g},\ c = \frac{n_{intra}}{g} \text{ and } b_k = \text{round}(\frac{L_k}{g}) \quad (14)$$

Note that the unit g must be chosen to be small enough to avoid high discretization errors and big enough to avoid a large state space.

The resultant discrete values of (14) have the following meaning in the DTMC: j is the number of occupied resources, c is the number of occupied resources by active users and b_k is the resource requirement of a service-class k call.

The conditional probability of c in state j is denoted by $\Lambda(c \mid j)$ and according to [14], [15] can be calculated by:

$$\Lambda(c|j) = \sum_{k=1}^{K} [P_{N,k}(j) + P_{H,k}(j)] v_k \Lambda(c-b_k | j-b_k) + \sum_{k=1}^{K} [P_{N,k}(j) + P_{H,k}(j)](1-v_k) \Lambda(c | j-b_k) \quad (15)$$

for $j = 1,\ldots,j_{\max}$ and $c \leq j$

where $\Lambda(0|0)=1$, $\Lambda(c|j)=0$ for $c>j$ and $j_{\max}$ represents the highest reachable system state.

The parameters $P_{N,k}(j)$ and $P_{H,k}(j)$ represent the service-class k *new* and *handoff* calls resource share in state j and similarly to [14] can be calculated by:

$$P_{N,k}(j) = \frac{\alpha_{N,k}(1 - F_{N,k}(j-b_k)) b_k q(j-b_k)}{j q(j)} \quad (16)$$

$$P_{H,k}(j) = \frac{\alpha_{H,k}(1 - F_{H,k}(j-b_k)) b_k q(j-b_k)}{j q(j)} \quad (17)$$

The *blocking factors*, $F_{N,k}$, and $F_{H,k}$, similarly to [3] and [15], can be calculated by:

$$F_{N,k}(j) = \sum_{c=0}^{j} \beta_{N,k}(c) \Lambda(c \mid j) \quad (18)$$

$$F_{H,k}(j) = \sum_{c=0}^{j} \beta_{H,k}(c) \Lambda(c \mid j) \quad (19)$$

In Fig. 1 we show a DTMC for a small system. This system consists of 4 states (0 to $j_{\max}=3$) and 2 service-classes with resource requirements $b_1=1$, $b_2=2$. In Fig. 1, $\lambda_{N,k}(j)$ and $\lambda_{H,k}(j)$ are the state-dependent transition rates, whose values are given by:

$$\lambda_{N,k}(j) = \lambda_{N,k}(1 - F_{N,k}(j)) \quad (20)$$

$$\lambda_{H,k}(j) = \lambda_{H,k}(1 - F_{H,k}(j)) \quad (21)$$

and $Y_{N,k}(j)$, $Y_{H,k}(j)$ are the average number of *new* and *handoff calls* in state j, respectively. Let us denote by $q(j)$ the probability that the system is in state j. By solving the one-dimensional DTMC, we can calculate the state probabilities, $q(j)$, by the following recursion:

$$q(j) = \frac{1}{j} \sum_{k=1}^{K} \alpha_{N,k}(1 - F_{N,k}(j-b_k))\, b_k\, q(j-b_k) + \frac{1}{j} \sum_{k=1}^{K} \alpha_{H,k}(1 - F_{H,k}(j-b_k))\, b_k\, q(j-b_k) \quad (22)$$

for $j = 1,..,j_{\max}$ and $q(j) = 0$ for $j<0$,

where $\sum_{j=0}^{j_{max}} q(j) = 1$

With the aid of (22) call blocking probabilities can be calculated by adding all state probabilities multiplied by the corresponding *blocking factors* for all possible system states. Therefore, the *new-call* blocking probabilities and the *handoff-call* blocking probabilities, are given by (23) and (24), respectively:

$$B_{N,k} = \sum_{j=0}^{j_{\max}} q(j) F_{N,k}(j) \quad (23)$$

$$B_{H,k} = \sum_{j=0}^{j_{\max}} q(j) F_{H,k}(j) \quad (24)$$

Furthermore, with the aid of (22) we can calculate the values of $Y_{N,k}(j)$, $Y_{H,k}(j)$ as follows:

$$Y_{N,k}(j) = \frac{a_{N,k} q(j-b_k)(1-F_{N,k}(j-b_k))}{q(j)} \quad (25)$$

$$Y_{H,k}(j) = \frac{a_{H,k} q(j-b_k)(1-F_{H,k}(j-b_k))}{q(j)} \quad (26)$$

The value of Eq. (25) and (26) will become clear in the next section where the case of quasi-random traffic is considered.

3 MULTI-SERVICE SYSTEM – QUASI-RANDOM TRAFFIC

The only difference compared to section 2 is the fact that calls (either *new* or *handoff*) of each service-class k come from a finite population of traffic sources (quasi-random traffic). Let us denote by $N_{N,k}$, $N_{H,k}$ the number of traffic sources of service-class k *new* and *handoff calls*, respectively. Furthermore, let $n_{N,k}$, $n_{H,k}$ be the in-service sources of service-class k *new* and *handoff calls*, respectively. Then we can denote the arrival rate $\lambda_{N,k}$, $\lambda_{H,k}$ of *new* and *handoff* idle sources, respectively, by the following equations:

$$\lambda_{N,k} = (N_{N,k} - n_{N,k})\gamma_{N,k} \quad (27)$$

$$\lambda_{H,k} = (N_{H,k} - n_{H,k})\gamma_{H,k} \quad (28)$$

where $\gamma_{N,k}$, $\gamma_{H,k}$ are the arrival rate per *new* and *handoff* idle source, respectively.

Similar to the Poisson case, both the service-class k *new-call* holding time and the service-class k *handoff call* holding time are exponentially distributed with mean values given by $\mu_{N,k}^{-1}$ and $\mu_{H,k}^{-1}$, respectively. The service-class k *new-calls* offered traffic-load per idle source is defined as:

$$a_{N,k} = \gamma_{N,k}\, \mu_{N,k}^{-1} \quad (29)$$

whereas the service-class k *handoff calls* offered traffic-load per idle source is given by:

$$a_{H,k} = \gamma_{H,k}\, \mu_{H,k}^{-1} \quad (30)$$

Following the analysis of subsection 2.4.2, we can calculate the conditional probability $\Lambda(c \mid j)$ of occupied cell resources c by active users in state j according to Eq. (15), where the parameters $P_{N,k}(j)$ and $P_{H,k}(j)$ are given by:

$$P_{N,k}(j) = \frac{N_{N,k}\, a_{N,k}\,(1-F_{N,k}(j-b_k))\, b_k\, q(j-b_k)}{j\, q(j)} - \frac{(n_{N,k}-1)\, a_{N,k}\,(1-F_{N,k}(j-b_k))\, b_k\, q(j-b_k)}{j\, q(j)} \quad (31)$$

$$P_{H,k}(j) = \frac{N_{H,k}\, a_{H,k}\,(1-F_{H,k}(j-b_k))\, b_k\, q(j-b_k)}{j\, q(j)} - \frac{(n_{H,k}-1)\, a_{H,k}\,(1-F_{H,k}(j-b_k))\, b_k\, q(j-b_k)}{j\, q(j)} \quad (32)$$

(compare Eq. (31) and (32) to Eq. (16) and (17), respectively). The *blocking factors*, $F_{N,k}$ and $F_{H,k}$, can be calculated by Eq. (18) and (19), respectively.

As far as the state probabilities $q(j)$ are concerned we propose the following recursion which is similar to recursion (22):

$$\begin{aligned} q(j) = \frac{1}{j}\sum_{k=1}^{K} [& N_{N,k}\alpha_{N,k}(1-F_{N,k}(j-b_k))b_k q(j-b_k) \\ & -(Y_{N,k}(j)-1)\alpha_{N,k}(1-F_{N,k}(j-b_k))b_k q(j-b_k) \\ & +N_{H,k}\alpha_{H,k}(1-F_{H,k}(j-b_k))b_k q(j-b_k) \\ & -(Y_{H,k}(j)-1)\alpha_{H,k}(1-F_{H,k}(j-b_k))b_k q(j-b_k)] \end{aligned} \quad (33)$$

To understand Eq. (33) note that we have approximated the terms ($N_{N,k} - n_{N,k} + 1$) and ($N_{H,k} - n_{H,k} + 1$) with the terms ($N_{N,k} - Y_{N,k}(j) + 1$) and ($N_{H,k} - Y_{H,k}(j) + 1$), respectively. The values of $Y_{N,k}(j)$ and $Y_{H,k}(j)$ are given by (25) and (26), respectively. Such approximations $n_{N,k} \approx Y_{N,k}(j)$ and $n_{H,k} \approx Y_{H,k}(j)$ have been proposed in the case of the EnMLM in order to simplify the $q(j)$'s calculations [24].

Having determined the values of $q(j)$'s according to Eq. (33) we can calculate the *new call* blocking probabilities and the *handoff-call* blocking probabilities according to Eq. (23) and (24), respectively.

4 APPLICATION EXAMPLES

In this section, we evaluate the accuracy of the proposed model for both Poisson and quasi-random traffic. To this end, using the SIMSCRIPT II.5 simulation tool, we have simulated the multi-service system model. Then, we have implemented the analytical model in VISUAL FORTRAN 6.0. The evaluation is based on the *new-call* and *handoff-call* blocking probabilities comparison between the analytical and simulation results. The presented simulation results are mean values from 6 runs. The resultant reliability ranges are very small; therefore, we do not show them in the figures.

In the application examples, presented below, we consider a W-CDMA system with two service-classes. The traffic parameters used for each service-class are the following:

- R_1=144 Kbps, $(E_b/N_0)_1$ = 3 dB and v_1 = 0.7
- R_2=384 Kbps, $(E_b/N_0)_2$ = 4 dB and v_2 = 1.0

As far as the *inter-cell interference* is concerned it is lognormally distributed with mean value $E[I_{inter}]$ = 2*E-18 mW and variance $VAR[I_{inter}]$= 2*E-18 mW. The thermal noise power spectral density is -174 dBm/Hz. For discretization, g=0.001 was chosen.

4.1 For Poisson Traffic

First, we examine the case where the offered traffic is Poisson. We determine the blocking probabilities for seven different traffic-load points (x-axis of Fig. 2) and for the following CAC thresholds: $n_{H,1} = n_{H,2} = n_{\max} = 0.8$ and $n_{N,1} = n_{N,2} = 0.7$. Each traffic-load point corresponds to some values of the offered traffic-load for the *new* and *handoff calls*, as it is shown in Table 1. In Fig. 2 we present the analytical and simulation results of the *new-call* and *handoff-call* blocking probabilities for both service-classes. In all traffic-load cases, the analytical results completely agree with the simulation results. This shows that the accuracy of the analytical calculations is very satisfactory. In Fig. 2, we also observe that, as it was anticipated, both the *new-call* and *handoff-call* blocking probabilities are increased when the offered traffic-load is increased.

Afterwards, we evaluate the model in respect of *handoff-call* blocking probabilities for different thresholds $n_{N,1}$ and $n_{N,2}$ (x-axis of Fig. 3). For presentation purposes, these thresholds are chosen to be equal for both service-classes. The thresholds $n_{H,1}$ and $n_{H,2}$ are kept at their maximum value 0.8. In Fig. 3 we observe that by lowering the thresholds $n_{N,1}$ and $n_{N,2}$ we can significantly reduce the *handoff-call* blocking probability. This is especially true in the case of service-classes with high resource demand (as it is the 2nd service-class).

4.2 For Quasi-Random Traffic

Herein, we consider two application examples. In the first example, we use the same thresholds for CAC as in the case of Poisson traffic. The number of sources of the *new* calls is $N_{N,1}$ = 100 and $N_{N,2}$ = 50, whereas the number of sources of the *handoff* calls is $N_{H,1}$ = 20 and $N_{H,2}$ = 10. Six different cases of the offered traffic-load are considered. The values of the offered traffic-load used in each case for both service-classes are given in Table 2. In Fig. 4 we present the analytical and the simulation results for the *new-call* and *handoff-call* blocking probabilities for both service-classes. On the horizontal axis of Fig. 4 the six traffic-load points (1 to 6) indicate the values of the offered traffic-load of the corresponding rows of Table 2. In Fig. 4 we see that the analytical results are very close to the simulation results. This is especially true in the case of low offered traffic-load as it is indicated by the points 1 to 4 on the horizontal axis of Fig. 4. Note also that due to the higher CAC thresholds for the *handoff* calls used in this example, the *handoff-call* blocking probabilities are much lower than the *new-call* blocking probabilities.

In the second example, we vary the CAC thresholds for the *new* calls of both service-classes, while the CAC thresholds for the *handoff* calls are kept at their maximum values, as in Poisson-traffic case (i.e. $n_{H,1} = n_{H,2} = 0.8$). The CAC thresholds of the *new* calls, used in this example, are given in the horizontal axis of Fig. 5. For presentation purposes, these thresholds are chosen to be equal for both service-classes. We examine two different cases of offered traffic-load: low and high. The values of the offered traffic-load used in each case are given in Table 3. In Fig. 5 we present the *handoff-call* blocking probabilities versus the CAC thresholds of *new* calls for both service-classes and for both low and high offered traffic-load. In the realistic case of low offered traffic-load, the analytical results almost coincide with the simulation results. In the case of high offered traffic-load, the differences between the analytical and simulation results are quite small, and within an acceptable range for call-level performance.

5 CONCLUSION

In this paper we evaluated a simple CAC scheme for W-CDMA cellular networks. Both Poisson and quasi-random traffic is considered. We have taken into account not only *new calls*, but also *handoff calls*. The multi-service W-CDMA system has been described as one-dimensional Markov chain. Based on this Markov chain, recurrent formulas for the calculation of system state probabilities are derived. Next, these recurrent formulas have been used for the determination of the *new-call* and *handoff-call* blocking probabilities. The accuracy of the proposed formulas was evaluated through simulation and was found to be quite satisfactory. Furthermore, we have shown that by using different CAC thresholds it is possible to reduce the *handoff-call* blocking probabilities significantly.

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6 REFERENCES

[1] M. Schwartz: Mobile Wireless Communications, Cambridge University Press (2005).

[2] H. Holma and A. Toskala: WCDMA for UMTS, 3rd ed., John Wiley & Sons Ltd., (2004).

[3] V. G. Vassilakis, G. A. Kallos, I. D. Moscholios, and M. D. Logothetis: On the Handoff-Call Blocking Calculations in W-CDMA Mobile Cellular Networks, The Fourth Advanced International Conference on Communications (AICT 2008), Athens, Greece, 8-13 June (2008).

[4] J. Kaufman: Blocking in a shared resource environment, IEEE Trans. Commun. COM-29 (10) pp. 1474–1481 (1981).

[5] J. W. Roberts: A service system with heterogeneous user requirements, in: G. Pujolle (Ed.), Performance of Data Communications systems and their applications, North Holland, Amsterdam, pp. 423-431 (1981).

[6] A. Greenberg and R. Srikant: Computational Techniques for Accurate Performance Evaluation of Multirate, Multihop Communication Networks, IEEE/ACM Trans. on Networking, Vol. 5, no. 2, pp. 266-277 (1997).

[7] M. Mehmet Ali: Call-burst blocking and call admission control in a broadband network with bursty sources, Performance Evaluation, Vol. 38, Issue 1, pp. 1-19 (1999).

[8] M. Logothetis and G. Kokkinakis: Path Bandwidth Management for Large Scale Telecom Networks, IEICE Trans. Commun., Vol.E83-B, no.9, pp. 2087-2099 (2000).

[9] I. D. Moscholios, M. D. Logothetis and G. K.Kokkinakis: Call-burst blocking of ON-OFF traffic sources with retrials under the complete sharing policy, Performance Evaluation, Vol. 59, Issue 4, pp. 279-312 (2005).

[10] W. Choi, J. Y. Kim: Joint Erlang Capacity of DS/CDMA Forward Link Based on Resource Sharing Algorithm, IEICE Trans. Fundamentals, vol. E84-A, no. 6, pp. 1406-1412 (2001).

[11] P. Fazekas, S. Imre and M. Telek: Modelling and Analysis of Broadband Cellular Networks with Multimedia Connections, Telecommunication systems, Vol. 19, pp. 263-288 (2002).

[12] J. Evans and D. Everitt: On the teletraffic capacity of CDMA cellular networks, Trans. Vehicular Tech., Vol. 48, pp. 153-165 (1999).

[13] K. Gilhousen et al.: On the capacity of a cellular CDMA system, Trans. Vehicular Tech., Vol. 40, pp. 303-311 (1991).

[14] D. Staehle and A. Mäder: An analytic approximation of the uplink capacity in a UMTS network with heterogeneous traffic, Proc. ITC-18, Berlin, pp. 81-90 (2003).

[15] V. G. Vassilakis, G. A. Kallos, I. D. Moscholios, and M. D. Logothetis: The Wireless Engset Multi-Rate Loss Model for the Call-level Analysis of W-CDMA Networks, 18th IEEE Annual Internatioanl Symposium on Personal Indoor and Mobile Radio Communications (PIMRC 2007), Athens, Greece, 3-6 Sept., (2007).

[16] G. Stamatelos and J. Hayes: Admission control techniques with application to broadband networks, Comput. Commun.-17, (9), pp. 663-673 (1994).

[17] M Glabowski, M Stasiak, A Wisniewski, and P Zwierzykowski: Uplink blocking probability calculation for cellular systems with WCDMA radio interference and finite source population, in Proc. HET-NETs'04, Ilkley, U.K., 26–28 July, pp.80/1–80/10 (2004).

[18] G. Fodor and M. Telek: A recursive formula to calculate the steady state of CDMA networks, Proc. ITC-19, Beijing, China, pp. 1285-1294 (2005).

[19] H. Akimaru and K. Kawashima: Teletraffic – Theory and Applications, Springer-Verlag (1993).

[20] B. P. Tsankov, R. A. Pachamanov, and D. A. Pachamanova: Modified Brandy voice traffic model for WLAN and WMAN, Electronics Letters, Vol. 43, No. 23 (2007).

[21] R. A. Pachamanov, D. A. Pachamanova, and B. P. Tsankov: An optimization-based connection admission control method for IEEE 802.16 wireless networks, Proc. IEEE Africon 2007, Namibia, (2007).

[22] A. Viterbi and A. Viterbi, "Erlang capacity of a power controlled CDMA system", IEEE Journal on Selected Areas in Commun., vol. 11, Aug. 1993.

[23] V. B. Iversen, V. Benetis, N. T. Ha, and S. Stepanov: Evaluation of multi-service CDMA networks with soft blocking, Proc. of ITC Specialist Seminar, Antwerp, Belgium, pp. 223-227 (2004).

[24] M. Glabowski and M. Stasiak: An approximate model of the full-availability group with multi-rate traffic and a finite source population, in Proc. MMB&PGTS'04, Dresden, Germany, pp. 195-204 (2004).

Table 1: offered traffic-load in the Poisson case.

	1st service-class		2nd service-class	
	$\alpha_{N,1}$ *(erl)*	$\alpha_{H,1}$ *(erl)*	$\alpha_{N,2}$ *(erl)*	$\alpha_{H,2}$ *(erl)*
1	0.25	0.05	0.05	0.01
2	0.375	0.075	0.075	0.015
3	0.50	0.10	0.10	0.02
4	0.625	0.125	0.125	0.025
5	0.75	0.15	0.15	0.03
6	0.875	0.175	0.175	0.035
7	1.0	0.2	0.2	0.04

Table 2: offered traffic-load in the quasi-random case (1st example).

	1st service-class		2nd service-class	
	$\alpha_{N,1}$ *(erl)*	$\alpha_{H,1}$ *(erl)*	$\alpha_{N,2}$ *(erl)*	$\alpha_{H,2}$ *(erl)*
1	0.10	0.02	0.05	0.01
2	0.20	0.04	0.10	0.02
3	0.30	0.06	0.15	0.03
4	0.40	0.08	0.20	0.04
5	0.50	0.10	0.25	0.05
6	0.60	0.12	0.30	0.06

Table 3: offered traffic-load in the quasi-random case (2nd example).

	Low traffic		High traffic	
	144 Kbps	384 Kbps	144 Kbps	384 Kbps
New	0.40	0.20	0.60	0.30
Handoff	0.08	0.04	0.12	0.06

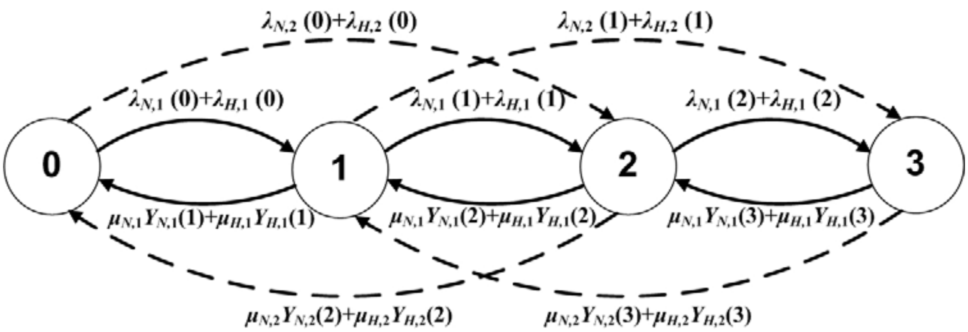

Figure 1: DTMC for a small example.

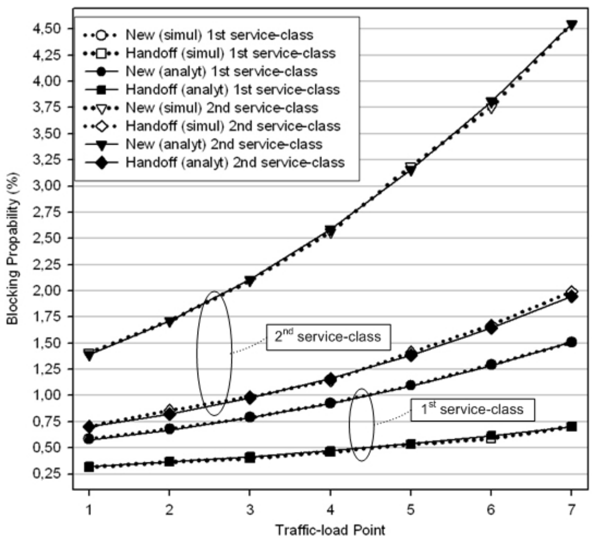

Figure 2: New-call and handoff-call blocking probabilities vs offered traffic-load (Poisson traffic).

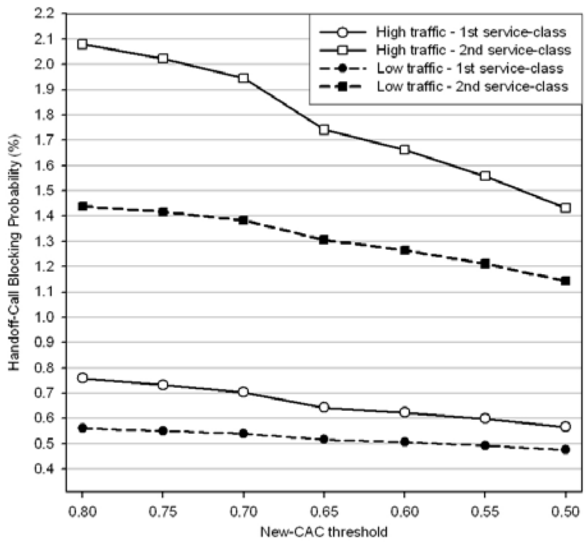

Figure 3: Handoff-call blocking probabilities vs new-call admission control thresholds (Poisson traffic).

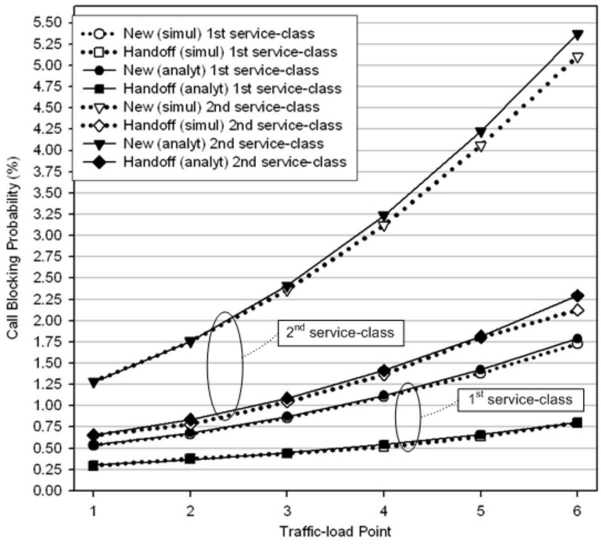

Figure 4: New-call and handoff-call blocking probabilities vs offered traffic-load (quasi-random traffic).

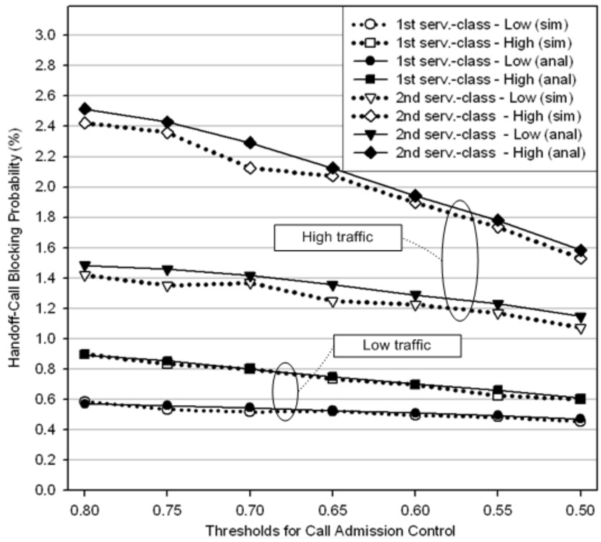

Figure 5: Handoff-call blocking probabilities vs new-call admission control thresholds (quasi-random traffic).