Thorough Analysis of Downlink Capacity in a WCDMA Cell

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Abstract. In WCDMA networks, the Call Blocking Probability (CBP) assessment is necessary for proper cell capacity determination, in respect of traffic load in erlangs, and network dimensioning. This paper focuses on the downlink capacity estimation, through CBP calculation in a WCDMA cell. To this end, we study an analytical model for the WCDMA cell by taking into consideration the effects of the following: the multi-service environment, the soft blocking, the imperfect power control and multipath propagation. In this model, the maximum transmission power of a base station in the downlink is considered as the shared system resource. To analyze the system, we follow the methodology proposed by Mäder & Staehle, and describe the WCDMA cell by a Markov chain, where each system state represents a certain number of resources occupied by mobile users. We solve the Markov chain and provide an efficient recurrent formula for the system occupancy distribution, as well as the so-called local blocking probabilities. Based on them, we calculate the CBP of different service-classes accommodated in the cell, versus the total offered traffic load. We evaluate the analytical model through simulation. The results show that the accuracy of the model is very satisfactory. The main contribution of this paper is the improved determination of several parameters involved in the downlink capacity estimation, in comparison to the calculations that appear in the work of Mäder & Staehle. In addition, we show the effect of the intra-cell interference (due to orthogonality factor) on the erlang capacity of the cell.

Keywords: WCDMA, downlink capacity, soft blocking, Markov chain, call blocking probability.

1 Introduction

Each cell covering a geographical area of a mobile cellular network is controlled by a *Base Station* (BS) which is named NodeB in Wideband Code Division Multiple Access (WCDMA) networks. Most of Third Generation (3G) networks operate with WCDMA over the air interface. The system bandwidth in WCDMA is 5MHz with 3.84 Mcps system chiprate [1]. WCDMA networks support applications with different QoS requirements and rates, while offering wide range of voice and data services.

Second Generation (2G) systems were designed for symmetric traffic such as voice and SMS. The 3G systems have introduced services, such as multimedia, internet and video stream, which have asymmetric traffic. Given that the offered-traffic load is

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heavier in the downlink than in the uplink, the downlink plays more important role, rather than uplink, in the cell capacity determination [1]. Especially in WCDMA networks, the downlink capacity determination is complicated because of soft blocking, multipath propagation, and intra-/inter-cell interferences.

In WCDMA systems, two blocking considerations are possible. The first is the *hard blocking* while the second is the *soft blocking*. Hard blocking means that blocking of a call occurs with probability one in some system states (*hard capacity*), while no blocking occurs (the blocking probability is zero) in all other states. On the other hand, soft blocking means that blocking of a call may occur in every system state with some probability. Soft blocking is a result of inter-cell interference, pseudo-orthogonality, multipath propagation and thermal noise. Due to the soft blocking, in WCDMA systems the resultant capacity is not deterministic, but it is a stochastic value. Thus, we talk about *soft capacity*. We consider both *hard* and *soft capacity*.

For the analysis of traditional connection-oriented networks with Poisson arriving calls, the well-known Erlang Multirate Loss Model (EMLM) is used (also known as Kauffman and Roberts (KR) recursion) [2], [3]. This is a recurrent formula that achieves efficient and accurate calculation of Call Blocking Probabilities (CBP). This recursion has been extended for the CBP calculation in the uplink of WCDMA systems [4]-[7]. In [4] CBP are calculated for Poisson arriving calls, imperfect power control, user activity and inter-cell interference. In [5], the authors calculate CBP in the WCDMA uplink, using the cell load estimation method based on the wideband received power. This work was further extended in [6] by providing an explicit distinction between the new and the handoff calls. In [7], the authors calculate CBP in the WCDMA uplink, using a throughput-based cell load estimation method.

As far as CBP calculation in the downlink of a WCDMA system is concerned, little progress has been done in comparison to the uplink. In [8], an analytical method is proposed which results in a closed formula for CBP calculation, in the absence of multipath signal propagation. In the same paper, in the case of multipath signal propagation, a Chernoff bound is determined for CBP. In [9] the CBP calculation is based on an analytical model which takes into account multiple service-classes, user activity, imperfect power control and multipath propagation. In this model, the maximum transmission power of the base station in the downlink is considered as the shared system resource. Based on this model, Mäder & Staehle (the authors of [9]) have developed an algorithm for the CBP determination per service-class.

In this paper, to analyze a WCDMA system in the downlink, we follow the methodology proposed by Mäder & Staehle, and describe the WCDMA cell by a Markov chain, where each system state represents a certain number of resources occupied by Mobile users (MUs). We solve the Markov chain and provide an efficient recurrent formula for the system occupancy distribution, as well as the so-called local blocking probabilities. Based on them, we calculate the CBP of different service-classes accommodated in the cell, versus the total offered traffic load in the cell. Both hard and soft blocking is considered. Then, we set a CBP boundary for each service-class and according to these boundaries the WCDMA cell capacity in erlangs is determined for the downlink, as the maximum traffic load which satisfies all CBP boundaries. That is, the erlang cell-capacity is defined by the maximum traffic load for which the CBP of each service class is below than the corresponding CBP boundary. We evaluate the presented analytical model through simulation. The results show that the accuracy of the model is very satisfactory. The main contribution of this paper is the improved determination of several parameters involved in the downlink capacity estimation, in comparison to the calculations that appear in the work of Mäder & Staehle. In addition, we evaluate the effect of the intra-cell interference due to the orthogonality factor on the erlang capacity.

The paper is organized as follows. In section 2 we describe the system model. In section 3 we present an algorithm for the CBP calculation of each service-class. Section 4 shows the validation of the algorithm through comparison with simulation results, the effect of the intra-cell interference (orthogonality factor) on the erlang capacity and the accuracy of the model. We conclude in section 5.

2 System Model

We consider a WCDMA reference cell surrounded by a number of neighbor cells. We use the index x to denote the BS that controls the reference cell. MUs generate calls within the reference cell. A call may belong to one out of S independent service-classes. By M_x we denote the number of all MUs within the reference cell (i.e. MUs that are power-controlled by the BS x). At any time instant some of these MUs are *active*, i.e. have a call in progress, whereas the rest of them are *passive*. The number of active users is denoted by A_x ($A_x \leq M_x$). The position of MUs within the reference cell is assumed an i.i.d. (independent and identically distributed) random variable.

By $S_{x,\max}$ we denote the maximum transmission power of BS x. By $S_{x,\mathrm{c}}$ we denote the power that BS x transmits for common channels; this power is assumed to be constant. A part of the transmission power of BS x is devoted to satisfy the QoS requirements of all active MUs. More precisely, the signal power, $S_{k,x}$, transmitted by BS x to an active MU k (k=1, …, A_k) depends on the position and on the service-class of the MU k. The total signal transmission power from BS x (to all active MUs and for common channels) at a time instant is denoted by S_x:

$$S_x = S_{x,c} + \sum_{k=1}^{A_k} S_{k,x} \tag{1}$$

The maximum transmission power of BS x, $S_{x,\max}$, can be considered as shared system resource, whereas the power requirements, $S_{k,x}$, of MUs, as resource requirements. A neighbor BS y transmits with S_{y}. This power, similarly to [9], is modeled as a log-normal random variable with mean $E[S_{\mathrm{y}}]$ and variance $VAR[S_{\mathrm{y}}]$. Due to path loss, the signal power received at the MU k is less than the power $S_{x,k}$, transmitted by BS x towards the MU k. This attenuation is described by the attenuation factor $\hat{d}_{k,x}$ in dB [9]:

$$\hat{d}_{k,x} = -128.1 - 37.6\log_{10}(\mathrm{dist}(x,k)) \tag{2}$$

In the above equation, the distance, dist(x,k), from BS x to the MU k is in Km. In the following, the linear value of the attenuation factor is denoted by $d_{k,x}$.

For the purposes of our analysis, the coverage area of the whole network is divided into small square subareas. Every subarea may fully or partially belong to the coverage area, F_x, of BS x, as shown in Fig. 1. The total traffic-load offered by MUs of a subarea f is denoted by a_f. We assume that the size of each subarea is small enough in order for the distances of all MUs within the same subarea from BS x to be equal. The probability that a subarea f is within the coverage area of the BS x is given by [9]:

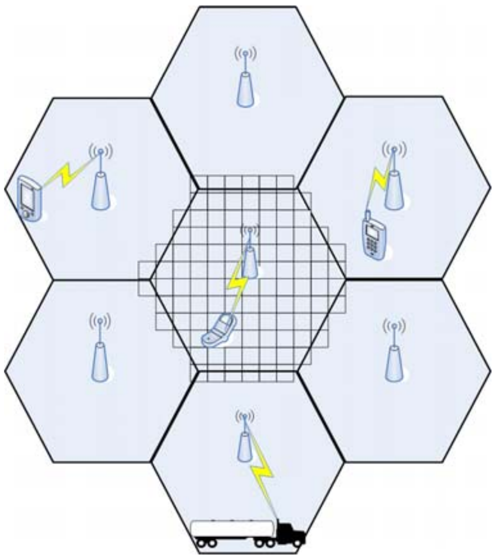

Fig. 1. Cellular concept and division of a cell into small subareas

$$p(f \in F_x) = P(d_{k,x} < \min\{d_{k,y}\}),\ y \in Y \tag{3}$$

where Y is the set of BSs that are neighbors for the BS x.

We consider that a service-class s (s=1, …,S) is characterized by:

- R_s: Transmission bit rate.
- $(E_b/N_0)_s$: QoS parameter - Signal energy per bit divided by noise spectral density, required to meet a predefined Block Error Rate.
- v_s: The user activity factor at physical layer.

Furthermore, we take under consideration three kinds of interference, namely, the thermal noise, N_0, the inter-cell interference, I_{inter}, and the intra-cell interference, I_{intra}.

One of the advantages of the WCDMA technology is that it separates different signals in the cell by using orthogonal spreading codes [1], aiming at illuminating the intra-cell interference. In practice, however, due to multipath propagation, the complete illumination is not possible. For this reason, the orthogonality factor, a, is introduced in order to describe the fraction of power which is seen by a MU as interference from other

MUs that are power controlled by the same BS. On the other hand, inter-cell interference results from signals coming from neighbor cells (without enough attenuation).

In order for a MU to be serviced by a BS, the latter must satisfy the MU's E_b/N_0 requirements, which depend on the MU service-class and on the distance of the MU from the BS. The required (target) E_b/N_0 of the MU k that is power-controlled by the BS x is denoted by $\varepsilon_{k,x}$ and is given by the outer loop power control [9]:

$$\varepsilon_{k,x} = \frac{W}{R_k} \frac{S_{k,x} d_{k,x}}{WN_0 + \sum_{y \neq x} S_y d_{k,y} + a d_{k,x} (S_x - S_{k,x})} \tag{4}$$

where W is the WCDMA system chip rate.

We make a reasonable consideration that the power control is not perfect. In that case, the ratio E_b/N_0 fluctuates around the target E_b/N_0 which results from eq. (4). The ratio E_b/N_0 can be modeled by a lognormal random variable [9].

Each time a MU starts a new call, the Call Admission Control (CAC) estimates the increase caused to the transmitting power of the BS. If the total required power of the BS after a new call acceptance is going to exceed $S_{x,\max}$, then the new call will be blocked; otherwise it will be accepted. The increase of BS power caused by a new call acceptance depends on the QoS parameter of the MU and its distance from the BS. Hence, in the downlink, the CAC is performed according to the following condition:

$$S_x < S_{\max} \tag{5}$$

Repeating, the CAC needs to know the current BS transmission power and the increase in the transmission power that a new call will cause. From (4) we can calculate the required transmission power of BS x towards the MU k [9]:

$$S_{k,x} = \omega_k (WN_0 \delta_{k,x} + \sum_{y \in Y} S_y \Delta_{y,k} + a S_x) \tag{6}$$

where $\delta_{k,x} = \frac{1}{d_{k,x}}$, $\Delta_{k,y} = \frac{d_{k,y}}{d_{k,x}}$ and ω_k is the *service load factor* of the MU k [1]:

$$\omega_k = \frac{\varepsilon_{k,x} R_k}{W + a \varepsilon_{k,x} R_k} \tag{7}$$

The sum of the service load factors of all active MUs in the cell defines the *cell load* n_x of the BS x:

$$n_x = \sum_{k=1}^{A_x} \omega_k \tag{8}$$

The cell load n_x can be considered as the shared system resource and the service load factor ω_k as the resource requirement of the MU k.

It is also useful to define the *position and service load factor* $\omega_{k,y}$:

$$\omega_{k,y} = \begin{cases} \omega_k \delta_{k,x} & \text{if } y = 0 \\ \omega_k a & \text{if } y = x \\ \omega_k \Delta_{k,y} & \text{if } y \neq x \text{ and } y \neq 0 \end{cases} \tag{9}$$

n (9), $\omega_{k,y}$ is the cell load introduced either due to the thermal noise (y=0), either due to BS x (y=x), or due to a neighbor BS ($y \neq x$ and $y \neq 0$).

The sum of the above position and service load factors of all active MUs in the cell defines the combined cell load $n_{x,y}$:

$$n_{x,y} = \sum_{k=1}^{A_x} \omega_{k,y} \tag{10}$$

In order to calculate the transmission power, S_x, of BS x we must sum all $S_{k,x}$ of the active users in the cell and the power $S_{x,c}$. Hence, from (1) and (4) we derive [9]:

$$S_x = \frac{1}{1 - n_{x,x}} \left(n_{x,0} W N_0 + \sum_{y \in Y} n_{x,y} S_y + S_{x,c} \right) \tag{11}$$

From (8) - (11) we have [9]:

$$\sum_{k=1}^{A_x} \omega_k \left(W N_0 \delta_{k,x} + \sum_{y \in Y} \Delta_{k,y} S_y + a S_{x,\max} \right) < S_{x,\max} - S_{x,c} \tag{12}$$

In the above equation, we denote by Q_k the quantity in the brackets. It is called *positional load factor* since it depends only on the position of the user k in the cell (i.e. Q_k is independent on ω_k and depends only on $\delta_{k,x}$ and $\Delta_{k,x}$) [9]:

$$Q_k = W N_0 \delta_{k,x} + \sum_{y \in Y} \Delta_{k,y} S_y + a S_{x,\max} \tag{13}$$

Based on (12), (13) and taking into account the activity factor, v_k, we obtain [9]:

$$\sum_{k=1}^{M_x} v_k \omega_k Q_k < S_{x,\max} - S_{x,c} \tag{14}$$

3 Algorithm for Capacity Calculation

When the system supports S service-classes its state space is S-dimensional. An example of the state space for S=2 is shown in Fig. 2. In this figure, different system states are denoted by circles, while the transitions between the states are denoted by arrows. A state is defined as an S-dimensional vector whose elements are the numbers of in-service calls of different service-classes. Upon each arrow the transition rate

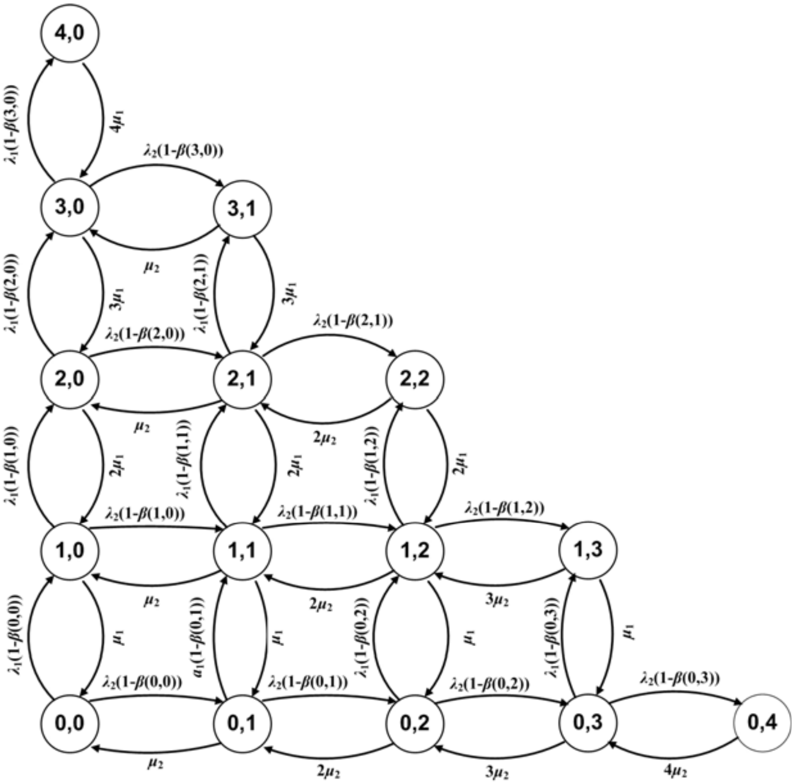

Fig. 2. Micro-state transition diagram for a system with S=2 service-classes

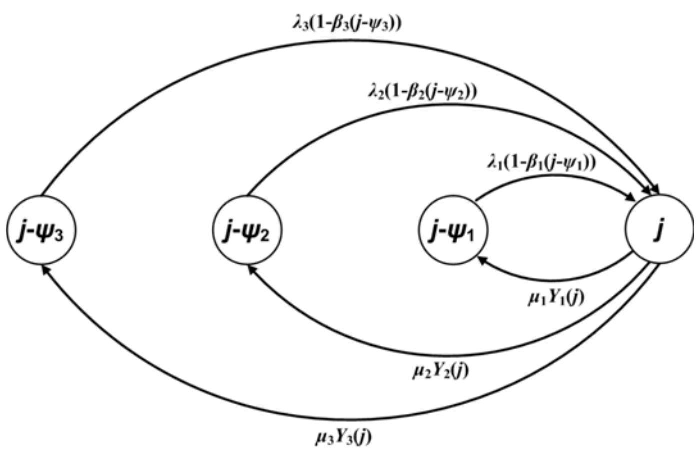

Fig. 3. Macro-state transition diagram (1-dimensional Markov chain)

from one state to another is shown. Even for S=2, solving the resultant Markov chain (in order to determine the state probabilities) is not an easy task. This problem is even more complicated for S>2. To simplify the problem, the S-dimensional state space is transformed into 1-dimensional. The idea is to combine all states (called micro-states) which have the same number of occupied resources into one state (macro-state).

The goal of the analysis presented below is to calculate the probability $q(j)$ of each (macro-)state j. Then, the CBP of each service-class can be determined as it is shown at the end of this section (see eq. (33)).

The first step is the discretization of ω_s with the aid of the *basic unit*, g [9]:

$$\psi_s = \left(\left\lfloor \frac{v_s \omega_s}{g} + \frac{1}{2} \right\rfloor \right) \tag{15}$$

From now, the discrete value ψ_s will be considered as the service-class s call resource requirement.

A segment of the 1-dimensional Markov chain for a system with three service-classes is shown in Fig. 3. In this figure, by λ_s and μ_s we denote the mean arrival rate and mean service rate of service-class s call, respectively. By $\beta_s(j)$ we denote the *local blocking probability*, defined as the probability that a new call of service-class s is blocked when the system is in state j. By $Y_s(j)$ we denote the mean number of service-class s calls in state j. Note that the transition rates from lower states (j -ψ_s) to higher (j) are reduced by the factors 1- $\beta_s(j\text{-}\psi_s)$, which denote the probability of non-blocking in state $j\text{-}\psi_s$.

For the calculation of the un-normalized state probabilities, $\tilde{q}(j)$, we use a modification of the KR Recursion while capturing the effect of soft blocking [9]:

$$\tilde{q}(j) = \begin{cases} 1, & \text{for } \ j=0 \\ \dfrac{1}{j}\displaystyle\sum_{s=1}^{S}\left(1-\beta_s\left(j-\psi_s\right)\right) a_s \psi_s \tilde{q}\left(j-\psi_s\right), & \text{for } \ j=1,...,j_{\max} \end{cases} \tag{16}$$

where $a_s = \lambda_s/\mu_s$ is the offered traffic-load of service-class s and $j_{\max}$ is the maximum reachable system state.

Then, the normalized state probabilities are computed by:

$$q(j) = \frac{\tilde{q}(j)}{\sum_{j \le j_{\max}} \tilde{q}(j)} \tag{17}$$

Let us denote by $P_s(j)$, the conditional probability that the current state j has been reached from the state $j\text{-}\psi_s$, through the arrival of a service-class s call:

$$P_s(j) = \frac{(1-\beta_s(j-\psi_s))a_s q(j-\psi_s)}{\sum_{s=1}^{S}(1-\beta_s(j-\psi_s))a_s q(j-\psi_s)} \tag{18}$$

Since a MU position in the cell is i.i.d., the quantities $E[\delta_{k,x}]$, $E[\varDelta_{k\,y}]$ and $E[Q_k]$ are independent of k; therefore, hereinafter we use the notations $E[\delta_x]$, $E[\varDelta_y]$ and $E[Q]$.

The first moment of $S_x(j)$ can be computed as follows [9]:

$$E\left[S_x(j)\right]=\begin{cases}0 & \text{for } j=0\\ \sum_{s=1}^{S}P_s(j)\left(E\left[S_x(j-\psi_s)\right]+v_sE\left[\omega_s\right]E\left[Q\right]\right) & \text{for } 0<j\le j_{\max}\end{cases} \tag{19}$$

While, for the second moment we have [9]:

$$E\left[S_x(j)^2\right]=\begin{cases}0 & \text{for } j=0\\ \sum_{s=1}^{S}P_s(j)(E\left[S_x(j-\psi_s)^2\right]+v_sE\left[\omega_s^{\,2}\right]E\left[Q^2\right]+ & \\ \quad 2v_sE\left[\omega_s\right]E\left[Q\right]E\left[S_x(j-\psi_s)\right] & \text{for } 0<j\le j_{\max}\end{cases} \tag{20}$$

From (20) with the introduction of mean cell load n_a, we obtain:

$$E\left[S_x(j)^2\right]=\begin{cases}0 & \text{for } j=0\\ \sum_{s=1}^{S}P_s(j)(E\left[S_x(j-\psi_s)^2\right]+v_sE\left[\omega_s^{\,2}\right]E\left[Q^2\right] & \\ +2v_sE\left[\omega_s\right]E\left[QQ'\right]E\left[n_a(j-\psi_s)\right]) & \text{for } 0<j\le j_{\max}\end{cases} \tag{21}$$

where

$$E\left[n_a(j)\right]=\begin{cases}0 & \text{for } j=0\\ \sum_{s=1}^{S}P_s(j)\left(E\left[n_a\left(j-\psi_s\right)\right]+v_sE\left[\omega_s\right]\right) & \text{for } 0<j\le j_{\max}\end{cases} \tag{22}$$

Here, we must define the first, second and combined moment of the positional load factor. The first moment is obtained by the following equation [9]:

$$E\left[Q\right]=WN_0E\left[\delta_x\right]+\sum_{y\in Y}E\left[\Delta_y\right]E\left[S_y\right]+aS_{\max} \tag{23}$$

We calculate the second moment as follows:

$$\begin{aligned}E\left[Q^2\right]=&\left(WN_0\right)^2E\left[\delta_x^{\,2}\right]+2WN_0\sum_{y\in Y}E\left[S_y\right]E\left[\Delta_y\delta_x\right]+2aS_{x,\max}WN_0E\left[\delta_x\right]\\ &+\left(aS_{x,\max}\right)^2+\sum\nolimits_{x\neq y}\sum E\left[S_{y1}\right]E\left[S_{y2}\right]E\left[\Delta_{y1}\Delta_{y2}\right]+\sum_{y\in Y}E\left[S_y^{\,2}\right]E\left[\Delta_y^{\,2}\right]\\ &+2aS_{x,\max}\sum_{y\in Y}E\left[S_y\right]E\left[\Delta_y\right]\end{aligned} \tag{24}$$

We calculate the combined moment by the following equation:

$$\begin{aligned} E[QQ'] &= (WN_0)^2 E[\delta_x]^2 + (aS_{x,\max})^2 + 2aS_{x,\max} WN_0 E[\delta_x] \\ &+ 2WN_0 \sum_{y\in Y} E[S_y] E[\Delta_y] E[\delta_x] + \sum_{y\in Y} E[S_y{}^2] E[\Delta_y]^2 \\ &+ \sum_{x\neq y} \sum E[S_{y1}] E[S_{y2}] E[\Delta_{y1}] E[\Delta_{y2}] + 2aS_{x,\max} \sum_{y\in Y} E[S_y] E[\Delta_y] \end{aligned} \tag{25}$$

The mean of $\delta_{k,x}$ and $\Delta_{k,x}$ are given by [9]:

$$E[\delta_x] = \sum_{f\in F_x} \frac{a_f p(f\in F_x)}{\sum_{s=1}^{S} a_{x,s}} E\left[\frac{1}{d_{f,x}} | f\in F_x\right] \tag{26}$$

$$E[\Delta_y] = \sum_{f\in F_x} \frac{a_f p(f\in F_x)}{\sum_{s=1}^{S} a_{x,s}} E\left[\frac{d_{f,y}}{d_{f,x}} | f\in F_x\right] \tag{27}$$

As we have already shown, one can compute the first and the second moment of the transmitting power $S_x(j)$ based on (19), (21) and (22). After a new call of service-class s is accepted in the system, the new transmitting power becomes $S_x(j)+S_s$, where $S_s = \omega_s Q$ is the additional power required for the new call. The first and the second moments of this new transmitting power are calculated according to [9]:

$$E[S_x(j)+S_s] = E[S_x(j)] + E[\omega_S] E[Q] \tag{28}$$

$$E\left[(S_x(j)+S_s)^2\right] = E\left[S_x(j)^2\right] + 2E[\omega_s] E[QQ'] E[n_a(j)] + E\left[\omega_s^2\right] E\left[Q^2\right] \tag{29}$$

Due to the fact that the new user is assumed to be active at the beginning of his call, the activity factor is neglected in (28), (29).

If now we assume that the random variable $S_x(j)+S_s$ is lognormally distributed, the local blocking probability $\beta_s(j)$ can be calculated by (based on (5), (28) and (29)) [9]:

$$\beta_s(j) = 1 - CDF_{\mu,\sigma}\left(S_{x,\max} - S_{x,c}\right) \tag{30}$$

Where *CDF*() is the Cumulative Distribution Function of the random variable $S_x(j)+S_s$.

We calculate the parameters μ and σ by:

$$\mu = \ln\left(E[S_x(j)+S_s]\right) - \frac{1}{2}\sigma^2 \tag{31}$$

$$\sigma = \sqrt{\ln\left(CV^2 + 1\right)} \tag{32}$$

where CV is the coefficient of variation of the random variable $S_x(j)+S_s$.

Finally, the CBP of a service-class s can be calculated by [9]:

$$P_{block}(s) = \sum_{j < j_{\max} - \psi_s} \beta_s(j) q(j) + \sum_{j_{\max} - \psi_s < j \le j_{\max}} q(j) \tag{33}$$

4 Application Example – Numerical Results

We evaluate the accuracy of the analytical model of Section 3, through comparison with simulation. The simulation model is based on the system model described in Section 2; it is developed by using the SIMSCRIPT II.5 simulation tool [10].

We consider the WCDMA network of Fig. 1 where three service-classes are accommodated. We calculate CBP by the analytical model and simulation. Then, we set a CBP boundary for each service-class and according to these boundaries the WCDMA cell capacity in erlangs is determined for the downlink, as the maximum traffic load which satisfies all CBP boundaries. Also, through the analytical model, we determine the erlang cell capacity for different orthogonality factors. The system parameters are given in Table 1, whereas the service-class parameters in Table 2. Regarding the user activity factors, we consider two scenarios. In the first scenario, the activity factors are v_1=0.3, v_2=0.7 and v_3=1.0. In the second scenario, the activity factors are v_1=0.4, v_2=0.6 and v_3=0.8.

Table 1. System Parameters

Distance between BSs	2 Km
Maximum transmission power of the BS	8 W
Transmission power required for common channels	2 W
Mean transmission power of neighbor BSs	3 W
St. dev. of transmission power of neighbor BSs	200 mW
Thermal noise power spectral density	-174 dBm/Hz
Bandwidth	5 MHz
Orthogonality factor	0.1

Table 2. Service-class Parameters

Service class	**1**	**2**	**3**
Transmission bit rate	12.2 Kbps	64 Kbps	144 Kbps
Target E_b/N_0	5.5	4	3.5
E_b/N_0 st.dev.	1.2	1.2	1.2
Traffic mix	96 %	3 %	1 %

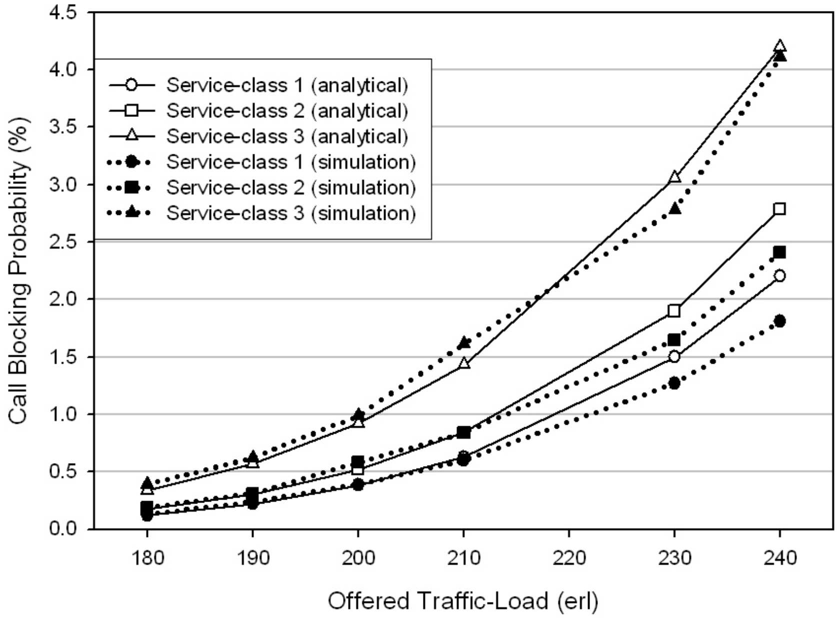

Fig. 4. CBP vs. Offered traffic-load for the 1st scenario

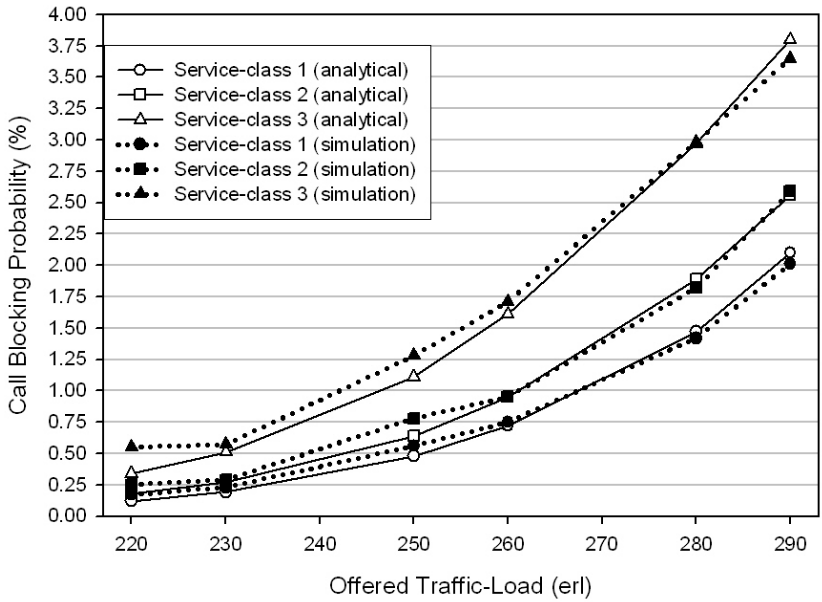

Fig. 5. CBP vs. Offered traffic-load for the 2nd scenario

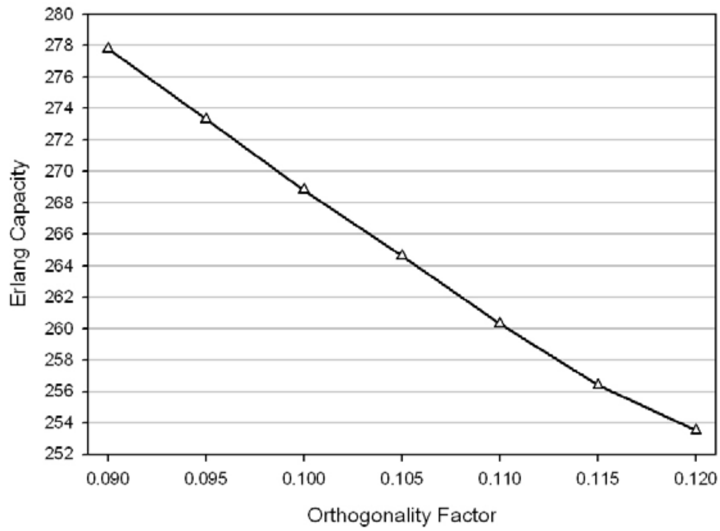

Fig. 6. Erlang capacity vs. Orthogonality factor

In Fig. 4 we present both analytical and simulation CBP results versus the offered traffic-load for the three service-classes, for the first scenario. The CBP results versus the offered traffic-load for the second scenario are presented in Fig. 5. In both Figs. 4 and 5 we observe that the accuracy of the calculations is satisfactory, especially for low, reasonable offered traffic-load.

In order to reveal the importance of the orthogonality factor for WCDMA systems, we determine the erlang capacity of the system for different orthogonality factors. To this end, first we calculate the CBP of each service-class (for each orthogonality factor) and then, based on the selected CBP boundaries per service-class, we determine the erlang capacity of the system. The CBP boundaries used in our example are 1%, 3% and 5% for the 1^{st}, 2^{nd} and 3^{rd} service-class, respectively. In Fig. 6 we present the erlang capacity versus the orthogonality factor. We observe that even small improvements in the orthogonality factors have huge impact in the erlang capacity of a WCDMA system.

5 Conclusion

In this paper, we described the WCDMA cell by a 1-dimensional Markov chain and provided an efficient recurrent formula for the system occupancy distribution, as well as the so-called local blocking probabilities. Based on them, we calculated the CBP of different service-classes accommodated in the cell, versus the total offered traffic load. We also calculated the erlang capacity of the cell for different orthogonality factors. The analytical model was evaluated through simulation. The results showed that the accuracy of the model is very satisfactory.

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