# Call Blocking Probabilities in a W-CDMA cell with interference cancellation and bandwidth reservation

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***Abstract*– In this paper, we study a multirate loss model for the calculation of Call Blocking Probabilities (CBP) in a W-CDMA cell that accommodates Poisson arriving calls of different service-classes under the Bandwidth Reservation (BR) policy. The latter is used to equalize CBP among service-classes or achieve a certain QoS. The proposed model takes into account multiple access interference, the notion of local (soft) blocking, user's activity and interference cancellation. Due to the existence of local blocking and the BR policy the steady state probabilities of the model do not have a product form solution. However, we show that the CBP calculation is based on an approximate but recursive formula whose accuracy is verified through simulation and found to be quite satisfactory.**

## I. INTRODUCTION

Wideband Code Division Multiple Access (W-CDMA) networks support heterogeneous traffic generated by a wide range of voice and data applications with different QoS requirements. The call-level analysis of such networks is complicated not only because of the existence of own-cell and other-cell interference but also because of Interference Cancellation (IC) receivers which increase the uplink capacity of W-CDMA networks.

Herein, we consider the uplink direction of a W-CDMA reference cell that supports Poisson arriving calls from $K$ different service-classes. The reference cell is modeled as a multirate loss system of fixed capacity which accommodates calls with fixed bandwidth requirements and exponentially distributed service time. A new service-class $k$ ($k$=1,…,$K$) call is accepted in the cell if: a) the requested bandwidth is available and b) the noise of all in-service calls, after the acceptance of the new call, remains below a tolerable level. Note that according to the W-CDMA principle, a call is noise for all other calls. In order to take into account the total interference increase (own-cell plus other-cell interference plus thermal noise) caused by the acceptance of the new call, we consider the notion of soft or Local Blocking (LB). The latter means that a call may be blocked in any state of the system if its acceptance violates the QoS, in terms of noise, of all in-service calls. This admission policy corresponds to the classical Complete Sharing (CS) policy, whereby all calls compete for all bandwidth resources [1].

The previous multirate loss model of a W-CDMA cell has been adopted in [2]-[6]. In these papers, the calculation of Call Blocking Probabilities (CBP) is based on formulas that resemble the classical Kaufman-Roberts formula used for the CBP calculation in the Erlang Multirate Loss Model (EMLM). The latter refers to a loss system of a single link that accommodates, under the CS policy, Poisson arriving calls of $K$ service-classes with different bandwidth requirements and generally distributed service time [7], [8]. In [2], [3] an extension of the EMLM is considered which is based on the Delbrouck's model [9]. The latter generalizes the EMLM by allowing the call-arrival process to have different peakedness factors. In [4], calls arrive in the cell according to a Poisson process. In [5], [6] calls are generated by a limited number of users, a case that is realistic in cells of limited coverage area. As far as the modeling of LB is concerned, two approaches exist in the literature. The first, proposed in [2], [3], is complex but maintains reversibility in the underlying Markov state transition diagram. The second, proposed in [4], is less complicated and is more realistic for W-CDMA systems. A comparison between these approaches is presented in [6]. Herein, we adopt the model of [4].

In this paper, we consider the abovementioned loss model of a W-CDMA cell and apply the Bandwidth Reservation (BR) policy. The BR policy can achieve CBP equalization among calls of different service-classes (by reserving bandwidth in favor of high-speed service-classes), or guarantee a certain QoS for each service-class. Applications of the BR policy in wired (e.g., [10]-[21]), wireless (e.g., [22]-[25]) and optical networks (e.g., [26]-[29]) show the policy's significant role in teletraffic engineering. Based on [5], [6], we also study the IC effect on CBP and provide a recursive formula for the CBP calculation. Note that IC receivers reduce the own-cell interference and not the other-cell interference or thermal noise [30]. This reduction results in the decrease of CBP.

This paper is organized as follows: In Section II, we review the basic formulas in the uplink direction of a W-CDMA cell. In Section III, we consider Poisson arrivals and propose an approximate but recursive formula for the CBP calculation when hard[1] and soft blocking co-exist, under the BR policy. In section IV, we present numerical results and evaluate the proposed CBP formula based on simulation results. We conclude in section V.

[1] Hard blocking occurs when the bandwidth requirement of a call is higher than the available resources of the system.

## II. Basic Formulas In The Uplink Direction of a W-CDMA Cell

Consider the uplink direction of a W-CDMA reference cell which is controlled by a Base Station (BS) and surrounded by other cells. We model this cell as a multirate loss system that supports $K$ service-classes of Poisson arriving calls. A service-class $k$ ($k$=1,…,$K$) call alternates between transmission (active) and non-transmission (passive) periods. The ratio of "active" over "active + passive" periods is the activity factor of a service-class $k$ call, $v_k$. Typical values of $v_k$ are: $v_k$ =0.67 or 1.0 if $k$ is a voice or a data service-class, respectively.

In the W-CDMA cell, a single user "sees" the signals generated by all other users as interference, since all users transmit within the same frequency band. In that case, the BS's capacity is limited by the Multiple Access Interference (MAI) [31]. The latter consists of the own-cell interference, $P_{\text{own}}$, caused by the users of the reference cell and the other-cell interference, $P_{\text{other}}$, which refers to the interference power received from users of the neighbouring cells. Due to the stochastic nature of MAI, we consider the soft or interference limited capacity of the radio interface [32]. We also consider thermal noise, $P_{noise}$, which corresponds to the interference of an empty W-CDMA system. A typical value of the thermal noise power density is 174 dBm/Hz [31]. The values of $P_{\text{own}}$ are reduced by the application of IC. The IC efficiency, $\beta$ , is defined by the ratio [30]:

$$\beta = \left(P_{own}^{NO\ IC} - P_{own}\right) \big/ P_{own}^{NO\ IC} \Rightarrow P_{own} = P_{own}^{NO\ IC}(1-\beta) \qquad (1)$$

where $P_{own}^{NO\ IC}$ is the own-cell interference without IC.

By denoting as $p_k$ the total received power from a service-class $k$ user, the power control equation for service-class $k$ is given by [30]:

$$\left(E_b/N_0\right)_k = G_k p_k \big/ \left[(P_{own} - p_k)(1-\beta) + P_{other} + P_{noise}\right] \qquad (2)$$

where $\left(E_b/N_0\right)_k$ is the signal energy per bit divided by the noise spectral density, $G_k = W/v_k R_k$ is the processing gain of service-class $k$ in the uplink with data rate $R_k$ and $W$ the chip rate of 3840 kcps.

Based on (2), the values of $p_k$ are given by:

$$p_k = \frac{\left(P_{own}(1-\beta) + P_{other} + P_{noise}\right)}{1-\beta + G_k \big/ \left(E_b/N_0\right)_k} \qquad (3)$$

Assuming that $P_{\text{own}} = p_k N_k$, where $N_k$ is the maximum number of service-class $k$ calls in the cell, we have [6]:

$$P_{own} = N_k \left(P_{other} + P_{noise}\right) \big/ \left[(1-\beta) - N_k(1-\beta) + G_k \big/ \left(E_b/N_0\right)_k\right] \qquad (4)$$

where $P_{total} = P_{own} + P_{other} + P_{noise}$ is the total received power at the BS.

Consider now the Noise Rise (NR), defined as [32]:

$$NR = P_{total}/P_{noise} = \left(P_{own} + P_{other} + P_{noise}\right) \big/ P_{noise} \qquad (5)$$

The NR is related to the total uplink cell load, $\eta_{UL}$, according to the formula [31]:

$$NR = 1 \big/ \left(1-\eta_{UL}\right), \quad \eta_{UL} = \left(P_{own} + P_{other}\right) \big/ P_{total} \qquad (6)$$

Based on (5) and (6) we have:

$$\left(P_{own} + P_{other} + P_{noise}\right) \big/ P_{noise} = 1 \big/ \left(1-\eta_{UL}\right) \qquad (7)$$

Substituting (4) in (7) and solving for $N_k$ we have [6]:

$$N_k = \left[(1-\beta) + G_k \big/ \left(E_b/N_0\right)_k\right] \frac{\left[\eta_{UL}\left(\delta+1\right) - \delta\right]}{\left[1-\beta\left(\eta_{UL}(\delta+1) - \delta\right)\right]}, \qquad (8)$$

$$\delta = P_{other} / P_{noise}$$

Having determined $N_k$ according to (8), we calculate the spread data rate $R_{s,k}$ of service-class $k$, as the proportion of $W$ utilised by a call of service-class $k$:

$$R_{s,k} = W / N_k \qquad (9)$$

Now, $W$ and $R_{s,k}$ are transformed to the uplink capacity $C$ and the bandwidth $b_k$, of each service-class $k$ call, respectively. To achieve this, consider a basic bandwidth unit (*bbu*) as the greatest common divisor of the required call resources of all service-classes, or as an arbitrarily chosen small value. E.g., if *bbu* = 20 Kcps then $C$ and $b_k$ are: $C = \lceil W/bbu \rceil = 192$ and $b_k = \lceil R_{s,k}/bbu \rceil$ channels.

## III. CBP In The Uplink Direction Of a W-CDMA Cell Under the BR Policy

In connection-oriented systems every system state $j$ ($j$=0, 1,…, $C$) which denotes the occupied bandwidth of a system can be a non-blocking or a blocking state for service-class $k$ calls, depending on the bandwidth requirement $b_k$. In W-CDMA networks we consider two types of states $j$: a) those that are blocking states for service-class $k$ calls (hard blocking states) and b) those that are blocking states with a probability $0 < L_{j,k} < 1$ (LB states) due to the existence of other-cell interference.

To consider in our model the other-cell interference, we approximate it by an independent, lognormally distributed random variable with parameters $\mu$ and $\sigma$:

$$\mu = \frac{P_{other} + P_{noise}}{P_{own} + P_{other} + P_{noise}} C \Rightarrow \mu = \frac{i + i/\delta}{1 + i + i/\delta} C, \quad \sigma = \mu \qquad (10)$$

where $i = P_{other} / P_{own}$ while $\mu$ is chosen to be equal to $\sigma$ as proposed in the literature (e.g., [6], [33]-[34]). The value of $\mu$ expresses the average capacity that is lost from the reference cell due to the other-cell interference.

Consider now a new service-class $k$ call which requires $b_k$ channels in order to be accepted in the cell and let $j$ be the occupied cell's channels at the time of arrival. Also, let $t_k$ be the BR parameter that expresses the reserved channels to benefit calls of all service-classes apart from service-class $k$. Due to the BR policy, the service-class $k$ call is not allowed to enter the reservation space which consists of the states $j = C - t_k + 1, \ldots, C$. This means, that after the acceptance of the call, $j \le C - t_k$, i.e. the available capacity upon the call arrival is $C - t_k - j$.

The LB probability (LBP) in state $j$, $L_j$, is the probability that the other-cell interference is greater than the available cell's capacity $(C - t_k - j)$:

$$L_j = P\left(j^{'} > C - t_k - j\right) = 1 - P\left(j^{'} < C - t_k - j\right) \Rightarrow$$
$$L_j = 1 - CDF(C - t_k - j) \tag{11}$$

where $j'$ refers to the occupied channels due to the other cell interference and $CDF(x)$ is the cumulative distribution function of the lognormal distribution.

The values of $CDF(x)$ are given by:

$$CDF(x) = \frac{1}{2}\left(1 + erf\left(\frac{\ln(x) - M}{S\sqrt{2}}\right)\right) \tag{12}$$

where *erf* is the error function, while $M$ and $S$ refer to the parameters of the normal distribution:

$$M = \ln\left(\mu^2 \Big/ \sqrt{\mu^2 + \sigma^2}\right), \quad S = \sqrt{\ln\left(1 + \left(\sigma^2/\mu^2\right)\right)} \tag{13}$$

The service-class $k$ call will be accepted in the cell if all $b_k$ channels are assigned to the call simultaneously. Thus, we can assume that the other-cell interference (and consequently the LBP) remains the same during this channel allocation process. We can express the passage factor $1 - L_{j,b_k}$, i.e., the probability that the call will not be blocked due to the other-cell interference as a function of the number of channels occupied in the cell and $b_k$:

$$1 - L_{j,b_k} = (1 - L_{j+b_k-1}) \overset{(11)}{=} CDF(C - t_k - j - b_k + 1) \tag{14}$$

Note that a similar approach, in the case of the CS policy, has been proposed in [4].

Due to the introduction of passage factor according to (14) the transition rate from state $(j - b_k)$ to $(j)$, equals $\left(1 - L_{j-b_k,b_k}\right)\lambda_k = \left(1 - L_{j-1}\right)\lambda_k$. Figure 1 presents an excerpt of the system's state transition diagram which is depicted by a one-dimensional Markov chain. Note that $\lambda_k$ and $\mu_k$ are the mean arrival and service rate of service-class $k$ calls, respectively, while $y_k(j)$ is the average number of service-class $k$ calls in state $j$.

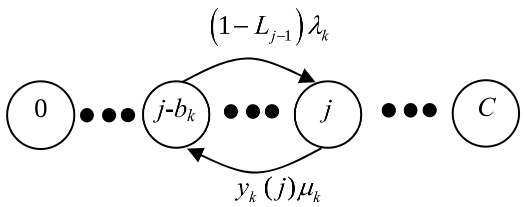


Figure 1: State transition diagram for service-class $k$ calls with LB between states $j$-$b_k$ and $j$.

To calculate the un-normalized values of the system state probabilities, $q(j)$, we propose the following approximate but recursive formula:

$$q(j) = \begin{cases} 1 & , \ for \ j = 0 \\ \frac{1}{j}\sum_{k=1}^{K} a_k D_k(j - b_k) q(j - b_k)(1 - L_{j-b_k,b_k}), & for \ j = 1,...,C \\ 0 & , \ otherwise \end{cases} \tag{15}$$

$$D_k(j\text{-}b_k) = \begin{cases} b_k & for \ j \le C - t_k \\ 0 & for \ j > C - t_k \end{cases} \tag{16}$$

where: $\alpha_k = \lambda_k/\mu_k$ is the offered traffic-load of service-class $k$ calls (in erl), $t_k$ is the BR parameter while the values of $\left(1 - L_{j-b_k,b_k}\right)$ are determined by (14):

$$\left(1 - L_{j-b_k,b_k}\right) = 1 - L_{j-1} = CDF(C - t_k - j + 1) \tag{17}$$

Note that (16) facilitates the introduction of the BR policy in the model. The underlying assumption of (16) is that the population of service $k$ calls, which require $b_k$ channels while $t_k > 0$, is negligible inside the reservation space of service-class $k$, i.e., when $j = C - t_k + 1, \ldots, C$. In the case of the CS policy, (15) takes the form [4], [6]:

$$q(j) = \begin{cases} 1 & , \ for \ j = 0 \\ \frac{1}{j}\sum_{k=1}^{K} a_k b_k q(j - b_k)(1 - L_{j-b_k,b_k}), & for \ j = 1,...,C \\ 0 & , \ otherwise \end{cases} \tag{18}$$

In addition, if the notion of LB is not considered then the classical Roberts' formula for the EMLM under the BR policy arises [10]:

$$q(j) = \begin{cases} 1 & , \ for \ j = 0 \\ \frac{1}{j}\sum_{k=1}^{K} a_k D_k(j - b_k) q(j - b_k), & for \ j = 1,...,C \\ 0 & , \ otherwise \end{cases} \tag{19}$$

where the values of $D_k(j - b_k)$ are given by (16).

Having determined $q(j)$'s according to (15), we can calculate CBP of service-class $k$, $P_{b_k}$, as follows:

$$P_{b_k} = \sum_{j=0}^{C} G^{-1} L_{j,j+b_k} q(j) \tag{20}$$

where $G = \sum_{j=0}^{C} q(j)$ is the normalization constant and the values of $L_{j,j+b_k} = 1 - CDF(C - t_k - j - b_k + 1)$.

## IV. NUMERICAL EXAMPLES - EVALUATION

In this section, we compare the analytical and simulation CBP results obtained by the proposed model for different values of the IC efficiency $\beta$. For comparison, we also show the corresponding analytical results obtained in the case of the CS policy. Simulations are based on the SIMSCRIPT III language [35] and are mean values of 7 runs.

Consider a W-CDMA reference cell that accommodates Poisson arriving calls of $K$=3 different service-classes. Accepted calls remain in the link for an exponentially distributed service time with mean value $\mu_1^{-1} = \mu_2^{-1} = \mu_3^{-1} = 1$. In Table I, we show the traffic characteristics of all service-classes. In addition, we assume that: $\eta_{UL}$=0.75, $i$=0.35, $\delta$=2.0, $bbu$=13.5 kcps while the IC efficiency $\beta$ takes the values 0.0 and 0.8. When $\beta$=0.0 then the bandwidth requirements and the corresponding BR parameters of all service-classes are: $b_1$ = 4, $b_2$ = 7, $b_3$ = 64 and $t_1$=60, $t_2$=57, $t_3$=0. Note that the values of the BR parameters are chosen according to the CBP equalization rule: $b_1 + t_1 = b_2 + t_2 = b_3$. Similarly, when $\beta$=0.8 then $b_1$ = 4, $b_2$ = 5, $b_3$ = 54 and $t_1$=50, $t_2$=49, $t_3$=0.

Table I: Traffic parameters of all service-classes.

| *Service-class k* | $R_k$ (kbps) | $v_k$ | $\left(E_b/N_0\right)_k$ (in dB) | $\left(E_b/N_0\right)_k$ | $a_k$ (in erl) |
|---|---|---|---|---|---|
| 1 | 7.95 | 0.67 | 4.0 | 2.51 | 3.0 |
| 2 | 12.20 | 0.67 | 4.0 | 2.51 | 2.0 |
| 3 | 144.00 | 1.0 | 2.0 | 1.58 | 0.05 |

In the x-axis of Figs 2-4 the offered traffic load of the 1st, 2nd and 3rd service-class increase in steps of 1.0, 1.0 and 0.01 erl, respectively. So, point 1 refers to: ($\alpha_1$, $\alpha_2$, $\alpha_3$) = (3.0, 2.0, 0.05) while point 6 to: ($\alpha_1$, $\alpha_2$, $\alpha_3$) = (8.0, 7.0, 0.10). Figures 2a-2b, present the analytical and simulation CBP results of the 1st service-class for $\beta$=0.0 and 0.8, respectively. Figures 3a-3b and 4a-4b, present the corresponding results of the 2nd and 3rd service-class, respectively. Based on these results, we conclude that: 1) The proposed CBP formula in the case of the BR policy gives quite accurate results compared to simulation. 2) The increase of $\beta$ results in the CBP decrease since the IC reduces the own-cell interference. 3) The CBP obtained by considering the CS policy fail to approximate the corresponding CBP in the case of the BR policy. 4) The application of the BR policy results in a slight decrease of the CBP of the 3rd service-class compared to the increase of the CBP of the other two service-classes.

## V. CONCLUSION

We propose a multirate loss model for the call-level analysis of a W-CDMA reference cell that supports Poisson arriving calls from different service-classes. The new model takes into account multiple access interference, the notion of local blocking, user's activity, interference cancellation and the BR policy. The latter is used to achieve CBP equalization among calls of different service-classes. Due to the existence of local blocking and the BR policy, the proposed model does not have a product form solution. However, we show an approximate but recursive formula for the calculation of occupancy distribution and CBP. Simulation results verify the accuracy of the proposed model.

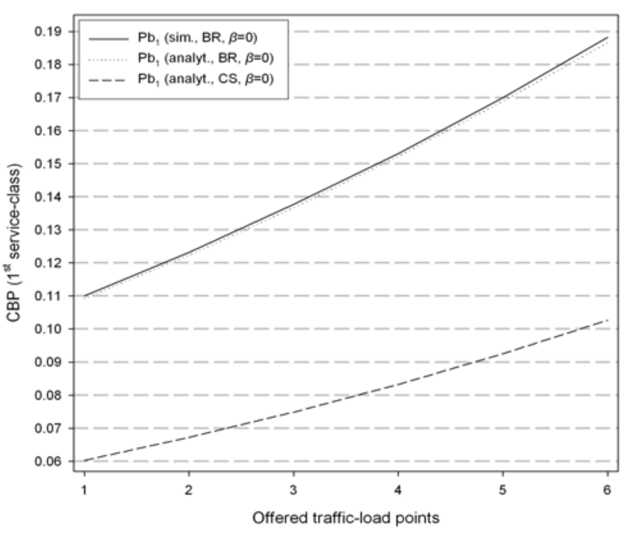


Figure 2a. TC probabilities – 1st service-class ($\beta$=0.0).

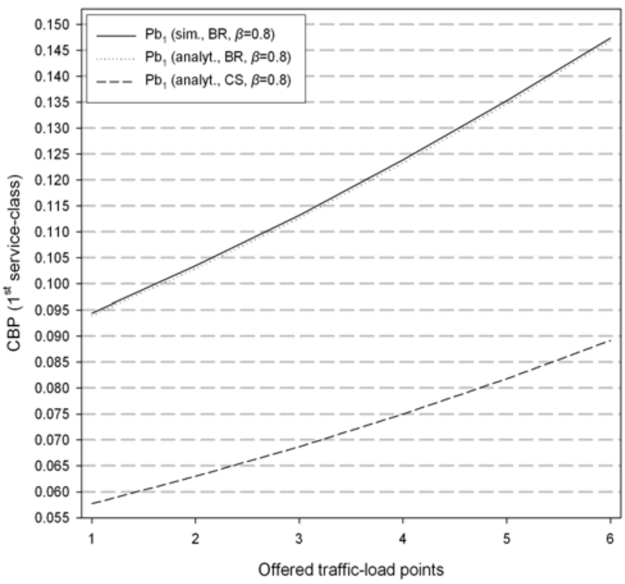


Figure 2b. TC probabilities – 1st service-class ($\beta$=0.8).

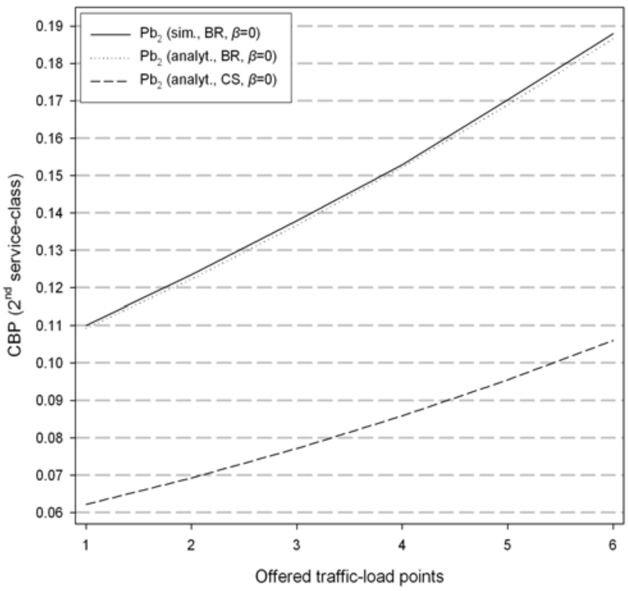


Figure 3a. TC probabilities – 2nd service-class ($\beta$=0.0).

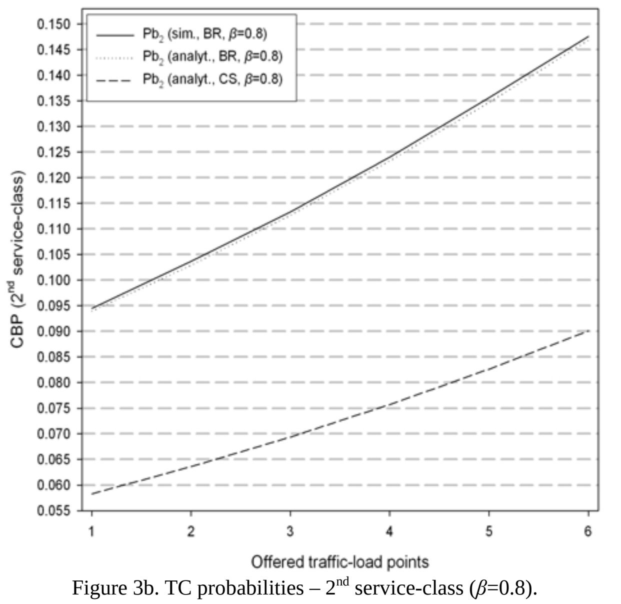


Figure 3b. TC probabilities – 2nd service-class ($\beta$=0.8).

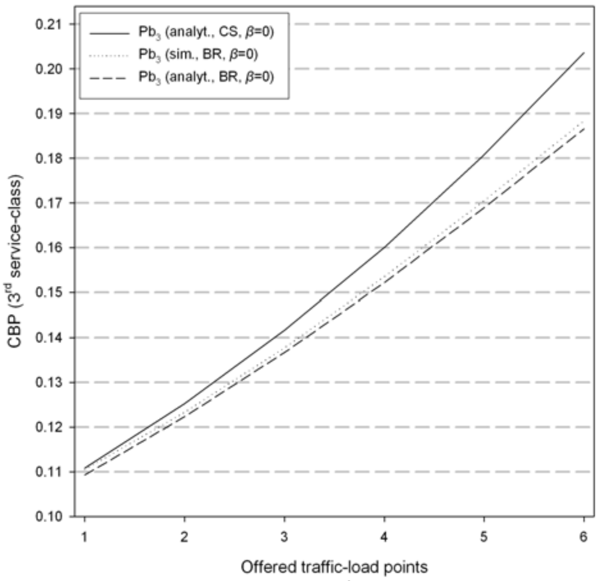


Figure 4a. TC probabilities – 3rd service-class ($\beta$=0.0).

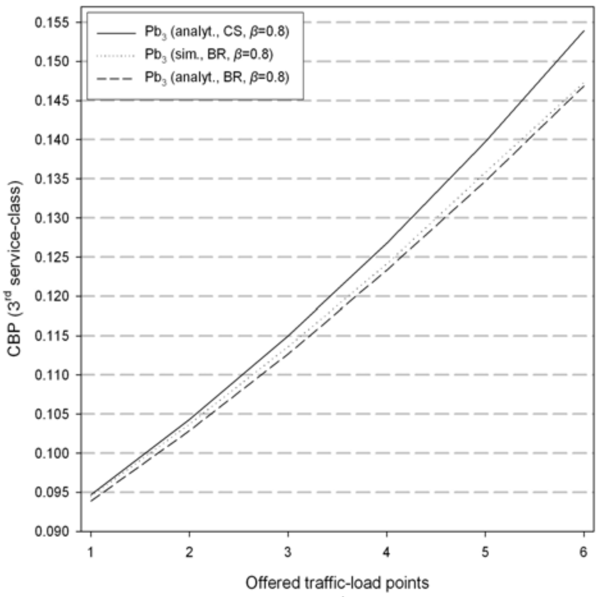


Figure 4b. TC probabilities – 3rd service-class ($\beta$=0.8).

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