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Approximated Mathematical Analysis Methods of Guard-Channel-Based Call Admission Control in Cellular Networks

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1. Introduction

Guard Channel-based call admission control strategies are a classical topic of exhaustive research in cellular networks (Lunayach et al., 1982; Posner & Guerin, 1985; Hong & Rappaport, 1986). Guard channel-based strategies reserve an amount of resources (bandwidth/number of channels/transmission power) for exclusive use of a call type (i.e., new, handoff, etc.), but they have mainly been utilized to reduce the handoff failure probability in mobile cellular networks. Guard Channel-based call admission control strategies include the Conventional Guard Channel (CGC) scheme[1] (Hong & Rappaport, 1986), Fractional Guard Channel (FGC) policies[2] (Ramjee et al., 1997; Fang & Zhang, 2002; Vázquez-Ávila et al., 2006; Cruz-Pérez & Ortigoza-Guerrero, 2006), Limited Fractional Guard Channel scheme (LFGC) (Ramjee et al., 1997; Cruz-Pérez et al., 1999), and Uniform Fractional Guard Channel (UFGC) scheme[3] (Beigy & Meybodi, 2002; Beigy & Meybodi, 2004). They have widely been considered as prioritization techniques in cellular networks for nearly 30 years because they are simple and effective resource management strategies (Lunayach et al., 1982; Posner & Guerin, 1985; Hong & Rappaport, 1986).

In this Chapter, both a comprehensive review and a comparison study of the different approximated mathematical analysis methods proposed in the literature for the performance evaluation of Guard-Channel-based call admission control for handoff prioritization in mobile cellular networks is presented.

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[1] An integer number of channels is reserved.

[2] FGC policies are general call admission control policies in which an arriving new call will be admitted with probability β_i when the number of busy channels is i (i = 0, ..., N-1).

[3] LFGC finely controls communication service quality by effectively varying the average number of reserved channels by a fraction of one whereas UFGC accepts new calls with an admission probability independent of channel occupancy.

2. System model description

The general guidelines of the model presented in most of the listed references are adopted to cast the system considered here in the framework of birth and death processes. A homogeneous multi-cellular system with S channels per cell is considered. It is also assumed that both the unencumbered call duration and the cell dwell time for new and handed off calls have negative exponential probability density function (pdf). Hence, the channel holding time is also negative exponentially distributed. $1/\mu_n$ and $1/\mu_h$ denote the average channel holding time for new and handed off calls, respectively. Finally, it is also assumed that new and handoff call arrivals follow independent Poisson processes with mean arrival rates λ_n and λ_h, respectively.

In general, the mean and probability distribution of the cell dwell time for users with new and handed off calls are different (Posner & Guerin, 1985; Hong & Rappaport, 1986; Ramjee et al., 1997; Fang & Zhang, 2002). The channel occupancy distribution in a particular cell directly depends on the channel holding time (i.e.: the amount of time that a call occupies a channel in a particular cell). The channel holding time is given by the minimum of the unencumbered service time and the cell dwell time. On the other hand, the average time that a call (new or handed off) occupies a channel in a cell (here called effective average channel holding time) depends on the channel holding time of new and handed off calls and its respective admission rate. However, these quantities depend on each other and can only be approximately estimated. Thus, to achieve accurate results in the performance evaluation of mobile cellular systems with guard channel-based strategies, the precise estimation of the effective average channel holding time is crucial.

3. Approximated mathematical analysis methods proposed in the literature

In the first published related works, new call blocking and handoff failure probabilities were analyzed using one-dimensional Markov chain under the assumption that channel holding times for new and handoff calls have equal mean values. This assumption was to avoid large set of flow equations that makes exact analysis of these schemes using multidimensional Markov chain models infeasible. However, it has been widely shown that the new call channel holding time and handoff call channel holding time may have different distributions and, even more, they may have different average values (Hong & Rappaport, 1986; Fang & Zhang, 2002; Zhang et al., 2003; Cruz-Pérez & Ortigoza-Guerrero, 2006; Yavuz & Leung, 2006). As the probability distribution of the channel holding times for handed off and new calls directly depend on the cell dwell time, the mean and probability distribution of the channel holding times for handed off and new calls are also different. On the other hand, the channel occupancy distribution in a particular cell directly depends on the channel holding time (i.e. the amount of time that a call occupies a channel in a particular cell). To avoid the cumbersome exact multidimensional Markov chain model when the assumption that channel holding times for new and handoff calls have equal mean values is no longer valid, different approximated one-dimensional mathematical analysis methods have been proposed in the literature for the performance evaluation of guard-channel-based call admission control schemes in mobile cellular networks (Re et al., 1995; Fang & Zhang, 2002; Zhang et al., 2003; Yavuz & Leung, 2006; Melikov and Babayev, 2006; Toledo-Marín et al., 2007). In general, existing models in the literature for the performance analysis of GC-based strategies basically differ in the way the channel holding time or the offered load per

cell used for the numerical evaluations is determined. Let us briefly describe and contrast these methods. Due to its better performance, the Yavuz and iterative methods are described more detailed.

3.1 Traditional approach

The "traditional" approach assumes that channel holding times for new and handoff calls have equal mean values (Hong & Rappaport, 1986) and it considers that the average channel holding time (denoted by $1/\gamma_{av_trad}$) is given by

$$\frac{1}{\gamma_{av_trad}} = \frac{\lambda_n}{\lambda_n + \lambda_h}\left(\frac{1}{\mu_n}\right) + \frac{\lambda_h}{\lambda_n + \lambda_h}\left(\frac{1}{\mu_h}\right) \tag{1}$$

However, this equation cannot accurately approximate the value of the average channel holding time in GC-based call admission strategies because new and handoff calls are not blocked equally.

3.2 Soong method

To improve the traditional approach, a different method using a simplified one-dimensional Markov chain model was proposed in (Zhang et al., 2003). Yan Zhang, B.-H- Soong, and M. Ma proposed mathematical expressions for the estimation of the conditional average numbers of new and handoff ongoing calls given a number of free channels and used them to calculate the call blocking probabilities. This method is referred here as the "Soong method".

3.3 Normalized approach

The issue of improving the accuracy of the traditional approximation was also addressed in (Fang & Zhang, 2002) by normalizing to one the channel holding time for new call arrival and handoff call arrival streams. By normalizing the channel holding time, this parameter is the same for both traffic streams. This is known as the "normalized approach".

3.4 Weighted mean exponential approximation

In (Re et al., 1995), the common channel holding time is approximated by weighting the summation of the new call mean channel holding time and the handoff call mean channel holding time and it is referred as the "weighted mean exponential approximation".

3.5 Melikov method

The authors in paper (Melikov & Babayev, 2006) also proposed an approximate result for the stationary occupancy probability. The bi-dimensional state space of the exact method is split into classes, assuming that transition probabilities within classes are higher than those between states of different classes. Then, phase merging algorithm (PMA) is applied to approximate the stationary occupancy probability distribution by the scalar product between the stationary distributions within a class and merged model. This method is referred here as the "Melikov method".

3.6 Yavuz method

On the other hand, in (Yavuz & Leung, 2006) the exact two-dimensional Markov chain model was reduced to a one-dimensional model by replacing the average channel holding

times for new and handoff calls by the so called average effective channel holding time (Yavuz & Leung, 2006). Based on the well-known Little's theorem, the average effective channel holding time was defined in (Yavuz & Leung, 2006) as the ratio of the expected number of arrivals of both call types to the expected number of occupied channels. However, the authors of (Yavuz & Leung, 2006) realized that this requires the knowledge of equilibrium occupancy probabilities and observed that the average channel holding time of each type of call is not directly considered in these equations when computing the approximate equilibrium occupancy probabilities since they are replaced by the average effective channel holding time. Hence, they proposed to initially set the approximate equilibrium occupancy probabilities with the values obtained by the normalized approach. This method is referred here as the "Yavuz method".

Inspired by the Litte's theorem, the inverse of the average effective channel holding time (denoted by $1/\mu_{eff}$) is defined as the ratio of expected number of both types of call arrivals to the expected number of occupied channels, that is,

$$\mu_{eff} = \frac{\sum_{j=0}^{S-1}\left(\lambda_n \beta_j q(j)\right) + \sum_{j=0}^{S-1}\left(\lambda_h q(j)\right)}{\sum_{j=0}^{S} j q(j)} \tag{2}$$

Let $q'(l)$, $l = 0, \ldots, S$ represent the occupancy probabilities. The probability that l channels are being used is approximated by the one-dimensional Kauffman recursive formula:

$$\left(\lambda_n \beta_{c-1} + \lambda_h\right) q'(l-1) = l \mu_{eff} q'(l) \quad ; l = 1, \ldots, S \tag{3}$$

where β_i represents the probability that an arriving new call is admitted when the number of busy channels is i ($i = 0, \ldots, S$-1). FGC policies use a vector $\mathbf{B} = [\beta_0, \ldots, \beta_{S-1}]$ to determine if new calls can be accepted and the components of this vector determine the strategy.

Using the normalization equation, $\sum_{j=0}^{S} q'(j) = 1$, equation (3) can be recursively solved for $q'(j)$,

$$q'(j) = \frac{\prod_{k=0}^{j-1}\left(\lambda_n \beta_k + \lambda_h\right)}{\mu_{eff}^{j} \cdot j!} q'(0) \quad ; 1 \le j \le S \tag{4}$$

where,

$$q'(0) = \left[1 + \sum_{j=1}^{S} \frac{\prod_{k=0}^{j-1}\left(\lambda_n \beta_k + \lambda_h\right)}{\mu_{eff}^{j} \cdot j!} \right]^{-1} \tag{5}$$

It is important to notice that to calculate the average effective channel holding time is necessary the knowledge of equilibrium occupancy probabilities. However, this probability

distribution cannot be calculated if the average effective channel holding time is unknown. To solve this, the authors of (Yavuz & Leung, 2006) proposed to initially set the approximate equilibrium occupancy probabilities $q(j)$ with the values obtained by the normalized approach.

3.7 Iterative method

Contrary to the Yavuz and Leung approach, in (Toledo-Marín et al., 2007) it is proposed an iterative approximation analysis method that does not require consideration of an initial occupancy probability distribution because the approximate equilibrium occupancy probabilities are iteratively calculated by directly considering the average channel holding time of each type of call. In (Toledo-Marín et al., 2007), the average effective channel holding $1/\gamma$ is iteratively calculated by weighting, at each iteration, the mean channel holding time for the different types of calls by its corresponding effective admission probability (also referred to as effective channel occupancy probability). This method is referred here as the "Iterative method".

Let P_b and P_h represent, respectively, the new call blocking and handoff failure probabilities. Then,

$$\frac{1}{\gamma} = \frac{\lambda_n(1-P_b)\dfrac{1}{\mu_n} + \lambda_h(1-P_h)\dfrac{1}{\mu_h}}{\lambda_n(1-P_b) + \lambda_h(1-P_h)} \tag{6}$$

As a homogenous system is assumed, the overall system performance can be analyzed by focusing on one given cell. Let β_i (for i = 0,. . . , S-1) denote a non-negative number no greater than one (i.e., $0 \le \beta_i \le 1$) and β_S=0. FGC policies use a vector $\mathbf{B} = [\beta_0,. . . ,\beta_{S-1}]$ to determine if new calls can be accepted and the components of this vector determine the strategy (Cruz-Pérez et al., 1999; Vázquez-Ávila et al., 2006). Let us also denote the state of the given cell as j, where j represents the number of active users in the cell. Let P_j denote the steady state probability with j calls in progress in the cell of reference; then, for the FGC scheme, the equilibrium occupancy probabilities are given by:

$$P_j = \frac{\dfrac{\prod_{i=0}^{j-1}(\beta_i\lambda_n + \lambda_h)}{j!\gamma^j}}{\sum_{k=0}^{S}\dfrac{\prod_{i=0}^{k-1}(\beta_i\lambda_n + \lambda_h)}{k!\gamma^k}}; \quad 0 \le j \le S \tag{7}$$

The new call blocking and handoff failure probabilities are given, respectively, by:

$$P_b = \sum_{j=0}^{S}\left(1-\beta_j\right)P_j \tag{8}$$

$$P_h = P_S \tag{9}$$

The iteration algorithm works as follows:

Input: S, μ_n, μ_h, λ_n, λ_h, **B**.
Output: P_b, P_h.
Step 0: $P_b \leftarrow 0$, $P_h \leftarrow 0$, $\varepsilon \leftarrow 1$, $\gamma \leftarrow 0$.
Step 1: If $|\varepsilon| < 10^{-5}\gamma$ finish the algorithm, else go to Step 2.
Step 2: Calculate new γ using (6), calculate P_j using (7), and calculate P_b and P_h using (8) and (9), respectively.
Step 3: Calculate new ε as the difference between the new γ and the old γ, go to Step 1.

For all cases studied in this work, the above procedure converges. The algorithm initially assumes arbitrary values for the new call blocking and handoff failure probabilities. Finally, note that recursive formulas can be alternatively employed for the calculation of the new call blocking and handoff failure probabilities in Step 2 (Santucci, 1997; Haring et al., 2001; Vázquez-Ávila et al., 2006).

4. Numerical results

In this section, the performance of the different approximated mathematical analysis methods is compared in terms of the accuracy of numerical results for the new call blocking and handoff failure probabilities and their computational complexity. To the best authors' knowledge, the comprehensive review and performance comparison have not been performed before in the open literature. In particular, no performance comparison of the PMA-based (referred to as Melikov) method against any other approximated analytical method has been previously reported. In (Yavuz & Leung, 2006), the performance of the Yavuz method is compared against the Exact (Li & Fang, 2008), Traditional (Hong & Rappaport, 1986), and Normalized (Fang & Zhang, 2002) methods; and in (Toledo-Marín et al., 2007), the performance of the One-Dimensional Iterative (referred to as Iterative) method is additionally compared against the Yavuz and Soong (Zhang et al., 2003) methods.

In this Section, numerical results for the new call blocking and handoff failure probabilities of the normalized, Melikov, Yavuz, and Iterative analytical methods are compared. As shown in the listed references, the other approximation methods show very poor performance in terms of its accuracy relative to the exact method and, therefore, are not considered here. In addition, all of these methods are compared against the exact solution (Exact method) given by the computation of a two-dimensional Markov chain and numerically solved by using the Gauss-Seidel method. In the evaluations, it is assumed that each cell has S = 30 channels. For the sake of comparison two different ranges of values for the traffic load are considered: 0-15 Erlangs/cell (light traffic load scenario) and 110-160 Erlangs/cell (heavy traffic load scenario). For the sake of clarity and similar to (Yavuz & Leung, 2006), the values of the new call and handoff rates, and the channel holding time for handoff calls are fixed and have been arbitrarily chosen. These values are shown in Table 1. Similar numerical results have been obtained for other scenarios. The range of the offered traffic per cell a is determined by the arrival rate and channel holding time of new calls, given by:

$$a = \lambda_n / \mu_n \tag{10}$$

Figures in this section plot the new call blocking and handoff failure probabilities versus the offered load per cell with the number of reserved channels for handoff prioritization (N) as parameter. It is observed that the Iterative method gives the best approximation to the exact

Evaluation scenario	λ_n	λ_h	$1/\mu_n$(s)	$1/\mu_h$(s)
Low traffic load	1/30	1/20	1500 - 100	200
Heavy traffic load	1/5	1/20	800 - 450	200

Table 1. System parameters values for the considered scenarios.

solution followed by the Yavuz method; this is particularly true for a low and moderate number of reserved channels, which typically is a scenario of practical interest (Vázquez-Ávila et al., 2006). The Soong method offers the worst approximation. All the approximations, except the Soong method, give exact solutions in the case of no handoff prioritization (i.e., $N = 0$), as shown in (Toledo-Marín et al., 2007). It is important to note that differences between approximation approaches and the exact solution rise with the increment of the number of guard channels and/or the offered load. Finally, it is important to note that the iterative method is applicable to any GC-based strategy and recursive formulas (Vázquez-Ávila et al., 2006) can be alternatively used for the calculation of the new call blocking and handoff failure probabilities.

4.1 Light traffic load scenario

In this section, under light-traffic-load conditions, the performance of the different approximated mathematical analysis methods for the performance evaluation of Guard-Channel-based call admission control for handoff prioritization in mobile cellular networks is investigated. In this Chapter, light traffic load means that the used values of the offered traffic load result in new call blocking probabilities less than 5%, which are probabilities of practical interest.

Figs. 2 and 3 (4 and 5) show the new call blocking probability (handoff failure probability) as function of traffic load for the cases when 1 and 2 channels are, respectively, reserved for handoff prioritization. Fig. 1 shows the new call blocking and handoff failure probabilities as function of traffic load for the case when no channels are reserved for handoff prioritization (i.e., N=0). Due to the fact that handoff failure and new call blocking probabilities are equal for the case when N=0, then, Fig. 1, also correspond to the handoff failure probability. From Fig. 1, it is observed that all the approximated methods give exact solutions in the case of no handoff prioritization (i.e., $N = 0$).

On the other hand, from Figs. 2-5, it is observed that differences between approximated approaches and the exact solution increase with the increment of the number of guard channels and/or the offered load. Notice, also, that these differences are more noticeable when the handoff failure probability is considered. It is interesting to note from Figs. 2-5 that, contrary to the *iterative*, *Yavuz* and *Melikov* methods, the *normalized* method underestimate both new call blocking and handoff failure probabilities.

In order to directly quantify the relative percentage difference between the exact and the different approximated methods, Figs. 6 and 7 plot in 3D graphics these percentage differences for the blocking and handoff failure probabilities, respectively. These differences are plotted as function of both offered load and the average number of reserved channels. It is observed that, irrespective of the number of reserved channels, the *iterative* and *Yavuz* methods have similar performance and give the best approximation to the exact solution followed by the *normalized* method. The *Melikov* method offers, in general, the worst approximation followed by the *normalized* method. For instance, for the range of values presented in Fig. 6 (Fig. 7), it is observed that the maximum difference between the exact method and the *iterative, Yavuz*, *normalized* and *Melikov* methods is respectively 2.44%,

2.55%, 5.77%, and 24.4% (7.56%, 7.30%, 46%, and 167%) when the new call blocking probability (handoff failure probability) is considered.

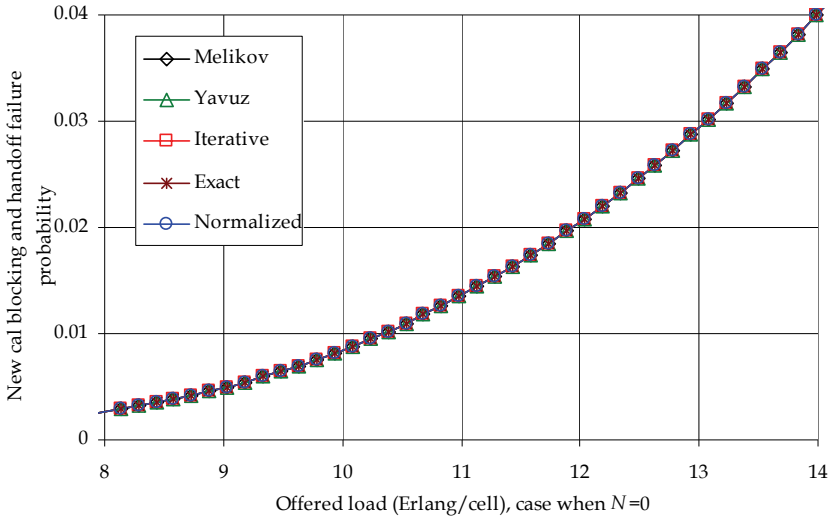

Fig. 1. New call blocking and handoff failure probability versus offered traffic per cell when N = 0, light traffic load scenario.

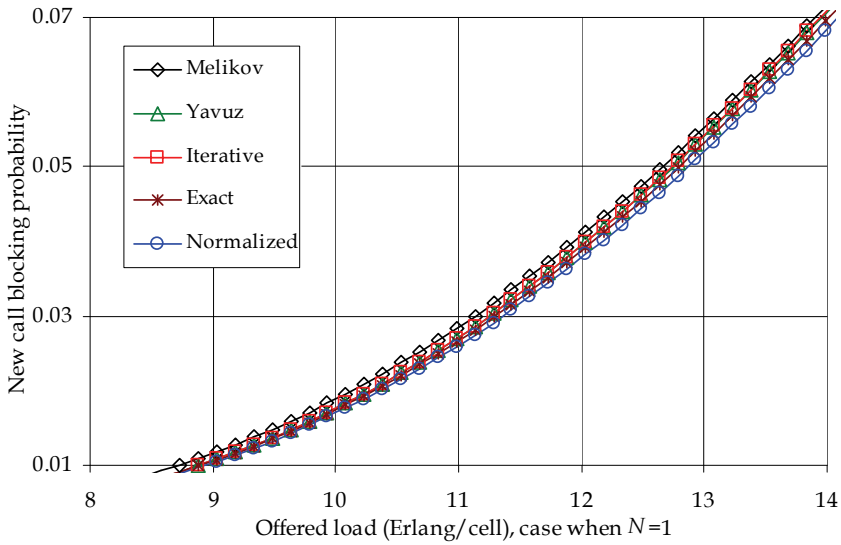

Fig. 2. New call blocking probability versus offered traffic per cell when N = 1, light traffic load scenario.

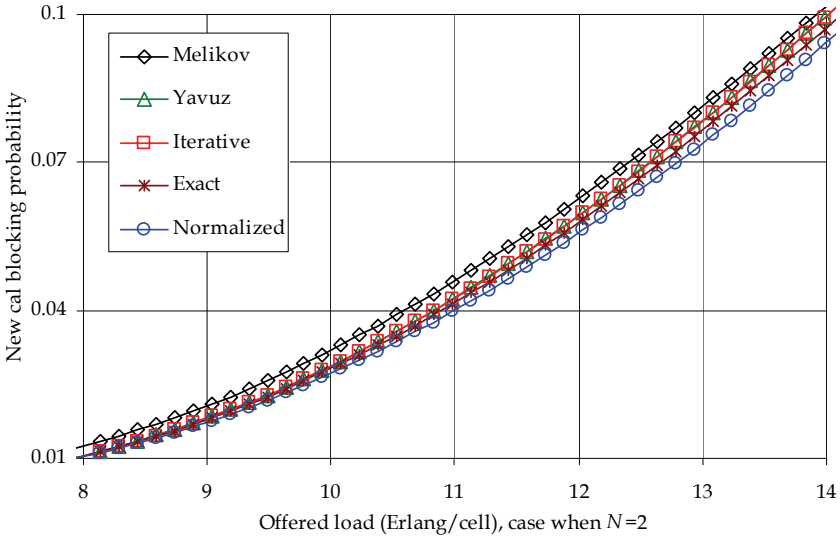

Fig. 3. New call blocking probability versus offered traffic per cell when N = 2, light traffic load scenario.

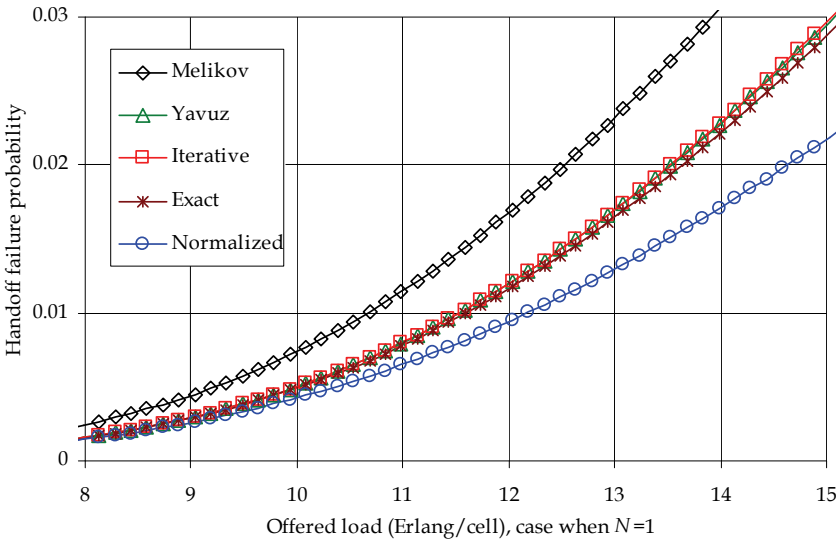

Fig. 4. Handoff failure probability versus offered traffic per cell when N = 1, light traffic load scenario.

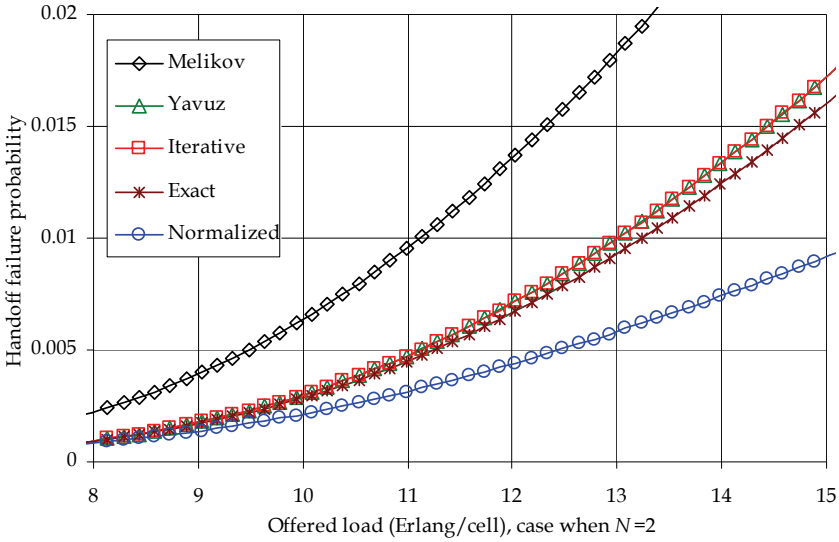

Fig. 5. Handoff failure probability versus offered traffic per cell when N = 2, light traffic load scenario.

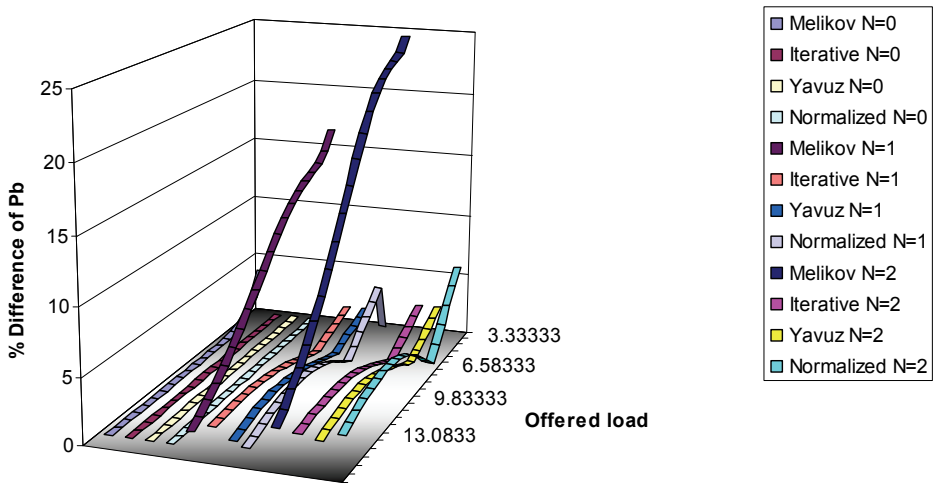

Fig. 6. Percentage difference between the new call blocking probabilities obtained with the exact and the different approximated methods, light traffic load scenario.

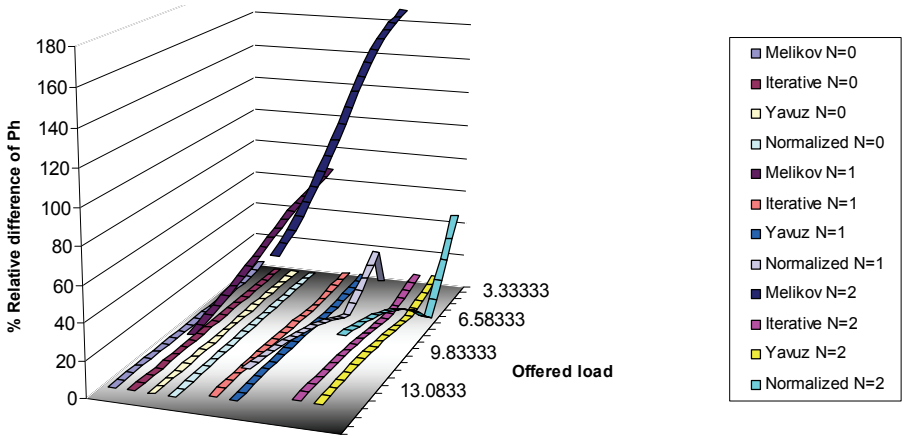

Fig. 7. Percentage difference between the handoff failure probabilities obtained with the exact and the different approximated methods, light traffic load scenario.

4.2 Heavy traffic load scenario

In this section, under heavy-traffic-load conditions, the performance of the different approximated mathematical analysis methods for the performance evaluation of Guard-Channel-based call admission control for handoff prioritization in mobile cellular networks is investigated. In this Chapter, heavy traffic load means that the used values of the offered traffic load result in new call blocking probabilities grater than 70%.

Figs. 9 and 10 (11 and 12) show the new call blocking probability (handoff failure probability) as function of traffic load for the cases when 1 and 2 channels are, respectively, reserved for handoff prioritization. Fig. 8 shows the new call blocking and handoff failure probabilities as function of traffic load for the case when no channels are reserved for handoff prioritization (i.e., N=0). From Fig. 8, it is observed that all the approximated methods give exact solutions in the case of no handoff prioritization (i.e., N = 0).

On the other hand, from Figs. 9-12, it is observed that differences between approximated approaches and the exact solution increase with the increment of the number of guard channels and/or the offered load. Notice, also, that these differences are more noticeable when the handoff failure probability is considered. It is interesting to note from Figs. 9 and 10 (11 and 12) that, contrary to the *iterative*, *Yavuz* and *Melikov* (*normalized*) methods, the *normalized* (*Melikov*) method overestimate new call blocking (handoff failure) probabilities.

On the other hand, Figs. 13 and 14 plot in 3D graphics the relative percentage difference between the exact and the different approximated methods for the blocking and handoff failure probabilities, respectively. These differences are plotted as function of both offered load and the average number of reserved channels. As expected, from these figures it is observed that all the approximated methods give exact solutions in the case of no handoff prioritization (i.e., N = 0). Figs. 8-11 show that the iterative method presents the best accurate results. Also, from Figs. 8 and 10, it is interesting to note that, referring to the blocking probability, the normalized approach performs slightly better than the Yavuz one; the opposite occurs when the handoff failure probability is considered (see Figs. 9 and 11). For instance, for the range of values presented in Fig. 10 (Fig. 11), it is observed that the

maximum difference between the exact method and the iterative, Yavuz, normalized, and Melikov methods is respectively 0.074%, 2.77%, 1.33%, and 3.25% (4.41%, 7.59%, 64.8%, and 165%) when the new call blocking probability (handoff failure probability) is considered.

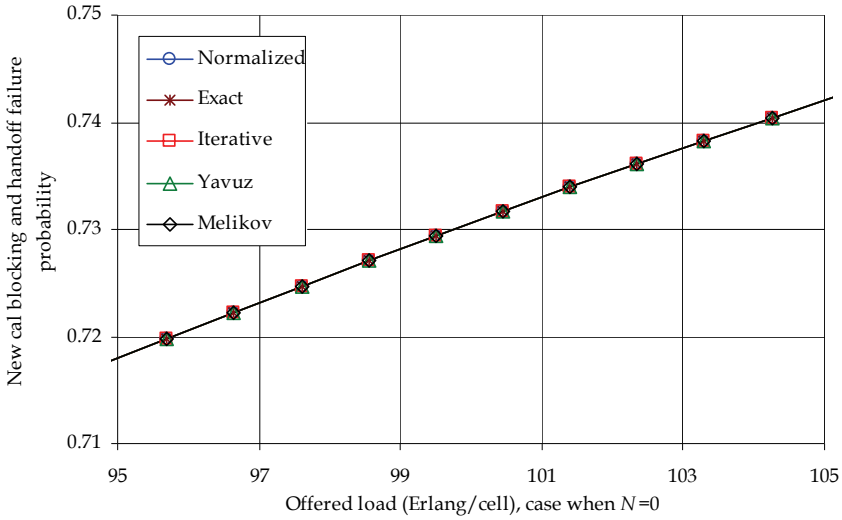

Fig. 8. New call blocking probability versus offered traffic per cell when N = 0, heavy traffic load scenario.

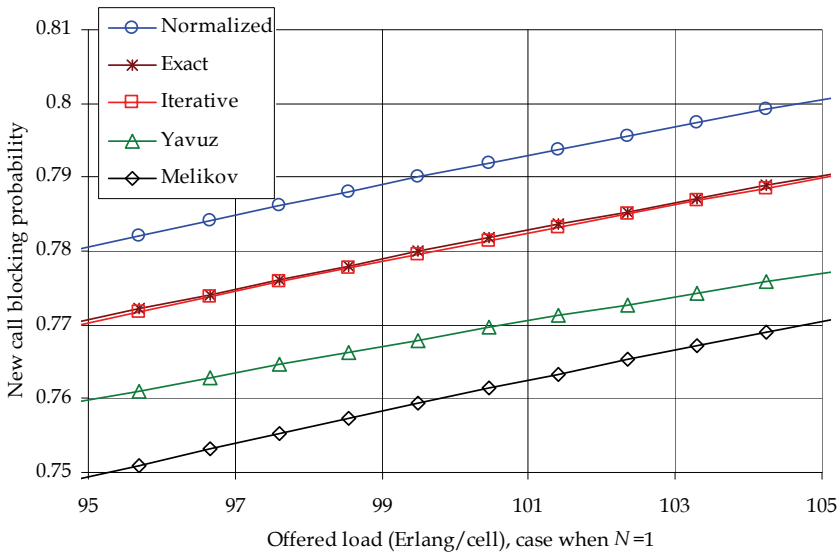

Fig. 9. New call blocking probability versus offered traffic per cell when N = 1, heavy traffic load scenario.

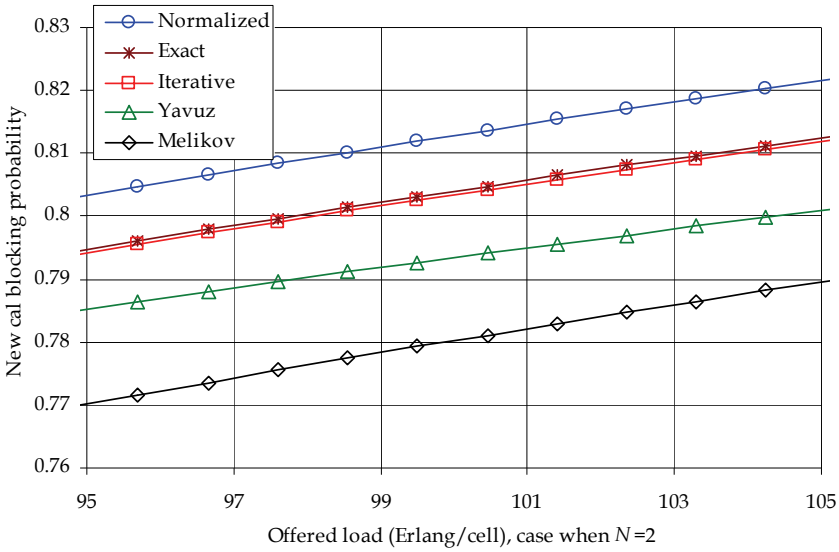

Fig. 10. New call blocking probability versus offered traffic per cell when N = 2, heavy traffic load scenario.

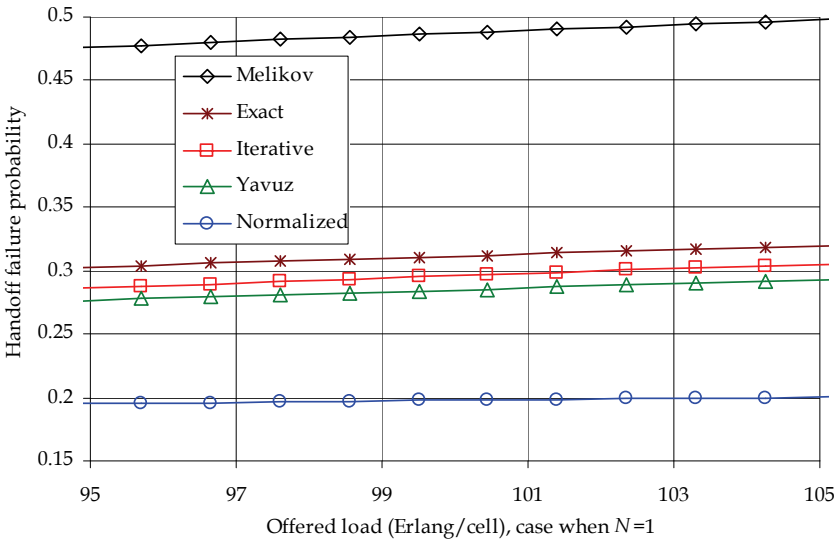

Fig. 11. Handoff failure probability versus offered traffic per cell when N = 1, heavy traffic load scenario.

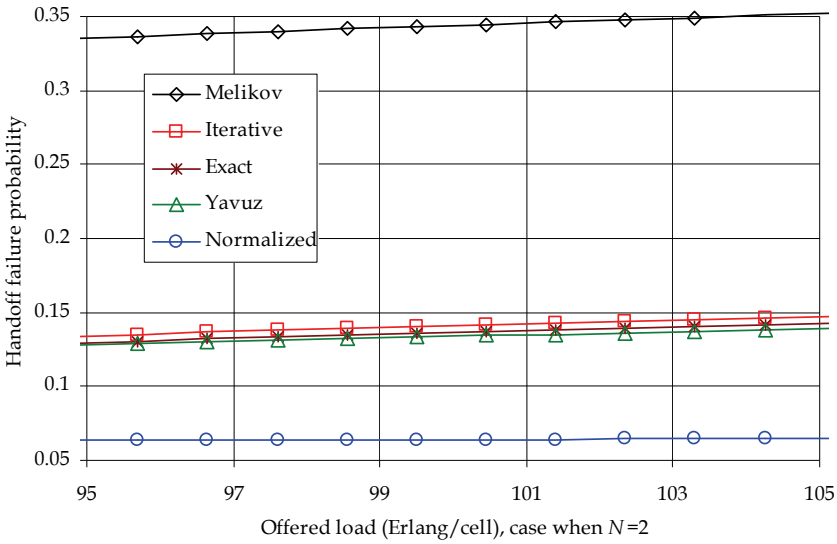

Fig. 12. Handoff failure probability versus offered traffic per cell when $N = 2$, heavy traffic load scenario.

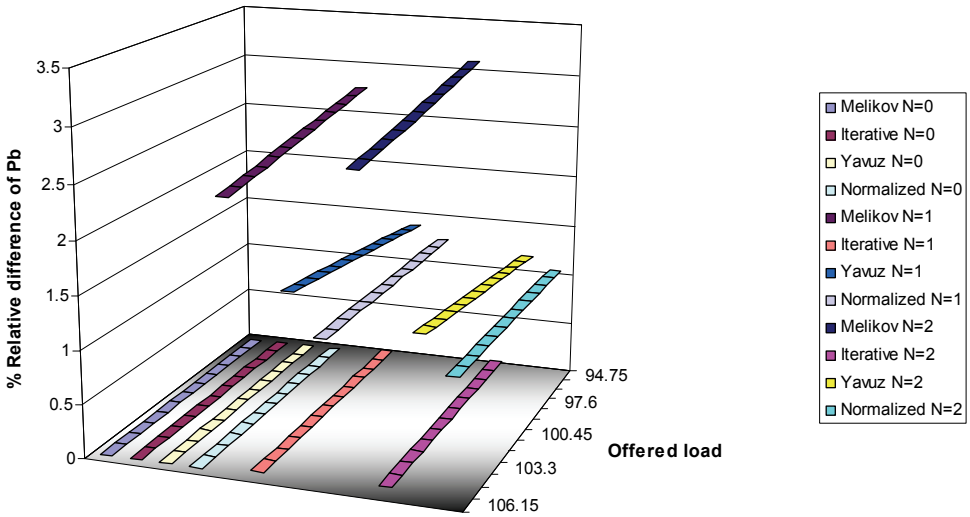

Fig. 13. Percentage difference between the new call blocking probabilities obtained with the exact and the different approximated methods, heavy traffic load scenario.

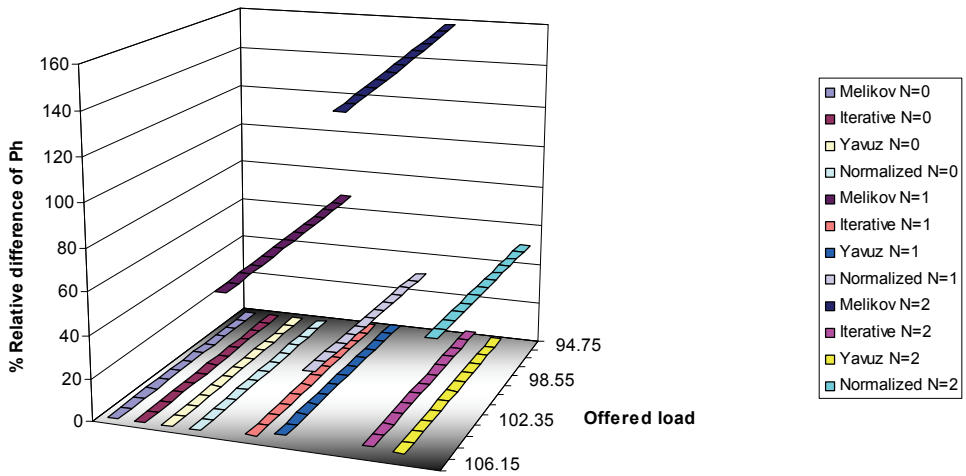

Fig. 14. Percentage difference between the handoff failure probabilities obtained with the exact and the different approximated methods, heavy traffic load scenario.

4.3 Comparison of computation complexity

In this section, the performance of the different approximated mathematical analysis methods is compared in terms of their computational complexity. As stated in (Yavuz & Leung, 2006), the reason why an acceptable approximation method is needed to evaluate the performance of a CAC scheme when an exact solution with a numerical method based on multidimensional Markov chain modeling exists is to avoid solving large sets of flow equations and, therefore, the curse of dimensionality. To give the reader a better idea regarding the "CPU time" and the amount of "memory" used for evaluating the performance of the approximated methods studied in this chapter, consider the Table V shown in (Yavuz & Leung, 2006). Yavuz and Leung implement one direct and two widely used iterative methods, which are the direct (LU decomposition), Jacobi (iterative), and Gauss–Seidel (iterative) methods, to compare their computational costs with that of the Yavuz method.

As shown in Table V of (Yavuz & Leung, 2006), as the number of channels increases, the values of CPU time for the numerical solution methods (both direct and iterative) become significantly greater than the corresponding values for the Yavuz method. The same observation can also be made for the used memory. This should not be surprising since the Yavuz method has much smaller number of states in its respective models and, also, those models have a closed-form formulation.

It is important to remark that the Yavuz method can be considered as a particular case of the iterative one. Both methods are based on the computation of an average effective channel holding time ($1/\gamma$). However, in the Yavuz method, in order to compute the average effective channel holding time, consideration of an initial estimation of occupancy probabilities is required. Moreover, the average channel holding time of each type of call (i.e., new and handed off calls) is not directly considered in these equations when computing the approximate equilibrium occupancy probabilities since they are replaced by the average effective channel holding time. On the other hand, the iterative method computes the equilibrium occupancy probabilities by directly considering the average channel of each type of call (Toledo-Marín et al., 2007). Because of these facts, it has been observed that the Iterative method has similar CPU time values to the corresponding ones for the Yavuz method.

5. Conclusions

Numerical results show that the differences between approximated approaches and the exact solution, in general, increase with the increment of the number of guard channels and/or the offered traffic load. Furthermore, the iterative approximated analytical method is identified as the most suitable for different evaluation conditions/scenarios. In general, at the cost of increasing the computational complexity (compared with the normalized method), the iterative and Yavuz methods provide the best approximation to the exact solution for both light to moderate traffic load and low to moderate average number of reserved channels (in this case, both methods provide similar results), which is a typical scenario of practical interest (Vázquez-Ávila et al., 2006). On the other hand, the iterative method provides the best accurate results at heavy offered traffic loads.

Even though guard-channel based call admission control schemes have been analyzed considering circuit-switched based network architectures, they will continue to be useful when applied with suitable scheduling techniques to guarantee quality of service at the packet level since most applications such as interactive multimedia are inherently connection oriented. Thus, the study of guard-channel based call admission control will continue to be a relevant topic in cellular networks for a long time. Additionally, it is important to note that the considered approximated analytical methods are applicable to any GC-based strategy and, recursive formulas[4], as those derived in (Santucci, 1997; Haring et al., 2001; Vázquez-Ávila et al., 2006), can be alternatively used for the calculation of the new call blocking and handoff failure probabilities.

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[4] Recursive formulas allow simple and stable computing of (new call and/or handoff) blocking probabilities, especially when the number of channels is large.

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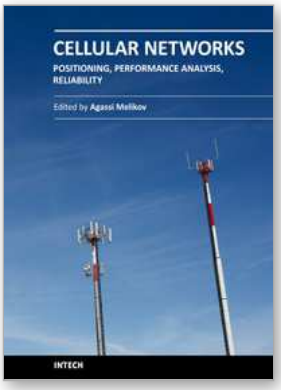

Cellular Networks - Positioning, Performance Analysis, Reliability

Edited by Dr. Agassi Melikov

ISBN 978-953-307-246-3
Hard cover, 404 pages
Publisher InTech
Published online 26, April, 2011
Published in print edition April, 2011

Wireless cellular networks are an integral part of modern telecommunication systems. Today it is hard to imagine our life without the use of such networks. Nevertheless, the development, implementation and operation of these networks require engineers and scientists to address a number of interrelated problems. Among them are the problem of choosing the proper geometric shape and dimensions of cells based on geographical location, finding the optimal location of cell base station, selection the scheme dividing the total net bandwidth between its cells, organization of the handover of a call between cells, information security and network reliability, and many others. The book focuses on three types of problems from the above list - Positioning, Performance Analysis and Reliability. It contains three sections. The Section 1 is devoted to problems of Positioning and contains five chapters. The Section 2 contains eight Chapters which are devoted to quality of service (QoS) metrics analysis of wireless cellular networks. The Section 3 contains two Chapters and deal with reliability issues of wireless cellular networks. The book will be useful to researches in academia and industry and also to post-gradute students in telecommunication specialitiies.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Felipe A. Cruz-Pérez, Ricardo Toledo-Marín and Genaro Hernández-Valdez (2011). Approximated Mathematical Analysis Methods of Guard-Channel-Based Call Admission Control in Cellular Networks, Cellular Networks - Positioning, Performance Analysis, Reliability, Dr. Agassi Melikov (Ed.), ISBN: 978-953-307-246-3, InTech, Available from: http://www.intechopen.com/books/cellular-networks-positioning-performance-analysis-reliability/approximated-mathematical-analysis-methods-of-guard-channel-based-call-admission-control-in-cellular

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