Analytical Modeling of Call Admission Control Schemes for Multiclass Traffic Mobile Wireless Networks

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***Abstract* — This paper studies and analyze two call admission control (CAC) schemes in multimedia cellular wireless networks. These call admission control algorithms are studied for different network configurations. These configurations include, employing the queuing techniques for voice handoff with finite lifetime, differentiating between voice and data calls in terms of the average channel holding time, data bandwidth requirements, and employing queuing techniques for voice handoff and data handoff calls with finite lifetime. The main contribution of this paper is the development of an analytical model for each of the two CAC algorithms specified in this study. In addition to the call blocking and termination probabilities which are usually cited as the performance metrics, in this work we derive and evaluate other metrics that have not be considered by previous work such as the average queue length, the average queue residency, and the time-out probability for handoff calls. We also develop a simulation tool to test and verify our results. Finally, we present numerical examples to demonstrate the performance of the proposed CAC algorithms and we show that analytical and simulation results are in total agreement.**

***Index Terms* — Analytical Performance, Call Admission Control, Handoff, QoS, Queuing.**

I. Introduction

The call admission control (CAC) mechanism is one of the most important components of radio resource management (RRM) affecting the resource management efficiency and QoS guarantees provided to users in current and forthcoming cellular networks, like Universal Mobile Telecommunication System (UMTS). In particular, effective call admission control for wireless sessions with a prioritization for handoff calls is an important research issue. The CAC denotes the process of making a decision whether to admit the new or handoff call taking into account the amount of available resources versus ongoing users' QoS requirements. Two important quality measures of cellular mobile systems are the probability of blocking for new call requests and the probability of calls blocked when a handoff is attempted due to unavailability of resources. A good CAC scheme has to balance the call blocking and call dropping in order to provide the desired QoS requirements.

Recently, a number of call admission control algorithms for cellular mobile systems have been proposed and analyzed in the literature. Different handoff priority-based CAC schemes have been proposed. A simple way of giving priority to handoff requests is to reserve a number of channels as in the priority reservation scheme [1]. An alternative is to support queuing either for handoff voice requests [1] or for both newly originating calls and handoff calls [8][9]. In the queuing based schemes, calls are accepted whenever there are free channels; otherwise they are queued with certain rearrangements in the corresponding queue.

Analytical results for these wide ranges of CAC algorithms have been proposed in the literature, for some performance metrics such as call blocking probabilities are obtained, however, for either invalid or at best limiting assumptions. For example, it is observed, that due to the mobility, some of usually used assumptions may not be valid which is the case when the average values of channel holding times for data calls and voice calls are not equal or when the life time of multi-queued handoff calls is finite. Also in case of multimedia traffic, the bandwidth requirements may not be equal for all types of traffic.

In this paper, we extend some of the analytical results for two call admission control schemes under more general assumptions and provide some easier-to-compute formulas. In addition to the typically cited blocking probability criterion in most previous studies, in this analytical framework we obtain other important performance criteria such as the average queue length, the average waiting time and the average number of calls in the systems. For comparison amongst the different schemes outlines above, we develop a framework that models the CAC process using Markov chains.

II. System Model

The system under consideration is a FDMA cellular network supporting multimedia media traffic. The priority classes of incoming call requests are divided into four types. These types are: 1) real-time (voice) service handoff requests (h1); 2) nonreal-time (data) service handoff requests (h2); 3) newly originating real-time (voice) calls (n1); and 4) newly originating nonreal-time (data) calls (n2).As shown in the generic system model depicted in Fig.1, we consider two classes of calls: voice and data. Additionally, for each class of traffic, handoff calls have priority over new call arrivals.

There are two queues for handoff calls of (voice) and (data). The capacities for these queues are K and L, respectively. A handoff call of type (h1) is queued in Q1 if on arrivals it finds no idle channels. On the other hand, a handoff call of type (h2) is queued in Q2 if on arrivals it finds greater than or equal to G2 occupied channels. A handoff calls is blocked if its queue is full. In addition, a handoff call is deleted from its queue if it passes the handoff area before getting a channel. New calls are blocked if upon arrival they find the number of occupied channels greater or equal to G1. When the G1 limit is imposed, if the number of occupied channels, by new or handoff calls, is G1 channels, then the arrived new call is blocked.

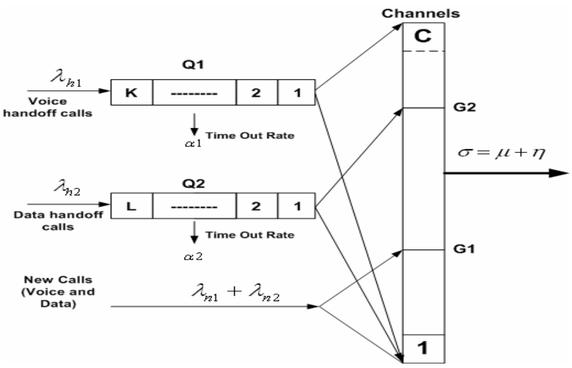


Fig. 1 : A Generic System Model

III. Analytical Model of two CAC Schemes in Multiple Traffic System

In this section, we conduct the performance analysis of two selected representative call admission control schemes for a multiclass traffic mobile wireless network. We focus our attention on integrated voice and data systems, and the results can be extended to other similar systems that support more than two types of traffic. These call admission control algorithms are studied for different network configurations. These configurations include, employing the queuing techniques for voice handoff with finite lifetime, differentiating between voice and data calls in terms of the average channel holding time, data bandwidth requirements, and employing queuing techniques for voice handoff and data handoff calls with finite lifetime. Using theses stated variations; this study considers two different CAC algorithms, referred to herein by schemes A, and B. For each of these algorithms, the Markov chain state diagram is specified and then solved analytically. The results are also verified and compared against those produced using a simulation tool developed in-house to test and evaluate various CAC algorithms and configurations. In most of the references such as [1-13] only the blocking probability of new call and the forced termination probability of handoff calls are evaluated. In this study, in addition to latter ones, other performance parameters such as average queue size, average-waiting time, and average number in the system are considered. Before introducing each of these schemes, we make the following assumptions throughout our analysis. The call holding time of voice calls and data calls are assumed to have an exponential distribution with rate μ_1 and μ_2, respectively. The residence time of mobile users in a cell is assumed to have an exponential distribution with rate η. The time spent in the handoff area by voice and data handoff request calls and is assumed to have an exponential distribution with rate α_1 and α_2, respectively [1]. Appling the memoryless property of the exponential distribution, the random variables for the channel holding time of data and voice calls are both exponentially distributed, with rates $\sigma_1 = (\eta + \mu_1)$ and $\sigma_2 = (\eta + \mu_2)$, respectively. We assume that the arrival processes of new voice and data calls, and voice and data handoff calls in a cell are Poisson. The arrival rates of new voice and data calls are designated as λ_{n1} and λ_{n2}, respectively. We denote the arrival rates of voice and data handoff requests by λ_{h1} and λ_{h2}, respectively.

In the following subsections, we present the performance analysis of our proposed system for two different schemes.

A. CAC for voice and data calls with different bandwidth requirements and different channel holding time

Unlike the previous scheme, with this scheme the data calls require multiple channels (C2 ≥1) while the voice calls require only one channel (C1=1). Also, in this scheme we consider the case where the channel holding time requirements for voice and data calls are different. Most of the current literature does not make a distinction between data and voice calls in terms of the channel holding time. The common assumption is that both data calls and voice calls are exponentially distributed with the same parameter. Also, Most of the current studies [1-13] do not consider the case where C2 is greater than one bandwidth unit. The other parameters of this case are Q1=Q2=0, G1=G2=C, C1 = 1, C2 ≥ 1. Let m be the maximum number of data calls that can be admitted into the system such that:

$$C = mC_2 + n \quad ; 0 \le n \le C_2 - 1$$

where n is the remainder of channels that are below the data bandwidth requirements. The set of states consists of all states (i,j) where i is the number of voice calls and j is the number of data calls such that each data effectively requires C2 channels, where $0 \le i \le C; 0 \le j \le m$. Let $\lambda_i = \lambda_{hi} + \lambda_{ni}$ for i = 1, 2, such that

$$\lambda_1 = \begin{cases} \lambda_{h1} + \lambda_{n1} & 0 \le i + j * C2 < C \\ 0 & i + j * C2 = C \end{cases} \quad (1)$$

$$\lambda_2 = \begin{cases} \lambda_{h2} + \lambda_{n2} \; 0 \le i + j * C2 < C \quad and \quad C - i \ge C_2 \\ 0 \qquad C - i < C_2 \quad or \quad j = m \end{cases} \quad (2)$$

The state of the cell of interest is defined by a pair of nonnegative integers (i,j), where i is the sum of busy channels occupied by voice calls (handoff or new) and j is the number of busy channels occupied by data calls (handoff or new). It is apparent from the above assumptions that (i,j) is a two-dimensional Markov chain. The state transition diagram of the cell with different channel holding time requirements for voice and data calls is shown add the general bandwidth requirements for data calls (C1 =1, C2 ≥ 1) is shown in Fig. 2. Let Pi,j (i, j = 0,1,2, …, C) denote the steady state probability that there are i voice calls (new and handoff) and j data calls (new and handoff) in the cell. The steady state probability Pi,j can be solved using product form solution corresponding to two individual M/M/C/C systems. Using the Jackson theorem by [14], if we let $\rho_i = \lambda_i \sigma_i^{-1}, i = 1,2$, where $\lambda_1 = \lambda_{n1} + \lambda_{h1}$, $\lambda_2 = \lambda_{n2} + \lambda_{h2}$, C2 ≥ 1, the steady state probability can be written as

$$P_{i,j} = P_{0,0} \frac{\rho_1^i}{i!} \frac{\rho_2^j}{j!} \quad ; i + j \le C \quad (3)$$

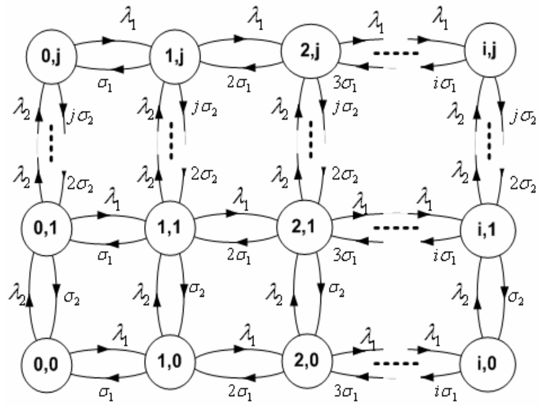
where $P_{0,0}$ is the normalization constant such that all state probabilities add to one. That is

$$P_{0,0} = \left\{ \sum_{j=0}^{m} \sum_{i=0}^{C - jC_2} \frac{\rho_1^i}{i!} . \frac{\rho_2^j}{j!} \right\}^{-1} \quad (4)$$

Using the above expression for Pi,j, the following performance measures of the system are computed. Data calls are lost if the number of the unoccupied channels (i.e, number of free channels) are less than the required bandwidth (defined above as n) and this occurs if the system is in the rightmost n states of any row, or when all available channel less than the bandwidth requirements. Summing these probabilities, we have:

$$B_2 = \sum_{j=0}^{m-1} \sum_{i=C-(j+1)C_2+1}^{C - jC_2} P_{i,j} + \sum_{i=0}^{n} P_{i,m} \quad (5)$$

$$B_2 = P_{0,0} \sum_{j=0}^{m-1} \sum_{i=C-(j+1)C_2+1}^{C - jC_2} \frac{\rho_1^i}{i!} \frac{\rho_2^j}{j!} + P_{0,0} \frac{\rho_2^m}{m!} \sum_{i=0}^{n} \frac{\rho_1^i}{i!} \quad (6)$$



State transition diagram of case A(C2 ≥ 1).

B. Voice and data handoff calls queuing CAC scheme

In this subsection, we consider the case where the voice handoff calls and data handoff calls are given the higher priority over new calls by deploying the queuing techniques. The voice handoff calls has higher priority over data handoff calls. For this scheme, a voice handoff call is queued in its queue (Q1) if all channels are busy upon its arrival. Also, data handoff call is queued in its queue (Q2) if all channels are busy upon its arrival .These queues have finite capacities K for Q1 and L for Q2.The other parameters of this case are: G1=G2=C,S=0, and the mean channel holding time is equal for both types of calls. The lifetime of each handoff call (voice and data) is exponential distributed with different mean value. The voice handoff calls are blocked only if there are no available channels in the system and Q1 is full. In addition, the data handoff calls are blocked only if there are no available channels in the system and Q2 is full. Other calls are blocked if all channels are busy.

Recent studies such as [7], [10] and [11] do not consider the lifetime of second queue (data handoff queue). Studies [12] and [13] present the dynamic priority for handoff calls and the lifetime of the second queue is considered but the detailed balanced equations and the closed form steady state probability were not derived. [12] is an extension to [13]. The only performance criteria considered in [12] are the blocking probability and forced termination probability of new and handoff calls. In our case, we present in detail a complete and general analytical model for the system with two queues with different life times for the two types of handoff calls. The detailed balance equations are derived and relevant performance criteria are evaluated. The state of the cell of interest is defined by (n, i, j), where n is the sum of the number of channels used by voice and data calls (including new calls and handoff calls), i is the number of voice handoff calls in the queue Q1, j is the number of data handoff calls in the queue Q2. Based on the above assumptions, (n, i, j) is a two-dimensional Markov chain as shown in Fig. 7. The steady state probabilities Pn,i,j (n = 0, 1,…, C; i = 0, 1,…, K, j = 0, 1, …, L) are related to each other through the following balance equations. When i = 0 or j = 0, the system reduces to

$$P_{n,0,j} = \begin{cases} P_{0,0,0}\dfrac{\lambda^n}{n!\sigma^n} & 0 \le n \le C; j = 0 \\ P_{0,0,0}\dfrac{\lambda^C}{C!\sigma^C}\displaystyle\prod_{j=1}^{i-C}\dfrac{\lambda^j}{[C\sigma + j\alpha_2]} & C \le j \le C+K, j = C \end{cases} \quad (7)$$

When i = K, j = L,

$$P_{n,i,0} = \begin{cases} P_{0,0,0}\dfrac{\lambda^n}{n!\sigma^n} \quad where \quad 0 \le n \le C, i = 0; \\ P_{0,0,0}\dfrac{\lambda^C}{C!\sigma^C}\displaystyle\prod_{j=1}^{i-C}\dfrac{\lambda^j}{[C\sigma + j\alpha_1]} \\ where\ C \le i \le C+K, n = C \end{cases} \quad (8)$$

$$P_{C,K,L} = (1 - C\sigma - K\alpha_1 - L\alpha_2)P_{C,K,L} + \lambda_{h1}P_{C,K-1,L} + \lambda_{h2}P_{C,K,L-1} \quad (9)$$

When i > 0 and j > 0

$$\begin{aligned} P_{C,i,j} &= P_{C,i,j}(1 - \lambda_{h1} - \lambda_{h2} - C\sigma - i\alpha_1 - j\alpha_2) \\ &+ \lambda_{h1}P_{C,i-1,j} + \lambda_{h2}P_{C,i,j-1} + P_{C,i+1,j}(C\sigma + (i+1)\alpha_1) \\ &+ P_{C,i,j+1}(j+1)\alpha_2 \end{aligned} \quad (10)$$

When i = 0 and j = L

$$\begin{aligned} P_{C,0,L} &= P_{C,0,L}(1 - \lambda_{h1} - C\sigma - L\alpha_2) \\ &+ (C\sigma + \alpha_1)P_{C,1,L} + \lambda_{h2}P_{C,0,L-1} \end{aligned} \quad (11)$$

When i = K and j = 0

$$P_{C,K,0} = P_{C,K,0}(1 - \lambda_{h2} - C\sigma - K\alpha_1) + +\alpha_2 P_{C,K,1} + \lambda_{h1}P_{C,K-1,0} \quad (12)$$

Using the above expressions for Pn,i,j we can obtain the following performance measures of the system. The average queue length of Q1 is given by:

$$L_1 = \sum_{i=1}^{K} i \sum_{j=0}^{L} P_{C,i,j} \quad (13)$$

While the blocking probability of voice handoff calls is equal to the probability that Q1 is full. Hence,

$$B_{h1} = \sum_{j=0}^{L} P_{C,K,j} \quad (14)$$

Since the average number of voice handoff calls arrivals without blocking is equal to $(1 - B_{h1})\lambda_{h1}$ whereas the mean dropped calls in unit time is given by αL_1, therefore, the time out probability is computed as

$$B_{th1} = \alpha L_1 \left[(1 - B_{h1})\lambda_{h1}\right]^{-1} \quad (15)$$

Furthermore, the forced termination probability of voice handoff calls is the blocking probability plus the time out probability of unblocked calls. Thus, BF1 is given by

$$B_{F1} = B_{h1} + (1 - B_{h1})B_{th1} \quad (16)$$

In a manner similar to equations (13)-(16), we can write the following formulas in regard to the performance of data traffic. The average queue length of Q2 is given by

$$L_2 = \sum_{j=1}^{L} j \sum_{i=0}^{K} P_{C,i,j} \quad (17)$$

While the blocking, time-out, and forced termination probabilities for data handoff calls are computed using

$$B_{h2} = \sum_{i=0}^{K} P_{C,i,L} \quad (18)$$

$$B_{th2} = \alpha L_2 \left[(1 - B_{h2})\lambda_{h2}\right]^{-1} \quad (19)$$

$$B_{F2} = B_{h2} + (1 - B_{h2})B_{th2} \quad (20)$$

, respectively. The blocking probability of new voice calls and new data calls are given by

$$B_{n1} = B_{n2} = \sum_{j=0}^{L}\sum_{i=0}^{K} P_{C,i,j} \quad (21)$$

Applying Little's formula, the average queuing time is calculated for voice and data using

$$W_{hi} = L_i \left[(1 - B_{hi})\lambda_{hi}\right]^{-1} \quad (22)$$

IV. Performance Results

In this section, the different cases are numerically studied. This main goal of this section is to study the performances metrics of each schemes using both analytical and simulation results. The results are also related to their counterparts found in previous studies. We assume that the number C of channels is 50 in each cell, the mean cell residency time is 90 seconds, while the mean call holding time is 180 seconds. The mean queuing times for voice and data handoff calls are 10 and 15 seconds, respectively. Arrival rates of all services are varied to reflect various loads. Furthermore, we assume that $\lambda_{h1} = 0.5\lambda_{n1}$ and $\lambda_{h2} = 0.5\lambda_{n2}$.The voice and data handoff queue size is 5.

For scheme A, we investigate the system performance of the systems assuming different channel holding times and different bandwidth requirements for data and voice calls. As mentioned earlier, throughout most of the cited literature the channel holding time is assumed to be equal for both type of calls. Studies such as [10] and

[11], where a scheme similar to scheme A is considered, did not consider the extra bandwidth requirements for data calls. Fig. 3 shows the blocking probabilities of data and voice calls when they have the same bandwidth requirements (C1 = C2 = 1) and when they have different bandwidth requirements (C1 = 1, C2 = 2). As seen in this figure, it is obvious that as the data calls bandwidth requirements increase their blocking probability will increase given that we have a fixed system capacity. At low and moderate offered load, as the bandwidth of data calls increase, the blocking probability of voice calls will increase because the data calls with higher bandwidth will occupy most of the channels. However, at high offered traffic the calls with less bandwidth requirements will be favored. This occurs to voice calls at high offered traffic loads. When all channels are occupied, and as soon as any of these channels are released (that means at least one channel is available) the arrived data calls will be blocked whereas a voice call will be assigned this channel. Therefore the blocking probability of voice calls will decrease at high offered traffic when data bandwidth requirements increase.

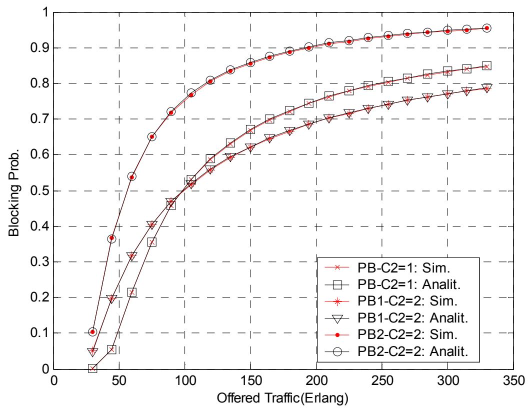


Fig 3: PB2 and PB1 when C2=1, (C2=2.

In scheme B, we consider the case where the voice handoff calls and data handoff calls are given the higher priority over new calls by employing queuing for handoff calls. The data calls are allowed to be queued for a finite time and given priority less than voice handoff calls and higher than new calls. As previously stated, relevant studies such as [7], [10] and [11] do not consider the lifetime of second queue (data handoff queue). Also, in our scheme, analytically and using simulations, we compute the average queue size and waiting time of voice and data handoff calls. The forced termination probability of data handoff calls dramatically decreases when we use the queue for data handoff calls as shown in Fig. 5. Fig. 6 shows the average waiting time and average queue size for both voice and data handoff calls. Allowing the data handoff calls to be queued results in a small increase in the average queue size and forced termination probability for voice handoff calls, but this increase is negligible comparing to the improvements gained in the data handoff calls performance. To summarize, this scheme results in better improvements comparing to the related work. Future work will be focused in finding the optimum queue size for voice and data handoff calls.

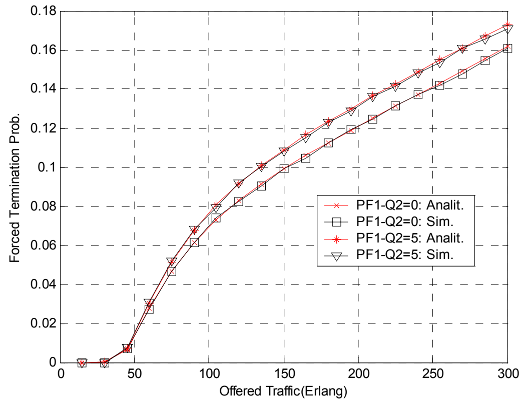


Fig. 4 : Forced termination probabilities of voice handoff calls with (Q2=0,Q2=5) .

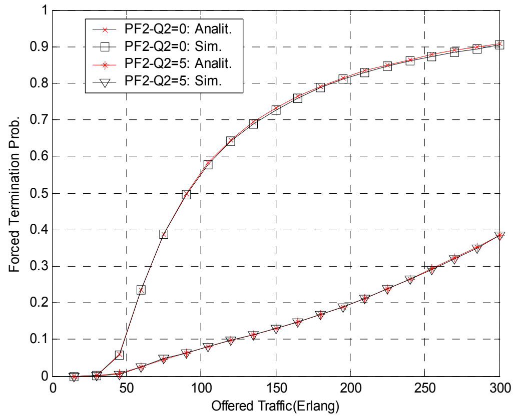


Fig. 5 : Forced termination probabilities of data handoff calls (Q2=0,Q2=5) .

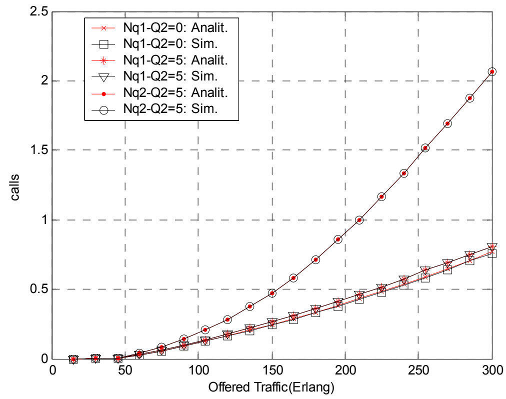


Fig. 6: Average queue size of voice and data handoff calls with (Q2=0,Q2=5) .

V. CONCLUSIONS

In this paper, we studied the performance analysis of two call admission control (CAC) schemes in multi-traffic mobile wireless networks. These schemes have been analyzed under different configurations including, classifying the handoff traffic to more than one class and employing queuing for one or more handoff call class in order to prioritize the handoff calls. In addition, we relaxed the often used assumption of equal mean channel holding times and equal bandwidth requirements for voice and data calls.

The analytical model of each scheme is derived and compared with simulation results. It is shown that the system analytical framework is in total agreement with simulation model results. In addition, the performance of each proposed scheme systems is compared with the related scheme that has been studied in the literature. The analytical framework derived in this paper can be used as solid base to evaluate CAC schemes of wireless networks employing different types of priority schemes in order to provide different types QoS requirements.

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REFERENCES

[1] D. Hong and S.S. Rappaport. "Traffic Model and Performance Analysis for Cellular Mobile RadioTelephone Systems with Prioritized and Non-prioritized Handoff Procedures," IEEE Transactions on Vehicular Technology, vol. VT- 35, no. 3, pp. 77-92, Aug. 1986.

[2] Y. B. Lin, S. Mohan, and A. Noerpel, "Queueing priority channel assignment strategies for handoff and initial access for a PCS network," IEEE Transactions on Vehicular Technology, vol. 43, no. 3, pp. 704–712, 1994.

[3] R. Ramjee, D. Towsley, and R. Nagarajan, "On optimal call admission control in cellular networks," Wireless Networks Journal, Vol. 3, No. 1, pp. 29-41, 1997.

[4] M. D. Kulavaratharasah and A. H. Aghvami, "Teletraffic performance evaluation of microcellular personal communication networks (PCN's) with prioritized handoff procedures," IEEE Transactions on Vehicular Technology, vol. 48,no. 1, pp. 137–152, 1999.

[5] Y. B. Lin, R. Anthony, and D. J. Harasty, "The subrate channel assignment strategy for PCS hand-offs," IEEE Transactions on Vehicular Technology, vol. 45, pp. 122–130, Feb. 1996.

[6] Wei Li, Yuguang Fang, and Robert R. Henry " Actual Call Connection Time Characterization for Wireless Mobile Networks Under a General Channel Allocation Scheme," IEEE Transactions on Wireless Communications, Vol. 1, No. 4,pp. 682-691, October 2002.

[7] Qing A. and Agrawal "Performance analysis of a Handoff scheme in integrated voice/data wireless networks," IEEE Transactions on Vehicular Technology, vol. 51, no. 6, pp. 1469-1478, Nov. 2002.

[8] V. K. N. Lau and S. V. Maric, "Mobility of queued call requests of a new call-queueing technique for cellular systems," IEEE Transactions on Vehicular Technology, vol. 47, no. 2, pp. 480–488, 1998.

[9] C. Chang, C. J. Chang, and K. R. Lo, "Analysis of a hierarchical cellular system with reneging and dropping for waiting new calls and handoff calls," IEEE Transactions on Vehicluar Technology, vol. 48, no. 4, pp. 1080–1091, 1999.

[10] Qing A. and Agrawal "An Analytical modeling of Handoff for integrated voice/data wireless networks with priority reservation and preemptive priority procedures," IEEE Personal Communications, pp. 523-529, Aug. 2000.

[11] Qing A. and Agrawal "Performance analysis of a Handoff scheme in integrated voice/data wireless networks," IEEE Transactions on Vehicular Technology vol. 4,pp. 1986-1992, 24-28 Sept. 2000.

[12] Ariton E. Xhafa, , and Ozan K. Tonguz, "Dynamic Priority Queuing of Handoff Calls in Wireless Networks: An Analytical Framework,", IEEE Journal on Selected Areas in Communications, VOL. 22, NO. 5, pp. 904-916 JUNE 2004

[13] Ariton E. Xhafa, , and Ozan K. Tonguz, "Dynamic priority queuing of handoff requests in personal communications systems: an analytical framework for performance evaluation", in, Proceedings of the IEEE personal, indoor, and mobile Communications (PIMRC'99), pp. 1346-1350, Osaka, Japan, Sept. 1999.

[14] Dimitri Bertsekas and Robert Gallaher ; Data Networks, Second Edition, , Prentice Hall, 1992.

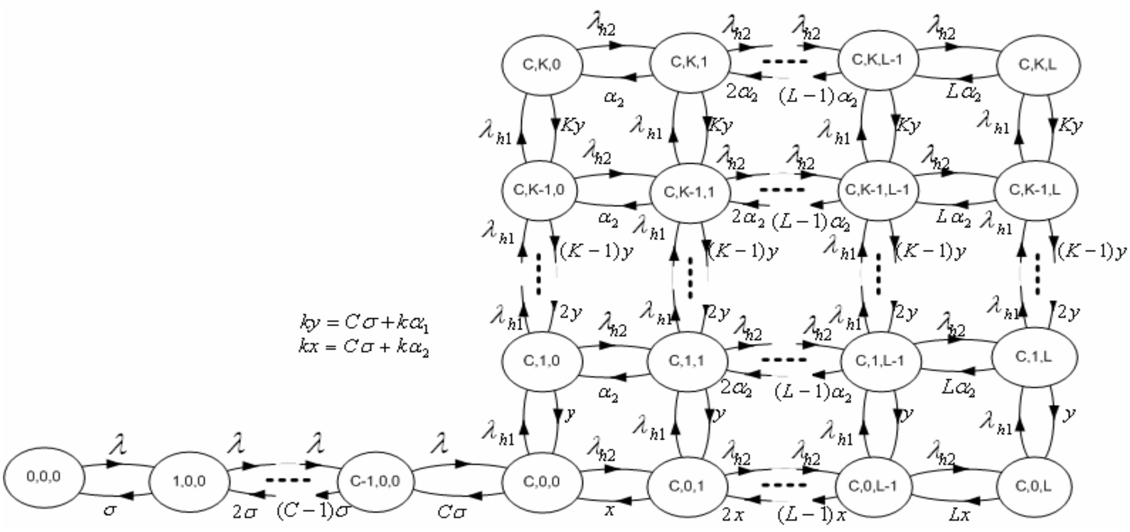

Fig. 7: State Diagram for Scheme B