Proceedings of the 10th WSEAS International Conference on COMMUNICATIONS, Vouliagmeni, Athens, Greece, July 10-12, 2006 (pp193-198)

Performance Evaluation of Hierarchical Multiservice CDMA Networks for Intelligent Transportation Systems

Shun-Ping Chung and Jhih-Dao Jhan
Department of Electrical Engineering
National Taiwan University of Science and Technology

Abstract: - In this paper we propose a hierarchical cellular CDMA network for ITS (Intelligent Transportation System) supporting both voice and video calls. It is assumed that voice calls have shorter average call holding time, whereas video calls have longer average call holding time. The video calls are assigned to the associated macrocell in order to reduce the number of handoffs and the voice calls are assigned to the associated microcell. One guard channel scheme is adopted to prioritize handoff calls over new calls. To increase resource utilization, voice calls in microcells can be allowed to overflow to macorcells. To avoid excessive overflow from the microcells, another guard channel scheme is adopted to prioritize video calls over voice calls. Another way to avoid excessive overflow in macrocells is to allow overflowed voice calls to be taken back to microcells. Two multi-dimensional Markov chains are used to describe microcells and macrocells, respectively, and the analytical results for the performance measures of interest are derived. Last but not least, simulation programs written in C are run to verify the analytical results.

Key-Words: - hierarchical networks, ITS, call holding time, overflow, takeback, guard channel.

1 Introduction

In the Intelligent Transportation Systems (ITS), wireless communication is necessary to provide efficient management of transportation systems, such as electronic toll collection, vehicle location and navigation services [1]. It is expected that future ITS should support not only voice calls, but multimedia calls, e.g., videophone, video clip, etc.

As is well known, cellular concept has made mobile communication affordable to the general public. Thus, how to apply cellular concept to ITS has been studied in [1][5]. In [1], microcellular structures based on CDMA are proposed to support various services in ITS, where soft handoff scheme is adopted to provide seamless handoff. Soft handoff schemes have been studied in [1]-[3][7].

In previous works hierarchical cellular systems have been proposed to solve the unequal forced termination probability issue where mobile users have different moving speeds [6]. Although in the ITS environment the speed differences of mobile users are normally not significant, the diverse call holding times still can lead to unequal forced termination probability. In our work we propose a two-layer cellular network supporting both voice calls and video calls. It is assumed that voice calls have shorter average call holding time, whereas video calls have longer average call holding time. The video calls are assigned to the associated macrocell in order to reduce the number of handoffs, and thus the forced termination probability, whereas the voice calls are assigned to the associated microcell. Furthermore, to enhance resource utilization in macrocells, voice calls may be allowed to overflow to the associated macrocell if they cannot find sufficient channels in the associated microcell [4]. However, excessive overflow may lead to QoS degradation of video calls in the upper layer. To avoid excessive overflow from the lower layer, guard channel policy can also be applied to prioritize video calls over voice calls [4]. Specifically, overflow calls cannot obtain any channel from the upper layer when the number of occupied channels in the macrocell is greater than a threshold. There is another approach to reducing the number of voice calls occupying the channels in the macrocells, i.e., takeback [8]. Specifically, overflowed voice calls have to go back to the lower layer whenever there are enough channels available in the associated microcell. It is also noted that generally forceful termination of an active call is less desirable than the blocking of a new call. Thus, handoff calls are usually given priority over new calls.

To summarize, we consider hierarchical multi-service cellular networks for ITS based on CDMA supporting soft handoff. Both voice and video calls are supported in the considered system. Handoff calls are given priority over new calls. Three models are compared: no overflows, overflow without takeback, and overflow with takeback. An analytical method is derived to calculate the performance measures of interest.

The rest of the paper is organized as follows. Section II presents the system characteristics, traffic model, and call admission control. An analytical method to calculate performance measures of interest is derived in Section III. Section IV presents the analytical and simulation results, and performance analysis. Lastly, Section V concludes the paper.

2 System Model

2.1 System Characteristics

The system studied covers a one-dimensional service area, e.g., one two-way road, where the mobile users can only move in one direction or the other. The moving direction of each mobile user is assumed to be fixed, i.e., no U turns are allowed. There are two classes of users: class-1 (voice) and class-2 (video). It is assumed that voice calls have shorter average call holding time, whereas video calls have longer average call holding time. To accommodate mobile users with different call holding times, a two-tier cellular network is proposed to implement the ITS as shown in Fig. 1. The two-tier cellular network consists of many micorcells in the lower layer and many macrocells in the upper layer, where each macrocell overlays N microcells. In each cell the radio resources are allocated in units of channels. It is assumed that there are $C^{(M)}$ codes or channels in each macocell and $C^{(m)}$ channels in each microcell. It is noted that each call needs to be supported by one channel.

To enhance the seamless communication, soft handoff scheme is adopted, instead of hard handoff. Specifically, in each of microcells and macrocells, there are two regions that overlap with corresponding neighbor cells as shown in Fig. 1. Those regions are referred to as soft handoff regions (SHR). The non-overlapping region is referred to as normal region (NR). The ratio of the area of one SHR to the whole area of a cell is assumed to be f , and that of the area of NR to the whole area of a cell is $1-2f$. One call in NR can connect to at most one base station (BS), normally the closest BS, whereas one call in SHR can connect to at most two BSs, the serving BS and the target BS. Throughout this paper, all of the parameters related to the microcells (macrocells) are represented with superscript m (M). As an example, The SHRs in the microcells are designated as $SHR^{(m)}$, wheresas those in the macrocells $SHR^{(M)}$.

To provide almost equal forced termination probability and reduce the number of handoff attempts, voice calls are assigned to and served by the associated microcell and video calls by the associated macrocell. For further improving the Grade of Service (GoS) of voice calls, the voice calls that cannot obtain one free channel from the associated microcell can overflow to the upper layer and try to obtain the required channel from the associated macrocell. To avoid excessive overflow traffic and thus degradation of video calls' GoS, the overflowed calls are regulated with the overflowed guard channel C_{of} and/or the takeback process, which is described in detail below.

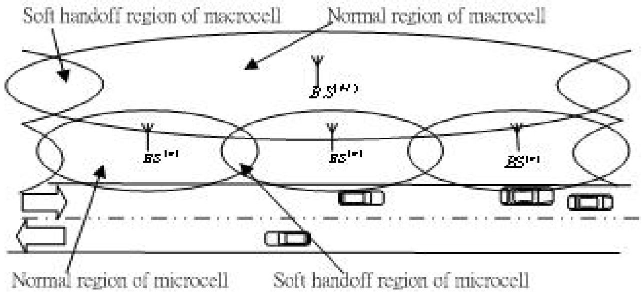

Fig.1 System architecture

With soft handoff, when a mobile station (MS) moves into SHR from NR, the MS will request the required resource from the target cell, while maintaining connected to the current cell until it moves out of the SHR into the NR of the target cell. Furthermore, we assume that when any voice call arrives at $SHR^{(m)}$ due to handoff or call initiation, it must obtain one free channel from each of the serving cell and the target cell; otherwise it should release the channel obtained from the microcell and tries to overflow to macorcell. Similarly, any video call arrives at $SHR^{(M)}$ due to handoff or call initiation, it must obtain one free channel from each of the serving cell and the target cell. If there are not enough free channels at the target macrocell, the connection to the serving macrocell can remain until moving out of the serving macrocell. In order to prioritize handoff calls over new calls, we also limit the accessible channels of the new calls by handoff guard channel mechanism. The number of channels reserved for handoff calls exclusively in the each microcell (macrocell) is $C_h^{(m)}$ ($C_h^{(M)}$).

2.2 Traffic Model

New call arrivals at a microcell (macrocell) are assumed to be Poison with average arrival rate λ_1 for voice calls (λ_2 for video calls). Handoff call arrivals for both voice and video calls are assumed to be Poisson. Overflow and takeback call arrivals for voice calls, if exist, are also assumed to be Poisson. The moving direction of any call is generated at random and the direction is unchangeable during the call lifetime. The unencumbered call holding time of voice (video) calls is assumed to be exponentially distributed with mean $1/\mu_1(1/\mu_2)$. The cell dwell time is related to user mobility pattern and cell size. We assume that the microcell (macrocell) dwell time is also exponential with mean $1/\mu_D^{(m)}\left(1/\mu_D^{(M)}\right)$, and the cell dwell time is independent of the call holding time. Furthermore, we assume that the dwell times of the normal regions and soft handoff regions are exponentially distributed. Specifically, the dwell times of $NR^{(m)}$ and $SHR^{(m)}$ are exponentially distributed with mean $1/\mu_D^{(m)}\cdot(1-2f^{(m)})$ and $1/\mu_D^{(m)}\cdot f^{(m)}$, respectively, and those of $NR^{(M)}$ and $SHR^{(M)}$ are exponentially distributed with mean $1/\mu_D^{(M)}\cdot(1-2f^{(M)})$ and $1/\mu_D^{(M)}\cdot f^{(M)}$, respectively.

2.3 Call Admission Control

Let $C^{(m)}(s^{(m)})$ ($C^{(M)}(s^{(M)})$) represent the current number of occupied channels of the microcell (macrocell) in question. For simplicity, assume that both overflow and takeback mechanisms are enforced.

2.3.1 New Call Arrivals

If a new voice call arrives at $NR^{(m)}$ of a particular microcell, it will be admitted into the system if $C^{(m)}(s^{(m)})\le C_T^{(m)}-C_h^{(m)}-1$; otherwise it will enter into the overflow process. If the new voice call arrives at $SHR^{(m)}$ of a particular microcell, it will be admitted if $C^{(m)}(s^{(m)})\le C_T^{(m)}-C_h^{(m)}-1$ for the serving microcell and $C^{(m)}(s^{(m)})\le C_T^{(m)}-1$ for the neighbor microcell; otherwise it will enter into the overflow process.

If a new video call arrives at $NR^{(m)}$ of a particular macrocell, it will be admitted into the system if $C^{(M)}(s^{(M)})\le C_T^{(M)}-C_h^{(M)}-1$; otherwise it will be rejected and blocked from the system. If the new video call arrives at $SHR^{(M)}$ of a particular macrocell, it will be admitted into the system if $C^{(M)}(s^{(M)})\le C_T^{(M)}-C_h^{(M)}-1$ for the serving macrocell and initiate a handoff request to the neighbor macrocell; otherwise it will be rejected and blocked from the system.

2.3.2 Handoff Call Arrivals

If a handoff voice call arrives at $SHR^{(m)}$ of a particular microcell from $NR^{(m)}$ of the neighbor microcell, it will be admitted into and obtain a channel from the associated microcell if $C^{(m)}(s^{(m)})\le C_T^{(m)}-1$; otherwise the call will enter into overflow process, if applicable. If a handoff voice call arrives at $SHR^{(M)}$ of the macrocell from $NR^{(M)}$ of the neighbor cell, it will be admitted into and obtain a channel from the associated macrocell if $C^{(M)}(s^{(M)})\le C_T^{(M)}-1$.

If a handoff video call arrives at $SHR^{(M)}$ of a particular macrocell from $NR^{(M)}$ of the neighbor cell, it will be admitted into and obtain a channel from the associated macrocell if $C^{(M)}(s^{(M)})\le C_T^{(M)}-1$.

2.3.3 Overflow

Assume that overflows from microcells to macrocells are allowed. If a new voice call cannot obtain one free channel from the associated microcell, or a handoff voice call cannot obtain one free channel from each of the serving microcell and the target microcell, it will enter into the overflow process and try to obtain the required resource from the associated macrocell. Specifically, the call will be admitted to the associated macrocell if $C^{(M)}(s^{(M)})\le C_T^{(M)}-C_{of}-1$; otherwise the call will be rejected and cleared from the system.

2.3.4 Takeback

Whenever an active voice call served by the associated macrocell enters the normal region of any microcell, it should be taken back to the associated microcell if $C^{(m)}(s^{(m)})\le C_T^{(m)}-C_{tb}-1$; otherwise the call will remain in the upper layer. Of course, once a voice call returns to the microcell, all of the channels obtained from the macrocell must be released and returned to the macrocell immediately.

2.3.5 Call Completion

If an active call is complete, all of the acquired channel(s) will be released and returned to the system.

2.3.6 Region Change

Whenever an active voice or video call leaves the associated cell, i.e., moves from the SHR of the associated cell to the NR of the target cell, the acquired channel(s) from that cell must be released immediately. Furthermore, if a handoff call cannot obtain the required channel from the target cell before it leaves the associated SHR, it will be forcefully terminated.

3 Analytical Method

An analytical method to compute the performance measures of interest for the considered hierarchical cellular networks is derived. For simplicity we consider a homogenous cellular network, i.e., each cell at the same layer is statistically identical. Thus, we can focus on one particular cell at each layer. In addition, new calls are assumed to be uniformly distributed within each cell. The performance measures of interest are new call blocking probability, handoff failure probability, and forced termination probability for both the voice and video calls, and channel utilizations.

We consider three different models for the considered two-tier cellular network: Model A, Model B, and Model C. In Model A no overflows from the microcells to the macrocells are allowed, i.e., the two layers are independent of each other. In Model B voice calls in microcells can overflow to macrocells, if necessary, but no voice calls served by the macrocells can be taken back to microcells. In Model C voice calls in microcells can overflow to macrocells, if necessary, and voice calls served by macrocells should be taken back to the microcells whenever it is possible. It is noted that by choosing appropriate values for overflow guard channels and takeback guard channels, Model C can be reduced to Model B or Model A. Specifically, if $C_{of} = C_T^{(M)}$, Model C reduces to Model A. Further, if $C_{of} \neq C_T^{(M)}$ and $C_{tb} = C_T^{(m)}$, Model C reduces to Model B. In this paper takeback calls are treated as handoff calls in microcell.

Due to lack of space, the detailed derivation is omitted in the following.

3.1 Microcell

The state of a particular microcell is defined to be $s^{(m)} = \{n_{1n}^{(m)}, n_{1h}^{(m)}\}$, where $n_{1n}^{(m)}$ is the number of active voice calls at $NR^{(m)}$, $n_{1h}^{(m)}$ is the total number of incoming and outgoing active voice calls that are located at $SHR^{(m)}$, where the incoming calls move toward the normal region of the serving cell, and the outgoing calls move away from the serving cell.

A 2-dimensional Markov chain is used to describe the state transitions of a microcell. The associated equilibrium state equations are solved iteratively. The performance measures of interest are found based on the steady-state probability distribution.

3.2 Macrocell

It is noted that in a macrocell, besides video new and handoff calls, there are new and handoff voice calls that overflow from microcells to macrocells due to insufficient resources in microcells. The state of a particular macrocell is defined to be $s^{(M)}$ = $\{n_{1n}^{(M)}, n_{1h}^{(M)}, n_{2n}^{(M)}, n_{2h}^{(M)}\}$, where $n_{1n}^{(M)}$ ($n_{2n}^{(M)}$) is the number of active voice (video) call at $NR^{(M)}$, $n_{1h}^{(M)}$ ($n_{2h}^{(M)}$) is the total number of incoming and outgoing active voice (video) calls at $SHR^{(M)}$.

A 4-dimensional Markov chain is used to describe the state transitions of a macrocell. The associated equilibrium state equations are solved iteratively. The performance measures of interest are found.

4 Numerical Results

The numerical results, including both the simulation results and analytical results, are presented in this section. The simulation program is written in C language. The performances of the Model A, Model B and Model C are compared. The parameters used in the numerical analysis are $C_T^{(m)}\left(C_T^{(M)}\right)$=8(8), $C_h^{(m)}\left(C_h^{(M)}\right)$=1(1), $C_{of} = 2$, $N = 3$, $f^{(m)}\left(f^{(M)}\right)$=0.15(0.15/ N), $\mu_D^{(m)}\left(\mu_D^{(M)}\right) = \frac{1}{100/3}\left(\frac{1}{100/3}\cdot\frac{1}{N}\right)$, $\mu_1 = 1/200\text{s}$, $\mu_2 = 1/1000s$.

The effects of the new voice call arrival rate on various performance measures are shown in Figs. 4-9 with $\lambda_2 = 0.002$. The new video call arrival rate is chosen so as to lead to $P_{2B} \leq 10^{-2}$ and $P_{2H} \leq 10^{-3}$ in Model A. According to these results, the analytical results are in reasonable agreement with the simulation results. The difference between analytical results and simulation results seems to appear in the heavy traffic conditions, where the analytical results overestimate simulation results. One of the possible reasons for the difference is that we assume the overflow and takeback traffic to be Poisson in our analysis. It has been shown in [6] that overflow traffic is more bursty than Poisson process.

Next, the effects of overflow and takeback on performance measures of interest are studied. The results are shown in Figs. 4 to 9. Recall that no overflows are allowed in Model A, only overflows are allowed but no takebacks in Model B, whereas both overflows and takebacks are allowed in Model C. Therefore, the performances of these three models are compared. First, it is observed from Figs. 4 to 7 that the blocking and forced termination probabilities of voice calls are lower in Model B and C than those in Model A. Obviously, this reduction in probabilities for voice calls results from the overflow process. Specifically, in Models B and C the voice calls that cannot obtain the required channel in microcells, including both new call and handoff call arrivals, try to overflow to the associated macrocell and have a second chance to obtain the required channel, and this action results in better GoS for voice calls. It is also observed that the improvement of GoS for voice calls due to overflows is accompanied by the degradation of GoS for video calls. Comparing the performances of Models B and C, it is concluded that by allowing takebacks, Model C can achieve almost the same improvement in GoS for voice calls as Model B, while the GoS degradation for video calls in Model C is much smaller than that in Model B. Table 1 shows the maximum allowable voice arrival rate under the constraints that new call blocking probability is 10^{-2} and handoff failure probability is 10^{-3}, whereas Table 2 shows the performance comparison for the three models with $\lambda_1 = 0.018$, to highlight the effects of overflow and takeback. Obviously, the takeback process reduces the number of overflow voice calls in macrocells, resulting in smaller degradation of blocking and handoff failure probabilities of video calls when the voice traffic increases. The average numbers of occupied channels in a microcell and macrocell are presented in Figs. 8 and 9, respectively. Models A and B result in the same channel utilization for a microcell. This is due to the fact that as long as a voice call cannot obtain the required channel from the associated microcell, it will leave that microcell, and specifically it will be rejected in Model A and it will overflow in Model B. Model C results in the highest channel utilization for a microcell among these three models, especially in heavy traffic load conditions This is obviously due to the fact that overflow voice calls may be taken back from macrocells to microcells. Similarly, the channel utilization for a macrocell in Model C is lower than that in Model B, but it is still higher than that in Model A.

Table 1. The maximum allowable voice arrival rate

	Model A	Model B	Model C
$P_{1B} \le 10^{-2}$	0.012	0.021	0.022
$P_{2B} \le 10^{-2}$	X	0.015	0.023
$P_{1H} \le 10^{-3}$	0.010	0.017	0.018
$P_{2H} \le 10^{-3}$	X	0.012	0.019
Overall	0.010	0.012	0.018

Table 2. Performance comparison with $\lambda_1 = 0.018$

	P_{1B}	P_{2B}	P_{1H}	P_{2H}
Model A	0.041	0.0038	0.0092	0.00066
Model B	0.0042	0.019	0.0013	0.0039
Model C	0.0028	0.0056	0.00098	0.00090

5 Conclusion

We consider three models of a two-tier cellular CDMA network for ITS. The analytical method to compute the performance measures of interest for three models is derived with multi-dimensional Markov chains. Both analytical and simulation results for performance measures of interest are presented. It is shown that for most of the scenarios considered the analytical results are in reasonable agreement with the simulation results. It is demonstrated that, compared with Model A, the overflow mechanism in Models B and C can achieve better GoS for voice calls at the expense of that for video calls. By comparing the performances of Models B and C, it is observed that the takeback mechanism in Model C can achieve almost the same GoS for voice calls as Model B, while Model C results in much better GoS for video calls than Model B.

References:

[1] Y.-U. Chung and D.-H. Cho, "Performance Evaluation of Soft Handoff for Multimedia Services in Intelligent Transportation Systems Based on CDMA," *IEEE Trans. Intel. Transpor. Sys.*, vol. 4, no. 4, Dec. 2003, pp. 189-197.

[2] D. K. Kim and D. K.Sung, "Characterization of Soft Handoff in CDMA Systems," *IEEE Trans. Veh. Tech.*, vol. 48 no. 4, July 1999, pp. 1195-1202.

[3] R. P. Narrainen and F. Takawira, "Performance Analysis of Soft Handoff in CDMA Cellular Networks," *IEEE Trans. Veh. Tech.*, vol. 50, no. 6, Nov. 2001, pp. 1507-1517.

[4] X. Wu, B. Mukherjee, and D.Ghosal, "Hierarchical Architectures in the Third- Generation Cellular Network," *IEEE Wireless Comm.*, vol. 11, no. 3, June 2004, pp. 62-71.

[5] H. Harada, K. Sato, and M. Fujise, "A Radio-on- Fiber Based Millimeter-Wave Road-Vehicle Communication System by a Code Division Multiplexing Radio Transmission Scheme," *IEEE Trans. Intel. Transpor. Sys.*, vol. 2, no. 4, Dec. 2001, pp. 165-179.

[6] S-P Chung and J-C Lee, "Call-Holding-Time- Based Random Early Blocking in Hierarchical Cellular Multiservice Networks", *IEICE Trans. on Comm.*, Vol.E84-B No.4, Apr. 2001, pp.814-822.

[7] S-L Su, J-Y Chen, and J-H Huang, "Performance Analysis of Soft Handoff in CDMA Cellular Networks," *IEEE JSAC*, vol. 14, no. 9, Dec. 1996, pp. 1762-1769.

[8] B. Li, C.-K.Wu, and Akira Fukuda, "Performance Analysis of Flexible Hierarchical Cellular Systems with a Bandwidth-Efficient Handoff Scheme," *IEEE Trans. Veh. Tech.*, vol. 50, no. 4, July 2001, pp. 971-980.

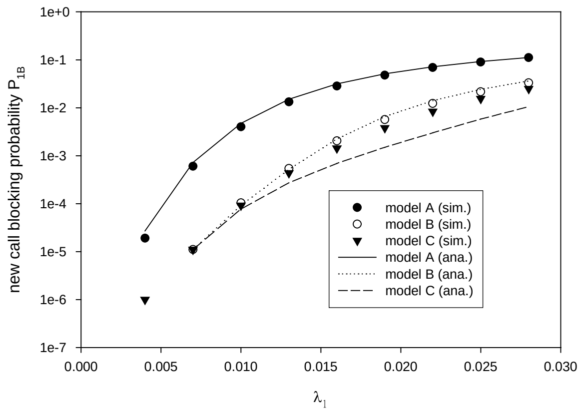

Fig.4 new call blocking probability of voice users vs. new voice call arrival rate

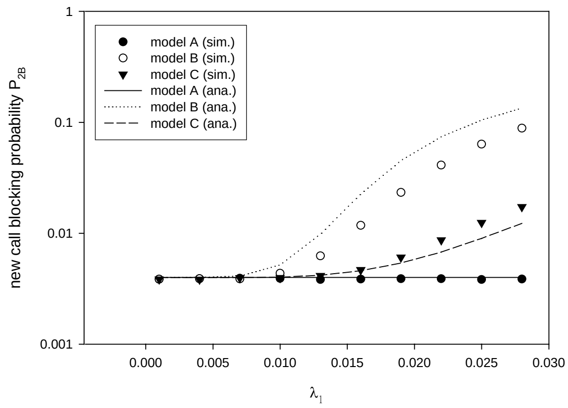

Fig.5 new call blocking probability of video users vs. new voice call arrival rate

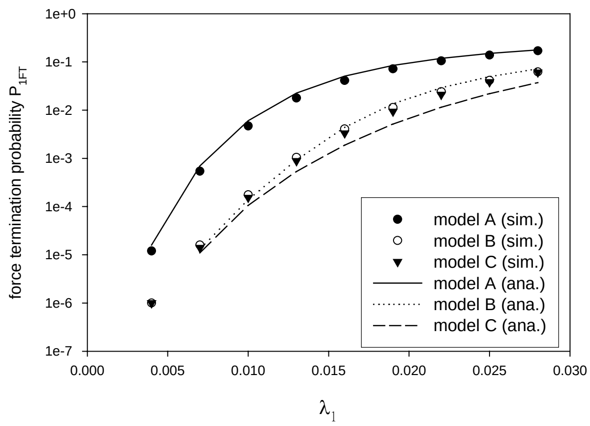

Fig.6 forced termination probability of voice users vs. new voice call arrival rate

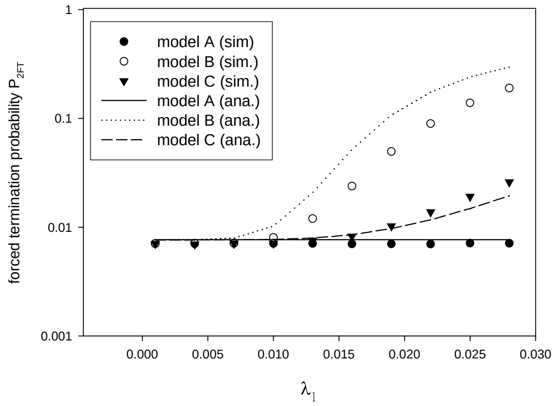

Fig.7 forced termination probability of video users vs. new voice call arrival rate

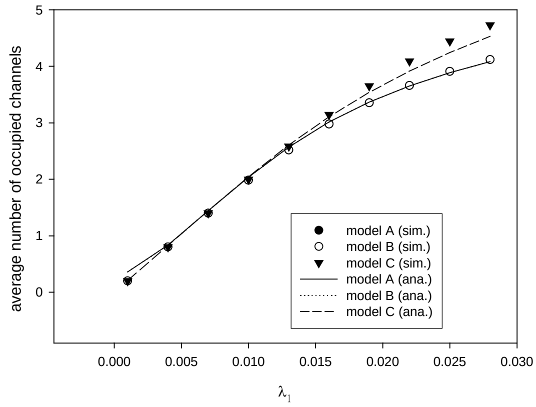

Fig.8 average number of occupied channels in microcell vs. new voice call arrival rate

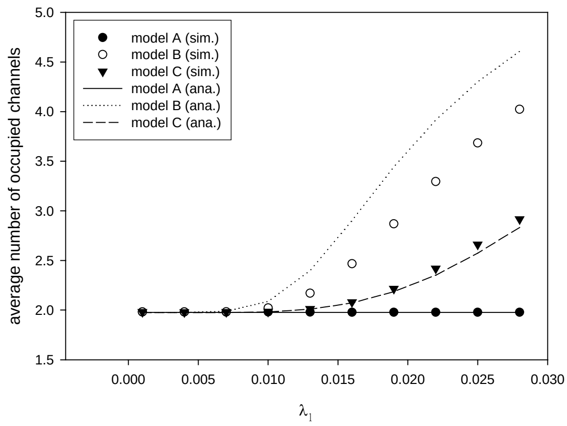

Fig.9 average number of occupied channels in macrocell vs. new voice call arrival rate