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The Study of Cut-off Priority Handoff Strategy in Multitier Cellular Systems

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Abstract

In this paper, we study the handoff overflow scheme in a multitier cellular system where microcells are used to address the high-teletraffic but primarily slow mobility areas, and macrocells are overlaid over the microcells to cater primarily to low-teletraffic but high mobility areas. The proposed handoff scheme is a flexible bi-directional cut-off priority scheme where handoffs are allowed in both directions, from low to high tier or from high to low tier. To investigate the loss probability, the threshold of the channels occupied and the channels lent out in each tier are studied and are obtained by simulation. The performance measures of the system using the BCOPH scheme are compared with those using the uni-directional handoff scheme. The results show that the sets of threshold values can effectively reduce the average loss probability which results in an increase in the total system capacity.

Keywords --- multitier cellular system, bi-directional cut-off priority, loss probability.

1. Introduction

An important goal in the design of cellular communication systems is to increase the total carried traffic while at the same time decrease the call blocking probability. In order to have low handoff rates, a macrocell system is usually planned for users with high mobility, and a microcell system is planned for users with low mobility. Considering the building cost of base stations, a macrocell system is generally appropriate for areas with low-population density and a microcell system is suitable for areas with high-population density. Multitier cellular systems [1-3] are thus designed with the goals of increasing the spectrum efficiency while at the same time decreasing the construction cost.

Several teletraffic analysis of multitier cellular systems with handoff overflow processes have already been studied [4-10,12]. A system with one-way overflow scheme, from microcell to macrocell, was proposed by Hu et al [4-7] with finite queue and guard channels to minimize the blocking probability of new and handoff calls, and meanwhile increase the total carried traffic. A system with one-way overflow and reversible scheme proposed by Chin et al [8,9] was demonstrated to have better performance. Jabbari et al [10] proposed a flexible two-way overflow mechanism, from microcell to macrocell, and from macrocell to microcell, with possible take-back of overflow traffic into the preferred cell layer to achieve a higher probability of successful handoff and higher total carried traffic.

Hu et al modeled the overflow traffic [4] to analyze a three-tier (microcell, macrocell, and satellite) cellular system where calls are admitted to try higher tiers if the lowest tier fails, and handoff calls can access the channels with priority. A Markov modulated Poisson process (MMPP) is used to model the overflow traffic from the microcell layer to the macrocell layer by Lagrange et al [5]. Calls will try to join the microcells first, if no free channels are available, only handoff calls overflow to macrocells. Lin et al [6] designed a five-step iterative algorithm to compute the one-way overflow traffic from a microcell to its overlay macrocell. In other words, blocked new and handoff microcell calls will try to access the macrocells, neverthless, blocked calls from the macrocell will not overflow to the microcell layer.

None of the above studies considered the provisioning of buffer. Chang et al [7] employed two finite queues for new and handoff calls, respectively, and considered the guard channel scheme to evaluate the performance of a hierarchical cellular system. New or handoff microcell calls overflow to macrocell if either the number of idle channels in the microcell is less than the number of guard channels or no free channels available in the microcell. The problem of this one-way overflow scheme would induce higher traffic load in the overlaying macrocell and thus deteriorates the performance in the macrocell.

Chin et al [8] proposed a teletraffic analysis of a three-layer hierarchical system based on Markov chains to evaluate the call blocking probability, call dropping probability, and channel utilization. Calls are admitted only if they find a channel in their initial tier. Handoff calls are allowed to try high tiers if the initial attempt fails. They will return to the lower tier when possible, although not in the particular cell where the original attempt failed. Beraldi et al [9] considered a reversible hierarchical scheme characterized at the presence of handoff attempts from macrocells to microcells. Although the results showed that the system performance can be improved at the expense of relatively small increase of network control overhead when compared with the nonreversible hierarchical scheme, however, higher traffic load is induced in the overlaying macrocell and thus deteriorates its performance. A flexible two-way overflow mechanism with possible take-back of overflow traffic into the preferred cell layer was developed by Jabbari et al [10]. Although the overload problem in the macrocell can be resolved, the problem of unnecessary borrowing between layers at high traffic load remains to be resolved.

In this paper, a flexible hierarchical cellular system with bi-directional cut-off priority handoff (BCOPH) is proposed and analyzed. Overlaid microcells cover primarily low-mobility users and high-teletraffic area, and provide channels for calls overflowing from the overlaying macrocell, but they may be taken back upon crossing the microcell boundary. Therefore, we assume that handoffs of fast mobile stations can be handled in the microcell area and these microcells are assumed to be statistically different. The performance measures of interest will be analyzed via a set of system states including the overlaying macrocell and each overlaid microcells [7,12]. In a more realist case, we consider the overlaying macrocell covers primarily high-mobility users and some low-mobility users originated in the macrocell-only region. In this realist case, the overlaying macrocell provides channels for calls overflowing from the overlaid microcells, but these channels will be taken back when the mobile crosses the microcell boundary. To avoid high traffic load in the overlaying macrocell, the overflow of high-mobility users to microcells and the take-back of low-mobility overflowed calls are allowed. Meanwhile the cut-off priority scheme [11], where some channels are reserved in each tier for overflowed calls, is used in both the macrocell and microcells so as to avoid unnecessary overflows at high traffic load. We assume implicitly that the system has a build-in mechanism to determine whether a mobile user is of low or high mobility so that a mobile station can select a preferred layer in the first call attempts.

The rest of the paper is organized as follows. The operation of a flexible hierarchical cellular system with BCOPH scheme is described in section 2. The set of threshold values pursued in the simulation results and discussions are presented in section 3, where the performance measures of the BCOPH scheme, the uni-directional cut-off priority handoff (UCOPH) scheme and the one-way overflow, reversible and without threshold scheme are compared. Finally, concluding remarks are given in section 4.

2. System Description

Fig. 1 shows a two-tier hierarchical cellular system where an overlaying macrocell covers a number of overlaid microcells represented by hot spots. These microcells constitute the low tier of the two-tier hierarchy, denoted by microcell i, $1 \le i \le N$. The area of each of these N microcells may not necessarily be the same and their union may not cover the whole macrocell area. The residue area, named as the macrocell-only region, is served only by macrocell 0 which is the high tier layer.

Assume each macrocell is allocated with C_0 channels, among these C_0 channels, C_{g0} are reserved for handoff calls, m is the threshold of occupied channels and T_M is the number of channels lent to the overlaid microcells with a threshold of n. The number of channels allocated to microcell i is C_i, i=1, 2, $\cdots$, N, among these C_i channels, C_{gi} are reserved for handoff calls. $m_i^{'}$ is the threshold of occupied channels of microcell i and T_{mi} is the number of microcell i channels lent to the overlaying macrocell. The channel allocation of the hierarchical cellular system is illustrated in Fig. 2.

Assume a large number of mobile stations traversing the coverage area in four directions randomly and a mobile user does not change its speed and direction during an entire call. For simplification, we consider the microcells are homogeneous in the sense that the area are the same and the number of channels allocated to each microcell are the same, i.e., $C_1=C_2=\cdots=C_N$, $C_{g1}=C_{g2}=\cdots=C_{gN}=C_g$, $m_1^{'}=m_2^{'}=\cdots=m_N^{'}=m^{'}$, and $T_{m1}=T_{m2}=\cdots=T_{mN}=T_m$.

The channel allocation using the bi-directional cut-off priority handoff scheme is described in the following.

1) A new call of fast mobile station originated in the macrocell region or a new call of slow mobile station originated in the macrocell-only region is first directed to the camped-on macrocell. It will be served immediately by macrocell 0, if the number of available channel is greater than C_{g0}. Otherwise, it may be overflowed to that overlaid microcell which provides radio

coverage to this mobile station. It will be accepted by microcell i except that the total number of occupied channels of microcell i reaches the threshold m' or the number of channels lent from microcell i to macrocell is T_m.

2) A new call originated in an overlaid microcell i, $1 \le i \le N$, is first directed to the camped-on microcell and will be served immediately if the number of available channels is larger than C_g. Otherwise, it may be overflowed to the overlaying macrocell. It will be accepted by macrocell 0 except that if the total number of occupied channels of macrocell 0 reaches the threshold m or if the number of channels lent from macrocell 0 to microcell i is T_M/N or if the total number of macrocell channels lent to overlaid microcells is n.

3) A handoff call of fast mobile station coming from neighboring macrocells is first directed to the target macrocell 0 independent of whether the current serving cell is a neighboring macrocell or a neighboring microcell. It will be served immediately by macrocell 0 if there are available channels. Otherwise, it may be overflowed to the overlaid microcell which provides radio coverage to this mobile station. It will be accepted by microcell i except that the total number of occupied channels of microcell i reaches the threshold m' or the number of channels lent from microcell i to macrocell is T_m.

4) A handoff call of slow mobile station coming from neighboring macrocells

will be directed to macrocell-only region or microcell i. If it is in the macrocell-only region, it will be served immediately by macrocell 0 if there are available channels, otherwise it will be dropped; if it is in microcell i, it will be served immediately by microcell i if there are available channels. Otherwise, it will be overflowed and accepted by macrocell 0 except that the total number of occupied channels of macrocell 0 reaches the threshold m or the number of channels lent from macrocell 0 to microcell i is T_M/N or the total number of macrocell channels lent to all microcells is n.

5) A handoff call of slow mobile station moving from microcell i to macrocell-only region will be served immediately by macrocell 0 if it has available channels. Otherwise, the handoff call will be dropped.
6) A handoff call of fast mobile station moving from microcell i to its neighboring microcell j will be firstly served by macrocell 0 if there are available channels. Otherwise, it will be overflowed and served by microcell j except that the total number of occupied channels of microcell j reaches the threshold m' or the number of channels lent from microcell j to macrocell is T_m.
7) A handoff call of slow mobile station moving from microcell i to its neighboring microcell j will be served immediately by microcell j if there

are available channels. Otherwise, it will be overflowed and accepted by macrocell 0 except that the total number of occupied channels of macrocell 0 reaches the threshold m or the number of channels lent from macrocell 0 to microcell j is T_M/N or the total number of macrocell channels lent to all microcells is n.

8) If a new or handoff call of slow mobile station originated in microcell i has been successfully overflowed to macrocell 0, a take-back request will be directed to the entered target microcell at each border crossing a microcell. This take-back request will be accepted by the target microcell if there are available channels. Otherwise, it will continue its roaming within a macrocell.

9) If a new or handoff call originated in macrocell 0 has been successfully overflowed to a microcell, a take-back request will be directed to the overlaying macrocell at each border crossing a microcell. This take-back request will be accepted by the target macrocell if there are available channels. Otherwise, it initiates a handoff request to a neighboring microcell.

In 8) and 9), it assumes that the take-back process [10] is delayed until the border-crossing epochs.

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3. Simulation Results and Discussions

In the simulation environment, a square street-map model is used. The hierarchical cellular system includes one overlaying macrocell with length 800m and two overlaid microcells with length 200m. Let (C_0, C_1, C_2) be (32, 14, 14). The speed of mobile stations is uniformly distributed between 0 and 17 m/sec, the average speed of slow and fast mobile stations are respectively 1m/sec and 10m/sec. The total call arrivals to the entire area follows a Poisson process with a mean rate λ , i.e., $\lambda = \lambda_0 + \sum_{i=1}^{N} \lambda_i$, a fraction p of this traffic is from slow mobile stations, and a fraction p' of these slow mobile stations is distributed in the macrocell-only region, this case is referred as the realist case. The call holding time is exponentially distributed with a mean of 110sec, which is the same for new and handoff calls.

We will consider the following scenarios in the hierarchical cellular system:

Scenario 1: a hierarchical cellular system with the BCOPH scheme

Scenario 2: a hierarchical cellular system with the UCOPH scheme

Scenario 3: a hierarchical cellular system with one-way overflow, reversible and without cut-off priority handoff

We will first find the threshold values for both the BCOPH and the UCOPH schemes, the performance measures of these three scenarios will then be compared.

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3.1 The BCOPH scheme

Let β represent the traffic intensity per channel between microcell and macrocell. With different values of β, the average blocking (P_b) and dropping(P_d) probability varies significantly as shown in fig. 3. In other words, β plays a key role in the selection of guard channel. The performance measures of β=1:1 and β=2:1 satisfy the requirement in each guard channel selection. But the guard channel is 1 for β=5:1, because the performance requirement (i.e., $P_b \leq 5\%$, $P_d \leq 0.5\%$) can't be satisfied. Fig. 4 shows the probability of dropping and blocking for varies combination of guard channels in the macrocell and microcell, e.g. (1, 0, 0) means that 1 guard channel in the macrocell, 0 in microcell 1, and 0 in microcell 2. From the figure, we see that the guard channel combination (1, 1, 1) performs better than (0, 1, 1) and (1, 0, 0) in terms of the average dropping probability, it means that the system with guard channel combination (1, 1, 1) have larger call arrival rate at the same performance measure.

Normalized thresholds of m, m' and n are used in the simulation. Fig. 5 shows that the loss probability decreases as the normalized threshold and channels lent (T_M) increase, but the loss probability increases as the normalized threshold is greater than 14/16 and the number of channels lent (T_M) is 24 at light load. It means that a proper choice of normalized threshold is 14/16, means that m and m' are 28 and 12 respectively, and the number of channels lent (T_M) is 24 at light load; but the normalized threshold is 1, means that m and m' are 32 and 14 respectively, and the number of channels lent (T_M) is 24 at heavy load.

Fig. 6 shows the results of the realistic case where 10% of slow-mobile user calls are originated in the macrocell-only region, i.e., p'=0.1 and the optimistic case where all slow-mobile user calls are originated in microcells, i.e., p'=0. The average dropping probability of the realistic case is higher than that in the optimistic case because of higher handoff rate in the realistic case. Non-homogeneous distribution of traffic in microcells 1 and 2 (β = 1:3) is compared with that with homogeneous distribution as shown in Fig. 7. From the figure, we can see that homogeneous traffic distribution performs better.

3.2 The UCOPH scheme

Parameters of guard-channel combination, threshold values (m and n), and channels lent (T_M) for the UCOPH scheme can be obtained by using the same method mentioned in the previous section. The best guard-channel combination is also (1,1,1). Fig. 8 shows that the loss probability decreases as the normalized threshold and channels lent increase. The loss probability is smaller when T_M equals 26, and the loss probability stays the same as the normalized threshold ranges from 12/16 to 14/16 at light load. Therefore, m may be 24, 26 or 28, and n is 20. The loss probability differs a little at heavy load. Thus, appropriate threshold values of m and T_M are 26 that means at heavy load as many channels as possible are lent to microcell.

3.3 Performance Measures

From the previous results, the proper set of parameters of scenario 1 and scenario 2 are respectively m=28, n=20, T_M=24, m'=14, T_m=1, and m=26, n=20, T_M=26, when the guard channel combination is (1, 1, 1). Fig. 9 shows that at heavy load scenario 1 has smaller average loss probability than scenario 2 and scenario 3, i.e., scenario 1 has higher system capacity than scenario 2 and scenario 3, while other performance measures are basically the same,. We can also find that the average loss probabilities of scenario 2 and 3 are almost the same, it means that the effect of threshold values of m, n and T_M are not significant.

4. Conclusions

In this paper, a flexible hierarchical cellular system with the BCOPH scheme is analyzed. The proper set of threshold values of the BCOPH and UCOPH schemes are obtained by simulation. We can see that when the traffic distribution is homogeneous among microcells the performance measures are better, furthermore, homogeneous distribution of traffic between microcell and macrocell results in better performance. The average dropping probability of the realistic case, i.e., p'=0.1, is higher than that in the optimistic case, i.e., p'=0, because of higher handoff rates.

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Three scenarios are considered in the hierarchical cellular system. Scenario 1 is a hierarchical cellular system with the BCOPH scheme, scenario 2 is a hierarchical cellular system with the UCOPH scheme, and scenario 3 is a hierarchical cellular system with one-way overflow, reversible and without cut-off priority handoff scheme. Scenario 1 outperforms scenario 2 and scenario 3 for about 30% in the average loss probability at heavy load, implying that scenario 1 gives higher system capacity than scenario 2 and scenario 3 do. The effect of threshold values in scenario 2 is not very significant because the average loss probability of scenario 2 is basically the same as that of scenario 3.

The analytical model with a set of system states including the overlaying macrocell and each overlaid microcells, and integrated voice and data service with the BCOPH scheme will be analyzed in multitier cellular systems where multi-dimensional birth-death modeling may probably be more effective. Work in this direction is currently carrying on.

5. References

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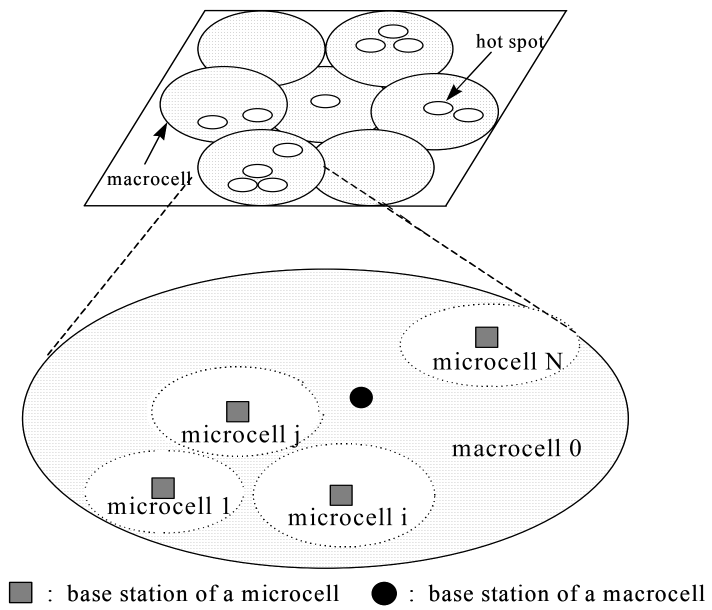

Fig. 1. A two-tier hierarchical cellular system

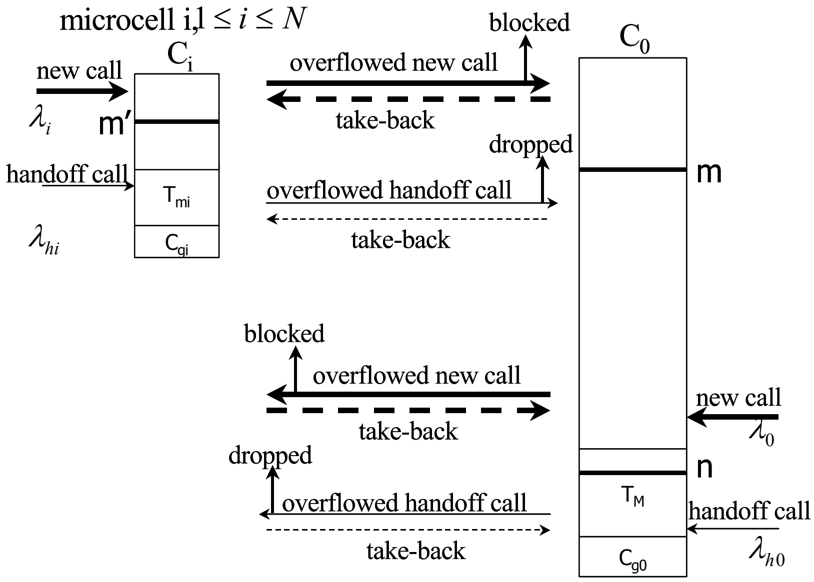

Fig. 2. Channel allocation of the BCOPH scheme

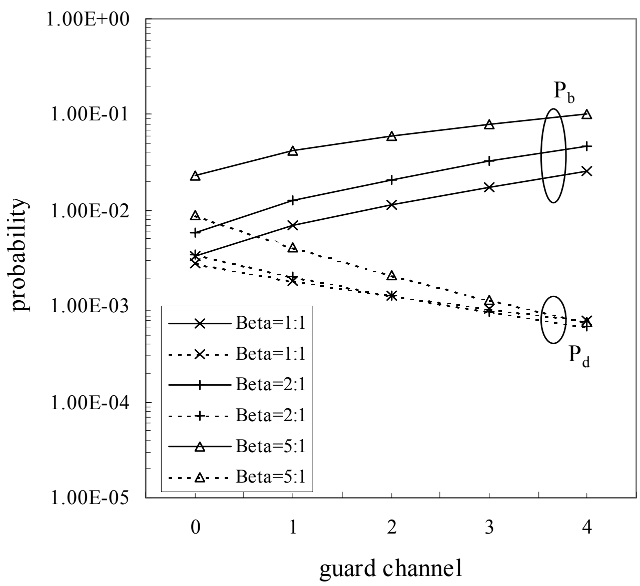

Fig. 3. Performance measures versus guard channels

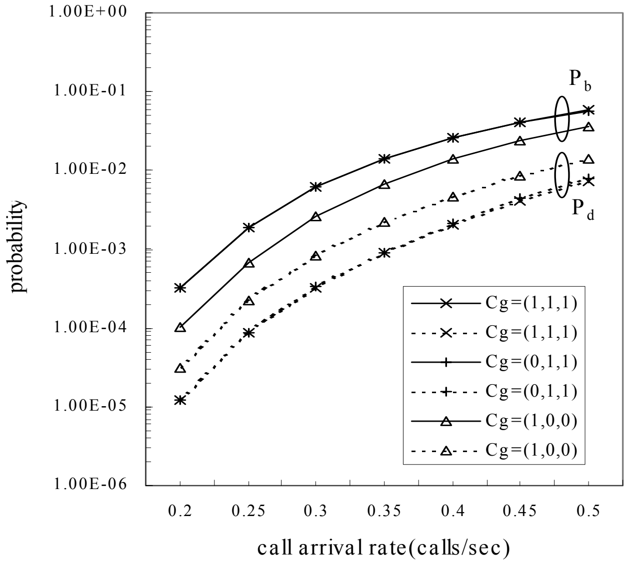

Fig. 4. Performance measures versus call arrival rate

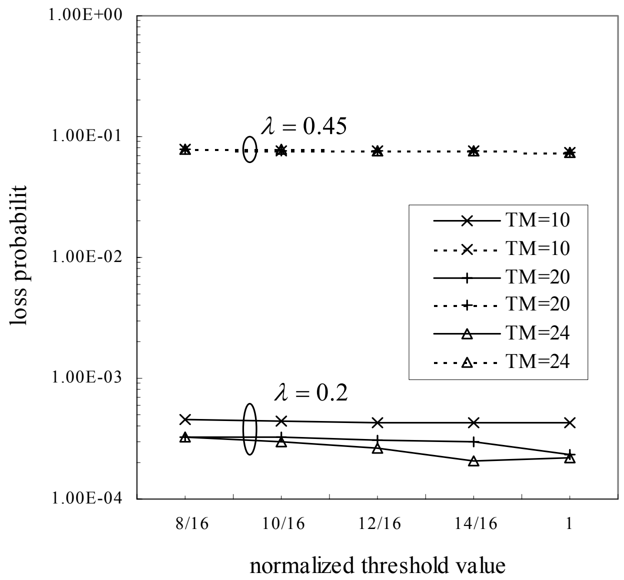

Fig. 5. Loss probability versus normalized threshold

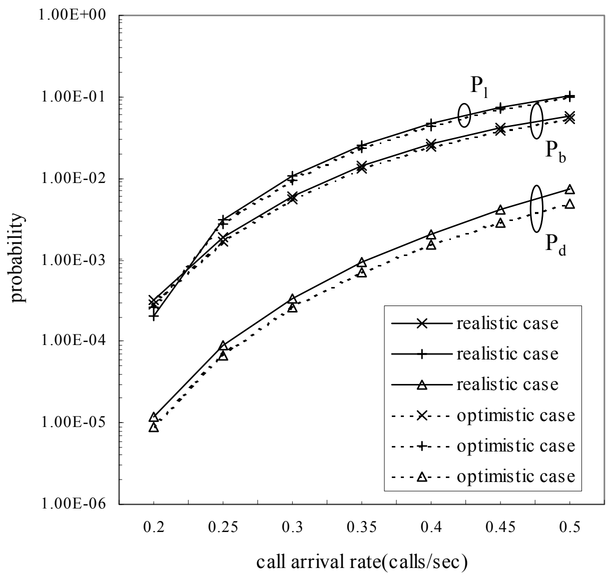

Fig. 6. Performance measures versus call arrival rates

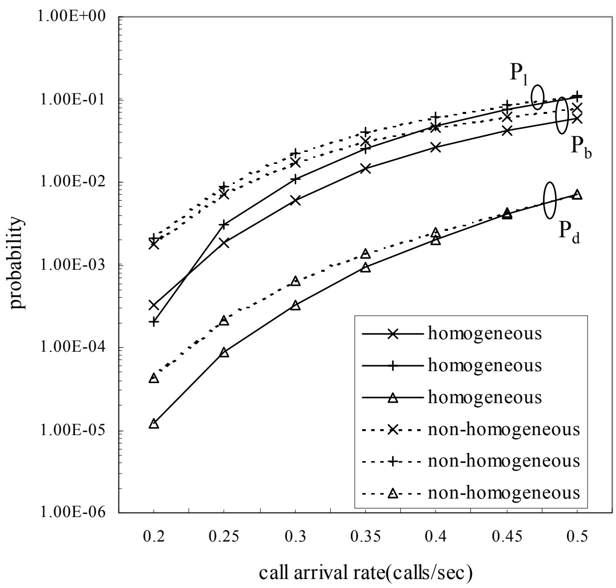

Fig. 7. Performance measures versus call arrival rates

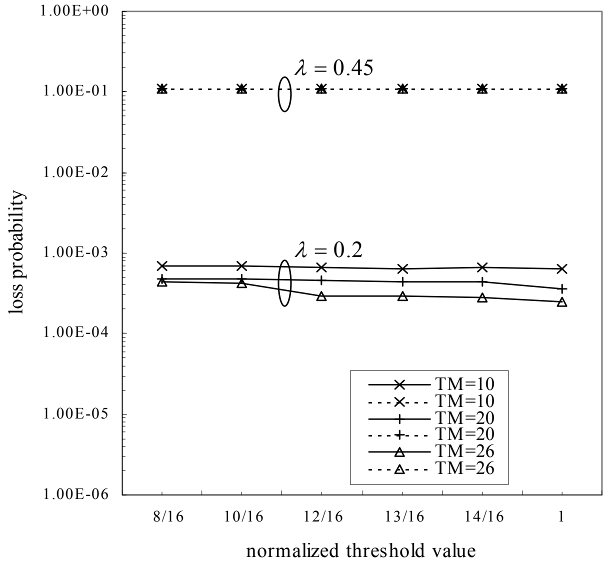

Fig. 8. Loss probability versus normalized threshold values

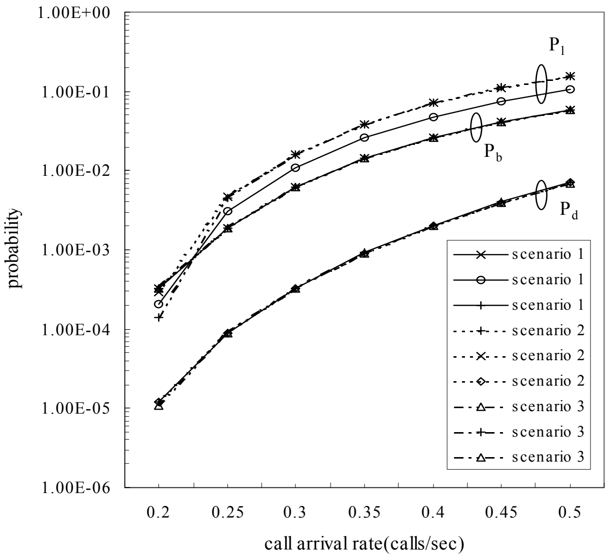

Fig. 9. Performance measures versus call arrival rates