A Spectrum Sharing Scheme in Two Cellular Wireless Networks

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Abstract. In this paper, we propose and investigate a spectrum sharing scheme in two cellular wireless networks. This scheme specifies various considerations of how to share the licensed radio spectrum of one network with another, including how to rent out the spectrum to another network and how to withdraw the original spectrum from the renting network. For each network, we figure out explicit expressions for important system performance measures, which include blocking probability of new calls and handoff calls and system throughput. We also show how to adjust our spectrum sharing scheme to achieve a better result for each of above performance measures.

Keywords: Spectrum sharing scheme, radio spectrum rent, call admission control, blocking probability.

1 Introduction

FCC in its reports "Spectrum policy task force" [1] and "Notice of proposed rule making and order" [2] indicated respectively that most licensed spectra are underutilized. Since then, there are many papers studied various problems of spectra sharing between various wireless networks to efficiently increase the utilization of the radio spectra. For example, in [3] and [4] the authors studied threshold call admission control scheme in a cellular wireless network with the spectrum renting feature and gave optimal values of the admission thresholds. The paper [5] outlined the issues related to how to make the spectrum sharing approach more close to the reality. The paper [6] addressed spectrum regulators with ways to increase the utility of future unlicensed allocations by improving the sharing of such bands between diverse systems. A survey of dynamic spectrum access techniques is provided in [7]. There are some more papers studied problems related the spectrum sharing schemes such as [8] and [9].

The key of the radio spectrum sharing is that the idle radio spectrum can be rented by other wireless networks. As radio spectrum can be normally divided into radio channels by using multiple access methods such as TDMA and FDMA etc., the spectrum sharing concept can be further explained as that one network can borrow

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idle radio channels from another network, and the system renting out channels may also withdraw its radio channels when these channels are needed. That is, when mobile users suffer insufficient channels in one radio system, they may attempt to use idle channels in other radio systems.

If we restrict our consideration on an environment in which there are only two wireless networks with possible spectrum sharing features, there are two situations we should pay attention to. In the first situation, only one network may borrow a channel from another one. In order to decrease the blocking probability for handoff calls, we assume only the handoff calls have this priority. Without loss of generality, we assume that the handoff calls of the network-1 may borrow channels from network-2 but not vise verse. In the second situation, in which handoff calls in any networks may rent a channel from another. There is another situation when network-1 and network-2 are two independent systems, which means no one will rent channels from another. In this case, the performance of the network is determined completely by its own capacity and the call arriving rate and call resident time. There are many research papers in the literature for this independent situation, such as [10-15]. In our paper, this situation will only act as a comparison sample. We will derive analytic results for four cases and then make comparison among these total five cases based on performance measures.

The rest of this paper is organized as follows. The parameter description and theoretic analysis of two network system is given in section 2. The explicit expression for each of the performance measures is provided in section 3. Section 4 devoted to the numerical results. Finally, our conclusion is given in section 5.

2 Description and Analysis of the Two-Network System

We consider two network systems with spectrum renting feature and withdrawn procedure. When an arrived handoff call finds all home channels are being used, the network may set up a renting procedure to rent a channel from another network if there is a free channel available. In another side, when an owner network needs its rented out channels, it can active its withdrawn protocol too. To give a detailed description of the input parameters of this general model, we introduce the following assumptions:

- The new call and handoff call arrival process to network-*k* are Poisson process with a rate λ_k^N and λ_k^H (k =1, 2), respectively. Hence, the total arrived rate to network-*k* is $\lambda_k = \lambda_k^N + \lambda_k^H$ (k =1, 2).
- The lifetime of a new call or a handoff call with network-*k* is exponentially distributed with a rate h_k (k =1, 2).
- The cell residence time of a new call or a handoff call with network-*k* is exponentially distributed with a rate r_k (k = 1, 2).
- When all channels in the network-*k* are being occupied and there is at least one channel in another network available, an arrived network-*k* call may rent a channel from another network. This will active the renting procedure and

the call arrival rate to network-k may change. To include the no-rental or independent networks as a special case of our model, we will assume the total arrival process of network-k call, under the condition that there is at least one free channel from another network, is a Poisson process with a new rate λ_k^T ($k = 1, 2$).

- If all channels from two networks are occupied and one of the networks is using some channels borrowed from another network, then the withdrawn procedure will be active if the owner network needs the rented channels. In this situation. The arrival process of the owner network calls will be adjusted depending on the withdrawn protocol. We use $\overline{\lambda_k}$ (k = 1, 2) to represent the arrival rate of the adjusted Poisson process of owner arrived calls.

We assume that there are totally M channels for network-1 and N channels for network-2. The purpose of this section is to find the steady-state probability of the system when there are m calls from network-1 and n calls from network-2 in the status of connection, where $m = 0, 1, \cdots, M + N$ and $n = 1, 2, \cdots, N + M - m$. In order to reach this goal, we will introduce two stochastic processes. One is the number of calls from network-1 in the status of connection at time t, $I(t)$, and the other one is the number of calls from network-2 in the status of connection at time t, $J(t)$. Based on the description of the scheme proposed in the previous section, it is not hard to show that $\{(I(t), J(t))\}$ forms a two-dimensional Markov process with the state space

$$\Omega = \{(m, n) : m + n \le M + N\}$$

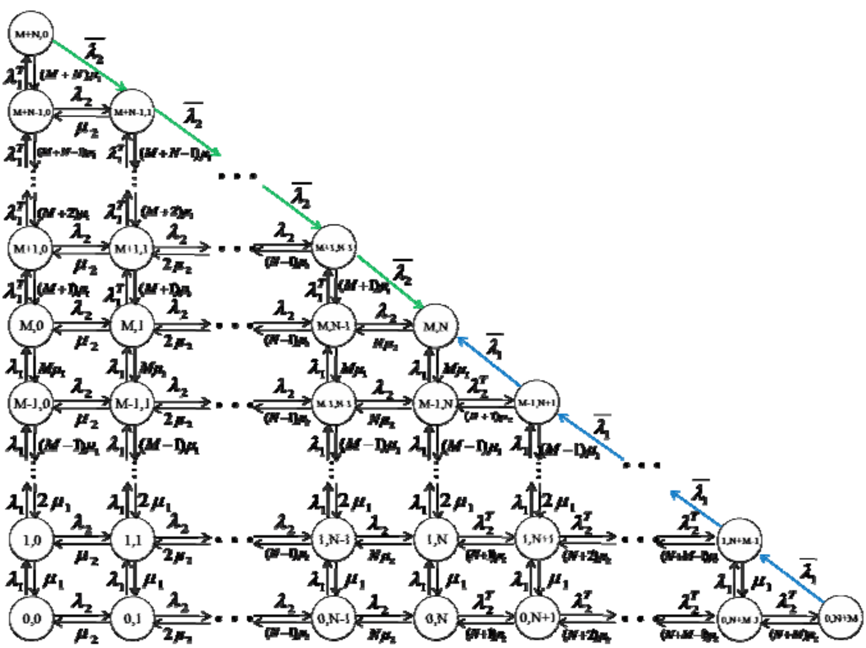

Fig. 1. Transition rate diagram

Based on the description of the system in Section 2, if we assume $\mu_k = h_k + r_k$ and $\lambda_k = \lambda_k^H + \lambda_k^N$ for $k = 1, 2,$ the transition rate diagram of the corresponding Markov process can be depicted as in Fig. 1.

We now take the step to find the steady state probability for this system. By using the transition rate diagram, the corresponding transition rate matrix Q of the general two dimensional Markov Process $\{(I(t), J(t))\}$ can be derived as follows

$$\boldsymbol{Q} = \begin{bmatrix} E_0 & A_0 & 0 & \cdots & 0 & \cdots & 0 & 0 \\ B_1 & E_1 & A_1 & \cdots & 0 & \cdots & 0 & 0 \\ 0 & B_2 & E_2 & \cdots & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & E_M & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & 0 & \cdots & E_{M+N-1} & A_{M+N-1} \\ 0 & 0 & 0 & \cdots & 0 & \cdots & B_{M+N} & E_{M+N} \end{bmatrix}$$

where the matrices A_i, B_i and E_i are briefly explained in the following:

- Matrix A_i $(i = 0, 1, 2, \cdots, M + N - 1)$ refers to the event that an arrived network-1 call successfully receives the connection with the system when there are already *i* connections of network-1 calls in the system. The expression for A_i is provided as follows.
  - if $i = 0, 1, 2, \cdots, M - 1$, A_i is a matrix with size of $(M + N - i + 1) \times (M + N - i)$ given by

$$A_i = \begin{bmatrix} \lambda_1 & 0 & \cdots & 0 & 0 \\ 0 & \lambda_1 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & \lambda_1 & 0 \\ 0 & 0 & \cdots & 0 & \lambda_1 \\ 0 & 0 & \cdots & 0 & \overline{\lambda_1} \end{bmatrix}.$$

  - if $i = M, M + 1, M + 2, \cdots, M + N - 1,$
    A_i is also a matrix with size of $(M + N - i + 1) \times (M + N - i)$ and has the expression

$$A_i = \begin{bmatrix} \lambda_1^T & 0 & \cdots & 0 & 0 \\ 0 & \lambda_1^T & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & \lambda_1^T & 0 \\ 0 & 0 & \cdots & 0 & \lambda_1^T \\ 0 & 0 & \cdots & 0 & 0 \end{bmatrix}.$$

- Matrix B_i ($i = 1, 2, \cdots, M + N$) refers to the event that a connected network-1 call departs from the system when there are i network-1 connected calls receiving the service. The expression for B_i is given as follows:
  - if $i = 1, 2, \cdots, M$, B_i is a matrix with size of $(M + N - i + 1) \times (M + N - i + 2)$ and is given by

$$B_i = \begin{bmatrix} i\mu_1 & 0 & 0 & \cdots & 0 & 0 \\ 0 & i\mu_1 & 0 & \cdots & 0 & 0 \\ 0 & 0 & i\mu_1 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & i\mu_1 & 0 \end{bmatrix}.$$

  - if $i = M + 1, M + 2, \cdots, M + N$,

    B_i is a matrix with size of $(M + N - i + 1) \times (M + N - i + 2)$ and is given by

$$B_i = \begin{bmatrix} i\mu_1 & 0 & \cdots & 0 & 0 & 0 \\ 0 & i\mu_1 & \cdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & i\mu_1 & 0 & 0 \\ 0 & 0 & \cdots & 0 & i\mu_1 & \lambda_2 \end{bmatrix}$$

- Matrix E_i ($i = 0, 1, 2, \cdots, M + N$) refers to the event that there are no changes in the total numbers of network-1 connected calls in the system when there are i network-1 calls receiving the service. The expression for E_i is given by,
  - if $i = 1, 2, \cdots, M - 1$, E_i is a square matrix with size of $(M + N - i + 1)$ given by

$$E_i = -i\mu_1 I + \begin{bmatrix} E_{11} & E_{12} \\ E_{21} & E_{22} \end{bmatrix}.$$

    where,

$$E_{11} = \begin{bmatrix} -(\lambda_1+\lambda_2) & \lambda_2 & 0 & \cdots & 0 & 0 \\ \mu_2 & -(\lambda_1+\lambda_2+\mu_1) & \lambda_2 & \cdots & 0 & 0 \\ 0 & 2\mu_2 & -(\lambda_1+\lambda_2+2\mu_2) & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & -[\lambda_1+\lambda_2+(N-2)\mu_2] & \lambda_2 \\ 0 & 0 & 0 & \cdots & (N-1)\mu_2 & -[\lambda_1+\lambda_2+(N-1)\mu_2] \end{bmatrix}.$$

$$E_{12}=\begin{bmatrix} 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & 0 & 0 \\ \lambda_2 & 0 & 0 & \cdots & 0 & 0 \end{bmatrix}. \quad E_{21}=\begin{bmatrix} 0 & 0 & 0 & \cdots & 0 & N\mu_2 \\ 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 \end{bmatrix}.$$

$$E_{22}=\begin{bmatrix} -[\lambda_1+\lambda_2^T+N\mu_2] & \lambda_2^T & 0 & \cdots & 0 & 0 \\ (N+1)\mu_2 & -[\lambda_1+\lambda_2^T+(N+1)\mu_2] & \lambda_2^T & \cdots & 0 & 0 \\ 0 & (N+2)\mu_2 & -[\lambda_1+\lambda_2^T+(N+2)\mu_2] & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & -[\lambda_1+\lambda_2^T+(N+M-i-1)\mu_2] & \lambda_2^T \\ 0 & 0 & 0 & \cdots & (N+M-i)\mu_2 & -[\overline{\lambda}_1+(N+M-i)\mu_2] \end{bmatrix}.$$

– if $i = M$, E_i is a square matrix with size of $(N+1)$ and is given by

$$E_M=-M\mu_1 I+\begin{bmatrix} -(\lambda_1^T+\lambda_2) & \lambda_2 & 0 & \cdots & 0 & 0 \\ \mu_2 & -(\lambda_1^T+\lambda_2+\mu_2) & \lambda_2 & \cdots & 0 & 0 \\ 0 & 2\mu_2 & -(\lambda_1^T+\lambda_2+2\mu_2) & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & -[\lambda_1^T+\lambda_2+(N-1)\mu_2] & \lambda_2 \\ 0 & 0 & 0 & \cdots & N\mu_2 & -N\mu_2 \end{bmatrix}.$$

– if $i = M+1, M+2, \cdots, M+N-1$,
E_i is a square matrix with size of $(M+N-i+1)$ given by

$$E_i=-i\mu_1 I+\begin{bmatrix} -(\lambda_1^T+\lambda_2) & \lambda_2 & 0 & \cdots & 0 & 0 \\ \mu_2 & -(\lambda_1^T+\lambda_2+\mu_2) & \lambda_2 & \cdots & 0 & 0 \\ 0 & 2\mu_2 & -(\lambda_1^T+\lambda_2+2\mu_2) & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & -[\lambda_1^T+\lambda_2+(M+N-i+1)\mu_2] & \lambda_2 \\ 0 & 0 & 0 & \cdots & (M+N-i)\mu_2 & -[(M+N-i)\mu_2]-\overline{\lambda_2} \end{bmatrix}.$$

– if $i = M+N$, we have that $E_{N+M} = -[\overline{\lambda_2} + (M+N)\mu_1]$.

Based on the result of Lemma 3 in [16], we will have the following conclusion.

Theorem 1: The steady-state probability of the investigated system can be calculated by

$$\pi_i = \pi_0 \prod_{j=1}^{i} \left[A_{j-1} \left(-D_j \right)^{-1} \right], \text{ for } i = 1, 2, \cdots, M+N, \tag{1}$$

where $\prod_{j=1}^{K} a_j \equiv a_1 a_2 \cdots a_{K-1} a_K$ for any matrix a_j, and $D_j\ (j = 0, 1, 2, \cdots, M+N)$ is recursively derived by $D_{N+M} = E_{N+M}$ and

$$D_j = E_j - A_j D_{j+1}^{-1} B_{j+1}, \quad \text{for } j = 0, 1, 2, \cdots, M+N-1 , \tag{2}$$

and π_0 can be calculated by $\pi_0 D_0 = 0$ and $\pi_0 \left[\boldsymbol{e} + \sum_{i=1}^{M+N} \left(\prod_{j=1}^{i} A_{j-1} \left(-D_j^{-1} \right) \right) \boldsymbol{e} \right] = 1$, where $\boldsymbol{e}$ is a column vector of suitable size with all its components equaling to one.

3 Performance Evaluations

Given the stationary probability distribution of the network as expressed in (1), many interesting performance measures of the system can be derived. In this section, the explicit expressions for the blocking probabilities and the system throughput are provided.

3.1 Blocking Probabilities

Call blocking probability is always important and has been considered to be a key measure of the quality of a network system. Let us first consider the new call blocking probability for network-1. When a new call arrives to the network-1, it will be blocked when all channels of network-1 are busy if we assume that the new call cannot borrow channels from other networks Therefore, by using the PASTA (Poisson Arrivals See Time Averages) rule [3], the new call blocking probability of network-1, defined as $P_1(B)$, can be expressed as

$$\begin{aligned} P_{1,N}(B) &= \left(1 - \frac{\overline{\lambda_1}}{\lambda_1} \right) \sum_{m=0}^{M-1} \pi_m \cdot e_{M+N-m} + \sum_{m=M}^{M+N} \pi_m \cdot e \\ &= \left(1 - \frac{\overline{\lambda_1}}{\lambda_1} \right) \sum_{m=0}^{M-1} \pi_{m,M+N-m} + \sum_{m=M}^{M+N} \sum_{n=0}^{M+N-m} \pi_{m,n} , \end{aligned}$$

where e_{M+N-m} is a $(M+N-m+1)$-dimensional column vector with 1 in the last element and zeroes for other elements. Similarly, the new call blocking probability for network-2 can be given by

$$P_{2,N}(B) = \left(1 - \frac{\overline{\lambda_2}}{\lambda_2} \right) \sum_{n=0}^{N-1} \pi_{M+N-n,n} + \sum_{n=N}^{M+N} \sum_{m=0}^{M+N-n} \pi_{m,n} .$$

Next we will proceed to the formulae for the handoff blocking probability of network-1. When a handoff call arrives to the network-1, it will be blocked when the channels for both networks-1 and network-2 are occupied. Therefore, by using the PASTA rule again, the handoff call blocking probability of network-1, defined as $P_{1,H}(B)$, can be expressed as

- $\lambda_1^T = \lambda_1^H$

$$P_{1,H}(B) = \left(1 - \frac{\overline{\lambda_1}}{\lambda_1}\right)\sum_{m=0}^{M-1} \pi_m \cdot e_{M+N-m} + \sum_{m=M}^{M+N} \pi_m \cdot e_{M+N+1-m} \\ = \left(1 - \frac{\overline{\lambda_1}}{\lambda_1}\right)\sum_{m=0}^{M-1} \pi_m \cdot e_{M+N-m} + \sum_{m=M}^{M+N} \pi_{m,M+N-m}.$$

where $e_{M+N+1-n}$ is a (M+N+1-m)-dimensional column vector with 1 in the last element and zeroes for other elements.

- $\lambda_1^T = 0$

$$P_{1,H}(B) = \left(1 - \frac{\overline{\lambda_1}}{\lambda_1}\right)\sum_{m=0}^{M-1} \pi_m \cdot e_{M+N-m} + \sum_{n=0}^{N} \pi_{M,n}.$$

Similarly, the handoff call blocking probability for network-2 can be obtained by

- $\lambda_2^T = \lambda_2^H$

$$P_{2,H}(B) = \left(1 - \frac{\overline{\lambda_2}}{\lambda_2}\right)\sum_{n=0}^{N-1} \pi_{M+N-n,n} + \sum_{n=N}^{M+N} \pi_{M+N-n,n}.$$

- $\lambda_2^T = 0$

$$P_{2,H}(B) = \left(1 - \frac{\overline{\lambda_2}}{\lambda_2}\right)\sum_{n=0}^{N-1} \pi_{M+N-n,n} + \sum_{m=0}^{M} \pi_{m,N}.$$

3.2 Throughput

We will consider the throughput of the network-k (k =1, 2) and the throughput of the whole system respectively. The throughput of network-k, denoted by TH_k, is defined as the long-run rate at which handoff call are processed through network-k. Since the handoff calls arrive at network-k according to a Poisson process with rate λ_k^H, we have

$$TH_1 = \lambda_1^H[1 - P_{1,H}(B)] = \lambda_1^H\left[1 - \sum_{m=0}^{M+N} \pi_{m,M+N-m}\right],$$

and

$$TH_2 = \lambda_2^H[1 - P_{2,H}(B)] = \lambda_2^H\left[1 - \sum_{n=0}^{M+N} \pi_{M+N-n,n}\right].$$

Because both network-1 and network-2 have the same handoff call blocking probability, the overall throughput from the all system, TH, can be obtained by,

$$TH = TH_1 + TH_2 = \lambda_1^H\left[1 - \sum_{m=0}^{M+N} \pi_{m,M+N-m}\right] + \lambda_2^H\left[1 - \sum_{n=0}^{M+N} \pi_{M+N-n,n}\right].$$

4 Numerical Analysis

To verify the validity of the analytical expressions obtained in the previous section and make a comparison for different situations, we have implemented the proposed model for five different cases:

Case 1. network-1 and network-2 are two independent networks, which means no one will borrow from others, i.e, in this case, $\lambda_k^T = 0$, and $\overline{\lambda_k} = 0$, $k = 1, 2$.

Case 2. The handoff calls of system-1 and system-2 can borrow from each other and occupy the borrowed channel until the call is finished, i.e, in this case, $\lambda_k^T = \lambda_k^H$, and $\overline{\lambda_k} = 0, k = 1, 2$.

Case 3. The handoff calls of system-1 and system-2 can borrow from each other, but need to return the borrowed channels if the owner needs the channels, i.e, in this case, $\lambda_k^T = \lambda_k^H$, and $\overline{\lambda_k} = \lambda_k, k = 1, 2$.

Case 4. Only the handoff call of one of the networks, for example, network-1, can borrow channels from another one and occupy the borrowed channels until the call is finished, i.e, in this case, $\lambda_1^T = \lambda_1^H, \lambda_2^T = 0$ and $\overline{\lambda_k} = 0$, $k = 1, 2$.

Case 5. Only the handoff call of one of the networks, for example, network-1, can borrow channels from another one, but need to return the borrowed channels if the owner needs them, i.e, in this case, $\lambda_1^T = \lambda_1^H, \lambda_2^T = 0$ and $\overline{\lambda_1} = \lambda_1, \overline{\lambda_2} = 0$, $k = 1, 2$.

The performance measures considered here are the new call and handoff call blocking probability, the whole system throughputs. The parameters for the network are assumed as follows:

1) The capability of both network-1 and network-2 is 60 channels, i.e., *M=N=60;*
2) The new call arrival rate λ_k^N of network-*k* is $\frac{4}{60}$, i.e., $\lambda_k^N = \frac{4}{60}$, $k = 1, 2$;
3) The handoff call arrival rate λ_k^H of network-*k* $(k = 1, 2)$ changes from 0 to $\frac{12}{60}$, i.e., $\lambda_k^H \in \left[0, \ \frac{12}{60}\right], k = 1, 2$
4) The average channel holding time of any call is 400 second, i.e., $\frac{1}{\mu_k} = 400, k = 1, 2$;

Fig. 2 illustrates the handoff call blocking probability of netwok-1 under varied traffic loads for five cases. The traffic load is measured in terms of traffic intensity unit, Erlang, which is equal to the number of calls originating in the mean holding time. It is obvious that the probabilities increase when the traffic load increases and any borrowing strategies have smaller handoff call broking probability than the case1: network-1 and network-2 are independent which means no one will borrow channels from another. Among those four kinds of borrowing strategies, the handoff calls in case 5 and case 3 have smaller blocking probability than that in case 2 and case 4, which means that returning the borrowed channel whenever the owner needs is a better strategy.

The comparison of new call blocking probability among five cases is presented in Fig. 3. It is obvious that the new call blocking probability for any cases with borrowing feature is bigger. This is reasonable. Based on our algorithm, any handoff call which is using the borrowed channel will switch to its own network channel

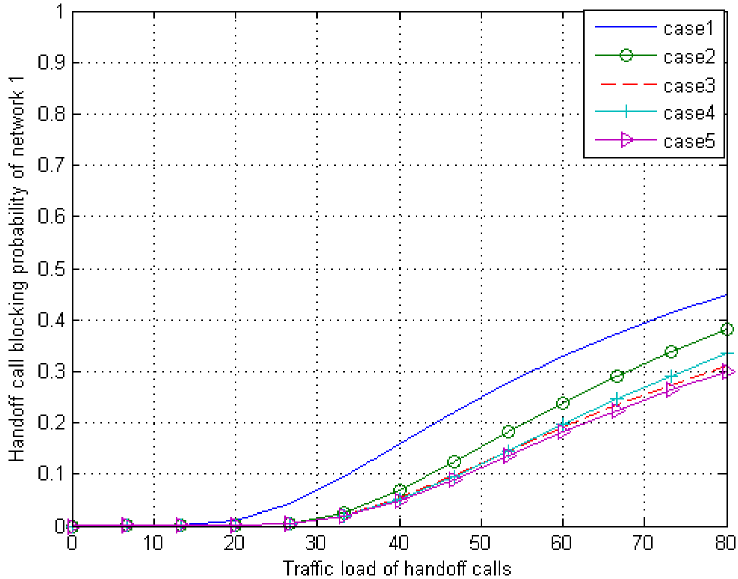

Fig. 2. Hand off call blocking probability of network-1 for five cases

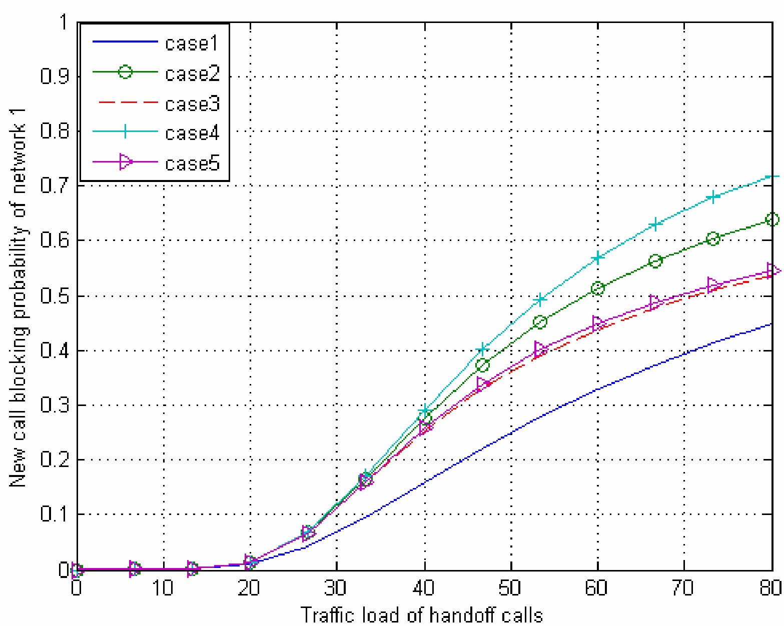

Fig. 3. New call blocking probability of network-1 for five cases

immediately as long as such a channel available. This approach actually gives a priority to handoff call and reduces the chance of new call getting connected in the same time. Among the "case 2" to the "case 5", the new call blocking probability in the "case 5" and the "case 3" show the lower value than that in the "case 2" and "case 4", which indicates the scheme that returning the borrowed channel in case the owner needs is also benefit to the new calls.

The throughputs of the whole system for five cases are shown in Fig. 4. The throughput is an important metric to judge a system. Fig. 4 shows that the "case 3" is the best choice in the view of whole system. The "case 3" means that the handoff call of both network-1 and network-2 can borrow the channel from the other and return the borrowed channel to the owner as long as the owner needs it.

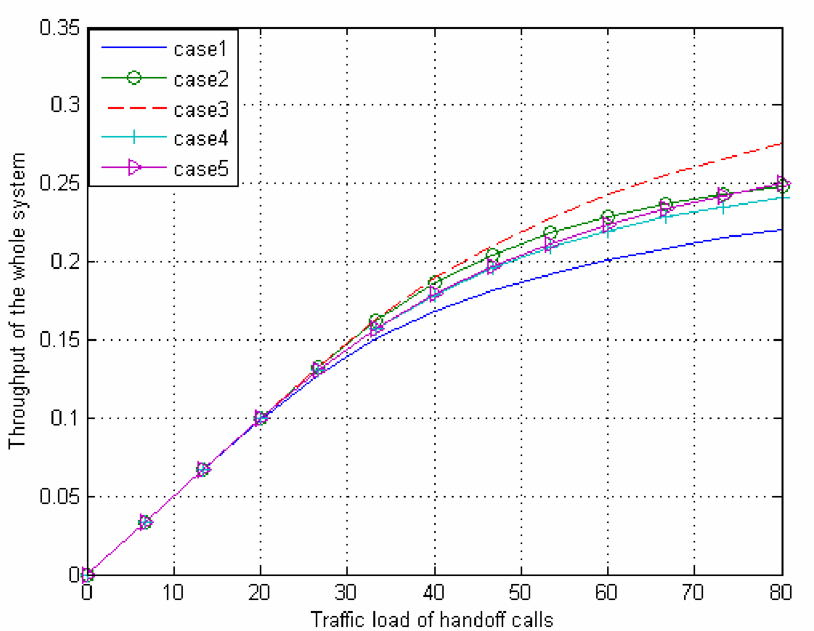

Fig. 4. Throughputs of the whole system for five cases

5 Conclusions

A novel two-network system with spectrum renting feature in the same area has been investigated in this paper. In order to better understand our scheme for the renting strategy, we developed five specific models: 1) network-1 and network-2 are two independent networks, which means no one will rent from another; 2) The handoff calls of network-1 and network-2 can rent from each other and occupy the borrowed channel until the call is finished; 3) The handoff calls of network-1 and network-2 can borrow from another, but need to return the borrowed channel if the owner needs the channel; 4) Only the handoff call of one of the network, for example, network-1, can borrow channels from another one and occupy the borrowed channel until the call is finished; 5) Only the handoff call of one of the networks, for example, network-1, can borrow channels from another one, but needs to return the borrowed channel if the owner needs it. For these five cases, analytical formulae of some important performance measures, such as new call and handoff call blocking probability, the throughput and utilization of the network are derived. The numerical implementation indicated that the proposed mathematical model is very accurate and the corresponding theoretic results are consistent with the simulation results. In addition, we made a comparison study among different situations. This comparison study shows that with the renting feature, the whole system can achieve higher throughput than that one with two independent networks; the handoff calls will always obtain high priority to new calls; in “case 3”, the system achieves the best performance in a view of the whole system.

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