Channel Management Based on Maximizing Customers' Satisfaction and Service Providers' Revenue

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Abstract—In this paper, we propose and analyze a different channel allocation scheme in mobile cellular networks which not only gives priority to handoff calls but also tries to protect originating calls. We use channel reservation to protect handoff calls and in contrast, to protect originating calls, we set a maximum reservable channel, *NG*, in our scheme. In channel reservation schemes, there are some periods that reserved channels are not actively utilized. In this paper, these periods are defined as dead time. Some new performance measures of the system such as the distribution and the mean dead time of a reserved channel are obtained. The main contribution of this work is to find optimum *NG* so as to maximize the service provider's revenue while customers' satisfaction (in term of connection continuity) and system utilization (in term of system capacity and less dead time) are justified jointly. We assume a general cost structure which is due to blocking of handoff calls, blocking of originating calls and unutilized periods of reserved channels. Based on the total cost, we investigate the trade-off between the service utilization and customers' satisfaction.

Keywords: **Resource management, revenue schemes, wireless communication systems, performance modeling.**

I. INTRODUCTION

Technological advances and rapid development of handheld wireless terminals have facilitated the rapid growth of wireless communications. Taking ergonomic and economic factors into account, and considering the new trend in telecommunications industry to provide ubiquitous information access, the population of mobile users will continue to grow at a tremendous rate, while customers are expecting the same quality of service (QoS)[1], availability and performance as the traditional wire-line networks. To cope with this challenge, many new modulation and multiple access techniques have been developed. But for a given spectrum and a specific technology used, the admitted traffic capacity and QoS of a cellular system depends on how channels are managed. Since from the subscriber's view point, forced termination due to handover calls is more annoying than blocking of a new call, therefore, protecting the connection continuity for mobile users, as a QoS constraint, has been studied extensively. Basic techniques to this protection are guard channel (GC) [1], handoff queuing [2], [3], and predictive channel reservation (PCR) [4], [5]. Other techniques for handoff protection include subrating [6], channel sharing [7], and channel carrying [8]. Indeed, the final goal of these schemes is to increase the connection continuity for an admitted call [9].

It has been declared in [9] that all of the three priority-based handoff protection schemes that are discussed frequently in the literature - GC, handoff queuing, and PCR - result in decreased handover failures but increased new call blocking. In other words, system capacity and QoS are two conflicting objectives and tradeoff is inevitable.

Some researchers have investigated the possibility of minimizing new call blocking while providing handoff protection. In [10], Oh and Tcha have proposed careful division of nominal channels into guard and nonguard sets so that handoff failure is reduced within the constraint of satisfying a predefined grade of service. Minor changes such as adding or removing one guarded channel affect the new user admission and handoff protection performance significantly. Therefore, the use of fractional guard channel [11] permits fine adjustment by setting aside a noninteger number of guarded channels. The dynamic channel allocation scheme in [12] permits guarded channels to be provisionally accessed by new users if the number of handoff requests is small. In [13], channels in each cell are divided into two parts. To increase the channel utilization while maintaining QoS of each type for traffic, handoff calls are allowed to borrow channels from the other under certain constraints.

In this paper, we propose and analyze a different handoff scheme which not only gives priority to handoff calls, due to importance of them from QoS standpoint, but also protects originating calls. The scheme is a composition of GC and PCR. In order to make prioritization on handoff calls, we use PCR technique and in contrast, to protect originating calls, we set an upper limit on reserved channels, denoted in this paper by *NG*. It is obvious that increasing the upper limit on reserved channels protects handoff calls better and in contrast

[1] We limit the QoS discussion to the issues of call dropping and connection continuity in order to minimize the dimensionality of the problem.

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the chance of channel assignment to a new call attempt is reduced. So, exact setting of *NG* is critical from the customers' satisfaction and system capacity viewpoint.

Besides the size of the maximum reservable channel (*N*G), the other important parameter in our scheme is dead time. In channel reservation schemes, there are some periods which reserved channels are not actively utilized. In this paper, these periods are defined as dead time. So, dead time is inactive period of a reserved channel before it becomes utilized, due to arrival of a handoff call, or released, due to arrival of a cancellation. As we see later in this paper, the more *NG*, the more dead time and consequently the less system utilization.

With respect to above explanations, there is a trade-off between system utilization (in term of system capacity and less dead time) and customers' satisfaction (in term of less blocking of handoff calls). The main contribution of this work is to achieve the optimal trade-off between the two by finding the optimum *NG* so as to maximize the service provider's revenue. To do so, we define the cost structure to be a function of blocking of handoff calls, blocking of originating calls and unutilized periods of reserved channels (dead times). Numerical results show that in the optimal *NG*, both customers' satisfaction and system utilization are justified jointly.

The paper is organized as follows. In Section II, we describe the proposed channel allocation scheme and its traffic model. Section III proposes a two dimensional Markov chain to study some basic performance measures of the network (handoff failure probability and new call blocking probability) and analyze the distribution of dead time and its mean. Cost function parameters are extracted in this section too. Our objective is to choose the upper limit on reserved channels, *NG*, so as to maximize the service provider's revenue. Section IV shows the numerical results obtained by solving the model. The existing trade-off between customers' satisfaction and system utilization is considered in this section. Finally, the paper concludes with Section V.

II. System Model

In this paper, we consider a system with homogenous cells and a fixed number of channels (*N*), which are permanently assigned to each cell. Generation of originating (new) calls into one cell is assumed to be a Poisson process with average arrival rate λ_n. Generation of handoff calls is a function of new call generation and user mobility characteristics [14], [15], but for simplicity we assume it is a process independent of new call and also with Poisson distribution with average arrival rate λ_n [9]. Consider a channel which is actively utilized (due to either assignment to an incoming handoff call or a new call); channel holding time (CHT) is defined as the minimum of cell dwelling time and call residual time [1].

As mentioned above, we use PCR for handoff call protection. The PCR we use is almost like the one in [4] and [9], so channel reservation is enforced only in the most likely target cell of the next handoff. When an active mobile user is detected to be approaching cell boundary, its remaining time

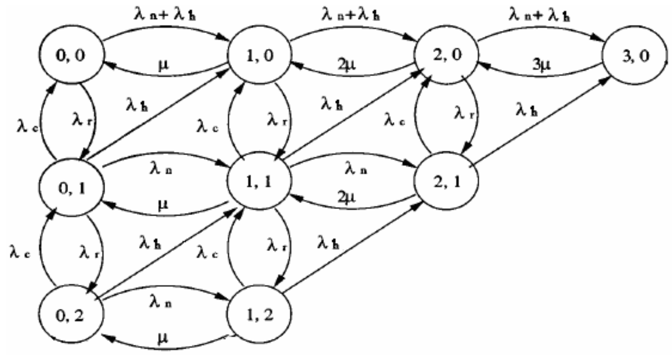

Fig. 1. A simplified example of the Markov Chain with *N*= 3 and *NG* = 2.

in the current cell is estimated. Once this time falls below a threshold time, defined as channel reservation time interval (*CRTI*), channel reservation request is sent to the target cell. If there is an idle channel in the target cell and also the number of reserved channels in it is less than *NG* (*NG* is integer and $0<NG<=N$), reservation request will be confirmed and one channel is immediately reserved in the target cell; otherwise the reservation request is cleared. We assume that the arrival of reservation request is governed by a Poisson process with rate λ_r. It is more realistic that we consider the period from arrival of reservation request to its handoff occurrence instant to be a random variable uniformly distributed between (0,*CRTI*), not exactly equal to *CRTI*. We need to cancel false reservation (due to redirection of active mobile or call completion); therefore, we define a cancellation process having a Poisson arrival rate λ_c too. When a cancellation request occurs, if there is a reserved channel in the target cell, it will be released; otherwise, cancellation request will be cleared. Final assumption is that each handoff call, before arriving to the target cell, has sent one and only one reservation request to it, so:

$$\lambda_r = \lambda_h + \lambda_c \quad . \tag{1}$$

When a cell receives a handoff call, if there is a reserved channel, allocates it to the call, else if there is a free channel allocates it, else the handoff call will be blocked. New (originating) call is accepted by the cell only if there is an idle channel available.

III. Performance Analysis

A. Markov Model

As mentioned before, our system is a system with homogenous traffic intensity and uniform channel allocation. In such a system, teletraffic performance of a single cell is analogous to one another; so we can focus our attention on a single cell. With respect to the previous section, the model can be described by a 2-*D* Markov chain with state (*i* , j) where *i* and *j* are the numbers of channels actively utilized and reserved, respectively. Fig. 1 gives a simplified example that depicts the one cell model with three channels (i.e., *N*=3) and maximum reservable channels is two (i.e., *NG*=2). In order to simplify the expression of balance equations, we also define six inclusion functions as follows:

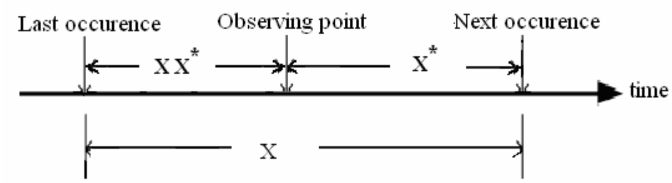

Fig. 2. Renewal process

$$\alpha_1(i,j)=\begin{cases}1 & i+j<N\\ 0 & else\end{cases}\qquad \alpha_2(i)=\begin{cases}1 & i\neq N\\ 0 & else\end{cases}\qquad \alpha_3(j)=\begin{cases}1 & j\neq 0\\ 0 & else\end{cases}$$

$$\alpha_4(i,j)=\begin{cases}1 & i+j<N,\ j<NG\\ 0 & else\end{cases}\qquad \alpha_5(i)=\begin{cases}1 & i\neq 0\\ 0 & else\end{cases}\qquad \alpha_6(j)=\begin{cases}1 & j\neq NG\\ 0 & else\end{cases}$$

The equilibrium equation for the state occupancy probabilities *P(i, j)*,where $i+j<=N$, $j<=NG$, can be written as:

$$P(i,j)\left[\alpha_1(i,j)\lambda_n+\alpha_2(i)\lambda_h+\alpha_3(j)\lambda_c+i\mu+\alpha_4(i,j)\lambda_r\right]=$$
$$\alpha_5(i)\left[\left[\lambda_n+(1-\alpha_3(j))\lambda_h\right]P(i-1,j)+\alpha_6(j)\lambda_h P(i-1,j+1)\right]+$$
$$\alpha_4(i,j)\ \lambda_c\ P(i,j+1)+\alpha_1(i,j)(i+1)\mu P(i+1,j)+\alpha_3(j)\lambda_r\ P(i,j-1)$$

where μ^{-1} is the mean CHT. Based on the probability set *P(i,j)*s, the following system performance parameters can also be obtained. The blocking probability P_{bn} of an originating (new) call is given by:

$$P_{bn}=\sum_{j=0}^{NG}P(N-j,j)\ . \tag{2}$$

The blocking probability for handoff call, P_{bh}, is given by:

$$P_{bh}=P(N,0)\ . \tag{3}$$

B. Dead Time

Now, we introduce another practical measure defined as dead time. Dead time *(DT)* is inactive period of a reserved channel before it becomes utilized (due to arrival of handoff call) or released (due to arrival of cancellation). Notice that in the former case utilization of a reserved channel can be due to either its handoff call arrival or an incoming handoff call which has not previously secured any reserved channel. Denote the latter handoff by HF_x and its occurrence probability by p_x. Therefore, p_x is the probability of handoff call arrival which has not previously reserved any channel (its reservation request has not been accepted by the system); so the target cell state probability just prior to arrival of HF_x' reservation request is:

$$p_x=\sum_{i=0}^{N-NG}P(i,NG)+\sum_{j=0}^{NG-1}P(N-j,j) \tag{4}$$

In order to compute the distribution function of the dead time, we use residual time and age time concepts [16, chap.3]. As shown in Fig. 2, for a renewal process, the time interval *X** from an arbitrary observation point to the next occurrence instant is called residual time and the time interval *XX** from the last occurrence epoch to the observation point is called the age time. In [16], it has been proved that the distribution function of both residual time and the age time of a renewal random variable *X* is as follows:

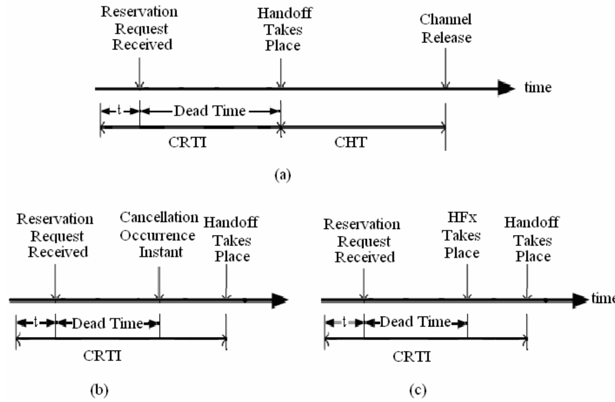

Fig. 3. Timing diagram. (a)neither HFx nor cancellation, (b) cancellation and (c)HFx occurs after reservation.

$$R(t)=P(X^*\le t)\frac{1}{m}\int_0^t[1-F(x)]\,dX \tag{5}$$

where m=*E*[*X*] and F(*X*) is the distribution of *X*.

Pay attention to Fig. 3. At first, suppose there is neither cancellation nor HF_x (Fig. 3(a)). So, in this case *DT* is the residual time for constant random variable *CRT*I. Therefore its distribution is:

$$R_1(t)=\frac{1}{CRTI}=\int_0^t[1-\int_0^x\delta(\xi-CRTI)\,d\xi]\,dX\ . \tag{6}$$

In other words, if we have neither cancellation nor HF_x, *DT* of a reserved channel is a random variable uniformly distributed between 0 and *CRTI*. Now consider the state either a cancellation or HF_x occurs after reservation (Fig. 3(b) and (c)). In this case, dead time is the age time for a uniformly distributed random variable (as mentioned in section II, the period from arrival of reservation request to its handoff occurrence instant is a random variable uniformly distributed between (0*, CRTI*)). So:

$$R_2(t)=\begin{cases}\displaystyle\int_0^t[1-\frac{X}{CRTI}]\,dX=\frac{2}{CRTI}\left(t-\frac{t^2}{2CRTI}\right) & 0\le t\le CRTI\\ 1 & t\ge CRTI\end{cases} \tag{7}$$

On the other hand, the probability of not having cancellation after reservation is:

$$P_A=\frac{1}{CRTI}\int_0^{CRTI}e^{-\lambda_c(CRTI-t)}\,dt=\frac{1}{\lambda_c CRTI}\left[1-\exp(-\lambda_c CRTI)\right] \tag{8}$$

And the probability of not having HF_x after reservation is:

$$P_{BNG}=\frac{1}{CRTI}\int_0^{CRTI}\sum_{k=0}^{\infty}\frac{e^{-\lambda_h(CRTI-t)}\times(\lambda_h(CRTI-t))^k}{k!}\times(1-p_x)^k\,dt$$
$$=\frac{1}{CRTI}\int_0^{CRTI}e^{-\lambda_h p_x(CRTI-t)}\,dt=\frac{1}{\lambda_h p_x CRTI}\left[1-\exp(-\lambda_h p_x CRTI)\right] \tag{9}$$

Finally, from (6)-(9) we have the distribution of a reserved channel dead time as:

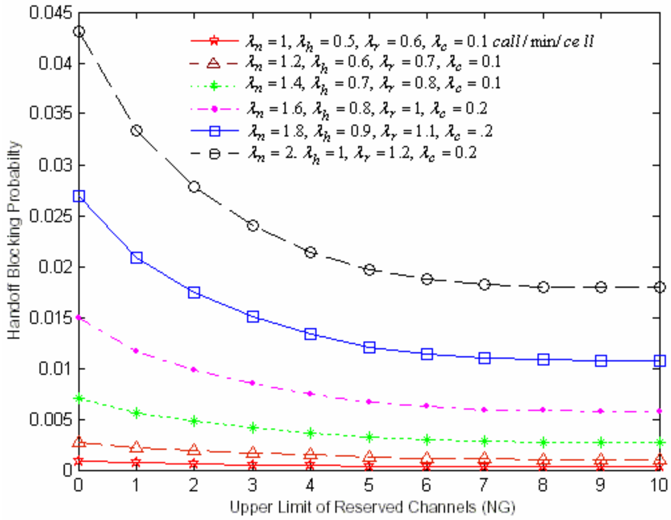

Fig. 4. Handoff blocking probability versus *NG*.

$$P(DT \le t) = P_A P_{BNG} R_1(t) + (1 - P_A P_{BNG}) R_2(t). \quad (10)$$

From (10), one can easily obtain the expectation of *DT* as:

$$E[DT] = \frac{CRTI}{6}(2 + P_A P_{BNG}). \quad (11)$$

Consequently, the mean dead time, *MDT*, for our reservation scheme can be derived as follows:

$$MDT = \sum_{j=1}^{NG} \sum_{i=1}^{N-j} E[DT] \times j \times P(i, j) \quad (12)$$

C. *Maximizing the Service Provider's Revenue*

Since from the subscriber's view point, forced termination due to handover calls is more annoying than blocking of a new call, therefore, we use the connection continuity for mobile users as the customers' satisfaction constraint. In other words, we use the blocking probability of a handoff call, Pbh, representing the customers' satisfaction.

As we see later, if the number of reservable channels *(NG)* increases, P_{bh} decreases. On the other hand, larger *NG* size incurs higher dead time *(DT)*. It is obvious that in channel reservation schemes, whatever the *DT* increases, traffic load carried by a channel and eventually system utilization decreases. Therefore, the trade-off in the cost due to blocking of handoff calls and unutilized periods of reserved channels *(DTs)* is closely related to the selection of maximum reservable channel, namely *NG*. However, to be fair to the customers who tend to make a new call (originating calls), we also consider the cost due to probably blocking of originating calls, P_{bh}. Indeed P_{bh} represents system capacity in our scheme like [15]. The sum of the penalties due to blocking of handoff calls, blocking of originating calls and the cost of unutilized periods of reserved channel is an optimization function in our work. The maximum service providers' revenue can be achieved by minimizing the cost function through careful selection of *NG*.

The sum of costs, due to blocking of handoff calls, blocking of originating calls and the mean dead time, is the total cost function and is as follows:

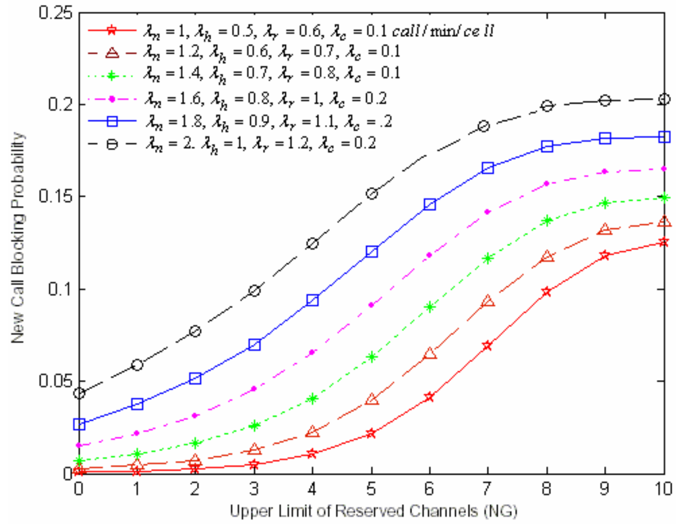

Fig. 5. New call blocking probability versus *NG*.

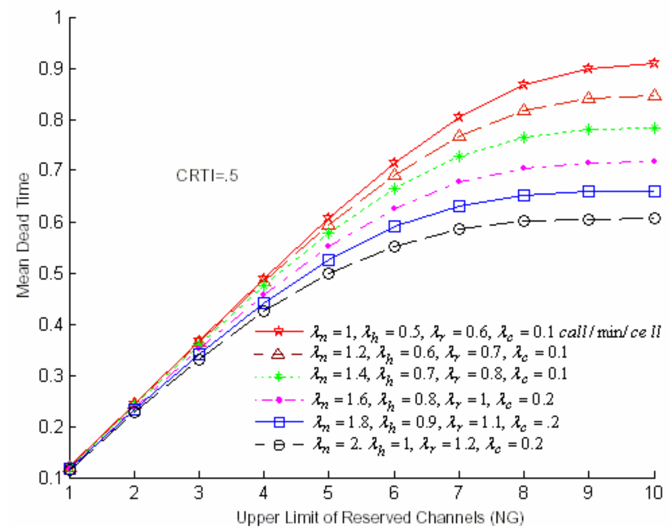

Fig. 6. System dead time versus *NG*.

$$C_{tot} = c_{bh} P_{bh} + c_{bn} P_{bn} + c_{DT} MDT \quad (13)$$

where c_{bh}, c_{bn} and c_{DT} have constant values and are the expected cost of blocking one handoff call, blocking one originating call and system mean dead time, respectively. The exact value of these parameters in a practical cellular mobile system depends on many parameters, such as the exact distribution of generation of originating and handoff calls and user mobility characteristics, which can be very diverse for different networks. Thus, in this paper, we will not dwell on the determination of these coefficients but, instead, choose some discrete values that cover most practical conditions, and investigate the performance of the network under those conditions. Furthermore, in numerical analysis, we will normalize c_{bh}, c_{bn} and C_{tot} so that they are expressed in units of c_{DT}.

IV. Numerical Results and Discussion

In this section, system characteristics are numerically illustrated. We assume that 10 channels are allocated to each cell (*N*=10) and the mean channel holding time is 2 min (μ^{-1}=2 min). We also assume that *CRTI* is equal to 0.5. Figs. 4 and 5 show how the performance measures depend on the upper limit of reserved channels (*NG*), under various call arrival rates. Notice that *NG*=10 is the same as conventional PCR [5], [6]. From these diagrams, we observe that in all traffic situations, bigger *NG* protects handoff call arrival rates. Coincident with our instinct, in a given traffic situation, bigger *NG* leads to more mean dead time. Indeed, Figs. 4-6 demonstrate the trade-off between service utilization (represented by system capacity and *MDT*) and customers' satisfaction due to connection continuity (represented by P_{bh}). Our purpose is to find such *NG* that causes the best balance between service utilization and customers' satisfaction. With respect to the sensitivity of each of these parameters (P_{bh}, P_{bn} and *MDT*) to *NG* (shown in Figs. 5-7), we select c_{bh}=10000 and c_{bn}=100.

Fig. 7 shows the existing trade-off between customers' satisfaction and system utilization represented based on cost function described in Section III-C. The optimal *NG* that balances this trade-off, NG_{opt}, can be obtained by minimizing the cost function. This figure is presented under two different traffic situations, as denoted in the figure.

As a whole, Fig. 7 shows that when *NG* is smaller than NG_{opt}, in which C_{tot} is minimum, P_{bh} is considerable and the cost due to blocking of handoff calls dominates the cost function, hence the total cost decreases as *NG* increases. By increasing *NG* more than NG_{opt}, the cost due to blocking of new calls and system dead time dominate the total cost function. In this case, the effect on less P_{bh} due to larger *NG* is small, and larger *NG* only increases the total cost. Numerical results also show that NG_{opt} is independent from the traffic load variations. It is because that variation of traffic load has different effects on P_{bh}, P_{bn} and *MDT* (as shown in Figs. 4-6) which totally compensate each other. Therefore, the optimum *NG* is relatively the same for different values of traffic load, as depicted in Fig. 7.

V. Conclusion

In this paper, we have proposed and analyzed a different handoff scheme which not only gives priority to handoff calls, due to importance of them from QoS standpoint, but also protects originating calls. In order to make prioritization on handoff calls, we used PCR technique and in contrast, to protect originating calls, we set an upper limit (say *NG*) on reserved channels. We also defined dead time concept in handoff reservation schemes and mathematically analyzed its mean in our scheme. The paper quantitatively shows that there is a trade-off between customers' satisfaction (in term of connection continuity) and system utilization (in term of system capacity and less dead time). The main contribution of this work was to find optimum *NG*, NG_{opt}, so as to maximize the service provider's revenue while customers' satisfaction, system capacity and less dead time were satisfied jointly. To do so, we defined cost structure to be a function of blocking of handoff calls, blocking of originating calls and unutilized periods of reserved channels (dead times). As a whole, numerical results show that when the size of *NG* is smaller than NG_{opt}, the cost of blocking of handoff calls dominates and hence we can expect the total cost decreases as *NG* increases.

When the size of *NG* is larger than NG_{opt}, the cost due to blocking of new calls and system dead time dominate the total cost function. Numerical results also show that NG_{opt} is relatively independent of traffic load variations.

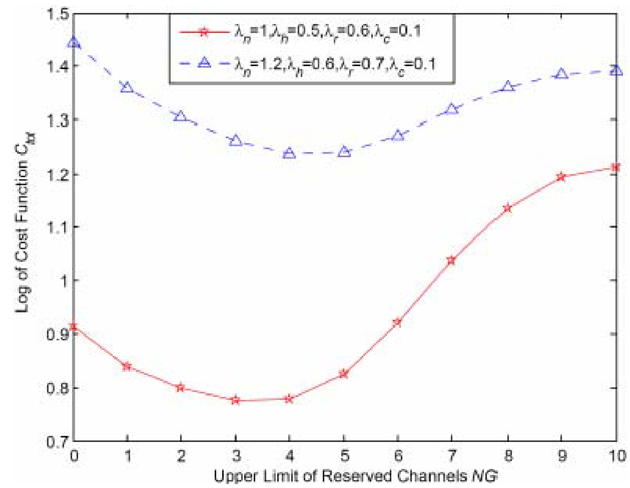

Fig. 7. C_{tot} versus *NG* at c_{bh}=10000 and c_{bn}=100.

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