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PERFORMANCE COMPARISON OF TWO-TIER CELLULAR NETWORKS: QUEUING THE HANDOFF CALLS

Geetanjali Sharma*, Kiranta Kumari and G. N. Purohit

Centre for Mathematical Sciences, Banasthali University-304022, Rajasthan, India

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ABSTRACT

One way of improving the performance of a cellular network is to build a second tier (layer) called the Macrocell on top of the existing single-tier called the Microcell. Multi-tier cellular networks provide mobility situations to both the high speed and low speed users. In this paper, we propose a new Markov model with increasing the number of channels and queue size for a two-tier cellular network having a FIFO queue in the Microcell tier. The performance of both models is then compared with those of a previously proposed model in [12] having a queue in the Microcell tier and without having a queue in the Macrocell.

Keywords: *Blocking probability, FIFO queue, Markov chain, Two-tier cellular networks.*

1. INTRODUCTION

The increasing mobility of today's lifestyle is largely due to the advent of wireless communication technology. As technology evolves, the demand for wireless networks and the necessity to provide more channels increases. Multi-tier cellular networks have been developed to deliver these demands to a large number of mobile users. In a multi-tier cellular network, cells are distributed in a number of layers (tiers) according to the population and the geographical area of the network. The small and large radiuses of the cells provide a more efficient system for different traffic densities.

Having more than one layer of cells in a network increases the number of channels hence, the amount of traffic in the system. However, this approach increases the number of handoff attempts between cells of the same layer and also between cells of different layers (overflow).

Tekinary and Jabbari (1992) presented a non-preemptive priority queuing method based on a mobile subscriber's power measurements to improve the quality of service while maintaining a high spectrum utilization. Hierarchical cellular networks with subscribers of varying mobility were considered by Jabbari and Fuhrmann (1997). Chang et. al. (1999) considered both the effect of the reneging of waiting new calls because of the cellular impatience and the effect of the dropping of queued handoff calls as the callers move out of the handoff area, besides the effect of guard channel scheme. To enhance overall system performance, Some handover priority-based channel assignment techniques proposed by Kulavaratharasah and Aghvami (1999) and also proposed a measurement-based handover channel adaptive reassignment technique (MHAR-A). A variable reservation scheme for mobile networks considered by Oliver and Borras (1999) and modeled the radio degration zone close to the cell border, which allows the delay of the handoff request. Chiu and Bassiouni (2000) proposed a set of predictive channel Reservation (PCR) schemes aiming at improving the QOS of mobile calls without deteriorating the throughput of the cellular system. Ekici and Erosy (2001) developed several methods used guard channels for handoff calls to decrease the blocking probability and to increase the performance of the cellular networks. Salih and Fidanboylu (2003) introduced a new two-tier cellular network consisting of microcells in the lower layer and macrocells with FIFO queues in the high layer that will decrease the handoff call blocking probability. Boggia et. al. (2003) developed an analytical model for two-level hierarchical cellular communication networks with two user classes and dynamic channel allocation in each level. A two layer cellular architecture model is studied and the performance of channel assignment scheme based on new call bounding, cutoff priority and subrating is analyzed by Jain and Agrawal (2005). Salih and Fidanboylu (2005) proposed a model of a two-tier cellular network with a FIFO queue in the microcell to study its effect on the users. To improve the performance of a cellular network Salih and Fidanboylu (2006) proposed three different cellular models with a FIFO queue; A single-tier cellular network with FIFO queue, a two-tier cellular network with a queue in the macrocell and a two-tier cellular network with a queue in the microcell tier. Parwani and Purohit (2011) proposed a Markov model for a two low layers (picocell and femtocell) of hierarchical cellular network with a FIFO queue.

Corresponding author: Geetanjali Sharma*
Centre for Mathematical Sciences, Banasthali University-304022, Rajasthan, India

The remainder of this paper is organized as follows: Section 2 describes the notation ans basic assumptions used in our analysis and also describes two different models. Numerical comparisons are presented in Section 3. Section 4 concludes this paper.

2. SYSTEM DESCRIPTION AND MODEL ASSUMPTIONS

We consider a two-tier cellular network that consists of microcell and macrocells covering a large geographical area with the FIFO queue in the microcell layer. Low and high speed users are assigned to the microcells and macrocells, respectively. The radius of the microcell is smaller than the macrocell and an integer number of microcells are covered by one macrocell.

We have assumed that once a low speed user call is overflowed to the macrocell, it cannot return back to the microcell and when a low speed user becomes a high speed user the call is overflowed to the macrocell. Calls overflow from the microcell to the macrocell also when the low speed users new or handoff call cannot find a free channel in the microcell. A channel is released under two conditions; when a user voluntarily terminates the ongoing call and when a handoff call completes either with success or failure.

We employ a single cell in the network and assume that the macrocell covers as N number of microcells and the cells are circular in shape. Each cell has C channels and a FIFO queue of size Q in the Microcell.

NOTATIONS:

C : Number of channels in each cell.
N : Number of microcells that are overlaid by one macrocell.
Q : Size of FIFO queue.
λ_{ln} : Arrival rate of new calls for low speed users.
λ_{hn} : Arrival rate of new calls for high speed users.
λ_{hl} : Arrival rate of handoff calls for low speed users.
λ_{hh} : Arrival rate of handoff call for high speed users.
$1/\mu$: Mean average holding time for both types of users.
$1/\mu_{dl}$: Mean cell dwelling time for low speed users.
$1/\mu_{dh}$: Mean cell dwelling time for high speed users.
$1/\mu_{ql}$: Mean queue time for low speed users.
$1/\mu_{qh}$: Mean queue time for high speed users.

The cell dwelling time can be calculated as shown in [4] as follows:

$\frac{1}{\mu_d} = \frac{\pi r}{2v}$, where r is the radius of the cell and v is the speed of the mobile user.

2.1 Analysis of the microcell tier

The first part of the analysis corresponds to the microcell tier represented by a Markov chain with a FIFO queue. Fig. 1 shows the state *s(i)*, where *i* denotes the number of low speed users in the microcell. We assume that the number of channels, *C*, equals 10 and the queue size, *Q*, equals 4 as shown in Fig. 1. In the above transition diagram, *m* and *q* are given by $m = \mu + \mu_{dl}$ and $q = \mu + \mu_{ql}$ respectively.

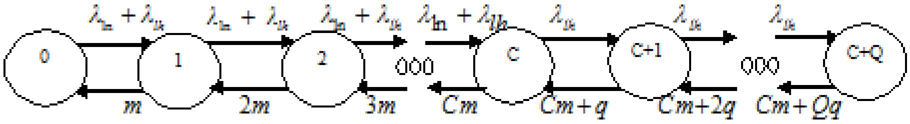

Fig.1. State transition diagram for a Microcell.

The State Transient Equations are given by:

$$p_0^{'}(t) = -(\lambda_{\ln} + \lambda_{lh})p_0(t) + mp_1(t)$$
$$p_1^{'}(t) = -(\lambda_{\ln} + \lambda_{lh} + m)p_1(t) + (\lambda_{\ln} + \lambda_{lh})p_0(t) + 2mp_2(t)$$

$\vdots$

$\vdots$

$$p'_{C-1}(t) = -(\lambda_{\ln} + \lambda_{lh} + (C-1)m)p_{C-1}(t) + (\lambda_{\ln} + \lambda_{lh})p_{C-2}(t) + Cmp_C(t)$$

$$p'_C(t) = -(\lambda_{lh} + Cm)p_C(t) + (\lambda_{\ln} + \lambda_{lh})p_{C-1}(t) + (Cm+q)\,p_{C+1}(t)$$

$$p'_{C+1}(t) = -(\lambda_{lh} + (Cm+q))p_{C+1}(t) + (\lambda_{lh})p_C(t) + (Cm+2q)\,p_{C+2}(t)$$

$\vdots$

$\vdots$

$$p'_{C+Q-1}(t) = -(\lambda_{lh} + Cm + (Q-1)q)p_{C+Q-1}(t) + (\lambda_{lh})p_{C+Q-2}(t) + (Cm+Qq)\,p_{C+Q}(t)$$

Now, take $\frac{d}{dt}p_0 = 0$ as t tends to ∞ and limit $p_0(t) = p_0$ as t tends to ∞, so above equations becomes

$$0 = -(\lambda_{\ln} + \lambda_{lh})p_0 + mp_1$$

$$0 = -(\lambda_{\ln} + \lambda_{lh} + m)p_1 + (\lambda_{\ln} + \lambda_{lh})\,p_0 + 2mp_2$$

$\vdots$

$\vdots$

$$0 = -(\lambda_{\ln} + \lambda_{lh} + (C-1)m)p_{C-1} + (\lambda_{\ln} + \lambda_{lh})p_{C-2} + Cmp_C$$

$$0 = -(\lambda_{lh} + Cm)p_C + (\lambda_{\ln} + \lambda_{lh})p_{C-1} + (Cm+q)\,p_{C+1}$$

$$0 = -(\lambda_{lh} + (Cm+q))p_{C+1} + (\lambda_{lh})p_C + (Cm+2q)\,p_{C+2}$$

$\vdots$

$\vdots$

$$0 = -(\lambda_{lh} + Cm + (Q-1)q)p_{C+Q-1} + (\lambda_{lh})p_{C+Q-2} + (Cm+Qq)\,p_{C+Q}$$

On solving these difference equations we get

$$p_1 = \left(\frac{\lambda_{\ln} + \lambda_{lh}}{m}\right)p_0$$

$$p_2 = \frac{1}{2!}\left(\frac{\lambda_{\ln} + \lambda_{lh}}{m}\right)^2 p_0$$

$\vdots$

$\vdots$

$$p_C = \frac{1}{C!}\left(\frac{\lambda_{\ln} + \lambda_{lh}}{m}\right)^C p_0$$

$$p_{C+1} = \frac{1}{C!}\left(\frac{\lambda_{\ln} + \lambda_{lh}}{m}\right)^C \frac{\lambda_{lh}}{(Cm+q)}\,p_0$$

$$p_{C+2} = \frac{1}{C!}\left(\frac{\lambda_{\ln} + \lambda_{lh}}{m}\right)^C \frac{(\lambda_{lh})^2}{(Cm+q)(Cm+2q)}\,p_0$$

$\vdots$

$\vdots$

$$p_{C+Q} = \frac{1}{C!}\left(\frac{\lambda_{\ln} + \lambda_{lh}}{m}\right)^C \frac{(\lambda_{lh})^Q}{(Cm+q)(Cm+2q).......(Cm+Qq)}\,p_0 \qquad (1)$$

From these equations, we conclude that

$$p_i = \begin{cases} \frac{1}{i!}\left(\frac{\lambda_{1n}+\lambda_{lh}}{m}\right)^i P_0 \; ; & i \le C \\ \frac{1}{C!}\left(\frac{\lambda_{1n}+\lambda_{lh}}{m}\right)^C \frac{(\lambda_{lh})^{i-C}}{\prod_{j=1}^{i-c}(Cm+jq)} P_0 \; ; & i > C \end{cases} \tag{2}$$

Since $\sum_{i=0}^{C} p(i) = 1$, then $p(0)$ can be expressed as:

$$p(0) = \left[1 + \sum_{i=1}^{C} \frac{(\lambda_{1n}+\lambda_{lh})^i}{i!(m)^i} + \sum_{i=C+1}^{C+Q} \frac{(\lambda_{1n}+\lambda_{lh})^C \lambda_{lh}{}^{i-C}}{C!(m)^C \prod_{j=1}^{i-c}[cm+jq]} \right]^{-1} \tag{3}$$

The blocking probability for new calls, p_n , is given by

$$p_n = \sum_{i=C}^{C+q} p(i) \tag{4}$$

The blocking probability for new calls, p_h , is given by

$$p_h = p_{C+Q} \tag{5}$$

The overflow traffic for speed new calls, λ_{ol}, and handoff calls, and handoff calls, λ_{olh} , is using the following equations

$$\lambda_{ol} = N\lambda_l p_n$$
$$\lambda_{olh} = N\lambda_l p_h$$

2.2 Analysis of the macrocell tier

The second part of the analysis corresponds to the macro cell tier without a queue. The system is analyzed using a Markov chain that contains the state *s(i,j)*, where *i* and *j* are the numbers of low and high speed users in the system, respectively. The Markov chain model with 10 channels is shown in Fig. 2.

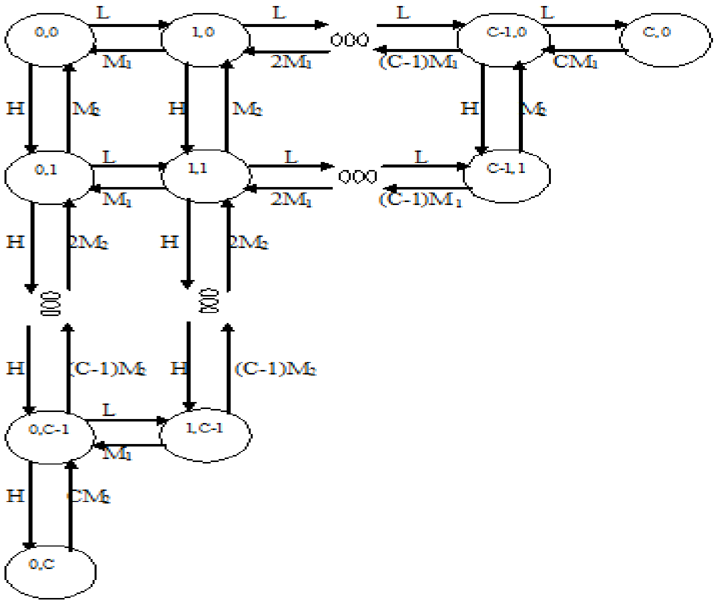

Fig. 2. Markov model for the Macrocell.

The parameters involved in the Markov chain are defined as follows:

$$L = \lambda_{ol} + \lambda_{olh}$$
$$H = \lambda_h + \lambda_{hh}$$
$$M1 = \mu + \mu_{dl}$$
$$M2 = \mu + \mu_{dh}$$

The steady state equations for this diagram are:

$$\begin{aligned}
&(L+H)p_{(0,0)} = M_1 p_{(1,0)} + M_2 p_{(0,1)} \\
&(L+H+M_1)p_{(1,0)} = Lp_{(0,0)} + 2M_1 p_{(2,0)} + M_2 p_{(1,1)} \\
&\vdots \\
&\vdots \\
&(L+H+(C-1)M_1)p_{(C-1,0)} = Lp_{C-2,0} + CM_1 p_{(C,0)} + M_2 p_{(C-1,1)} \\
&(L+H+M_2)p_{(0,1)} = Hp_{(0,0)} + M_1 p_{(1,1)} + 2M_2 p_{(0,2)} \\
&(L+H+M_1+M_2)p_{(1,1)} = Lp_{(0,1)} + Hp_{(1,0)} + 2M_1 p_{(2,1)} + 2M_2 p_{(1,2)} \\
&\vdots \\
&\vdots \\
&(L+H+(C-2)M_1+M_2)p_{(C-2,1)} = Lp_{(C-3,1)} + Hp_{(C-2,0)} + (C-1)M_1 p_{(C-1,1)} + 2m_2 p_{(C-2,2)} \\
&\vdots \\
&\vdots \\
&(L+H+(C-3)M_2)p_{(0,C-3)} = Hp_{(0,C-4)} + M_1 p_{(1,C-3)} + (C-2)M_2 p_{(0,C-2)} \\
&(L+H+M_1+(C-3M_2)p_{(1,C-3)} = Lp_{(0,C-3)} + Hp_{(1,C-4)} + 2M_1 p_{(2,C-3)} + (C-2)M_2 p_{(1,C-2)} \\
&(L+H+2M_1+(C-3)M_2)p_{(2,C-3)} = Lp_{(1,C-3)} + Hp_{(2,C-4)} + 3M_1 p_{(3,C-3)} + (C-2)M_2 p_{(2,C-2)} \\
&(L+H+(C-2)M_2)p_{(0,C-2)} = Hp_{(0,C-3)} + M_1 p_{(1,C-2)} + (C-1)M_2 p_{(0,C-1)} \\
&(L+H+M_1+(C-2)M_2)p_{(1,C-2)} = Lp_{(0,C-2)} + Hp_{(1,C-3)} + 2M_1 p_{(2,C-2)} + (C-1)M_2 p_{(1,C-1)} \\
&(L+H+(C-1)M_2)p_{(0,C-1)} = Hp_{(0,C-2)} + M_1 p_{(1,C-1)} + CM_2 p_{(0,C)}
\end{aligned} \tag{6}$$

We define the following inclusion functions to find the equilibrium equation of the state probabilities using the approach presented in [3].

$$\alpha(i,j,q) = \begin{cases} 1\,; & i+j<c \\ 0\,; & else \end{cases}$$
$$\beta(i,j,q) = \begin{cases} 1\,; & i \neq 0 \\ 0\,; & else \end{cases}$$
$$\delta(i,j,q) = \begin{cases} 1\,; & j \neq 0 \\ 0\,; & else \end{cases}$$

The equilibrium equation for the state occupancy probabilities p(i,j,q) can be calculated as follows:

$$\begin{aligned}
&(\alpha(i,j)(L+H) + \beta(i,j)iM_1 + \delta(i,j)jM_2)p(i,j) = \\
&\alpha(i,j)(p(i,j+1)(j+1)M_2 + p(i+1,j)(i+1)M_1) + \beta(i,j)p(i-1,j)L + \delta(i,j-1)H
\end{aligned} \tag{7}$$

The blocking probability for new calls, p_{bn}, in the macro cell is given by

$$p_{bn} = \sum_{i+j=C} p(i, j) \tag{8}$$

Since the macro cell does not have a queue, the blocking probability for handoff calls, p_{bh}, in the macro cell can be calculated using the same equation for p_{bn}.

3. NUMERICAL RESULTS

In this section, we show comparison of the numerical results for the proposed two-tier cellular network having a queue in the microcell with those presented in [12]. Furthermore, the same results are compared with these obtained for a two-tier cellular network without having a queue. For the computation of the numerical results, we have assumed a homogeneous two-tier cellular network with one macrocell covering 7 microcells and each cell containing 10 channels and queue size Q=4 for microcell tier. We assumed that the speed of the mobile users is pre-calculated so that once a call is originated the low speed users are assigned to the microcell tier and the high speed users are assigned to the macrocell tier. The data for the Figs. 3.1, 3.2, 3.3 and 3.4 are given in table I,II,III, and IV respectively.

Fig. 3.1 shows the effect of the new arrival rate (λ_n) on the blocking probabilities (P_b) of low speed user in microcell for our model and [12] model. It is clear from the figure that the blocking probability of our model is decreasing than existing model.

Fig. 3.2 shows the effect of the new call arrival rate (λ_n) on the handoff call probability in microcell of low speed user for our model and the model presented in [12]. It is observed that from the figure that the handoff call probability of their model is increasing than our models probabilities.

Fig. 3.3 indicates the effect of arrival rate (L) on the blocking probability in macrocell. It is clear that the blocking probability of our model is slightly increasing than existing model.

Fig. 6 shows the effect of arrival rate (L) on the handoff dropping probability in macrocell. It is observed that the handoff dropping probability is increasing than the existing model.

Table I: Blocking Probability of our model (C=10) and their model (C=3)

λ_n	Pb (Model I), C=3	Pb (Model II), C=10
1	0.248605	7.2E-05
2	0.500849	0.008716
3	0.648303	0.116836
4	0.734432	0.432840
5	0.788690	0.718819
6	0.825354	0.859079
7	0.851549	0.920819
8	0.871101	0.950180
9	0.886206	0.965708
10	0.898202	0.974738

Table II: Handoff dropping probability of two models

λ_n	Ph (Model I), C=3	Ph (Model II), C=10
1	0.075888	1.39E-05
2	0.152888	0.001682
3	0.197899	0.022545
4	0.224191	0.083521
5	0.240753	0.138703
6	0.251945	0.165767
7	0.259942	0.177681
8	0.265910	0.183346
9	0.270521	0.186342
10	0.274183	0.188085

Table III: Blocking Probability of two models

L	Pb (Model I), C=3	Pb (Model II), C=10
0	0	0
0.1	0.552777	0.856487
0.2	0.75892	0.925781
0.3	0.835982	0.949958
0.4	0.875786	0.962255
0.5	0.900052	0.969702
0.6	0.916387	0.974694
0.7	0.928132	0.978274
0.8	0.936983	0.980967
0.9	0.943893	0.983065
1	0.949436	0.984747

Table IV: Handoff dropping probability of two models

L	PD (Model I), C=3	PD (Model II), C=10
0	0	0
0.1	0.552777	0.856487
0.2	0.75892	0.925781
0.3	0.835982	0.949958
0.4	0.875786	0.962255
0.5	0.900052	0.969702
0.6	0.916387	0.974694
0.7	0.928132	0.978274
0.8	0.936983	0.980967
0.9	0.943893	0.983065
1	0.949436	0.984747

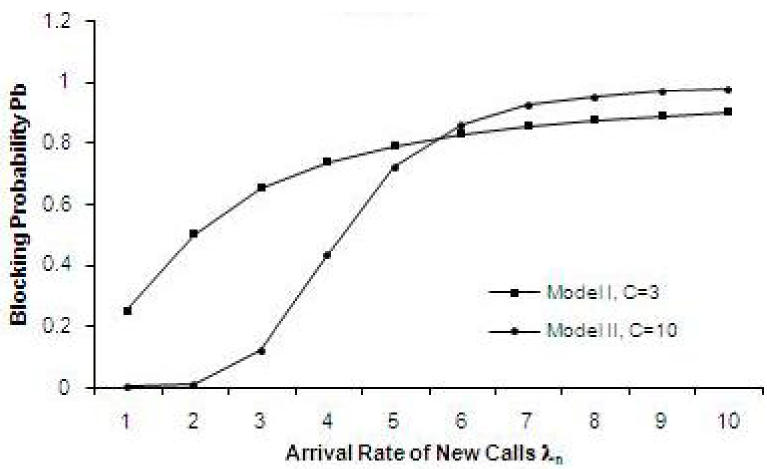

Figure 3.1: Blocking probability Vs New call arrival rate (λ_n)

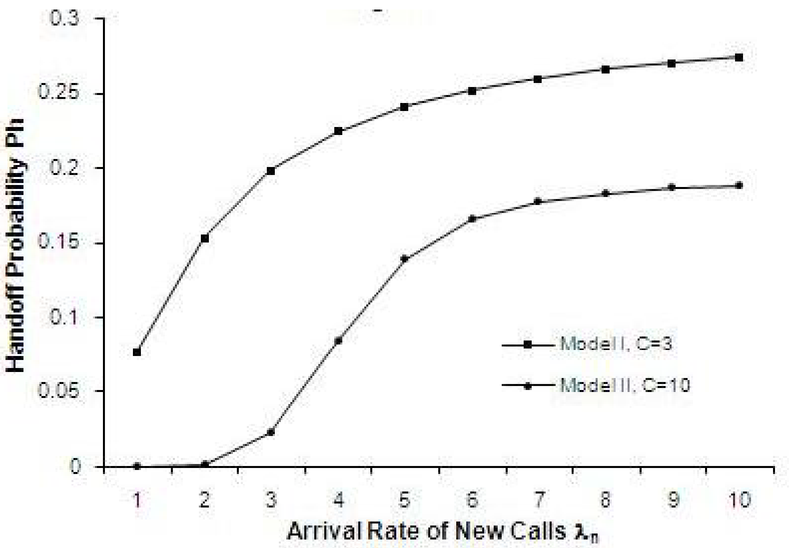

Figure 3.2: Handoff probability Vs New call arrival rate (λ_n)

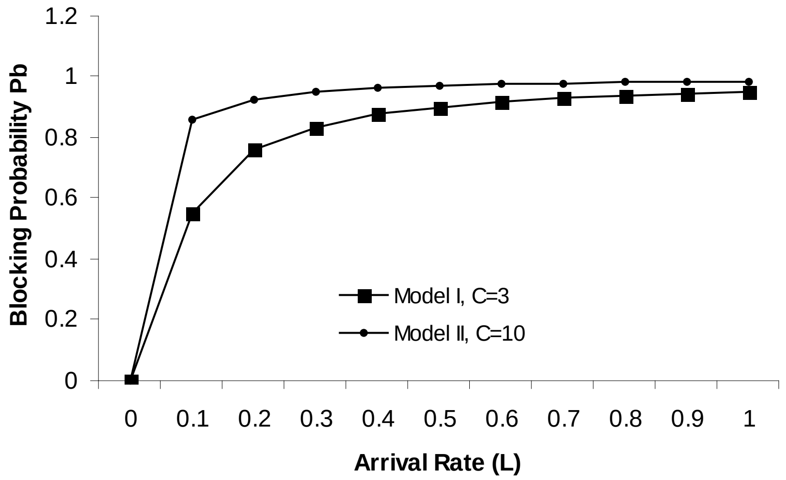

Figure 3.3: Blocking probability Vs New call arrival rate (L)

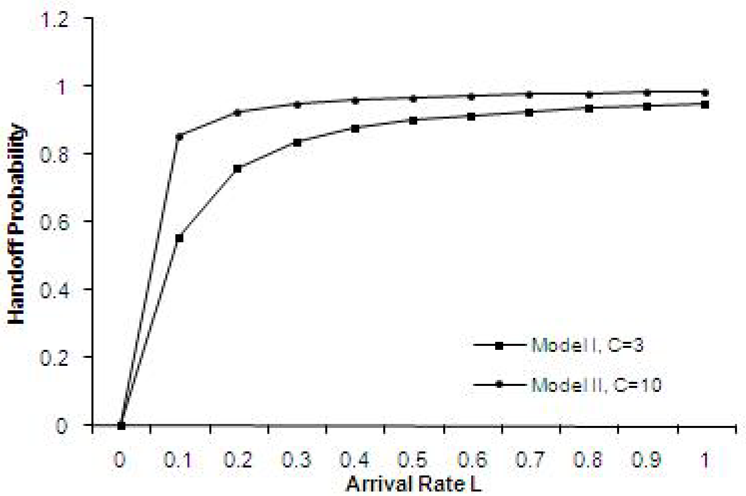

Figure 3.4: Handoff probability Vs New call arrival rate (L)

CONCLUSION

In this paper, we have proposed and developed a model for two-tier cellular network with a FIFO queue in the Microcell tier. We have proved that by increasing the number of channels and the queue size. In the case of microcell, the blocking probability of new call is reduced. In the case of macrocell, the handoff call probability increased than previous model presented in [12]. The results obtained from the new model were compared with those in Salih's work [12]. It has been shown that blocking probability is reduced but handoff probability increased.

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