Performance Measures of Hierarchical Cellular Networks on Queuing Handoff Calls

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Abstract—Hierarchical Cellular Networks provide an enhanced use of the indoor networks. These two lower layers called picocell and femtocell consist both high and low speed users. To prevent the dropping and blocking probabilities of ongoing calls in a network, cells are spitted into the small sizes. Although, many effective approaches are used but these delaying calls reach in a queue until a channel becomes available. In this paper, we propose M/M/C Markov model for two low layers of HCN having a FIFO queue in the femtocell layer and picocell layer, thereby comparing with a queue and without a queue. The effect of having a queue in the femtocell and picocell on both high and low speed users is observed.

Keyword—Hierarchical Cellular Network (HCN), Blocking Probability, Markov Model, FIFO queue, Two low layer (picocell and femtocell).

I. INTRODUCTION

With the increasing demand of wireless communication service, the hierarchical cellular technology provides a back bone for indoor networks. HCN have four type of layers i.e. macrocell, microcell, picocell and femtocell but our concentration is only on two low layer of HCN i.e. picocell and femtocell. In the past, source of indoor coverage was only provided by an outdoor antenna. And at present the only way to increase indoor coverage is to add more cells and this led to the creation of more small outdoor cells (microcells) providing more capacity for the network. Unfortunately, this approach is expensive for operators because it requires to install more sites, which dramatically increase the maintenance costs.

Finally, the more recent solution is the installation of small indoor base stations like picocells or femtocells. A multtier cellular network can improve the system performance by having larger cells overlaying the smaller cells and high speed users are assigned to the layer with larger cell sized. We propose a model of two tier cellular network with a FIFO queue in the femtocell to study on the both high and low speed users and compare with the result having a queue in the femtocell and having no queue in picocell.

II. RELATED WORK


In [14] found out the challenges in the technical and commercial aspects of femtocells for facilitation of the mass deployment of femtocells in the global scenario. Jung-Min.Moon et. al. [15], studied the performance of a combined guard channel and channel reservation with queuing resource management scheme for efficient handing of handoff calls in a macro/ femtocell hierarchical cellular network. A bandwidth efficient handoff strategy is proposed [12] and analyzed for hierarchical cellular system.
III. SYSTEM DESCRIPTION

In this paper, two low layers of HCN with a FIFO queue in the femtocell is proposed. A small geographical area is covered by this proposed model. Low and high speed users are assigned to the femtocells and the picocells, respectively. The radius of the femtocell is smaller than the picocell, and an integer number of femtocells are covered by one picocell. A handoff call is blocked when it cannot find a free channel in the desired cell. This happens due to the queue is full or the queue time assigned to the user is too short, a new call is blocked when it cannot find a free channel in the cell at that time calls will be overflowed. Once a low speed user call is overflowed to the picocell it cannot return back to the femtocell and when a low speed user becomes a high speed user the call is overflowed to the picocell. Calls overflow from the femtocell to the picocell when the low speed user becomes a high speed user and when the low speed user’s new and handoff call cannot find a free channel in the femtocell.

IV. MODEL DESCRIPTION

We assume that the cells are circular in shape. Table 1 shows the parameters have used for modeling cellular network. The arrival rates of new calls and handoff calls for both low and high speed users are assumed to be Poisson process. The cell dwelling time is the time a mobile user spends in a cell. It depends on the speed of the mobile user and the size of the cell.

We consider a single cell which present in the network and the picocell covers N number of femtocells and the cells are circular in shape. Each cell has C channels, and FIFO queue size Q in the picocell. The arrival rates of new calls for low and high speed users are Poisson processes with a rate of \( \lambda_l \) and \( \lambda_h \) calls per second respectively. The arrival rate of handoff calls for low and high speed users are Poisson processes with a rate of \( \lambda_{hl} \) and \( \lambda_{hh} \) calls per second respectively. The average holding time for both types of users is negatively exponentially distributed with a mean of 1/\( \mu \). The cell dwelling time can be calculated as:

\[
\frac{1}{\mu_d} = \frac{\pi r^2}{2v}
\]

Where r in the radius of the cell and v is the speed of the mobile users. The cell dwelling time for low and high speed users are negatively exponentially distributed with a mean of 1/\( \mu_{dl} \) and 1/\( \mu_{dh} \) respectively. In [6], it is shown that the mean queue time depends on two parameters.

i) The mean cell dwelling time

ii) The maximum cross distance M, over the overlapping zone between two cells. Hence queue time = (M/100)*cell dwelling time. We assume that the queue time for low and high speed users is negatively exponentially distributed with a mean of 1/\( \mu_{ql} \) and 1/\( \mu_{qh} \), respectively.

A femtocell layer with two types of users and without a queue is analyzed with a state \( s(i) \), where \( i \) denotes the number of low speed users using the c channels. The state transition diagram is as follows:

![State transition diagram for a femtocell containing 3 channels.](image)

The steady state probability of the system is given by:

\[
P(i)=P(0)\left(\frac{\lambda_l + \lambda_h}{(\mu + \mu_d)}\right)^i, \quad i \leq c
\]

since \( \sum_{i=0}^{c} P(i) = 1 \), then \( P(0) \) can be calculated as follows:

\[
P(0) = \left[1 + \sum_{i=1}^{c} \left(\frac{\lambda_l + \lambda_h}{(\mu + \mu_d)}\right)^i\right]^{-1}
\]

To find the arrival rate of handoff calls, we use the method in [7] as follows:

\[
\lambda_{hl} = \sum_{i=1}^{c} (iP(i))\mu_{dl}
\]

The blocking probabilities for the new and handoff calls are the same since no prioritization is used. Both probabilities are used as in [20] to calculate the overflow traffic to the picocell. The new call blocking probabilities for low speed users in the femtocell, \( P_n \) is given by

\[
P_n = \sum_{i=e} P(i) = P(c)
\]
B. Femtocell layer with queue:

Fig (3) shows the state \(s(i)\), where \(i\) denotes the number of low speed users in the femtocell and represented by a Markov Chain with FIFO queue. We assume that the number of channels, \(C=3\) and the queue size \(Q=3\).

![Figure 3. State transition diagram for a femtocell with 3 channel and a queues size 3.](image)

In the above transition diagram, \(m\) and \(q\) are given by \(m=\mu+\mu_{dl}\) and \(q=\mu+\mu_{dq}\), respectively.

By solving the Markov chain; we find that the state prob. \(P(i)\):

\[
P(i) = \begin{cases} 
  P(0) \left( \frac{\lambda_{in}+\lambda_{ih}}{\mu+\mu_{di}} \right)^i & \text{if } i \leq C \\
  P(0) \left( \frac{\lambda_{in}+\lambda_{ih}}{\mu+\mu_{di}} \right)^C \left( \frac{\lambda_{in}}{\mu+\mu_{di}} \right)^{i-C} \left( \frac{\lambda_{ih}}{\mu+\mu_{di}} \right)^C & \text{if } i > C 
\end{cases} 
\]

![Figure 4. Markov model of the picocell with 3 channels.](image)

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

\[
L=\lambda_{ol}+\lambda_{olh}+\lambda_{lh}, \quad H=\lambda_{h}, \quad M1=\mu+\mu_{di}, \quad M2=\mu+\mu_{dh}
\]

To find the equilibrium eq. of the state probabilities using [9],

\[
\alpha(i,j,q)=\begin{cases} 
1 & i+j \leq C \\
0 & \text{else}
\end{cases} \\
\beta(i,j,q)=\begin{cases} 
1 & i+j=0 \\
0 & \text{else}
\end{cases} \\
\delta(i,j,q)=\begin{cases} 
1 & i+j=0 \\
0 & \text{else}
\end{cases}
\]

The equilibrium eq. for the state occupancy probabilities \(P(i,j,q)\) can be calculated as follows:

\[
(\alpha(i,j)(L+H)+\beta(i,j)\delta(i,j)+M1)P(i,j)+\beta(i,j)P(i,j+1)M1+\beta(i,j)\delta(i,j+1)H=\alpha(i,j)P(i,j)+\beta(i,j)P(i,j+1)+M2+P(i,j+1)M1+\beta(i,j)\delta(i,j+1)H
\]

The blocking probability for new calls, \(P_{bh}\), in the picocell is given by

\[
P_{bh} = \sum_{i=C+Q}^{C+q} P(i)
\]

The overflow traffic for low speed new calls, \(\lambda_{ol}\) and handoff call, \(\lambda_{olh}\) are calculated using following equations.

\[
\lambda_{ol} = N\lambda_{in}P_{in}, \quad \lambda_{olh} = N\lambda_{in}P_{n}
\]

VI. Analysis of the Picocell

In this section, the analysis corresponds to the picocell layer without queue. Fig (4) shows the state \(s(i,j)\) where \(i\) and \(j\) are the number of low and high speed users in the system and Markov chain model with 3 channels is shown in figure 3.
is larger than the femtocell and radius of the femtocell = 2 meters and the picocell 10 meters. The maximum cross distance of the overlapping zone between two cells is 13% of the diameter of a cell. Queue time $q_t = 3 \times 0.13 = 0.39$ sec $\approx 0.4$ sec. The cell dwelling time $= 3 \sqrt{7} = 7.8 \approx 8$ sec. Fig. 5. shows that the model with a queue in the femtocell layer has higher blocking probability then the others because it has a queue and other two are having lower blocking probability because they have no queue. Fig. 6 shows that the blocking probability for handoff call is increases due to having a queue in femtocell and decreases as there is no queue in femtocell and picocell.

$$T = 3 \sqrt{7} = 7.8 \approx 8 \text{ sec.}$$

**TABLE II. BLOCKING PROBABILITY OF NEW CALLS**

<table>
<thead>
<tr>
<th>$\lambda_n$</th>
<th>$P_r$ (Femtocell without q)</th>
<th>$P_r$ (Femtocell with q)</th>
<th>$P_r$ Picocell (without q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.0059</td>
<td>0.0130</td>
<td>0.0040</td>
</tr>
<tr>
<td>0.2</td>
<td>0.0073</td>
<td>0.0190</td>
<td>0.0093</td>
</tr>
<tr>
<td>0.3</td>
<td>0.0089</td>
<td>0.0272</td>
<td>0.0132</td>
</tr>
<tr>
<td>0.4</td>
<td>0.0091</td>
<td>0.0360</td>
<td>0.0333</td>
</tr>
<tr>
<td>0.5</td>
<td>0.0111</td>
<td>0.0903</td>
<td>0.0390</td>
</tr>
<tr>
<td>0.6</td>
<td>0.0129</td>
<td>0.1212</td>
<td>0.0630</td>
</tr>
<tr>
<td>0.7</td>
<td>0.0174</td>
<td>0.1406</td>
<td>0.0941</td>
</tr>
<tr>
<td>0.8</td>
<td>0.0191</td>
<td>0.1454</td>
<td>0.1320</td>
</tr>
<tr>
<td>0.9</td>
<td>0.0221</td>
<td>0.1573</td>
<td>0.1710</td>
</tr>
<tr>
<td>1.0</td>
<td>0.0311</td>
<td>0.1801</td>
<td>0.1610</td>
</tr>
</tbody>
</table>

**TABLE III. BLOCKING PROBABILITY OF HANDOFF CALLS**

<table>
<thead>
<tr>
<th>$\lambda_n$</th>
<th>$P_r$ (Femtocell without q)</th>
<th>$P_r$ (Femtocell with q)</th>
<th>$P_r$ Picocell (without q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0001</td>
<td>0.0013</td>
<td>0.0040</td>
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<tr>
<td>2</td>
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<td>0.0090</td>
<td>0.0093</td>
</tr>
<tr>
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<td>0.0272</td>
<td>0.0132</td>
</tr>
<tr>
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<td>0.0333</td>
</tr>
<tr>
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<td>0.0903</td>
<td>0.0590</td>
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<td>0.0941</td>
</tr>
<tr>
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</tr>
<tr>
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<td>0.1573</td>
<td>0.1710</td>
</tr>
<tr>
<td>10</td>
<td>0.0040</td>
<td>0.1801</td>
<td>0.1610</td>
</tr>
</tbody>
</table>

**CONCLUSION**

In this paper, we proposed a Markov Model for a two low layers (picocell and femtocell) of hierarchical cellular network with a FIFO queue. We considered the cell size, the cell dwelling time and the mobility of users to calculate the queue times of both types of users. We have proved that by having a queue of the handoff call blocking probability is reduced. The performance of the proposed model shows that having a queue in one of layer of the cellular network depends on the distribution of the users in the geographical area of the network.

**REFERENCES**


