Queueing for Handover Calls in a Hierarchical Cellular Network

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Abstract—In this work, the performance of queues for handover calls in both a micro- and a macrocell is analysed, by varying the number of microcell under a macrocell, arrival rates of new calls in micro- and macrocell, cell dwell times, signal degradation time interval, queue size of both micro- and macrocell. In the model, the role of a macrocell is a secondary server for handover calls overflowed from microcells and the overflow process of handover calls from microcells is modelled by Poisson and Markov Modulated Poisson Process (MMPP) approximation, respectively. In the numerical examples, it is found that Poisson approximation op-timistically estimates call performance, compared to MMPP and that queues in a macrocell are more effective than those in micro-cells.

Keywords—Handover; MMPP;

I. INTRODUCTION

There are numerous studies to investigate the effects of queueing for handover calls in a microcell-layer in the literature. In contrast, queueing for handover calls in a macrocell-layer is less concerned. Generally, the attention on the performance of a macrocell is much paid for a server of calls with high mobility and the secondary server which serves calls over -flowed from microcells or covering large area less populated in [1]–[6]. In [7], queueing for handover calls in both micro- and macrocell-layer is studied by assuming the overflow process of handover calls from microcells to macrocell to be a Poisson process. From [5][6], it was found that Poisson approximation very accurately estimates the system performance, especially, in underload condition, and that MMPP approximation accurately evaluates the overflow process and the system performance. The performance variation of an underload condition may be more important than that of an overload condition, in that it is reasonable to maintain the low dropping probability of handover calls, e.g., less than 0.3. Further, as it is well known that the role of queue is to remove especially the occurrence of the short periods of an overflow process, it is under question how much queueing effect of a macrocell providing large channel holding times, which means less handover requests, one can obtain. Surprisingly, there is no analytic study on the queueing effect in a hierarchical cellular network with approximating handover overflow process from microcells as to be both Poisson and MMPP in the literature. In this work, we perform such an analysis, compare the call performance of Poisson and MMPP approximation for handover calls’ overflow process, and the discrepancy in numerical results of each modeling and the queueing effects with the parameters, such as, queue size and signal degradation time interval are discussed. Through this work, we assume that a macrocell has its own service area as well as acts as the secondary server that assigns its channels to handover calls overflowed from microcells. And overflow handover calls is not further buffered in macrocell layer. The organization of this work is as follows. In section II, the system and its parameters are introduced. With these, analysis of microcell and macrocell is given in section III. In section IV, numerical examples are discussed, mainly with respect to the call performance of macrocell. The concluding remarks are given in section V.

II. SYSTEM DESCRIPTION AND PARAMETERS

The system of interest has \( M \) number of microcells under a macrocell. Each microcell and a macrocell has \( C \) and \( C^c \) number of channels shared by new and handover calls, and handover calls’ queue size of \( C_h \) and \( C^c_H \), respectively. New call arrival process in microcells and a macrocell follows a Poisson process with the rate, \( \lambda_u \) and \( \lambda_N \), respectively. We assume that call holding times are exponentially distributed with the mean, \( T_c = \mu_c \). Cell dwell times and signal degradation time interval in handover region of both micro- and macrocell are also assumed to be exponential distributions with each mean, \( T_d = \mu_d \), \( T_D = \mu_D \). In addition, we assume that the mean of cell dwell times in a macrocell is determined by \( T_D = \sqrt{M} \cdot T_d \).

When call holding times are greater than cell dwell times, a handover occurs. This is defined as the mobility factor of a microcell, \( \theta^+ \), which is given by

\[
\theta^+ = \Pr \{ t_c > t_d \} \approx \mu_d \cdot (\mu_c + \mu_d)^{-1}
\]

where \( t_c \) and \( t_d \) are the random variables representing call holding times and cell dwell times in a microcell, respectively. Accordingly, the mobility factor of a macrocell, \( \theta^* \), is
\[ \theta^* = \mu_D \cdot (\mu_T + \mu_H)^{-1} \] (2)

With the parameters introduced, we make the following three assumptions. First, the queueing policy in both micro- and macrocell layer is FIFO (First-In First Out). Secondly, in handover region, we assume that a handover call may be dropped, if the handover call waiting in the queue does not receive a channel within the signal degradation time interval or it moves out of this handover region without receiving a channel. In other words, it is declared that a call is successfully handed over, when the call receives a channel within signal degradation time interval. With the help of memoryless property of cell dwell times and signal degradation time interval, the handover region dwell times of micro- and macrocell is not further buffered in macrocell layer. The third assumption is that the overflow handover calls from microcells is not further buffered in macrocell layer. The arrival process of handover calls in micro- and macrocell is assumed to be a Poisson process whose parameter is derived from the system equilibrium condition in section III, respectively.

III. ANALYSIS

A. Analysis on Microcell

With the parameters introduced in the previous section, a microcell with handover calls’ queue can be modelled by an \( M/M/C/C \) queue. By the standard queueing theory[9], each stationary state probability of a microcell can be expressed as

\[
\pi_k = \frac{(\lambda_n + \lambda_h)^{\min[k,C]} \cdot (\lambda_0)^{\max[0,k-C]}}{(\min[k,C])! \cdot \mu_0^{\min[k,C]} \cdot \gamma_{mk}} \pi_0
\] (3)

with \( \gamma_{mk} = \prod_{i=1}^{\max[0,k-C]} (C \mu_0 + i \mu_{mh}) \) and \( 1 \leq k \leq C+C_h \).

where \( \min[\cdot] \) and \( \max[\cdot] \) are the functions to take the minimum and maximum of its arguments, and \( n! = n \cdot (n-1) \cdot 2 \cdot 1 \).

Using (3), \( \pi_0 \) can be computed by \( \sum_{k=0}^{C+C_h} \pi_k = 1 \).

One can readily obtain the new call blocking probability, \( P_{nb} \), of a microcell which is

\[
P_{nb} = \sum_{i=C}^{C+C_h} \pi_i
\] (4)

The handover call dropping probability, \( P_{hd} \), of a microcell is derived by the following flow balance equation which inherently involves our second assumption.

\[
P_{hd} = \lambda_h \sum_{i=0}^{C_h} (i \mu_h \cdot \pi_{C+i}^*) + \lambda_0 \pi_{C+C_h}^*
\] (5)

The handover call’s arrival rate can be recursively obtained by

\[
\lambda_h^{(k+1)} = \left[ (1 - P_{nb}) \lambda_n + (1 - P_{hd}) \lambda_h^{(k)} \right] \cdot \theta^*
\] (6)

Equation (3) is solved with an initial guess for \( \lambda_h \), and then a new \( \lambda_h \) is obtained using (6). When the difference between the previous and current \( \lambda_h \) approaches a certain limit, the iteration ends.

B. Analysis on Macrocell

1) Poisson Approximation:

We assume that a macrocell overlays \( M \) number of homogeneous microcells. Thus total arrival rate of handover calls overflowed from \( M \) microcells which is denoted by \( \overline{X}_m^0 \), is expressed as

\[
\overline{X}_m^0 = M \cdot P_{hd} \cdot \lambda_h
\] (7)

As (4), each stationary state probability of a macrocell is given by

\[
\pi_k^* = \frac{(\lambda_N + \lambda_H + \overline{X}_m^0)^{\min[k,C]} \cdot (\lambda_H)^{\max[0,k-C]}}{\mu_M^{\min[k,C]} \cdot (\min[k,C])! \cdot \gamma_{M,k}} \pi_0^*
\] (8)

with \( \gamma_{M,k} = \prod_{i=1}^{\max[0,k-C]} (C \mu_M + i \mu_{MH}) \), \( \pi_0^* \) is also computed by \( \sum_{k=0}^{C} \pi_k^* = 1 \) and \( 1 \leq k \leq C+C_H \).

As (5)–(7), the new call blocking and the handover call dropping probability, \( P_{NB} \) and \( P_{HD} \), of a macrocell are respectively obtained by

\[
P_{NB} = \sum_{i=0}^{C} \pi_i^*
\] (9)

\[
P_{HD} = (\lambda_H)^{-1} \sum_{i=0}^{C} (i \mu_H \cdot \pi_{C+i}^*) + \pi_{C+C}^*
\]

It is assumed that the handover calls overflowed from microcells can share all channels of a macrocell and the queue in a macrocell buffers only the handover calls from neighboring macrocells. Thus, the arrival rate of handover calls in a macrocell is expressed as the following recursive equation.

\[
\lambda_H^{(k+1)} = \left[ (1 - P_{NB}) \lambda_M + (1 - P_{HD}) \lambda_H^{(k)} \right] \cdot \theta^*
\] (10)

where \( P_{NB}^0 \) is the overflow success probability, which means the overflow handover calls from microcells receive the channels of macrocell. It is defined as
Instead of summing the following infinitesimal generator, $Q_1$, and the arrival rate matrix, $A_1$, of an IPP, which are

$$Q_1 = \begin{bmatrix} -\sigma_1 & \sigma_1 \\ \sigma_2 & -\sigma_2 \end{bmatrix} \quad \text{and} \quad A_1 = \begin{bmatrix} 0 & 0 \\ 0 & \lambda_h \end{bmatrix}$$

where $\sigma_1 = \tau_c \cdot P_{hd}$ and $\sigma_2 = \tau_c \cdot (1 - P_{hd})$ and the time constant, $\tau_c$, is given in [8].

Instead of summing $M$ number of IPPs by Kronecker-sum, the sum of $M$ number of homogeneous IPPs can be approximately described by the infinitesimal generator, $Q$, and arrival rate matrix, $A_m$, whose elements $q_{i,j}$ and $a_{i,j}$ are respectively expressed as

$$q_{i,j} = \begin{cases} (M-i) \cdot \sigma_1 & \text{if } j=i+1 \\ -(q_{i,i-1}+q_{i,i+1}) & \text{if } j=i \\ i \cdot \sigma_2 & \text{if } j=i-1 \\ 0 & \text{otherwise} \end{cases}$$

and

$$a_{i,j} = \begin{cases} i \lambda_h & \text{if } i=j \\ 0 & \text{otherwise} \end{cases}$$

With the parameters introduced above, the macrocell can be modelled by $\text{MMPP}/M/\bar{C}/\bar{C}_H$ queue and its state space can be expressed as $\{(J, J') : 0 \leq J \leq \bar{C} + \bar{C}_H, 0 \leq J' \leq M\}$. The number $J$ corresponds to the sum of the number of channels and handover queue in a macrocell, and $J'$ corresponds to the number of the microcells which produce overflow handover calls. The infinitesimal generator of the Markov process for macrocell, $Q$, can be expressed as the following matrix equations which can be solved by block Gauss-Seidel iteration[9].

If $J = 0$

$$0 = \pi_0 (Q - A) + \pi_B$$

If $1 \leq J \leq \bar{C} - 1$

$$0 = \pi_{j-1} A + \pi_j (Q - A - B_j) + \pi_{j+1} B_{j+1}$$

If $J = \bar{C}$

$$0 = \pi_{\bar{C}-1} A + \pi_{\bar{C}} (Q - A_{\bar{C}} - B_{\bar{C}}) + \pi_{\bar{C}+1} B_{\bar{C}+1}$$

where the dimension of each state probability vector, $\pi_i$, $i \forall J$, is $(M+1)$.

In (15), the arrival matrixes and the channel holding times’ matrixes are expressed as

$$A = (\lambda_N + \lambda_H) \cdot I + A_m^Q \quad A_H = \lambda_H \cdot I$$

and

$$B_{i,i} = i \mu_H \cdot I \quad B_{i,i}^* = (\bar{C} \mu + i \mu_{\bar{C}H}) \cdot I$$

where $I$ is an identity matrix and its dimension is $(M+1) \times (M+1)$.

The new call blocking and handover call dropping probability are obtained by

$$P_{NB} = \sum_{i=\bar{C}}^{\infty} \pi_i$$

$$P_{HD} = (\lambda_H)^{-1} \sum_{i=1}^{\infty} (i \mu_H \cdot \pi_{i+1}) + \pi_{\bar{C}+1}$$

IV. NUMERICAL EXAMPLES

In the following examples, the number of channel in microcell and macrocell is set to 20 and 15 channels, respectively. The mean of call holding times, $T_h = 1/\mu_h$, is set to 7 minutes and the mean of cell dwell times in microcell, $T_d = 1/\mu_d$, is set to 6 minutes, except Figs.5-6. New call arrival rate of each microcell is set to 3.5 calls/min. Each parameter of micro- and macrocell denoted by superscript of micro and macro is specified in the figures where the solid and dashed lines denote Poisson and MMPP approximations, respectively. Call performance of our interest is mainly below 0.1-dropping probability of handover calls.

The effects of queue size in microcells on macrocell's performance. In Figs.1 and 2, the dropping probability of handover calls in macrocell with three and six microcells is respectively depicted. The increase of queue size in each microcell does not significantly reduce the dropping probability of macrocell. This can be explained that queue in microcell layer only suppresses the occurrence of the short overflow periods which are related to low handover overflow rate. In low new call arrival rate at macrocell, i.e., below 1 calls/min, Poisson and MMPP approximation shows maximally 0.18- and 0.39-dropping probability differences, respectively. Poisson approximation estimates call performance as optimistic as we cannot accept it in Figs.1 and 2. In addition, by observing...
MMPP approximation in the same figures, the new call arrival rate of each microcell should be lowered, if we would expect the dropping probability below 0.1.

The effects of queue size in macrocell on its own performance: In Figs.3 and 4, we vary the queue size of macrocell layer by setting the queue size of three microcells to zero. As increasing queue size, new call blocking probability is increased in Fig.3 and handover call dropping probability is decreased in Fig.4 as we expected. The performance is considerably enhanced with respect to handover calls. From Fig.1-3, in high new call arrival rate at macrocell, Poisson and MMPP approximations show good agreements. This is due to the dominance of macrocell’s own new call or handover call arrival rate over other call arrival processes. In other words, it comes from that random arrivals in macrocell, i.e., background noise, are dominant over the bursty arrival, e.g., handover calls overflowed from microcells. Accordingly, the agreement between Poisson and MMPP approximation mainly depends on the amount of traffic mix between macrocell’s own traffic and the overflow hand-over calls. Although such good agreements, the dropping probability is too high to be accepted.

The effects of the mean cell dwell times in microcell: In Fig.5, the mean cell dwell times of 6 microcells is decreased by 2 min and queue size of macrocell is varied. In this case, the mobility factor of microcell, $\theta_D$, is 1.45 times higher than that in Fig.6. Disagreements between Poisson and MMPP approximation are larger than those in the previous Figures. This is caused by higher handover requests in each microcell, which is the increase of the amount of overflow handover calls from microcell due to high mobility.

Queue size combination of micro- and macrocell: In Fig.6, with some combinations of the number of queue in each layer, handover call dropping probability of macrocell is given. We confirm that queue in microcell gives minor effects on the call performance of macrocell. In macrocell, queueing effects to give significant improvement on its own call performance can be explained by that the short periods of overflow in macrocell are observed, due to its large service area for reducing handover call requests.

The effects of signal degradation time interval: Although not presented here, we summarize the numerical result. The increase of the signal degradation time interval of microcells with two queues does not considerably affect handover call dropping probability of macrocell. Although not presented here, in macrocell layer, large signal degradation time interval, i.e., large queuing times, decently reduces the handover call dropping probability.

As summary, queue size over two does not contribute significant improvement on handover call performance any more, which may be called noneffective queue size. In [10], we observed the second order behavior of handover overflow process, which explains that more than two queue cannot reduces the long periods of overflow. Signal degradation time interval of micro- and macrocell only improves handover dropping probability of the respective cell layer and does not considerably affect the call performance between micro- and macrocell layer. Note that it is physically hard to flexibly control or increase signal degradation time interval. When overflow scheme for handover calls from microcell and macrocell is deployed, call admission control of microcell layer is carefully considered, taking the state of macrocell into account.

V. CONCLUSION

In this work, a hierarchical cellular system with queue for handover calls is analysed by Poisson and MMPP approximation for handover calls overflowed from microcells and the queueing effect of handover calls mainly in macrocell is examined. In general, the agreement between Poisson and MMPP approximation can be found, when Poisson traffic of macrocell is dominant over overflow handover call traffic. However, Poisson approximation estimates call performance as optimistically as we can not accepted. Queueing for handover calls with over two queue and signal degradation time interval in microcell layer does not significantly affects the call performance in macrocell layer. It can be interpreted that queueing for handover calls by increasing queue size or signal degradation time interval which is directly related to queueing times can reduce only short term overflow periods in macrocell layer. Compared to this observation, those in a macrocell layer significantly reduces the dropping probability of the calls, due to infrequent handover requests from large service area in macrocell layer.
REFERENCES


