# A Novel Ring-Based Performance Analysis for Call Admission Control in Wireless Networks

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***Abstract*—In Orthogonal Frequency Division Multiplex (OFDM) wireless networks such as 3GPP LTE and IEEE 802.16 WiMAX, the scheduler should allocate more resources to users with lower channel quality, such as users near the edge of the Base Station (BS) coverage area who are attempting handovers. In conventional queue-based models, this feature has not been considered in Call Admission Control (CAC) so far. In this letter, we propose a new ring-based model of the BS coverage area to allow a more detailed and accurate analysis. We determine mobility-related parameters such as call dropping probability due to mobility, and validate our results using simulations.**

***Index Terms*—Call admission control, Ring-based queueing model, Effective resource**

## I. Introduction

Unlike conventional wireline and Frequency/Time/Code Division Multiple Access (FDMA/TDMA/CDMA) networks, Orthogonal Frequency Division Multiple Access (OFDM) wireless networks, (e.g. 3GPP LTE and WiMAX), assign resources to a connection depending on the scheduling scheme and on channel quality. For example, the resources required to support a given data rate (in terms of power, bandwidth, and time slots) are greater for a user located farther from the base station (BS). In particular, mobiles performing horizontal handoffs are typically located near the cell boundary and therefore require more resources than other users. So far, this aspect of resource assignment has not been considered in performance evaluations of call admission control (CAC) for OFDM systems.

In CAC models, call arrivals and terminations were modeled using Poisson processes and simple M/M/1 queueing models, e.g. by using effective bandwidth [1]. These models also considered channel holding time and handoffs, where a call requiring a certain amount of resources can be accepted or rejected to satisfy call blocking/handoff failure probabilities as well as the outage probability of the existing connections [1], [2]. Realtime traffic is of the greatest concern in CAC due to its strict quality-of-service (QoS) requirements in terms of delay and rate. Here, a constant bit rate (CBR) traffic is considered since it simplifies the analysis and matches applications such as voice [3].

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In this letter, we propose a more detailed mobility model by dividing the cell into a set of concentric rings, where the amount of resources needed by a mobile is obtained based on the distance from the BS, by taking into account the received signal quality and multi-user scheduling. We define the equilibrium balance equations for the mobile user populations in each of the annular regions in the cell, accounting for the mobiles performing handovers at the cell boundary. We introduce and evaluate the call dropping probability due to mobility, which quantifies the effect of calls being dropped because the mobile moved to a region where lower channel quality required it to consume too much of the BS's resources. We compare the ring-based model to a conventional queueing model, in which the cell is considered as a single region. We use simulations to evaluate the performance of our model and to compute blocking and handoff failure probabilities.

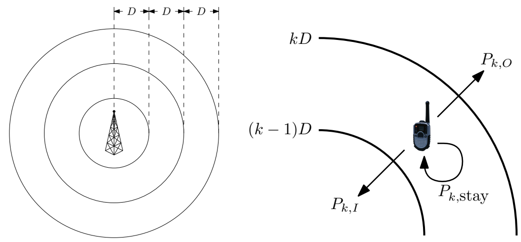
## II. System Modeling

In our model, the cell is divided into $K$ concentric rings. Each ring has a width of $D$, and the innermost one is a circle with a radius of $D$. Fig. 1(a) shows an example topology with $K = 3$ rings. $n_k$ is the number of users in the $k$th ring and $S = (n_1, n_2, ..., n_K)$ is the state of the access network. $\lambda$ is the new call arrival rate and $P_k$ is the probability that a user is located in the $k$th ring, and is given by

$$P_k = \frac{\text{Area of the } k\text{th ring}}{\text{Cell area}} = \frac{2k-1}{K^2}.$$

Then, $\lambda_k = \lambda P_k$ is the new call arrival rate in the $k$th ring. We assume that the call holding time is exponentially distributed with a mean of $1/\mu$ s and that handoffs occur according to a Poisson process with rate $\lambda_h$. As shown in Fig. 1(b), when an active mobile enters a given ring, it is assumed to reside there for an exponentially distributed residual time whose mean is $1/\gamma$. At the end of that time period, the mobile may move outward, inward, or stay inside the ring with probabilities of $P_{k,O}$, $P_{k,I}$, and $P_{k,\text{stay}}$, respectively, where $P_{k,O} + P_{k,I} + P_{k,\text{stay}} = 1$. If the mobile remains in the ring, or equivalently it moves within the ring, it stays there for another exponentially distributed period with mean $1/\gamma$.

We define $r_k$ to be the amount of resources required by a mobile that is located in the $k$th ring. If the network allows multiple traffic types with different QoS requirements, then there is a set of $r_k$ values in each ring. For this letter, we assume that there is only one traffic type, i.e., a single value of $r_k$ in each ring. The total load on the BS is denoted as $R(S) = \sum_{k=1}^{K} n_k r_k$. The BS's capacity is $C$ and the amount of resources reserved for handoff and *mobility* is $C_g$.




(a) BS coverage area (3 rings)

(b) Transition probabilities for a mobile node

Fig. 1. Aspects of the nested ring model

### A. Mobility-related parameters

We now compute the mobility parameters, by generating the balance equations that model the mobile's migration between neighboring rings. At each ring boundary, the average inward-rate should be equal to the average outward-rate. The resulting set of relations can be expressed as follows:

$$P_1\gamma_1 = P_2 P_{2,I}\gamma \tag{1}$$
$$P_k P_{k,O}\gamma = P_{k+1}P_{k+1,I}\gamma,\ k=2,\dots,K-1 \tag{2}$$
$$P_K P_{K,O}\gamma = \gamma_R, \tag{3}$$

where $1/\gamma_1$ and $1/\gamma_R$ are the mean residual times in the first ring and the BS coverage area, respectively.

The mean residual time is assumed to be proportional to the cell radius [4], i.e., $1/\gamma_R = \alpha R$, $1/\gamma_1 = \alpha D$, and $1/\gamma = \alpha\frac{D}{2}$, where $R = KD$ is the cell radius and $\alpha$ is a constant that depends on the mobiles' movement. Assuming a user's direction of movement is uniformly distributed, we can obtain $P_{k,stay} = 1/2$, i.e., a user in a given ring remains in that ring after an epoch with a probability of $1/2$. Using the balance equations we can get the probabilities $\{P_{k,I}\}_{k=1}^{K}$ and $\{P_{k,O}\}_{k=1}^{K}$. In addition, the handoff rate $\lambda_h$ is simply given by $\lambda_h = \lambda\frac{\gamma_R}{\mu}$, where the second term in right side is the ratio of the mean call holding time to the mean cell dwell time [4].[1]

### B. Steady-state analysis

Now the state transitions occur in the following cases;

- Call arrivals: When a mobile with a new call appears in the $k$th ring, $n_k \to n_k + 1$ if $R(S) + r_k \le C - C_g$. Otherwise, the call is blocked.
- Call termination: When a call belonging to a mobile in the $k$th ring terminates, $n_k \to n_k - 1$.
- Handoff arrival: Calls associated with handoffs arrive only at the the $K$th ring and therefore, $n_K \to n_K + 1$ if $R(S) + r_K \le C$; otherwise, the handoff fails.
- Move outward: When a user in the $k$th ring ($k = 1,\dots,K-1$) moves outward, it requires more resources. If $R(S)+\Delta r_k \ge C$, the user can maintain its connection, where $\Delta r_k = r_{k+1} - r_k$ is the additional resource required by the outward moving mobile In the outmost ring ($K$th ring), the user can be handed off to a neighbor cell, i.e., $n_K \to n_K - 1$.
- Move inward: When a user moves inward from the $k$th ring, $k = 2,\dots,K$, $n_{k-1} \to n_{k-1} + 1$ and $n_k \to n_k - 1$.

The set of steady-state probabilities, $\{\pi(S)\}_S$, can be easily obtained using the state transitions given above and the normalization condition $\sum_{\text{all } S}\pi(S) = 1$. The size of transition matrix is $M \times M$, where $M$ is the total number of states. From the state transitions described above, the number of nonzero elements is $M \times (4K + 1)$ at most and this sparseness can make the calculation more tractable.

The call blocking probability ($P_B$) and handoff failure probability ($P_f$) are respectively given by

$$P_B = \sum_{k=1}^{K}\sum_{S\in\Omega_k}\pi(S)P_k \tag{4}$$
$$P_f = \sum_{S\in\Gamma}\pi(S), \tag{5}$$

where $\Omega_k = \{S|R(S) + r_k > C - C_g\}$ and $\Gamma = \{S|R(S) + r_K > C\}$. In addition, we introduce $P_D$, the call dropping probability due to mobility. A call may be dropped when moving away from the BS since a call moving outward requires more resources. When the user moves inward, there is no blocking because the user needs fewer resources. We can write $P_D$ as

$$P_D = \sum_{S\in\Psi_1}\pi(S)P_1 + \sum_{k=2}^{K-1}\sum_{S\in\Psi_k}\pi(S)P_kP_{k,O}, \tag{6}$$

where $\Psi_k = \{S|R(S) - r_k + r_{k+1} \ge C\}$. Note that the reserved resource $C_g$ can be assigned to outward-moving calls as well as handoff calls. Otherwise, $P_D$ was found to be significant compared to $P_f$ even in situation where the mobiles had low mobility.

## III. Simulations and Numerical Results

### A. Simulation parameters

First, we use simulations to get the required resources, $r_k$, in each ring. We set the Simulation parameters based on the 3GPP LTE system. The cell size is set to be $R = 300$ m, with $K = 3$ rings. Total transmit power at the BS is set at 43dBm and the target BER is 0.1%; the noise power density $N_0$ is -174 dBm/Hz. The path loss (in dB) is given by $39.95 + 43.375\log_{10}(d/10)$, where $d$ is distance from the BS in meters. We used a frequency selective fading channel with 6 taps that according to 3GPP is typical for urban areas [5]. The available bandwidth is 5 GHz band, containing 25 resource blocks (RBs), where each RB consists of 12 subcarriers with a spacing of 15 kHz. The resulting data rate at RB $j$ of user $i$ is given by $R_{i,j} = 12\log_2(1+\beta\text{SNR}_{i,j})$, $\beta = \frac{1.5}{-\ln(5\text{BER})}$, and $\text{SNR}_{i,j}$ is the SNR of user $i$ averaged over 12 subcarriers in RB $j$ . The target CBR data rate is 10 kb/s with single antenna configurations for both BS and User Equipment (UE).

When the target data rate can be supported with partial use of an RB (i.e. the RB doesn't need to be used continuously in time domain), we assume the BS uses time-sharing. In

[1]For simplicity, we neglect the handoff failure probability and we assume the distribution of the cell dwell time is the same for new and handoff calls.

the simulations, we modeled this by letting the amount of resources for a user be less than one while the remaining resource was assigned to other users. The scheduling for CBR traffic is done based on the *heuristic* max-min method [3]. The required resource is measured by the amount of resource blocks to support the CBR target rate, assuming an equal power distribution over the frequency band, since it has been shown that the water-filling has an insignificant impact after multi-user scheduling.

Fig. 2 shows the average resources ($\mathbf{r} = (r_1, r_2, r_3)$) required by users in each ring, observed during 500 simulation runs. Note that the variation in each member of $\mathbf{r}$ is small enough (on the order of 0.01) that three rings are sufficient to model the cell in this scenario. Interestingly, if $r_1$ is normalized to be one, $\mathbf{r}$ can be approximated as $(1, 1.5, 2)$, i.e. a user in the 3rd ring may require twice the resources that a user in the innermost region needs.

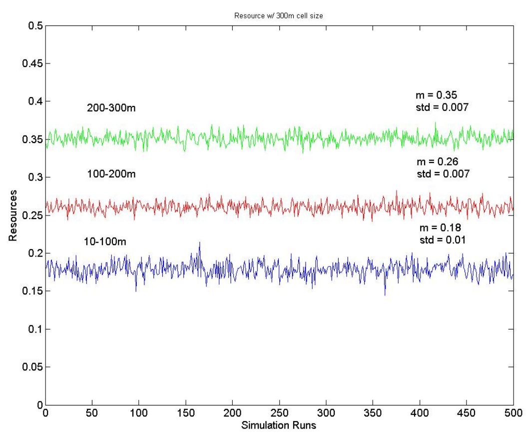



Fig. 2. Plot of required resource in each of the three rings in the cell

## *B. Performance evaluation*

To verify the proposed ring-based model, we considered a cell where $\mathbf{r} = (1, 1, 1)$. Its performance was compared with a conventional queueing model.[2] With different numbers of channels and even with different numbers of rings ($2 \le K \le 7$), we found that the blocking and handoff failure probabilities well matched with both models.

Next we considered $\mathbf{r} = (1, 1.5, 2)$ with $C = 30$. We varied the number of guard channels as follows: $0 \le C_g \le 7$. The mean call arrival rate was $\lambda = 0.08$ calls/s, the mean call holding time was $1/\mu = 100$ s, and we let $\alpha = 1/3$, so that $\lambda_h = \lambda$. For comparison, we modified the conventional queueing model so that a mobile requires the area-average resource once it enters the cell, i.e., the mobile requires $\frac{31}{18} = 1 \cdot \frac{1}{9} + 1.5 \cdot \frac{3}{9} + 2 \cdot \frac{5}{9}$ resources instead of $\mathbf{r} = (1, 1.5, 2)$, depending on which ring it belongs to. Fig. 3 shows the three performance metrics $P_B$, $P_f$, and $P_D$, obtained numerically for both queueing models and through simulations. We can obtain $P_D$ only by using the proposed ring-based queueing model, and its value is small because the guard channels can be assigned to mobiles moving outward as well as to handoffs. With $C_g = 0$, $P_f$ is slightly higher than $P_B$ since it requires a larger resource, which can not be observed in a conventional queueing method. In the basic model with $K = 1$, as $C_g$ increases, $P_f$ is underestimated with respect to the 3-ring model, as shown in the figure. This occurs because the handoff call enters from the cell boundary and therefore, it requires more resources than the existing calls inside the cell.

[2]"Conventional queueing model" implies a model without rings ($K = 1$).

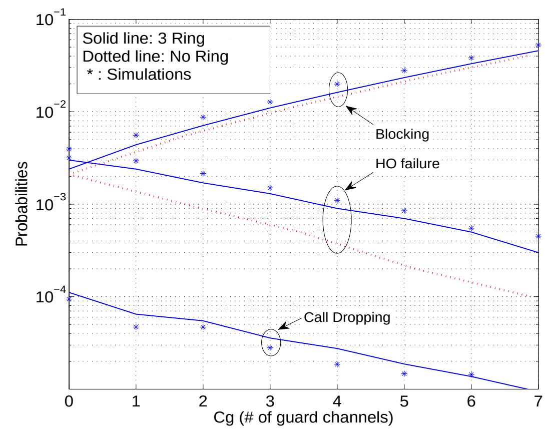



Fig. 3. Plot of blocking probability ($P_B$), handoff failure probability ($P_f$), and probability of dropped call due to mobility ($P_D$) in modified conventional ($K = 1$) and ring-based ($K > 1$) queueing models.

# IV. CONCLUSIONS

In this letter, we proposed a ring-based model of a cell, which accounts for user mobility as well as the effect of handovers from adjacent cells. We obtained the required resources in each of the annular zones for the CBR traffic through intensive simulations based on 3GPP LTE systems. We demonstrated that, compared to conventional queueing model that does not use annular zones, the proposed ring-based model is more accurate. The performance improvement associated with our model is especially noticeable in the case of modeling handoff failure performance when the BS uses guard channels. In addition, we introduced the call dropping probability due to mobility as a new performance measure and showed that it can be reduced through the use of a sufficient number of guard channels.

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