Analytical Evaluation of Call Admission Control for SFR-Based LTE Systems

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***Abstract*—Inter-cell interference coordination (ICIC) is considered to be a promising technique for Long Term Evolution (LTE) to increase spectral efficiency. One efficient approach for ICIC is Soft Frequency Reuse (SFR). In this paper, we consider a call admission control in SFR-based systems and derive the call blocking and forced termination probabilities using a Markov chain analysis. In addition, SFR with spectrum handoff, called S-SFR, is proposed. Numerical results show that the analytic derivations are valid, and the proposed scheme outperforms the SFR scheme without spectrum handoff for the forced termination probability.**

Keywords- call admission control; inter-cell interference; soft frequency reuse; Markov chain; spectrum handoff.

I. INTRODUCTION

The Third Generation Partnership Project-Long Term Evolution (3GPP-LTE) system has focused on several interference management schemes for improving system performance. These schemes include an optimized frequency allocation policy based on semi-static radio resource management approaches, optimal power assignment and control schemes, and smart antenna techniques to null interference from other cells [2]. In particular, a Fractional Frequency Reuse (FFR) scheme has been proposed for 3GPP-LTE systems as an inter-cell interference coordination (ICIC) technique [3].

There are two major variants of FFR, which are static FFR and adaptive FFR. Static FFR includes pre-planned Frequency Reuse factor 1 (FR1) scheme, or FR3 scheme, or a combination of these schemes, such as Fractional Reuse Partitioning (FRP). Further improvements can be achieved by dynamically adapting FFR with techniques such as Soft Frequency Reuse (SFR).

In FRP and SFR, a cell is divided into two regions, namely the *cell-center zone* and the *cell-edge zone*. The *cell-center users* arriving in the cell-center zone utilizes the entire frequency band, whereas the *cell-edge users* arriving in the cell-edge zone operate in a sub-band using an FR 3 scheme, as shown in figure 1. Thus, the effective overall frequency reuse factor is still close to ensuring a high spectral efficiency [4]. SFR differs from FRP as follows. Because the cell-center users share bandwidth with neighboring cells, they typically transmit at lower power levels than the cell-edge users in SFR,

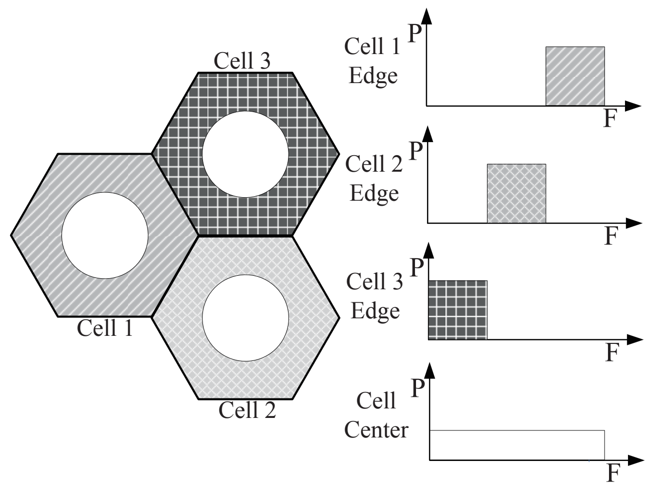

Fig. 1: Frequency-Power arrangement of SFR scheme. P and F denote the power and frequency, respectively.

as shown in figure 1. It is possible that when no resources for the cell-edge users are available, the eNodeB (base station) forcibly terminates (preemption) one of the cell-center users that occupies resources of a sub-band with an FR 3 if any such user exists[1].

In [1], a Markov chain model with 3-dimensional state variables was proposed to describe the call admission control (CAC) in SFR-based LTE systems. Throughout this model, the authors evaluated the system performance in terms of the call blocking probability and the forced termination probability. When comparing SFR with static FFR using FR 3, the call blocking probability of SFR is lower than that of static FFR. However, SFR suffers from a non-zero forced termination probability. From the user's point of view, the forced termination of an ongoing call is significantly less desirable than blocking of a new call attempt [5].

In this paper, we propose a SFR with the spectrum handoff technique, called S-SFR. For the spectrum handoff technique, when cell-center users using cell-center resources are released,

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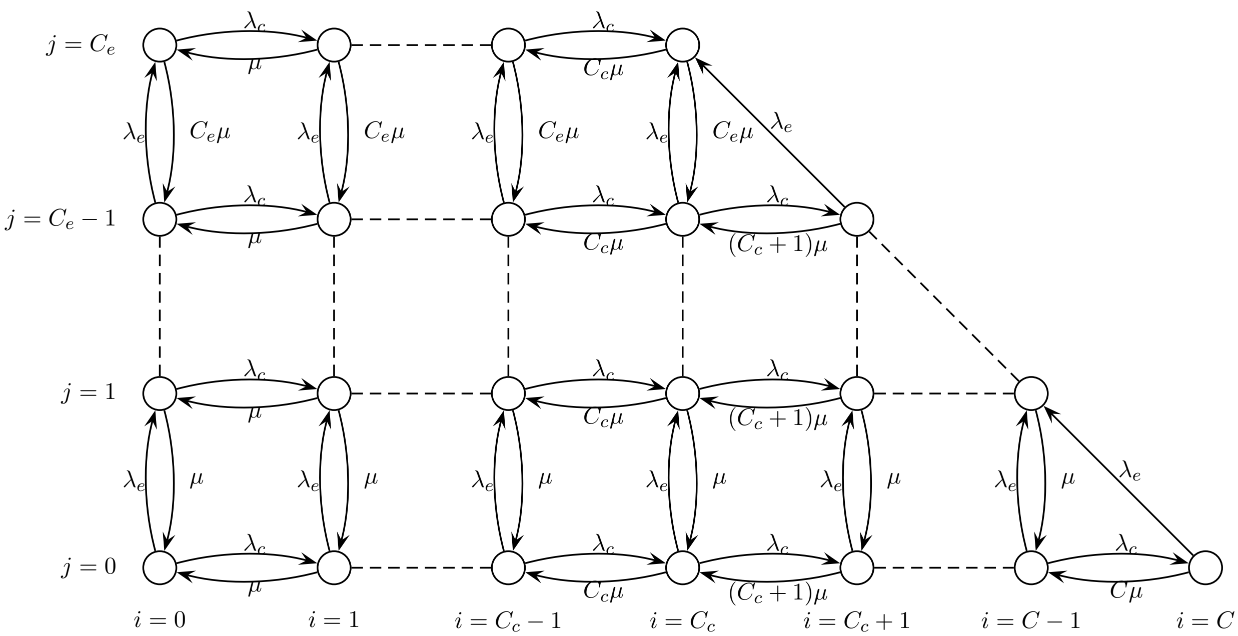

Fig. 2: 2-dimensional Markov chain model for S-SFR.

TABLE I: SUMMARY FOR VARIOUS SCHEMES.

Technique	S-SFR	SFR	FRP
Preemption	Yes	Yes	No
Spectrum handoff	Yes	No	No

a cell-center ongoing call occupying the cell-edge resource can be reconnected using the cell-center resource. Thus, by reducing the number of the cell-center users utilizing cell-edge resources, we can reduce the amount of forced termination of the cell-center users. Specifically, we describe the CAC for S-SFR and provide a 2- dimensional Markov chain analysis, where the state variables are the number of cell-center users and cell-edge users. This scheme is similar to channel reservation used in circuit-switched networks [8].

Additionally, we compare the performances of S-SFR, SFR, and FRP schemes, where each scheme is summarized as shown in Table 1.

This paper is organized as follows. In section 2, we present the system model. In section 3, we introduce an analytic model for the evaluation of performance of SFR based LTE systems. Section 4 presents numerical results, and concluding remarks are given in section 5.

II. System Model

A. Model Description

An SFR-based LTE system is considered. There is one eNodeB in the center of the cell. In this paper, user equipments (UEs) located in the cell-center zone or the cell-edge zones are called *cell-center UEs* or *cell-edge UEs*, respectively. A number of UEs can initiate multiple calls trying to occupy radio resources, where the basic unit of radio resources is referred to as Physical Resource Block (PRB).

We assume that there are C PRBs that consists of C_c *cell-center PRBs* and C_e *cell-edge PRBs*, where $C_c = C - C_e$. For the sake of simplicity, we assume that the eNodeB can only assign one PRB to the UE at the time it initiates a call and, via an appropriate power allocation, the data rate of each call with one PRB is fixed regardless of its location within the cell.

As mentioned in [1], the data rate of the UE can be maintained using two approaches. First, more than one PRB can be allocated to the UE. Second, appropriate powers are allocated to the PRBs. Thus, the co-channel interference from adjacent cells can be minimized. Hence, the data rate of the UE can be guaranteed. In our model, it is assumed that, via an appropriate power allocation scheme, the data rate of each UE with one PRB is fixed regardless of its location within the cell.

B. New Call Arrival Processes and Call Duration Time

Traditionally, since CAC schemes have been based on call-level QoS measures, such as call blocking and dropping probabilities for voice or data, we assume that the eNodeB serves voice traffic call [6,7]. We also assume that the new call arrival process within a cell is a Poisson process with a mean request rate of λ calls/sec, and the UEs are uniformly distributed over the cell. Let ω be the ratio of the area of the cell-edge zone to the total area of the cell. The new call arrival rates of the cell-center UE and cell-edge UE are assumed to be $\lambda_c = (1-\omega)\lambda$ and $\lambda_e = \omega\lambda$, respectively. The call duration time is assumed to be exponentially distributed with mean μ^{-1} sec.

III. SOFT FREQUENCY REUSE WITH SPECTRUM HANDOFF

A. Call Admission Control

When a new call from the cell-center UE (*cell-center call*) is initiated, it will attempt to occupy a cell-center PRB. If one or more cell-center PRBs are available, it will be admitted. If no cell-center PRB is available, then it will further attempt to occupy a cell-edge PRB. It will be blocked once no cell-edge PRB is available. When a cell-center call occupying a cell-center PRB is released, a cell-center ongoing call occupying a cell-edge PRB is reconnected using a released PRB. This is called *spectrum handoff*.

When a new call from the cell-edge UE (*cell-edge call*) is initiated, it will attempt to occupy a cell-edge PRB. At this time, if all cell-edge PRBs are in use by cell-edge ongoing calls, the call will be blocked. If at least one cell-edge PRB is available, it will be admitted. If no cell-edge PRB is available, but one or more cell-edge PRBs are occupied by cell-center ongoing calls, one of the cell-center calls is randomly chosen and forced to release the cell-edge PRB it is occupying. The released PRB is then assigned to the newly arriving cell-edge call. The probability that the cell-center call is forcibly terminated is referred to as the *forced termination probability*.

B. Traffic Analysis

Assuming the characteristics of traffic, the process of PRB occupation can be modeled as a continuous time Markov chain. For CAC of S-SFR, the state transition diagram is described by an integer pair $(i,\ j)$, as shown in figure 2, where i and j denote the *number of cell-center calls* and *cell-edge calls*, respectively. As the cell-edge UEs have priority to utilize the cell-edge PRBs, the cell-center UEs utilizing the cell-edge PRBs can be preempted by the cell-edge UEs. Depending on the existence of the cell-center UE occupying the cell-edge PRB, a forced termination in state $(i,\ j)$ can move the state to $(i-1,\ j+1)$, where i is greater than C_c. This is because there are only cell-center UEs occupying cell-edge PRB by spectrum handoff.

Let $P(i,\ j)$ be the state probability. From figure 2, the following set of balance equations can be obtained:

(i) Four extreme points:

$$(\lambda_c+\lambda_e)P(0,0)=\mu P(1,0)+\mu P(0,1)$$
$$(\lambda_c+C_e\lambda_e)P(0,C_e)=\lambda_c P(0,C_e-1)+\mu P(1,C_e)$$
$$(C_c+C_e)\mu P(C_c,C_e)=\lambda_c P(C_c-1,C_e) + \lambda_e P(C_c,C_e-1)+\lambda_e P(C_c+1,C_e-1)$$
$$(\lambda_e+C\mu)P(C,0)=\lambda_e P(C-1,0)$$

(ii) $i=0,\ \ 0<j<C_e$:

$$(\lambda_c+\lambda_e+j\mu)P(0,j)=\lambda_e P(0,j-1) + (j+1)\mu P(0,j+1)+\mu P(1,j)$$

(iii) $0<i<C,\ \ j=0$:

$$(\lambda_c+\lambda_e+i\mu)P(i,0)=\lambda_c P(i-1,0) + \lambda_e P(i,1)+(i+1)\mu P(i+1,0)$$

(iv) $0<i<C_c,\ \ j=C_e$:

$$(\lambda_c+i\mu+C_e\mu)P(i,C_e)=\lambda_c P(i-1,C_e) + \lambda_e P(i,C_e-1)+(i+1)\mu P(i+1,C_e)$$

(v) $0<i<C,\ 0<j<C_e$:

$$(\lambda_c+\lambda_e+i\mu+j\mu)P(i,j)=\lambda_c P(i-1,j)+\lambda_e P(i,j-1) + (i+1)\mu P(i+1,j)+(j+1)\mu P(i,j+1)$$

(vi) $C_c<i<C,\ 0<j<C_e,\ i+j=C$:

$$(\lambda_c+i\mu+j\mu)P(i,j)=\lambda_c P(i-1,j) + \lambda_e P(i,j-1)+\lambda_e P(i+1,j-1) \tag{1}$$

$P(i,\ \ j)$ can be found by solving the balance equations together with the following normalization condition:

$$\sum_i\sum_j P(i,j)=1. \tag{2}$$

C. Performance Measures

As performance measures, we consider the aggregate call blocking and forced termination probabilities.

From $P(i,\ \ j)$, the call blocking probabilities of the cell-center UE and the cell-edge UE are, respectively,

$$P_{B_c}=\sum_{i=C_c}^{C}P(i,C-i),\qquad P_{B_e}=\sum_{i=0}^{C_c}P(i,C_e). \tag{3}$$

From (3), we can calculate the aggregate call blocking probability as follows

$$P_B=(1-\omega)\cdot P_{B_c}+\omega\cdot P_{B_e}. \tag{4}$$

For the forced termination probability, P_f, it is the total UE forced termination rate divided by the total UE connection rate. That is,

$$P_f=\frac{\lambda_e\displaystyle\sum_{i=C_c+1}^{C}P(i,C-i)}{\lambda(1-P_B)}. \tag{5}$$

IV. NUMERICAL RESULTS

In this section, we present the simulation results and compare them with our analysis. For all results, it is assumed that $C=48$ and $C_e=C/3$. In figures 3 and 4, the curves are numerically obtained from the equations given in the preceding analysis, whereas the symbols indicated the corresponding simulation results.

Figures 3(a)-(c) show the call blocking probabilities of the center-, edge-, and aggregate-UE with respect to different values of ω. These numerical examples show that the results of our analysis closely approximate those of the simulations. In figures 3(a)-(c), as the value of ω decreases, the call blocking probabilities of the edge- and the aggregate-UE tend to decrease, whereas the blocking probability of the center-UE increases. This is because as ω decreases, the number of UEs arriving in the edge area decreases, and thus the number of

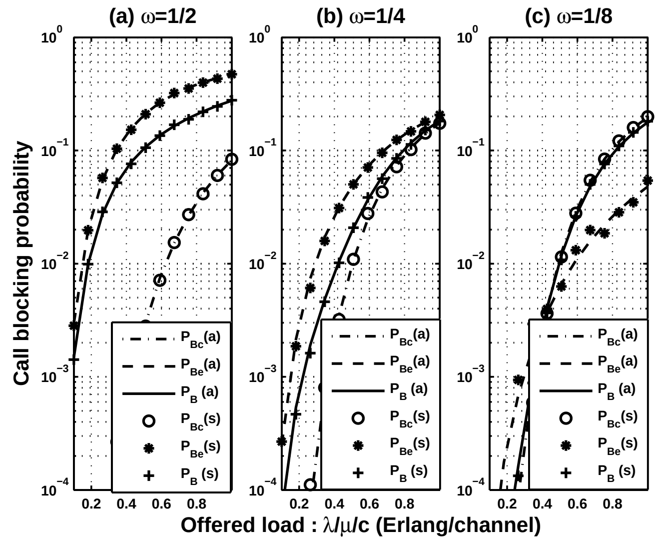

Fig. 3: Call blocking probabilities versus offered load with various ω.

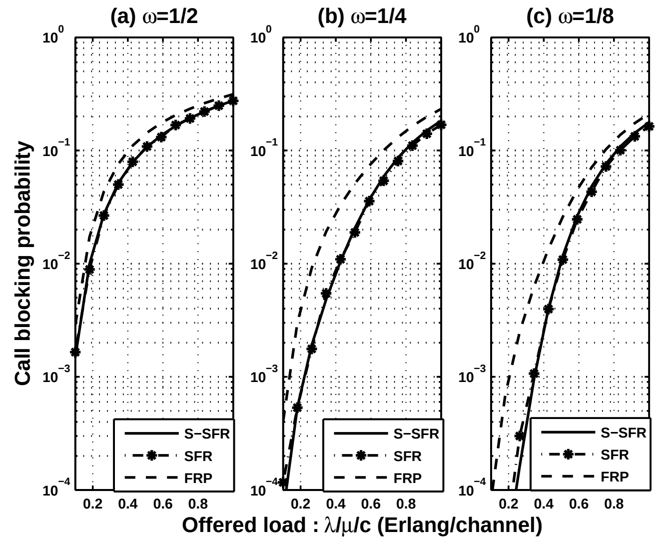

Fig. 5: Call blocking probabilities versus offered load with various schemes.

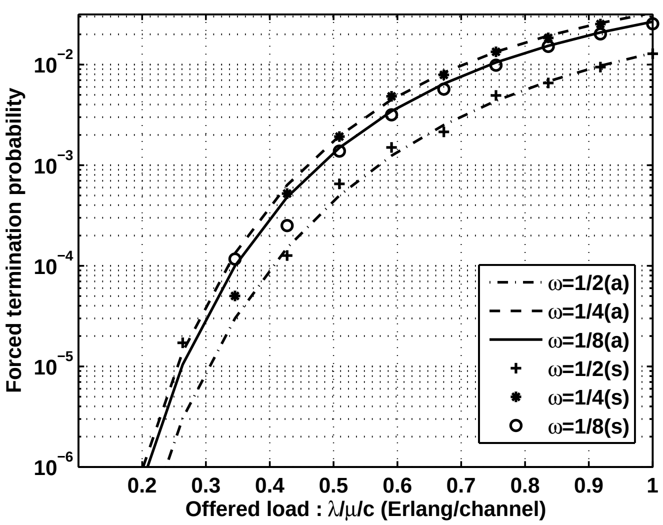

Fig. 4: Forced termination probabilities versus offered load with various ω.

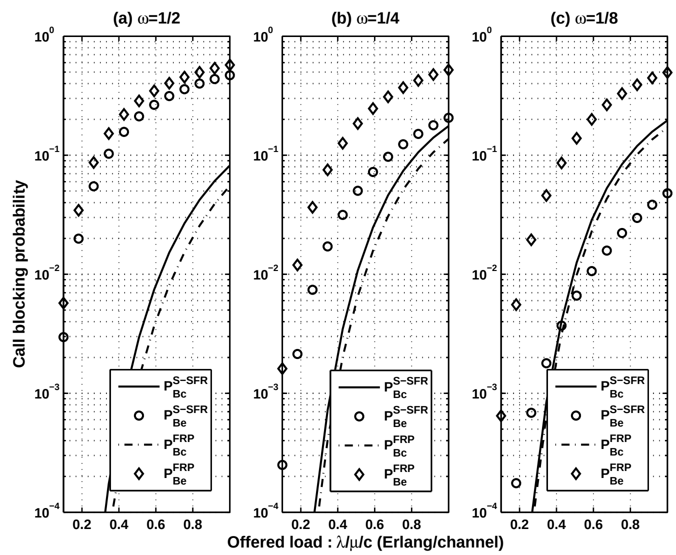

Fig. 6: Cell-center and cell-edge call blocking probabilities versus offered load with various schemes.

blocked cell-edge calls decreases. Figures 3(a)-(c) also show that as the value of ω increases, the difference of the call blocking probabilities between the center- and the edge-UE increases rapidly. We note that the center- and edge-calls are not evenly blocked. The reason is that the cell-edge PRBs are more heavily utilized than the cell-center PRBs.

Figure 4 shows the forced termination probability for S-SFR. It is observed that the results of the mathematical analysis agree reasonably well with those of the simulations. Figure 4 also shows that P_f increases as ω decreases. This is because as ω decreases, the number of cell-center UEs increases, thus leading to the decrement of terminated cell-center calls. When ω is very small, P_f decreases, because the number of cell-edge UEs is reduced.

Additionally, we compare the performance of S-SFR, SFR, and FRP schemes.

Figures 5(a)-(c) show the effect of ω on the aggregate call blocking probabilities for S-SFR, SFR, and FRP. As ω decreases, the aggregate call blocking probabilities of S-SFR, SFR, and FRP tend to decrease. We observed that the call blocking probabilities of both S-SFR and SFR are less than that of FRP. This is because the call blocking probability of the cell-edge UE in SFR-based schemes is decreased by using the forced termination of the cell-center UE using a cell-edge PRB.

Figure 6 shows the cell-center and cell-edge call blocking

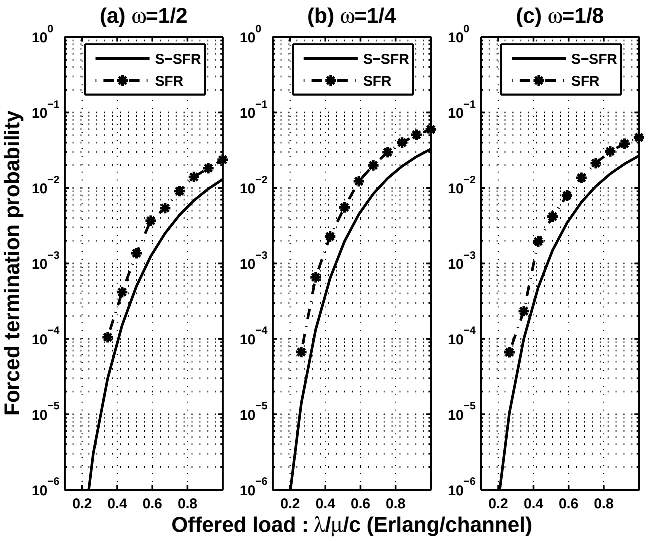

Fig. 7: Forced termination probabilities versus offered load with S-SFR and SFR.

probabilities for S-SFR and FRP schemes. From this figure, we note that the performance of the cell-edge call is improved for S-SFR by using the channel assignment as forced termination technique.

Figure 7 shows the effect of the spectrum handoff technique on the forced termination probabilities for S-SFR and SFR. Because FRP does not consider the forced termination technique, P_f is 0. From this figure, we note that the forced termination probability of S-SFR is less than that of SFR.

V. Conclusion and Future Work

In this paper, we considered a call admission control in SFR-based systems and derived the call blocking and forced termination probabilities using a Markov chain analysis. In addition, SFR with spectrum handoff, called S-SFR, have proposed. The analytical results show good agreement with the simulations. Numerical comparisons among S-SFR, SFR, and FRP schemes have shown that there are differences in the call blocking and forced termination probabilities. By using the forced termination technique, we have shown that S-SFR and SFR have decreased the call blocking probability. For cell-edge calls, these schemes provide an improved call blocking probability. We have also shown that by using spectrum handoff, the forced termination probability of S-SFR is less than that of SFR.

One of the possible research topics is to consider a SFR-based cellular system in the interference scenario. In reality, the system throughput may be calculated by the signal to interference ratio, depending on the level of interference power received from neighboring cell. Therefore, it is worthwhile to study the cases where one UE or BS may have interference signals from neighboring BSs or other UEs.

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