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Analysis of Cutoff Priority Scheme Impact of Soft Frequency Reuse in LTE-Advanced networks

Mahammad A. Safwat, Hesham M. El-Badawy, Ahmad Yehya, H. El-motaafy

Abstract— Call admission control (CAC) plays a significant role in providing the desired quality of service in wireless networks. Soft frequency Reuse (SFR) has been introduced as one of the most promising inter-cell interference coordination (ICIC) schemes in LTE-Advanced networks. Applying CAC in soft frequency reuse scheme especially users in cell edge part is a challenge as they already suffer from limited resources. Many CAC schemes have been proposed. In this paper, the effect of cutoff priority scheme in SFR in LTE-Advanced network will be investigated in terms of Blocking and Dropping probability. The SFR with cutoff priority scheme in single cell of wireless network is modeled using queuing analysis. The impact of cutoff priority scheme will be evaluated in edge and core part separately. A set of equations of the queuing model is solved using Successive over Relaxation (SOR) method to get steady state probability.

Index Terms— Call admission control, Soft Frequency Reuse, Cutoff Priority, Queuing Model, LTE-Advanced.

1 Introduction

OFDM is widely accepted as an elected Access technology in next generation mobile networks. With OFDM, available spectrum is split into a number of parallel orthogonal narrowband subcarriers. These subcarriers can be independently assigned to different users in a cell. When applied to mobile cellular systems, a key issue with OFDMA is Inter-cell interference (ICI). User Equipments (UEs) located at the cell edge largely suffers from the power radiated by the base station of neighboring cells in their communication band.

Inter-cell interference (ICI) occurs when neighboring cells assign the same frequency bandwidth to different UEs. In such a context, it is only natural that the most severe form of inter-cell interference is the result of frequency conflictions that occur on or near the edge of a given cell. Inter-cell interference coordination (ICIC) is one of effective methods to mitigate ICI in OFDM system. ICIC guaranteed that cell-edge users in adjacent cells will not interfering with each other [1]. In this vein, various frequency reuse schemes have been proposed in the literature [2], [3]. The most straightforward approach is called fixed frequency reuse scheme whereby the whole available bandwidth is divided into three non-overlapping parts which are assigned to three neighboring cells. This frequency planning scheme allows eliminating frequency conflictions at the cost of spectrum efficiency. To overcome this drawback, there are many suggested models to eliminate ICI while maintain spectrum efficiency [4], [5], [6], [7], [8]. A comparison of different frequency reuse schemes is introduced in [9] in terms of outage probability, network throughput, spectral efficiency, and average cell edge user SINR.

Soft Frequency Reuse scheme, which has been introduced in [10], one of the most promising inter-cell interference coordination (ICIC) schemes, and it has been introduced in LTE-Advanced networks [10], [11]. The SFR scheme divides the available spectrum into two reserved parts: a cell edge bandwidth and a cell core bandwidth. UEs within each cell are also divided into two groups, cell core UEs and cell edge UEs, depending on which type of bandwidth they are assigned or have access to. Cell edge users are confined to cell edge Resource Blocks (RBs) while cell core users can access the cell core RBs and can also access the cell edge RBs but with less priority than cell edge users. It means that cell core users can use cell edge RBs only when there are remaining available cell edge RBs [12].

Handover is a key element in wireless cellular networks in order to sustain the provided QoS to the users and to support users' mobility. There are two QoS parameters in these networks; new call blocking probability and handover call dropping probability. The probability of assigning no channel to handover call is defined as handover call dropping probability P_D. The probability of assigning no channel to new call is defined as new call blocking probability P_B. There is a trade-off between P_B and P_D. Call Admission Control (CAC) schemes are some strategies to keeping this parameters under desired level. The concept of these strategies is to reserve a number of channels called guard channels (GC) exclusively for handovers. This strategy is called cutoff priority scheme. Applying cutoff priority has great impact in soft frequency reuse scheme especially users in cell edge part as they already suffer from resources availability.

Queuing analysis is an accurate method that can study the resources availability depending on actual values of service and arrival rates. In [13], a queuing model is proposed to

- *Mahammad A. Safwat is currently pursuing Ph.D in Network Planning Department, National Telecommunication Institute, Cairo, Egypt.E-mail: Mahammad.safwat@gmail.com*
- *Hesham M. El-Badawy is currently working as head of Network Planning Department, National Telecommunication Institute, Cairo, Egypt. E-mail: heshamelbadawy@ieee.org*
- *Ahmad Yehya is currently working in Department of Electrical Engineering, Al-azhar University, Cairo, Egypt. E-mail: ahmed_yahya_1@yahoo.com*
- *H. El-motaafy is currently working in Department of Elecronics and Computer Engineering, HIT, Egypt. E-mail: hosni.motaafy@gmail.com*

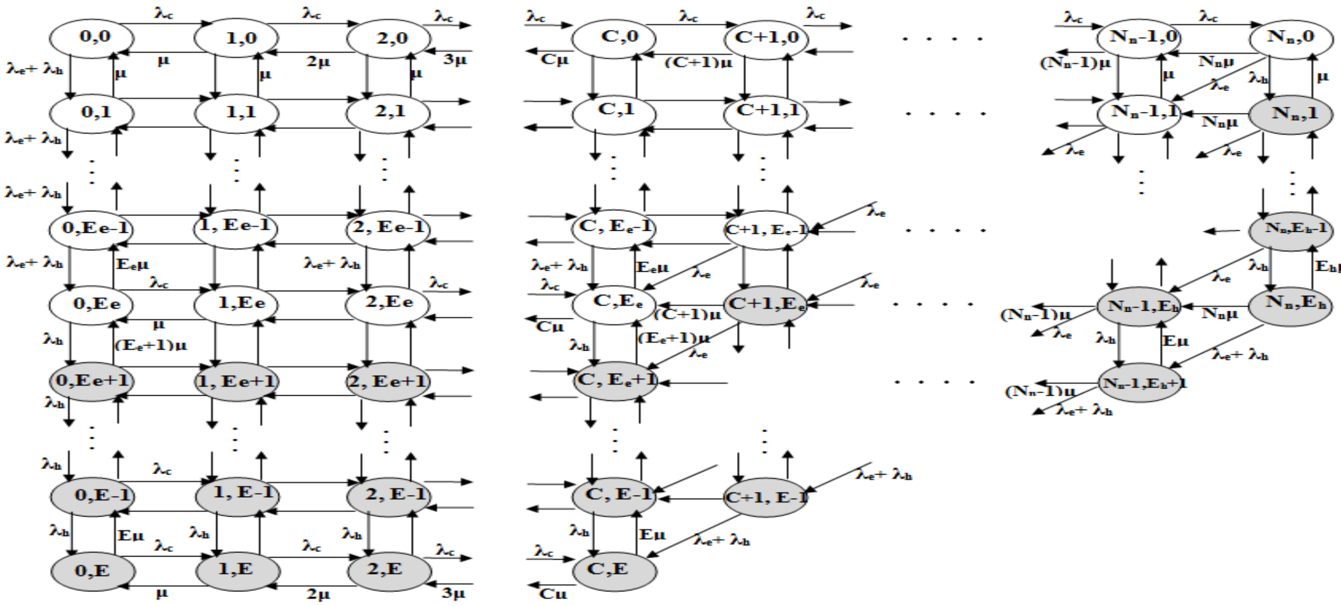

Fig.1. the state diagram of SFR with cutoff priority scheme

represent SFR and has been used to get system resources utilization.

In [14], an algorithm for finding the optimal value of cutoff priority parameters in order to minimize the blocking probability of new calls with the constraint on the upper bound on dropping probability of handover calls.

In the current work, the queuing model proposed in [13] will be modified and enhanced in order to consider handover using cutoff priority scheme. This modified queuing model reflects practical deployed system with sufficient accuracy, and a set of linear balance equations is deduced from the queuing model. A Successive over Relaxation iterative algorithm is used to solve these balance equations to get steady state probability. Performance metrics of blocking, and dropping probability are obtained as a function of handover arrival rate. This metrics will be evaluated in edge and core part of SFR separately. The impact of increasing the RBs dedicated for edge users over the system performance is studied. The effect of increasing (or decreasing) the number of guard channels in system analysis will be investigated.

Finally the optimal value for the parameter of cutoff priority will be obtained to minimize the blocking probability of new calls with the constraint on the upper bound on the dropping probability of handoff calls.

This paper is organized as follows: In section 2, the system model for SFR with cutoff priority scheme is presented. The performance metrics is introduced in section 3. Numerical results and analysis are provided in section 4. Finally conclusion is presented in section 5.

2 Model Description

A two dimension Markov chain is used to model SFR with cutoff priority scheme considered. Horizontal axis stands for the number of RBs used by cell core users whereas; the vertical axis represents the number of RBs used by cell edge users.

2.1 Assumptions

In this paper the following assumptions are considered and in consistence with previously published work in [16]. So it may be summarized in the following parts:

- The basic resource element considered in this paper is the physical resource block (PRB) which spans both frequency and time dimensions. The component frequencies of one PRB can be either contiguous or disjoint. The time duration of the PRB is defined by one transmission time interval (TTI). A PRB can be assigned to only one user at a time.
- N is the number of available PRBs that can be used for transmission in each TTI in the cell. The maximum number of PRB that can be assigned to the edge-users and core-users is E and C respectively; the ratio of cell-edge PRBs to the total number of PRBs each cell is η, so $E = \eta N$ where $E+C=N$.
- Let G_e be the percent of cell-edge PRB reserved for guard channel PRB, and Eh is the PRB assigned to handover users and E_e is PRB assigned to resident users,so $E_h = G_e E$ and $E=E_e+E_h$, also let N_n the total number of PRB assigned for resident users in the whole cell so we have $N_n = C+E_e$.
- Users are uniformly distributed in a cell. A new call follows a Possion process with the mean arrive rate λ. Users are divided into cell edge users and cell core users by SINR. The distance between users to LTE-Advanced base station (eNodeB) in a cell is the only determining factor to SINR. The target cell can be modeled by two queues with the mean arrival rates

$$\lambda_c = \xi_c \lambda$$
$$\lambda_e = \xi_e \lambda \quad (1)$$

where ξ_c represents the ratio of cell core area to the whole cell area, while ξ_e represents the ratio of cell edge area to the whole cell area. λ_h is call arrival rate for handover calls.

- The cell edge PRB is available for both cell edge users and handover users and if there are none of them; it can be occupied by cell core users.
- A cell edge user may be blocked if there are no available cell edge RBs in target cell. A cell core user may be blocked if there are no more cell core RBs or cell edge RBs in target cell
- An ongoing handover call may be dropped if all guard channels in the target cell are occupied.
- System may force the cell core call which has already connected to the networks to be terminated if the cell core call has occupied cell edge RBs and a new cell edge user initialized a new call simultaneously or an ongoing handover call entered the cell.
- The service rate of a cell core user, a cell edge user and handover users are exponentially distributed with rate μ and for simplicity it is assumed to be equal for three users.

2.2 Queuing Model

We define the system state as (i,j) with i representing the number of PRBs used by cell core users and j the number of PRBs used by cell edge users or handover users. Then, a two dimensional state space Γ can be defined as:

$$\Gamma = \{(i,j) \mid 0 \le i \le N, 0 \le j \le E, i+j \le N\} \quad (2)$$

Figure 2 explains the state diagram in SFR with guard channels,

Let $\Pi(i, j)$ be the steady state probability distribution for a valid state $(i, j) \in \Gamma$.

The steady state probabilities should satisfy the normalization constraint.

$$\sum_{(i,j)\in\Gamma} \prod(i,j) = 1 \quad (3)$$

In the following, based on the state diagram shown, the set of global balance equations is introduced:

For the state $(i, j) = (0,0)$

$$(\lambda_c + \lambda_e + \lambda_h)\, \pi(0,0) = \mu\, (\pi(1,0) + \pi(0,1)) \quad (4)$$

For the states $1 \le i < N_n; j=0$

$$(\lambda_c + \lambda_e + \lambda_h + i\mu)\, \pi(i,0) = \lambda_c\, \pi(i-1,0) + (i+1)\mu\, \pi(i+1,0) + \mu\, \pi(i,1) \quad (5)$$

For the states $1 \le j < E_e; i=0$

$$(\lambda_c + \lambda_e + \lambda_h + j\mu)\, \pi(0,j) = (\lambda_e + \lambda_h)\, \pi(0,j-1) + (j+1)\mu\, \pi(0,j+1) + \mu\, \pi(1,j) \quad (6)$$

For the states $1 \le i < N_n; 1 \le j < E_e$

$$(\lambda_c + \lambda_e + \lambda_h + i\mu + j\mu)\, \pi(i,j) = \lambda_c\, \pi(i-1,j) + (i+1)\mu\, \pi(i+1,j) + (\lambda_e + \lambda_h)\, \pi(i,j-1) + (j+1)\mu\, \pi(i,j+1) \quad (7)$$

For the states $(i,j) = (0,E_e)$;

$$(\lambda_c + \lambda_h + E_e\mu)\, \pi(0,E_e) = \lambda_e\, \pi(0,E_e-1) + \mu\, \pi(1,E_e) + (E_e+1)\mu\, \pi(0,E_e+1) \quad (8)$$

For the states $(i,j) = (N_n,0)$;

$$(\lambda_e + \lambda_h + N_n\mu) * \pi(N_n,0) = \lambda_c\, \pi(N_n-1,0) + \mu\, \pi(N_n,1) \quad (9)$$

For the states $1 \le i < C;\ j = E_e$

$$(\lambda_c + \lambda_h + i\mu + E_e\mu)\, \pi(i,E_e) = \lambda_c\, \pi(i-1,E_e) + (i+1)\mu_c\, \pi(i+1,E_e) + (\lambda_e + \lambda_h)\, \pi(i,E_e-1) + (E_e+1)\mu\, \pi(i,E_e+1) \quad (10)$$

For the states $C < i < N_n,\ i+j = N_n$;

$$(\lambda_e + \lambda_h + i\mu + j\mu)\, \pi(i,j) = \lambda_c\, \pi(i-1,j) + \lambda_e\, \pi(i,j-1) + (\lambda_e + \lambda_h)\pi(i+1,j-1) + (j+1)\mu\, \pi(i,j+1) + (i+1)\mu\, \pi(i+1,j) \quad (11)$$

For the states $(i,j) = (C,E_e)$;

$$(C\mu + E_e\mu + \lambda_h)\, \pi(C,E_e) = \lambda_c\, \pi(C-1,E_e) + (\lambda_e + \lambda_h)\, \pi(C,E_e-1) + \lambda_e\, \pi(C+1,E_e-1) + (C+1)\mu\, \pi(C+1,E_e) + (E_e+1)\mu\, \pi(C,E_e+1) \quad (12)$$

For the states $E_e < j < E;\ i=0$

$$(\lambda_c + \lambda_h + j\mu)\, \pi(0,j) = \lambda_h\, \pi(0,j-1) + (j+1)\mu\, \pi(0,j+1) + \mu\, \pi(1,j) \quad (13)$$

For the states $1 \le i < C;\ E_e < j < E$

$$(\lambda_c + \lambda_h + i\mu + j\mu)\, \pi(i,j) = \lambda_c\, \pi(i-1,j) + (i+1)\mu\, \pi(i+1,j) + \lambda_h\, \pi(i,j-1) + (j+1)\mu\, \pi(i,j+1) \quad (14)$$

For the states $(i,j) = (0,E)$;

$$(\lambda_c + E\mu) * \pi(0,E) = \lambda_h\, \pi(0,E-1) + \mu_c\, \pi(1,E) \quad (15)$$

For the states $i = C;\ E_e < j < E$

$$(\lambda_h + C\mu + j\mu)\, \pi(i,j) = \lambda_c\, \pi(C-1,j) + (C+1)\mu\, \pi(C+1,j) + \lambda_h\, \pi(C,j-1) + (j+1)\mu\, \pi(C,j+1) + \lambda_e\, \pi(C+1,j-1) \quad (16)$$

For the states $1 \le i < C;\ j = E$

$$(\lambda_c + i\mu + E\mu)\pi(i,E) = \lambda_c\, \pi(i-1,E) + (i+1)\mu\, \pi(i+1,E) + \lambda_h\, \pi(i,E-1) \quad (17)$$

For the states $C < i < N_n;\ 0 < j < E;\ i+j > N_n;\ i+j < N$ (18)

$$(\lambda_e + \lambda_h + i\mu + j\mu) * \pi(i,j) = \lambda_h\, \pi(i,j-1) + (i+1)\mu\, \pi(i+1,j) + \lambda_e\, \pi(i+1,j-1) + (j+1)\mu\, \pi(i,j+1)$$

For the states $i = N_n;\ 0 < j < E_h\text{-}1$

$$(\lambda_h + \lambda_e + N_n\mu + j\mu) * \pi(i,j) = \lambda_h\, \pi(N_n,j-1) + (j+1)\mu\, \pi(N_n,j+1) \quad (19)$$

For the states $(i,j) = (N_n,E_h)$;

$$(N_n\mu + E_h\mu + \lambda_e + \lambda_h) * \pi(N_n,E_h) = \lambda_h\, \pi(N_n,E_h-1) \quad (20)$$

For the states $C < i < N_n;\ i+j=N$

$$(\lambda_e + \lambda_h + i\mu + j\mu) * \pi(i,j) = \lambda_h\, \pi(i,j-1) + (i+1)\mu\, \pi(i+1,j) + \lambda_e\, \pi(i+1,j-1) + (j+1)\mu\, \pi(i,j+1) \quad (21)$$

For the states (i,j) = (C,E);

$$(C\mu + E\mu)\,\pi(C,E) = \lambda_c\,\pi(C-1,E) + \lambda_h\,\pi(C,E-1) + (\lambda_e + \lambda_h)\,\pi(C+1,E-1) \quad (22)$$

2.3 Deployment of Successive Over Relaxation Algorithm

In this section, the iterative algorithm of the Successive over Relaxation [13], [15] is used to solve the set of linear equation; the method of successive over-relaxation (SOR) is a variant of the Gauss Seidel method for solving a linear system of equations, resulting in faster convergence.

In this method, a new set of equations, called SOR equations, is deduced from balance equations, the left hand side of these equations is a new value of steady state probability which is obtained iteratively using previous value for steady state probability on the right hand side. The speed of convergence is determined by relaxation factor ω. The choice of relaxation factor is not necessarily easy, and depends upon the properties of the coefficient matrix. For symmetric, positive-definite matrices it can be proven that $0 < \omega < 2$ will lead to convergence, but we are generally interested in faster convergence rather than just convergence.

The first step of SOR deployment is deducing SOR equations as follow:

For the state $(i, j) = (0,0)$

$$\pi^{(k)}(0,0) = (1-w)\pi^{(k-1)}(0,0) + w\lambda^{-1}(\mu\,\pi^{(k-1)}(1,0) + \mu\,\pi^{(k-1)}(0,1)) \quad (23)$$

For the states $1 \le i < N_n;\ j=0$

$$\pi^{(k)}(i,0) = (1-w)\pi^{(k-1)}(i,0) + w(\lambda + \lambda_h + i\mu)^{-1}(\lambda_c\,\pi^{(k)}(i-1,0) + (i+1)\mu\,\pi^{(k-1)}(i+1,0) + \mu\,\pi^{(k-1)}(i,1)) \quad (24)$$

For the states $1 \le j < E_e;\ i=0$

$$\pi^{(k)}(0,j) = (1-w)\pi^{(k-1)}(0,j) + w(\lambda + \lambda_h + j\mu)^{-1}((\lambda_e + \lambda_h)\,\pi^{(k)}(0,j-1) + (j+1)\mu\,\pi^{(k-1)}(0,j+1) + \mu\,\pi^{(k-1)}(1,j)) \quad (25)$$

For the states $1 \le i < N_n;\ 1 \le j < E_e$

$$\pi^{(k)}(i,j) = (1-w)\pi^{(k-1)}(i,j) + w(\lambda + \lambda_h + i\mu + j\mu)^{-1}(\lambda_c\,\pi^{(k)}(i-1,j) + (i+1)\mu\,\pi^{(k-1)}(i+1,j) + (\lambda_e + \lambda_h)\pi^{(k)}(i,j-1) + (j+1)\mu\,\pi^{(k-1)}(i,j+1)) \quad (26)$$

For the states $(i,j) = (0,E_e)$;

$$\pi^{(k)}(0,E_e) = (1-w)\pi^{(k-1)}(0,E_e) + w(\lambda_c + \lambda_h + E_e\mu)^{-1}(\lambda_e\,\pi^{(k)}(0,E_e-1) + \mu\,\pi^{(k-1)}(1,E_e) + (E_e+1)\mu\,\pi^{(k-1)}(0,E_e+1)) \quad (27)$$

For the states $(i,j) = (N_n,0)$;

$$\pi^{(k)}(N_n,0) = (1-w)\pi^{(k-1)}(N_n,0) + w(\lambda_e + \lambda_h + N_n\mu)^{-1}(\lambda_c\,\pi^{(k)}(N_n-1,0) + \mu\,\pi^{(k-1)}(N_n,1)) \quad (28)$$

For the states $1 \le i < C;\ j = E_e$;

$$\pi^{(k)}(i,E_e) = (1-w)\pi^{(k-1)}(i,E_e) + w(\lambda_c + \lambda_h + i\mu + E_e\mu)^{-1}\Big(\lambda_c\,\pi^{(k)}(i-1,E_e) + (i+1)\mu\,\pi^{(k-1)}(i+1,E_e) + \lambda_e + \lambda_h\,\pi^{(k)}(i,E_e-1) + (E_e+1)\mu\,\pi^{(k-1)}(i,E_e+1)\Big) \quad (29)$$

For the states $C < i < N_n,\ i+j = N_n$;

$$\pi^{(k)}(i,j) = (1-w)\pi^{(k-1)}(i,j) + w(\lambda_e + \lambda_h + i\mu + j\mu)^{-1}(\lambda_c\,\pi^{(k)}(i-1,j) + \lambda_e\,\pi^{(k)}(i,j-1) + (\lambda_e + \lambda_h)\,\pi^{(k-1)}(i+1,j-1) + (j+1)\mu\,\pi^{(k-1)}(i,j+1) + (i+1)\mu\,\pi^{(k-1)}(i+1,j)) \quad (30)$$

For the states $(i,j) = (C,E_e)$;

$$\pi^{(k)}(C,E_e) = (1-w)\pi^{(k-1)}(C,E_e) + w(C\mu + E_e\mu + \lambda_h)^{-1}(\lambda_c\,\pi^{(k)}(C-1,E_e) + (\lambda_e + \lambda_h)\pi^{(k)}(C,E_e-1) + \lambda_e\,\pi^{(k)}(C+1,E_e-1) + (C+1)\mu\,\pi^{(k-1)}(C+1,E_e) + (E_e+1)\mu\,\pi^{(k-1)}(C,E_e+1)) \quad (31)$$

For the states $E_e < j < E;\ i=0$

$$\pi^{(k)}(0,j) = (1-w)\pi^{(k-1)}(0,j) + w(\lambda_c + \lambda_h + j\mu)^{-1}(\lambda_h\,\pi^{(k)}(0,j-1) + (j+1)\mu\,\pi^{(k-1)}(0,j+1) + \mu\,\pi^{(k-1)}(1,j)) \quad (32)$$

For the states $1 \le i < C;\ E_e < j < E$

$$\pi^{(k)}(i,j) = (1-w)\pi^{(k-1)}(i,j) + w(\lambda_c + \lambda_h + i\mu + j\mu)^{-1}(\lambda_c\,\pi^{(k)}(i-1,j) + (i+1)\mu\,\pi^{(k-1)}(i+1,j) + \lambda_h\,\pi^{(k)}(i,j-1) + (j+1)\mu\,\pi^{(k-1)}(i,j+1)) \quad (34)$$

For the states $(i,j) = (0,E)$;

$$\pi^{(k)}(0,E) = (1-w)\pi^{(k-1)}(0,E) + w(\lambda_c + E\mu)^{-1}(\lambda_h\,\pi^{(k)}(0,E-1) + \mu_c\pi^{(k-1)}(1,E)) \quad (35)$$

For the states $i = C;\ E_e < j < E$

$$\pi^{(k)}(i,j) = (1-w)\pi^{(k-1)}(i,j) + w(\lambda_h + C\mu + j\mu)^{-1}(\lambda_c\,\pi^{(k)}(C-1,j) + (C+1)\mu\,\pi^{(k-1)}(C+1,j) + \lambda_h\,\pi^{(k)}(C,j-1) + (j+1)\mu\,\pi^{(k-1)}(C,j+1) + \lambda_e\,\pi(C+1,j-1)) \quad (36)$$

For the states $1 \le i < C;\ j = E$

$$\pi^{(k)}(i,E) = (1-w)\pi^{(k-1)}(i,E) + w(\lambda_c + i\mu + E\mu)^{-1}(\lambda_c\,\pi^{(k)}(i-1,E) + (i+1)\mu\,\pi^{(k-1)}(i+1,E) + \lambda_h\,\pi^{(k)}(i,E-1)) \quad (37)$$

For the states $C < i < N_n;\ 0 < j < E;\ i+j > N_n;\ i+j < N$ (38)

$$\pi^{(k)}(i,j) = (1-w)\pi^{(k-1)}(i,j) + w(\lambda_e + \lambda_h + i\mu + j\mu)^{-1}(\lambda_h\,\pi^{(k)}(i,j-1) + (i+1)\mu\,\pi^{(k-1)}(i+1,j) + \lambda_e\,\pi^{(k)}(i+1,j-1) + (j+1)\mu\,\pi^{(k-1)}(i,j+1))$$

For the states $i = N_n;\ 0 < j < E_h - 1$

$$\pi^{(k)}(i,j) = (1-w)\pi^{(k-1)}(i,j) + w(\lambda_h + \lambda_e + N_n\mu + j\mu)^{-1}(\lambda_h\,\pi^{(k)}(N_n,j-1) + (j+1)\mu\,\pi^{(k-1)}(N_n,j+1)) \quad (39)$$

For the states $(i,j) = (N_n,E_h)$;

$$\pi^{(k)}(N_n,E_h) = (1-w)\pi^{(k-1)}(N_n,E_h) + w(N_n\mu + E_h\mu + \lambda_e + \lambda_h)^{-1}(\lambda_h\,\pi^{(k)}(N_n,E_h-1)) \quad (40)$$

For the states $C < i < N_n;\ i+j=N$

$$\pi^{(k)}(i,j) = (1-w)\pi^{(k-1)}(i,j) + w(\lambda_e + \lambda_h + i\mu + j\mu)^{-1}(\lambda_h\,\pi^{(k)}(i,j-1) + (\lambda_e + \lambda_h)\,\pi^{(k)}(i+1,j-1)) \quad (41)$$

For the states $(i,j) = (C,E)$;

$$\pi^{(k)}(C,E) = (1-w)\pi^{(k-1)}(C,E) + w(C\mu + E\mu)^{-1}(\lambda_c\,\pi^{(k)}(C-1,E) + \lambda_h\,\pi^{(k)}(C,E-1) + (\lambda_e + \lambda_h)\,\pi^{(k)}(C+1,E-1)) \quad (42)$$

The SOR algorithm comprises three main parts [15]. First, all equations are started using initial valid state probability and convergence criteria and relaxation factor. Second, we iterate SOR equations aforementioned until the steady probability distribution satisfies the convergence condition or iterations exceed 1000. This equation should be solved in sequence as some of its values depend on the values from the former equation. Finally, performance metrics can be obtained if the algorithm could acquire the steady state probability corresponding with the convergence condition.

1. the number of total valid states in the set Γ are Computed;

$$S = (N_n+1)\times(E+1) - 0.5 \times (E_e+1) \times (E_e) \qquad (43)$$

2. For $\forall(i, j) \in \Gamma$, let the initial probability be

$$\Pi^{(0)}(i,j) = {}^{1}/_{S} \qquad (44)$$

3. Let the convergence criteria be ε, the relaxation factor be ω $(1 \le \omega < 2)$, and the iteration $k = 1$;
4. Calculate the SOR equations in sequence:
5. If we have

$$\Pi^{(k)}(i,j) = \frac{\Pi^{(k)}(i,j)}{\sum_{(i,j)}\Pi^{(k)}(i,j)} \qquad (45)$$

$$\left\|\Pi^{(k)}(i,j) - \Pi^{(k-1)}(i,j)\right\| \le \varepsilon \qquad (46)$$

Then exit to step 6); otherwise let $k = k + 1$ and reexecute steps 4 and 5.

6. Output the steady state probability and calculate the performance metrics.

3 Assessment Criteria

3.1 System performance metrics

In this work, we will use blocking probability and dropping probability to evaluate system performance. Cell blocking probability is the probability that a new arriving cell core user and a cell edge user are blocked. Let ψ_{bc} and ψ_{be} be the subsets of states where a new arriving cell core user and a cell edge user are blocked, respectively. Then the Blocking Probability (P_B) is calculated as [13]:

$$P_B = \sum_{(i,j)\in\Psi_{bc}} \xi_c \prod(i,j) + \sum_{(i,j)\in\Psi_{be}} \xi_e \prod(i,j) \qquad (47)$$

Finally let ψ_d be the subsets of states where the system forces to terminate the ongoing handover call. Then the cell Dropping Probability (P_D) is calculated as:

$$P_D = \sum_{(i,j)\in\Psi_d} \xi_e \prod(i,j) \qquad (48)$$

3.2 Optimization of the number of guard channels T_{obt}

The objective of this part is to minimize the number of guard channels that provide the minimum new call blocking probability P_B subjected to a hard constraint on handover dropping probability P_h.

We will follow the algorithm mentioned in [14] to find T_{obt}. This algorithm is illustrated in Fig. 2 and can be described as follows. At the beginning, the algorithm starts with minimum number of guard channels (T_{obt}=1) then increase

Let $T_{obt} = 1$

If $P_D\,(T_{obt}) \le P_h$ then

Return T_{obt}

else

While $(T_{obt} < E)$ & $P_D\,(T_{obt}) > P_h$ do

$T_{obt} = T_{obt} + 1$

end while

If $P_D\,(T_{obt}) \le P_h$ then

Return T_{obt}

else

Return 0

end if

Fig. 2. Algorithm for obtaining optimal value of T_{obt}

T_{obt} until the handover dropping probability P_D meets its constraint. If $T_{obt} = E$ while handover dropping probability P_D does not meet its constraint then the available resources for handover calls does not satisfy the level of QoS and the number of allocated channels to the cell is not sufficient and the algorithm terminates.

4 Numerical Results and Analysis

In this section, the performance of SFR scheme in presence of guard channel is analysed and evaluated using enhanced queuing model, the aforesaid performance metric of blocking probability and Outage probability and dropping probability is used for evaluation. The effect of increase the PRB reserved for guard channel in SFR performance is studied. In addition, the effect of the increase of percent of cell-edge η to cell core PRB in SFR performance is evaluated.

System parameters are chosen in consistence with [16] is as follow: the available PRB in the cell (N) is 48; the mean service period is 90 seconds. The SOR parameter is relaxation factor ω=1.05 $\varepsilon = 10^{-5}$, k =1000.

4.1 Performance Assessment for Different Handover Arrival Rates

Figures 3 to 5 explain the performance assessments of the system in different handover arrival rates when $\xi = 1/2$ and $\eta = 1/3$ (Huawei proposal [10]) and $G_e = 0.25$. For convince and reasonability, the values of handover arrival rate were chosen to be not to exceed the arrival rate of new call for cell edge user.

Figure 3 &4 show the cell blocking probability for edge users and core users respectively. The interpretation of the current results is indicating that by having more handover requests, the system will starve to serve the handover requests in price of blocking more and more new call requests.

The effect of λ_h in blocking probability of edge users is greater than its effect in core users, this is clear when comparing figure 3 &4. This is because the cell edge RBs is admitted for both edge and handover users while the cell core RBs is dedicated for core users and so λ_h has limited impact on it as

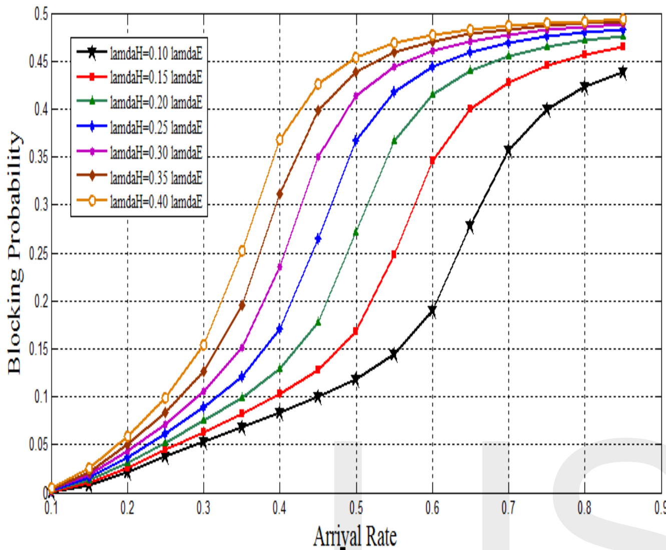

Fig. 3. Blocking probability of edge part for different λ_h

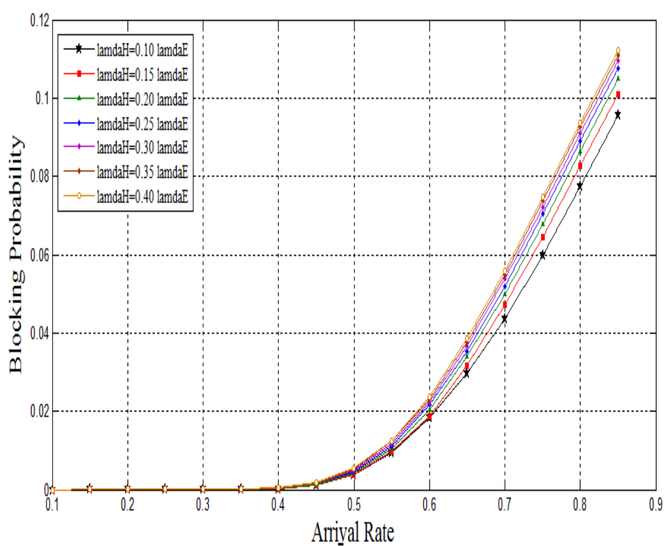

Fig. 4. Blocking probability of core part for different λ_h

illustrated in figure 4. The blocking of cell core users due to handover request is due to the cell core users can also access the cell edge RBs but with less priority than cell edge users.

It is observed from figure 3 that when the percentage of handover arrival rate equal to 40% of arrival rate of edge new call, the blocking probability increase more rapidly than the blocking at 10%, this is because of the effect of increase the total call requests (due to increase of handover call rate), consequently available RBs will be occupied faster and blocking probability will increase rapidly.

Figure 5 shows the dropping probability of handover call as a function of new call arrival rate. It is shown that by having more handover request, more resources are occupied. Then, the probability for serving handover calls is reducing.

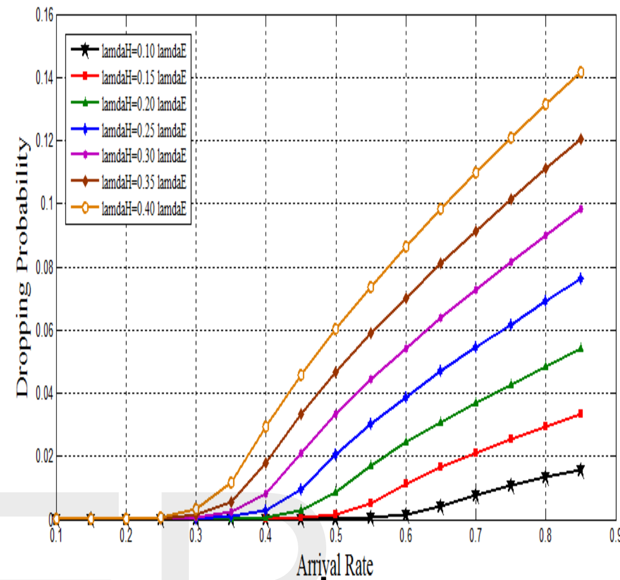

Fig. 5. Dropping probability for different λ_h

4.2 Performance Assessment for Different G_e

In the following, the effect of changing the reserved guard channels in the performance metric is introduced. The handover arrival rates λ_h = 0.25 of new call arrival rates at cell edge.

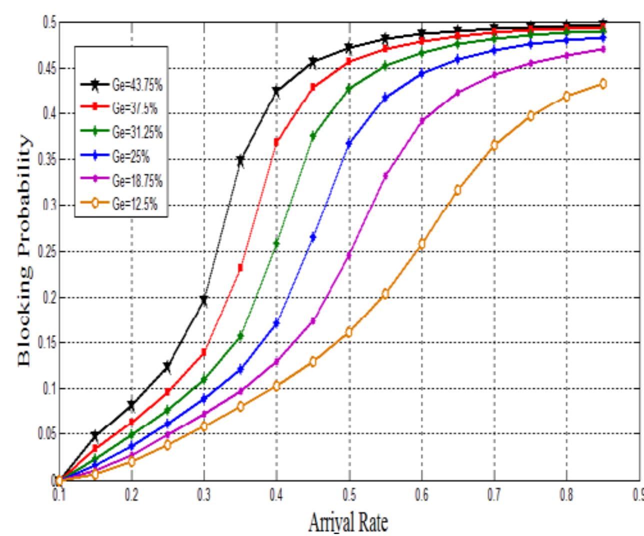

Fig. 6. Blocking Probability with different percent of Guard Channel G_e at cell edge

Figure 6 shows the blocking probability at different values of G_e as a function of arrival rate at cell edge users. It is observed that as G_e increases, the blocking probability increases rapidly. This because of the remaining RBs for new calls will decrease and so block more and more new call requests.

Figure 7 explains the impact of G_e on blocking probability for cell core users. This impact is a result of accessing of the core users the edge resources when there are no edge or handover users. This impact is limited in comparison with

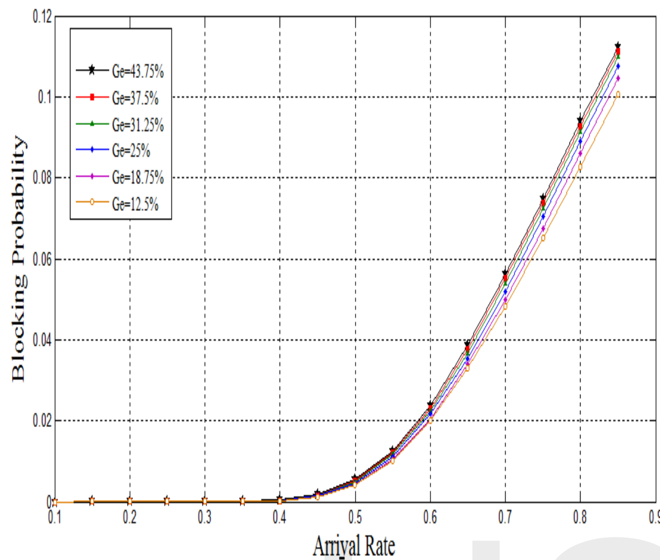

Fig. 7. Blocking Probability with different percent of Guard Channel G_e at cell core

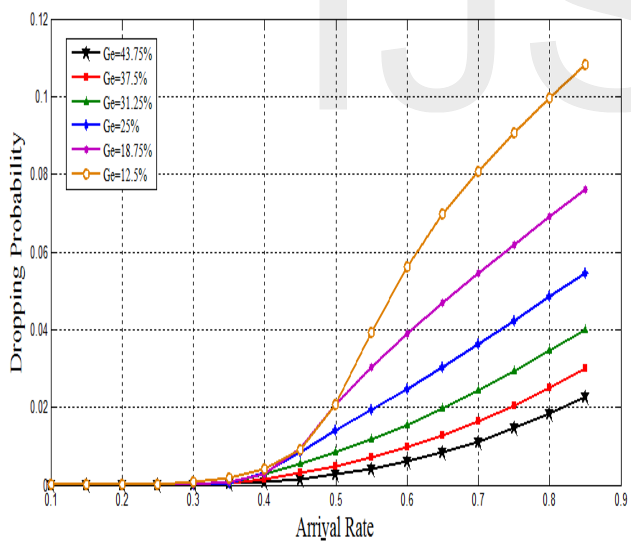

Fig. 8. Dropping Probability with different percent of Guard Channel G_e

cell edge case; this is due to blocking of new call in cell core part is occurred as a result of full usage of the resources. Consequently, the effect of G_e is limited.

Figure 8 explains the positive effect of reserving more guard channels for handover requests in improvement the dropping rate but this is in price of blocking probability of new call requests as indicated previously in Figure 6.

4.3 Performance metrics with optimized guard channels T_{opt}

Figure 2 illustrates the algorithm to find out the optimized value of the number of guard channels T_{obt} that provide minimum blocking probability under hard constraint of dropping probability P_h.

In figure 9, for P_h varies from 0.008 to 0.2 the optimized value of T is obtained following figure 2 algorithms. At each point of T, the equivalent value of dropping probabili

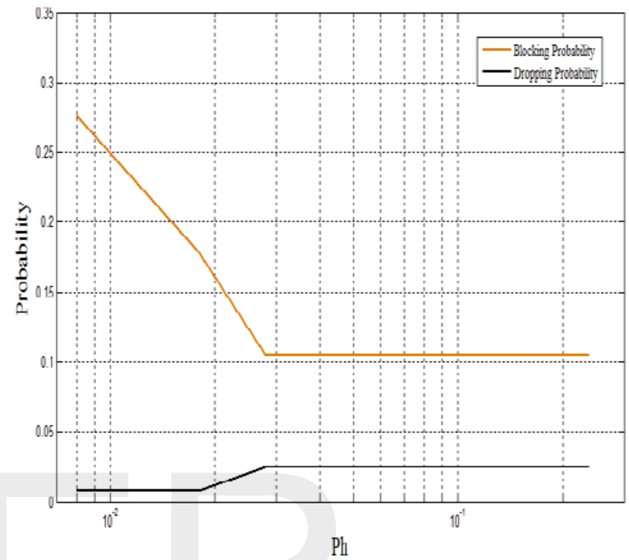

Fig. 9. Blocking probability and Dropping Probability with different values of P_h

ty P_D and blocking probability P_B are calculated. The new call arrival rate λ and handover arrival rate λ_h is taken to be 0.5 and 0.05 respectively in the shown results.

5 Conclusion

In this paper, the effect of SFR with cutoff priority scheme is investigated using Queuing model, a steady state probability is deduced using successive over relaxation method. Our numerical results and analysis illustrates the effect of guard channels in decreasing the dropping rate in handover calls but this is in price of overall blocking probability in system. System is strongly influenced by the greater rate of handover service request. Not only cell edge users suffers from this impact, but also cell core users with lesser extent. In addition, the higher the proportion of the guard channel is the greater the impact on the blocking probability.

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