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Performance Analysis of a Cellular Networks Using Power Control Based Frequency Reuse Partitioning

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ABSTRACT

This paper focuses on evaluating the performance of a cellular network using power control based frequency reuse partitioning (FRP) in downlink (DL). In our work, in order to have the realistic environment, the spectral efficiency of the system is evaluated through traffic analysis, which most of the previous works did not consider. To further decrease the cell edge user's outage, the concept of power ratio is introduced and applied to the DL FRP based cellular network. In considering network topology, we first divide the cell coverage area into two regions, the inner and outer regions. We then allocate different sub-bands in the inner and outer regions of each cell. In the analysis, for each zone ratio, the performance of FRP system is evaluated for the given number of power ratios. We consider performance metrics such as call blocking probability, channel utilization, outage probability and effective throughput. The simulation results show that there is a significant improvement in the outage experienced by outer UEs with power control scheme compared to that with no power control scheme and an increase in overall system throughput.

Key Words : Inter-Cell Interference (ICI), Interference Management, Frequency Reuse Partitioning (FRP).

Ⅰ. Introduction

1.1 Motivation and Related Work

In order to achieve high system capacity and simplify the radio network planning, most OFDMA based fourth-generation (4G) systems (such as WiMAX) IEEE 802.16[1] and 3GPP-LTE[2] are targeting the frequency reuse factor of 1 (FRF = 1). FRF 1 implies that the base stations in cells share all feasible time-frequency resource blocks (RBs) simultaneously. However, in OFDMA multi-cell systems deployed with frequency reuse 1, co-channel interference (CCI) occurs due to the simultaneous use of the same channel or subcarrier by different users in the neighboring cells. There is a severe increase in the outage experienced by the users especially cell edge users who suffer severe performance degradation due to the very strong CCI from neighboring cells and the out-of-cell transmissions which leads to poor cell coverage. Thus to mitigate CCI, FRF of three or more has generally been employed.

Interference mitigation technique by controlling the degree of frequency reuse is one of the most important techniques for interference mitigation[3]. In [4], several inter-cell interference coordination (ICIC) schemes have been proposed, one among them being Frequency Reuse Partitioning (FRP). In [5], FRP has been proposed for the OFDMA based IEEE 802.16m and 3GPP-LTE systems as ICIC technique. In addition, through using different cluster sizes, FRP has been suggested in [6] to be

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a very useful technique to achieve high spectrum efficiency in cellular systems.

The main idea of FRP is to divide the cell into concentric regions and to further reduce ICI; each region is allocated different sub-bands. The same set of sub-bands is not used in the neighboring cell edges.

The performance of the FRP approach has been reported in [7], [8] and [9]. In [7], the performance of the reuse partitioning was evaluated and analytical model for the FRP based system was proposed. In [8], the power division reuse partitioning scheme and successive interference cancellation was proposed. The performance of power control to an improved fractional frequency reuse (IFFR) scheme was investigated in [9]. However, [8] did not consider the effect of power control. In addition, in [7] and [8], the performance was evaluated in the uplink (UL) transmission where user equipments (UEs) transmit with the same average power and hence the effect relies only on the path loss and shadowing effect. On the other hand, [8] and [9] did not take into account the traffic analysis which is necessary part for the evaluation of the spectral efficiency of the system.

1.2 Contribution and Organization

To the best of our knowledge, we have seen that there is no work that discussed the performance of FRP taking into consideration the analysis of the traffic in the network for downlink (DL) transmission and power control. Traffic analysis provides realistic environment as it provides the details of the channels used and the accepted calls. In contrast with that of [7], the performance of our system not only relies on the path loss and shadowing effect but also the effect of the transmission power of the BS which takes different values for inner and outer regions. In this paper, we therefore added the traffic analysis part in the power control based two-tier FRP system. In addition, for each zone ratio, different power ratios are simulated and the system performance is evaluated. The results of the channel utilizations and call blocking probabilities for the inner UEs, outer UEs and overall UEs are presented. Furthermore, outer UEs outage, inner UEs outage in terms of offered load and effective throughput in terms of the outage probability are also presented.

The remainder of this paper is organized as follows: Section II outlines the details of system model. In Section III, the proposed algorithm is described in detail, and the performance metrics are discussed in Section IV. Simulation results and analysis are discussed in Section V. Finally, Section V concludes the paper.

Ⅱ. System Model

2.1 Model Descriptions

As shown in Figure 1, we consider a system topology of a two-tier network with 19 hexagonal macrocells of equal sizes. It is assumed that the BS of each cell is positioned at the center of the cell and it is represented by small dots in each cell. In addition, each cell is further partitioned into two regions: the inner region and the outer region of concentric radii R and r respectively. Through Received Signal Strength (RSS) which is measured and reported by UE, the distance between the BS and UE is estimated. Accordingly, the zone ratio, ε is defined as the ratio of the inner zone area to the overall cell area or simply the fraction area of the inner zone as shown in (1)

$$\varepsilon = \frac{\pi^* r^2}{\pi^* R^2} = \left(\frac{r}{R}\right)^2. \tag{1}$$

The total spectrum is divided into three sub-bands; F_0, F_1 and F_2. To further enhance the system capacity through interference mitigation, different sub-bands are allocated for the outer regions while the remaining sub-bands are reused in the inner regions of each cell avoiding the sub-band located in their respective outer regions. In other words, users in the outer region have exclusive use of the outer channels and users in the inner region use the remaining channels not used by the outer users.

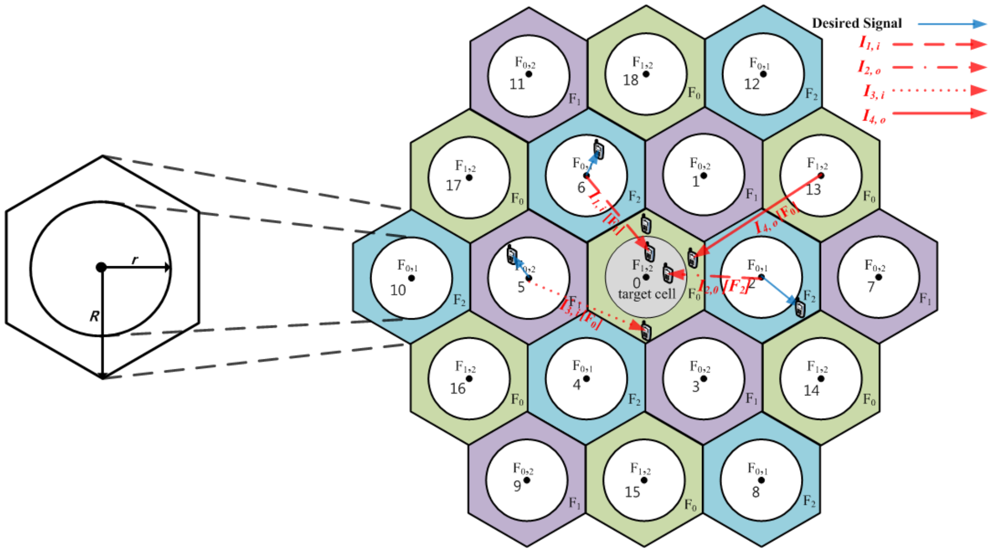

Fig. 1. The system topology and interference effect in the FRP system.

2.2 Recieved Signal Power Model

We assume that the received signal power, $P_{k,z}$ at user is

$$P_{k,z} = P_t^k r_z^{-\alpha} L_z, \tag{2}$$

where P_t^k refers to transmit power of the target cell, BS_0 i.e. cell 0 in region k . Throughout our paper, we refer $k=(i,o)$ as the region of transmission in the cell where i for inner region and o for outer region, r_z is the distance between the BS, z and user, α is path loss exponent, and L_z being the shadowing effect with log-normal distribution with zero-mean and a standard deviation of σ.

2.3 Traffic Model

In this section, we describe the system traffic model. For the DL transmission, we assume that only one channel which is channelized from resource elements or sub-carriers can be assigned to UE from BS[11]. We also assume that there are a total of C channels in each cell and that each of the sub-bands F_0, F_1 and F_2 has total outer channels, $C_o = C/3$ and total inner channels, $C_i = C - C_o$. The new call is scheduled to get serving on one channel only whenever the channel is available. If the channel is not available, the call is blocked.

In addition, the traffic model has the following assumptions:

The call inter arrival time is exponentially distributed with mean $1/\lambda$ seconds per cell

For the inner region, the call inter arrival rate is λ_i and that of the outer region is λ_o and they are related according to equations (3) and (4) below

$$\lambda_i = \varepsilon\lambda, \tag{3}$$

$$\lambda_o = (1-\varepsilon)\lambda, \tag{4}$$

The call serving/holding time is exponentially distributed with mean $1/\mu$ seconds[10].

Ⅲ. Proposed Algorithm for Frequency Reuse Partitioning (FRP)

In this section, we discuss the channel allocation procedure, power control, interference types and the signal to interference ratio (SIR). The proposed power control based FRP system is explained.

3.1 Channel Allocation Procedure

In this section, we introduce the channel allocation procedure for the FRP. When a new call first arrives, it requests a channel. Note that the request of the channel depends on the region upon which the call arrives i.e. in the inner or outer region. If the call arrives in the inner region of the cell, it requests a channel from the inner region and if the call arrives in the outer region of the cell, it requests a channel from the outer region. If the channel is available, then this channel is assigned to the UE while other UEs in the same cell cannot use the same channel. Upon completion of its transmission, the assigned UE releases the channel so that it becomes available to other UEs. On the other hand, when all the channels are fully utilized, the newly arriving call is rejected and we call this as initial call block. The channel selection procedure is shown in Table 1.

Table 1. Channel Allocation

Channel Selection Procedure Algorithm
Call Arrival **Case 1:A UE arrives in the inner region** UE requests a channel **If a channel is available** Accept the call and assign inner channel **Else** Reject the call **Case 2:A UE arrives in the outer region** UE requests a channel **If a channel is available** Accept the call and assign outer channel **Else** Reject the call

3.2 Power Control

In this section, we propose the power control scheme to improve the system throughput of FRP system. To do this, we first define the power ratio. In power ratio, the BS transmit power is controlled according to the user location.

Let P_t^i and P_t^o be the BS transmit powers in the inner and outer regions of the cell, respectively, we define power ratio, β as in (5)

$$\beta = \frac{P_t^i}{P_t^o}. \quad (5)$$

When the transmission power level is the same in the inner and outer regions (i.e. $\beta = 1$), we refer this case as no power control (no PC) scheme. When the inner and outer regions transmit with different power levels (i.e. $\beta \neq 1$), we refer this case as power control (PC) scheme.

3.3 Co-channel Interference (CCI) Types

Depending on whether the interference originated from transmission to inner user or outer user owing to the neighboring cells, the interference may be one of the four types.

Suppose that $I_{l,k}$ is the interference with $l = 1,2,3,4$ being interference types and k denote whether the interference originated from inner or outer regions of the neighboring cells to the target cell, the four types of interference due to CCI are described below:-

- $I_{1,i}$: Interference originating from inner region of the neighboring cell to the inner region of the BS_0 for users using the same channel in these cells
- $I_{2,o}$: Interference originating from outer region of the neighboring cell to the inner region of the BS_0 for users using the same channel in these cells
- $I_{3,i}$: Interference originating from inner region of the neighboring cell to the outer region of the BS_0 for users using the same channel in these cells.
- $I_{4,o}$: Interference originating from outer region of the neighboring cell to the outer region of the BS_0 for users using the same channel in these cells.

Though there are many co-channel interfering signals from different neighboring cells, to provide a clear understanding of these interference configurations, only four cells which show the four types of interference are presented in Figure 1.

In addition, depending on weather the UE in BS_0 is using an inner channel or an outer channel, there are two cases of interference configurations.

- Case 1: UE uses an inner channel. In this case, assume that the UE arrived in the inner zone of the BS_0 and use a channel in F_1. There will be interferences received from neighboring cells 2, 4, 6, 8, 10, 12, 13, 14, 15, 16, 17 and 18 from the inner channels of these cells. There will be other interferences from neighboring cells 1, 3, 5, 7, 9 and 11 from the outer channels of these cells.

- Case 2: UE uses an outer channel. In this case, assume that the UE arrived in the outer zone of the BS_0 and use a channel in F_0, there will be interferences received from neighboring cells 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 from the inner channels of these cells and other interferences from neighboring cells 13, 14, 15, 16, 17 and 18 from the outer channels of these cells.

Summary of four types of interference from any user served by any of the neighboring cells to the user served by the target cell are presented in Table II, in which the notations used are the same as the one presented in Figure 1.

Table 2. Interference types from neighboring cells

Interference Type	Channel used by UE in the target cell	Origin of interference	
		First-tier cells	Second-tier cells
$I_{1,i}$	F_1	2,4,6	8,10,12,13,...,18
	F_2	1.3.5	7,9,11,13,...,18
$I_{2,o}$	F_1	1,3,5	7,9,11
	F_2	2,4,6	8,10,12
$I_{3,i}$	F_0	All	7,...,12
$I_{4,o}$		None	13,...,18

3.4 SIR Formulation

We assume that the system interference is only limited to CCI, so noise and other kinds of interferences are negligible. The signal to interference ratio (SIR), γ_k for the DL transmission to user from BS_0 in region k of the cell is given by

$$\gamma_k = \frac{P_{k,0}}{P_t^i \Sigma_{z \in Z_i} r_z^{-\alpha} L_z \chi_z + P_t^o \Sigma_{z \in Z_o} r_z^{-\alpha} L_z \chi_z}\ , \quad (6)$$

where χ is the interference index taking value of 1 when the interference occurs or 0 when the interference does not occur, and $Z_*(*=i,o)$ is the set of co-channel cells.

It is important to note that a transmission in a cell inner region or cell outer region that is assigned a specific channel may cause interference to both inner users and outer users of the other cells that are assigned the same channel.

Ⅳ. System Performance Measurement

4.1 Call Blocking Probability

Let $N_{f,k}$ and $N_{t,k}$ be the number of failed calls and total number of call trials in region k of the cell respectively; the inner, outer and total call blocking probabilities; $P_{b,i}$, $P_{b,o}$ and P_b are respectively given by equations (7), (8) and (9)

$$P_{b,i} = \frac{N_{f,i}}{N_{t,i}}, \quad (7)$$

$$P_{b,o} = \frac{N_{f,o}}{N_{t,o}}, \quad (8)$$

and

$$P_b = P_{b,i} + P_{b,o}. \quad (9)$$

4.2 Channel Utilization

The channel utilization defines not only the channel occupancy ratio but also the probability of interference occurrence that the neighboring cells will suffer from the target/serving cell.

Let S be simulation time and the total served time of succeeded calls in region k be T_k, then the inner channel utilization, ρ_i and the outer channel utilization, ρ_o and the overall channel utilization, ρ are respectively given as

$$\rho_i = \frac{T_i}{S^* C_i}, \quad (10)$$

$$\rho_o = \frac{T_o}{S^* C_o}, \quad (11)$$

and

$$\rho = \frac{T_i + T_o}{S * C}. \qquad (12)$$

4.3 Outage Probability

We define the outage probability, η_k in either of the region of the cell as the probability that the user's SIR in region k, γ_k falls below the SIR threshold, $\gamma_{threshold}$ and is given as

$$\eta_k = P(\gamma_k < \gamma_{threshold}, k = i, o). \qquad (13)$$

The total outage probability, η is calculated by considering the outage of accepted calls in each region of the cell and is given as

$$\eta = \frac{\lambda_i(1 - P_{b,i})\eta_i + \lambda_o(1 - P_{b,o})\eta_o}{\lambda_i(1 - P_{b,i}) + \lambda_o(1 - P_{b,o})}, \qquad (14)$$

where λ_i and λ_o are the same as in (3) and (4) respectively, $(1 - P_{b,i})$ and $(1 - P_{b,o})$ give the number of accepted inner calls and that of outer calls respectively.

4.4 Effective Throughput

The throughput of the FRP based cellular system is measured by the effective throughput and is obtained from the effective carried load per cell. From the obtained call blocking probability and the outage probability, we calculate the effective throughput, T for a given offered load, λ/μas

$$T = [\lambda_i(1 - P_{b,i})(1 - \eta_i) + \lambda_o(1 - P_{b,o})(1 - \eta_o)]/\mu, \qquad (15)$$

where $(1 - \eta_i)$ and $(1 - \eta_o)$ define the probability of no outage in the inner and outer regions respectively.

V. Simulation Results and Analysis

The cellular system being simulated is composed of 19 two-tier hexagonal cells in which UEs are assumed to be uniformly distributed within a cell's coverage area. The UEs access the channels randomly and the assignment of the channel to the UE follows the channel allocation procedure described in section III. For all of the simulation results, it is assumed that $C = 51$, $C_o = 17$ and $C_i = 34$. The radius of the cell is normalized and assumed to be one. In addition, the normalized inner zone radius, r is assumed to take values of 0.6, 0.7 and 0.8. For $r = 0.6, 0.7$ and 0.8, the inner regions occupies 36%, 49% and 64% of the total region of the cell respectively. Other additional simulation parameters are presented and described in Table III.

We evaluate and analyze the simulation results of call blocking probability, the channel utilization, outage probability and the effective throughput versus normalized offered load when $r = 0.6, 0.7$ and 0.8. The performance analysis of power control based FRP is done by examining the

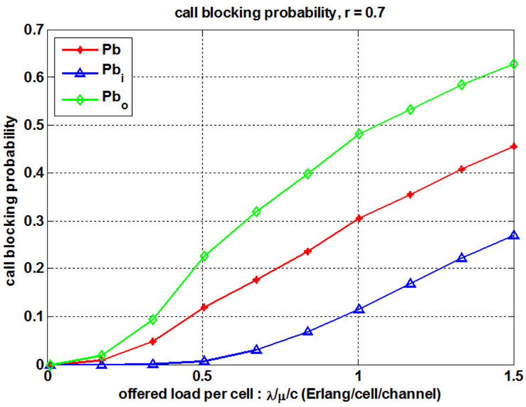

Fig. 2. Channel Utilization versus offered load with r=0.7.

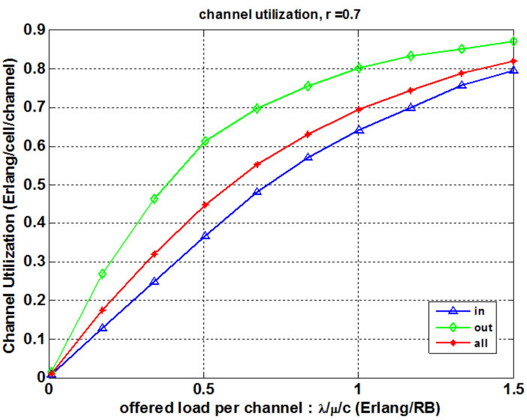

Fig. 3. Call blocking probability versus offered load with r=0.7.

Table 3. Simulation Parameters

Parameters	Values
BS transmit Power	15W, 25W, 40W
Number of cells	Two-tier 19 cells
Cell radius	1000m
Call inter arrival time	Exponential distribution
Call serving time	Exponential distribution
User distribution	Uniform distribution
Path loss exponent, α	4
Total Channel, C	51
Normalized r	0.6, 0.7, 0.8
$\gamma_{threshold}$	-6 dB
Standard deviation, σ	8 dB

system performance change in each of the zone ratio for the range of the given power ratio, ε. In our work, we compare the performance of proposed PC scheme to the one with no PC scheme. Figure 2 and Figure 3 plot the results of channel utilization and call blocking probability respectively with respect to the offered load, when $r = 0.7$.

The call blocking probabilities of the inner UEs, the outer UEs and the overall UEs is shown in Figure 3. From the figure, P_b, P_{b_i} and P_{b_o} represents the overall, inner UEs and outer UEs probabilities respectively. The outer UEs suffer from much higher call blocking probability than the inner UEs. This is due to the fact that the outer channel utilization is higher for the outer UEs than the inner channel utilization for the inner UEs.

Figure 4 and Figure 5 show the outage probabilities of the inner UEs and outer UEs respectively for different values of PR with respect to different values of the offered load. With no PC scheme, it can be seen that the outer UEs suffers from high outage in Figure 5 compared to that of inner UEs shown in Figure 4. Although there is an increase in inner UEs outage of about 3.8% but since there is significant decrease in the outage for outer UEs with PC scheme, we still believe that our scheme performs better. From Figure 5, it can clearly be seen that with no PC scheme (i.e. PR = 1), the outer UEs outage is about 0.36 (36%) where as with PC scheme, the outage is decreased to about

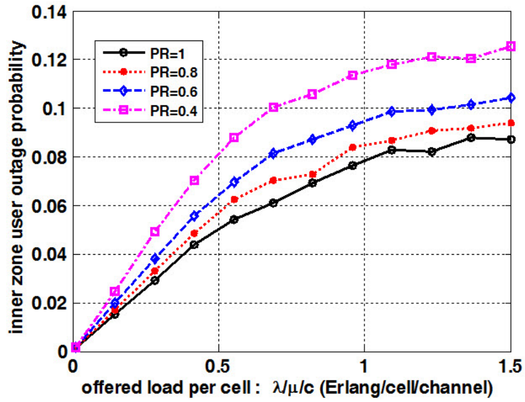

Fig. 4. Inner UEs outage versus offered load at different power ratio (PR).

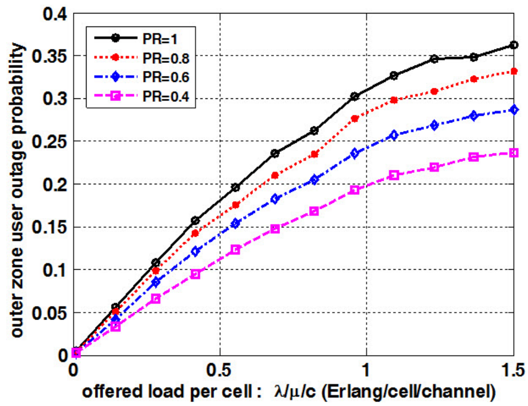

Fig. 5. Outer UEs outage versus offered load at different power ratio (PR)

0.23 (23%).

Fig. 6 shows the outage probabilities for different values of PR with respect to different values of the offered load. From this figure, it was observed that the outage probability with no PC scheme (i.e. $PR = 1$) was higher compared to the ones with PC scheme. There was further decrease of the outage in the system with PR decrease as it can be seen that the lowest outage was found at $PR = 0.4$ for all values of r.

Figure 7 shows the relationship between the effective throughput and the outage probability with respect to different values of PR (i.e., $PR = 1.0, 0.8, 0.6$ and 0.4). Figure 7 shows that the effective throughput can not be increased without not only increasing the tolerance of the outage probability for all users but also decreasing the PR. For example, the system can

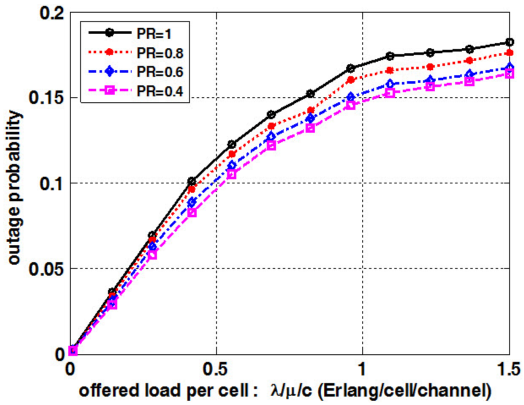

Fig. 6. Outage probability versus offered load at different power ratio (PR).

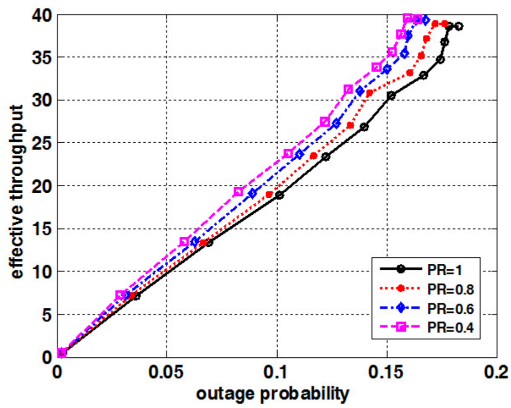

Fig. 7. Effective throughput versus Outage probability at different power ratio (PR).

reach the effective throughput of over 8 with the outage probability of 0.15 for $PR=0.4$ and with the outage probability of 0.17 for $PR=1$.

For the extreme values of normalized inner radius r. $r=0$ means that $\lambda_i=0$ and $\lambda_o=\lambda$, hence the system efficiency is solely from the external UEs. $r=1$ means that $\lambda_i=1$ and $\lambda_o=0$, hence the whole cell area is solely covered by inner UEs and hence the system performance is only from inner UEs. In either case of r at this point, the system performance is constrained to only one type of user and that the UEs will transmit with the same power i.e. P_t^i or P_t^o, for UEs in the inner or outer regions respectively. Accordingly, the PC scheme results agree with the results of no PC scheme for each extreme value of r.

Ⅵ. Conclusion and Future Work

In this paper, we investigated the performance of the cellular network using power control based FRP scheme. From the simulation results, it was observed that the system performance depends not only on the offered load but also on both the size of the inner zone and BS transmit power. With PC scheme showed significant decrease in the outage experienced by the outer UEs which led to the system performance improvement as compared to its counterpart i.e. no PC scheme. This significant improvement was found to occur at power ratio (PR), $\varepsilon=0.4$ for all values of r. For better performance for the system of this kind, as it was seen from simulation results, the size of the inner zone and the power ratio are recommended to be 0.7 and 0.4 respectively for high offered load. For low offered load systems, inner zone size of 0.8 is recommended for the same power ratio.

This paper presents only the inner zone ratio and the power ratio that give the optimum system capacity. The future work of this paper is to utilize our results in [8-9] and compare the performance.

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