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Optimal Transmit Power Configuration for Soft Frequency Reuse in Irregular Cellular Networks

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***Abstract*—Optimal configuration of base station (BS) parameters is a key requirement in current cellular networks. For acceptable user (UE) performance, the bandwidth and transmit power parameters of each BS need to be intelligently chosen. Soft frequency reuse (SFR) is a resource allocation algorithm that specifies efficient frequency and power distribution for different locations within a BS. By classifying UEs into two regions based on their signal-to-interference-plus-noise ratio (SINR), SFR adjusts BS parameters to cater for the most vulnerable UEs. However, since typical cellular networks consist of irregular BS placements and varying UE distribution, more dynamic SFR models and schemes need to be developed. In this paper, we present an SFR implementation that provides optimal choices for macro BS transmit power in the different network regions. We show how edge UEs exposed to high levels of inter-cell interference (ICI) can be compensated based on a fairness index. The algorithm is well suited for irregular network deployments and is shown to guarantee edge UE capacity enhancement and a greater control over system performance.**

***Index Terms*—inter-cell interference; Frequency Reuse; Soft frequency reuse; Fractional frequency reuse; 4G/5G; cellular networks; resource allocation; irregular networks; self organised networks; optimization**

I. Introduction

Current 4G cellular networks are challenged by the heavy data requirements of users (UEs) and also the effects of inter-cell interference (ICI). The Soft frequency reuse (SFR) algorithm is an effective technique that addresses the problem of ICI thereby enhancing UE performance. In SFR, each macro base station's (BS) coverage region is divided into two based on UE signal-to-interference-plus-noise ratio (SINR). Furthermore as Fig. 1 shows, the UE are classified as: 1) Center UE are close to the macro BS antenna and have relatively high SINR 2) Edge UE are closer to the BS boundaries and receive higher levels of ICI from neighbouring macro BS. Consequently, edge UE experience lower SINR than the center UE. SFR caters for the vulnerable edge UE through allocation of higher transmit powers to individual edge UE than to individual center UE [1], [2].

There is a growing need to model cellular networks using realistic assumptions about BS and UE positioning [3], [4]. This is because real network deployments do not always follow regular grid BS patterns and uniform UE placements. In [5], we have proposed a model for SFR that considers the irregular deployment of BS and derived the exact amounts of ICI received by different UE classes. In this paper, we present an optimization framework for the transmit power configuration in a homogeneous cellular network. A technique is proposed for the selection of the edge to center transmit power ratio based on a defined measure of fairness.

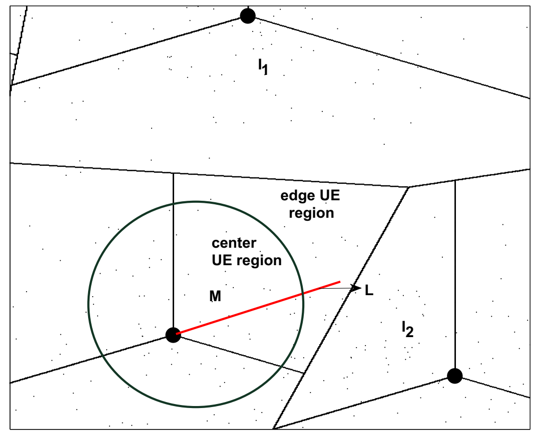

Fig. 1. System Model description.

II. System Model

We consider a neighbourhood of tri-sector macro BSs comprising a reference macro BS sector, M and a set, $I_m(\{I_1, I_2\})$, of interfering macro BS sectors, as shown in Fig. 1. Our analysis is carried out by considering the performance of UEs connected to M. Similar to [2], we approximate the performance of UEs within M by assuming a reference UE located at the center of gravity, CoG or central position of the region of M. If r is the coverage radius, let the distance between a CoG UE and M be λr, the distance between an interfering BS, I and M be γr, the angle (anticlockwise) between a line, L (through the center of the coverage of M) and the line connecting M to the CoG UE be θ and the angle between L and the line connecting M to I be ω. Therefore the distance, D, between the CoG UE and I will be $D = r\sqrt{\lambda^2 + \gamma^2 - 2\lambda\gamma(\cos(\omega - \theta))}$.

Power parameters: Fig. 2 shows the power and bandwidth allocation for the SFR algorithm where $E_M, C_M, E_{I,j}, C_{I,j}$ represent the bandwidth allocations to the edge region of M, center region of M, edge region of I_j and the center region of I_j, respectively. Let μ be the ratio of the edge transmit power, P_e, to the center transmit power P_c i.e.

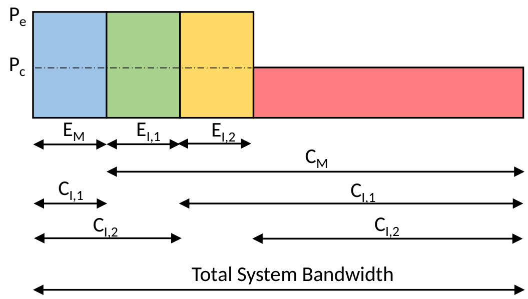

Fig. 2. Frequency/Power allocation for 3 neighbouring BS.

$\mu = \frac{P_e}{P_c}$. The power budget, P_t at any BS sector is given as $P_t = n_e P_e + n_c P_c$, where n_e and n_c are the number of edge and center UEs, respectively. Assuming the total number of UEs in the sector is n_t, $n_e + n_c = n_t$, and P_e, P_c can be derived as $P_e = \frac{\mu P_t}{n_e(\mu-1)+n_t}$ and $P_c = \frac{P_t}{n_e(\mu-1)+n_t}$, respectively.
Interference parameter: Let f_e and f_T be the total frequency allocations to the edge region of the BS and the total available frequency, respectively. Since the assigned frequencies overlap across the different BS regions as Fig. 2 shows, we calculate the different probabilities of interference. The probability that transmission from the edge region of any interfering BS, I will interfere with the center CoG UE in M is $\beta_1 = \frac{f_e}{f_T - f_e}$ while the probability of interference from the center region transmission of I to the center CoG UE is $\beta_2 = \frac{f_T - 2f_e}{f_T - f_e}$. The probability of interference from the edge and center regions of I to the edge CoG UE of M are 0 and 1, respectively.
Performance parameters: The SINR of the center CoG UE, $U^C_{m,i}$ connected to M is given as:

$$SINR^i_{m,c} = \frac{P_{c,i} h (\lambda_c r)^{-\alpha}}{\sigma^2 + \sum_{j=1, j \epsilon I_m}^{n^I_m} [(\beta_1 P_{e,j} + \beta_2 P_{c,j}) h (d_{i,j})^{-\alpha}]}, \quad (1)$$

where the transmit power from any arbitrary BS, a, to any arbitrary UE, b, is represented as $P_{a,b}$ and the distance between a and b is $d_{b,a}$. n^I_m, is the number of interfering macro BS in the set I_m. In addition, h, σ^2, α represent the fading component, noise component and the path loss exponent, respectively. We can also compute the SINR of the edge CoG UE, $U^E_{m,i}$ connected to M as:

$$SINR^i_{m,e} = \frac{P_{e,i} h (\lambda_e r)^{-\alpha}}{\sigma^2 + \sum_{j=1, j \epsilon I_m}^{n^I_m} P_{c,j} h (d_{i,j})^{-\alpha}}. \quad (2)$$

The capacity for $U^C_{m,i}$ is:

$$Cap^i_{m,c} = \mathcal{B}_m [\log_2(1 + SINR^i_{m,c})], \quad (3)$$

where $\mathcal{B}_m$ is the individual UE bandwidth, assumed to be the same for all UE because of the condition that M is fully loaded. Similarly, the capacity for $U^E_{m,i}$ is:

$$Cap^i_{m,e} = \mathcal{B}_m [\log_2(1 + SINR^i_{m,e})], \quad (4)$$

(1) and (2) can be expanded upon using the parameters specified earlier and assuming n_e and μ have the same values in all BS, we can reformulate (3) and (4) as:

$$Cap^i_{m,c} = \mathcal{B}_m [\log_2(1 + \frac{(\lambda_c r)^{-\alpha} (f_T - f_e)}{(\mu f_e + f_T - 2 f_e) \sum_{j=1, j \epsilon I_m}^{n^I_m} D^{-\alpha}_{c,j}})], \quad (5)$$

$$Cap^i_{m,e} = \mathcal{B}_m [\log_2(1 + \frac{\mu (\lambda_e r)^{-\alpha}}{\sum_{j=1, j \epsilon I_m}^{n^I_m} D^{-\alpha}_{e,j}})], \quad (6)$$

where $D_{c,j}$ and $D_{e,j}$ represent the distance between the jth interfering BS and the center and edge CoG UE, respectively. σ^2 is considered negligible because the interference component far exceeds that of noise.

III. Optimization problem

We formulate an optimization problem with a goal to providing an acceptable capacity of edge UE based on the transmit power. The task is to find a value of μ that guarantees fairness to a certain degree in different UE performance. Recall that the edge UE have been identified as the class of UE more exposed to ICI from neighbouring BS. Our goal is to devise a means by which the power parameters of a macro BS can be selected with an assumed guarantee of the power transmitted to the edge UE. An increasing value of μ causes the SINR and capacity of the CoG edge UE to increase while that of the CoG center UE decreases. We can obtain a point where $Cap^i_{m,c} = Cap^i_{m,e}$ by finding where $|Cap^i_{m,c} - Cap^i_{m,e}| = 0$. The optimization problem is given as:

$$minimize\ f(\mu) = [Cap^i_{m,c} - \psi Cap^i_{m,e}]^2 s.t\ \mu > 1. \quad (7)$$

ψ is the parameter added to control and guarantee a minimum performance measure for edge UE. $f(\mu)$ is a continuous differentiable single-variable function whose differential is given as:

$$\frac{d_f}{d_\mu} = -2 \times (A_1 (A_2 - A_3)) \times (B_1 + B2) \quad (8)$$

where $A_1 = \frac{B_m}{\ln 2}$,
$A_2 = \ln(1 - \frac{(\lambda_c r)^{-\alpha} (f_e - f_T)}{(f_T - 2f_e + f_e \mu) \sum_{j=1, j \epsilon I_m}^{n^I_m} D_{c,j}})$,
$A_3 = \psi \ln(\frac{(\lambda_e r)^{-\alpha} \mu}{\sum_{j=1, j \epsilon I_m}^{n^I_m} D_{e,j}} + 1)$,
$B_1 = \frac{B_m (\lambda_e r)^{-\alpha} \psi}{((\lambda_e r)^{-\alpha} \mu + \sum_{j=1, j \epsilon I_m}^{n^I_m} D_{e,j}) \ln 2}$ and
$B_2 = \frac{B_m (\lambda_c r)^{-\alpha} f_e (f_e - f_T)}{(\frac{(\lambda_c r)^{-\alpha} (f_e - f_T)}{f_T - 2f_e + f_e \mu} - \sum_{j=1, j \epsilon I_m}^{n^I_m} D_{c,j})(f_T - 2f_e + f_e \mu)^2 \ln 2}$
Setting (8) to 0 and solving numerically gives the solution to (7).

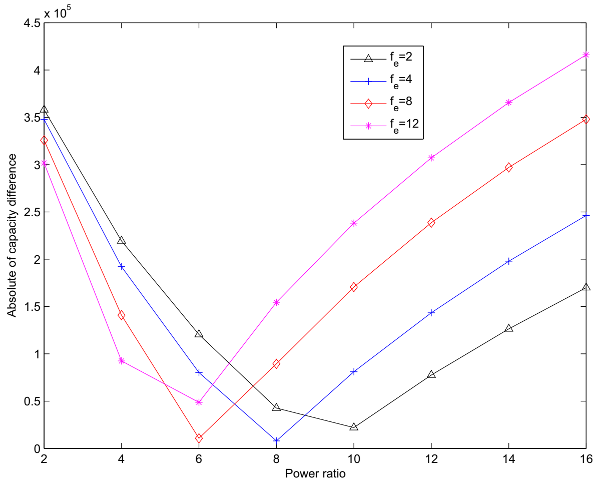

Fig. 3. Comparison of capacity differences for CoG UE

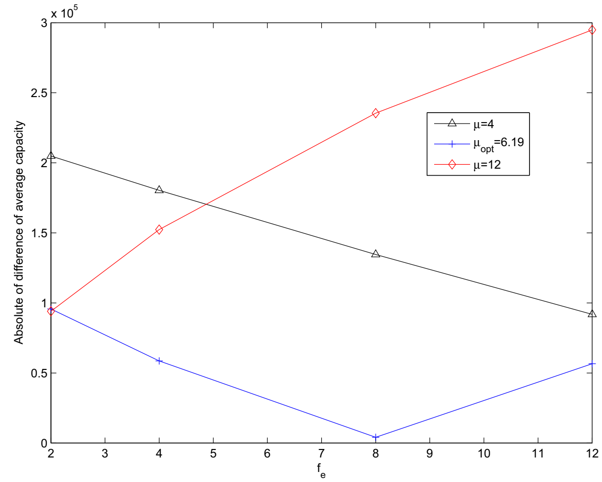

Fig. 4. Capacity differences with optimal μ

IV. Results and Analysis

The following assumptions were made for the system: $P_t = 43$dBm, $r = 0.5$Km, $h = 1, \alpha = 3, \lambda_c = 0.45, \lambda_e = 0.9, n_m^I = 2, \gamma_{m,1} = \gamma_{m,2} = \sqrt{3}, \theta_c = \theta_e = 0^o, \omega_{m,1} = 20^o, \omega_{m,2} = -35^o, n_e = 8, n_t = f_T = 48$. The system bandwidth is 10MHz and $\mathcal{B}_m = 180$KHz. Simulations were carried out using MATLAB software.

We first investigate the impact of μ on the performance difference between center and edge UE in an irregular homogeneous network. Fig. 3 shows the plot of $|Cap^i_{m,c} - Cap^i_{m,e}|$ against μ over different selections of f_e. The plots show that the absolute of the difference initially reduces with increasing μ, then approaches a minimum value, and then it starts rising. This can be explained from (5)-(7) which show that $Cap^i_{m,c} > Cap^i_{m,e}$ for lower values of μ and $Cap^i_{m,c} < Cap^i_{m,e}$ for higher values of μ. For any f_e, there is a value of μ that minimizes the absolute difference i.e where $Cap^i_{m,c} = Cap^i_{m,e}$. As expected, lower values of f_e would require higher values of μ for the edge UE performance to approach that of the center UE. This preliminary analysis shows the significant impact of μ on the performance of the two classes of UE. It also implies that the solution of (7) will provide better fairness in the system and improve the performance of the edge UE.

To verify the proposed optimization framework, a cellular network using the parameters specified was modelled in MATLAB. The SINR and capacities of all the center and edge UE were computed over different f_e and μ. The values of μ used were $4, 6.19(\mu_{opt})$ and 12 where μ_{opt} is the power ratio obtained from solving (7). ψ was selected as 1, which is the state that guarantees the highest fairness in performance between center and edge UE. This is the condition when the difference between the performance of $Cap^i_{m,c}$ and $Cap^i_{m,e}$ is minimal. Fig. 4 shows the plot of the absolute value of the difference of the average capacities of the center and edge UE. As observed, μ_{opt} gave the least difference for all cases of f_e. This proves the capability of the proposed framework in aiding the control of UE performance by specifying how much fairness (based on transmit power) should be allowed between different classes of UE.

V. Conclusion

In this paper, we presented an optimization framework for the transmit power parameter in SFR based cellular networks. The concept of the center of gravity user was adopted to approximate the overall UE performance. Closed-form expressions were derived for the performance of UE at the center and edge regions of the macro BS. An optimization framework that captures a fairness based system was presented. Results showed a guarantee for edge UE capacity enhancement through a greater control over the BS transmit power. In ongoing research, we are extending the framework to the case of Heterogeneous cellular networks.

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References

[1] A. S. Hamza, S. S. Khalifa, H. S. Hamza, and K. Elsayed, "A survey on inter-cell interference coordination techniques in ofdma-based cellular networks," *IEEE Commun. Surveys Tuts*, vol. 15, no. 4, pp. 1642–1670, Fourth 2013.

[2] O. G. Aliu, M. Mehta, M. A. Imran, A. Karandikar, and B. Evans, "A new cellular-automata-based fractional frequency reuse scheme," *IEEE Trans. Veh. Technol.*, vol. 64, no. 4, pp. 1535–1547, April 2015.

[3] A. Adejo and S. Boussakta, "Performance analysis of frequency reuse techniques under varying cellular network scenarios," in *2016 IEEE Wireless Communications and Networking Conference*, April 2016, pp. 1–6.

[4] D. Gonzalez, M. Garcia-Lozano, S. R. Boque, and D. S. Lee, "Optimization of soft frequency reuse for irregular lte macrocellular networks," *IEEE Trans. Wireless Commun.*, vol. 12, no. 5, pp. 2410–2423, May 2013.

[5] A. Adejo, S. Boussakta, and J. Neasham, "Interference modelling for soft frequency reuse in irregular heterogeneous cellular networks," in *2017 IEEE International Conference on Ubiquitous and Future Networks*, July 2017, pp. 1–6.