Load-Driven Resource Allocation for enhanced Interference mitigation in Cellular Networks

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***Abstract*—Cellular users are often considered to be uniformly distributed within the communication network for the purposes of simplified analysis. Based on this assumption, the inter-cell interference experienced by users has been handled using soft frequency reuse (SFR) techniques. However, in real networks, the distribution of users in the network regions are not uniform. Therefore, analysis for random deployment of users under SFR is essential for improved accuracy of analysis and better handling of interference. This research presents an SFR algorithm (Load-Driven SFR) that intelligently adjusts resource allocation parameters (base station bandwidth assignment) according to the load distribution in the network. Interference mitigation is enhanced and Load-Driven SFR outperforms several implementations of the standard SFR algorithm using fixed bandwidth allocation, especially for edge user's SINR (up to 3.2% improvement) and edge user's Capacity (up to 202% improvement).**

***Index Terms*—Resource allocation, Cellular networks, 5G networks, User distribution, Algorithm, Frequency reuse, Soft frequency reuse, Network Load, Simulation**

I. Introduction

Cellular communication has evolved tremendously and consistently for over five decades. There has been progression from the transmission of speech by large and cumbersome radio through fixed devices to the use of compact, handheld, wireless and mobile devices to transmit speech, texts and media. The development of more portable technology and better interconnection systems came with notable advances in networking of wireless communication and sustenance in its usage [1, 2].

There has been a characteristic growth in the number of connected devices with the smartphone taking the centre stage. In order to differentiate advances made in network architecture and device hardware, the revolutions have been christened as Generations (G) [2]. From the first generation to the fifth generation of cellular communication technologies which is currently being developed and implemented, defined radio frequencies and frequency reuse have been employed. This enables the provision of service to large number of subscribers while maximizing the available bandwidth. It also enables the creation of wide communication networks by fully integrating the advanced capabilities of the mobile phone [3-5]. The development of 5G technology is to provide solution to the exponential rise in the number of connected devices in modern cellular networks requiring more data rates that are beyond the theoretical upper cap of 200Mbps achieved by the 4G networks [4]. One distinctive feature of 5G is its intrinsic flexibility allowing the support of several use cases of the spectrum in an optimal manner [6]. Coupled with this, another technique deployed to achieve high data rate and Capacity in 5G is network densification. Densification is achieved by deploying more base stations (either macro or small) to increase user capacity and wider coverage [3].

However, the higher number of cells in the network introduces the challenge of inter-cell interference which can be mitigated by intelligent spectrum allocation using frequency reuse techniques. Fractional frequency reuse (FFR) and SFR techniques have been presented as effective ways to optimize spectrum and control the ICI in developing 5G networks. However, most of the previous works have not considered network load (the effect of the number, location and demand of users) in their frequency reuse algorithms. We therefore present an improved SFR algorithm that takes into consideration the user deployment in network regions before the base stations carry out bandwidth allocation. SFR is selected because it gives a better relationship between interference management and bandwidth utilization [7].

Related Work: Several frequency reuse strategies have been proposed to address the problem of bandwidth resource allocation for improved interference mitigation. A Multi-level SFR (ML-SFR) was presented in [5] where in each cell, the SFR algorithm is further divided; thereby having at least two SFR with the transmit power level divided accordingly. This approach achieves spectral efficiency (SE) improvement due to reduction of ICI. However, a uniform load distribution was assumed. In our earlier work in [7], a framework was presented for accurate modelling of cellular networks with SFR deployment but under the assumption of uniform user deployment. In [8], an enhanced fractional frequency reuse algorithm was proposed to mitigate the interference in femtocell networks by using the method of service area and frequency division.

In [9], the authors proposed a hybrid Soft Sectored Fractional Frequency Reuse (SSFFR), to analyse the uplink worst

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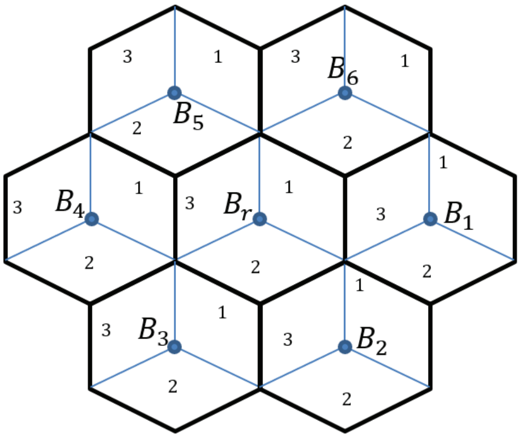

Fig. 1. Typical cellular network depicting base stations

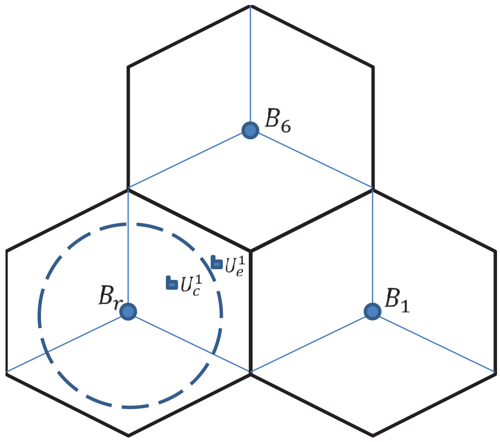

Fig. 2. Soft Frequency Reuse for three sectors including a Reference sector in B_r

case Signal to Interference power Ratio (SIR) while considering the effect of power control exponent, path loss exponent and inner radius. A novel fractional frequency reuse (FFR) based on dynamic user distribution is proposed in [10], where a macro cell is divided into two regions, i.e. the inner and outer regions. The authors show in [11] that Inter-cell Interference (ICI) is a significant obstacle which is degrading the efficiency of mobile cellular networks particularly for end users. Frequency reuse is an ICI synchronization technique which helps to mitigate ICI by assigning dissimilar frequency reuse factors based on its position to User equipment. This paper proposes a Self-organized resource allocation (SORA) framework that chooses the reuse factors randomly. The output of this strategy is configured using MATLAB and correlated with numerous reuse factor combinations. Results from simulation show improved efficiency for Cell Edge Users.

User Distribution: The importance of considering the User distribution for analysing cellular network performance has also been presented in literature. An early work in [12] showed three non-uniform user density models for analysing performance in typical CDMA implementation scenarios. These are the linear, exponential, and Gaussian models. The results in this paper provide additional insight into the performance of CDMA systems, and are useful for purposes of network planning and resource allocation. Furthermore, the authors in [13] developed a model for simulating CDMA systems by considering clustered and uniform user distributions. The effects of these distributions were then studied via a spatial analysis revealing that the outage mean values are similar while a higher standard deviation was obtained for the clustered compared to the uniform distribution. In [14], a WCDM system was investigated using a selected user distribution. Capacity and coverage were analysed for both uniform and non-uniform distributions. The authors in [15] also proposed a non-uniform user distribution model where user density is depended on the distance from users to their connected base stations.

II. System Model

A network model is considered where the improved SFR algorithm is deployed and tested. The model consists of several base stations arranged regularly to provide cellular network coverage for users in a defined geographical area as shown in Figure 1. A base station B_r is centrally placed as the reference base station. It is surrounded by six base stations, i.e $\{B_1, B_2, B_3, B_4, B_5, B_6\}$ offering interference to it and each other during transmission of signals in the downlink transmission channel. All base stations used in this model are Macro base stations. The coverage area of each of the base stations is designed to be hexagonal for simplicity of analysis. In order to study the behaviour of the network, the coverage area of each base station is divided into three sectors as seen in Figure 1. The base stations are separated from each other based on their coverage radius.

The deployment of cellular users is assumed to be random across the entire coverage area. This depicts a practical network architecture where user positions change at different moments. Each user connects to the base station from which it receives the highest signal strength.

III. Standard Soft Frequency reuse

A. *Coverage Division and User Classification*

In the conventional SFR algorithm, resource allocation guidelines describe how the bandwidth available in a base station is shared among its connected users in the downlink (DL). The SFR algorithm is carried by considering three close sectors from three neighbouring macro base stations. For example, Figure 2 shows Sector 1 from B_r, 2 from B_6 and 3 from B_1. The base station coverage area is divided into central and edge regions, depicted using the dotted circle in the reference base station. Consequently, users found in the central region are classified as central users (e.g U_c^1 as shown) while those in the edge region are called edge users (e.g U_e^1 as shown). All analysis of user performance is carried out in Sector 1 of B_r, the reference base station. The set

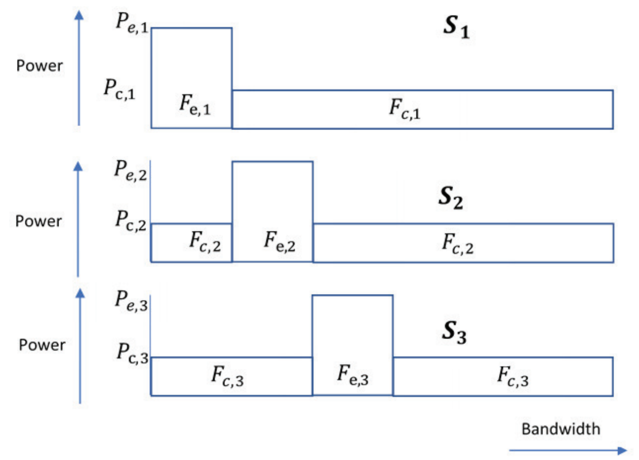

Fig. 3. Standard Downlink Resource allocation for Sectors in S_1, S_2 and S_3

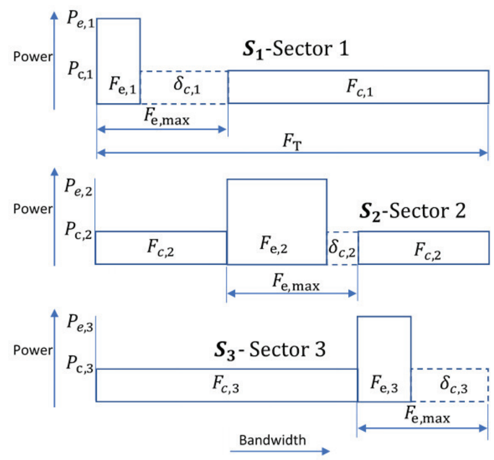

Fig. 4. Improved Downlink Resource Allocation for Sectors S_1, S_2 and S_3

of Interfering base stations to B_r is $\{B_1, B_2, B_3, B_4, B_5, B_6\}$, the set of Central cellular users in the reference sector is $\{U_c^1, U_c^2, ..., U_c^c\}$ and the set of Edge Cellular users in the reference sector is $\{U_e^1, U_e^2, ..., U_e^e\}$.

B. Bandwidth Allocation

Recall that each base station coverage area is divided into three sectors, each sector is further divided into two regions and occupied by center and edge users and the available bandwidth and power resources are deployed to the user groups using rules. Considering a sector, S_1 of the reference base station and sectors S_2 and S_3 of two interfering base stations, the resource allocation in the sectors is presented in Figure 3.

If the total bandwidth at each sector is denoted by F_t and the total power budget at each sector is denoted as P_t, then

$$F_t = F_{e,1} + F_{c,1} = F_{e,2} + F_{c,2} = F_{e,3} + F_{c,3} \tag{1}$$

where $F_{e,1}$ is the total bandwidth for edge users in Sector 1 and $F_{c,1}$ is the total bandwidth for center users in Sector 1.

$$\begin{aligned} P_t &= n_{e,1}P_{e,1} + n_{c,1}P_{c,1} \\ &= n_{e,2}P_{e,2} + n_{c,2}P_{c,2} = n_{e,3}P_{e,3} + n_{c,3}P_{c,3} \end{aligned} \tag{2}$$

where $n_{e,1}$ is the total number of edge users in Sector 1, $n_{c,1}$ is the total number of center users in Sector 1, $P_{e,1}$ is the transmitted power to each edge user in Sector 1 and $P_{c,1}$ is the transmitted power to each center user in Sector 1.

$P_{e,1}$ and $P_{c,1}$ are related by the power ratio constant μ:

$$P_{e,1} = \mu P_{c,1} \tag{3}$$

Performance Equations: An expression for SINR of any user located at the central part of any sector of the reference base station is derived as follows [7]:

$$SINR_{c,i} = \frac{P_{c,1} h d_{i,r}^{-\alpha}}{\left[\frac{P_{c,2}(F_{c,2}-(F_{e,1}+F_{e,2}))+F_{e,2}P_{e,2}}{F_{c,1}}\right] h d_{2,r}^{-\alpha} + \left[\frac{P_{c,3}(F_{c,3}-(F_{e,1}+F_{e,3}))+F_{e,3}P_{e,3}}{F_{c,1}}\right] h d_{3,r}^{-\alpha}} \tag{4}$$

where h is the fading component, $d_{i,r}$ is the distance between the user and the reference base station B_r, $d_{2,r}$ is the distance between the user and the interfering base station B_6 and $d_{3,r}$ is the distance between the user and the interfering base station B_1.

An expression for SINR of any user located at the edge part of any sector of the reference base station is derived as follows:

$$SINR_{e,i} = \frac{P_{e,1} h d_{i,r}^{-\alpha}}{P_{c,2} h d_{2,r}^{-\alpha} + P_{c,3} h d_{3,r}^{-\alpha}} \tag{5}$$

With a known bandwidth and SINR values, the Capacity of the base stations at any instant can be determined using the Shannon Capacity equation;

$$C = W \log_2 (1 + SINR) \tag{6}$$

where C is the Capacity (in bits/sec), W is the bandwidth (in Hz) and $SINR$ represents the users SINR value.

IV. Load-Driven Soft Frequency Reuse

This is an enhanced SFR scheme that considers user deployment. The key principle of the algorithm is to perform intelligent bandwidth allocation based on the user distribution in the reference sector. In the standard resource allocation algorithm shown in Figure 3, the following assumptions were made which serve as a limitation when user deployment is random: **1)** The size of the total center bandwidth in each of the sectors S_1, S_2 and S_3 is the same, i.e $F_{c,1} = F_{c,2} = F_{c,3}$. **2)** The size of the total edge bandwidth in each of the sectors S_1, S_2 and S_3 is the same, i.e $F_{e,1} = F_{e,2} = F_{e,3}$. **3)** The algorithm assumes that the number of users in Sectors S_1, S_2 and S_3 and within their various central and edge regions are always uniform which may not always be guaranteed. There could be situations in which the spread of users to the regions may differ significantly.

Based on these limitations, a new algorithm is hereby proposed. In order to account for the random redeployment of users in the various sectors of the base stations, this resource allocation algorithm is proposed. The following improvements have been implemented in the new SFR algorithm:

- A new parameter ($\delta_{c,i}$) has been added to make the sharing of the total bandwidth in each sector more flexible to the user distribution. This is shown in Figure 4. Each Sector of a base station has its total bandwidth, F_T available for reuse given as:

$$F_T = F_{e,i} + F_{c,i} + \delta_{c,i} \tag{7}$$

- Each sector has a maximum bandwidth allowed for the edge regions $F_{e,max} = \frac{1}{3}F_T$. NB: The bandwidth available to edge users in any part of the sector must be less or equal to the maximum bandwidth. i.e. $F_{e,i} \leq F_{e,max}$, also depicted in Figure 4.
- Any change in the number of users in any part of each of the sectors causes a corresponding change in the bandwidth available for reuse in that part of the sector, i.e. $n_{e,i} \propto F_{e,i}, n_{c,i} \propto F_{c,i}$. $\delta_{c,i}$ is intelligently allocated to the Central region based on the number of users in these areas. The information obtained from the distribution of the users is used to adjust the bandwidth allocation more intelligently thereby reducing the influence of interference.

However, the following assumptions are maintained from the standard SFR algorithm:

- The power allocation per user in all the edge regions, $P_{e,i}$, as well as all the Central regions, $P_{c,i}$ are assumed to be the same.
- The center ratio which is used for the classification of cellular users as central or edge users is also held constant.

Details of the Algorithm are presented in Algorithm 1.

V. Results and Discussion

A. Simulation Parameters

MATLAB was used to simulate the network scenario, by defining the network environment including the layout of the base stations and network users and running the bandwidth allocation algorithm. The base stations were arranged in hexagonal format. The reference base station is assumed to be placed at the origin (0,0), surrounded by six interfering base stations. The coordinate location for the interfering base stations are therefore [(0.433,0.75), (0.866,0), (0.433,-0.75), (-0.433,-0.75), (-0.866,0), (-0.433,0.75)], based on an assumed coverage radius of 0.5km. Table 1 has details of other base station parameters selected.

Edge User bandwidth for fixed SFR: For the case of the standard (Fixed) user SFR, several fixed number of bandwidth slots for the edge users were used, i.e [7,10,13,16]×180kHz. Results obtained in each case were used to compare with the proposed algorithm where bandwidth assignment to edge users is intelligently performed.

Cellular User parameters: User variation (random user deployment is the major feature of this project). The simulation of the user variation was achieved based on the following description:

- The same number of users is assumed for each simulation.
- However, the user classification into center and edge changes randomly.

Based on the base station coverage radius of 0.5km (r = 0.5km), the center user classification was varied 9 times between $0.5r$ to $0.9r$, i.e [0.250,0.272,0.294,0.317,0.339,0.361,0.383,0.406,0.428]km. This corresponds to the following percentage of edge users [69.4, 67.3, 51.0, 49.0, 36.7, 28.6, 18.4, 10.2, 2.0]%.

Algorithm 1 Load-driven SFR

Input: Three sectors (S_1, S_2, S_3), Total System Bandwidth ($F_T = \{f_1, f_2, f_3, ...f_N\}$), Maximum allowable edge bandwidth ($F_{e,max}$), Number of edge and center users per sector ($n_e = [n_{e,1}, n_{e,2}, n_{e,3}], n_c = [n_{c,1}, n_{c,2}, n_{c,3}]$)

Output: Bandwidth to edge and center users, i.e ($F_{e,1}$, $F_{e,2}$, $F_{e,3}$) and ($F_{c,1}$, $F_{c,2}$, $F_{c,3}$)

Stage 1: First allocation of Edge bandwidth for macro network

Divide the total bandwidth into 3 and assign each portion to the edge region of each of the three sectors, i.e $F_T = \left\{f_1, f_2, f_3, ...f_{N/3}\right\} \cup \left\{f_{N/3+1}, f_{N/3+2}, f_{N/3+3}, ...f_{2N/3}\right\} \cup \left\{f_{2N/3+1}, f_{2N/3+2}, f_{2N/3+3}, ...f_N\right\}$

Find the fraction of edge users in each sector, i.e $\frac{n_{e,i}}{n_{e,i}+n_{c,i}}$, for each sector S_i

Compare the fraction of edge users to the maximum allocated edge bandwidth and note the remaining (unused) bandwidth if any, i.e $R_i = F_{e,max} - \frac{n_{e,i}}{n_{e,i}+n_{c,i}}.\delta_{c,i}$ is then calculated and bandwidth assignment is made to the edge region accordingly.

Stage 2: Final allocation of Edge and Center bandwidths based on $\delta_{c,i}$

Determine the total remainder bandwidth across all sectors $\sum \delta_{c,i}$

Using R_i and $\sum \delta_{c,i}$, consider the sectors with under-allocated edge bandwidth and find the fraction of under-allocation.

Allocate more bandwidth to under allocated edge regions based on fraction of under allocation, and available remainder bandwidth.

Perform edge and center bandwidth allocation ($F_{e,1}, F_{e,2}, F_{e,3}, F_{c,1}, F_{c,2}, F_{c,3}$).

TABLE I
Summary of Base station parameters

Parameter	Value
Base station type	Macro base station
Base station radius	0.5km
Number of sectors per base station	3
Number of users per sector	49 (Full user deployment)
Number of bandwidth slots per base station	48
Transmit Power threshold to a user	1.2W
Power budget per base station	43W
Power ratio, μ	2.5

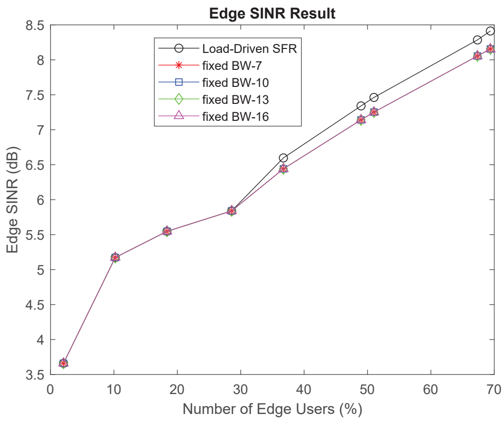

Fig. 5. Average Edge User SINR performance

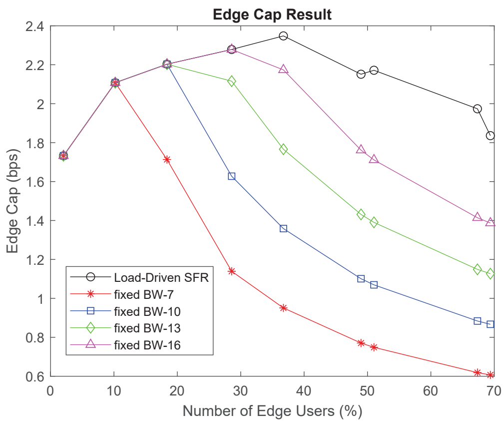

Fig. 6. Average Edge User Capacity performance

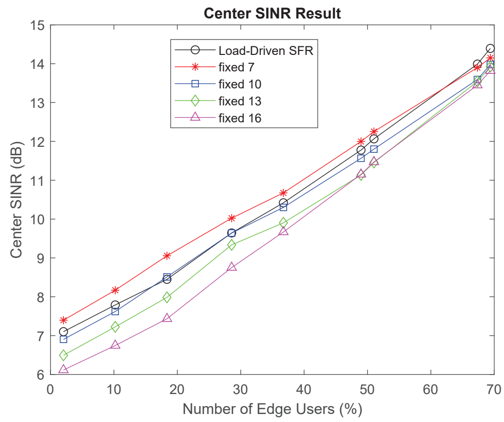

Fig. 7. Average Center User SINR performance

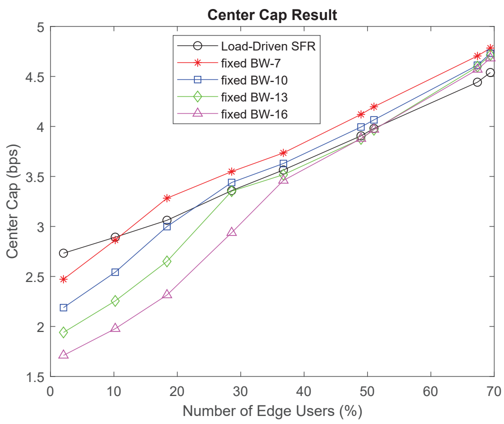

Fig. 8. Average Center User Capacity performance

B. Network Assumptions

The following assumptions were made for the network simulation: **1)** Only the dominant interfering base stations were considered, i.e the closest base station neighbours to the sector under consideration. **2)** The scheduling assumption is fair scheduling, i.e the channel conditions are not considered when allocating bandwidth to users. This guarantees a baseline testing of the algorithm performance without any external influence. **3)** Dense user deployment with center and edge users available in all cases of simulation. **4)** No antenna beamwidth considered. **5)** Same power parameters used in all macro base stations i.e power ratio and threshold.

C. Results

Edge User Performance: The results for average performance (SINR and Capacity) for edge users are presented when the proposed algorithm is applied in the network and compared with several fixed soft frequency reuse algorithm. The result for average SINR for edge users is shown in Figure 5. It can be observed that when the percentage of edge users is low, there is no difference in the results across all the algorithms. In addition, the results for all the fixed soft frequency reuse cases are the same always. However, the proposed algorithm (Load-driven SFR in the Figure) outperforms the fixed cases when the number of edge users increases to more than 30% of the total users in the sector. As much as 3.2% improvement is obtained.

The result for average Capacity for edge users is shown in Figure 6. It can be observed that the proposed algorithm (userSFR in the Figure) gives a better result in capacity of edge users than the fixed algorithm cases and this is especially when the number of edge users increases to more than 30% of the total users in the sector, similar to the case of SINR. As much as 202% improvement is obtained.

Center User Performance: The results for average performance (SINR and Capacity) for center users are presented in Figures 7 and 8. It can be observed that the best performance for most cases is the fixed-7 algorithm which has the lowest edge bandwidth allocation (and the highest center bandwidth allocation). The proposed algorithm performs averagely for SINR and Capacity compared to the fixed cases. The proposed algorithm however performs as the best algorithm for SINR (i.e 1.73% - 4.16% improvement) when the number of edge users is very high (70% of users), but the worst algorithm

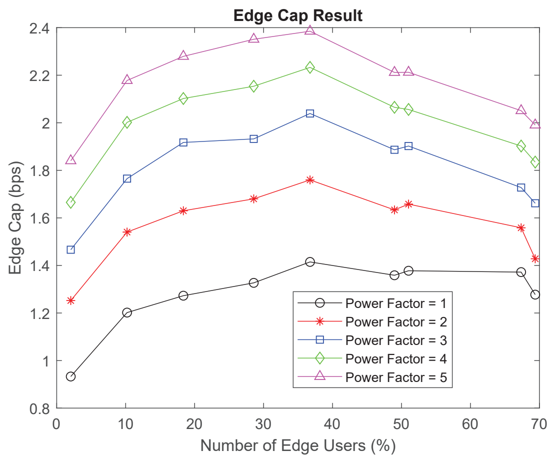

Fig. 9. Impact of Power ratio on Average Edge Capacity performance

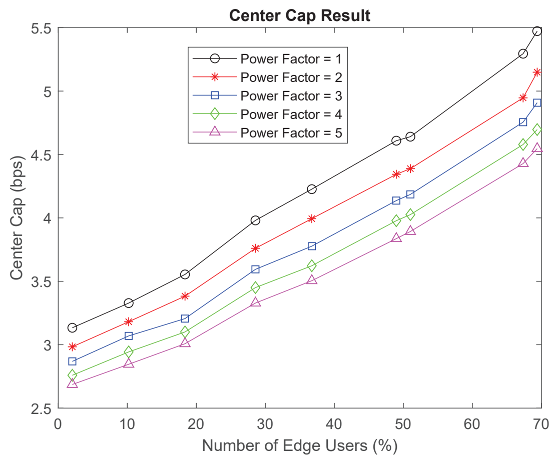

Fig. 10. Impact of Power ratio on Average Center Capacity performance

for Capacity in that case. It is important to note that even though the performance for Center users is not the best for capacity, the gap in performance is minimal, and the focus of the proposed algorithm is mainly to improve the performance of edge users which are the most affected by interference.

Effect of Power Ratio: The final set of results which are presented in this section show a deeper analysis of the algorithm based on observed Capacity according to variation in the power ratio. As expected, It can be observed from Figure 9 that the higher the power ratio, the better the Capacity performance for edge users and from Figure 10, the higher the power ratio, the lower the Capacity performance for center users. Figure 9 further shows that the maximum Capacity for Edge users occurs when the percentage of edge users is between 30% and 40%.

VI. Conclusion

In this Paper, cellular networks have been considered and analysed with the realistic assumption of non-uniform user distributions. Furthermore, an improved SFR algorithm called Load-Driven SFR has been presented. It intelligently adjusts resource (bandwidth) allocation according to the load distribution in the network regions. Neighbouring base stations use the information of user distribution in their adjacent sectors to allocate bandwidth based on demand in a flexible manner. When compared with several fixed SFR algorithms, the algorithm outperforms them in the results for average edge user SINR and average edge user capacity, giving up to 3.2% improvement and up to 202% improvement respectively.

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