The 11th International Conference on Communications, Circuits and Systems

Capacity Analysis and Hybrid Power Allocation for Multi-cell 5G Networks

Mingjun Ying and Shuyu Wang
School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications
Chongqing 400065, China
2019214568@stu.cqupt.edu.cn

***Abstract*—With the evolution of wireless communication, faster mobile data traffic is continuously increasing, boosting the demand for spectrum resources. It is essential to utilise the bandwidths efficiently and optimise the power allocation scheme intelligently to achieve higher capacity in the cellular network. This study aims at finding a hybrid power allocation method with fast, flexible and intelligent supply to meet the requirements of potential users. By applying the Integer frequency reuse (IFR), Simultaneous Water-Filling (SWF) and Forward-looking Water-Filling (FWF), this study analyses the capacity of each algorithm in a multi-cell network. After that, Monte-Carlo simulations are conducted to quantify which one obtains the highest capacity among these methods. Simulation results reveal that the capacity of the FWF+IFR3 was 3% higher than the SWF+IFR3 and 23% higher than the IFR1+IFR3. Furthermore, by applying the proposed algorithm for Soft Frequency Reuse (SFR) scenario, the network capacity is found to be smaller than the strict Fractional Frequency Reuse (sFFR) scenario but still greater than applying a conventional algorithm for both scenarios.**

***Index Terms*—Fractional Frequency Reuse, Integer Frequency Reuse, Forward-looking Water-Filling, Soft Frequency Reuse**

I. INTRODUCTION

The booming data transmission leads to a rapidly increasing demand for data services with limited power and spectrum resources. Therefore, it would be of great significance to utilise the spectrum resources efficiently and adjust the current power allocation method to improve the energy efficiency and achieve higher capacity in a cellular network. The fifth-generation (5G) wireless systems relieve the increasing stress of current data service with various techniques [1]. 5G cellular wireless network mainly aiming at providing high data rates, increasing the base station (BS) capacity, improving users quality of service (QoS), and reducing the energy consumption [2]. The heterogeneous cellular network is considered a robust network architecture proposed in 5G to improve spectrum and energy efficiency [3].

Among all these heterogeneous cellular networks, the basic structure is the hexagonal grid for the BS. And by applying frequency reuse methods, the utilisation of spectrum resources will be more efficient and serve a larger area with these methods. While the frequency reuse methods allow a wireless communication network to allocate the same frequency channels to more than one cell, the integer frequency reuse (IFR) scheme proposed for GSM systems (reuse factor equals 3) lower the intercell interference compared with the IFR1 method. In the meantime, only a third of these spectral resources are allocated for each cell. And even if we apply the IFR1 scheme in which all the spectral resources are used for each cell, interference at the cell edge might be critical due to the co-channel interference [4].

The Fractional Frequency Reuse (FFR) and Soft Frequency Reuse (SFR) schemes [9], [13] have been evaluated as inter-cell interference (ICI) mitigation methods in a two tier Orthogonal Frequency Division Multiple Access (OFDMA) based multi-cell deployed next generation wireless network [5], [7], with the target of enhancing the spectral efficiency of wireless networks by allocating each cell to its resources in such a way that the ICI in the multi-cell OFDMA network is reduced [6].

As for FFR, sFFR [8] and SFR are the most common FFR deployment methods. While FFR may be used in both the uplink and the downlink, this research mainly concentrates on the downlink scenario.

In this paper, we propose hybrid fractional frequency reuse (HFFR) power allocation method based on the forward-looking game water-filling (FWF) and simultaneous water-filling (SWF) for a multi-cell network to achieve higher capacity in a sFFR and SFR system. The major contributions of this paper are summarized as follows:

- A construction method for an multi-cell network has been introduced that allows an arbitrary number of cells.
- Hybrid Fractional frequency reuse methods combining SWF, FWF and IFR are proposed to get high network capacity and serve as many users as possible.
- By considering various combinations of the algorithm for the cell-centre and the cell-edge, the comparison between the sFFR and SFR schemes is per-formed depending upon the obtained analytical expressions in Section III, and thereafter validated through Monte-Carlo simulation.

The rest of this paper is organized as follows. The system model and the mathematical derivations are presented in Section II. The numerical results for network capacity simulation are presented in Section III. Section IV concludes the work in this paper.

II. SYSTEM MODEL

In this paper, a downlink hybrid fractional frequency reuse model for an M-cell cellular network is considered. The same transmit power, p_1 is assumed for all the users at the cell centre, while the same transmit power, p_2 is assumed for the user equipment (UE) at the cell edge. Here, the transmit power is from each BS to the user equipments (UEs). Besides, we assume each user can access to all the frequency channels from

978-1-6654-6988-3/22/$31.00 ©2022 IEEE

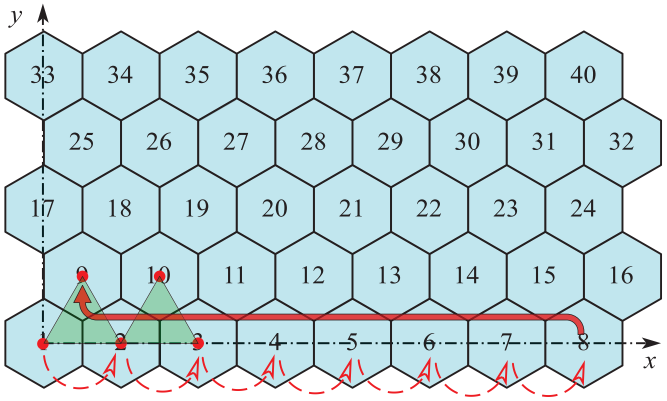

Fig. 1. A method of multi-cell generation.

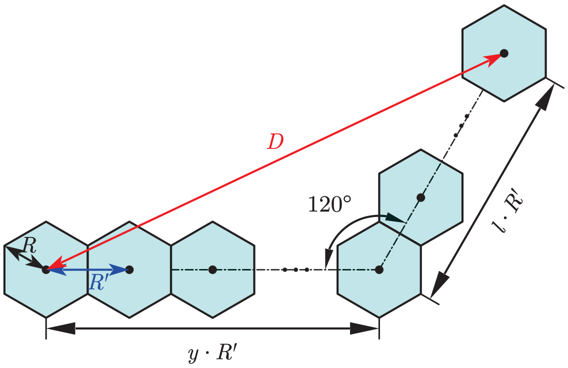

Fig. 2. The schematic of finding the same group of cells.

the cell's BS. When the users in each cell centre use OFDMA, we assume there is no interference power among different frequency channels because of the limited transmit power and the relatively long distance between the cells which share the same frequency channels. For general trade-off analysis of communication system designs, a simplified path-loss model that captures most of the essence of signal propagation is useful. Therefore, it will be utilised for the following analysis. This paper analysed the statistical performance of the network capacity in sFFR and SFR scenarios.

Here, we define a set $m = \{1, 2, \ldots, M\}, i, j \in m, i \neq j$.

Considering the transmit power of each BS is finite, therefore, the received power of each user in the same cell have a threshold. Also, motivated by [12], we consider following constraints.

Constraint. 1 The maximum received power threshold of each user in the same cell is given by

$$\sum_{f=1}^{N_i} p^f \leq p_{\max}, \tag{1}$$

where p^f is the transmit power for frequency channel f, and $p_{\max}$ is the threshold of one user, N_i is the number of frequency channel in cell i.

Constraint. 2 The maximum transmit power threshold of each base station is given by

$$\sum_{u=1}^{U_i} \sum_{f=1}^{N_i} p^{u,f} \leq P_{\max}, \tag{2}$$

for $u = \{1, 2, \ldots, U_c\}$, $f = \{1, 2, \ldots, N_i\}$, where U_i is the user number of cell i, and $P_{\max}$ is the threshold of BS's power.

A. The construction of an M-cell network

To construct an M-cell network, I initially start with a network consists $M = R(row) \times C(column)$ cells. The basic idea of this structure is to add a cell next to the existing partition to form an approximate rectangle. And there are three main principles of this method, which can be seen from figure1 that add the next cell from left to right, from bottom to the top and using the mathematical relation between adjacent cell centres. Fig. 1 aims at illustrating the general pattern of the M-cell network. From the bottom dash line, can we see that the principle is from left to right. After that, the green triangle shows the relation between each cell centre and also help to find the relation between the odd and even rows.

III. THE STATE-OF-THE-ART ALGORITHMS

A. Integer Frequency Reuse (IFR)

As for the cellular network, frequency reuse is a fundamental technology, and most frequency allocation methods are derived from traditional frequency reuse for hexagonal cells. Therefore, it would be necessary to find out how does frequency reuse functioning. Frequency Reuse Factor (FRF) is a crucial parameter for Integer Frequency Reuse. For different FRF that contributes to different frequency reuse patterns, we always use N to represent this factor.

As illustrated in Fig. 2, R is the cell radios; the distance between adjacent BS is $R' = \sqrt{3}R$, and the distance between two cells in the same frequency reuse group is D, and the FRF can be derived as

$$N = \frac{D^2}{3R^2}. \tag{3}$$

Also, based on cosine law for sides, we can get

$$D^2 = 3R^2(y^2 + yl + l^2). \tag{4}$$

Therefore,

$$N = y^2 + yl + l^2, \tag{5}$$

$$D = \sqrt{3N}R. \tag{6}$$

Longer distance leads to more significant path loss, and the power of the received signal or the co-channel interference can be demonstrated as

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}, \tag{7}$$

where P_t represents the transmit power; $G_t(G_r)$ represents the transmit (receive) antenna gain; λ represents the wavelength, and d represents the distance.

More generally,

$$P_r = P_0 d^{-\alpha}, \tag{8}$$

where P_r denotes the UE's received power; P_0 denotes the BSs source power; d denotes the distance between the user and

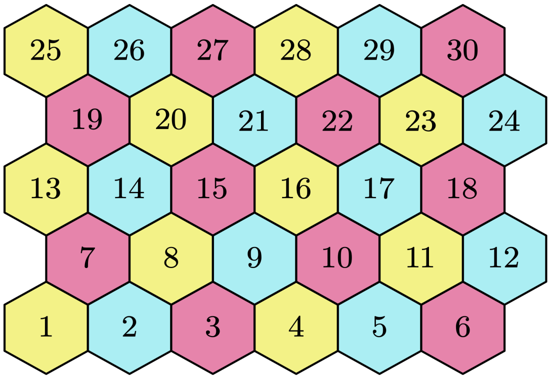

Fig. 3. Frequency allocation scheme for IFR3 in a 30-cell network.

the BS; and α denotes the path loss exponent, which varies corresponding to the environment.

After the selection, the same frequency batch will be allocated for those cells in the same group. Then, to explain the frequency with different reuse factors, Fig. 3 use different colours to represent different groups which help explain the schematic of the frequency allocation with FRF equals 3 for a 30-cell network.

In multi-cell networks, the IFR1 and IFR3 methods are frequently employed. Modern cellular networks primary goal is to attain a high spectral efficiency with FRF equals one. However, the IFR1 system has significant flaws, such as inter-cell interference, which restricts overall network capacity and leads to high interference and low data rates for consumers in cell-edge regions. The IFR3 technique divides the system bandwidth into three sub-band groups. Each cell is assigned a group of frequencies that is distinct from the sub-bands given to its neighbours.

To develop a method to increase the average capacity, the calculation for the network capacity is vital. For IFR1, we analyse an M-cell network, the capacity for the frequency channel f in the cell i can be calculated by

$$C_f^{i,u}=\sum_{f=1}^{N_i}\log_2\left(1+\frac{|h_{i,i}|^2 p_i^u}{\sum\limits_{j=1}^{M}\rho_{j,i}|h_{j,i}|^2 p_j+\sigma^2}\right)(i\neq j), \quad (9)$$

where $h_{i,i}$ is the channel coefficient from the BS i to its user, and $h_{j,i}$ is regarded as the channel coefficient from the BS j to users severed by another BS i, which share the same frequency channels as BS j; P_i is the transmit power from the BS i; P_j denotes the transmit power from the BS j; σ^2 is the noise power, and in the following system, the noise is all considered as the zero-mean white Gaussian noise; $\rho_{j,i}$ is the parameter that adjusts the amount of interference from cell j to cell i, which can be calculated by $\rho_{j,i}=D_{j,i}^{-\alpha}$, $D_{j,i}$ is the central distance between cell j and i. Thus, the capacity of a network using IFR can be derived as

$$C_{\text{IFR}}=\sum_{i=1}^{M}\sum_{u=1}^{U_i}C_f^{i,u}, \quad (10)$$

When we use IFR1, each cell will be allocated with all frequency channels. However, since the adjacent cell will have extensive interference, the total capacity will be relatively low. In contrast, if the FRF gets more prominent, each cell will have less interference because fewer channels are allocated for each cell. The cells that share the same frequency channel will have less interference, and the capacity will increase.

The Integer Frequency Reuse provide one unique channel for each user in the same cell to prevent co-channel interference in the same cell. However, this frequency allocation method is not flexible enough. The high Signal-to-Interference and Noise Ratio (SINR) can only be achieved by applying a larger FRF, which will decrease the number of available channels for each cell. And it would be unacceptable when there exist too many users per cell that cannot be served.

B. Fractional Frequency Reuse (FFR)

Due to the limited spectrum resources, the traditional frequency reuse method can hardly serve the increasing number of users. But Fractional Frequency Reuse (FFR) is a wise allocation method based on the idea of applying different frequency reuse methods for the cell centre and cell edge, respectively. Every cell uses OFDMA technology, with BSs located at the cell centre. There is no interference between users accessing orthogonal resources in the cell since the spectrum resources are split into a series of orthogonal subcarriers distributed to various users [13]. An FFR method is used to differentiate each tiny region in order to enhance the systems spectral efficiency and decrease cell interference. IFR would generally have less interference when the cell centre uses a minor FRF, and the cell edge uses a more prominent FRF.

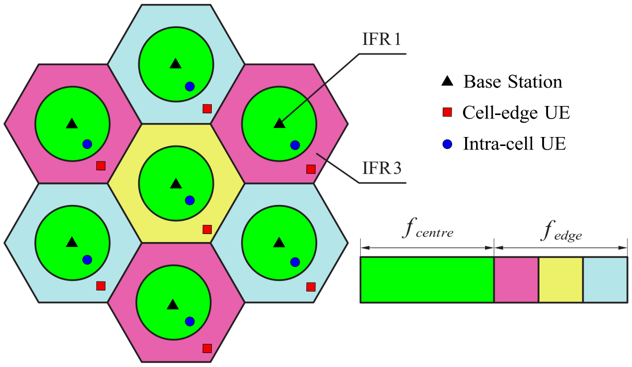

Fig. 4. Strict FFR for IFR1+IFR3 in a 7-cell network.

Fig. 4 demonstrates a sFFR scenario that applies IFR1 for the cell centre and IFR3 for the cell edge in a typical 7-cell network. Each colour represents a defined group of the frequency channel, and the frequency channel varies in each cell centre and edge. P_1 and P_2 denotes the average power allocation for each user at the cell centre and the cell edge.

On the right side, f_{centre} denotes the spectrum allocated for all cell centres, and f_{edge} is the spectral resources for cell edge. As for sFFR, here is no overlap between f_{centre} and f_{edge}. Therefore, there exists no co-channel interference between the cell centre and cell edge.

The capacity of all cell centres in the network is given by

$$C_{\text{centre}} = \sum_{i=1}^{M} \sum_{u=1}^{U_i^1} \sum_{f=1}^{N_i} \log_2 \left(1 + \frac{|h_{i,i}|^2 p_1^f}{\sum\limits_{j=1}^{M} \rho_1^{j,i} |h_{j,i}|^2 p_1^f + \sigma^2} \right), \tag{11}$$

The capacity of all cell edges in the network is given by

$$C_{\text{edge}} = \sum_{i=1}^{M} \sum_{u=1}^{U_i^2} \sum_{f=1}^{N_i} \log_2 \left(1 + \frac{|h_{i,i}|^2 p_2^{u,f}}{\sum\limits_{j=1}^{M} \rho_2^{j,i} |h_{j,i}|^2 p_2^{u,f} + \sigma^2} \right), \tag{12}$$

where U_i^1 denotes the number of users at the cell centre of cell i and U_i^2denotes the number of users at the cell edge of cell i. It is noteworthy that $\rho_1^{j,i}$ and $\rho_2^{j,i}$ are path loss matrixes with the same dimension but different values because the cell edge applies the IFR3 and will have no co-channel interference with the adjacent cell.

And for the entire network, the capacity can be derived as

$$C_{\text{FFR}} = C_{\text{centre}} + C_{\text{edge}}. \tag{13}$$

As we already define the capacity for sFFR scenario, the frequency channel can be utilized more efficiently by applying SFR, allowing the same group of frequencies allocated for both the cell centre and the cell edge in the same cell.

Then, for the SFR scenario, we have

$$\begin{aligned} C_{\text{SFR}} &= \sum_{i=1}^{M} \sum_{u=1}^{U_i} \sum_{f=1}^{N_i} \log_2 \left(1 + \frac{|h_{i,i}|^2 p_i^{u,f}}{I_1 + I_2 + \sigma^2} \right), \\ I_1 &= \sum_{j=1}^{M} \rho_1^{j,i} |h_{j,i}|^2 p_1, I_2 = \sum_{j=1}^{M} \rho_2^{j,i} |h_{j,i}|^2 p_2^{u,f}, \end{aligned} \tag{14}$$

where $p_t^{i,u}$ denotes the transmit power from cell i's BS to its user u, when the user is at cell centre p_t equals to p_1, for those at the cell edge, p_t equals to p_2^u. Besides, $\rho^{j,i}$ is the path loss matrix from cell j to cell i, and I_1 is the interference power from all cell centres, I_2 is the interference power from the cell edges that share the same frequency channels.

Although the FFR and SFR soften the weakness of not having enough frequency channel for the cell centre, it is still not flexible enough to deal with the increasing data requirements. To reduce the tremendous amount of interference in each cell centre. Therefore, it is necessary to apply other methods to decrease the interference and achieve higher network capacity at the same time.

C. Description of Simultaneous Water-filling (SWF)

Consider a multi-user frequency allocation scenario, we can use Simultaneous Water-Filling power allocation to allocate each frequency channel's power for each user intelligently, and suppose $H_i^{u,f}$ is the channel coefficient for each frequency channel. The capacity of user u in cell i is given by

$$C_i^u = \sum_{f=1}^{N_i} \log_2 \left(1 + \frac{p_i^{u,f} |H_i^{u,f}|^2}{\sigma^2} \right), \tag{15}$$

where $p_i^{u,f}$ denotes the power allocated for one particular frequency channel f in cell i for user u. Based on the above model, the total capacity with constraining for one user is given by

$$\begin{aligned} \max_{\{p_i^{u,f}\}} \; & C_{\text{SWF}}^u = \sum_{f=1}^{N_i} \log_2 \left(1 + \frac{p_i^{u,f} |H_i^{u,f}|^2}{\sigma^2} \right), \\ \text{s.t.} \; & \sum_{f=1}^{N_i} p_i^{u,f} \le P_{\max}. \end{aligned} \tag{16}$$

Using the Lagrange multiplier method in [11] can help solve the maximisation question in (16)

$$\mathcal{L} = \sum_{f=1}^{N_i} \log_2 \left(1 + \frac{p_i^{u,f} |H_i^{u,f}|^2}{\sigma^2} \right) + \lambda \left(\sum_{f=1}^{N_i} p_i^{u,f} - P_{\max} \right), \tag{17}$$

where λ represents the Lagrange multiplier param.

For $\forall f$, set $\frac{\partial \mathcal{L}}{\partial p_i^{u,f}} = 0$, $\frac{\partial \mathcal{L}}{\partial \lambda} = 0$, then we have

$$p_i^{u,f} = \left(\frac{1}{\lambda} - \frac{\sigma^2}{|H_i^{u,f}|^2} \right)^+. \tag{18}$$

And the water-level $\frac{1}{\lambda}$ is the solution that satisfies

$$\sum_{f=1}^{N_i} \left(\frac{1}{\lambda} - \frac{\sigma^2}{|H_i^{u,f}|^2} \right)^+ = P_{\max}. \tag{19}$$

where $(x)^+$ equivalent to $\max\{0, x\}$.

A more sophisticated method for a larger network with more users can be derived as a loop, which can help find the best power allocation scheme for all the users. More general, the capacity for each user will be calculated at first considering the co-channel interference, then repeat the calculation until its convergence, then it will be the final power allocation scheme.

IV. THE PROPOSED ALGORITHMS

A. Forward-looking Water-filling(FWF)

Forward-looking Water-filling constructs a self-optimising OFDMA cognitive radio network that approaches forward-looking equilibrium(FE)[10], which have no co-channel interference because the channels are orthogonal.The power allocation for user u at time t is updated by (20) using the previous power allocation information,

$$\begin{aligned} p_u^t[f] &= \left(w_u^t - \frac{\left(c_u^t[f]\right)^2 + \varphi_u^t[f] \left(p_u^{t-1}[f]\right)^2}{c_u^t[f] - \varphi_u^t[f] p_u^{t-1}[f]} \right)^+, \\ \varphi_u^t[f] &= -\sqrt{\frac{c_u^t[f]}{2c_u^t[f] + p_u^{t-1}[f]}} \quad \forall u. \end{aligned} \tag{20}$$

where $c_u[f] \triangleq \sigma_u[f] + I_u[f]$ corresponds to the overall noise on the frequency channel f for user u. And the power allocation is based on the forward-looking. In particular, a cognitive transmitter may choose to allocate more power on its good subcarriers to boost its capacity but will interfere with other users more on these sub-carriers. Based on the above power updating scheme, the network capacity using FWF for user u is

$$\begin{aligned} \max_{\{p_i^{u,f}\}} \ & C_{\text{FWF}}^u = \sum_{f=1}^{N_i} \log_2 \left(1 + \frac{p_u^t[f] |H_i^{u,f}|^2}{\sigma^2}\right), \\ \text{s.t.} \ & \sum_{f=1}^{N_i} p_i^{u,f} \leq P_{\max}. \end{aligned} \tag{21}$$

As for the entire network, the capacity maximization problem can be formulated as

$$\begin{aligned} \max_{\{p_i^{u,f}\}} \ & C_{\text{FWF}} = \sum_{i=1}^{M} \sum_{u=1}^{U_i} C_{\text{FWF}}^u, \\ \text{s.t.} \ & \sum_{f=1}^{N_i} p_i^{u,f} \leq P_{\max}. \end{aligned} \tag{22}$$

B. SWF(FWF)+IFR3

As for scenarios, most of the users are at the cell centre, and the conventional integer frequency reuse can hardly satisfy many users. Then we may use the SWF or FWF to solve such problems. However, using the Water-Filling allocation will cause significant interference between each cell. Therefore, we propose applying FWF or SWF at the cell centre and applying IFR3 at the cell edge can decrease the co-channel interference between adjacent cells and simultaneously serve more users. As we already demonstrate the sFFR in figure 4, we will illustrate the SFR using SWF(FWF) and IFR3.

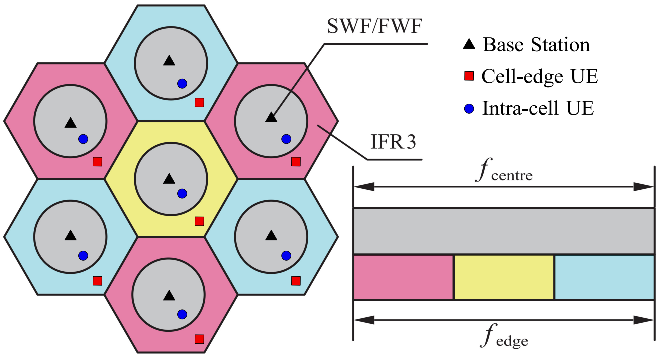

Fig. 5. SFR for SWF(FWF)+IFR3 in a 7-cell network.

Fig. 5 shows a scenario that the f_{centre} contains all the frequency channel and f_{edge} has occupied one-third of all frequencies that have no overlap between each other. To be more general, they can be derived as

$$\begin{aligned} f_{\text{centre}} &= \{f_1, f_2, \ldots, f_{N_i}\} \\ f_{\text{edge}} &= \left\{ \begin{array}{c} f_1, f_2, \ldots, f_{\frac{N_i}{3}} \\ f_{\frac{N_i}{3}+1}, f_{\frac{N_i}{3}+2}, \ldots, f_{\frac{2N_i}{3}} \\ f_{\frac{2N_i}{3}+1}, f_{\frac{2N_i}{3}+2}, \ldots, f_{N_i} \end{array} \right\} \end{aligned} \tag{23}$$

where f_{centre} contains the frequency channels from f_1 to f_{N_i}, f_{edge} contains three groups of frequency channels which can be allocated for cell-edge. Also, the SFR can serve more users than sFFR with the same frequency channel by sacrificing some network capacity.

In this paper, we design a iterative-based hybrid power allocation algorithm, as shown in Algorithm 1.

Algorithm 1 Proposed hybrid power allocation algorithm

```
Initialize system parameters $M$, $P_{\max}$, $N$, $U$, $p_{\max}$, $\rho$, $h$, $\sigma^2$
Set the maximum iteration times $T_{\max}$ and the convergence accuracy $\delta$, set the initial iteration index $t = 0$.
while $\sum_{u=1}^{U_i} \sum_{k=1}^{N_i} \left|p_u^{t+1}[k] - p_u^t[k]\right| \geq \delta$ and $t \leq T_{\max}$ do
    Calculate $p_u^t[k]$ using (18) or (20) for all the cell centre.
    Calculate the capacity in all the cell centre,
        $C_{\text{centre}} = \sum_{i=1}^{M} \sum_{u=1}^{U_i} \sum_{f=1}^{N_i} \log_2 \left(1 + \frac{p_u^t[f] |H_i^{u,f}|^2}{\sigma^2}\right).$
    Calculate the capacity in all the cell edge,
        $C_{\text{edge}} = \sum_{i=1}^{M} \sum_{u=1}^{U_i^2} \sum_{f=1}^{N_i} \log_2 \left(1 + \frac{|h_{i,i}|^2 p_2^{u,f}}{\sum_{j=1}^{M} \rho_2^{j,i} |h_{j,i}|^2 p_2^{u,f} + \sigma^2}\right).$
    Calculate the overall network capacity: $C_{\text{FFR}} = C_{\text{centre}} + C_{\text{edge}}$.
    $t = t + 1$.
end while
```

First, the algorithm find the optimal values of all variables of (20) or (21) in each iteration. After that, the network capacity can be calculated based on the power allocation scheme. And to find the highest capacity, we get into the next iteration with former information until it converges.

V. SIMULATION RESULTS

In this section, simulation results are provided to verify the performance of the proposed algorithm. The results of the network capacity can be valued as the criterion for the performance of different allocation schemes. We consider a 30-cell network and assign 6 frequency channels to both the cell centre and the cell edge, and use poisson distribution to generate the user number of each cell, and each user's location was generated using poisson point processes. The radius of the cell centre and cell edge is 150 m and 200 m, since the 200 m cell radius has weaker interference but has lower spectral efficiency in most cases [14]. Other simulation parameters are given as follows: $U_c = 12$, $p_{\max} = 35.2$ dBm, $P_{\max} = 46$ dBm (with 12 UEs) [15], $\alpha = 3$, $T_{\max} = 300$.

Fig. 6 provide a complete comparison between FWF+IFR3, SWF+IFR3, IFR1+IFR3. It shows the combination of FWF and IFR3 has the highest capacity for the entire range of the SNR. And both SWF+IFR3 and FWF+IFR3 are higher than IFR1+IFR3. Specifically, the capacity of SWF+IFR3 is 20% higher than IFR1+IFR3, and FWF+IFR3 has a 3% improvement compared to SWF+IFR3. Also, the simulation results reveal that with the same amount of frequency channels, the FWF+IFR3 can reach a higher capacity and serve more users simultaneously.

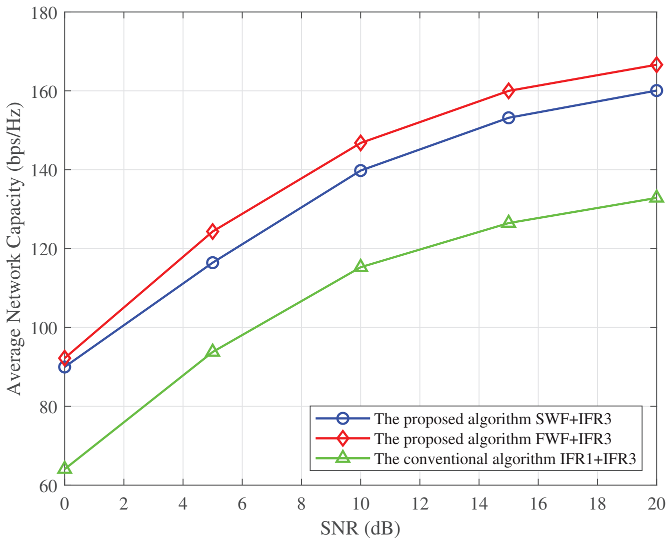

Fig. 6. Capacity of different hybrid power allocation schemes.

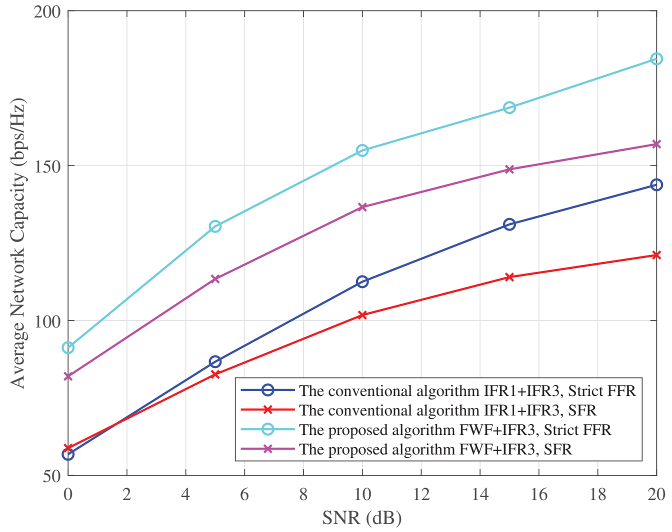

Fig. 7. Comparison between sFFR and SFR in capacity.

Fig. 7 presents the comparison between sFFR and SFR for a 30-cell network's capacity, which shows the FWF+IFR3 have reached the highest capacity, and its SFR is also greater than IFR1+IFR3 using sFFR. Besides, the sFFR has a better performance than SFR in capacity since it has less co-channel interference, leading to decreasing capacity. When the SNR is less than 5dB, the sFFR and SFR of IFR1+IFR3 have a slight difference in capacity because IFR distributes one frequency channel per user.

VI. CONCLUSION

In this paper, the average capacity of an M-cell network for different hybrid frequency reuse methods has been analysed in idealistic downlink sFFR and SFR scenarios, including IFR1+IFR3, SWF+IFR3 and FWF+IFR3. Initially, we developed a method of generating an M-cell network. Then, based on the theory of IFR, SWF and FWF, we studied the hybrid FFR power allocation scheme to find a relatively effective method that can provide a high network capacity and serve more users simultaneously.

Simulation results revealed that the FWF+IFR3 obtained a slightly 3% higher capacity than SWF+IFR3 in sFFR and SFR, and overall 23% higher than the tranditional algorithm. Besides, by applying the proposed algorithm FWF+IFR3 in SFR scenario, the network capacity is found to be smaller than the sFFR scenario but still greater than applying a conventional algorithm for both scenarios. ALso, with 50% of spectrum resources, the proposed algorithm reaches nearly 80% of the capacity in sFFR scenario. The simulation results provided intriguing technological insights into an 5G Multi-cell power allocation behaviour, which might be beneficial in designing and implementing future power allocation schemes.

REFERENCES

[1] W. S. H. M. W. Ahmad, N. A. M. Radzi, F. S. Samidi, *et al.* "5G Technology: Towards Dynamic Spectrum Sharing Using Cognitive Radio Networks," *IEEE Access*, vol. 8, pp. 14460-14488, Jan. 2020.

[2] F. Hu, B. Chen and K. Zhu, "Full Spectrum Sharing in Cognitive Radio Networks Toward 5G: A Survey," *IEEE Access*, vol. 6, pp. 15754-15776, Feb. 2018.

[3] B. Xie, Z. Zhang, R. Q. Hu *et al.*, "Joint Spectral Efficiency and Energy Efficiency in FFR-Based Wireless Heterogeneous Networks," *IEEE Trans. Veh. Technol.*, vol. 67, no. 9, pp. 8154-8168, Sept. 2018.

[4] S. H. Lee, M. Kim, H. Shin and I. Lee, "Belief propagation for energy efficiency maximization in wireless heterogeneous networks," *IEEE Trans. Wireless Commun.*, vol. 20, no. 1, pp. 56-68, Jan. 2021.

[5] S. Han, C.-L. I, G. Li, S. Wang and Q. Sun, "Big data enabled mobile network design for 5G and beyond," *IEEE Commun. Mag.*, vol. 55, no. 9, pp. 150157, 2017.

[6] Y. Medjahdi, M. Terre, D. L. Ruyet *et al.*, "Performance analysis in the downlink of asynchronous OFDM/FBMC based multi-cellular networks," *IEEE Trans. Wireless Commun.*, vol. 10, no. 8, pp. 26302639, Aug. 2011.

[7] J. Garca-Morales, G. Femenias and F. Riera-Palou, "Higher order sectorization in ffr-aided ofdma cellular networks: Spectral-and energy-efficiency," *IEEE Access*, vol. 7, pp. 11127-11139, 2019.

[8] N. Al-Falahy and O. Y. K. Alani, "Network Capacity Optimisation in Millimetre Wave Band Using Fractional Frequency Reuse," *IEEE Access*, vol. 6, pp. 10924-10932, Oct. 2018.

[9] Z. H. Abbas, M. S. Haroon, F. Muhammad *et al.*, "Enabling Soft Frequency Reuse and Stienen's Cell Partition in Two-Tier Heterogeneous Networks: Cell Deployment and Coverage Analysis," *IEEE Trans. Veh. Technol.* , vol. 70, no. 1, pp. 613-626, Jan. 2021.

[10] J. Ren and K. Wong, "Cognitive Radio Made Practical: Forward-Lookingness and Calculated Competition," *IEEE Access*, vol. 7, pp. 2529-2548, 2019.

[11] P. He, L. Zhao, S. Zhou and Z. Niu, "Water-Filling: A Geometric Approach and its Application to Solve Generalized Radio Resource Allocation Problems," *IEEE Trans. Wireless Commun.*, vol. 12, no. 7, pp. 3637-3647, July 2013.

[12] G. Scutari, D. P. Palomar and S. Barbarossa, "Asynchronous Iterative Water-Filling for Gaussian Frequency-Selective Interference Channels," *IEEE Trans. Inf. Theory*, vol. 54, no. 7, pp. 2868-2878, July 2008.

[13] T. Novlan, R. Ganti, A. Ghosh *et al.*, "Analytical Evaluation of Fractional Frequency Reuse for OFDMA Cellular Networks," *IEEE Trans. Wireless Commun.*, vol. 10, no. 12, pp. 4294-4305, Dec. 2011.

[14] S. Sun, T. S. Rappaport, M. Shafi, and H. Tataria, "Analytical framework of hybrid beamforming in multi-cell millimeter-wave systems," *IEEE Trans. Wireless Commun.*, vol. 17, no. 11, pp. 75287543, Nov. 2018.

[15] Saleh, Ali M., Le, Ngon T. *et al.*, "Inter-Cell Interference Coordination Using Fractional Frequency Reuse Scheme in Multi-Relay Multi-Cell OFDMA Systems," *2018 IEEE Canadian Conference on Electrical Computer Engineering (CCECE)*, doi=10.1109/CCECE.2018.8447574

CERTIFICATE OF PRESENTATION

2022 11th International Conference on Communications, Circuits and Systems

Paper ID: **CS22-345**

Mingjun Ying

Chongqing University of Posts and Telecommunications, China

Paper Title: **Capacity Analysis and Hybrid Power Allocation for Multi-cell Cellular Networks**

For your excellent oral presentation at the conference and your significant contribution to the success of the 11th International Conference on Communications, Circuits and Systems (ICCCAS 2022), Virtual Conference during May 13-15, 2022.

Session Chair

ICCCAS

Conference Committee