A smarter algorithm-IFR3+FFR in wireless network to optimize frequency allocation

Zanwen Fu1, a, †, Rui Zhou2, b, †

1Electronic and Information Engineering, South China University of Technology, Guangdong, Guangzhou, China;
2Electronic and Electrical Engineering, University of Leeds, Leeds, United Kingdom.

a202030243208@mail.scut.edu.cn, bml19r5z@leeds.ac.uk.

†These authors contributed equally.

Abstract. All latest technologies require frequency channels to be allocated intelligently so that interference can be avoided. Nowadays, it is still quite challenging for people to propose an effective method to enhance the frequency allocation system, which reduces interference further and allows more users to utilize the base station at the same time. Here we describe the method of improving the frequency allocation system-IFR3 (Integer frequency reuse) plus FFR (fractional frequency reuse) in a nineteen-cell network. We simulate the system based on MATLAB, comparing capacity results against different parameters. We draw some useful conclusions after the simulation. When the number of frequencies increases, average network capacity also increases. When SNR increases, average network capacity increases at the beginning, and then at a certain critical point, it starts to decrease. Thereby, it is required to find the best system with both the appropriate number of frequencies and SNR to maximize the network capacity. As for users who are in the distance, the interference will be large when using IFR1 but small if using IFR3. Therefore, finding the best reuse factor when using FFR is indispensable. Smaller transmit power should be allocated to users in the cell's inner area, and larger transmit power allocated to users in the outer area of the cell. This system is more advanced and capable of reducing interference efficiently.

1. Introduction
The current fixed spectrum allocation scheme leads to significant spectrum white spaces. Several new spectrum management models have been proposed to improve spectrum usage. One promising technology is opportunistic spectrum usage. Subleasing is widely regarded as another potential way to share spectrum if we ensure that primary users' spectrum usage is not interfered with [1]. Because of that, they are reducing channel interference, and using frequencies effectively are fundamental problems in wireless networks based on Frequency Division Multiplexing (FDM) technology. In FDM networks, service areas are usually divided into cellular regions or hexagonal cells, each containing one base station. Base stations can allocate radio frequencies to serve the phone calls in their cells. The allocation strategy is to choose different frequencies for calls in the same cell or the neighboring cells to avoid interference [2]. What is more, in mobile OFDMA networks with 1 2-5 frequency reuse, cell sector division and the well-known Fractional Frequency Reuse (FFR) and its adaptive implementation are widely accepted ICIC schemes in the downlink (DL) [3]. IFR components proven by Barlow & Proschan cannot be extended to all s-coherent systems [4]. A basic challenge in cellular
networks based on Orthogonal Frequency Division Multiple Access (OFDMA) is inter-cell interference coordination. To solve this challenge, various solutions using Fractional Frequency Reuse (FFR) have been proposed in the literature [5], and race frequency reuse (FFR) has been proposed as a technique to overcome this problem because it can effectively use the available spectrum [6].

Fractional frequency reuse (FFR) can coordinate inter-cell interference (ICI) and improve the communication quality of cell-edge users. The key idea is to balance between improving frequency utilization efficiency and suppressing ICI [7] first, and then expand the mathematical model to include elastic data flow analysis in the FFR system [8]. Analytical models are proposed for integer frequency reuse (IFR), fractional frequency reuse (FFR). These models are based on a fluid model originally proposed for CDMA networks [9]. And the future wireless systems are envisaged to offer ubiquitous high data-rate coverage in large areas. With the Orthogonal frequency division multiple access (OFDMA) transmission technique, great benefits in handling inter-symbol interference, inter-carrier interference, and high flexibility in resource allocation can be reaped. Nevertheless, the co-channel interference (CCI) or so-called inter-cell interference (ICI) as a big challenge issue with OFDMA is still remained, which encumbers to attain wide area [10]. Curiously, steady improvement in national IFR forecast scores was not sustained. Terminal aerodrome forecast (TAF) performance metrics decreased in 2011 and 2012, although there was no obvious reason for the decline. However, it was noted by both NWS headquarters personnel and forecasters in the field that observed IFR conditions occurred with less frequency during the 2011–2012 period. It was suspected that the diminished percentage of observed IFR frequency (henceforward termed "IFR Frequency") was related to the reduction in IFR forecast performance. The NWS Aviation Services Branch responded to this concern and investigated the relationship between IFR forecast metrics and IFR Frequency. It was found that when forecast data sets containing a large number of TAF locations were normalized for IFR Frequency, the 2009–2012 period actually exhibited an improvement trend [11]. Unlike dynamic spectrum allocation, which uses spectrum occupancy statistics, opportunistic spectrum access uses the instantaneous spectrum availability by opening the licensed spectrum to secondary users [12].

2. Method

The system model is as follows:

\[
\begin{align*}
f_1 &= [1 \ 2 \ 3 \ 4 \ 5 \ 6] \quad \bullet \\
f_2 &= [7 \ 8 \ 9 \ 10 \ 11 \ 12] \quad \bullet \\
f_3 &= [13 \ 14 \ 15 \ 16 \ 17 \ 18] \\
f_4 &= [7 \ 8 \ 9 \ 10 \ 11 \ 12] \\
f_5 &= [13 \ 14 \ 15 \ 16 \ 17 \ 18] \\
f_6 &= [7 \ 8 \ 9 \ 10 \ 11 \ 12] \\
f_7 &= [13 \ 14 \ 15 \ 16 \ 17 \ 18] \\
\vdots \\
f_{19} &= [1 \ 2 \ 3 \ 4 \ 5 \ 6] \quad \bullet 
\end{align*}
\]

Figure 1. The 19-cell network

In Figure 1, if IFR3 (i=1, j=1) is used, then each cell is given six frequencies. \( f_n \) stands for frequency for entire cells, from cell one to cell nineteen.
When it comes to the specific method to simulate this system, it can be explained as follows. To begin with, the tool we utilize to construct the frequency allocation system is MATLAB, a powerful mathematical tool to perform a complicated operation. What we have done is to, first, compile MATLAB code to establish functions against formulas such as computing reuse factor N and Signal to Interference Ratio, and then, run the function repetitively against different parameters to attain groups of capacity results, at last, compare results and draw conclusions. Here we will offer a detailed explanation of some key formulas.

\[ N = k^2 + kl + l^2 \]  
(1)

Where \( N \) represents frequency reuse factor, \( k \) represents the number of cells moving along any of the 6 directions perpendicular to the sides of the hexagons, \( l \) represents the number of cells moving subsequently after turning clockwise 120°.

\[ Q = \frac{D}{R} = \sqrt{3N} \]  
(2)

Where \( D \) and \( R \) can be explained as formula (3), (4), (5), and (6).

The frequency reuse factor \( N \) is defined as the number of channel sets in the reuse pattern, depending on \((k, l)\).

\[ A = 6 \left( \frac{D}{\sqrt{3}} \right)^2 \sin 60^\circ = \frac{\sqrt{3}D^2}{2} \]  
(3)

\[ a = 6 \left( \frac{1}{2} R^2 \sin 60^\circ \right) = \frac{3\sqrt{3}R^2}{2} \]  
(4)

\[ N = \frac{A}{a} = \frac{D^2}{3R^2} \]  
(5)

\[ \frac{D}{R} = \sqrt{3N} \]  
(6)

\[ SIR = \frac{1}{\left( (Q+1)^{\alpha} + (Q-1)^{\alpha} \right) \cdot \left( (Q+0.5)^{\alpha} + (Q-0.5)^{\alpha} \right) + 1} \]  
(7)

Where \( \alpha \) represents path loss exponent.

\[ C_n = \log_2 \left( 1 + \frac{|h_{n,n}|^2 \rho_n}{\sum_{m \neq n} |h_{m,n}|^2 \rho_{m,n} + \sigma^2} \right) \]  
(8)

Where \( P_n \) represents transmit power from base station \( n \), \( \sigma \) represents noise power, \( |h_{m,n}| \) represents channel from base station \( n \) to user \( m \), \( P_m \) represents transmit power from base station \( m \).

\[ C_{total} = \sum_n C_n \]  
(9)
2.1. IFR3 +FFR

As for the IFR3 network, this model uses Integer Frequency Reuse algorithm to analyze the average network capacity in a 7-cell system by fixing other parameters like available channels, running times to get average network capacity, discover how Signal Noise Ratio (SNR), average people in one cell, Power transmission(P) affect average network capacity respectively. From Figure 3, we can see that, as for IFR1, when the number of channels per cell is maximum at \( N_c \) (where \( N_c \) represents the total number of channels), interference would be nearest and most severe. Whereas, when the number of channels per cell is reduced to \( N_c/3 \), interference will be further away and much weaker. Thereby, replacing IFR1 with IFR3 is capable of decreasing interference remarkably. However, there is no denying that the SIR analysis is based on the worst case and the frequency channel allocation is predefined and inflexible. To cap it all, larger \( N_c \) improves the SIR but reduces the number of available channels in a cell (the number of channels per cell is \( N_c/N \), where \( N \) represents reuse factor). Consequently, we come up with an idea, incorporating IFR3 with FFR, which can significantly resolve the problems of the IFR3 network. Formulas (1), (7), (8), and (9) are the staple formulas of the IFR3 network.

In the FFR network, different transmit power is used to serve users in the inner and outer areas of a cell. Smaller power \( P_1 \) to serve the cell's inner area helps reduce the interference to the other cells. A larger power \( P_2 \) to serve the cell's outer area is needed because of the longer distance. As Figure 4 suggests, interference can be decreased by increasing frequencies from six to eight in each cell.
In Figure 4, frequency planning is improved, where each cell now has eight frequencies. $f_n$ represents frequencies for all inner-cells.

3. Results and Discussion

In Figure 5 When other crucial parameters are fixed (SNR, available channels, average people in one cell, running times), the average network capacity fluctuates in a certain range, here is 49.8-51. Consider the error due to the 'poisrnd' syntax in MATLAB, and it concludes that change the P in the 7-cell IFR3 system will not affect the average network capacity.
In Figure 6, the reuse factor is 3, and SNR_DB is fixed in 10db. We also assume the available channel number is 18 and the average number of people in each cell is 6. We run 1000 times for the average network capacity of the system. This shows that under some conditions the increased transmit power will affect the capacity a little. When other crucial parameters are fixed (SNR, available channels, average people in one cell, running times), the average network capacity fluctuates in a certain range, here is 49.8-51. Consider the error due to the 'poissrnd' syntax in MATLAB, and it concludes that change the P in the 7-cell IFR3 system will not affect the average network capacity.

![Figure 6. SNR in DB vs average network capacity in IFR3 network](image)

In Figure 7, we set the variable values the same with Figure 6. When other crucial parameters are fixed (available channels, average people in one cell, running times, P) with an increase of SNR, the average network capacity rise in the form of logarithm function, which means if we increase the SNR in this system, we can significantly improve the average network capacity.

![Figure 7. Average person in one cell vs average network capacity in IFR3 network](image)
In Figure 8, the reuse factor is 3, and SNR_DB is fixed in 10db. We also assume the transmit power is 1 and available channel. We also run 1000 times for the average network capacity of the system. This shows when the number of people in each cell increases, the capacity decreases as the interference among different users becomes larger. This results in our simulation. When other crucial parameters are fixed (SNR, available channels, running times, P), First, the average network capacity drops significantly and slowly becomes a line when increasing the average people in one cell. So, by analyzing this phenomenon, the 7-cell IFR3 network system has its 'limitation'; for this particular case, available channels are 18, reuse factor is 3, it is designed to serve 6 people in one cell (18/3). For example, if too many individuals gather around, it will be a burden to this system. So, we can calculate the minimum value of the average network capacity in this system in advance and try to adjust it when the above situation happened.

As for the IFR3+FFR network, here are the results of this system.

Figure 8. SNR in dB vs average network capacity in IFR3+FFR network

Figure 9. Average person in one cell vs average network capacity in IFR3+FFR network
From Figure 8 and Figure 9, we can easily notice the significant difference of average network capacity between IFR3 (as shown in Figure 6, 7, 8) and IFR3+FFR, which prominently optimizes the integral network increasing the average network capacity dramatically in different situations. Frequency planning is improved as in Figure 4, increasing the number of frequencies from six to eight in each cell. In this way, we can compute frequency reuse more precisely, based more on real life situations. Plus, deemed as an advanced promotion on the IFR3 system, FFR reduces interference among different cells significantly.

4. Conclusion

In this paper, we study FFR+IFR3, and this method plays an important role in the real environment. We describe the method of improving the frequency allocation system, which uses the algorithm of IFR 3 (Integer Frequency Reuse) plus FFR (Fraction Frequency Reuse) in a nineteen-cell network. The system is simulated based on MATLAB, and the capacity results under different parameters are compared. After the simulation, we have reached the following conclusions. As the average network capacity also increases, the number of frequencies increases. As well as the signal-to-noise ratio. However, then at some points, it begins to fall. Therefore, the aim is to find the best system with the appropriate number of frequencies and signal-to-noise ratio to maximize network capacity. Compared to IFR1, the interference would be much larger than IFR3 for users in the distance. So, it is crucial to find the best reuse factor when using FFR. Finally, the conclusion is that smaller transmission power should be allocated to users in the inner area of the cell, and larger transmission power should be allocated to users in the cell's outer area; this system is more sophisticated and can effectively reduce interference.

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