AFFR: An Adaptive Approach to Fractional Frequency Reuse for Enhanced Cellular Communication Efficiency

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**Abstract.** Frequency reuse in cellular communication has been a significant issue in modern communication technology. The paper presents a proposal for improving the Fractional Frequency Reuse (FFR) technique in Orthogonal Frequency Division Multiple Access (OFDMA) via the introduction of novel frequency reusable architecture. The proposed structure, termed the AFFR (Adaptive Fractional Frequency Reuse) system, will be elucidated along with its functionality and operating methodologies. The current model’s degree of interference is a primary factor contributing to its subpar performance in cellular networks, compounded by the ineffective allocation of cell centre and cell edge areas, leading to diminished frequency availability at the cell edges. The paper discusses the network’s efficiency and throughput, providing a mathematical explanation of both the existing method and the proposed scheme. The performance enhancement and conceptual significance are validated through calculations facilitated by the implementation of a simulation process.

# INTRODUCTION

The aim is to use the sub-carriers in the OFDM architecture to gain maximum coverage in the communication system. OFDM is a concept of Long-Term Evaluation for Orthogonal Frequency Division model in cellular communication technology. It is best suited for heavy data transmission bands. The OFDM scheme is widely used in cellular and Wi- max communication bands. The throughput of the system increases if the concept is used in the network [1]. Radio signals are the main element of wireless cellular communication technologies. Hence, there should be a frequency reusing scheme in the OFDM architecture for a network to maintain the limited bandwidth with the ever-increasing demand of the user requirement. The FFR architecture divides the cells into micro-cells, which helps limit the frequency of use in broader areas of communication. FFR enables the division of cell users into (1) cell center users and (2) cell-edge users [2]. The main working principle of a cellular network is dependent upon a base station. A single base station is divided into some of the cells. The cells are the regions or zones working separately in a specific frequency range. The stations in the town are more powerful compared to the ones in rural areas. Thus, the number of base stations in the city and busy industrial areas is higher than the number of stations in rural areas, as the frequency requirement is high in the cities. Figure 1 shows the Cellular division and density in rural and city areas.



**FIGURE 1.** Cellular division and density in rural and city areas

In each cell, two different types of zones make up the cellular architecture. The cell center and cell edge users in the cell have different amounts of frequency allocation in the cellular network. There is a specific rate for cell edge on a wireless network where the coverage area of the cell center decreases according to the increment of the cell edge rate and vice versa [3]. There are forward and reverse communication channel transportation, where the first one implies communication from base to mobile and the second one is from the device to the base. A specific frequency band is allocated for both the forward and reverse bands [4].

The paper is going to focus on the FFR (Fractional Frequency Reuse) scheme for an adaptive approach to frequency allocation that may provide efficient frequency-reusing ability in the network. Thus, the wastage of radio signals will be reduced along with the increased throughput in the system [5]. The contribution of this article is to build an enhanced FFR architecture for a heterogeneous network that can serve the needs of customers and provide a scheme for frequency reuse for higher coverage according to the adaptation. In this article, the first section is about the system model, and the second and third sections consist of related work on frequency reuse and the methodology of the research. The fourth section is based on the proposed model of the AFFR scheme. The performance measure, throughput of the model, simulation process, and result discussion are in the fifth and sixth sections of this paper.

# RELATED WORK

The related articles regarding the frequency reuse of architecture are described here in this portion. Fractional and Soft Frequency Reuse (FFR & SFR) are the most usable and effective systems for maintaining the interference that occurs in OFDMA networks. In this paper, the authors proposed a new framework that can perform in a composite fading environment as well. They tested the system in both ways (fully and partially). To provide FFR, the available resources are divided into two separate divisions: cell-center and cell-edge. As a result, the same frequency can be used in both divisions without any performance leakage. SFR is one kind of FFR as it also follows the dual-ring frequency method. SFR requires power control to maintain its performance. Yet, for a system, all types of simulation should be conducted for testing [6].

Orthogonal Frequency Division Multiple Access (OFDMA) based networks are mostly Inter-Cell Interference (ICI). ICI makes a signal week. To solve this problem, the authors have proposed a solution using the Center of Gravity (CoG). It provides a self-organized feature, which means that if the system fails, it can recover automatically. They also used Cellular Automata (CA) to enhance the existing FFR scheme. The first sector’s performance is much better than the existing one, and it’s about 75%. Still, the second sector’s performance is not satisfactory. The existing system performance is 25% higher than the proposed one [7].

In terms of downlink frequency, the FFTS (Fractional Frequency Transmission System) provides better service output and gain in terms of power. The efficiency of the power is with the use of a cyclo converter. It is made of 3 converters, and each of the ends is connected to the source of voltage. It seems that there is a scope of transmission increment if it touches the angle of phase at nearly 63°. Thus, the measured output/input ratio of the cyclo converter system is more than 96%. The absorbed power is the same as that of high-voltage direct current, which contradicts the experiment. The FFTS system can prolong the life of the converter circuit. Resistance is 2 times greater than the theoretical calculation of the actual phenomenon. So, efficiency gets a little less and is reduced by 78% [8].

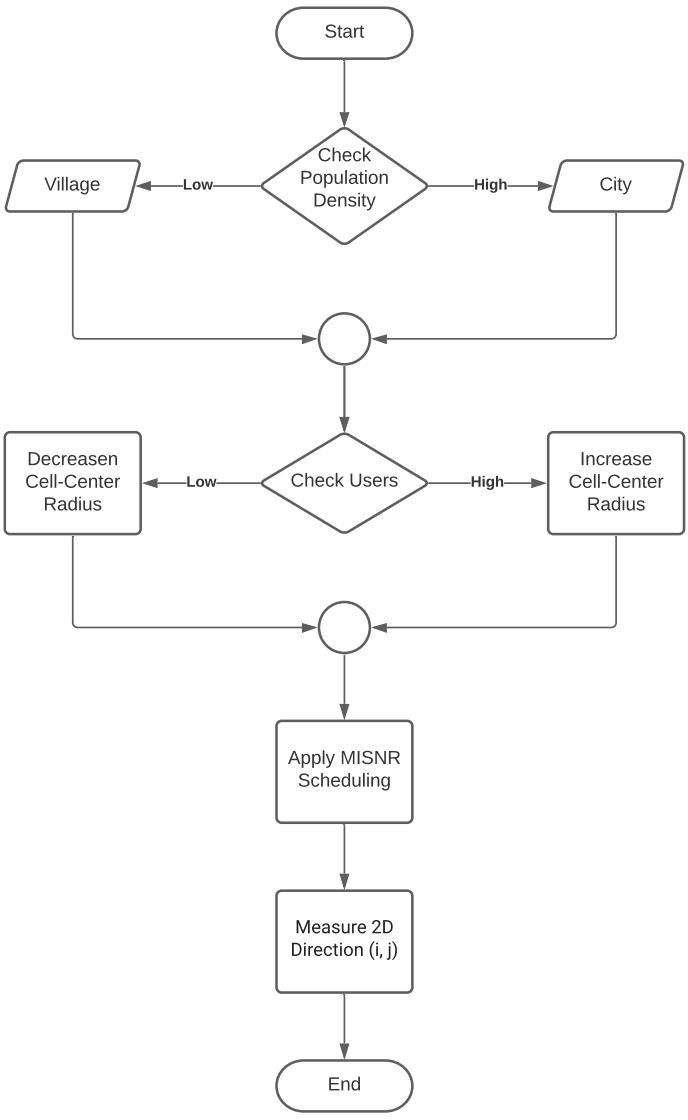
The graph coloring is the conversion of frequency allocation in the next article. Here, each node has been considered the MS according to the ease of cellular communications. 2 schemes, named FFR-A and FFR-B, have been visualized. Different cells colored with different colors in the design mean that these are using different frequency bands. Simulation results show that the dynamic-graph-based FFR-A and FFR-B schemes have better cell throughput than the reuse-3 scheme and the normal fixed FFR scheme. The service rate also shows a similar type of comparison. Though the cell edge and cell center MS users can be noted with overlapping white color [9].

This can create confusion in terms of frequency division among the center and edge users, and overlapping of the allocation may occur. The authors developed an efficient two-looped algorithm to solve the optimization problem for reusing the fractional frequency. The designed FFR scheme is much better as it can give a satisfactory data rate with a low cost [10]. Yet, the simulation is done only for wireless heterogeneous networks. In the power shortage cases, the system cannot provide enough data rates because of high interference.

The authors have derived a new technique for frequency reuse with the help of in-band relays for a distributed resource allocation. Yet, if the number of nodes increases, it will still be able to provide better performance at a very low cost [11, 12]. According to FFR, managing resources is hard because the spectrum is split into areas with different reuse factors, which need a lot of planning and organization [13]. It may also waste spectrum in low- density locations where cell-edge users may hardly consume resources. In heavily populated areas, the efficiency of FFR is reducing [14]. The fixed characteristics of conventional FFR systems restrict their capacity to adjust to real-time variations in traffic and user mobility, resulting in poor network performance. The modern 5G networks can be partitioned into 4 sub regions to avoid co channel interference [15, 16]. This contradicts the concept of adaptation of frequency. The paper has proposed a model for a fractional frequency reuse scheme. The proposal and the concept have been constructed over a literature review. Then, the simulation environment has been discussed to assume the performance of the adaptive fractional frequency reuse proposed here, with the conventional frequency reuse scheme. The operation of this AFFR scheme has been demonstrated in an algorithm. The MISNR procedure of frequency management will be maintained in the work. The adaptivity of the cell center and the direction for reusing cell energy through the MISNR strategy are designed in such a way that the frequency will be retrieved into fractional parts in the directed cell regions. The collisions needed to be avoided in terms of the cell edge regions using nature and the amount of modulation power a cell possesses. So, the 2-dimensional direction is directed in the algorithm for the frequency reusing tasks among the cell regions in the network.

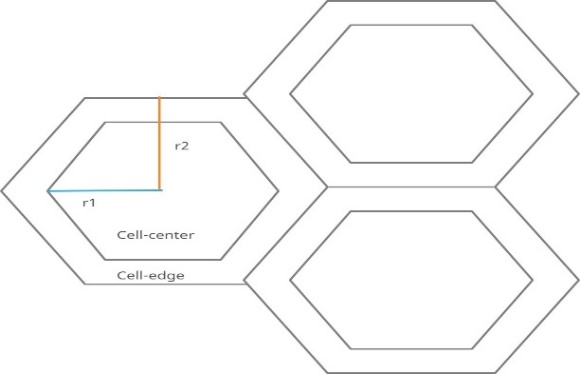
# PROPOSED SYSTEM: AFFR

The proposed scheme has been named Adaptive Fractional Frequency Reuse (AFFR) in Figure 2. First, cell radius adaptivity is required to gain the optimal measure of the cell center and cell edge users. The optimal measure is about 0.63 km for the city cell area, and slightly higher than this can be considered in the village area cell [1]. Then, the scheduling scheme must ensure an efficient and even distribution of frequency bands inside the cell users [5]. The threshold of radius shrinking or expanding depends on the design of engineers for a certain network zone. The MISNR scheduling is used in the proposed scheme as it gives privileges according to the SINR of the users in the cell.



**FIGURE 2.** Flowchart of the proposed model of AFFR

The Signal to Noise ratio can be considered as the principal parameter of this proposed scheme for cell radius changeability according to the requirement or user demand. In Figure 3, *r1* and *r2* stand for the cell center and cell edge radius, respectively, and Figure 3 shows the proposed model work follow. The adaptation capability of the cell centers is ensured in such a manner that the radius can increase if there is high demand in the cell edge and decrease in the opposite case. The detection has been based on the density of users in the cell. The SINR is the measure of a certain network traffic in the cell. The MISNR scheduling is done with the precedence of a smaller SINR in the cell. Next, the co-channel is indicated by the 2-dimensional directions for variables *i* and *j*. It is used to locate the co-channel for frequency reuse in cells.



**FIGURE 3.** Adaptive Cell-edge and Cell Center Radius

# PERFORMANCE, THROUGHPUT AND EFFICIENCY

The Soft Frequency Reuse scheme is divided into multiple blocks of power levels. The FFR scheme is efficient in such a manner compared to the Soft Frequency Reuse (SFR) model as it uses the same power level in the entity blocks [12]. The interference is less in the proposed FFR model, as there is no sharing of frequency bands among the cell edge and cell center users. As per Figure 2 in the proposed model, there is a different radius readings (*r1,r2*) for the cell center and edge zone of the cell. As the scheduling is based on the precedence of the lower SINR users in the cell, it may be beneficial for all the cell users to get a fair distribution of frequency bands for a successful communication process. The users in the system get evenly balanced frequency signals as per the requirement. The possibilities of interference in the cell should be as low as *r1<r2* in this model. The reusing manners is also very cost-effective, and the energy consumption is very low [13]. The above description supports that the enhanced adaptive cellular frequency reuse model can provide satisfactory throughput through the efficient use of frequency signals in the network.

# SIMULATION PROCESS

## Environment Description

The network is assumed to be a cellular communication network with several cells in its region. There are base stations for down-link communication to the end devices in the network cells. Each of the cells is divided into channels. It needs to be kept in mind that there should not be any unwanted co-channel interference, which can create issues. Table 1 shows the different simulation parameters of the proposed model.

**TABLE 1.** Simulation parameters of the proposed model

|  |  |
| --- | --- |
| **Simulation Parameter** | **Description** |
| Simulation platform | *MATLAB R0219* version |
| Simulation Target environment | Cellular communication with cell-divided regions |
| Area of the network | 45 sq. kilometers |
| Number of cells cluster size (*N*)  The average number of channels in each cell | 12-13  20 |
| Available channel (S) | To be calculated from equations |

There are three important parameters in this simulation process. These are the channels available for use (*S*), the number of channels in each cell (*k*), and cluster size, or the number of cells in the cluster (*N*). Thus, the calculation of the comparative capacity in terms of the available channels in use for a cell is conducted. The corresponding points of the graph for *C* vs. *S* are simulated after plotting under the demonstrated environment with the parameters considered earlier. There are 20 channels in the 45 square-kilometer area for both the proposed AFFR and the normal scheme of FFR. The dedicated cells in the cluster are under the control of Figure 4. Figure 4 may help to demonstrate the calculation for cluster size, *N*, and lead to an understanding of better capacity for the schemes.

## Calculation Over the Environment

The system’s parameters are:

*S*: Channel available for use.

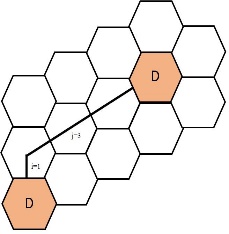
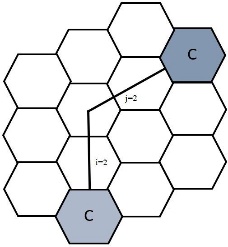
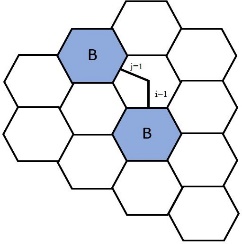
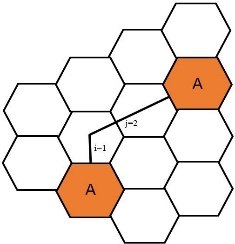
*K*: Channel in each cell.

*N*: Cluster size.

If we use the Equation (1) for cluster size,

(1)

The number of channels available for use will be high if MISNR scheduling is used for frequency resource allocation. Our proposed systems’ cell supports 35% of the available channel. This is slightly higher than the conventional percentage of channel availability. Table 2 demonstrates the 2D (*i,j*) propagation for the reuse of the same frequency in different cells. Here, *i* is the top-bottom propagation, and *j* is the left-right propagation. In Equation (1), the cluster size is calculated with these.



(a) *i* and *j* co-channel (b) *i* and *j* co-channel (c) *i* and *j* co-channel (d) *i* and *j* co-channel

**FIGURE 4.** *i* and *j* co-channel for locating cell

|  |  |
| --- | --- |
| **TABLE 2.** *i* and *j* propagation for cell frequency reuse in cluster | |
| ***i* (top-bottom)** | ***j* (left-right)** |
| 1 | 2 |
| 1 | 1 |
| 2 | 2 |
| 1 | 3 |

It is to be noted that the values of *i* and *j* are non-negative and arbitrary. These determine the co-channel cells of the cellular system and the reusable amount to be directed to other cells of the cluster.

For instance, 1, *N*1 = [12 + 1*x*2 + 22 = 7]

For instance, 2, *N*2 = [12 + 1*x*1 + 12 = 3]

For instance, 3, *N*3 = [22 + 2*x*2 + 22 = 12]

For instance, 4, *N*4 = [12 + 1*x*3 + 32 = 13]

There are 20 channels in the 45 *Km*2 area.

## For Proposed System

*K* = 0.35x 20 = 7, so there are 7 channels per cell. It is fixed. As there are 35% availability channels in a cell for a normal approach using the Equation (2) here,

(2)

As per Equation (2), *S*1 *= KN*1 = 7x7 = 49, *S*2 *= KN*2 = 7x3 = 21, *S*3 *= KN*3 = 7x12 = 84, *S*4 *= KN*4 = 7x13 = 91

Now, the multiplying factor *M* is constant. That is *M = 3*. The amount of capacity can be calculated from the Equation (3) for the proposed model according to Shannons Capacity concept [17]

(3)

The values of C1, C2, C3 and C4 using Equation (3),

*C*1 *= MS*1 = 3x49 = 147, *C*2 *= MS*2 = 3x21 = 63, *C*3 *= MS*3 = 3x84 = 252, *C*4 *= MS*4 = 3x91 = 273.

## Experimental Frequency Reusing scheme before

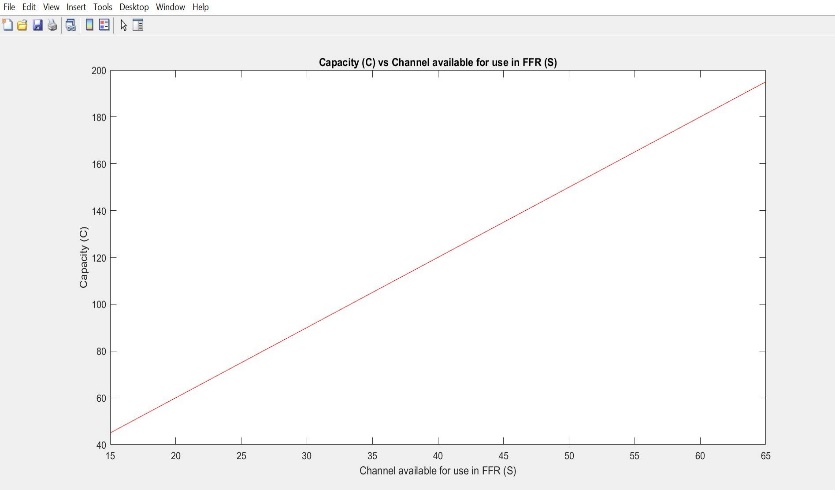
*K* = 0.25x 20 = 5, so there are 5 channels per cell. It is fixed. As there are 25% availability of channels in a cell for normal approach, hence from Equation (2)

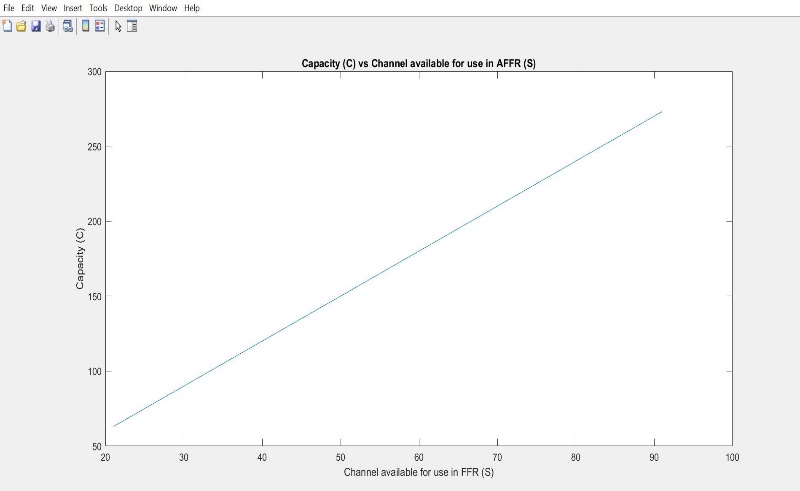
*S*1 *= KN*1 = 5x7 = 35, *S*2 *= KN*2 = 5x3 = 15, *S*3 *= KN*3 = 5x12 = 60, *S*4 *= KN*4 = 5x13 = 65.

The gain for the capacity can be calculated from Equation (3)

*C*1 *= MS*1 = 3x35 = 105, *C*2 *= MS*2 = 3x15 = 45, *C*3 *= MS*3 = 3x60 = 180, *C*4 *= MS*4 = 3x65 = 195.

## Result

The simulation process is done over two different linear equations. One is the channel availability for use, which is *S=KN*, and the other is the capacity of the network, which is *C=MS*. Where M is the multiplication factor. The coordinates have been plotted in MATLAB for both the cases of AFFR and FFR schemes for the same network. The target is to generate the number of channels available for use in both cases. The value is the multiplication of the percentage of the channels in use for each cell and the number of channels per cell in the network. It is seen in Figure 5 that the capacity for the proposed AFFR scheme is higher than that of the capacity for the FFR model. Here, the multiplication factor *M* is 3 in both cases.



(a) Capacity of the Conventional FFR (b) Capacity of the Proposed AFFR model

**FIGURE 5.** Comparison between conventional FFR and proposed AFFR model

The highest capacity for the FFR scheme is 195 bit/s and 273 bit/s for the AFFR scheme. So, it can be assumed that the proposed AFFR scheme has better frequency reusing capabilities than the conventional FFR model. Capacity is considered in bps.

# CONCLUSION

This paper aims to enhance the throughput and performance of the cellular network by modifying the FFR model. The proposed AFFR scheme enhances cellular network performance by dynamically adjusting the radius of cell-center and cell-edge regions based on user density and SINR values. The model separates frequency use between cell-center and edge users, which eliminates overlap and minimizes co-channel interference. Simulation results confirm that AFFR increases network capacity from 195 bit/s to 273 bits and raises channel availability per cell from 25% to 35%. The scheme also lowers energy consumption and ensures better spectral efficiency. In future, the proposed scheme can be more optimized by the application of AI oriented scheduling scheme in 5G cellular subnetworks. These outcomes establish AFFR as a scalable and adaptive solution for improving frequency reuse in OFDMA-based heterogeneous networks.

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