Optimal Algorithm Comparison in Frequency Allocation -IFR, Water Falling and FLG

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Abstract

The capacity of the communication network can be influenced by changing the channel allocation in various settings. Researchers are working on it to come up with useful frequency assignments. This paper analyzed the capacity of different common frequency allocation modes to discover a better solution with many users. In a large classroom, for example, pupils can seat in a regular pattern and every one of them will connect to the network. As a result, during the experiment, modulations based on standard methods were included. All simulations are aimed at determining the ideal network capacity, hence self-improving algorithm-based networks are used. The results reveal that: a) in the pure IFR situation, network capacity is determined by the cellular network specification and the integer frequency reuse factor; and b) in the mixed IFR case, network capacity is determined by the cellular network specification and the integer frequency reuse factor. b) Among all the approaches individually, FLG is the best option. c) When using multiple methods using FFR, the best scenario is tx-ITL (beta5) with FFR (10). Overall, depending on the approach used, it can function differently in a small network. It's crucial to remember, especially in network design, that even one parameter might influence the outcome.

Keywords: Frequency Allocation, IFR, FFR, FLG, 19-cell cellular network

1. INTRODUCTION

In the field of wireless communication, especially in the development of 5G and 6G in recent years, different algorithms have been calculated and applied to find applications in different network conditions. Therefore, it is worthwhile to explore the signal distribution in different application environments. Several recent experimental experiments, however, reveal that the radio spectrum is utilized inefficiently in both space and time. [1] In the reports of other researchers, I found that very few people compared the network capacity under different distribution methods. It is important and need to be considered, especially for customers who have different needs, which can be more efficient. A more premium and smarter allocation to optimize signals need to be analyzed. Therefore, in this research includes the comparison among integer frequency reuse (IFR) method (1,3,4&7), fractional frequency reuse (FFR) method, simultaneous water filling (SWF) method, transmit interference temperature limit both with and without the beta (tx-ITL) method, and forward-looking game (FLG) method by changing several parameters under a 19-cell situation network. Mainly the modulations are separated into two parts, one for pure IFRN and rest for compare the impact on hybrid types of method. The IFR and FFR algorithm are basic and easy to achieve, however, they are both limited by the inflexibility of the model. Still the result from merely one method cannot be optimal, therefore, more combined methods are being modulated by adding a FFR process into every single method. That is, in a world increasingly filled by smart wideband radios, cooperating rather than separately sharing the signal space may be the best counsel. [2] The overall network capacity has been improved as expected, however, still a little difference has occurred. As a proof of application, hybrid methods of uses need to be chosen. For example, beneath this specific situation, choosing the SWF or tx-ITL +FFR method during the daytime and use a lower one at night can be wise.

2. SYSTEM MODELS

2.1 Integer Frequency Reuse (IFR)

In a cellular network, IFR is basic modulation method being mentioned. All subcarriers assigned to a cell can be used anywhere in the cell without specifying the user's location in integer frequency reuse. [3]

The way calculated for a single cell can be written as:

International Conference on Intelligent Systems, Communications, and Computer Networks (ISCCN 2022),
edited by Tok Wang Ling, Proc. of SPIE Vol. 12332, 123321L

$$C_n = log_2(1 + \frac{|h_{m,n}|^2 P_n}{\sum_{m \neq n} \rho_{m,n} |h_{m,n}|^2 P_m + \sigma^2}) \quad (1)$$

where $h_{m,n}$ is the channel from base station 'm' to user 'n'; P_n is the transmit power from base station 'n'; P_m is the transmit power from base station 'm'; σ^2 is the noise power; $\rho_{m,n}$ is a parameter that regulates the amount of interference between cells 'm' and 'n'. Therefore, total capacity is merely summing up (1):

$$C_{total} = \sum_n C_n \quad (2)$$

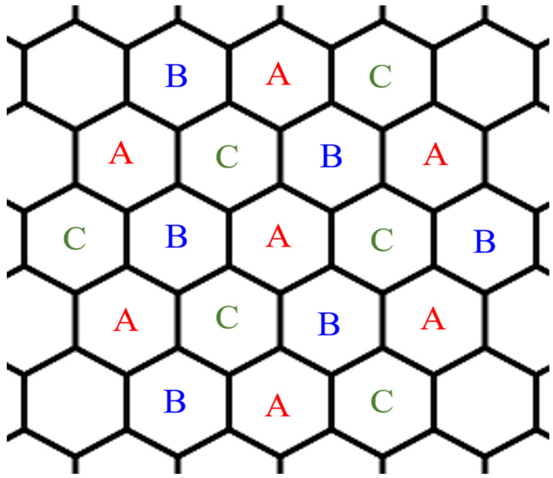

Fig. 1, 19-cell IFR3 allocation demonstration, i.e., k=1, l=1

The reuse factor N is defined as:

$$N = k^2 + kl + l^2 \quad (3)$$

Where both k and l are directional distance from the cell to another.

The frequency allocation for 19 cell IFR3 case is shown in figure 1. For the same channel, the reuse factor is 3 as the k and l from observation is both 1.

2.2 Fractional Frequency Reuse (FFR)

In this example, both inner and outer cells are considered, with each cell having higher frequencies. The transmit power used to service consumers in the cell's inner and outside areas is different. Smaller power P_1 to service the cell's inner area helps prevent interference to neighboring cells; bigger power P_2 to serve the cell's outer area is required due to the greater distance. As a result, FFR can handle a bigger network capacity.

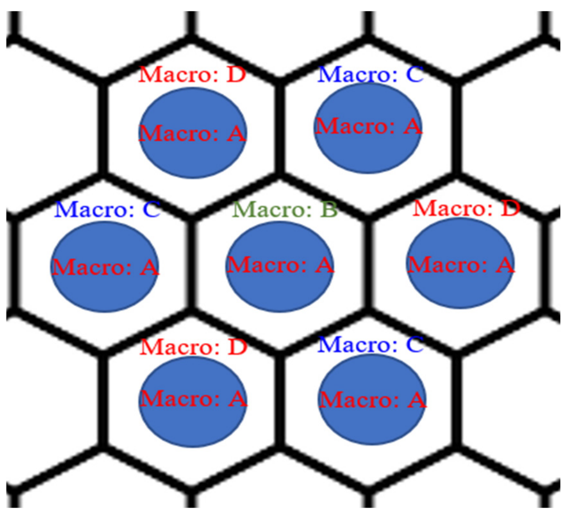

Fig. 2, 7-Cell FFR allocation demonstration

In figure 2, it shows the channel allocation for FFR case. In this case, all frequency channels are separated into 2 part and all channels share the inner frequency and differ from outer frequency. The outer frequency is arranged in a IFR3 pattern.

The adoption of FFR results in a natural trade-off improvement in various variables, including coverage, throughput, and spectral efficiency, while also ensuring an adequate level of service for cell-edge users.[4]

2.3 Simultaneous Water-Filling (SWF)

It introduced a self-optimizing algorithm that distribute frequency wisely.

The water-filling solution given for each user k is:

$$p_k[n] = (w_k - c_k[n])^+ \text{ for all n} \tag{4}$$

$$\sum_{n=1}^{N}(w_k - c_k[n])^+ = P_k \tag{5}$$

Where k is the k-th user; $c_k[n]$ is the invers SINR on the n-th frequency for the k-th user; P_k is the power budget for the k-th user; w_k is the water level.

The operation method is based on a loop which consider from user 1 and then repeat equation (4) and (5) and then moved to another user until convergence.

Some users are allowed to update their approach considerably more frequently than others under this asynchronous procedure, and they execute these adjustments using likely obsolete knowledge on the interference produced by others.[5]

2.4 Transmit Interference Temperature Limit (tx-ITL)

In 2003, the Federal Communications Commission (FCC) proposed a new metric for controlling spectrum access termed interference temperature. [6-8] The basic idea is to let both primary users and secondary users use licensed frequencies instantaneously, but the secondary users should guarantee that the interference level perceived by the primary licensed holders due to the secondary users should be maintained below a pre-defined level by using advanced technologies logies in the software and cognitive radio contexts. [8-9]

By introducing a parameter S_k that controls the level of interference will let user only occupies the frequencies that do not have a lot of interference will improve indeed.

$$p_k[n] = \begin{cases} (w_k - c_k[n])^+ & \text{if } c_k[n] \leq S_k \\ 0 \; if \; c_k[n] > S_k \end{cases}, \forall n \tag{6}$$

$$\sum_{n=c_k[n]\leq S_k}^{N}(w_k - c_k[n])^+ = P_k \tag{7}$$

Also, the parameter can be optimized by:

$$\widetilde{S_k} = max(S_k, \frac{\sum_{n=1}^{N} I_k[n] sng(p_k[n])}{\sum_{n=1}^{N} sng(p_k[n])}) \tag{8}$$

Which chooses a larger number between S_k and average interference power on a frequency.

The operation method is based on a loop which consider from user that satisfies $c_k[n] \leq S_k$ and then repeat (6) and (7) and then moved to another user until convergence.

2.5 Forward Looking Game (FLG)

Using the concept from Game Theory, it can be further considered as a game that analyses interaction between individuals.

$$p_k[n] = (w_k - \frac{{c_k}^2[n] + \varphi_k[n]{p_k}^2[n]}{c_k[n] - \varphi_k[n]p_k[n]})^+ \tag{9}$$

$${\varphi_k}^*[n] \geq -\sqrt{\frac{{c_k}^*[n]}{2{c_k}^*[n] + {p_k}^*[n]}} \tag{10}$$

Researchers show that the Nash equilibria of the vector game can be reached using the so-called asynchronous iterative water filling algorithm. [10]

3. RESULTS

All data are being processed on a PC with a processor AMD Ryzen 7 1800X (@3.8GHz) with MATLAB 2018b. All data are being collected and plotted into figures that illustrated with a x-coordinate of SNR in dB and network capacity in bps/Hz. (Except for Fig.3)

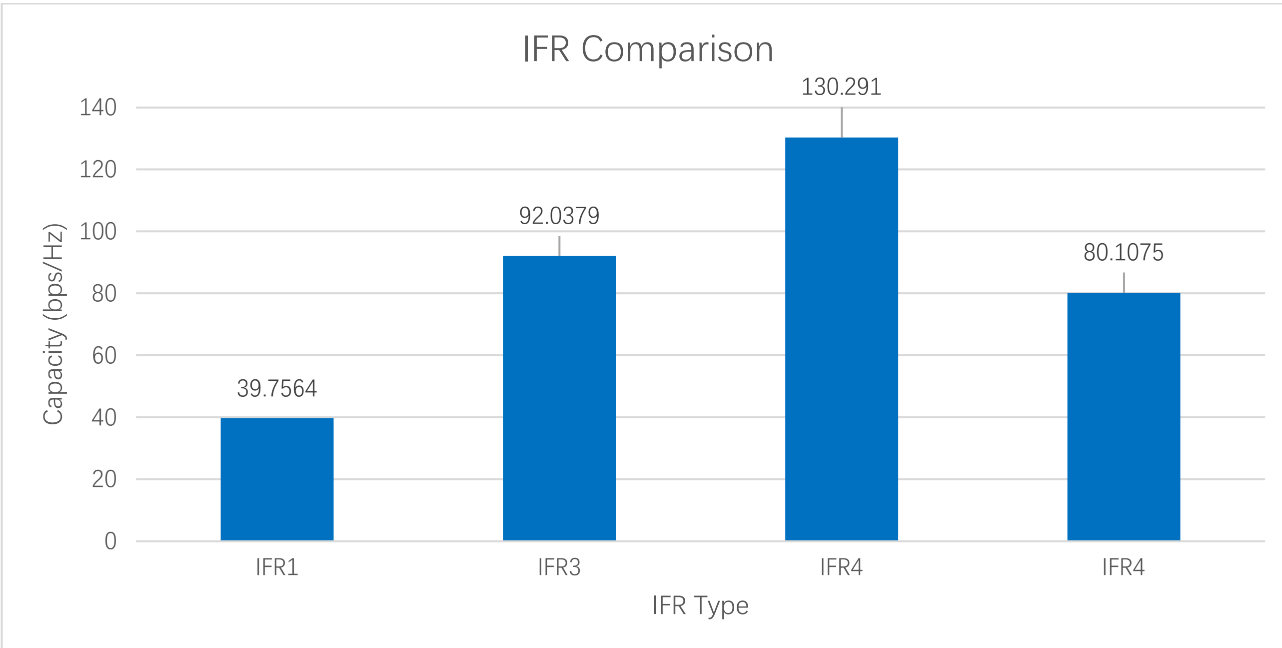

Fig. 3, Um= 8 Nf=18 avSNRdB=15

In figure 3, which is the pure IFRN experiment, it compares network capacity under different reuse factors. It is interesting to notice that the capacity of the network rises linearly through the first three approach due to the increase of N. However, a sharp drop can be witnessed in IFR, reasons can be found in discussion section.

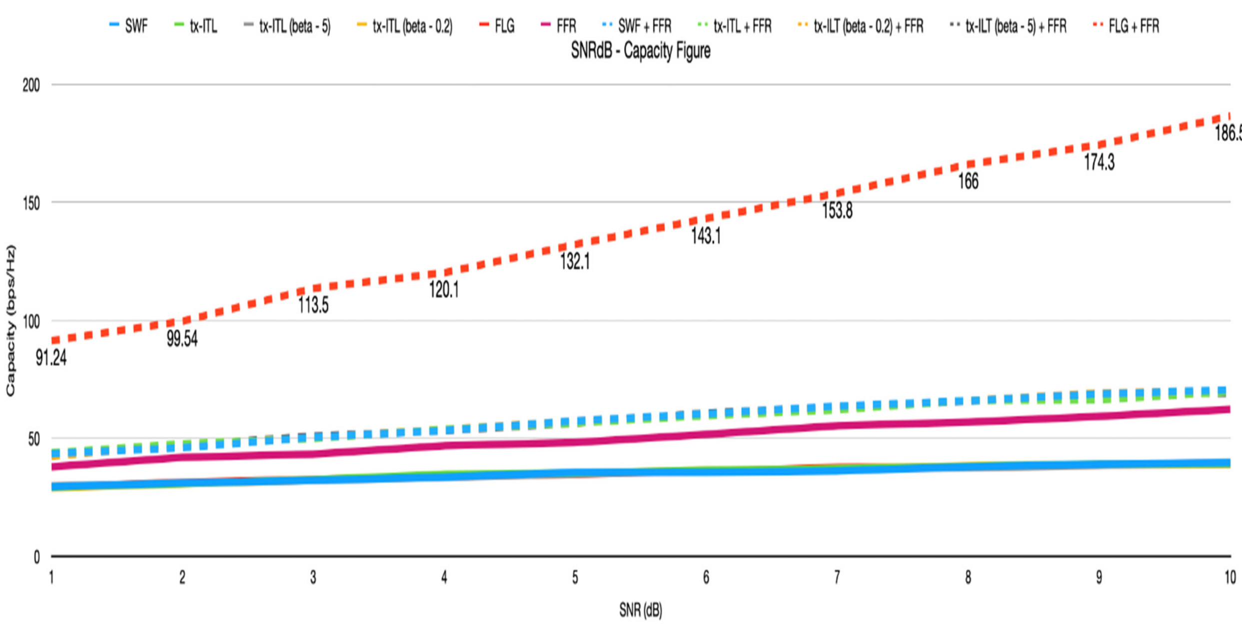

Fig.4, B=10 Um=5 Nf=3 avSNRdB=1:10 Nrun=100 S=100 beta=0.2/5 Umi=2 Umo=3

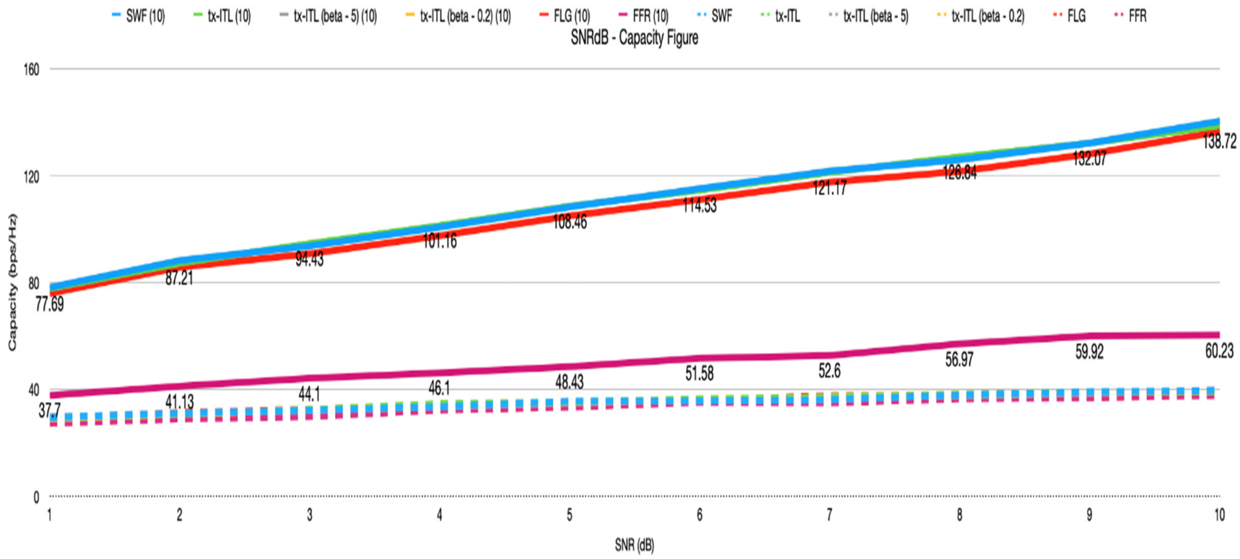

Fig.5, B=10 Um=5 Nf=3/10 avSNRdB=1:10 Nrun=100 S=100 beta=0.2/5 Umi=2 Umo=3

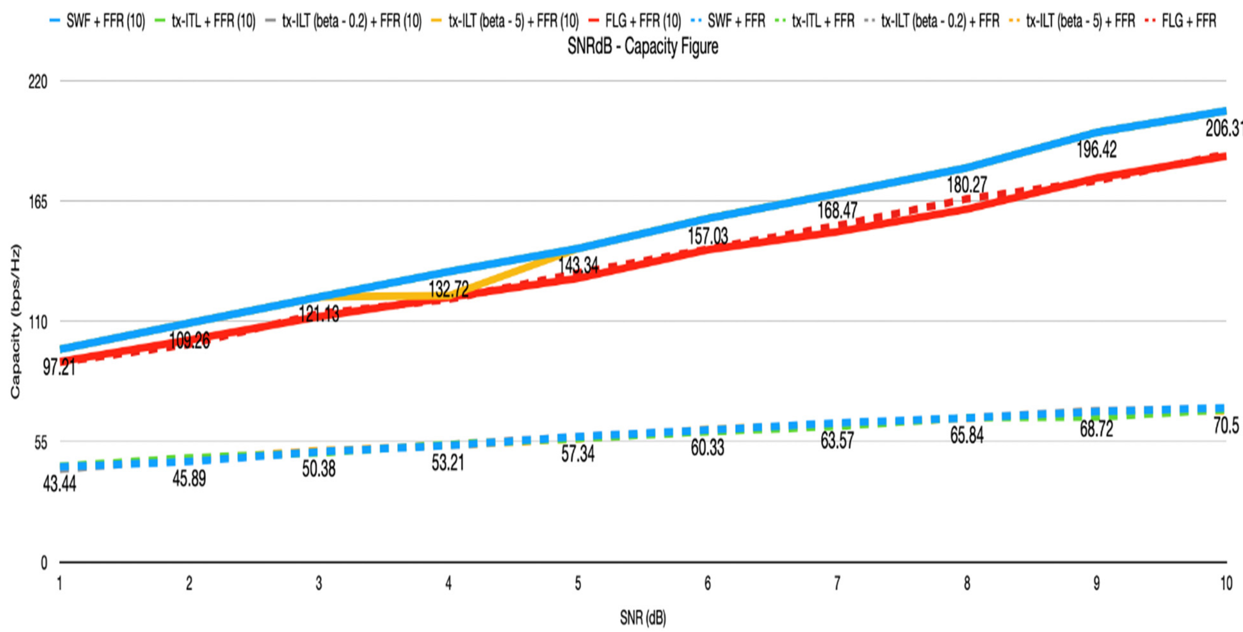

Fig.6, B=10 Um=5 Nf=3/10 avSNRdB=1:10 Nrun=100 S=100 beta=0.2/5 Umi=2 Umo=3

In the hybrid experiment, the default number of base stations 10, the average number of users per cell 5, the number of frequency channel 3, SNR range per user in dB 1 from 10, the transmit interference temperature limit of 100, the beta coefficient of 0.2 and 5 for two experiments, the average number of center users per cell 2 and the average number of edge users per cell 3, and the number of modulations of 100.

4. ANALYSIS AND DISSUSION

From the data, in pure IFR cases, the network capacity increases linearly from IFR1, IFR3 and IFR4, however, drop down in the IFR7 case which caused by poor network coverage. In this case, a 19-cell network, the cell in the center can not be repeated evenly would cause poor network capacity. Therefore, both a given network specification and the frequency reuse factor N needed to be considered during design.

The limitations can be concluded into mainly 3 factors. One is that the SIR analysis assumes the worst-case scenario. As a result, it can never be the perfect scenario. In addition, the frequency channel distribution is rigid and predetermined. Furthermore, increasing N improves SIR while decreasing the number of accessible channels in the cell (the number of channels per cell is N_c/N)

O. Popescu and C. Rose introduce the sum of capacities, which they name the collective capacity to distinguish it from the information-theoretic sum capacity employed when receivers can participate, to evaluate the overall performance of the system. [11] For hybrid cases, all plotted data show in a linear relationship at the first glance. In figure 4, the FFR method contributes to capacity which almost makes the original modulation increase by a factor of 2 in total, especially for FLG, the capacity nearly increases 5 times. The interpretation is that equation (10) ensures that users "compete" in a calculated manner to reconcile their DFA solutions autonomously. No information exchanges between the BSs will be required and the BSs literally teach and learn from each other by iterating their strategies using equation (9). [12]

However, for general FLG concept applying in a cognitive radio made practical, there is problems for this typical case. In an ideal world, a player's strategy should be optimized based on the eventual payoff, rather than the immediate reward when all the other players' tactics have settled. This will necessitate the player's ability to think beyond the present moment and into the future. However, traditional game theory lacks the mechanism to allow for such optimization, and uncontrolled competition would result in suboptimal equilibria. [13] Therefore, further study on developing an algorithm is necessary. Jie Ren and Kai-Kit Wong used a belief function to introduce cognition for each player, allowing them to quantify how the environment would react to any of their actions.

Also, it is interesting to observe the changes in beta during the experiment. Both 1 over 5 which is 0.2 and 1 times 5 which is 5, as it is shown in the result, it does not differ a lot in figure 5. In figure 5, a higher frequency channel factor reveals that it can result in a higher capacity and when the frequency channel changes from 3 to 10 in the experiment, the capacity increases more than doubled. In the case of FFR individually, it increases less and almost remains the same. In figure 6, the comparison object becomes of the one within FFR inside, still, changing the number of frequency channels seems to be more direct and effective in influencing the capacity.

However, due to two major constraints, both pure IFR and FFR approaches are rigid and inflexible. For starters, certain cells may lack sufficient frequency channels to satisfy their users, even if other cells do not require their frequencies. Second, even if frequency resources are plentiful, they cannot be used to increase capacity for active users. Therefore, a combination of frequency allocation method needs to be introduced. Instead of pursuing various signal space separation tactics or even complex joint coding/decoding methods, which would only boost capacity incrementally, both systems would be better served by developing ways to pool information and collaborate in the event of significant interference. [14] What has been discovered is that, in a relatively small cellular network, a more comprehensive coverage will increase the network capacity. Besides, to maximize network capacity, FLG with the FFR method was the most effective with a small number of frequency channels. If there are more frequency channels, doing modulations choosing methods with FFR included, avoiding using FLG, is needed. Another interesting phenomenon using methods within FFR is commonly higher than the one without and the reason caused is FFR considers both center interference and edge interference separately so that it can reduce interference compared with the traditional IFR3 method.

5. CONCLUSION

This research discovered how different methods of allocation performs in a 19-cell cellular network, from only IFRN case, FFR, tx-ITL, SWF, FLG only cases, and hybrid methods with FFR. In further frequency allocation design, attentions need to be taken on whether choose IFR, or other methods, or FFR based on methods according to the network specification. The research has demonstrated a comparison between IFRN in each case and proves that when channel for each cell is evenly distributed, the capacity can achieve ideal maximum. Moreover, if you want to maximize network capacity, priory choosing FLG with the FFR method when there is a small number of frequency channels. If there are more frequency channels, modulations methods with FFR included are an ideal option, remembering to avoid using FLG is needed. Generally, little difference in capacity under normal conditions can be seen, and the changes with dB are similar FLG performs well in the FFR environment, with plenty of capacity improvement. With the increase of dB, the capacity increase speed is accelerated FLG, and SWF performs well in the environment of Fc=10. Their capacity has been greatly improved, and the rate of change of dB also increases. Fc conditions can also increase the channel capacity; therefore, combination can make the channel capacity further increased. Among these methods, the best performance is SWF, tx-ITL, and generally, the best performance is SWF and tx-ITL under FFR+Fc=10.

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