Research on dynamic spectrum allocation method based on number of users in wireless communication system

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Abstract. As wireless communication has developed rapidly, spectrum plays an essential role in system performance. How to allocate the limited spectrum is a critical problem. In this paper, we research spectrum allocation algorithms in the wireless system, such as Simultaneous Water-Filling (SWF), Fractional Frequency Reuse (FFR), and Forward-Looking Game (FLG). Then we combine the SWF and FFR to make a new method. We demonstrate the performance of each method. Our method saves spectrum in a wireless system, and it can also reduce the interference between different users. Our method, namely Dynamic Method, has an actual meaning because the number of users always changes in some cell, and this method can adjust to the wireless system dynamically. In this way, our method might have a more general use.

1. Introduction

Improving the quality of each communication channel is very important in cellular telephone networks. One factor that affects speech quality is the level of co-channel interference. Co-channel interference results when two cells, located close to one another geographically, use the same frequency. One way to solve this interference is to assign a dedicated group of frequency channels to each cell in the network so that no two cells utilize the same frequency channel. While this would avoid co-channel interference, the network would quickly run out of frequency channels since there are only a fixed number of frequency channels available. To avoid running out of available frequency channels, cellular telephone networks employ reuse plans. Reuse plans allow a network to assign a frequency channel to more than one cell. While some co-channel interference is expected, excessive co-channel interference can be avoided by ensuring the two or more frequency channels are located apart far enough.

A fixed reuse plan involves assigning a fixed, dedicated group of frequency channels to each cell in the network. Frequency channels can be assigned to more than one cell so long as the cells are located apart far enough to avoid excessive co-channel interference. However, fixed reuse plans are inherently inflexible. The result is a degradation in channels quality.

Therefore, many reuse plans were conceived. For example, H. Eriksson suggests using mobiles to measure the signal quality of the downlink for each channel. Then channels are assigned based on those having the highest carrier to interference (C/I) ratios [1]. A somewhat different approach is expressed by G. Riva [2], where frequency channels may be allocated if their signal quality measurements meet or exceed a preset C/I threshold. In Y. Furuya et al., an adaptive channel allocation plan is described whereby the recent history of signal quality for each channel is measured and used in making channel allocation decisions [3].
FFR is based on the idea of applying frequency reuse of one in areas close to the base station and a higher reuse in areas closer to the cell border. This idea was first proposed for GSM networks (e.g. [4]) and has been adopted in the WiMAX forum [5], but also in the course of the 3GPP Long Term Evolution (LTE) standardization, e.g., in [6-7], where the focus lies on practically implementable algorithms. Several variations of such a scheme are possible. The proposals that tightly couple resource management and interference coordination fall into two categories, namely soft frequency reuse discussed in [6] and partial frequency reuse originally proposed in [8]. In [8], the reuse 1 and reuse 3 areas are on disjoint frequency bands, while [6] and [7] use the full set of available resources in the reuse 1 areas and one-third of the same resources in the reuse 3 areas. Variations are also possible concerning the transmit power level in each of the areas. In [6], the reuse 1 areas are covered with a reduced power level, while in [7], the transmit power of interfering base stations is reduced. The average cell capacity under different frequency reuse schemes is estimated in various scenarios in [9]. In [10], the authors investigated a global interference coordination scheme with beamforming antennas and full system knowledge in a dynamic 802.16e-system. Although such a global scheme is not realizable, it provides an important reference for future distributed solutions. In [11, 12], the authors study the impact of limited coordination between base stations. They use the full set of resources for reusing 1 areas and one-third of the same resources for the mobiles in the reuse 3 areas. The power is not controlled as part of the interference coordination but in the burst profile management course.

This paper proposes some efficient methods to allocate frequencies. The main method is a combination of SWF, FFR, and FLG.

2. System and Method
This section shows the research in detail.

2.1. Water-Filling Power Allocation
To one user, if there are \( N_c \) frequency channels available, the capacity for the user is given by:

\[
C = \sum_{f=1}^{N_c} \log_2 \left(1 + \frac{P_f |H[f]|^2}{\sigma^2}\right)
\]

where \( P_f \) is the transmit power at frequency \( f \). \( \sigma^2 \) is the noise power. \( H[f] \) represents the channel to each frequency. Based on the model, the total user capacity is given by:

\[
C = \max_{\{P_f\}} \sum_{f=1}^{N_c} \log_2 \left(1 + \frac{P_f |H[f]|^2}{\sigma^2}\right)
\]

Subject to: \( P_1 + P_2 + \cdots + P_{N_c} \leq P \)

The maximum value can be solved by the Lagrange multiplier method:

\[
\zeta = \sum_{f=1}^{N_c} \log_2 \left(1 + \frac{P_f |H[f]|^2}{\sigma^2}\right) + \lambda \left(\sum_{f=1}^{N_c} P_f - P\right)
\]

Where \( \lambda \) represents Lagrange multiplier param.

Setting \( \frac{\partial \zeta}{\partial P_f} = 0 \forall f \) and \( \frac{\partial \zeta}{\partial \lambda} = 0 \), we obtain:

\[
P_f = \left(\frac{1}{\lambda} - \frac{\sigma^2}{|H[f]|^2}\right)^v
\]
The water-level \( \frac{1}{\lambda} \) is the solution that satisfies:

\[
\sum_{f=1}^{N} \left( \frac{1}{\lambda} - \frac{\sigma^2}{|H(f)|^2} \right)^+ = P
\]

Water-Filling can be easily illustrated by Fig 1:

2.2. FLG

WF can maximize the value of capacity in one cell, while the algorithm of FLG can handle several cells. It can be described as follows:

\[
p^i[f] = (w^i - \frac{(c^i[f])^2 + \phi^i[f](p^{i-1}[f])^2}{c^i[f] - \phi^i[f]p^{i-1}[f]})^+
\]

\[
w^i = \frac{1}{\lambda}
\]

\[
c[f] = \frac{\sigma^2}{|H[f]|^2}
\]

\[
\phi^i[f] = -\frac{c^i[f]}{\sqrt{2c^i[f] + p^{i-1}[f]}}
\]
Where \( \phi \) is to avoid great jam to ensure that distribution is sensible. \( f \) represents frequency channel. \( i \) represents cell i. \( \lambda \) represents Lagrange multiplier param. \( p^i[f] \) represents the transmitted power of channel \( f \) in cell i.

2.3. Fractional Frequency Reuse (FFR)

The number of frequencies is very limited, so Frequency Reuse is a must for a practical system. But if all the cells reuse all the frequencies, the interference will be extremely large. If we use IFR3 (3 relative cells use 3 groups of different frequencies), frequencies may also be not enough.

FFR is based on the idea of applying frequency reuse of one in areas close to the base station and higher reuse in areas closer to the cell border. There are different powers for inner users and outer users.

![Figure 2. FFR](image)

Figure 2 is a map of FFR+IFR3. Inner users all use frequencies F, and adjacent outer users use frequencies F1, F2, and F3, respectively. \( P_1 \) is the power for inner users, which is always a small power. As the inner users in different cells reuse the same frequencies, small \( P_1 \) can reduce the interference among different cells. \( P_2 \) is the power for outer users, which is larger than \( P_1 \) because it should be enough to serve the outer users. Outer users reuse different frequencies from inner users.

2.4. A method mixing SWF and IFR

Practically, the spectrum is always limited. There is a balance between the number of frequencies and interference. If we just give out all the frequencies to each cell, all the frequencies are used to not save the spectrum, and the interference will be large.
If we allocate one frequency to one user when there are too many users, the frequency will not be enough. But if we use SWF, no matter how many users are concerned, any user can be allocated frequencies to communicate. To avoid such problems, we propose a method that combines SWF and IFR. That is to say, when there are a small number of users in one cell, we just allocate one frequency to each of them. While there are too many users, we use SWF to allocate frequencies described in Figure 3.

Figure 3. FFR+IFR3+SWF

Figure 4. Flowchart of dynamic spectrum allocation
Figure 4 is the Flowchart of dynamic spectrum allocation. To each area, including the inner and outer area, we first get the number of users and frequencies. Second, we decide to use SWF or allocate one different frequency to each user in this area. This research is trying to find whether the capacity of the network will be larger in this way.

3. Results and Discussion
In this section, we will discuss SWF or FLG, which is better? In Figure 5, the blue line is a 19-cell IFR1 and SWF system, and the grey one is a 19-cell IFR and FLG system. There are 5 users in each cell on average, and the number of total frequencies is 5.

As we can find in Figure 5, SWF is clearly better than FLG. That is because Water-Filling can allocate good frequency channels to users, and the noise will be small. The average network capacity grows with the increase of average SNR. If the noise becomes smaller, interference becomes smaller, which directly leads to the growth of capacity.

We take distance into consideration, as the distance increases, the power of other cells’ users becomes weaker. So, the interference will be different. We introduce matrices to show the distance. We simulate 7 or 19-cell IFR1 or IFR3 networks, 4 different matrices are needed. For example, Figure 6 shows the matrices for the 19-cell IFR1 network.
Figure 6. Distance matrix

$r, t, u, v$ is designed to show the different distance and $t = 0.9$  $r = 0.5$  $u = 0.3$  $v = 0.1$. If we take the hexagon structure into consideration, it will be more accurate.

Figure 7. The comparison of SWF and FLG

In Figure 7, there are 5 users in each cell on average, and the number of total frequencies is 5. As is shown in the figure, SWF with rho matrix and FLG with rho matrix networks’ average capacity is larger.
than without rho matrices. That’s because the interference from other cells becomes weaker as we use the rho matrices, which results in the growth of capacity.

When it comes to FFR, there are two areas in one cell. So, there will be more frequencies in each cell. Different transmit power is used to serve users in the cell's inner area and outer area. Smaller power to serve the inner area of the cell helps reduce the interference to the other cells. Larger power to serve the outer area of the cell is needed because of the longer distance. We set smaller power equals 0.5, and larger power equals 1.

Figure 8. The comparison of SWF and SWF+FFR

In Figure 8, the red line stands for IFR1+ SWF in a 19-cell network, and the blue line stands for IFR1 +SWF+ FFR in a 19-cell network. Although to 1 or 2 dB of SNR, the average capacity of SWF is larger, if the SNR is larger than 3 dB, the average capacity of SWF+FFR is larger. As the result shows, if smaller power equals 0.5, the FFR+SWF network is better than just the SWF network.

To FFR, if we change the power of the inner area(P1), we can get different results. How can we decide the power so that we can have the largest capacity? We try different P1 to find which value is the best.
Figure 9 is the simulation of IFR3+FFR in a 19-cell network. There are 5 users in each cell on average, and the number of total frequencies is 15. The X axis is the average SNR, Y axis is the power of the inner area, Z axis is the average network capacity. In Figure 10, we can find that 0.7 is the best power for P1 because the network's capacity in 0.7 is the largest. As is demonstrated, when we use the IFR3 structure, the cells using the same frequencies are relatively far than using the IFR1 structure.

Next step, we take IFR1+FFR and IFR3+FFR in a 19-cell network, for example, to find the change of capacity. Different colours of lines stand for the different number of frequencies.
Figure 11 is the result of the simulation of an SWF +IFR3 +FFR in a 19-cell network. Figure 12 is the result of the simulation of an FLG +IFR3 + FFR in a 19-cell network. Figure 13 is the result of the simulation of an SWF +IFR1+ FFR in a 19-cell network. Figure 14 is the result of the simulation of an FLG +IFR1+ FFR in a 19-cell network. There are 10 users in each cell on average in all the simulations.

We can find that in certain circumstance, the result of SWF and FLG is similar. The capacity will be larger if we use the IFR3 structure rather than IFR1.

Figure 15 is the result of the simulation of an SWF +IFR3+FFR in 10, 20, and 50 channels. Figure 16 is the result of the simulation of an FLG +IFR3+FFR in 10, 20, and 50 channels. Figure 17 is the result of the simulation of an SWF +IFR1+FFR in 10, 20, and 50 channels. Figure 18 is the result of the simulation of an FLG +IFR1+FFR in 10, 20, and 50 channels.
Figure 15 is the result of the simulation of a (mix)SWF, IFR3, and FFR in a 19-cell network. Figure 16 is the result of the simulation of a (mix)FLG, IFR, and FFR in a 19-cell network. Figure 17 is the result of the simulation of a (mix)SWF +IFR1+ FFR in a 19-cell network. Figure 18 is the result of the simulation of a (mix)FLG +IFR1 +FFR in a 19-cell network. There are 10 users in each cell on average in all the simulations.

We can find that the capacities of the new methods are smaller than before. Despite the decrease of capacity, it still has its practical meanings and advantages. And we can also find that if the number of channels is larger, the capacity increases faster with the increase of SNR.

4. Conclusion
In this paper, we research some algorithms in spectrum allocation. We propose a method that combine IFR and SWF. We also research the relationship between the number of users and spectrum. Such a method can promote the spectrum's efficiency and reduce the interference between different users.

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