SPECIAL TOPIC

Soft Fractional Frequency Reuse

Abstract:
A soft fractional frequency reuse scheme is proposed to fulfill full frequency reuse for the 4G mobile communications system. This scheme can be implemented in three types, and using what type of the scheme can be decided during practical applications, depending on the link gain of the physical layer. The implementation of soft fractional frequency reuse in one of the three types is studied. The study results show that the frequency reuse factor of this scheme may reach 1/3–1. The simplified form of this scheme has been successfully applied in the 4G experimental network in Shanghai , and provides a way to fulfill full frequency reuse in systems.

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The frequency reuse factor of the First Generation (1G) system is far less than 1. For example, for 7–cell frequency reuse, the frequency reuse factor is 1/7. The frequency reuse factor of the Second Generation (2G) system has been improved greatly. For example, in the Global System for Mobile communication (GSM), which is FDMA plus Time Division Multiple Access (TDMA) system, the frequency reuse factor can reach 1/4–1/3; in the 2G Code Division Multiple Access (CDMA) system[1] and the 3G digital mobile communications system, such as Wideband Code Division Multiple Access (WCDMA) system, the frequency reuse factor can reach 1, which enhances the efficiency of the spectrum and reduces network deployment costs. Therefore, as for the future Enhanced 3G (E3G) and the Fourth Generation (4G) mobile communication systems, it is hoped that 1 or higher frequency reuse factor would be used.

The three mainstream standards of 3G systems are all based on CDMA technology. After the in–depth study of E3G technologies such as Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO), MIMO is regarded as the basic technology for future E3G and 4G systems, with its advantage of high communication capacity. Orthogonal Frequency Division Multiple Access (OFDMA) technology, with the industrial recognition for its advantages such as higher spectral efficiency, is likely to become the basic multiple access technology for E3G and 4G systems. The 3rd Generation Partnership Project (3GPP) Long Term Evolution plan (LTE)[2] has confirmed to use OFDMA[3] as the multiple access technology for downlink in the E3G system. Moreover, a large number of research institutions has claimed that they will use OFDMA to replace CDMA as the basic multiple access technology. But OFDMA technology, based on FDMA, also brings a new challenge to frequency reuse. If inter–cell interference, intra–frequency network and the improvement of frequency efficiency in OFDMA system can not be solved well, the OFDMA–based E3G and 4G systems are bound to face application difficulties. Thus, the frequency reuse scheme based on FDMA becomes one of the research priorities in E3G and 4G systems.

The studies of frequency reuse scheme for E3G have started in 3GPP LTE. This paper proposes a soft fractional frequency reuse scheme. The scheme provides a method to solve the problem of frequency reuse in mobile communication systems. It's simplified form has been used in Shanghai's 4G experimental network, successfully. This paper is structured as follows; in section 1, system model of soft fractional frequency reuse is introduced; section 2 introduces three forms of the soft fractional frequency reuse scheme, and analyzes the features of the second form; section 3 presents their application in 4G experimental network. Conclusion is given at the end of the article.

1 System Model

The users in every cell of the wireless cellular network are divided into two groups. One is the edge user group, and the other is the central user group. The whole available frequency is divided into two non–overlapping parts: $\boldsymbol{G}$ and $\boldsymbol{F}$. $\boldsymbol{F}$ is further divided into 3 sub–channels: $\boldsymbol{F}_1$, $\boldsymbol{F}_2$ and $\boldsymbol{F}_3$, all of which are available for edge users in adjacent cells 1, 2, and 3 respectively. Each cell edge is divided into 12 edge fields, and the 12 edge

This work was funded by the National Natural Science Foundation of China under Grant 60496312, and by 863 Program of China under Grants 2003AA12331004 and 2006AA01Z260.

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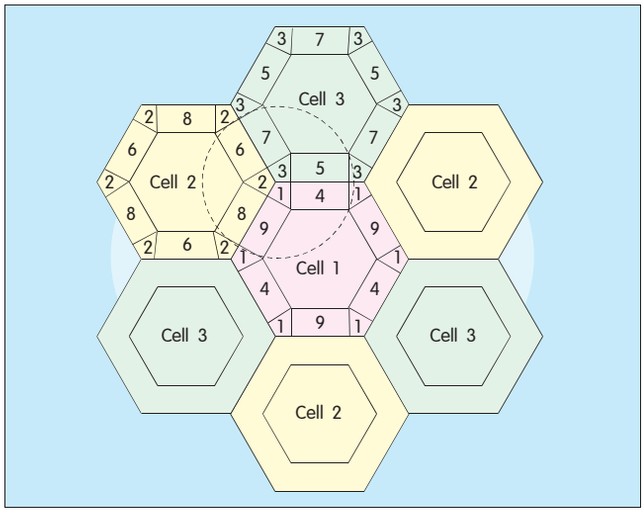


◀ Figure 1. System model.

▼ Table 1. Mapping relationship of frequency sets and edge fields

Edge Fields	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Form Ⅰ	$f_1f_4f_9$	$f_2f_6f_8$	$f_3f_5f_7$	$f_1f_4f_9$	$f_3f_5f_7$	$f_2f_6f_8$	$f_3f_5f_7$	$f_2f_6f_8$	$f_1f_4f_9$
Form Ⅱ	f_1f_4	f_2f_6	f_3f_5	f_1f_4	$f_3f_5f_8$	f_2f_6	$f_3f_5f_7f_9$	$f_2f_6f_8$	$f_1f_4f_7f_9$
Form Ⅲ	f_1	f_2	f_3	$f_1f_4f_6$	$f_3f_5f_8$	$f_2f_4f_6$	$f_3f_7f_9$	$f_2f_5f_8$	$f_1f_7f_9$

fields are then divided into two sorts, namely Sort 1 Edge Field and Sort 2 Edge Field. Sort 1 Edge Field refers to the junction area of the three bordering cells (see the edge fields marked "1", "2" and "3" in Figure 1). Sort 2 Edge Field refers to the remaining edge areas, except Sort 1 (see the edge fields marked "4", "5", "6", "7", "8" and "9" in Figure 1). For the bad communication environment at the cell edge, the nine edge fields in the dashed circle become the main study object during frequency planning.

2 Soft Fractional Frequency Reuse Scheme

Table 1 shows a frequency planning solution based on soft fractional frequency reuse in the edge fields 1–9 (named C_1–C_9) in Figure 1.

Take Form II in Table 1 as an example. The soft fractional frequency reuse scheme is introduced in detail as follows and illustrated in Figure 2.

The sub-band sets of $\boldsymbol{G}$ and $\boldsymbol{F}$ are available frequencies for users at the centers of the cells.

The frequency planning for users at the edges of the cells is: let $\boldsymbol{F} = \bigcup_{i=1}^{3} \boldsymbol{F}_i = \bigcup_{j=1}^{5} \boldsymbol{u}_j$ ($\boldsymbol{u}_1 = f_1 \cup f_4$, $\boldsymbol{u}_2 = f_2 \cup f_6$, $\boldsymbol{u}_3 = f_3 \cup f_5$, $\boldsymbol{u}_4 = f_7 \cup f_9$, $\boldsymbol{u}_5 = f_8$), where $\boldsymbol{u}_j$ (j =1,..,5) represents non-overlapping frequency sub-band set. The frequencies in each set can be continuous or discontinuous. Frequency sub-band sets $\boldsymbol{u}_1$, $\boldsymbol{u}_2$ and $\boldsymbol{u}_3$ are respectively allocated to the edges of Cells 1, 2, and 3, providing services for the edge users. The allocation of sub-band set $\boldsymbol{u}_4$ and $\boldsymbol{u}_5$ is:

(1) Reassign a frequency sub-band set $\boldsymbol{u}_4$ for the field marked "4" in Figure 1; $\boldsymbol{u}_4$ serves users in this region.

(2) Reassign a frequency sub-band set $\boldsymbol{u}_5$ for the field marked "8" in Figure 1; $\boldsymbol{u}_5$ serves users in this region.

(3) Reassign a frequency sub-band set $\boldsymbol{u}_5$ for the field marked "5" in Figure 1; $\boldsymbol{u}_5$ serves users in this region.

(4) Reassign a frequency sub-band set $\boldsymbol{u}_4$ for the field marked "7" in Figure 1; $\boldsymbol{u}_4$ serves users in this region.

Characteristics of soft fractional frequency reuse scheme Form Ⅱ:

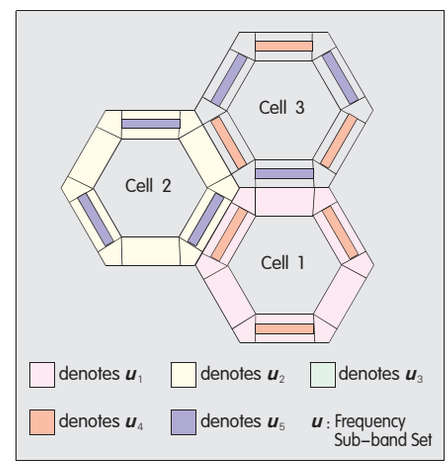
(1) Making better performance for cell edge users, and improving the frequency reuse ratio.

(2) Although the pre-programming of frequency is different formally, it will not result in unfair resource assignment. For example, Fields 4, 8, 5, and 7 can choose frequencies (or sub-carriers) from frequency sub-band sets $\boldsymbol{u}_4$, $\boldsymbol{u}_5$, $\boldsymbol{u}_4$ and $\boldsymbol{u}_5$, respectively. If frequencies in these sub-band sets are not sufficient for them, Fields 4, 8, 5, and 7 can then choose frequencies from frequency sub-band sets $\boldsymbol{u}_1$, $\boldsymbol{u}_2$, $\boldsymbol{u}_3$ and $\boldsymbol{u}_3$, respectively, according to some rules. However, Fields 9 and 6 will only choose frequencies from frequency sub-band sets $\boldsymbol{u}_1$ and $\boldsymbol{u}_2$ respectively. But they can coordinate available frequencies with Fields 1 and 2, respectively. The numbers of available frequency sub-bands are same in edges of three cells.

(3) When the interference of cell edge users is serious, there are two solutions to mitigate the interference: deducing the number of frequencies in sub-band sets $\boldsymbol{u}_4$ and $\boldsymbol{u}_5$; or increasing the area of the edge field appropriately. When there is hardly or no serious interference for cell edge users, the number of frequencies in set $\boldsymbol{u}_4$ and $\boldsymbol{u}_5$ may be adjusted properly, or the area of the edge field may be decreased to improve the frequency reuse.

3 Application in Shanghai FuTURE 4G TDD Experiment Network

The simplified form of soft fractional frequency reuse scheme has been applied in the 4G TDD experimental network in Shanghai successfully. As shown in Figure 3, there are two Access Points (AP), namely AP_1 and AP_2, in the experimental network. The distributed antenna arrays at the lecture theatre and the Golden Sun connect to AP_1; the



▲ Figure 2. Soft fractional frequency reuse scheme Form Ⅱ.

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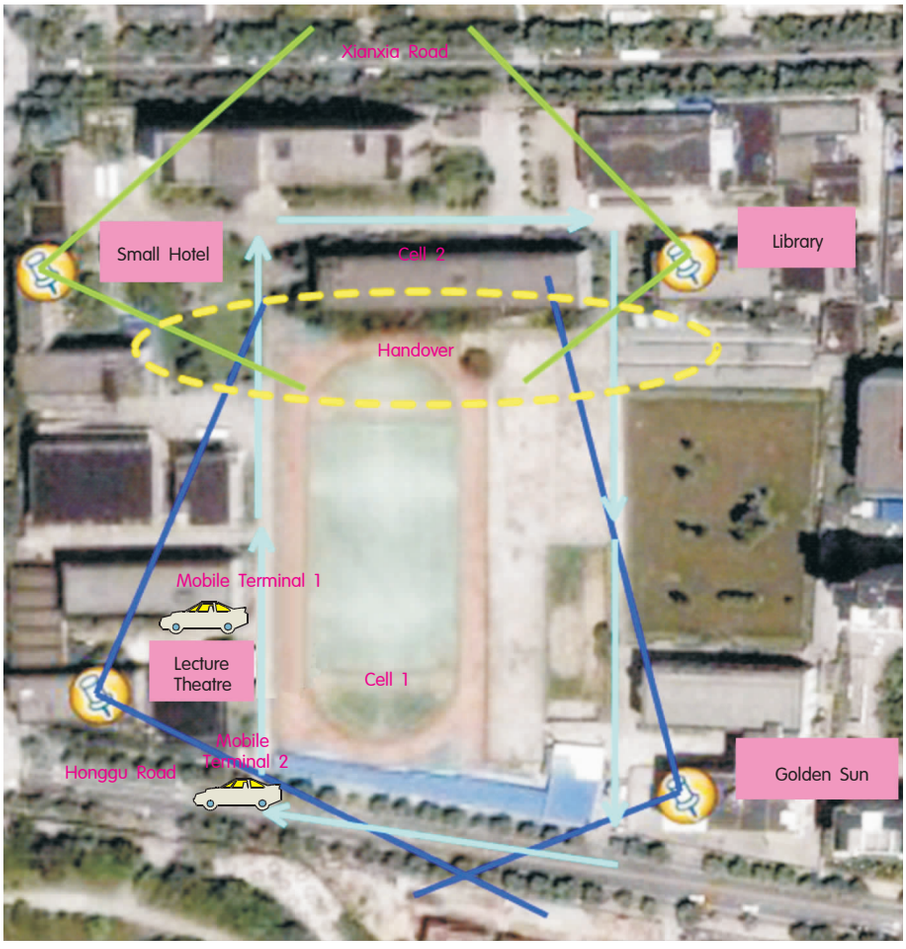

▲Figure 3. Shanghai 4G experimental network with two users and two base stations.

distributed antenna arrays at the small hotel and the library connect to AP_2. Each site has four antennas. In Figure 3, the region circled by the blue line represents Cell 1, and that circled by the green line represents Cell 2.

The soft fractional frequency reuse scheme with two cells is applied in Shanghai 4G experimental network. Its results are as follows:

(1) When there is only user, MT_1, in Cell 1, MT_1 will use the whole spectral resources in Cell 1, and the rate can reach 100 Mb/s.

(2) When there are two users, MT_1 and MT_2, in Cell 1, each user uses half of the frequency resource, enjoying the highest rate of 50 Mb/s.

(3) When MT_1 and MT_2 move inside Cell 1, each user uses half of the frequency resource, and can also get the highest rate of 50 Mb/s.

(4) When MT_2 in Cell 1 moves to the handover region, but maintains the connection with Cell 1, MT_1 and MT_2 respectively use half of the frequency resource of Cell 1, enjoying the highest rate of 50 Mb/s.

(5) When MT_2 moves to the handover region, and connects with Cell 2, MT_1 uses half of the frequency resource of Cell 1, and MT_2 uses the half resource of Cell 2. Each user enjoys the highest rate of 50 Mb/s, and the frequency reuse factor is 0.5.

(6) When MT_1 in Cell 1 and MT_2 in Cell 2 move to appropriate positions, (for example, MT_1 is near the lecture theatre, while MT_2 moves to the library), the two users enjoy the total frequency resources in both Cells 1 and 2, and can get the highest rate of 100 Mb/s. The frequency reuse factor is 1.

4 Conclusions

This paper proposes a soft fractional frequency reuse scheme in order to meet the requirements of improving spectral efficiency and intra-frequency network in 4G mobile communication systems. The scheme has three forms for implementation, and a proper form may be selected according to the link gain of the physical layer in practical applications. The soft fractional frequency reuse scheme has been simply applied in Shanghai FuTURE 4G TDD experimental network, with a successful result. The studies show that the system frequency reuse factor can be up to 1/3–1 when adopting the soft fractional frequency reuse scheme, which provides a good solution to improving intra-frequency network and frequency utilization.

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Biographies

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Xu Xiaodong, Phd, is a lecturer at the WTI of BUPT. He is engaged in researches on advanced mobile communication systems and key technologies, including generalized distributed network architecture, radio resources management strategies, and 3G enhancement and standardization. He has published 10 papers and applied for 5 patents.

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