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Virtual-Cell Frequency Reuse Scheme to Support Seamless Service in Femtocell Environments

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Abstract: Multiple access technologies based on Orthogonal Frequency Division Multiplexing (OFDM) yield evolutionary advantages for the next generation wireless communication systems. Wireless communication systems based on Orthogonal Frequency Division Multiple Access (OFDMA) increase channel capacity over broad bandwidth and improve the bandwidth efficiency. To maximally use resource in OFDMA-based wireless networks, frequency reuse factor should be one. However, this leads the degradation of performance caused by co-channel interference (CCI). Due to this, we propose an Virtual-Cell Frequency Reuse (VCFR) Scheme to eliminate CCI in cell edge as well as to increase spectral efficiency. Since VCFR allocates the same subset of channel bandwidth in three adjacent sectorized outer regions within three different cells, it is suitable for femtocell environment. Simulation result validates that proposed scheme improves the maximum throughput compared with existing frequency reuse schemes.

1. Introduction

In wireless mobile environments, large bandwidth and high Quality of Services (QoS) are recently required to support the increased demand of users for multimedia services. OFDMA is one of promising solutions for the next generation broadband wireless access systems. It has been adopted for Worldwide Interoperability for Microwave Access (WiMAX), Ultra Mobile Broadband (UMB) and the 3rd Generation Partnership Project Long Term Evolution (3GPP LTE) [1], [2], [3].

OFDMA is a multi-user version of the OFDM digital modulation scheme. OFDM that uses many slowly-modulated narrowband signals instead of rapidly-modulated wideband signal is developed to eliminate the Inter Symbol Interference (ISI) caused by radio multipath fading channel [4]. In OFDMA, multiple users simultaneously transmit their symbols through different orthogonal subcarriers [4]. Subsets of one or more subcarriers can be applied different modulation schemes and they may be mapped into different users. Therefore, OFDM systems support high data rate services by optimally using spectrum and improve channel efficiency with dynamic resource allocation.

To efficiently use limited downlink resource in OFDMA-based wireless communication system, Frequency Reuse Factor (FRF) should be increased by up to one [1], [5]. However, as FRF approaches to one, channel quality is degraded due to CCI. It is difficult to provide reliable services to users nearby cell boundary. In OFDMA cellular networks, various frequency reuse schemes have been proposed to alleviate inter-cell interference [1], [2], [5]. Among them, sectorization scheme divides a cell into several sectorized cells and uses two types of frequency reuse schemes [5]. One is that each sector in a cell uses all the system channel bandwidth allocated to the cell, and the other is that channel bandwidth is divided into several sub-channels and each sub-channel is allocated in only one sector. However, it has disadvantage that users located at cell edge experience the reduction of the Signal to Interference and Noise Ratio (SINR) due to CCI. To eliminate CCI in cell boundary region, Fractional Frequency Reuse (FFR) has been proposed [2]. In FFR, each cell is divided into two concentric regions and FRF used in cell core differs from that in cell edge. The FRF of cell core is one while that of cell boundary is less than one.

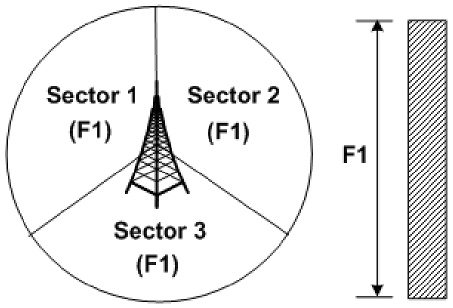
In general, Break-Before-Make (BBM) handoff is used in the OFDMA-based wireless broadband networks because each cell uses the same system channel bandwidth [6]. Make-Before-Break (MBB) handoff, however, will be necessity for femtocell environments, because handoff will frequently occur due to the very small cell. This concept can be applied to the Beyond 3rd Generation (B3G) communication systems or the 4th Generation (4G) communication systems including WiMAX, and LTE [7]. As cell size decreases, frequency reutilization and system capacity increase. However, this leads numerous Base Stations (BSs) and induces inter-cell handoff frequently. If handoff has failed, the service may be temporarily disrupted or even terminated abnormally. The smaller the cell size is, the more necessity of MBB handoff is required to provide seamless service.

In this paper, we propose an VCFR to support seamless services in femtocell environments. In VCFR, a cell is divided into two concentric regions, cell core and cell edge, and the cell edge is partitioned into three sectors. Adjacent three sectors in three different cells use the same subset of system channel bandwidth. Since it supports seamless service in femtocell environments as well as reduces CCI of users at cell edge, VCFR scheme yields better performance than sectorization and FFR schemes.

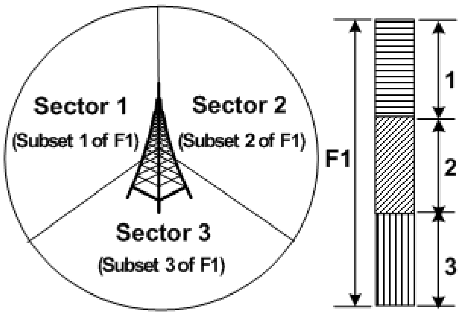
The rest part of the paper is organized as follows. Section 2illustrates frequency reuse and handoff schemes, and Section 3.describes the VCFR. In Section 4. performance of VCFR is compared with those of sectorization and FFR schemes in terms of throughput. Finally, Section 5gives conclusion.

2. Related Work

To achieve optimal system capacity in cellular systems, various kind of channel assignment schemes have been researched [8], [9]. In Fixed Channel Allocation (FCA)



(a)Type A



(b)Type B

Figure 1. Example of sectorization scheme in case that a cell is divided into three sectorized cells.

scheme, the number of channels used in a cell is fixed and is permanently allocated to each cell. If system channel bandwidth is divided into subsets, the minimum number of subsets is calculated as

$$\sqrt{N} = \frac{D}{\sqrt{3}R}, \tag{1}$$

where D is frequency reuse distance and R is the radius of each cell. FCA yields good performance under heavy traffic conditions. However, if traffic is unevenly distributed all cells, FCA is unable to efficiently use wireless resource due to its low flexibility of channel assignment. In Dynamic Channel Allocation (DCA) scheme, all channels are kept in a central pool and free channels are dynamically allocated to new calls arrived. Since DCA adaptively assigns channels to new calls as reuse distance, future blocking probability in the vicinity of the cell, usage frequency of the candidate channel, average blocking probability of the overall system, and instantaneous channel occupancy distribution, it can maximize overall utilization of channel [9]. However, before channel allocation to call, DCA should perform complex computation to determine appropriate channel. Therefore, DCA can increase call set up delay and can disrupt service.

Two frequency reuse schemes for OFDMA system have been proposed [1], [2], [5]. In sectorization scheme, each cell is divided into typically three or more sectors and BS is equipped with directional antennas as many as the number of sectors covering sectorized area in a cell. Sectorization scheme has two types of frequency reuse schemes as shown in Fig. 1 [5]. One is that each sectorized cell uses all the system channel bandwidth allocated to a cell as shown in Fig. 1(a). This improves system capacity and spectrum efficiency, but users can suffer not only inter-cell interference but also intra-cell interference. Fig. 1(b) shows the other frequency reuse method for sectorization scheme. Available bandwidth for each sector is a part of entire channel bandwidth, F1. Subsets 1, 2, and 3 in F1 are allocated to sectors. This method can reduce inter-cell interference as well as intra-cell one, compared with the previous one. However, users located in cell boundary experience degradation of SINR.

To get rid of the interference of users in cell boundary, FFR has been proposed in [1] and [2]. In FFR, each cell is partitioned into two concentric regions with different radius as shown in Fig. 2. System channel bandwidth is partitioned into four subsets, 0, 1, 2 and 3, and only two of them are able to use in a cell. For example, cell A uses subset 0 in inner region and subset 1 in outer region. Cell B uses subset 0 in inner region and subset 2 in outer region and Cell C uses subset 0 in inner region and subset 3 in outer region. Thus, a cell uses multiple reuse factors, i.e., FRF of cell core is one while FRF in cell boundary is 1/3. Accordingly, connection quality and throughput of users near by cell boundary is assured by overcoming interference problem. However, some subsets are unable to use in a cell, this may cause the decrement of system capacity.

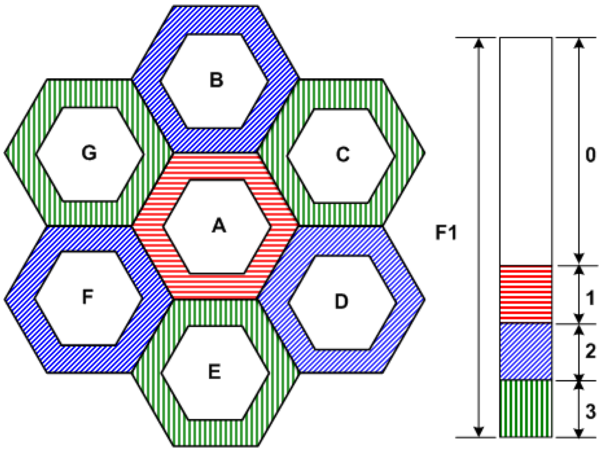


Figure 2. Example of FFR scheme in case that FRF in cell core is one and FRF in cell boundary is 1/3.

Two types of handoffs such as BBM handoff and MBB handoff are used in OFDMA-based networks [1], [5], [7]. In BBM handoff referred as hard handoff, serving BS connected to a user releases the allocated channel before it transfers to target BS located in a cell that the user intends to move. In MBB handoff referred as soft handoff, the connection to the target BS is established before the connection to the serving BS is broken. In IEEE 802.16e system, BBM handoff is default mode and MBB handoff is optional [5]. All the cells use the same frequency channel in OFDMA-based system, because its FRF becomes one. Hence BBM handoff is inevitable in sectorization and FFR schemes.

3. Virtual-Cell Frequency Reuse Scheme

A cell is divided into two concentric regions, inner and outer, and outer region is partitioned into three sectorized regions.

Therefore, each cell is configured to an omni-directional antenna for inner region and three sector antennas for sectorized outer regions. System channel bandwidth is partitioned into four disjoint subsets for each region of a cell. These partitions are related to different size of regions. In other words, the proportion of a region size out of a cell size is associated with that of a subset out of system channel bandwidth for a cell. And the size of concentric regions, inner and outer regions, dynamically depends on traffic conditions.

System channel bandwidth is divided into four disjoint subsets, and one of them is allocated in inner region, and other subsets are allocated in sectorized outer regions considering the sub-channel bandwidth used in sectorized regions of adjoining two cells. Fig. 3 depicts an example of the VCFR scheme. A subset 0 of system channel bandwidth, F1, is for inner region so that FRF is one. And the other subsets,1, 2, and 3, of F1 is allocated in partitioned three outer regions in a cell, respectively, so that FRF is also one. In this scheme, frequency subsets allocated in a part of outer region are different among cells. For example, sector A_1 in cell A uses a subset 1, A_2 uses a subset 2, and A_3 uses a subset 3. In an adjacent cell, cell B, B_1 uses a subset 3, B_2 uses a subset 1, and B_3 uses a subset 2. In other adjacent cell C, C_1 uses a subset 2, C_2 uses a subset 3, and C_3 uses a subset 1. Therefore, adjacent three sectorized outer regions from three different cells, A_1, B_2, and C_3, make a virtual cell using same subset of system channel bandwidth. And this reuse pattern repeats through all the system.

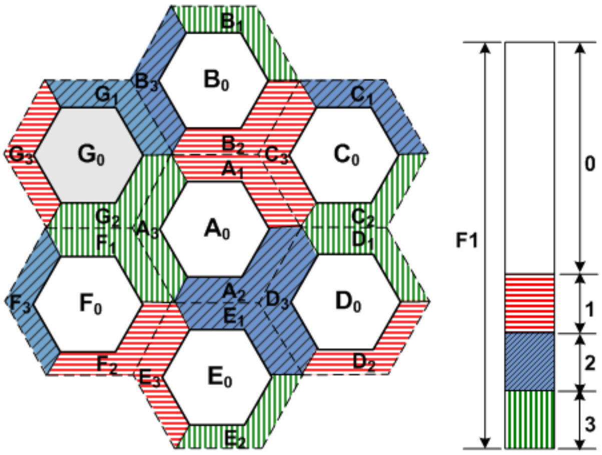


Figure 3. Example of VCFR.

VCFR enhances the spectral efficiency compared with the FFR because VCFR scheme can utilize all the subcarriers allocated in a cell while FFR is unable to use a part of it. And reuse distance of outer region is increased as illustrated by Fig. 4, so it overcomes CCI in cell boundary compared with the sectorization scheme. Moreover, VCFR scheme can support MBB handoff to users within cell edge if they move to adjacent cell by employing the same subset in three adjacent sectors. Since VCFR scheme makes possible to support smooth handoff, it is well suitable in femtocell environments.

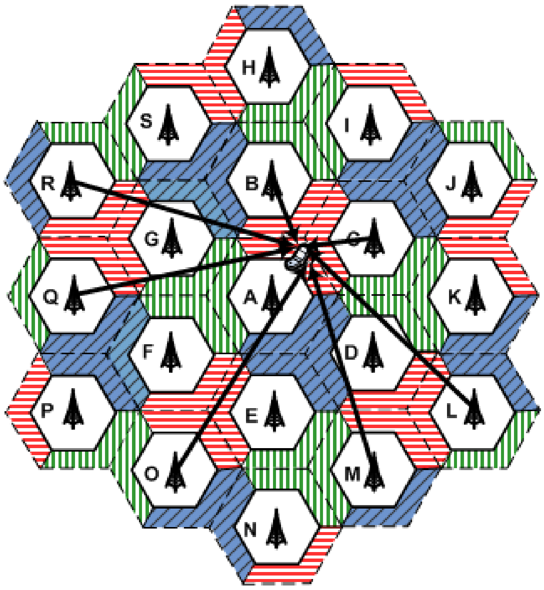


Figure 4. Example of CCI in case that a user locates in a partitioned outer region for VCFR.

4. Performance Evaluation

To evaluate the performance of the proposed VCFR scheme, we consider IEEE 802.16 standard and perform simulations using c++. For performance comparison, we choose original version of FRF one, sectorization, and FFR scheme. The cellular system consists of 19 cells and the distance between base stations is 1 km. The transmission power of each BS is 20 W. The carrier frequency is 2.3 GHz, system channel bandwidth is 10 MHz, and the number of subcarriers is 1024. Excluding the physical layer overhead such as pilot signal, the number of subcarriers for data transmission is 768. 768 subcarriers consist of 96 subchannels by grouping the contiguous subcarriers so that a BS maximally accommodates 96 users at once. Modulation and coding scheme (MCS) are determined by the reported SIR from a user as shown in Table 1. Considering the carrier frequency and the cell radius, COST-WI urban micro model is applied as channel model [10]. Therefore, path loss is calculated as

$$PL(d) = 31.81 + 40.5 \log(d), \tag{2}$$

where d is the distance between the transmitter and receiver.

Fig. 5 shows the throughput of four schemes, basic, sectorization, FFR, and VCFR. In the basic scheme, entire cells in the system use the same channel bandwidth. Therefore, the throughput of basic is the worst since there is inevitably inter-cell interference.s FFR reduces CCI in cell boundary, however, interference in cell core still exist like basic scheme as FRF of cell core is one. And FFR is impossible for a BS to accommodate maximum users since it is disallow transmission on some subsets of subcarriers allocated in each sector. In sectorization scheme, we assume that each BS is configured with three sectorized cell and frequency reuse scheme is applied as Fig. 1(b). Because interference from other cells is alleviated by using directional antenna, it achieves better per-

Table 1. MCS table.

Modulation	Coding Rate	SIR(dB)
QPSK	1/12	-4.34
QPSK	1/8	-2.80
QPSK	1/6	-1.65
QPSK	1/4	0.13
QPSK	1/3	1.51
QPSK	1/2	4.12
QPSK	2/3	6.35
16QAM	1/2	9.50
16QAM	2/3	12.21
64QAM	1/2	13.32
64QAM	2/3	16.79
64QAM	5/6	20.68

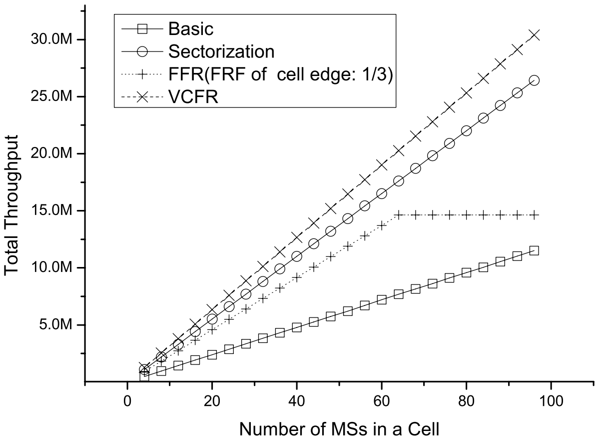


Figure 5. Total throughput.

formance compared with basic and FFR schemes. However, sectorization scheme do not consider users in cell boundary, so that throughput of it is less than that of proposed VCFR. In addition, VCFR supports more users and increases spectral efficiency compare with FFR.

5. Conclusion

In this paper, we proposed VCFR to support high spectral efficiency and seamless service in OFDMA-based femtocell networks. In VCFR, a cell divided into two concentric region, inner and outer, to improve performance of users located in cell boundary and a outer region is divided into three sectors to reduce interference and provide high spectral efficiency. Since three adjacent sectorized regions in different three cells use same frequency bandwidth, VCFR scheme has an advantage of supporting smooth handoff by applying MBB handoff which is is very befitting in femtocell network.

Acknowledgment

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