SUBCHANNEL BEAMFORMING TECHNIQUES FOR FRACTIONAL FREQUENCY REUSE IN OFDMA SYSTEMS

PichayaChaipanya

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Telecommunication Engineering

Suranaree University of Technology

Academic Year2013

เทคนิคก่อรูปลำคลื่นช่องสัญญาณย่อยสำหรับการใช้ความถี่บางส่วนซ้ำในระบบโอเอฟดีเอ็มเอ

นางสาวพิชญาชัยปัญญา

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรดุษฎีบัณฑิต
สาขาวิชาวิศวกรรมโทรคมนาคม
มหาวิทยาลัยเทคโนโลยีสุรนารี
ปีการศึกษา 2556

SUB CHANNEL BEAMFORMING TECHNIQUES FOR

FRACTIONAL FREQUENCY REUSE IN OFDMA SYSTEMS

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

Thesis Examining Committee

____

(Asst. Prof. Dr. Chutima Prommak)

Chairperson

____

(Asst. Prof. Dr. Monthippa Uthansakul)

Member (Thesis Advisor)

____

(Asst. Prof. Dr. Peerapong Uthansakul)

Member

____

(Asst. Prof. Dr. Chanchai Thaijiam)

Member

____

(Dr. Dheerasak Anantakul)

Member

____

(Prof. Dr. Sukit Limpijumnong)

Vice Rector for Academic Affairs

and Innovation

____

(Assoc. Prof. Flt. Lt. Dr. Kontorn Chamniprasart)

Dean of Institute of Engineering

พิชญา ชัยปัญญา : เทคนิคก่อรูปลำคลื่นช่องสัญญาณย่อยสำหรับการใช้ความถี่บางส่วนซ้ำในระบบโอเอฟดีเอ็มเอ (SUB CHANNEL BEAMFORMING TECHNIQUES FOR FRACTIONAL FREQUENCY REUSE IN OFDMA SYSTEMS) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.มนต์ทิพย์ภา อุฑารสกุล, 135 หน้า.

ปัจจุบันมาตรฐานของเครือข่ายเซลลูลาร์บรอดแบนด์ เช่น ไวแมกซ์ หรือ แอลทีอี ล้วนแล้วแต่อาศัยการใช้เทคโนโลยีโอเอฟดีเอ็มเอ เนื่องจากเทคโนโลยีโอเอฟดีเอ็มเอสามารถเพิ่มประสิทธิภาพแบนด์วิดธ์ของระบบ และสามารถลดปัญหาสัญญาณแทรกสอดได้ อย่างไรก็ตามเพื่อเป็นการใช้ความถี่ให้มีประสิทธิภาพสูงสุดในระบบเซลลูลาร์ จึงมีการใช้ความถี่ซ้ำในทุก ๆ เซลล์ ด้วยเหตุนี้จึงทำให้เกิดสัญญาณแทรกสอดระหว่างเซลล์ที่อยู่ติดกัน ดังนั้นเพื่อหลีกเลี่ยงปัญหาดังกล่าวจึงมีการเสนอแนวทางแก้ปัญหาในเทคโนโลยีโอเอฟดีเอ็มเอ โดยการกำหนดพื้นที่บริเวณกลางเซลล์หรือขอบเซลล์ให้ใช้ความถี่ซ้ำได้บางส่วน (Fractional Frequency Reuse: FFR) นอกจากนี้ การใช้เทคนิคการก่อรูปลำคลื่นในแนวระนาบถูกนำเสนอเพื่อแก้ปัญหาสัญญาณแทรกสอดจากเซลล์ข้างเคียง อย่างไรก็ตามปัญหาดังกล่าวยังคงเกิดขึ้นได้หากทิศทางของผู้ใช้และทิศทางของสัญญาณแทรกสอดจากเซลล์ข้างเคียงตรงกัน เพื่อแก้ปัญหาดังกล่าว การใช้สายอากาศรูปแบบต่าง ๆ เพื่อก่อรูปลำคลื่นในแนวดิ่งในระบบเซลลูลาร์ที่มีการใช้ความถี่บางส่วนซ้ำจึงถูกนำเสนอ แต่เมื่อพิจารณาถึงการใช้งานจริงในระบบเซลลูลาร์ปัจจุบันซึ่งมีการจัดวางสายอากาศที่สถานีฐานในลักษณะแถวลำดับเชิงเส้นในแนวดิ่ง ดังนั้นการนำเอาแนวคิดของการก่อรูปลำคลื่นที่ได้กล่าวมาแล้วนั้นมาใช้จึงเป็นเรื่องที่ยุ่งยากและสิ้นเปลือง เนื่องจากต้องเปลี่ยนชุดระบบสายอากาศใหม่ทั้งหมด

ดังนั้นในวิทยานิพนธ์นี้จึงมีความสนใจในการลดปัญหาสัญญาณแทรกสอดจากเซลล์ข้างเคียงโดยใช้หลักการก่อรูปลำคลื่นในแนวดิ่ง เพื่อก่อรูปลำคลื่นให้กับกลุ่มความถี่ที่แตกต่างกันในพื้นที่บริเวณกลางเซลล์และขอบเซลล์ โดยใช้สายอากาศต้นแบบจากสายอากาศจริงที่สถานีฐานในระบบเซลลูลาร์ เพื่อพิจารณาอัตราขยายของสายอากาศเมื่อก่อรูปลำคลื่นในแนวดิ่งที่มุมต่างกัน โดยสายอากาศต้นแบบจากสายอากาศจริงที่สถานีฐานในระบบเซลลูลาร์ถูกจำลองด้วยโปรแกรม CST Microwave Studio เพื่อเปรียบเทียบแนวโน้มของแบบรูปการแผ่พลังงานของสายอากาศกับผลจากเอกสารข้อมูลของสายอากาศจริง โดยแบบรูปการแผ่พลังงานที่ได้จากโปรแกรมจะถูกนำไปพิจารณาเปรียบเทียบประสิทธิภาพของระบบเมื่อระบบมีการใช้การก่อรูปลำคลื่นเพียงหนึ่งลำคลื่นในแต่ละเซกเตอร์ซึ่งเป็นการก่อรูปลำคลื่นของสายอากาศที่สถานีฐานในระบบเซลลูลาร์ในปัจจุบันเทียบกับการก่อรูปลำคลื่นให้กับกลุ่มความถี่ที่แตกต่างกันในพื้นที่บริเวณกลางเซลล์และขอบเซลล์

จากนั้นมีการวัดแบบรูปการแผ่พลังงานของสายอากาศในสภาพแวดล้อมจริง เพื่อหาแนวโน้มประสิทธิภาพของผู้ใช้งานในระบบเซลลูลาร์ที่มีการใช้ความถี่บางส่วนซ้ำ จากการทดสอบพบว่าผลที่ได้จากการทดสอบมีแนวโน้มใกล้เคียงกับค่าที่ได้จากการจำลองในคอมพิวเตอร์ ซึ่งสามารถยืนยันได้ว่า เทคนิคก่อรูปลำคลื่นช่องสัญญาณย่อยสำหรับการใช้ความถี่บางส่วนซ้ำสามารถเพิ่มประสิทธิภาพให้แก่ผู้ใช้งานในระบบเซลลูลาร์ที่มีการใช้ความถี่บางส่วนซ้ำได้

สาขาวิชา วิศวกรรมโทรคมนาคม ลายมือชื่อนักศึกษา ____________________

ปีการศึกษา 2556 ลายมือชื่ออาจารย์ที่ปรึกษา ______________

PICHAYA CHAIPANYA : SUB CHANNEL BEAMFORMING TECHNIQUES FOR FRACTIONAL FREQUENCY REUSE IN OFDMA SYSTEMS. THESIS ADVISOR : ASST. PROF. MONTHIPPA UTHANSAKUL, Ph.D., 135 PP.

BEAMFORMING/FRACTIONAL FREQUENCY REUSE/LINEAR ARRAY CELLULAR SYSTEM/OFDMA

Several occurring standards for cellular broadband networks, such as WiMAX or LTE, are based on OFDMA. This is because it can reduce multipath interference and enhance bandwidth efficiency of the systems. However, the OFDMA technique cannot provide full benefits due to the problem of Inter-Cell Interference (ICI) from neighboring cells. To tackle the problem, the frequency resource is divided and differently allocated between cell-center and cell-edge area, so called Fractional Frequency Reuse (FFR). Furthermore, the concept of horizontal beamforming technique has been proposed to tackle ICI problem. However, the problem still remains when the directions of ICI signal from neighboring cells are the same as the one of desired signal in the cell of interest. Moreover, several antenna types used to perform vertical beamforming cooperating with FFR technique have been proposed to steer their beams to desired directions. Nevertheless, the mentioned concepts are considerably not practical as there are some difficulties in installing the large antennas at Base Station (BS).

Therefore, this thesis aims to reduce ICI using vertical beamforming in two areas: cell-center and cell-edge, separately. Moreover, beam patterns are simulated according to the BS antenna currently utilized nowadays in order to see its real performance. Then, the radiation patterns are tested under real circumstance. The radiation pattern from experimental results is compared with the ones from simulation and commercial data. Also, the performance in terms of SINR and channel capacity employing experimental results are exposed to confirm that the proposed concept is able to improve the performance of cellular networks.

School of Telecommunication Engineering Student's Signature_________________

Academic Year 2013 Advisor's Signature_________________

ACKNOWLEDGEMENTS

The author wishes to acknowledge the funding support from Suranaree University of Technology (SUT).

The grateful thanks and appreciation are given to the thesis advisor, Asst. Prof. Dr. Monthippa Uthansakul for her consistent supervision and thoughtfully comment on several drafts and advice towards the completion of this study.

My thanks go to Asst. Prof. Dr. Peerapong Uthansakul, Asst. Prof. Dr. Chutima Prommak, Asst. Prof. Dr. Chanchai Thaijiam and Dr. Dheerasak Anantakul for their valuable suggestion and guidance given as examination committees.

The author is also grateful to the financial support from Telecommunications Research and Industrial Development Institute (TRIDI).

Finally, I would also like to express my deep sense of gratitude to my parents for their support and encouragement me throughout the course of this study at the Suranaree University of Technology.

Pichaya Chaipanya

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

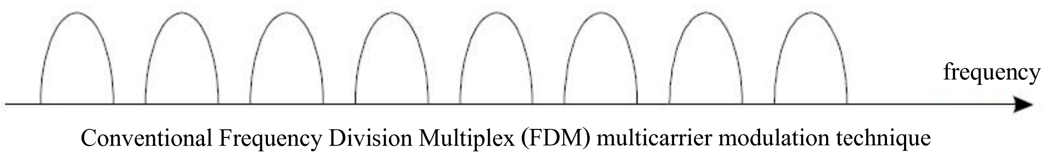
Figure **Page**

CHAPTER I

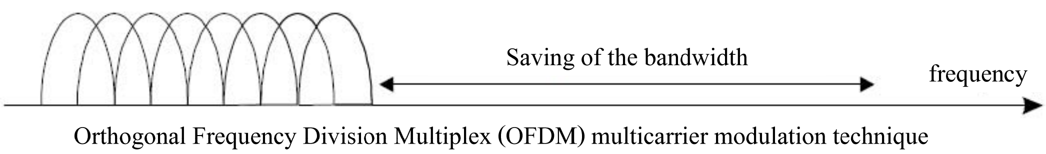
INTRODUCTION

1.1 Background of problems

Several occurring standards for cellular broadband networks, such as WiMax or Long-Term Evolution (LTE), are based on Orthogonal Frequency Division Multiple Access (OFDMA). The multiple access in OFDMA technique is based on Orthogonal Frequency Division Multiplexing (OFDM) technique which is developed from Frequency Division Multiplexing (FDM) technique. In FDM technique, all of the frequency band is divided into several bands, each band is called subchannel. To protect interfering between subchannels, bandwidth of each subchannelmust not be overlapped. In OFDM technique, subchannel is separated to several groups which are called subcarrier. Bandwidth of each subcarrier can overlap the other subcarriers using



(a)



(b)

Figure 1.1 Subchannel in(a) FDMAand (b) OFDMAtechnique.

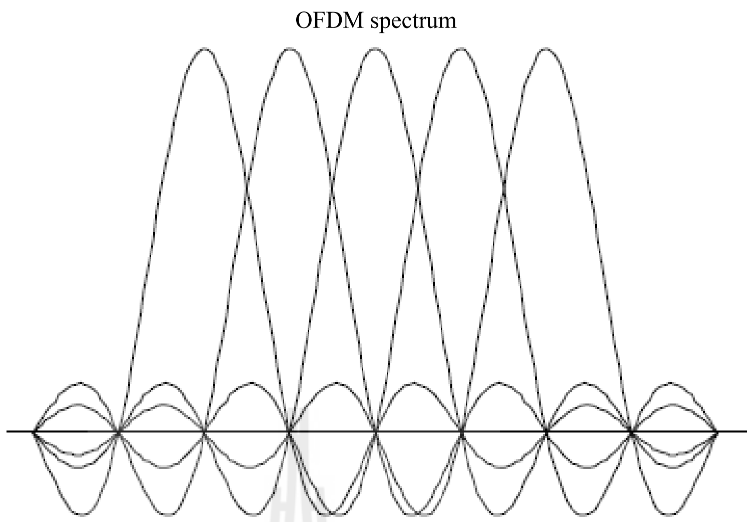


Figure 1.2 Subchannel inOFDMAtechnique.

orthogonality as shown in Figure 1.1.From Figure 1.2, side band of orthogonal signal aftermodulation doesnot interfere the other subcarriers. According to this, OFDM technique can improve bandwidth efficiency due to bandwidth of each subcarrier can overlap the other adjacent subcarriers. In OFDMA technique, subcarriers are separated to each user which is varied in time and frequency as shown in Figure 1.3. For this reason, the side band interference is eased. Therefore, several occurring standards are based on OFDMA technique.

However, the OFDMA technique cannot provide full benefits due to the problem of Inter-Cell Interference (ICI) from neighboring cells. In cellular networks, the users staying in cell-center area exploit high signal strength as they are close to the Base Station (BS). On the other hand, the signal strength is degraded when users are moving close to the cell-edge. Moreover, the users located at cell-edge also experience interference signal coming from neighboring cells as shown in Figure 1.4. To tackle the problem, the frequency resource is divided and differently allocated between cell-

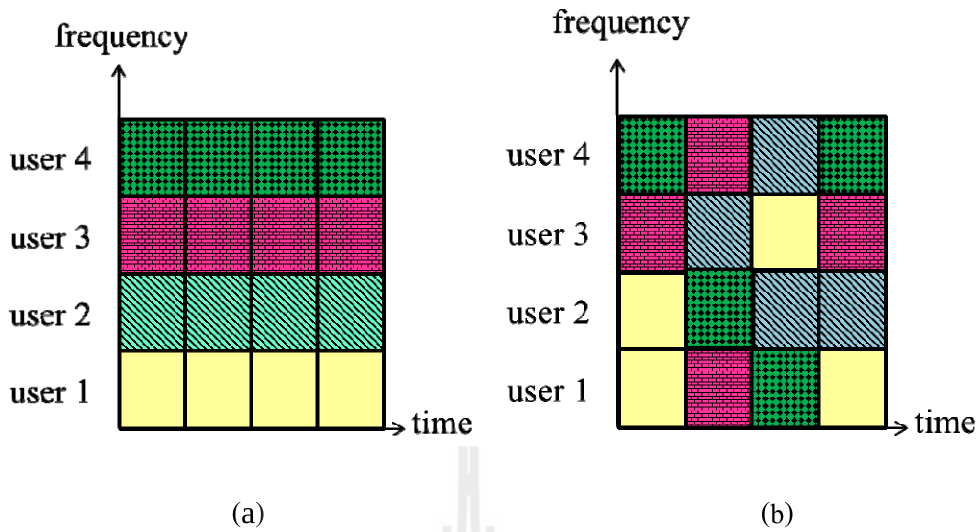


Figure 1.3 Subcarrier separation of(a) FDMAand (b) OFDMAtechnique in time and frequency domains.

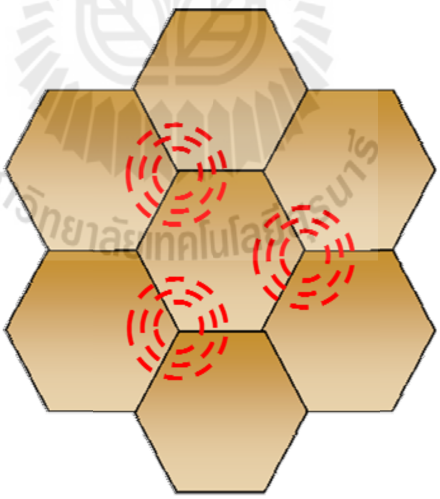


Figure 1.4 Inter-cell interference when using the same frequency in every cell for cellular networks.

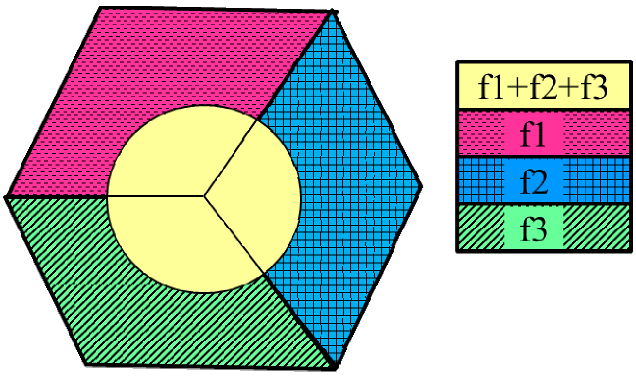


Figure 1.5 Fractional frequency reuse.

center and cell-edge areas, this technique is called Fractional Frequency Reuse (FFR) as shown in Figure 1.5.

From several literatures, many FFR schemes have been proposed. However, the problem of ICI still remains due to interference signals coming from cell-center to cell-edge of neighboring cells which are using the same subcarrier group. Therefore, the concept of horizontal beamforming has been proposed to tackle the ICI problem. However, the problem still remains when the directions of ICI signal from neighboring cells are the same as the one of desired signal in the cell of interest. Moreover, several antenna types have been proposed to steer beam toa desired direction. Nevertheless, this concept is considerably not practical as there are some difficulties in installing a planar array at BS.

Therefore, this thesis aims to reduce ICI using vertical beamforming in two areas: cell-center and cell-edge, separately. Moreover,the BS antenna which is currently employed at cellular BS is taken into account in order to see real performance when implementing the proposed concept at BS. A vertical beamforming technique with different mainbeam directions is designed. In addition, the desired beam direction mention earlier is selected to provide the highest performance of cellular networks.

1.2 Research objectives

The objectives of this research are as follows:

1.2.1 To study FFR technique for OFDMA systems in order to choose a suitable FFR scheme to reduce interference signal.

1.2.2 To propose a concept of vertical beamforming to BS antenna in order to enhance the performance of cellular networks.

1.3 Scope and limitation of the study

1.3.1 Performance of cellular networks when utilizingFFR and vertical beamforming is considered.

1.3.2 An antenna array is designed using CST Microwave Studio according to the BS antenna currently employed at cellular BS.

1.3.3 A vertical beamforming having two different mainbeam directions for cell-center and cell-edge is designed.

1.3.4 Radiation pattern of BS antenna currently employed at cellular BS is measured and compared with commercial data from Commscope company.

1.3.5 Some experiments are performed off-line. Then, the recorded data is simulated in computer including FFR techniques to evaluate the performance of cellular networks.

1.4 Contributions

1.4.1 The performance in terms of SINR employing FFR technique with different frequency allocation schemes is considered. The FFR scheme providing maximum performance is adopted for the rest of this thesis.

1.4.2 The performance comparison of vertical and horizontal beamforming is discussed to confirm that vertical beamforming provides higher SINR to the system.

1.4.3 BS antenna currently utilized nowadays is applied to vertical beamforming concept, two beams separately utilized for cell-center and cell-edge areas.

From literatures, the vertical beamforming has never been demonstrated with the commercial antenna utilized at BS.

1.4.4 The optimum different angles of mainbeam directions are revealed in this thesis work. These mainbeam directions providing maximum SINR at cell-center and cell-edge areas are used to reveal the system performance comparing with the one employing single beam.

1.4.5 The radiation patterns of fabricated antennas are tested under real circumstance. The performance in cellular networks obtained from experimental results is exposed to confirm that the proposed concept is able to improve the performance of cellular networks.

1.5 Thesis organization

The remainder of this thesis is organized as follows. Literature review is discussed in Chapter 2. This chapterpresents severalFFR techniques, each scheme of

FFR is discussed. Then, this section explains beam-formation in cellular networks.In addition, detail of beamforming collaborating with FFR technique is presented.

Chapter 3 presents the fundamental and principle of OFDM technique. Then, OFDMA technique based on OFDM technique is described.

Chapter 4 describes the fundamental of cellular networks. Afterwards, the classification of FFR techniques is presented. Then, a basic and classification of beamforming technique is shown. Then, the performance in cellular networks in terms of Signal to Interference plus Noise Ratio (SINR) and channel capacity is discussed in this chapter.

Chapter 5 presents the performance of cellular networks with FFR techniques. Furthermore, radiation pattern of BS antenna from CST Microwave Studio is investigated. Then, the performance of cellular networks using simulation results from CST Microwave Studio and MATLAB programming is shown.

In Chapter 6, experimental setup and the obtained results are presented. The performance in cellular networks obtained fromexperimental results is simulated. Then, the performance obtained from experimental results are compared with the ones from simulation results.

In the last chapter, Chapter 7 provides conclusion of the research work and suggestion for further study.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter presents fundamental concept of FFR techniques and also beamforming scheme. Some literatures related to FFR and beamforming are discussed to light up the motivation and contribution of the proposed thesis work.

2.2 Fractional Frequency Reuse

Principle of FFR technique has been proposed for GSM networks. Also, FFR technique has been provided in WiMax Forum and used for LTE technology. This technique separates the area of cellular network into two regions: cell-center and cell-edge. From literature review, there are several forms of subcarrier allocation in FFR technique. For example as shown in Figure 2.1, all subcarriers are used at cell-center region for every cell while those all subcarriers are also separated to three groups which are used at each cell-edge area as shown in the figure. In addition, different transmitted power is assigned to each subcarrier. The transmitted power of subcarrier utilized at cell-center region is reduced in order to limit its coverage (Huawei Tech. Rep., 2005). Also, transmitted power of subcarrier groups at cell-edge region is reduced when those group are not used (Ericsson Tech. Rep., 2005). For another type of FFR as shown in Figure 2.2, all available subcarriers are divided into four parts: one part is used at cell-center area while other parts are separated used at cell-edge as shown in the figure. In general, the cell-center and cell-edge areas are separated by

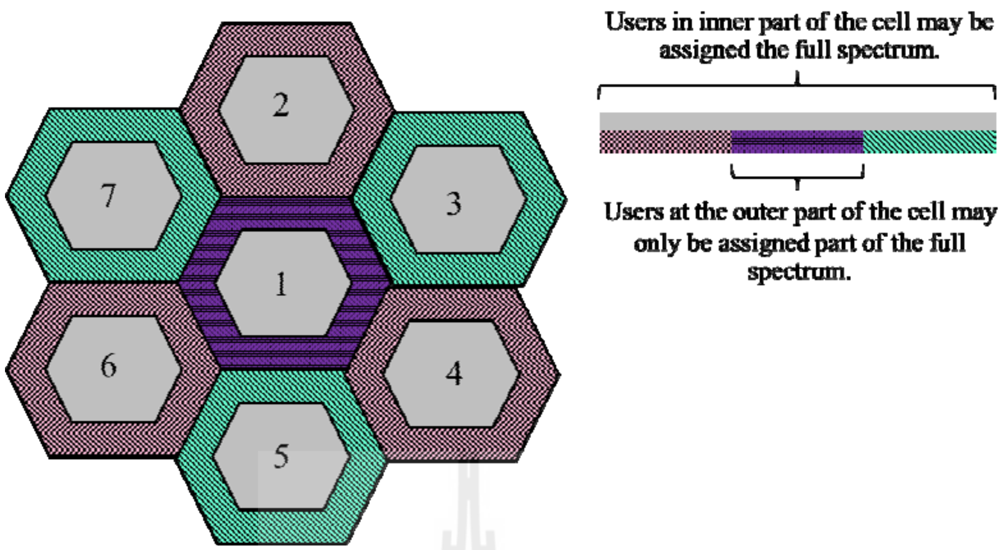


Figure 2.1 FFR technique with three subcarrier groups division.

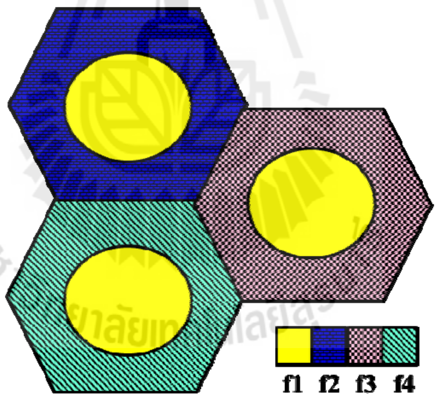


Figure 2.2 FFR technique with four subcarrier groups division.

considering distance between BS and user. In case of distance between BS and user is less than the threshold distance, subcarrier group of cell-center is utilized. In the other hand, subcarrier group of cell-edge is utilized when distance between BS and user is longer than the threshold distance (Sternad, Ottosson, Ahlen and Svensson, 2003). The SINR is also one parameter to determine which subcarrier utilized in cell-center or cell-edge regions is chosen. For example, subcarrier group for cell-center is utilized when SINR is higher than a threshold SINR. On the other hand, subcarrier group utilized in cell-edge area is chosen (Necker, 2007). Furthermore, to improve the system capacity and reduce ICI, not only FFR technique but cell sectorization is also employed in which each cell is divided into three sectors. According to this, all available subcarriers are used at cell-center area. For cell-edge area, all available subcarriers are separated to three groups in which each group is used in each sector. In addition, relay stations are installed at cell-edge area to reduce ICI as shown in Figure 2.3 (Yue, Ximing, Xiaopeng, Zhengguang and Yan, 2009). For other type, all available subcarriers are separated to two groups. One is called cell-center group employed at cell-center area and another one is called cell-edge group. The cell-edge group is divided into three groups where each group is employed at different sector as shown in Figure 2.4. As pointed out earlier, the threshold value for both distance and SINR (Lei, Zhang and Yang, 2007) is significant to determine the performance of cellular networks. Therefore, this thesis also takes this issue into account for research work.

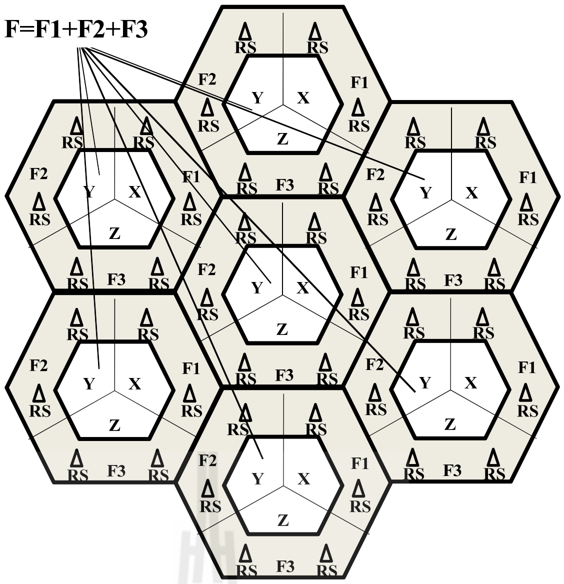


Figure 2.3 FFR technique with cell sectorization and relay stations.

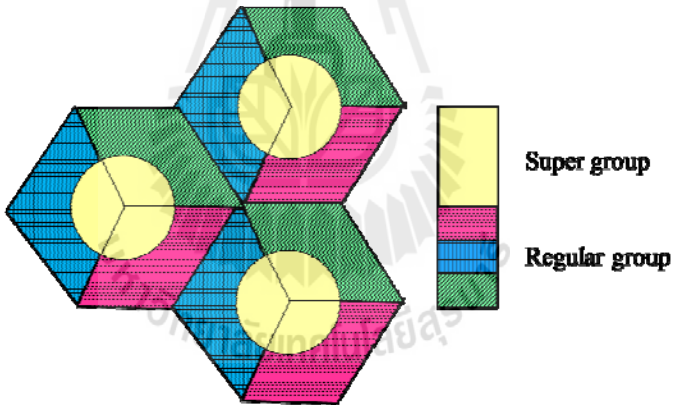


Figure 2.4 FFR technique including cell sectorization with two subcarrier group division.

2.3 Beamforming in cellular networks

Nowadays, the demand of cellular networks have been dramatically increased over the last decades. One technique capable of improving the cellular network performance is a smart antenna technique. The smart antennas are constituted by multiple element antennas accompanied by suitable signal processing units either at the transmitter or receiver side of a communication link. The term of beamforming means pointing the antenna beam towards a desired user and nulls or low side lobes towards interfering sources. According to this, the smart antennas are capable of considerable improving the quality of signal transmission in a multi user environment. There are lots of literatures concerning beamforming in cellular networks such as simulation of SINR performance in GSM System employing switched-beam smart antenna system (Akma, Ismail and Jumari, 2002). The switched-beam antenna systems are a typical type of smart antenna used to reduce co-channel interference of GSM cellular systems. The obtained results have indicated that the system SIR can be improved when applying switched beam antennas. Also, some works (Tianmin, R. and Richard, J.L., 2005; Tianmin, R. and Richard, J.L., 2006) have revealed that beamforming can handle unknown ICI in multi cell environment. The obtained results have confirmed that this basic approaches can be easily extended to handle unpredictable interference in cellular networks.

2.4 Beamforming with FFR technique

As mentioned earlier, interference signal can be reduced using FFR technique and the performance of the cellular networks can be improved using beamforming technique. Therefore, the performance of cellular networks can be extremely improved when using FFR collaborating with beamforming technique. From literatures, combination of FFR technique and semi-smart antennas with learning Genetic Algorithm (GA) (Yapeng, Xu, Ma and Cuthbert, 2010; Yapeng, Xu, Ma and Cuthbert, 2009) has been proposed. The outcome results have revealed that the semi-smart antennas can produce flexible coverage patterns for BS and the learning algorithm can coordinate the coverage patterns between BS to minimize interferences for user as shown in Figure 2.5. According to this, the total capacity improvement is a result of improving channel condition on user in terms of minimizing ICI. However, this system is complex due to the requirement of an accurate calculation for covering area of all users. Next, horizontal beamforming with FFR technique in cellular networks has been proposed (Wendy, Qinghua and Shilpa, 2010). The FFR technique has been used at cell-edge region and horizontal beamforming scheme is used for pointing mainbeam towards a desired user and pointing nulls towards interfering Direction. From the research work presented (Lott, 2006), collision statistic of antenna beams depends on mobile terminal distribution. The authors have also shown that the more collisions happened in the frames, the more beams are directed in that area to subdivided the region with the most collision probability as shown in Figure 2.6. However, the mentioned scheme cannot improve the performance of the system when the direction of ICI signal coming from neighboring cell is at the same direction of a desired signal in the cell of interest. Then Naizheng, Per-Henrik, Jens, Claudio and Jeroen, 2008 have proposed the utilization of vertical beamforming scheme with FFR

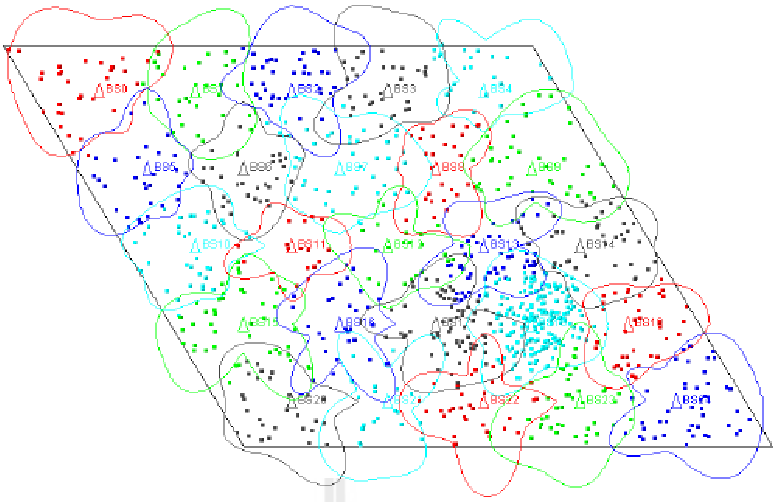


Figure 2.5 Coverage patterns for BS using semi-smart antennas and GA algorithm (Yapeng, Xu, Ma and Cuthbert, 2010; Yapeng, Xu, Ma and Cuthbert, 2009)

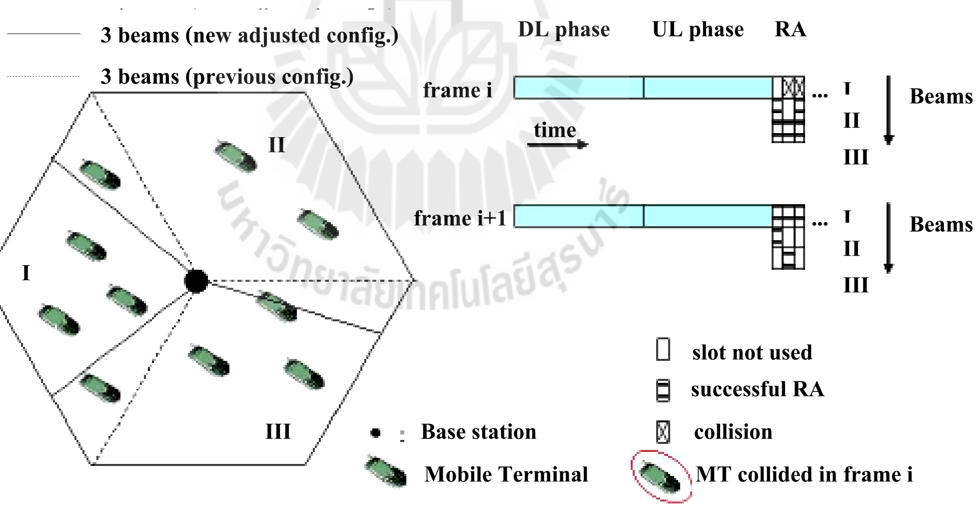


Figure 2.6 Horizontal beamforming with FFR technique in cellular networks (Lott, 2006)

in cellular networks. The mainbeam direction producing the highest performance of the system and coverage all of the sector is considered. Nevertheless, the signal strength in cell-center is degraded when changing a downtilt angle. On the other hand, the signal-strength at cell-edge is degraded when a downtilt angle of antenna is increased.

From above literature reviews, those proposed concept has not been taken into account for the real BS antenna. Therefore, this research aims to apply a vertical beamforming technique to reduce interference signal from neighboring cells. The antenna array commercially utilized at BS is also adopted to see the real performance for cellular systems. To validate the proposed concept, some experiment are performed using the real antenna at BS.

2.5 Chapter summary

This chapter gives a detail and literature survey of beamforming scheme for FFR technique in cellular networks. A principle of FFR technique in cellular networks and the different allocation subcarrier groups of FFR technique are presented. Then, reduction of interference signal transmitted from neighboring cells using beamforming scheme is described. Afterwards, beamforming scheme for FFR technique in cellular networks to reduce ICI from neighboring cells and enhance the signal in a desired direction is discussed. Nevertheless, the mentioned concept does not work very well for the case having ICI signal coming from the same direction of the desired signal for the cell of interest. In addition, the beam coming from cell-center introduces high level of interference to the neighboring's cell-center. To handle this problem, this thesis applies a vertical beamforming scheme collaborating with FFR technique for cellular network. Furthermore, BS antenna utilized nowadays is taken into account to see the real performance for cellular systems.

CHAPTER III

INTRODUCTION TO OFDMA TECHNIQUE

3.1 Introduction

In this chapter, two methods for full duplex in communication systems, Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) are delineated (Ray, H., 2002). Then, four multiplexing and access techniques are described. First, the principle of FDMA technique is presented, which is the basic of Orthogonal Frequency Division Multiple Access (OFDMA) technology. Then, Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) technique are described. The different structures of each technique are indicated. Finally, the fundamental of OFDMA technique is also depicted followed by the concept of subchannel division in OFDMA technique.

3.2 Full-duplexing systems

For bidirectional communication, many users want to send data as well as receive data. A half-duplex system provides communication for both directions, but only one direction at a time. A full-duplex system allows communication for both directions simultaneously. For this system, the user simultaneously requires two channels, one for sending the information from mobile to BS (reverse link) and the other for receiving the information from BS to mobile (forward link). This system can be separated into two methods, FDD and TDD (Sajal, K.D, 2010).

3.2.1 Frequency Division Duplexing (FDD)

FDD is a duplexing in terms of frequency domain. Two separated frequency bands are used in this technique. One is used to transmit the information from BS to mobile so called forward band. The other one is called reverse band which is used for transmitting information from mobile to BS as shown in Figure 3.1. The frequency bandwidth of 5 MHz is used for forward and reverse bands separately, so the total bandwidth is 10 MHz. For this case, the information is transmitted with the rate of 5 Mbps as same as for the received information.

3.2.2 Time Division Duplexing (TDD)

TDD is a duplexing in terms of time domain. This technique only utilizes a single frequency band for transmitting the information. The frequency band is divided into 2 time slots, forward and reverse time slots. For forward time slot, the information is transmitted from BS to mobile while transmission from mobile to BS is called reverse time slot. There is a gap between forward and reverse time slot to reduce interference between those two time slots. The configuration of forward and reverse time slots in TDD is shown in Figure 3.2. This utilizes frequency bandwidth of

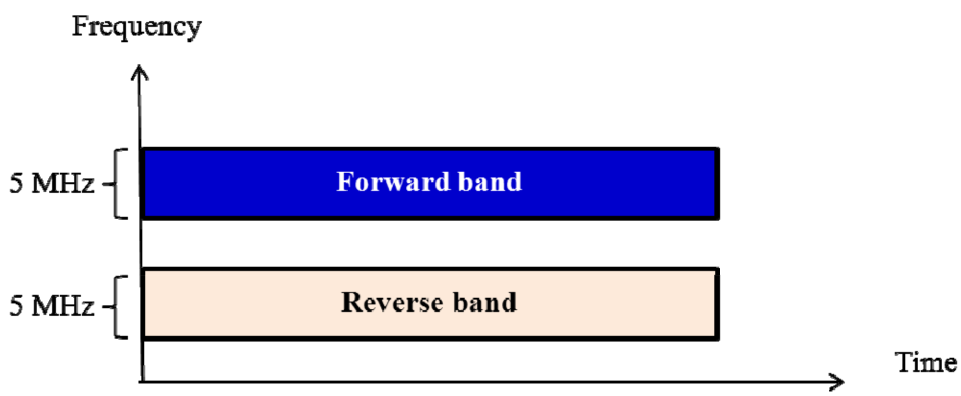


Figure 3.1 FDD configuration.

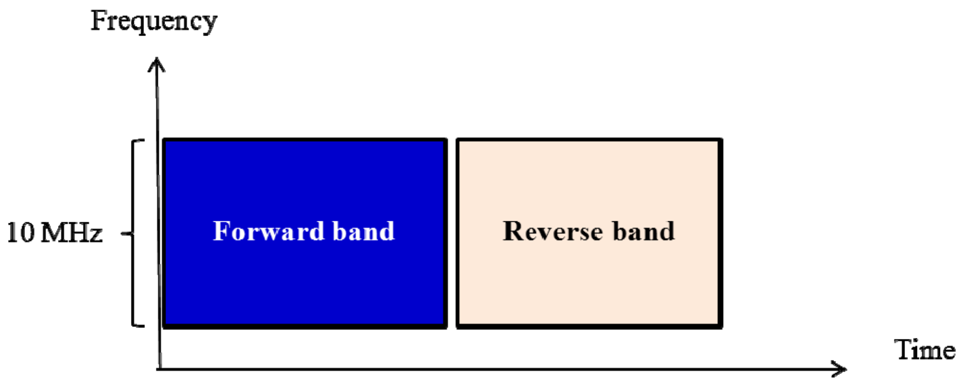


Figure 3.2 TDD configuration.

10 MHz, 50% for each receiving and transmitting. The information is transmitted with the rate of 10 Mbps as same as for the received information.

3.3 Multiplexing and access techniques

In communication systems, it is necessary to have a scheme that enables several multiple users to access and use the limited frequency band simultaneously. To ease the mentioned problem, there are four basic multiplexing techniques: FDMA, TDMA CDMA and OFDMA techniques.

3.3.1 Frequency Division Multiple Access (FDMA)

FDMA technique is a multiple access scheme of FDM. Principle of FDM technique is to divide a frequency band into several bands, each band is called subchannel. To protect interfering between subchannels, bandwidth of each succhannel must not be overlapped. Each subchannel is obstructed by narrow frequency band, so called guardband as shown in Figure 3.3. However, the FDMA technique cannot provide full benefits due to some of frequency band is used for guardband. In case of multiple access, each subchannel is used for each user separately. Therefore, some of subchannels are useless when the number of users is less than the number of subchannels.

In FDMA technique, FDD and TDD are used for sending and receiving the information. Figure 3.4 and 3.5 show the FDMA/FDD and FDMA/TDD structures, respectively. So far, some popular systems such as Advanced Mobile Phone System (AMPS) employs FDMA/FDD technique and Digital European Cordless Telephone (DECT) employs FDMA/TDD technique.

3.3.2 Time Division Multiple Access (TDMA)

TDMA technique is a multiple access scheme in time domain as shown in Figure 3.6. In TDMA technique, subchannel is divided to multiple blocks of time, so celled time slot. Each time slot is used by one user so there are many users in a subchannel. There are several constructions of time slot division depending on the systems. Figure 3.7 shows an example of time slot division. A frequency is divided

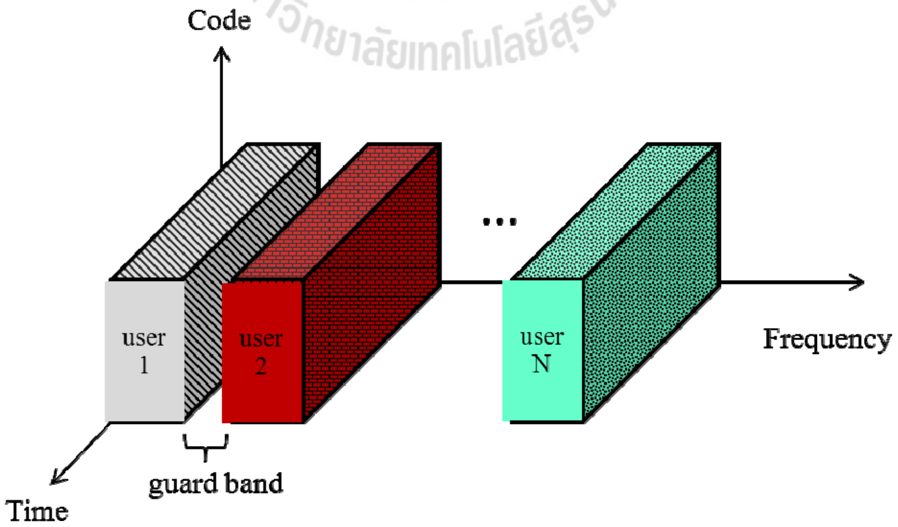


Figure 3.3 FDMA technique configuration.

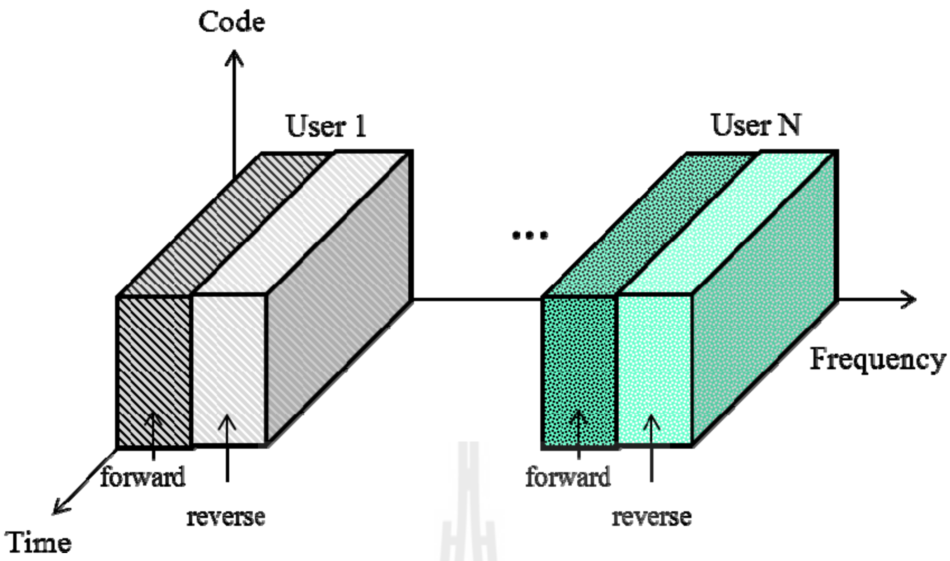


Figure 3.4 FDMA/FDD technique configuration.

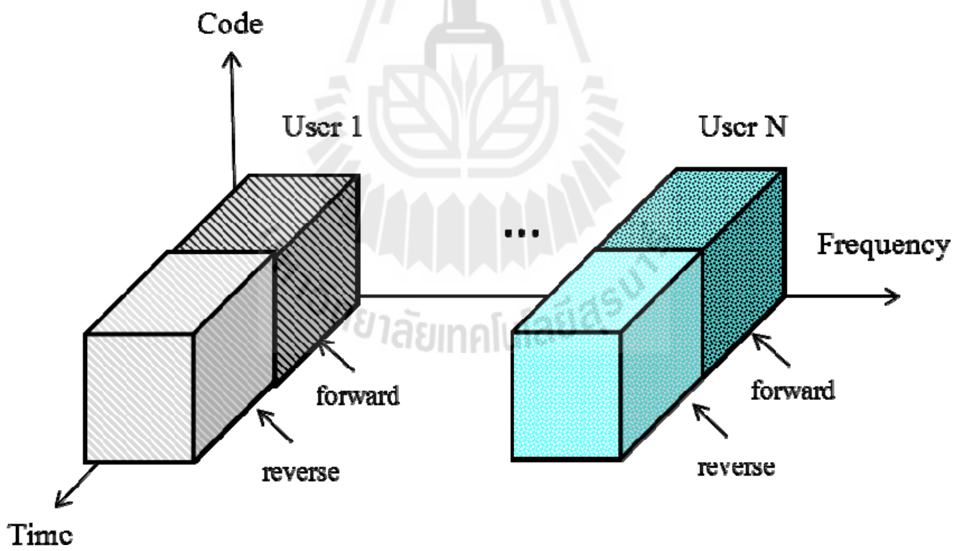


Figure 3.5 FDMA/TDD technique configuration.

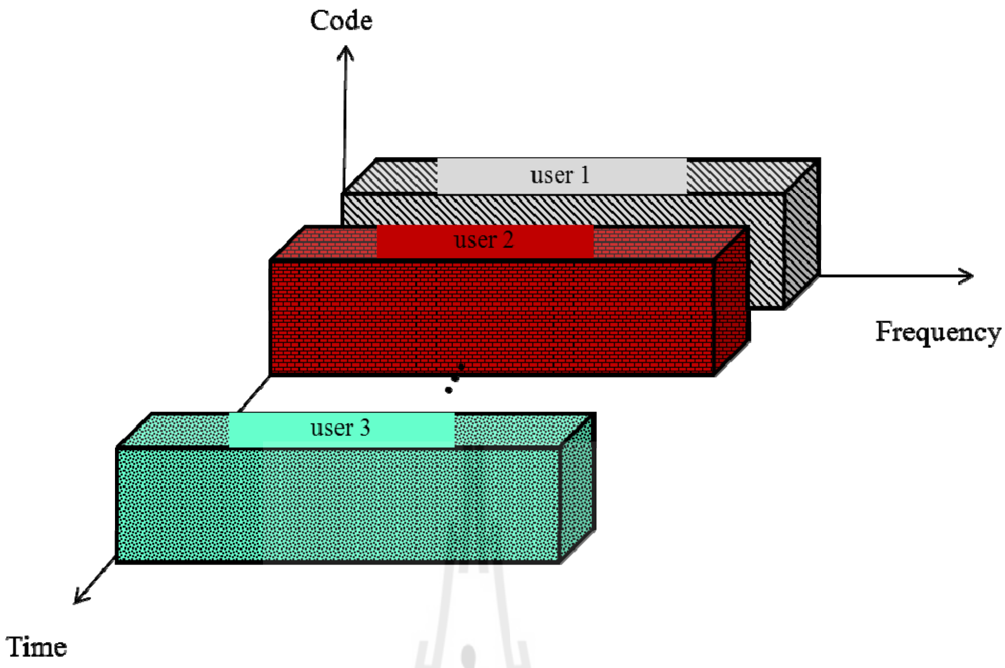


Figure 3.6 TDMA technique configuration.

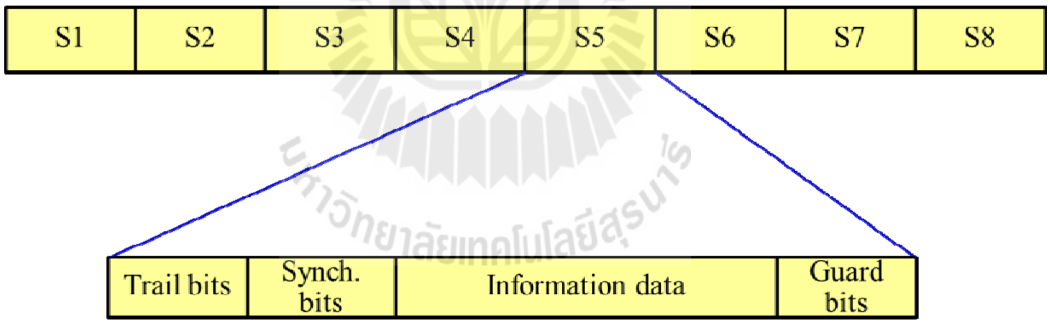


Figure 3.7 Time slot division in TDMA technique.

into 8 time slots, S1 to S8. Each slot is consisted of trail bits, synchronization bits, information data and guard bits. Firstly, tail bits are designed to indicate the starting point of the slot. Next, each slot in every frame must be synchronized against all others using synchronizing bits. Then, actual conversation is included in information data. Finally, guard bits are empty area to protect interference between adjacent slots.

However, TDMA technique cannot use full benefit of bandwidth as there are many compositions which is not the actual data in each slot. In TDMA technique, FDD and TDD are used for sending and receiving the information. The structures of TDMA/FDD and TDMA/TDD are shown in Figures 3.8 and 3.9, respectively. The examples of the systems employing TDMA/FDD and TDMA/TDD techniques are Global System for Mobile (GSM) for TDMA/FDD and Medium Access Control (MAC) protocol in IEEE 803.16 for TDMA/TDD technique (Pedro, C., Francisco, M.D., Jesus, D., Luis, O.B., 2008).

From the mentioned problem of frequency for FDMA and TDMA techniques, the idea to utilize full benefit of frequency has been proposed, so called CDMA technique. The principle of CDMA technique is described in next section.

3.3.3 Code Division Multiple Access (CDMA)

For the foundation of CDMA technique, all users can use the same frequency at the same time using spread spectrum technique. This technique indicate the user by code as each user is assigned by a specific code in which different code is used for different user as shown in Figure 3.10. According to this, CDMA technique has an advantage over the others as the systems can use the same frequency for every cell in the networks. Therefore, CDMA technique is able to provide full efficiency in terms of frequency utilization. Furthermore, CDMA technique can support the systems having a large number of users.

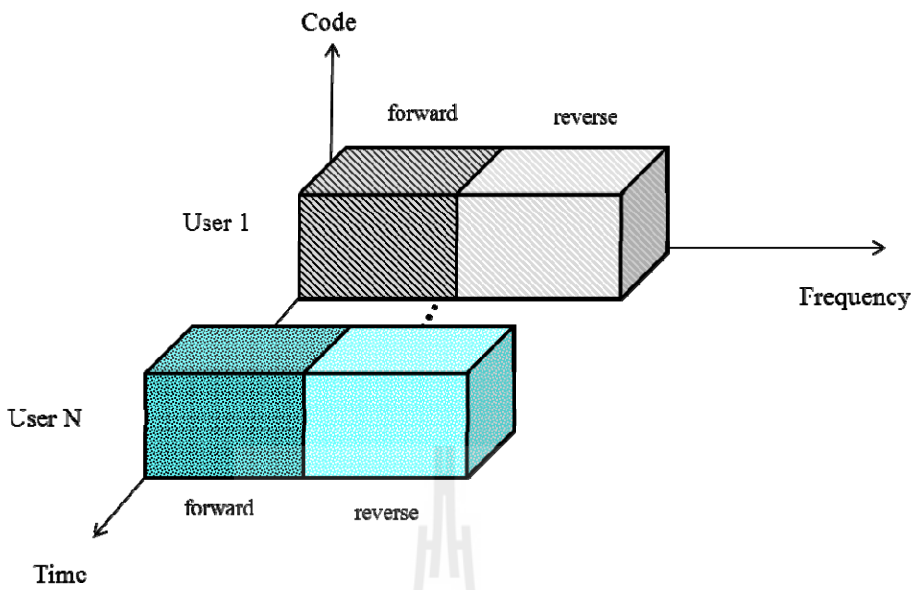


Figure 3.8 Configuration of TDMA/FDD technique.

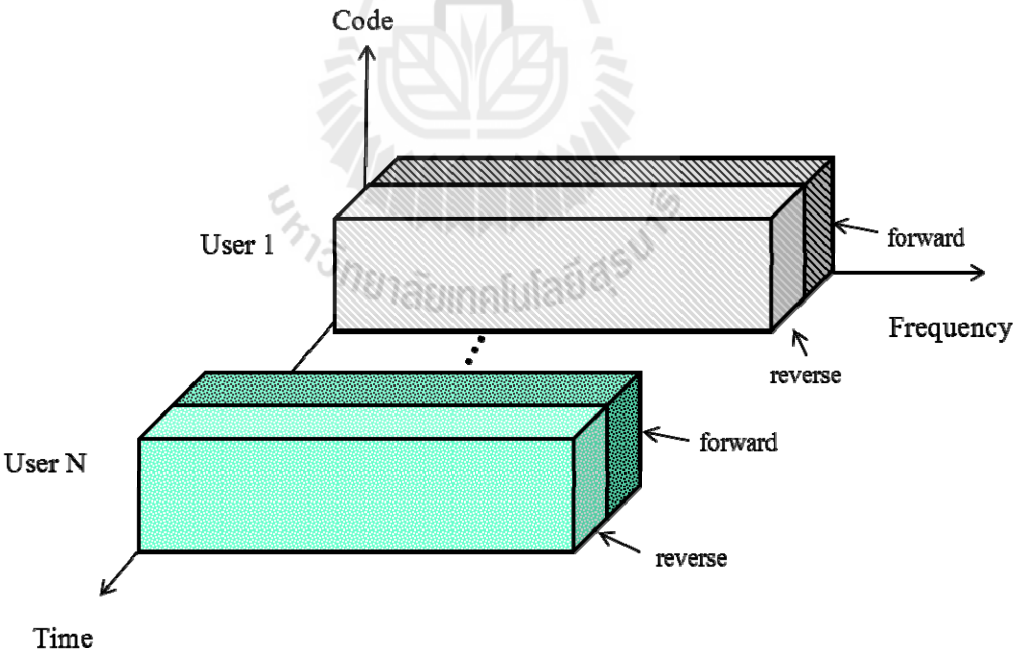


Figure 3.9 Configuration of TDMA/TDD technique.

In CDMA technique, FDD and TDD are used for sending and receiving information as shown in Figures 3.11 and 3.12, respectively. An example of the systems employing CDMA/FDD is US Narrowband Spread spectrum (IS-95). Also, an example of systems employing CDMA/TDD is Universal Mobile Telecommunications System (UMTS) in 3GPP standard (Zhu, H. and Ray Lin, K.J., 2008).

3.3.4 Orthogonal Frequency Division Multiple Access (OFDMA)

A multiple access in OFDMA technique is based on Orthogonal Frequency Division Multiplexing (OFDM) technique which has been developed from FDM technique described in Section 3.3.1. To tackle the problems of FDM technique mentioned earlier, the OFDM technique has been proposed to provide full benefits of frequency utilization (Chang, R.W., 1996). In OFDM technique, subchannel is separated to several groups, so called subcarrier. Bandwidth of subcarriers can be

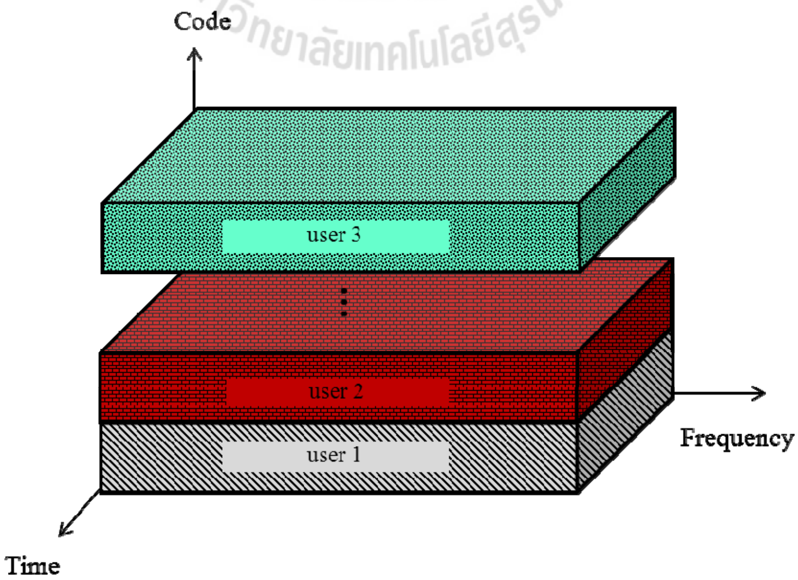


Figure 3.10 Configuration of CDMA technique.

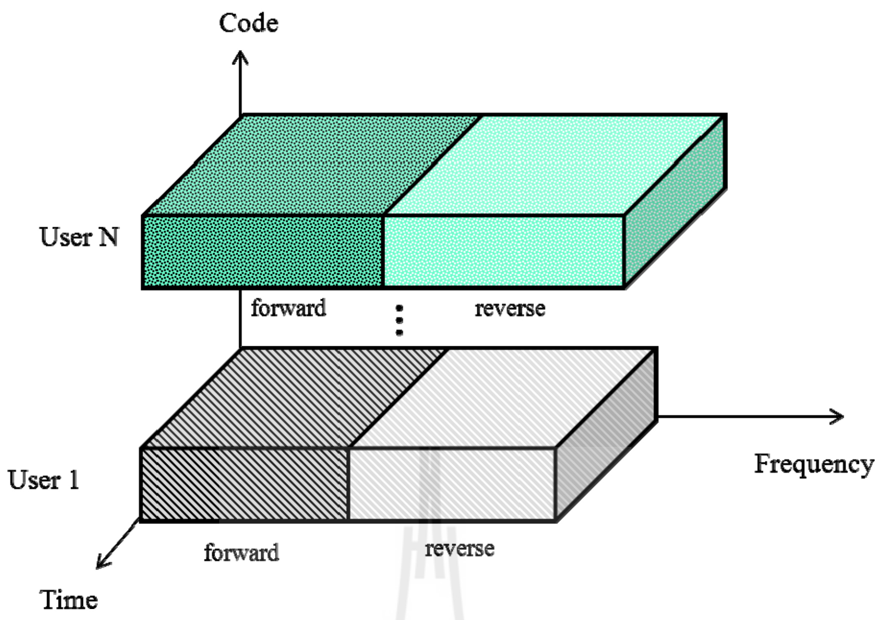


Figure 3.11 Configuration of CDMA/FDD technique.

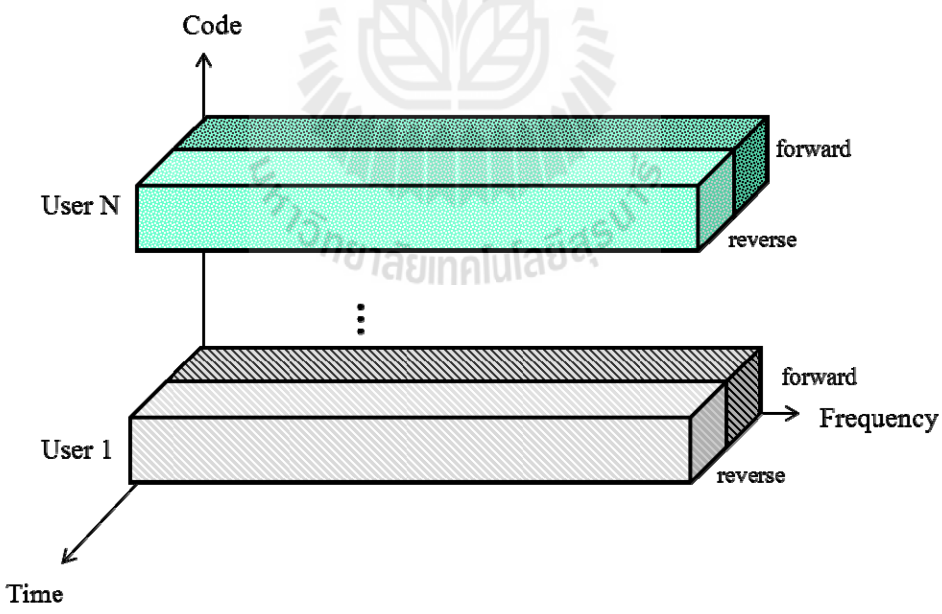
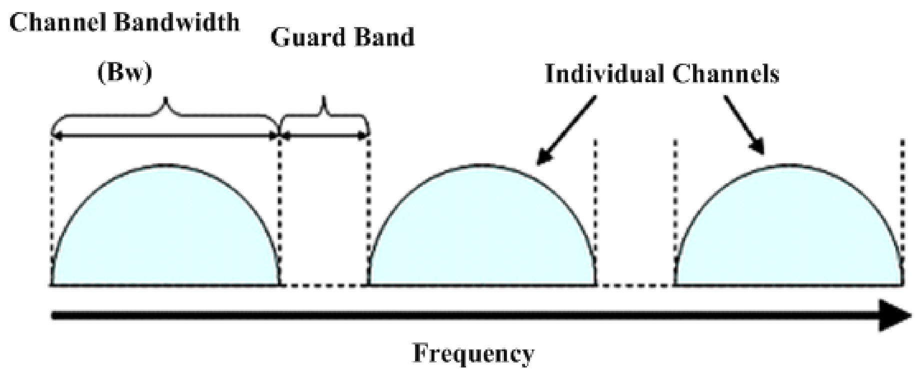
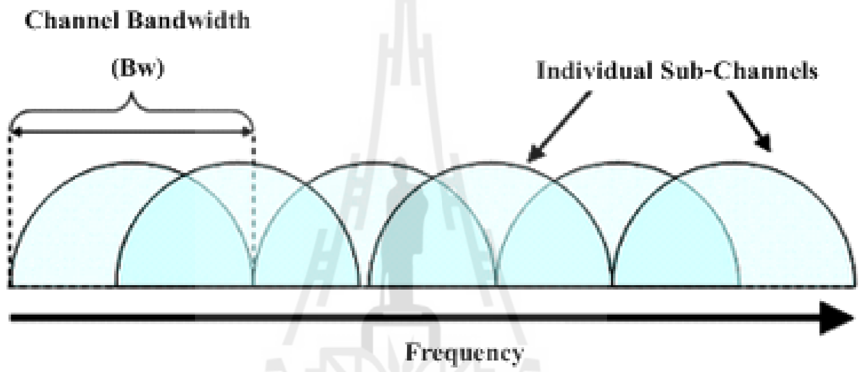


Figure 3.12 Configuration of CDMA/TDD technique.



(a)



(b)

Figure 3.13 Subchannel division in (a) FDM and (b) OFDM techniques.

overlapped using orthogonally as shown in Figure 3.13. According to this, OFDM technique can improve bandwidth efficiency due to bandwidth of each subcarrier can overlap adjacent subcarriers. Moreover, groups of data are transmitted at the same time as shown in Figure 3.14 (b) while a single carrier band is used to send all data using spread spectrum technique as shown in Figure 3.14 (a). According to this, OFDM technique provides higher accuracy over spread spectrum technique as shown in Figure 3.15.

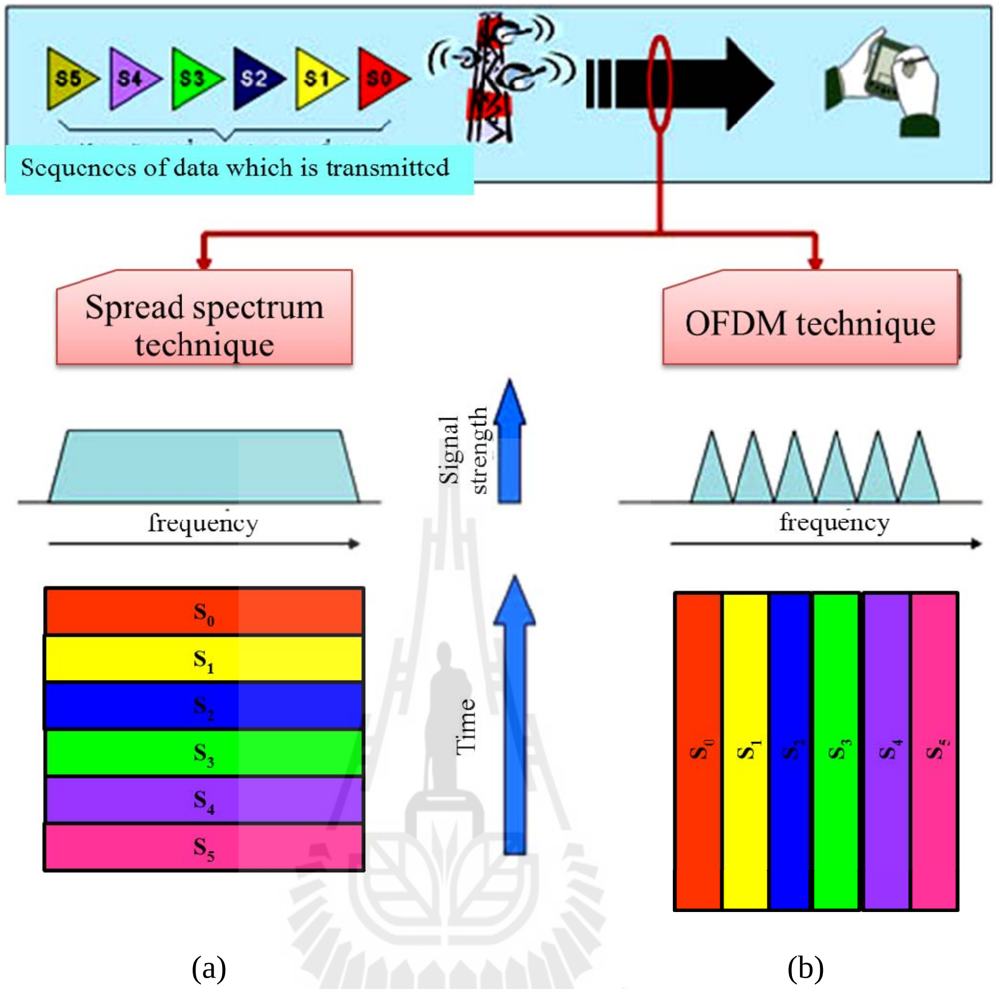


Figure 3.14 Data transmission in (a) spread spectrum and (b) OFDM technique.

The principle of OFDM technique is adding a cyclic prefix to solve a problem of multipath in communication systems as shown in Figure 3.16 (WiMAX Forum, Tech. Rep., 2006). The cyclic prefix is a copy of last part of OFDM symbol and placed in front of the symbol. The length of cyclic prefix is longer than the length of the dispersive channel to completely remove inter symbol interference.The foundation of OFDM technique can be separated into 2 parts, transmitter and receiver. In transmitting part, signal is separated into several groups. The groups are modulated

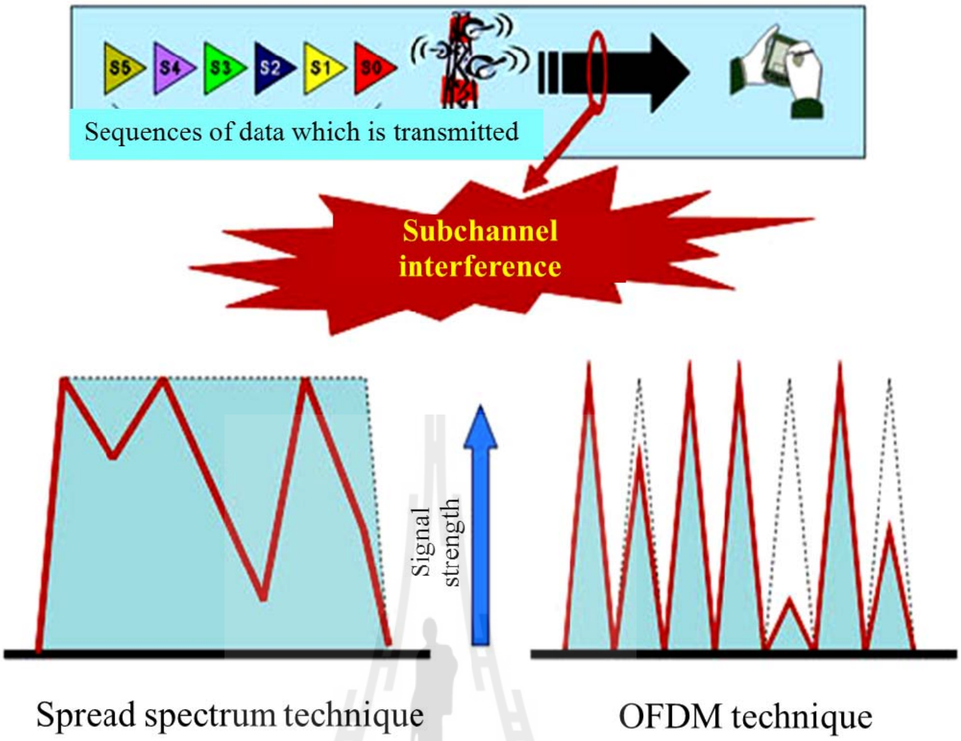


Figure 3.15 Impact from interference when (a) spread spectrum and (b) OFDM technique are used.

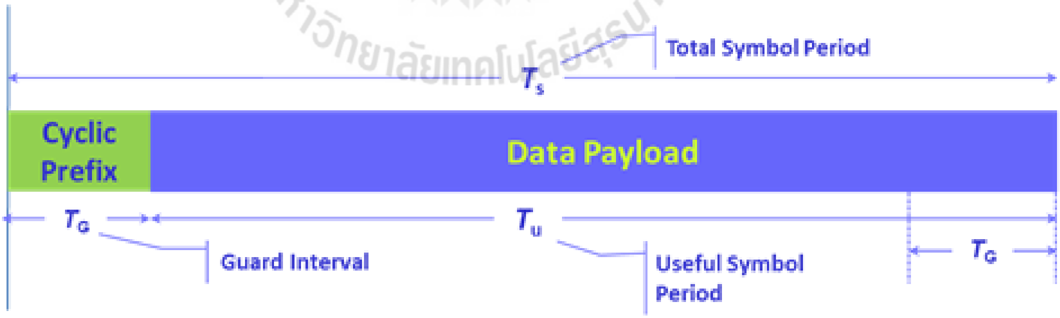
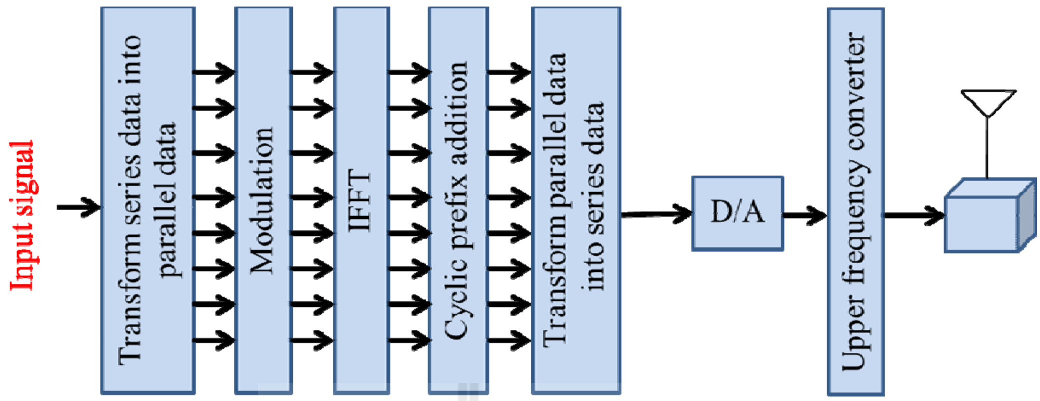
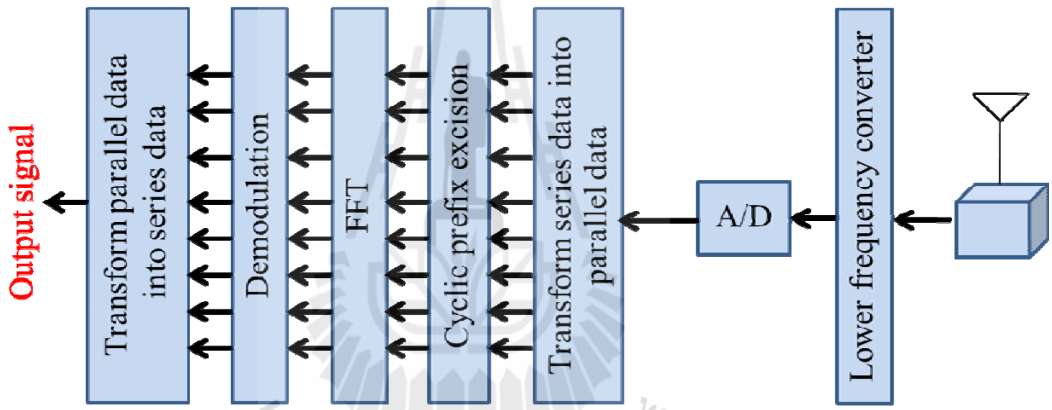


Figure 3.16 Cyclic prefix in OFDM technique.



(a)



(b)

Figure 3.17 (a) Transmitting and (b) receiving parts in OFDM technique.

with subcarriers. After modulation, these groups are in frequency domain and transmitted in parallel. To transform the signal in frequency to time domains, the Inverse Fast Fourier Transform (IFFT) scheme is employed. Then, cyclic prefix is added. Afterwards, the signals in time domain are multiplexed into signal series as shown in Figure 3.17 (a). In receiving part, there is reverse process with respect to the transmitting part. The Fast Fourier Transform (FFT) scheme is used to transform signal in time to frequency domains as shown in Figure 3.17 (b).

After brief foundation of OFDM technique, OFDMA technique which is multiple access of OFDM technique is discussed. In OFDMA technique, the multiple user signals are separated in the time and frequency domains as shown in Figure 3.18. The structure of OFDMA technique is contained with data subcarrier, pilot subcarrier and null subcarrier as shown in Figure 3.19. In the first part, data subcarrier is contained with actual data. For the next part, pilot subcarrier is used for synchronization. Moreover, this part is used for estimating and following the channel. For the last part, null subcarrier is used to reduce interference between adjacent channels. A Combination of data and pilot subcarriers to transmit and receive data is called subchannel. The subchannel can be classified into 2 types (Srikanth, S., Kumaran, V., Manikandan, C., Murugesapandian) as follows. The one is the Adjacent Subcarrier Method (ASM) which is suitable for stationary utilization and the other

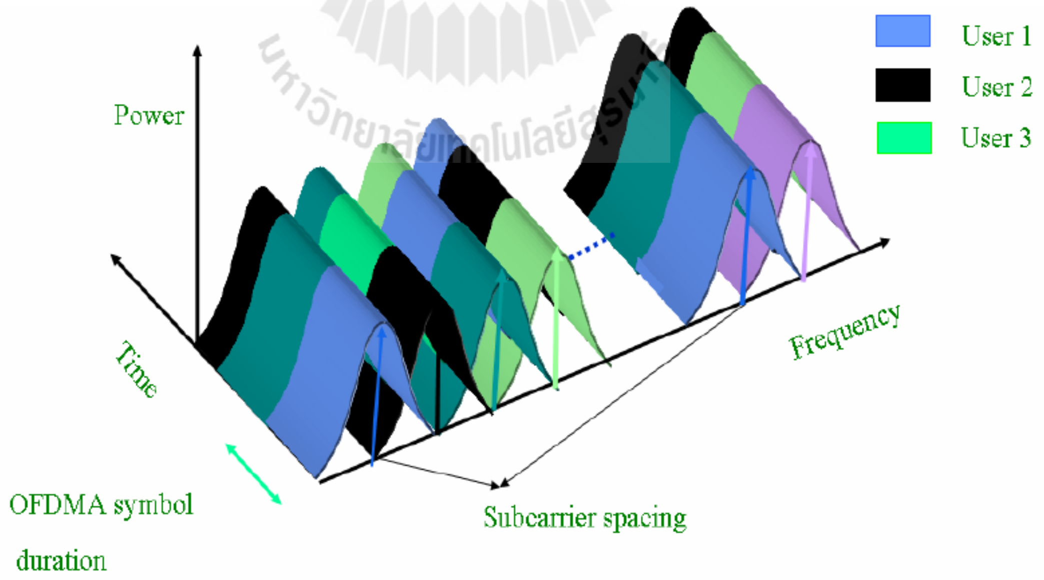


Figure 3.18 Multiple user signals separated in the time and frequency domains in OFDMA technique.

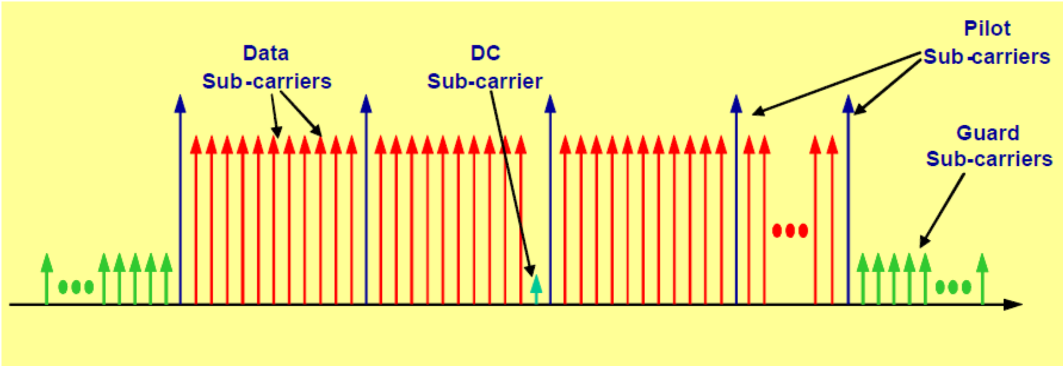
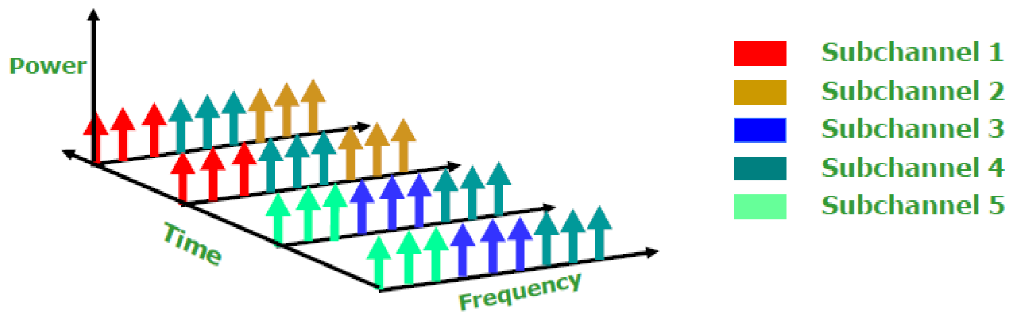


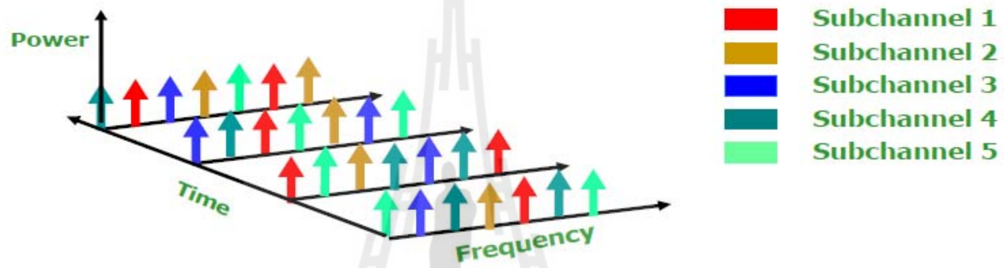
Figure 3.19 Structure of OFDMA technique.

one is the Diversity Subcarrier Method (DSM) which is suitable for mobile as shown in Figure 3.20.

In ASM method, uplink and downlink systems have the same subchannel formation. Firstly, 8 adjacent data subcarriers and 1 pilot subcarrier are grouped into 1 bin. Then, bins are combined to form subchannel which can be classified into 4 types. For the first type, a subchannel is consisted of 6 bins. For the second type, a subchannel is consisted of 3 bins. For the third type, a subchannel is contained with 2 bins. In the last type, a subchannel is consisted of 1 bin. Next, a multiplication between the number of bin and symbol become a slot. After multiplication, 1 slot must be 6. For example, 1 subchannel is multiplied by 1 symbol in the first type. For the second type, 1 slot is composed with 1 subchannel and 2 symbols. For the third type, 1 slot is composed with 1 subchannel and 3 symbols while 1 subchannel and 6 symbols are utilized for the last type. Therefore, each slot is contained with 48 data subcarriers and 6 pilot subcarriers.



(a)



(b)

Figure 3.20 Formation of subchannel for (a) ASM and (b) DSM methods.

In DSM method, uplink and downlink systems have different subchannel formation. In downlink systems, subchannel formation can be categorized into 2 types, Partial Usage of Subcarrier (PUSC) and Full Usage of Subcarrier (FUSC). In downlink FUSC, all subcarriers are grouped into 48 groups. Each group is contained with 32 subcarriers. Then, one of 32 subcarriers of each group is chosen to aggregate with the others that become 1 subchannel as shown in Figure 3.21. For downlink PUSC, all subcarriers of OFDM symbol are split to cluster. Each cluster is contained with 14 adjacent subcarriers which are 12 data subcarriers and 2 pilot subcarriers. After subcarriers are grouped into a cluster, each cluster is rearranged.

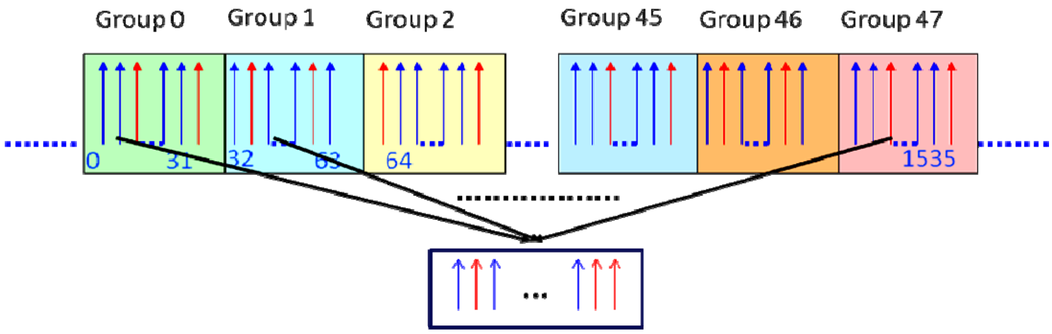


Figure 3.21 Downlink systems of FUSC in DSM method.

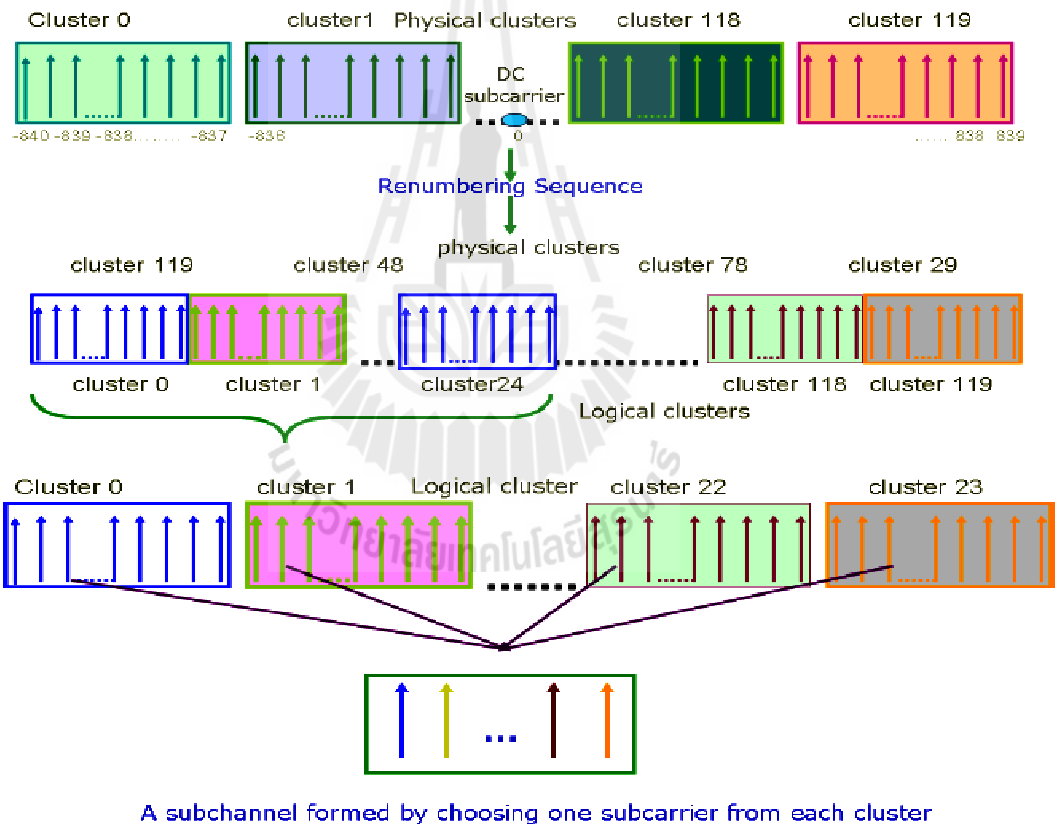


Figure 3.22 Downlink systems of PUSC in DSM method.

Then, 24 clusters are considered. One subcarrier of each cluster is chosen and collected into 1 subchannel as shown in Figure 3.22.

In uplink systems, subchannel is created using PUSC method which is different from downlink PUSC. There are 4 subcarriers in 1 symbol in which 3 symbols are a tile. Therefore, 1 tail is contained with 12 subcarriers (8 data subcarriers and 4 pilot subcarriers). Then, a subchannel is an inclusion of 6 tiles. This means that a subchannel in uplink PUSC is contained with 48 data subcarriers and 24 pilot subcarriers.

An example of OFDMA technique employing FDD is LTE technology while TDD is currently used for WiMAX technology.

3.4 Chapter summary

In OFDM technique, bandwidth of each subcarrier can overlap the other subcarriers using orthogonally. For this reason, OFDM technique can improve bandwidth efficiency due to bandwidth of each subcarrier can overlap the other adjacent subcarriers. Moreover, groups of data are parallel transmitted using OFDM technique. Therefore, this technique provides higher accuracy comparing the others. The multiple access in OFDM technique is called OFDMA technique in which multiple user signals are separated in time and frequency domains. Therefore, the bandwidth efficiency in cellular networks can be improved using OFDMA technique. Furthermore, utilizing the same frequency in every cell for cellular networks can provide full benefit of bandwidth efficiency. However, this can be a cause of inter cell interference to neighboring cells. To tackle this problem in OFDMA technique, fractional frequency reuse technique has been proposed and will be described in next chapter.

CHAPTER IV

BACKGROUD THEORY

4.1 Introduction

This chapter describes the performance enhancement of cellular networks. A cell allocation scheme in cellular networks, FFR in OFDMA technique and beamforming technique which have been proposed to improve the capacity of wireless systems are also discussed in this chapter. In addition, the system performance in terms of SINR and channel capacity are also considered.

4.2 Cell allocation in cellular networks

To fully utilized benefit of limited frequency spectrum, all areas are separated into cells. There are several shapes of cells such as circular, triangle, square and hexagonal cells as shown in Figure 4.1. As we can see, there are inter cell interference from adjacent cells when the circular shapes are used. Therefore, hexagonal shapes which resemble with the circular shapes are conventional used. Moreover, inter cell interference from neighboring cells are reduced when using hexagonal cells.

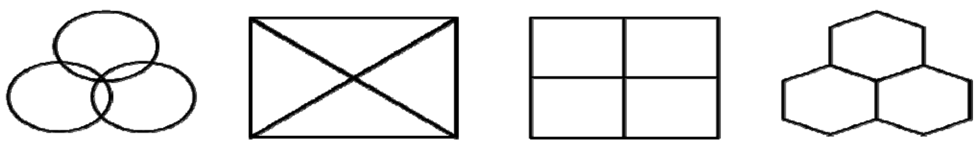
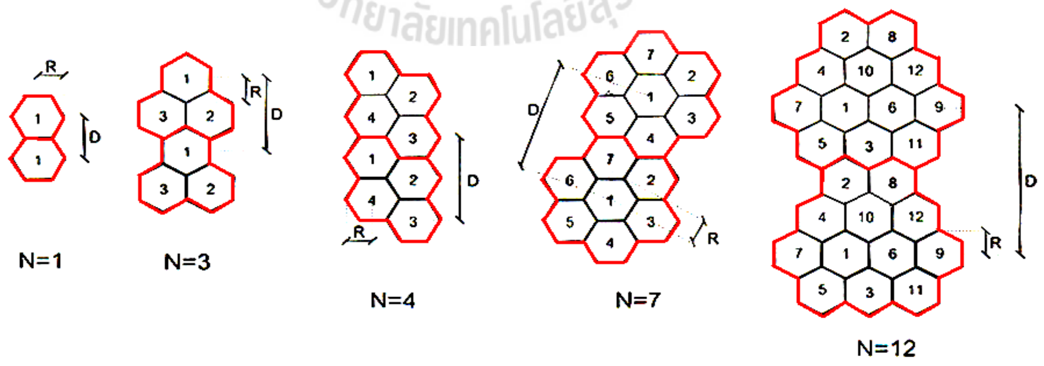


Figure 4.1 Cell shapes of cellular networks.

Next, frequency allocation is considered. In cellular networks, utilizing the same frequency in every cell can provide full benefit of bandwidth efficiency. However, cells which use the same frequency interfere each other, so called Co-Channel interference (CCI). To tackle this problem, combination of many cells to one group, so called cluster, is performed. Cluster can be classified into several types such as all available frequency are divided into three groups which are used in three cells as shown in Figure 4.2 (b). In Figure 4.2 (e), all available frequency are divided into twelve groups which are used for twelve cells in a cluster. As we can see, frequency bandwidth is reduced when the numbers of cell in a cluster is increased. This can be a cause of channel capacity reduction. On the other hand, in case of having a few number of cell in a cluster, distance between cells which use the same frequency is short. This results in stronger CCI. So far, there are three schemes to improve the channel capacity and reduce CCI: cell splitting, cell sectorization and microcell zoning.



(a) (b) (c) (d) (e)

Figure 4.2 Numbers of cell in a cluster.

4.2.1 Cell splitting

For this scheme, cell is divided into many small cells as shown in Figure 4.3. The number of user in small cell is equal to the number of user in a cell without division. Therefore, the system capacity remains as the same as of the small cell. However, this scheme is of high cost due to the BS must be installed in every small cells. In addition, utilizing the same transmitted power with a cell without division is a cause of CCI problem in small cells. Therefore, transmitted power must be decreased to reduce ICI when cell splitting scheme is performed.

4.2.2 Cell sectorization

Sectorization is a cell division into many equivalent parts as each part is called sector. For example, cell is divided into three sectors and six sectors as shown in Figure 4.4 (a) and (b), respectively. The directional antennas having their radiation covering all of sector areas are replaced by omni directional antennas. Therefore, CCI in the system is reduced due to the beamwidth of directional antenna pattern is

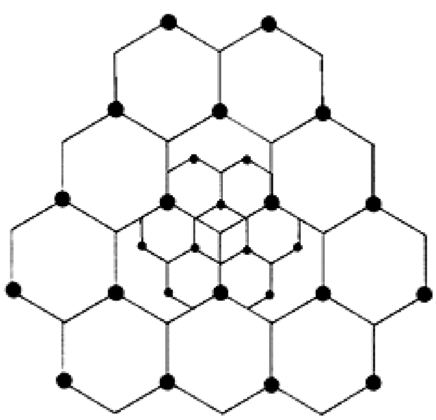


Figure 4.3 Cell splitting configuration.

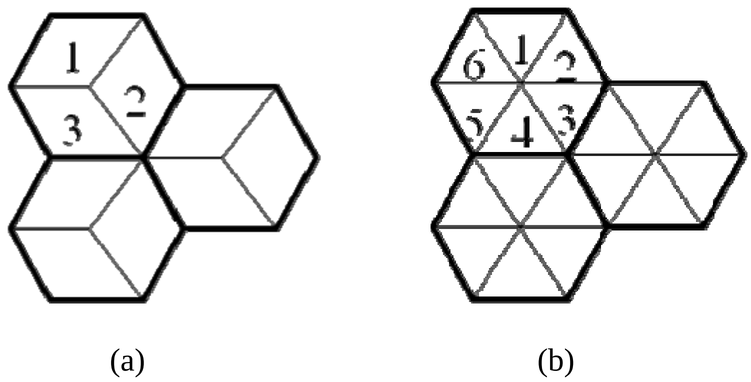


Figure 4.4 Cell sectorization for (a) 3 sectors and (b) 6 sectors.

narrower than the beamwidth of omni directional pattern. For example, CCI is reduced to two directions when a cell is divided into 3 sectors as shown in Fig. 4.5 (a). In this figure, we also see that CCI are coming from 7 cells without sectorization. In case of cell is divided into 6 sectors as shown in Fig. 4.5 (b), there is only one CCI when a cluster is contained with 7 cells. However, BS antennas are increased when sectors are increased. Moreover, frequency bandwidth division is depended on the number of sector. This can be a cause of channel capacity reduction when there are many sectors in a cell.

4.2.3 Microcell zone

In this scheme, a cell is divided into three areas. Transmission equipment is set at cell edge in each area as shown in Figure 4.6. Each transmission equipment is connected with the same BS in a cell using fiber optic. There is only one equipment working at a time. In case of users move away from one equipment and near to another equipment, the equipment nearby the user is activated.

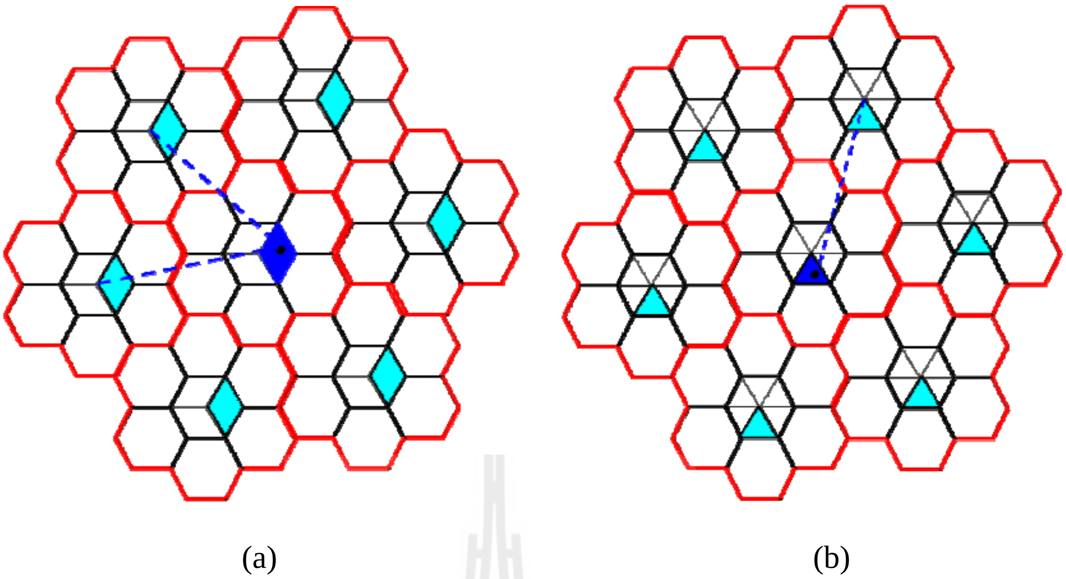


Figure 4.5 Directions of CCI when cell is divided into (a) 3 sectors and (b) 6 sectors.

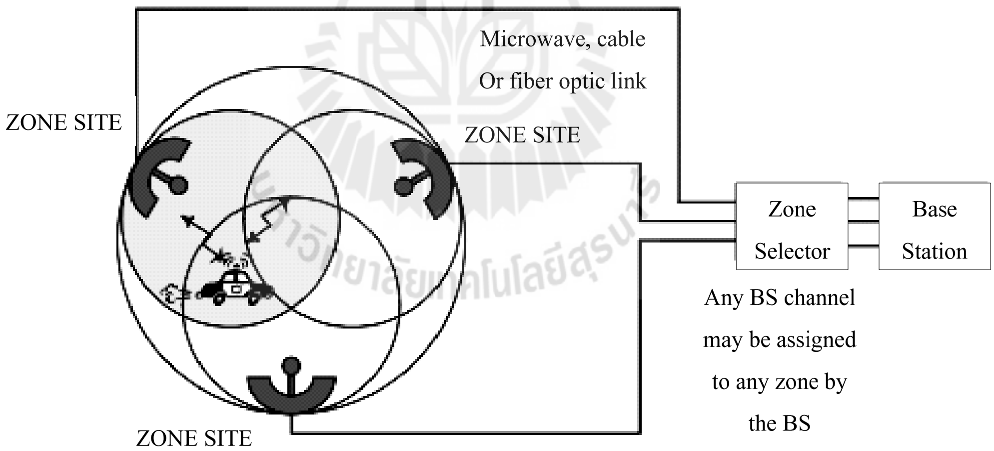


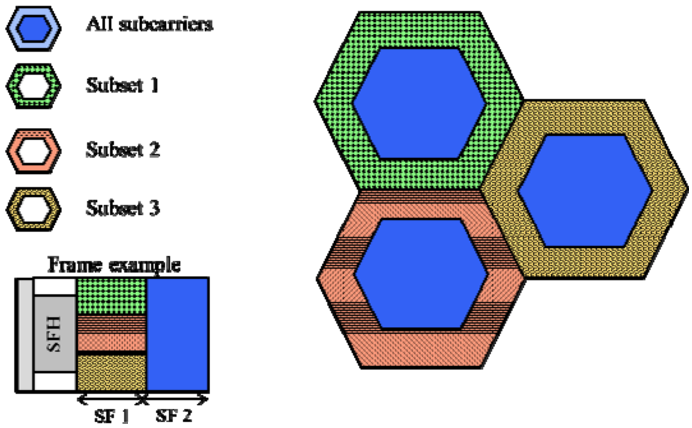
Figure 4.6 Microcell zone.

4.3 Fractional Frequency Reuse (FFR) in OFDMA technique

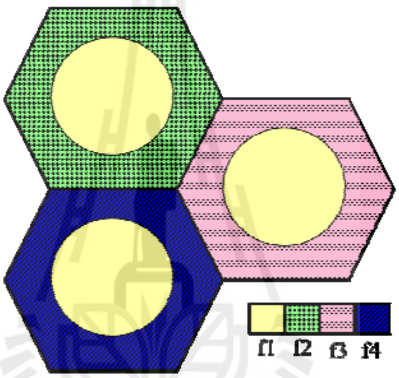
Form chapter 3, bandwidth efficiency can be increased using OFDMA technique. Moreover, utilizing the same frequency in every cell for cellular networks can provide full benefit of bandwidth efficiency. However, in cellular networks the users staying in cell-center area exploit high signal strength as they are close to BS. On the other hand, the signal strength is degraded when users are moving close to the cell-edge. Moreover, the users located at cell-edge also experience interference signal coming from neighboring cells. To tackle this problem in OFDMA technique, FFR technique is proposed.

FFR technique separates the area of cellular networks into two regions: cell-center and cell-edge. There are several forms of subcarrier allocation in FFR technique. For example, all subcarriers are used at cell-center region for every cell while those all subcarriers are also separated to three subsets which are used at each cell-edge area as shown in Figure 4.7 (a). For another type of FFR, all available subcarriers are divided into four parts: one part is used at every cell-center areas while other parts are separated used at cell-edge as shown in Figure 4.7 (b). In addition, all available subcarriers are divided into two groups. One group is used at cell-center areas while the other group is separated into three subgroups that separated used at cell-edge area as shown in Figure 4.7 (c).

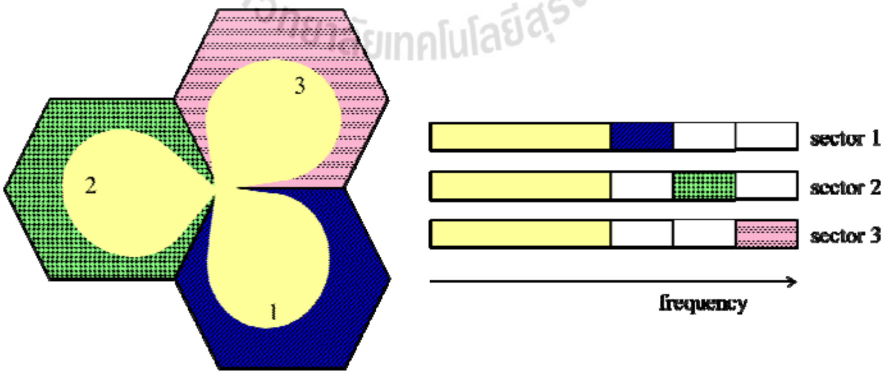
To improve the system capacity and reduce ICI, not only FFR technique but cell sectorization is also employed in which each cell is divided into three sectors as shown in Figure 4.8. All available subcarriers are separated into two groups, one



(a)



(b)



(c)

Figure 4.7 Examples of FFR techniques.

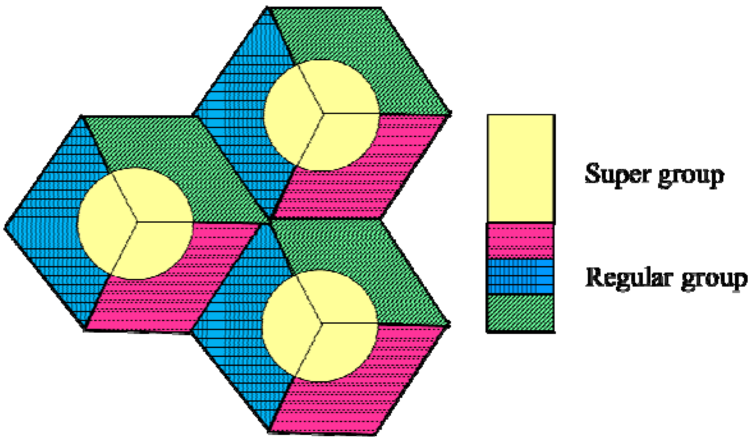


Figure 4.8 Cell sectorization scheme with FFR.

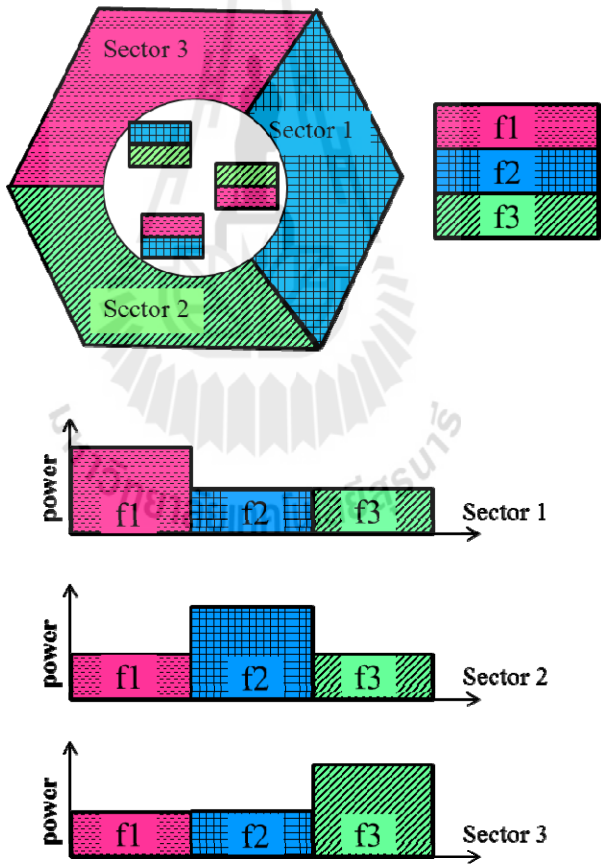


Figure 4.9 Cell sectorization with different transmitted power at cell-center and cell-edge area.

group is used at cell-center area, so called super group, and the other one is used at cell-edge area, so called regular group. For a regular group, all available subcarriers are separated to three subgroups in which each group is used in each sector. In addition, cell sectorization can be employed with different transmitted power at cell-center and cell-edge area as shown in Figure 4.9. All available subcarriers are divided to three groups, each group is used at cell-edge area. At cell-center area, two groups which are not used at cell-edge area are utilized. The transmitted power of subcarrier utilized at cell-center area is reduced to half of power that transmitted at cell-edge area.

4.4 Beamforming technique

Beamforming technique in smart antenna systems can improve the performance in cellular networks due to this technique are capable of forming beam in desired direction and nulls in the interference directions. Beamforming technique in smart antenna systems can be classified into two categories: fixed and adaptive beamforming systems.

4.4.1 Fixed beamforming systems

In fixed or switched beamforming systems, there are fixed numbers of main beam and a switching network is used to select its main beam to desired user. This system is easy to implement due to it is not complex and low of cost. However, this system is not able to provide any protections to path components. Moreover, this system cannot be continuously updated based on the received signals. This can be a cause of low signal strength when the desired direction is out of half power beamwidth of main beam.

4.4.2 Adaptive beamforming systems

The fundamental of adaptive beamforming systems is based on fixed beamforming systems. These systems have many advantages as follows. The antenna beams adaptively track any desired signal direction and its null can be placed in the direction of interferences. These systems have better capability over fixed beamforming systems because main beam continually tracks the desired user. However, adaptive beamforming systems have disadvantage in complication and high cost (Fakoukakis, Diamantis, Orfanides and Kyriacou, 2005; Morgan, 2008).

In this thesis, beamforming technique using antenna which is currently employed at cellular BS (Andrew A CommScope Company, 2009) is considered. From the commercial data, the half power beamwidth in horizontal plane of this array antenna is 120 degree which can cover all of a sector area. However, the half power beamwidth in vertical plane is 7 degree. This beamwidth cannot cover all of users at cell-center or cell-edge area in a sector. Therefore, beamforming technique is used to improve the performance of beam covering at cell-center and cell-edge area. From advantage and disadvantage points of views for fixed and adaptive beamforming systems presented in sections 4.4.1 and 4.4.2, fixed beamforming systems are in focus for this thesis as they are not complicated. Moreover, high speed signal processing is not necessary to continually track the desired user in fixed beamforming systems. Therefore, fixed beamforming system is suitable to use with the antenna which is currently employed at cellular BS.

In beamforming technique, array antennas can form beam while array factor is used for assigning the direction of main beam. The antenna which is currently employed at cellular BS is linear array antennas which is the basic of array antennas. The linear array antennas are the simplest and most practical array. There are two or more elements antenna placing along a line. In Figure 4.10, there are *N* antenna elements which are equally spaced to each other. All elements have identical amplitudes but each succeeding element has a progressive phase leading current excitation relative to the preceding one. An array of identical elements with identical magnitude and each with a progressive phase is referred to as a uniform array. The total field can be formed by multiplying the array factor of the isotropic sources by the field of a single element. The array factor of linear array antenna is given by

$$AF = 1 + e^{j(kd\cos\theta+\beta)} + e^{j2(kd\cos\theta+\beta)} + \ldots + e^{j(N-1)(kd\cos\theta+\beta)} \tag{4.1}$$

where k is the propagation constant, with $k=2\pi/\lambda$. The antenna elements are equally

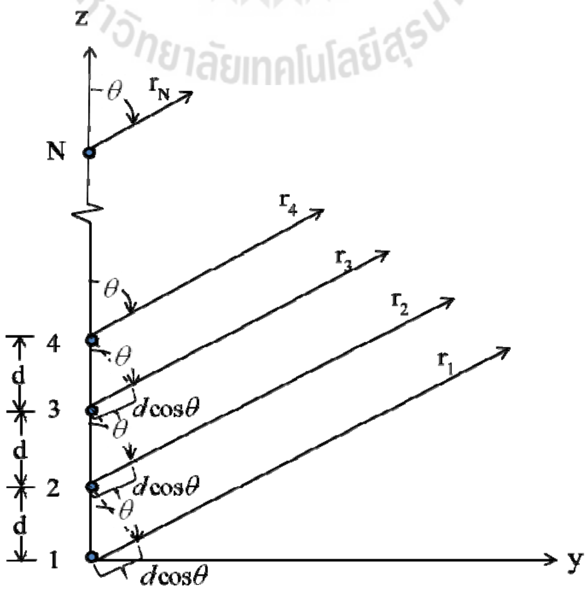


Figure 4.10 Geometry of *N* element array positioned along the z-axis.

spaced by d. The angle represented by θ is measured from the z-axis in spherical coordinate. Also, β is the phase shift between adjacent elements which can be expressed by

$$\beta = -kd\cos\theta_0 \tag{4.2}$$

where angle represented by θ_0 is the direction of maximum radiation.

The array factor of (4.1) reduces to

$$AF = 1 + e^{j\psi} + e^{j2\psi} + \ldots + e^{j(N-1)\psi} \tag{4.3}$$

where

$$\psi = kd\cos\theta + \beta \tag{4.4}$$

Multiplying both sides of (4.3) by $e^{j\psi}$, it can be written as

$$e^{j\psi}AF = e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \ldots + e^{jN\psi} \tag{4.5}$$

Subtracting (4.3) from (4.5), it can also be written as

$$AF = \frac{e^{jN\psi} - 1}{e^{j\psi} - 1}$$

$$= e^{j[(N-1)/2]\psi} \left[\frac{e^{j(N/2)\psi} - e^{-j(N/2)\psi}}{e^{j(1/2)\psi} - e^{-j(1/2)\psi}} \right] \tag{4.6}$$

$$= e^{j[(N-1)/2]\psi} \left[\frac{\sin\left(\frac{N}{2}\psi\right)}{\sin\left(\frac{1}{2}\psi\right)} \right]$$

If the reference point is the physical center of the array, the antenna elements are equally space by $d=0$ and $\beta=0$. Therefore, $\psi = kd\cos\theta + \beta = 0$ which the array factor of (4.6) reduces to

$$AF = \left[\frac{\sin\left(\frac{N}{2}\psi\right)}{\sin\left(\frac{1}{2}\psi\right)} \right] \tag{4.7}$$

The maximum value of (4.7) is equal N. To normalize the array factors so that the maximum value of each is equal to unity, (4.7) is written in normalized form as

$$AF = \frac{1}{N} \left[\frac{\sin\left(\frac{N}{2}\psi\right)}{\sin\left(\frac{1}{2}\psi\right)} \right] \tag{4.8}$$

Form the array factor in (4.8), the total field radiated of array antenna can be expressed by

$$\mathbf{E}(\text{total}) = [\mathbf{E}(\text{single element at reference point})\,] \times [\text{array factor}] \tag{4.9}$$

4.5 The performance in cellular networks

The SINR is commonly used in cellular networks as a parameter to measure the system quality. The SINR is defined as the power of a certain signal of interest divided by the sum of the interference power and the power of some background noise. The received SINR can be expressed by

$$SINR = \frac{P_r}{N_0 B + P_I} \tag{4.10}$$

where N_0B is the power of noise in which N_0 is the power spectrum density and B is the bandwidth of subcarriers. Also, the P_r and P_I are the power of interesting cell and interfering cells, respectively. The P_r and P_I are assumed to experience the effects from transmitted power of their cells, propagation path loss and shadowing fading.

The propagation path loss is the reduction of received power due to the distance between user and BS which can be given by

$$PL = 120.9 + 37.6\log_{10}(R) \tag{4.11}$$

where R is the distance between user and BS in kilometers.

Shadowing is caused by obstacles between transmitter and receiver which attenuates signal power through absorption, reflection, scattering and diffraction. Then, we consider the following correlation model for shadowing.

$$X(d) = 2^{\frac{-\Delta d}{d_{corr}}} \tag{4.12}$$

$$S_n = X(d) \cdot S_{n-1} + \sqrt{1 - X(d)^2} \cdot N(0, \sigma) \tag{4.13}$$

Where *X(d)* is normalized autocorrelation function, d_{corr} is decorrelation length and Δd is the moving distance of the mobile station after calculating shadowing. The S_n and S_{n-1} are the shadowing values at the two consecutive calculations. The $N(0,\sigma)$ presented in (4.13) is a Gaussian random variable with zero mean and standard deviation of σ is eight.

Multipath fading is caused by user moving. This can be a cause of signal power attenuation. Multipath fading can be expressed by

$$H = \sum_{l=0}^{L-1} h_l(T_s) e^{-j2\pi\Delta f \cdot \tau_1} \tag{4.14}$$

where h_l is the wide-sense stationary narrow band complex amplitude Gaussian process of the L^{th} path. The T_s stands for the OFDM symbol period and Δf is the neighboring subcarrier spacing, with $\Delta f = 1/T_s$. Also, τ_1 is the corresponding delay.

The P_r and P_I in (4.10) can be calculated by substituting propagation path loss in (4.11), shadowing in (4.13) and multipath fading in (4.14) as can be expressed by

$$P_r = P_t \cdot 10^{-\frac{PL}{10}} \cdot S \cdot |H|^2 \tag{4.15}$$

$$P_I = P_{tI} \cdot 10^{-\frac{PL_I}{10}} \cdot S_I \cdot \left|H_I\right|^2 \tag{4.16}$$

where PL_I, S_I and H_I are propagation path loss, shadowing and multipath fading of interference signal, respectively. The P_t and P_{tI} presented in (4.15) and (4.16) are transmitted power from BS and interfering BS, respectively. Substituting (4.15) and (4.16) into (4.10), it can be written as

$$SINR = \frac{P_t \cdot 10^{-\frac{PL}{10}} \cdot S \cdot \left|H\right|^2}{N_0 B + \sum_{j=1}^{q}\left(P_{tI} \cdot 10^{-\frac{PL_I}{10}} \cdot S_I \cdot \left|H_I\right|^2\right)} \tag{4.17}$$

where the parameter q is the number of ICI cells.

The channel capacity of user is the one important performance in cellular networks other than SINR which can be express by

$$C = \left(\frac{m}{M}\right)\log_2\left(1 + SINR\right) \tag{4.18}$$

where m is the number of subcarrier groups utilized at desired area and M is all available subcarrier groups. In case of FFR is used in the systems, the channel capacity is given by

$$C = C_{cell-center} + C_{cell-edge} \tag{4.19}$$

where $C_{cell\text{-}center}$ and $C_{cell\text{-}edge}$ are the channel capacity at cell-center and cell-edge area, respectively. Figure 4.7 (b) shows an example of the cellular networks employing

FFR. All subcarriers are separated into four groups, one group is used at cell-center area while other groups are separately used at cell-edge areas. The channel capacity at cell-center area can be expressed by

$$C_{cell-center} = \left(\frac{1}{4}\right)\log_2\left(1+SINR_{cell-center}\right) \tag{4.20}$$

where $SINR_{cell\text{-}center}$ is the SINR at cell-center area. On the other hand, the channel capacity at cell-edge area can be expressed by

$$C_{cell-edge} = \left(\frac{3}{4}\right)\log_2\left(1+SINR_{cell-edge}\right) \tag{4.21}$$

where $SINR_{cell\text{-}edge}$ is the SINR at cell-edge area. Substituting (4.20) and (4.21) into (4.19), it can be written as

$$C = \left(\frac{1}{4}\right)\log_2\left(1+SINR_{cell-center}\right)+\left(\frac{3}{4}\right)\log_2\left(1+SINR_{cell-edge}\right) \tag{4.22}$$

4.6 Chapter summary

In this chapter, several techniques have been proposed to improve the performance of cellular networks. First, cell allocation scheme has been proposed such as cell splitting, cell sectorization and microcell zoning. Then, FFR in OFDMA technique has been used to improve the system performance and reduce ICI from neighboring cells. Finally, beamforming technique utilizing FFR is considered to give an enhanced performance in cellular networks.

CHAPTER V

PROPOSED VERTICAL BEAMFORMING EMPLOYING FFR TECHNIQUE

5.1 Introduction

A vertical beamforming concept for the cellular networks utilizing FFR is investigated in this chapter. The performance in terms of SINR employing different FFR schemes is discussed. Then, the performance comparison of vertical and horizontal beamforming is considered. Afterwards, beam patterns are simulated according to the BS antenna currently utilized nowadays in order to see its real performance. Two separate beams are utilized for cell-center and cell-edge. Finally, the proposed concept is validated using computer simulation in terms of SINR and channel capacity comparing with single beam concept.

5.2 Performance of cellular networks employing FFR technique with different frequency allocation schemes

From Chapter 4, utilizing the same frequency in every cell for cellular networks can provide full benefit to utilization of frequency bandwidth. However, this is can be a cause of ICI from neighboring cells. To tackle the problem, the frequency resource is divided and differently allocated between cell-center and cell-edge areas, so called FFR technique. In this section, the performance of cellular networks employing FFR is compared with the one without FFR. The simulation result in terms of SINR obtained from MATLAB is compared with result adopted from literature review (Haipeng, Lei and Xin, 2007). Furthermore, SINR when employing different FFR schemes is shown to indicate the formation of FFR which provides maximum performance.

From literature reviews discussed in Chapter 2, there are several forms of subcarrier allocation in FFR technique. The popular form is division of all subcarriers into two groups (Haipeng, Lei and Xin, 2007). One group is used at cell-center while the other one is separated into three subgroups. Each cell is divided into three sectors which each sector employs each subgroup of all subcarriers as shown in Figure 5.1. Figure 5.2 shows the directions of ICI when an OFDMA cellular environment is contained with two-tier 19 cells. When the i^{th} user is located in cell 1, the number of ICI at cell-center from neighboring cells is 18 (cell 2 to cell 19). At the cell-edge area, the interference signal is coming from 7 cells. For example, when the i^{th} user is in cell 1, the ICI signal is coming from cell 6, 7, 15, 16, 17, 18 and 19. The received SINR of the i^{th} user when staying at cell-center area can be expressed by

$$SINR = \frac{P_t \cdot 10^{-\frac{PL}{10}} \cdot S \cdot |H|^2}{N_0 B + \sum_{j=1}^{18} \left(P_{tI} \cdot 10^{-\frac{PL_I}{10}} \cdot S_I \cdot |H_I|^2 \right)} \tag{5.1}$$

when the received SINR when the i^{th} user stays at cell-edge area can be expressed by

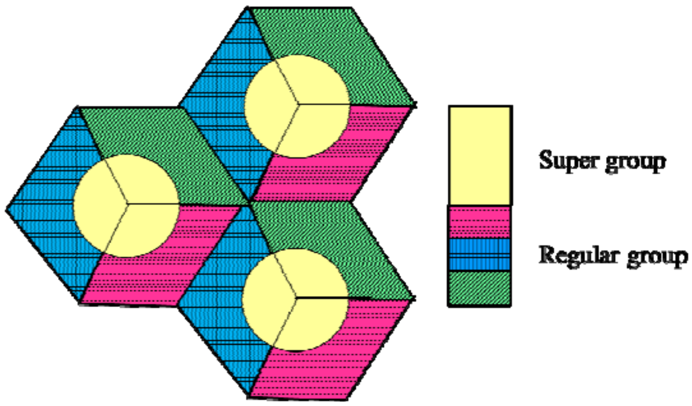


Figure 5.1 FFR technique including cell sectorization with two-subcarrier group division.

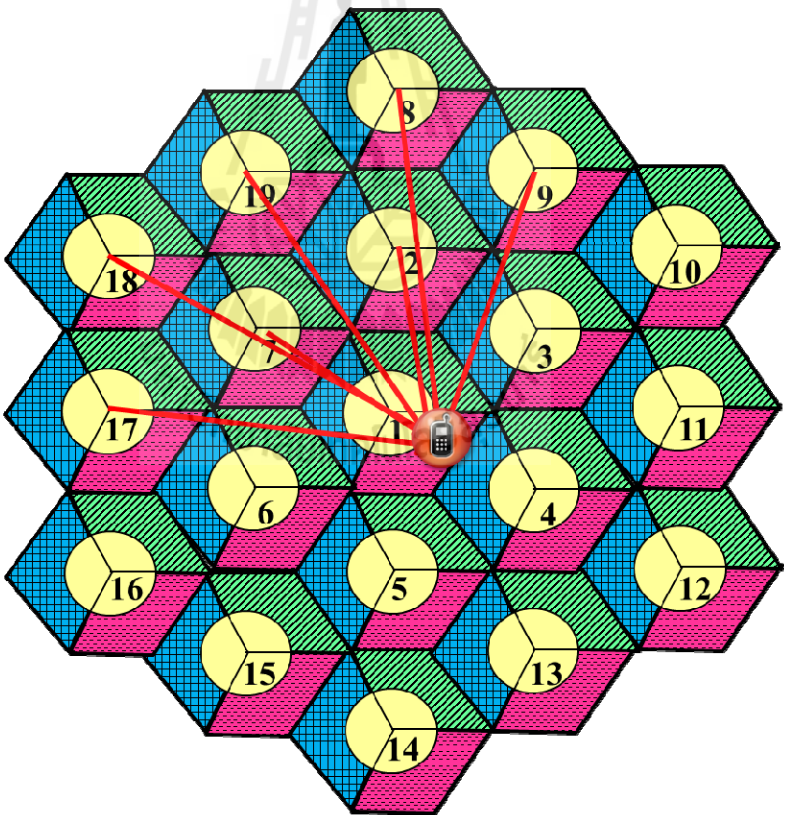


Figure 5.2 Cellular structure of OFDMA systems and interference at cell-edge.

$$SINR = \frac{P_t \cdot 10^{-\frac{PL}{10}} \cdot S \cdot |H|^2}{N_0 B + \sum_{j=1}^{7} \left(P_{tI} \cdot 10^{-\frac{PL_I}{10}} \cdot S_I \cdot |H_I|^2 \right)} \tag{5.2}$$

where the parameters presented in (5.1) and (5.2) are described in Section 4.5. The parameters given in this literature are listed in Table 5.1. Then, the performance comparison of utilized and unutilized FFR technique is shown in Figure 5.3. There are two cases of separation between cell-center and cell-edge areas from this literature, consideration of distance between BS and user and determination of SINR of the user. For the first case, subcarrier group of cell-center is utilized when the distance between BS and user is less than 800 meters. On the other hand, subcarrier group of cell-edge is utilized when distance between BS and user is longer than 800 meters. Therefore, SINR increases after 800 meters due to ICI is reduced when FFR technique is

Table 5.1 Parameters for simulation.

Parameters	Values
Subcarrier spacing	15 kHz
White noise power density	-174 dBm/Hz
Inter-cell distance	2 km
BS transmit power	43 dBm
Carrier frequency	900 MHz
d_{corr}	5 m
Channel model	Pedestrian B

employed. For the second case, SINR is a parameter to determine which subcarrier utilized in cell-center and cell-edge regions. In this case, subcarrier group for cell-center is utilized when SINR is higher than zero. On the other hand, subcarrier group utilized in cell-edge area is chosen.

From the results mentioned above, the performance in terms of SINR is simulated via MATLAB utilizing the same equations and parameters from the literature. The simulation result is shown in Figure 5.4. As we can see, the simulation result has a good agreement with the one from literature. This means that this MATLAB code is convincing to define the performance of the systems.

Next, the performance in terms of SINR employing FFR techniques with different frequency allocation schemes is discussed. The kinds of FFR are shown in Figure 5.5. In Figure 5.5 (a), all available subcarriers are used at cell-center region and some of subcarriers are used at cell-edge. Furthermore, all available subcarriers are divided into four parts, one part is used at cell-center area while other parts are used at cell-edge area in different cells as shown in Figure 5.5 (b). For Figure 5.5 (c), all available subcarriers are separated into two groups: cell-center and cell-edge groups. The cell-edge group is separated into three groups employed at cell-edge for different neighboring cells. In addition, to improve its capacity and reduce ICI, FFR technique is utilized including with cell sectorization as shown in Figure 5.5 (d) in which each cell is divided into three sectors. All available subcarriers are separated to two groups. One is called cell-center group employed at cell-center area and another one is called cell-edge group. The cell-edge group is divided into three subgroups where each subgroup is employed at different sector.

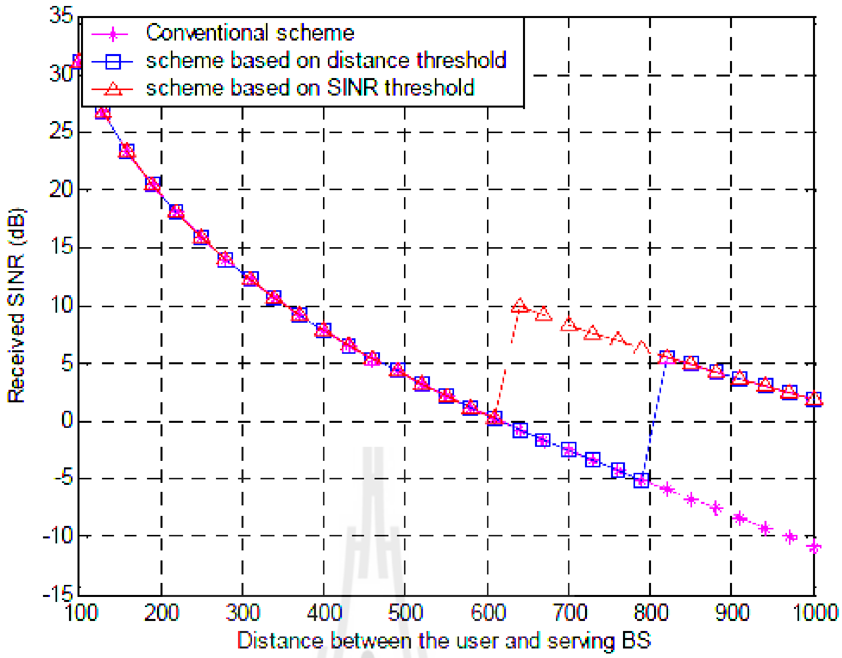


Figure 5.3 SINR vs. distance between BS and user from literature review (Haipeng, Lei and Xin, 2007).

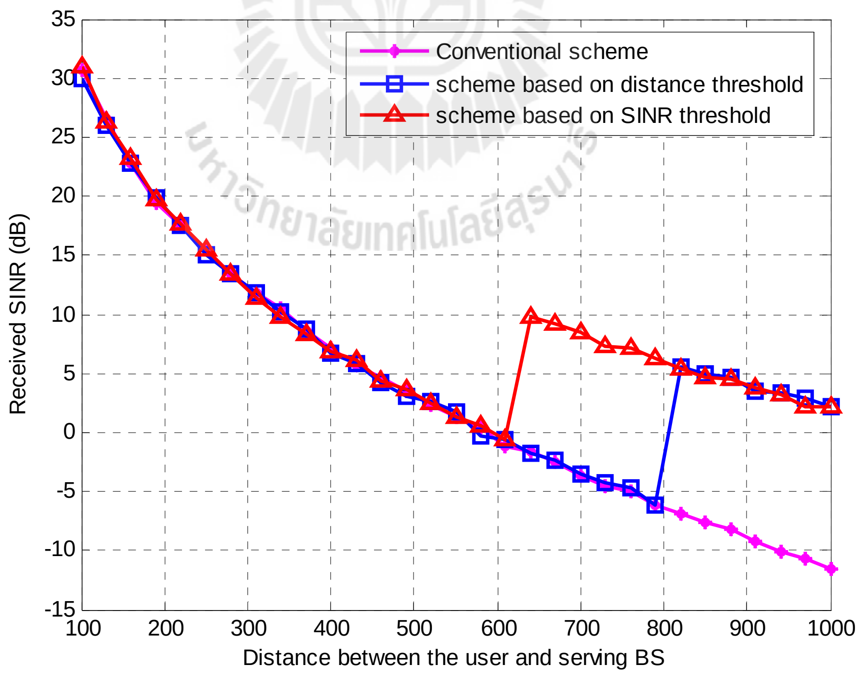


Figure 5.4 SINR vs. distance between BS and user from simulation result.

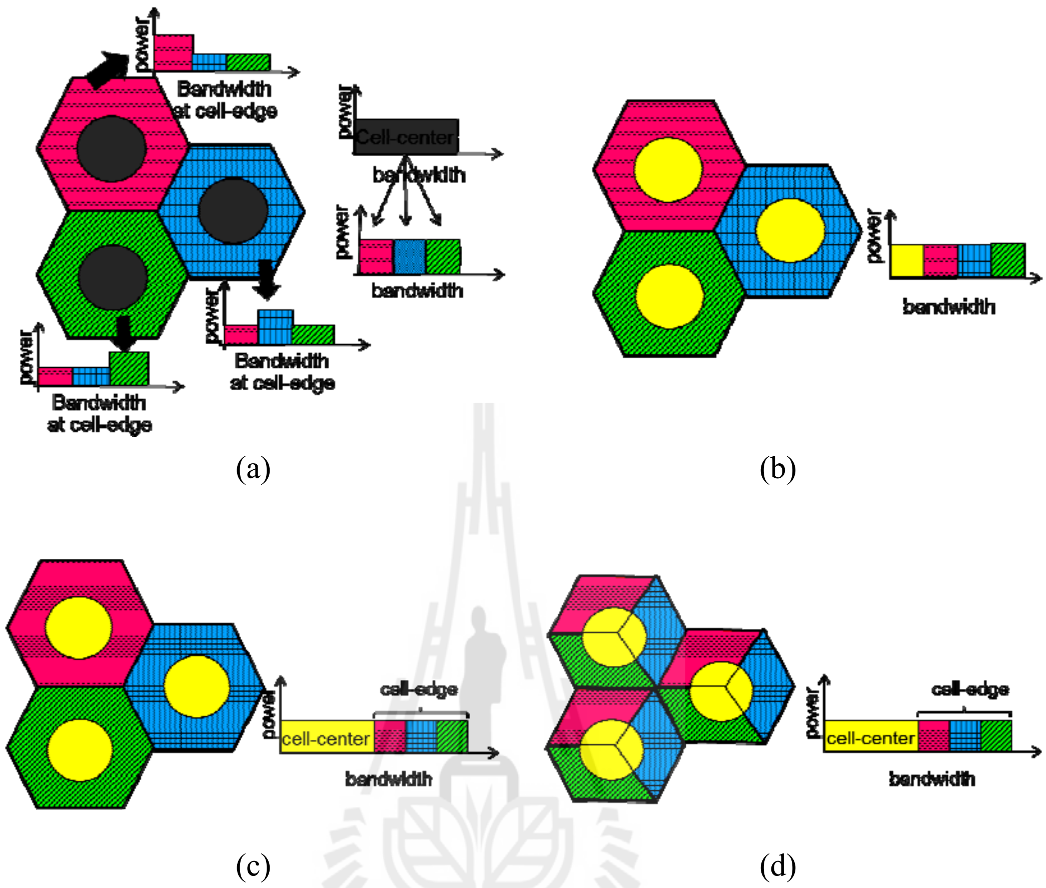


Figure 5.5 Examples of FFR techniques with different frequency allocation schemes.

The SINR employing different FFR scheme is shown in Figure 5.6. Please note that FFR technique used in Figure 5.6 is referred to the one shown in Figure 5.5. As a result, FFR cooperating with cell sectorization provides maximum performance. This is because it provides full benefit of frequency reuse in every cell. Therefore, the concept of FFR plus cell sectorization is adopted for the rest of this thesis. Please note that SINR shown in Figure 5.6 is rapidly changed at distance of 400 meters as this distance is initially given as a threshold distance between cell-center and cell-edge regions.

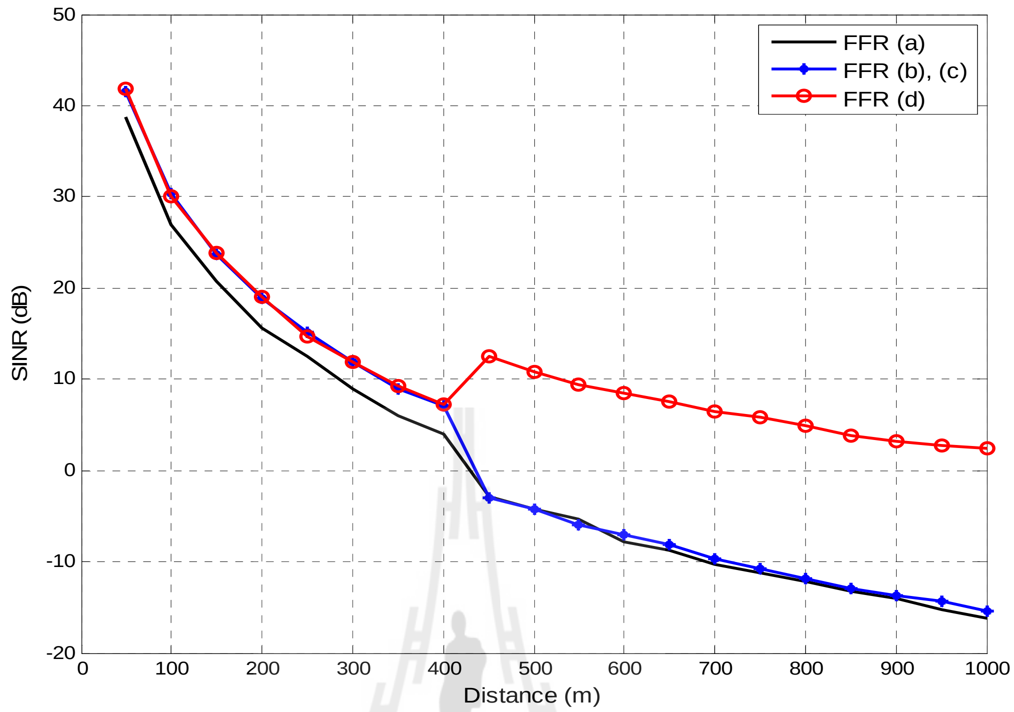


Figure 5.6 SINR vs. distance between BS and user for different types of FFR.

5.3 Horizontal and vertical beamforming

Although, interference signal coming from neighboring cells is reduced using FFR, it cannot cope the problem of ICI. This problem is due to the subcarrier from neighboring cells interferes the one in the cell of interest, so called ICI problem. To handle this problem, several researchers (Yapeng, Xu, Ma and Cuthbert, 2010, Yapeng, Xu, Ma and Cuthbert, 2009, Wendy, Qinghua and Shilpa, 2010, Lott, 2006 and Wongchompa and Uthansakul, 2011) have proposed the beamforming techniques when the beam pattern is steerable in horizontal plane as shown in Figure 5.7. As we can see that different beams are employed in different azimuth directions. Consequently, it cannot only reduce interference signal transmitted from the neighboring cells but also enhance the signal in a desired direction. Nevertheless, the mentioned concept does not work very well for the case having ICI signal coming from the same direction of the desired signal for the cell of interest as shown in Figure 5.8. In addition, the beam coming from cell-center introduces high level of interference to the neighboring's cell- center. Therefore, the work presented in (Chaipanya and Uthansakul, 2011) has proposed an idea to reduce ICI problem using vertical beamforming concept as shown in Figure 5.9. As we can see, the FFR technique is utilized along with the concept of different subcarriers in different beams. This is a full utilization of parameters in both frequency and space domains. The performance comparison of vertical and horizontal beamforming is shown in Figure 5.10. The parameters given in the simulation are listed in Table 5.1 (Haipeng, Lei and Xin, 2007). As we can see, utilizing vertical beamforming provides higher SINR to the systems. This is because interference from cell-center to the neighboring's cell-center is reduced.

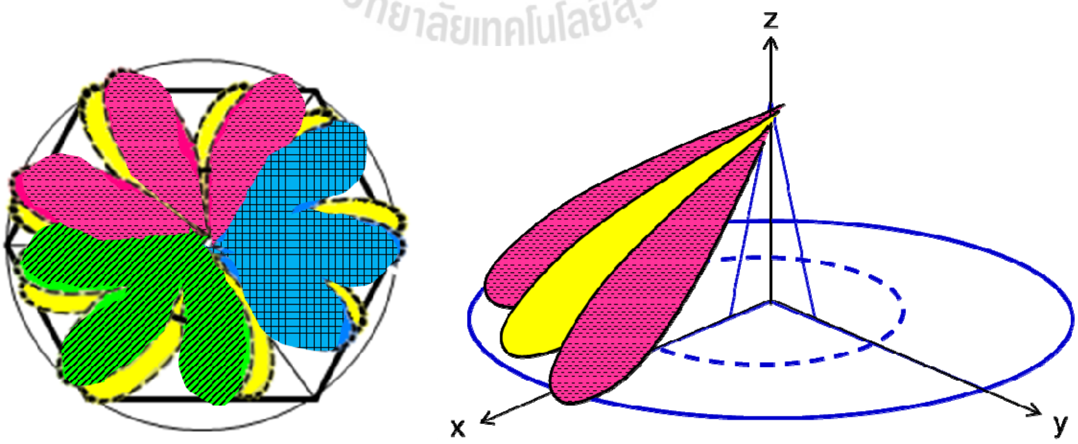


Figure 5.7 Horizontal beamforming.

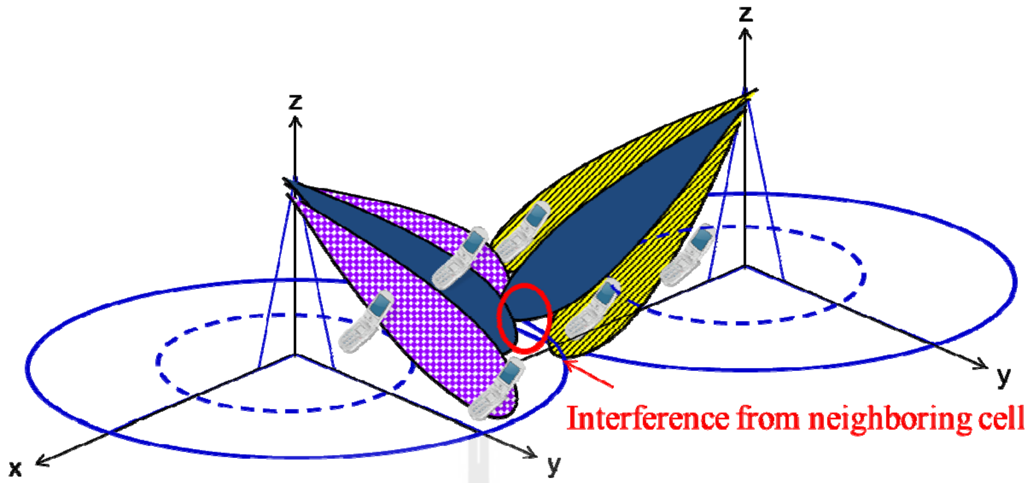


Figure 5.8 Interference from neighboring cell when performing horizontal beam formation.

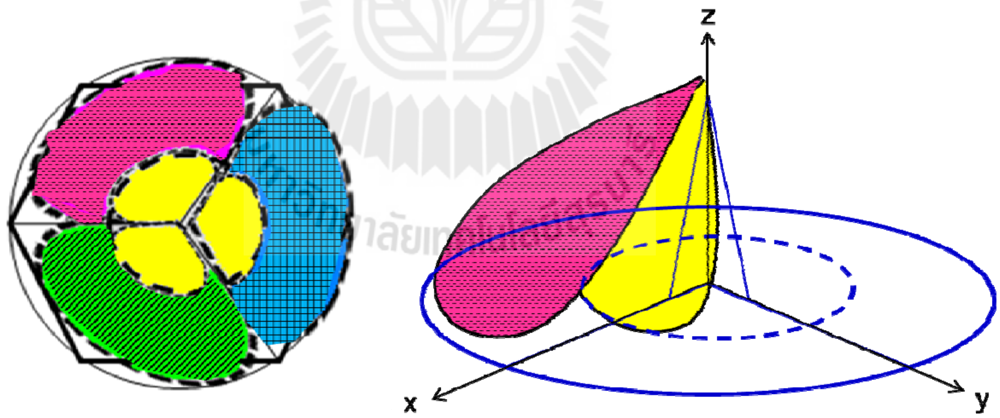


Figure 5.9 Vertical beamforming.

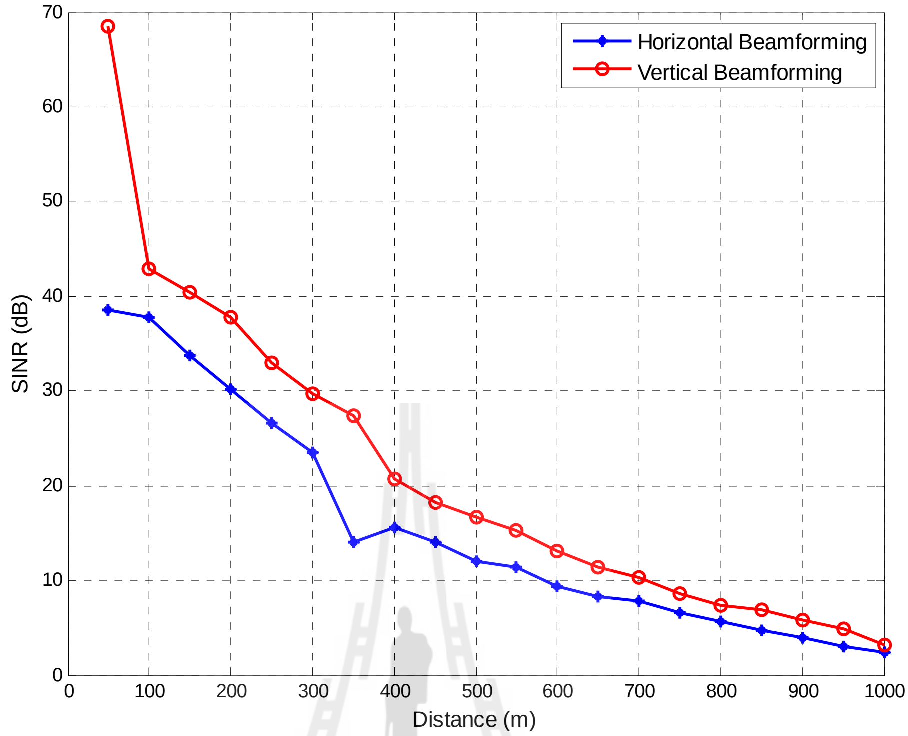


Figure 5.10 SINR vs. distance between BS and user when performing horizontal and vertical beamforming.

5.4 Antenna simulation

From Chapter 2, several antenna types have been proposed to steer their beam to desired direction such as the work presented in (Chaipanya and Uthansakul, 2011) which has presented inter-cell interference reduction using vertical beamforming scheme for fractional frequency reuse technique. In this work, 7×7 planar array antenna is utilized. This scheme can reduce ICI and improve performance of the cellular networks. Nevertheless, this concept is considerably not practical as there are some difficulties in installation planar array at BS. In addition, system level analysis of vertical sectorization for 3GPP LTE and self-optimization of coverage and capacity in LTE using adaptive antenna systems have been presented in (Yilmaz and

Hamalainen,2009 and Yilmaz, 2010). In these works, performance with various vertical half-power beamwidths and electrical tilt angles have been observed to obtain the optimized space of the overlap between two vertical sectors and the gain in terms of cell capacity. From these schemes, the system capacity can be improved. However, the schemes proposed in (Yilmaz and Hamalainen, 2009 and Yilmaz, 2010) cannot reflect the true performance for cellular networks as a real antenna currently employed at BS has not been taken into account. In addition, the work presented in (Tsakalaki, Maestro, Haapala, Roman and Arauzo, 2012) has revealed the performance of vertical beam formation applied to a commercial active antenna. In the mentioned work, a min-norm technique has been proposed to accomplish beam formation which is considerably complicated to be implemented at BS, thus the hardware is costly. Therefore, this thesis presents the concept of vertical beamforming suitable for BS

Figure 5.11 Reference antenna.

antennas as they are currently linearly stacked in vertical manner. This vertical beamforming technique is simple and practical to be installed at BS. The performance of proposed concept is validated through computer simulation comparative with the ones currently utilized at BS.

In this thesis, the antenna created in simulation according to the one appeared in (Andrew A CommScope Company, 2009) is currently employed at cellular BS. The photograph of the reference antenna is shown in Figure 5.11. It includes 9-elements antenna array where the inter-element spacing is 0.83λ as shown in Figure 5.12. The phase shift between adjacent elements that designed in CST Microwave Studio is referred from (4.2). The simulation results obtained from CST Microwave Studio are compared with the commercial data from Commscope Company. The photograph of reference antenna is compared with the one created in CST Microwave Studio as shown in Figures 5.12 and Figure 5.13, respectively. In this Figure, the BS antenna is included with 9-elements antenna arrays, 9 feed lines and reflector. The horizontal pattern of commercial data and simulation results are shown in Figures 5.14 (a) and (b), respectively. Also, the vertical pattern from commercial data and simulation results are shown in Figures 5.15 (a) and (b), respectively. In addition, some parameters given in simulation are compared with the ones from commercial data as shown in Table 5.2. As we can see, the simulation results have a good agreement with the ones from commercial data. Also, the obtained half-power beamwidth in horizontal and vertical planes and also beam tilt angle are similar. Also, gain and front to back ratio of antenna are moderately comparable.

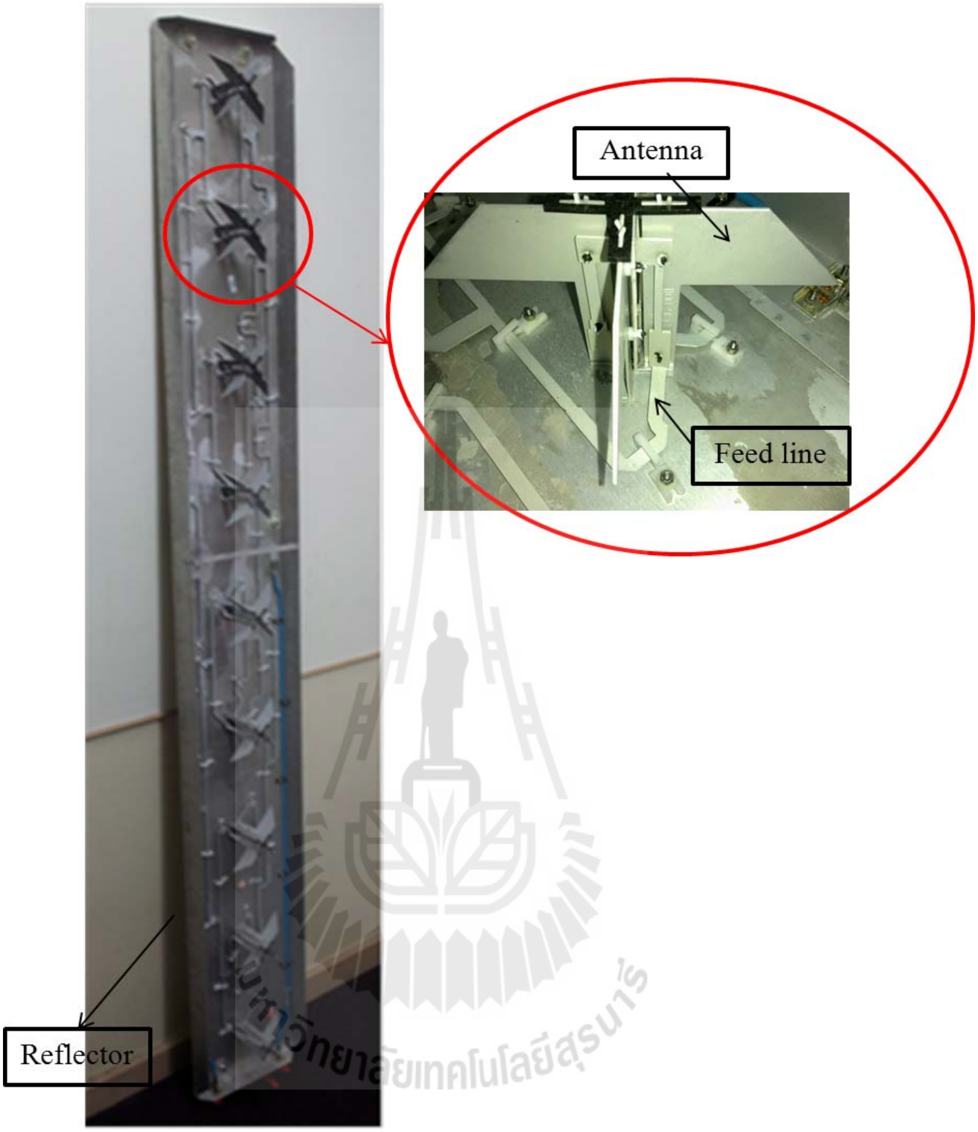


Figure 5.12 Photograph of reference antenna.

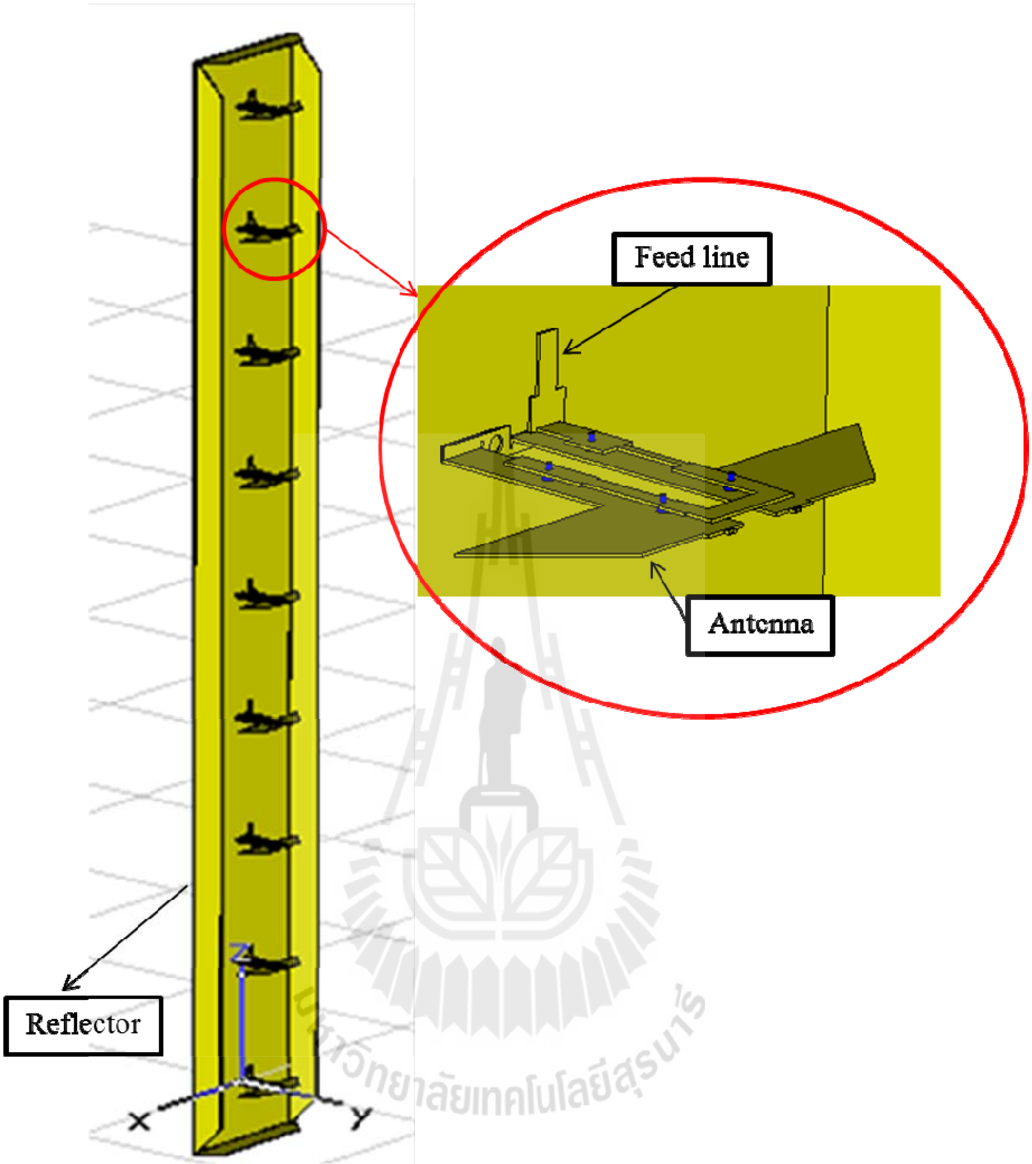
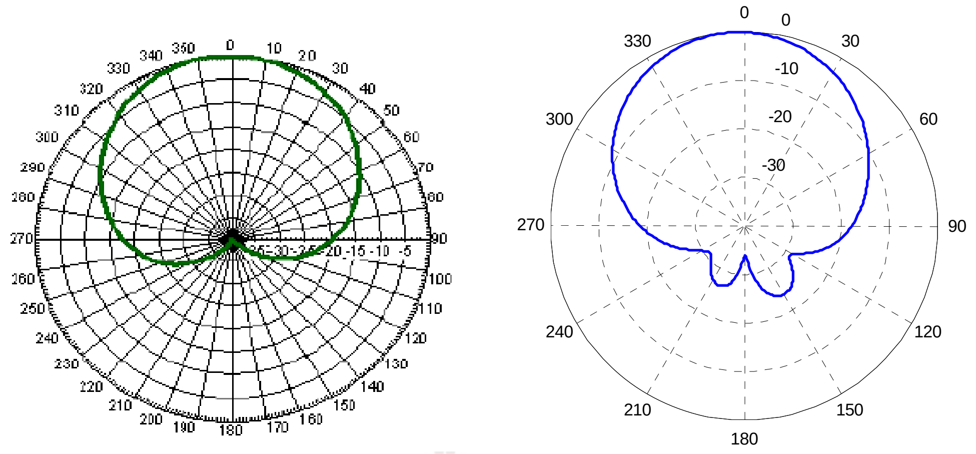
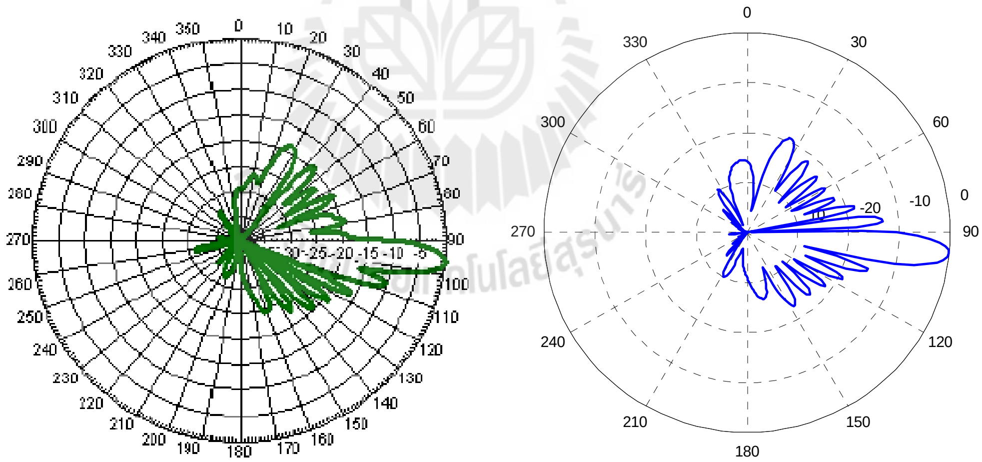


Figure 5.13 Photograph of antenna which created in CST.



(a) (b)

Figure 5.14 Radiation pattern in azimuth of reference antenna (Andrew A CommScope Company, 2009) obtained from (a) commercial data and (b) simulation.



(a) (b)

Figure 5.15 Radiation pattern in elevation of reference antenna (Andrew A CommScope Company, 2009) obtained from (a) commercial data and (b) simulation.

Table 5.2 Parameters of antenna.

Parameters	Commercial data	Simulation results
Frequency (MHz)	870-960	900
Horizontal, half power beamwidth (dBi)	65	64.1
Gain (dBi)	17.8	18.7
Vertical, half power beamwidth (dBi)	7	7
Beam tilt (degree)	6	6
Upper sidelobe suppression (dB)	18	13.1
Front to Back Ratio at 180° (dB)	30	30.95

5.5 Vertical beamforming in cellular networks

The performance in terms of SINR presented in (4.17) is assumed that omnidirectional antenna is used at BS. Therefore, users obtain the same transmitted power all over the cell. This is because the gain of antenna is radiated in omnidirection. However, when FFR included with beamforming technique is employed, all areas in each cell experience unequal transmitted power. This is due to the omnidirectional antenna is replaced by directional antenna. Therefore, the direction experiencing maximum transmitted power is the direction of maximum radiation. According to this, SINR is considered with the radiation pattern of antenna which can be express as

$$SINR = \frac{P_t \cdot G(\theta,\phi) \cdot 10^{-\frac{PL}{10}} \cdot S \cdot |H|^2}{N_0 B + \sum_{j=1}^{q} \left(P_{tI} \cdot G_I\left(\theta_I,\phi_I\right) \cdot 10^{-\frac{PL_I}{10}} \cdot S_I \cdot \left|H_I\right|^2 \right)} \tag{5.3}$$

where $G(\theta,\phi)$ is gain in θ and ϕ directions of desired cell. $G_I\left(\theta_I,\phi_I\right)$ is gain in θ_I and ϕ_I directions of interfering cells. $G(\theta,\phi)$ and $G_I\left(\theta_I,\phi_I\right)$ are calculated by array factors equation in (4.8) and equal to unity (Balanis, C.A., 1997).

Substituting (5.3) into (5.1) and (5.2), the received SINR when FFR is included with beamforming technique can be expressed as

$$SINR = \frac{P_t \cdot G(\theta,\phi) \cdot 10^{-\frac{PL}{10}} \cdot S \cdot |H|^2}{N_0 B + \sum_{j=1}^{18} \left(P_{tI} \cdot G_I\left(\theta_I,\phi_I\right) \cdot 10^{-\frac{PL_I}{10}} \cdot S_I \cdot \left|H_I\right|^2 \right)} \tag{5.4}$$

$$SINR = \frac{P_t \cdot G(\theta,\phi) \cdot 10^{-\frac{PL}{10}} \cdot S \cdot |H|^2}{N_0 B + \sum_{j=1}^{7} \left(P_{tI} \cdot G_I\left(\theta_I,\phi_I\right) \cdot 10^{-\frac{PL_I}{10}} \cdot S_I \cdot \left|H_I\right|^2 \right)} \tag{5.5}$$

where (5.4) and (5.5) are the received SINR when user stays at cell-center and cell-edge area, respectively.

Next, the performance of cellular networks is shown in terms of SINR and channel capacity using the proposed scheme through the computer simulation. Please note that the parameters given in the simulation are listed in Table 5.1 (Haipeng, Lei and Xin, 2007). The antenna gain values employed in (5.4) and (5.5) in case of cell-center and cell-edge are obtained from own developed computer program using CST Microwave Studio. Please note that the linear array antenna operating at 900 MHz is employed (Andrew A CommScope Company, 2009). The choice of mainbeam direction can be chosen by adjusting the phase shift between the antenna elements of the array. BS antenna height of 50 meters is considered in simulation. In the cell-center area, the inference signal is assumed to be coming from 18 cells. At the cell-edge area, the interference signal is coming from 7 cells (cell 6, 7, 15, 16, 17, 18 and 19) as demonstrated in Figure 5.2. The threshold distance is assumed to be 400 meters. This distance is the criteria to switch the utilized beam. The beam at cell-center is utilized when the distance between user and serving BS is less than 400 meters, otherwise the beam at the cell-edge is exploited.

In case of one spot beam, the coverage area is all over the sector hence the cell-center and cell-edge utilize the same beam pattern. The different mainbeam directions are assumed in order to give variety in simulation cases. From simulation, mainbeam direction of 98° seems to provide the maximum SINR to the systems as shown in Figure 5.16. However, SINR is relatively low in the cell-center region (0 to 400 meters) when mainbeam direction is small, from 96 to 100 degrees. This is due to the half-power beamwidth in vertical plane of antenna cannot cover all of the sector area. However, SINR can be improved when applying the proposed concept utilizing vertical beamforming, two beams for cell-center and cell-edge as shown in Figure 5.9.

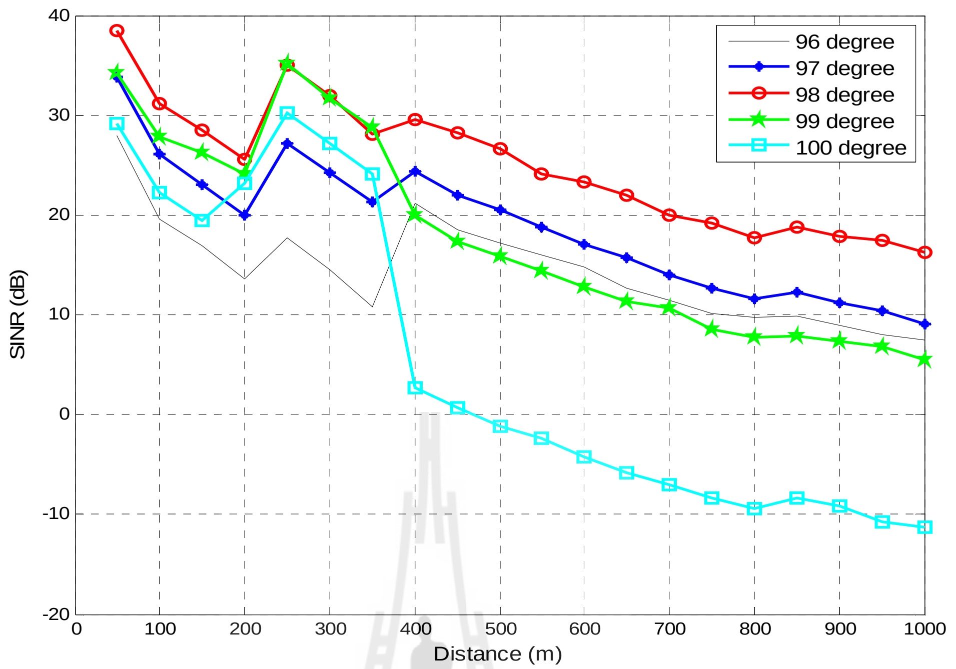


Figure 5.16 SINR vs. distance between BS and user when varying tilted-angle of mainbeam for cell-edge area.

Next, an appropriate angle of mainbeam direction covering cell-center area is discussed. Some different angles of mainbeam directions have been utilized in simulation to improve performance of cell-center area as its outcome is shown in Figure 5.17. As we can see, mainbeam direction of 106° seems to provide the maximum SINR at cell-center area. Nevertheless, it cannot provide maximum performance in the cell-edge region (from 400 to 1000 meters) comparing with utilizing main beam direction of 98°. This is because the half-power beamwidth in vertical plane of antenna cannot cover the cell-edge area. Furthermore, the users at the cell-edge area suffer from high level of interference coming from neighboring cells. Therefore, this work proposes utilization the different beams in cell-center and cell-

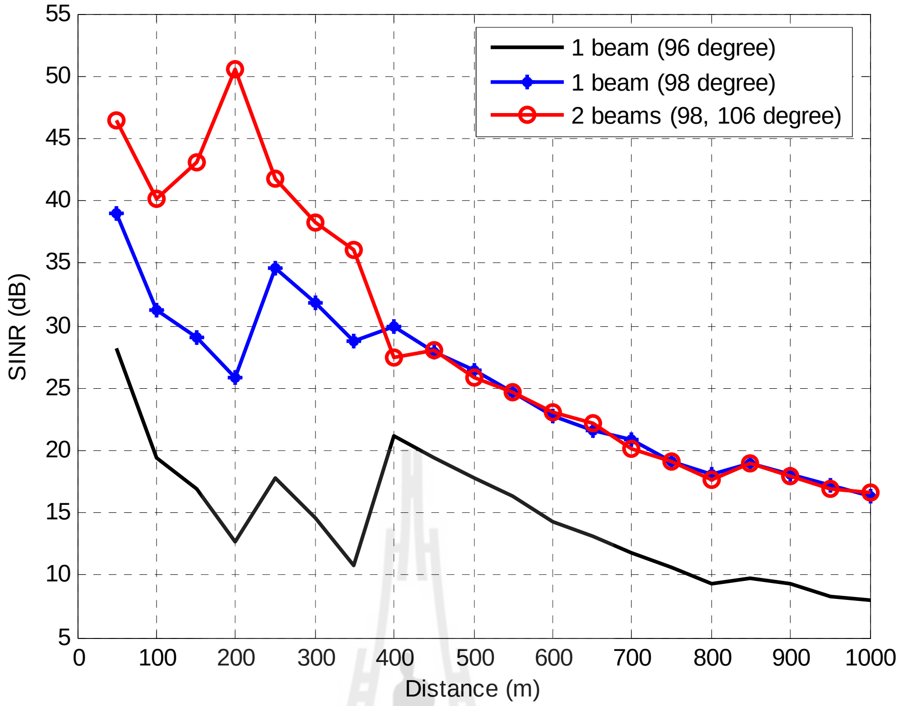


Figure 5.18 SINR vs. distance between BS and user for 3 cases, single beam, 1-beam vertical beam and 2-beam vertical beam.

edge area separately. The mainbeam direction of 106° is used for covering cell-center area and 98° is used for covering cell-edge area.

Latter, the proposed concept is validated comparing with single beam scheme providing one spot beam covering all over the sector, hence the cell-center and cell-edge areas utilize the same beam pattern. The obtained comparison is shown in Figure 5.18. Two assumed cases provide similar performance in the cell-edge region (after 400 meters). In addition, SINR is relatively low in the cell-center region (0 to 400 meters) when applying single beam scheme. However, in this area, the SINR can be improved when applying the proposed concept utilizing vertical beamforming, two separate beams for cell-center and cell-edge areas.

Next, the channel capacity of two cases is described in Figure 5.19. As we can see, for the case of vertical beamforming, two beams separately utilized for cell-center and cell-edge can improve the system capacity. However at 350 meters, the capacity of proposed scheme is lower than the capacity of one spot beam scheme. This may be caused by changing beam from cell-center to cell-edge. However, the proposed vertical beamforming enhances performance of cellular networks.

The results discussed earlier have been obtained by assuming the region in one-dimensional from 0 to 1000 meters. Anyway, it cannot illustrate the overall performance throughout the sector. Therefore, the SINR throughout the sector is revealed in Figure 5.20. As we can see, the area having higher SINR in case of

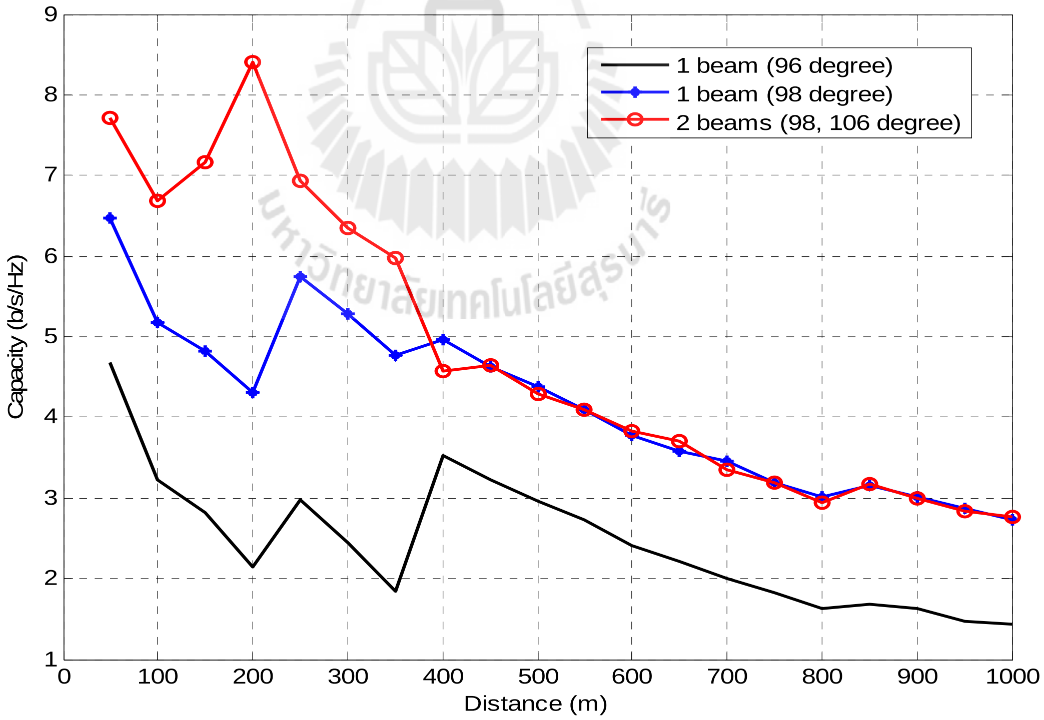
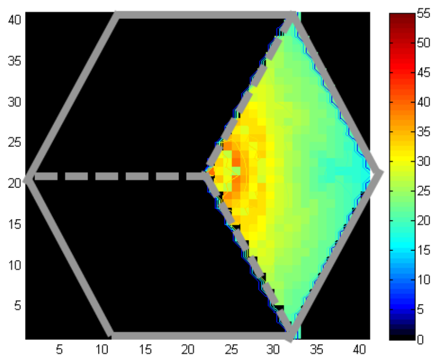
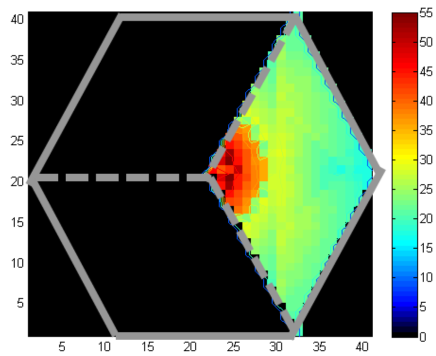


Figure 5.19 Capacity vs. distance between BS and user for 3 cases, single beam, 1-beam vertical beam and 2-beam vertical beam.



(a)



(b)

Figure 5.20 Contour plots of SINR over the sector (a) single beam and (b) vertical beamforming.

utilizing the proposed concept is wider comparing to the one employing single beam, particularly at the cell-center. This means that the vertical beamforming enhances the performance of cellular networks.

5.6 Chapter summary

In this chapter, beam patterns are simulated according to the BS antenna currently utilized nowadays. The performance in terms of SINR is considered with radiation pattern of antenna. Two separate beams are utilized for cell-center and cell-edge areas. The results show that mainbeams in directions of 106° and 98° provide the maximum SINR at cell-center and cell-edge areas, respectively. This results in reduction of the inter-cell interference coming from neighboring cells. The obtained results have indicated that the vertical beamforming concept can improve the performance of the cellular networks comparing with the one employing one spot beam.

CHAPTER VI

EXPERIMENTAL RESULTS

6.1 Introduction

In this chapter, the designed antenna is constructed based on CST Microwave Studio simulation. Then, the antenna is tested for two cases: with and without phase shifters. The parameters in terms of return loss and impedance are measured. Moreover, the radiation patterns of antenna are tested under real circumstance for both two cases. Also, the performance in terms of SINR and channel capacity using experimental results are exposed to confirm that the proposed concept is able to improve the performance of cellular networks.

6.2 BS antenna

The antenna is created based on CST Microwave Studio programming as shown in Figure 5.12 (b). First, single antenna with reflector is created as shown in Figure 6.1. The parameters of single antenna are measured using network analyser. In addition, impedance matching of this antenna at 900 MHz is done by adjusting the gap between antenna and feed line as shown in Figure 6.1. The results in terms of return loss and impedance of an antenna are shown in Figures 6.2 (a) and (b), respectively. The obtained results show less than -20 dB return loss and higher than 43 ohm impedance. These results can confirm that this antenna can be used in practical (Stutzman and Thiele, 2013). Next, nine-element antenna array is included with in a reflector as shown in Figure 6.3 (b) comparing to a photograph of antenna as

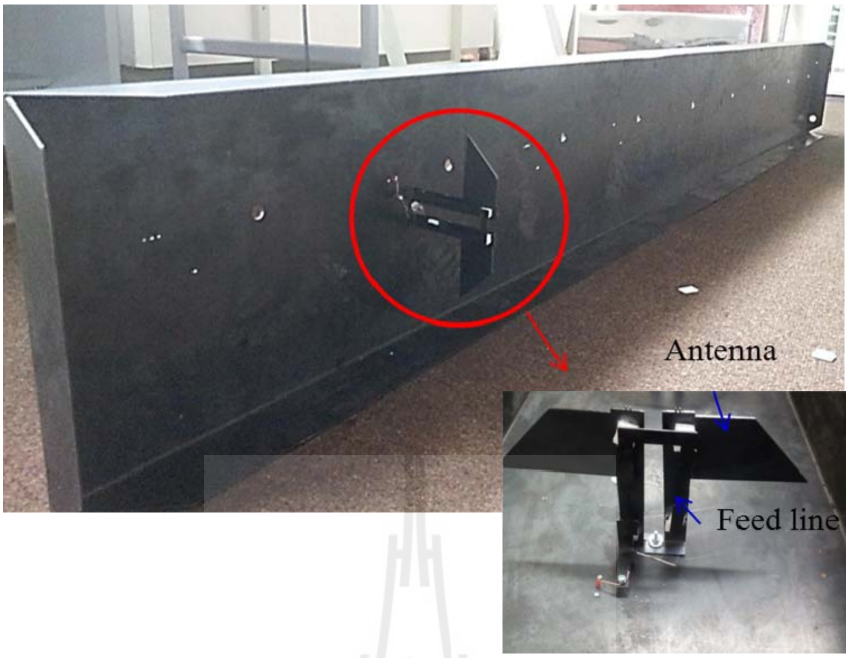
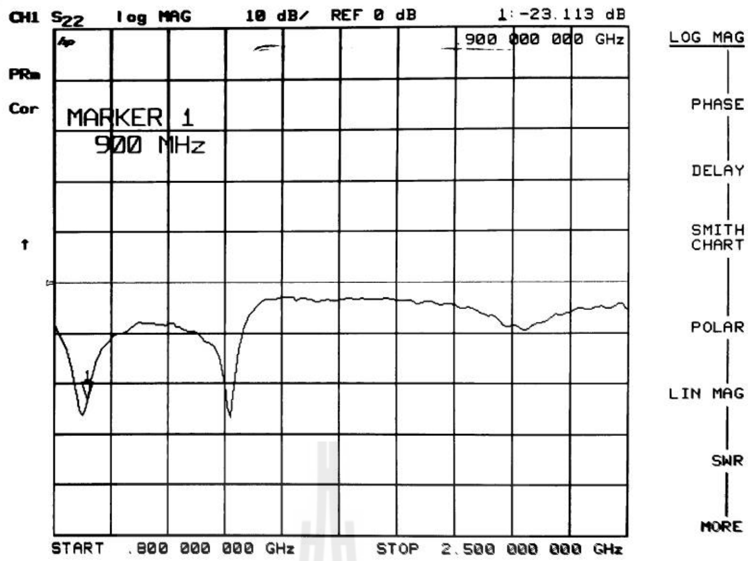
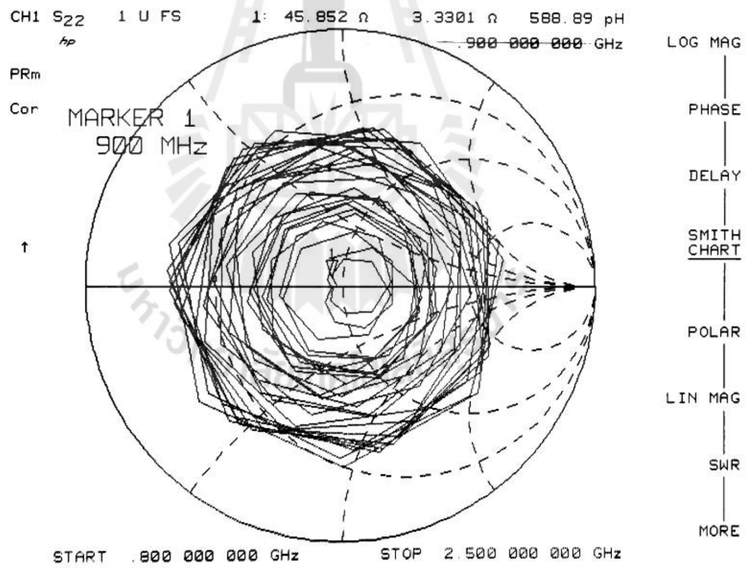


Figure 6.1 Single antenna with reflector.

shown in Figure 6.3 (a). The return loss and impedance of each element are measured as shown in Table 6.1. As a result, the return loss of each element is about 23 dB and impedance of each element is about 45 ohm. This means that each element can work very well in practical. Afterwards, input power is divided into individual element at the same power level using power divider as shown in Figure 6.4. This power divider is used for one input separated into three equal outputs. One power divider is used for 3-element antenna array. Therefore, four power dividers are used for this antenna. Three power dividers are used for 9-element antenna array and another one is used for separating input power into three power dividers. The inclusion of 9-element antenna array with 4 power dividers is shown in Figure 6.5. The return loss and impedance of the antenna is measured using network analyzer and the results are shown in

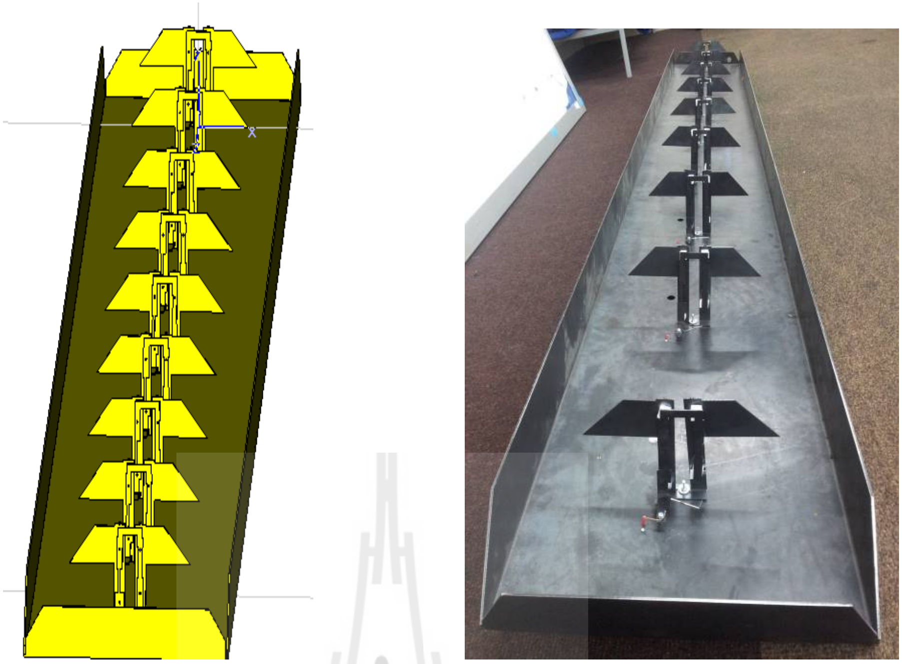


(a)



(b)

Figure 6.2 (a) Return loss and (b) impedance of single antenna with reflector.



(a) (b)

Figure 6.3 Photograph of (a) antenna created in simulation and (b) fabricated antenna.

Table 6.1 Parameters of each element.

No. of antenna	**Return loss (dB)**	**Impedance (Ohm)**
1	-24.881	46.393+j4.2754
2	-24.734	46.078+j0.0000
3	-22.074	43.266+j0.0000
4	-19.843	43.172-j3.06640
5	-16.797	43.672-j10.0800
6	-18.675	42.926-j6.2930
7	-17.078	40.869-j6.2813
8	-20.430	42.506+j0.0000
9	-20.659	42.336+j0.9863

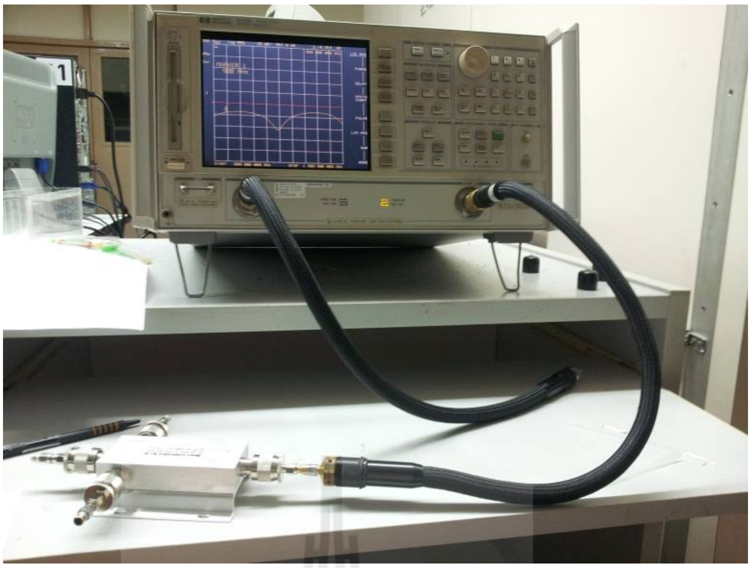
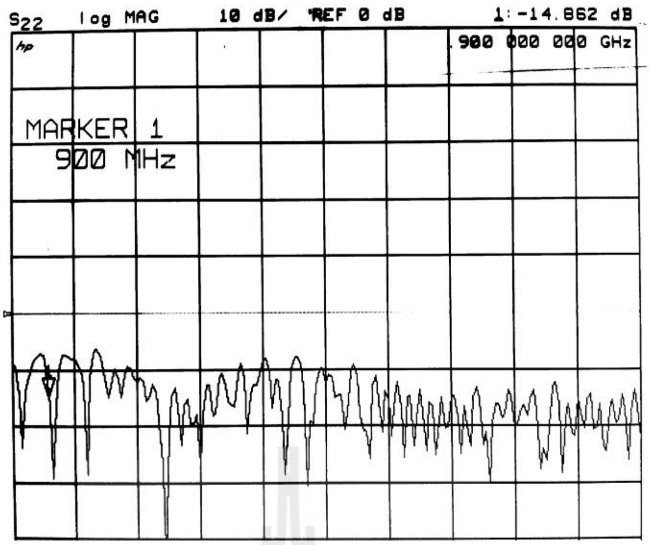


Figure 6.4 Power divider at 900 MHz.

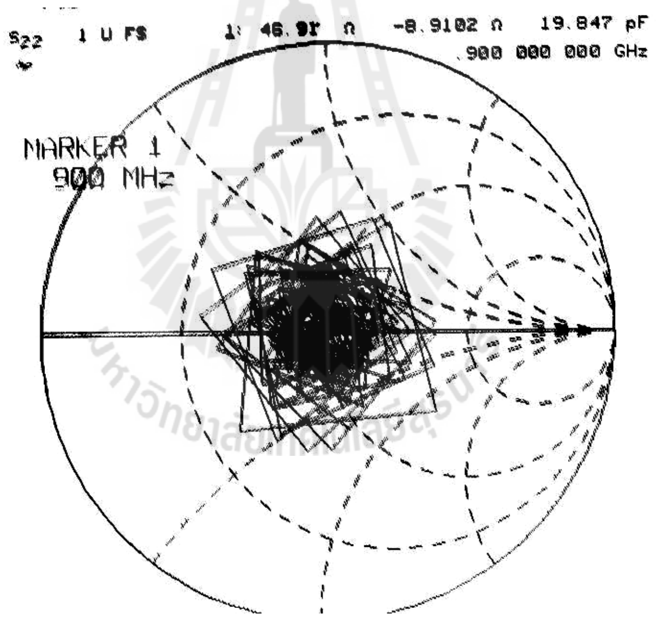
Figure 6.5 Photograph of 9-element antenna array with 4 power dividers.

Figures 6.6 (a) and (b), respectively. The obtained results show less than -14 dB return loss and more than 47 ohm impedance. This can confirm that the antenna is able to use in practical environment.

Afterwards, the environment under test is considered. The spectrum signal at 900 MHz is explored using spectrum analyser in the testing area as shown in Figure 6.7. As a result, interference signal is relatively low during frequencies from 894.6 to 939.4 MHz. This result can confirm that radiation pattern of antenna can be measured in this area at 900 MHz without interference. Then, this constructed antenna is tested in testing area as shown in Figure 6.8. At the receiver, monopole antenna at 900 MHz is utilized to be a receiving antenna followed by low noise amplifier as shown in Figure 6.9. The results shown in network analyzer screen are recorded every 0.5 degree relative to the transmitter. At the transmitter, the constructed antenna transmits the input power fed by network analyzer through power amplifier as shown in Figure 6.10 (a). The constructed antenna is rotated by 0.5 degree at a time using servo motor as shown in Figure 6.10 (b). The obtained results at receiver are shown in terms of radiation patterns as shown in Figure 6.11. Figures 6.11 (a) and (b) show horizontal and vertical patterns from the experiment, respectively. As we can see, the experimental results have a good agreement with the ones obtained from simulation results as illustrated on Figure 5.13 (b) and Figure 5.14 (b). Also, the obtained half-power beamwidth in horizontal and vertical planes and also beam tilt are similar.

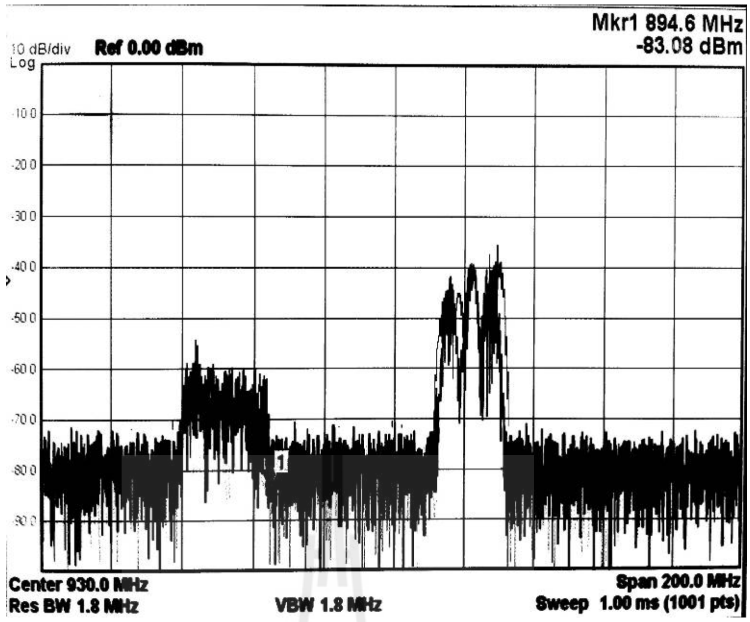


(a)

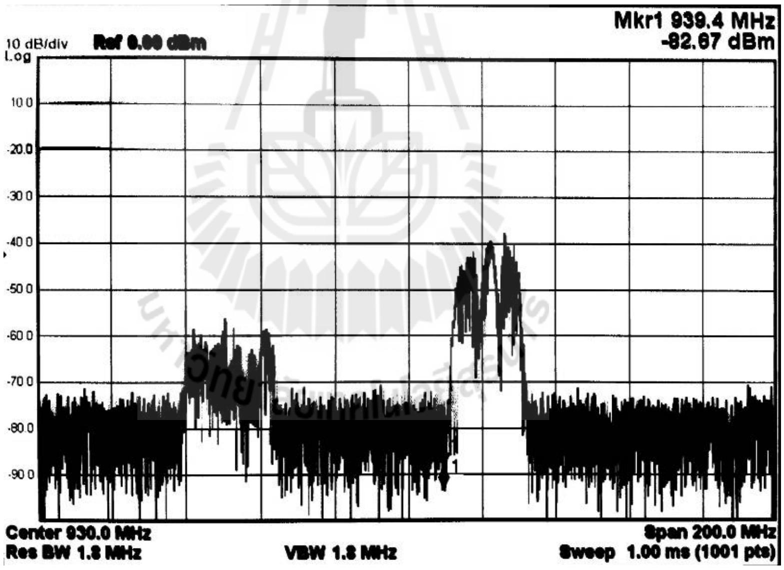


(b)

Figure 6.6 (a) Return loss and (b) impedance of constructed antenna.



(a)



(b)

Figure 6.7 Frequency spectrum in testing area for frequencies between (a) 894.6 to (b) 939.4 MHz.

Figure 6.8 Testing area for radiation pattern measurement.

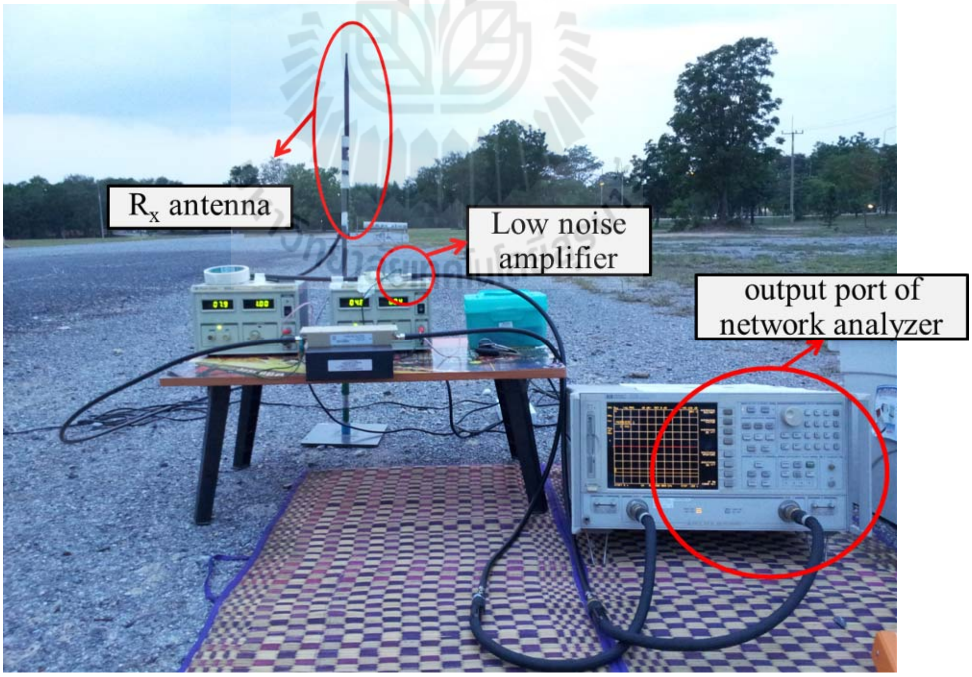
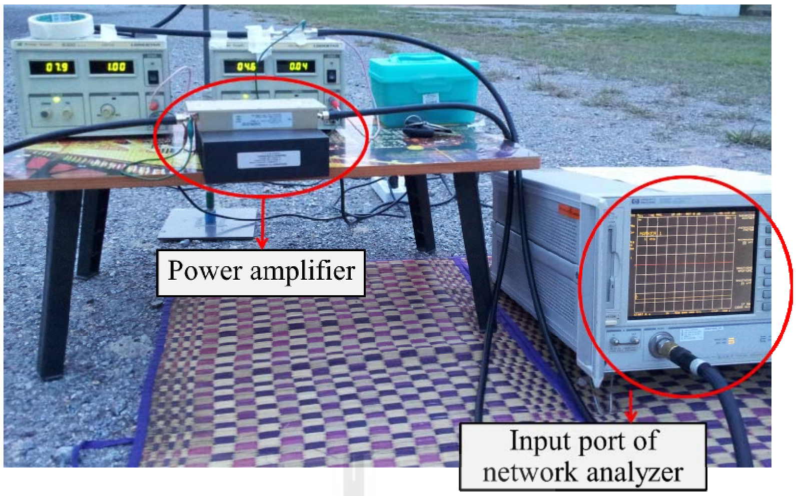
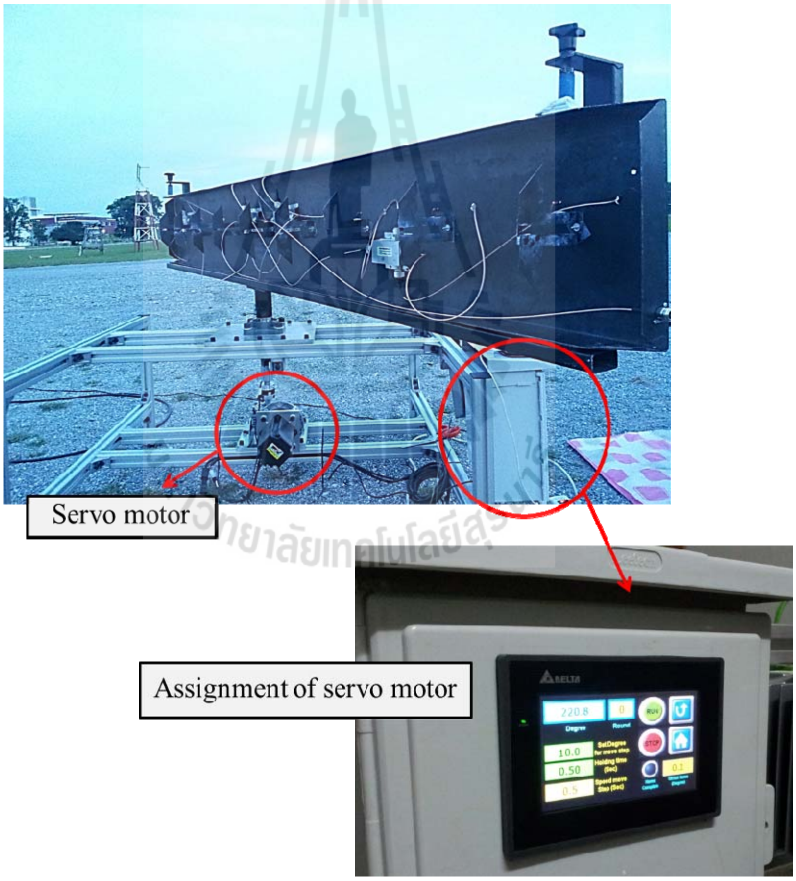


Figure 6.9 Receiving antenna followed by low noise amplifier.

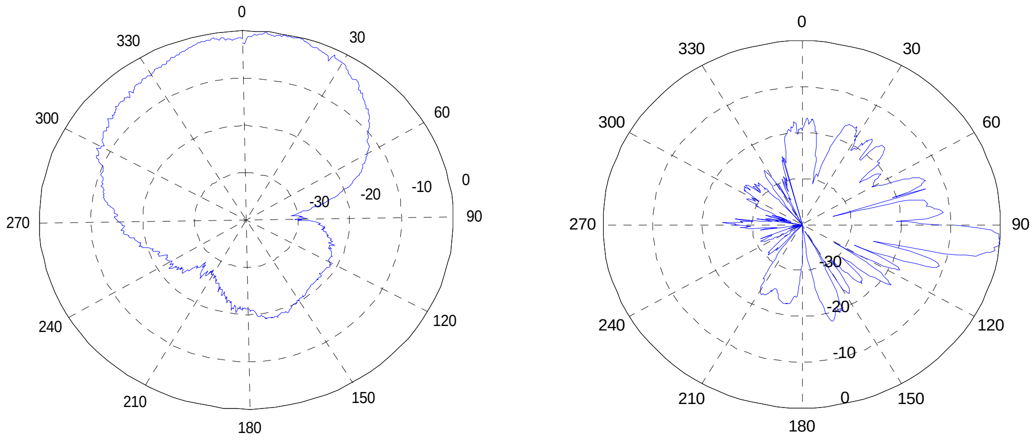


(a)



(b)

Figure 6.10 (a) Input power fed by network analyzer through power amplifier and (b) BS antenna at transmitter.



(a) (b)

Figure 6.11 Measured radiation pattern in (a) azimuth and (b) elevation.

6.3 BS antenna with phase shifter

Next, main beam direction can be changed by adjusting the phase shift between the antenna elements of the array. One method to adjust the phase shift between the antenna elements is to control the input voltage of individual phase shifter. In this thesis, op amp circuit is chosen to control input voltage of each phase shifter. The op amp circuit is shown in Figure 6.12 in which its output voltage can be express by (Boylestad and Nashelsky, 2002)

$$V_{out} = V_{in}\left(1 + \frac{R_2}{R_1}\right) \tag{6.1}$$

where R_1 and R_2 are resistors of the op amp circuit. Also, V_{out} and V_{in} are output and input voltage of op amp circuit. In this thesis work, V_{in} and R_1 are constant values

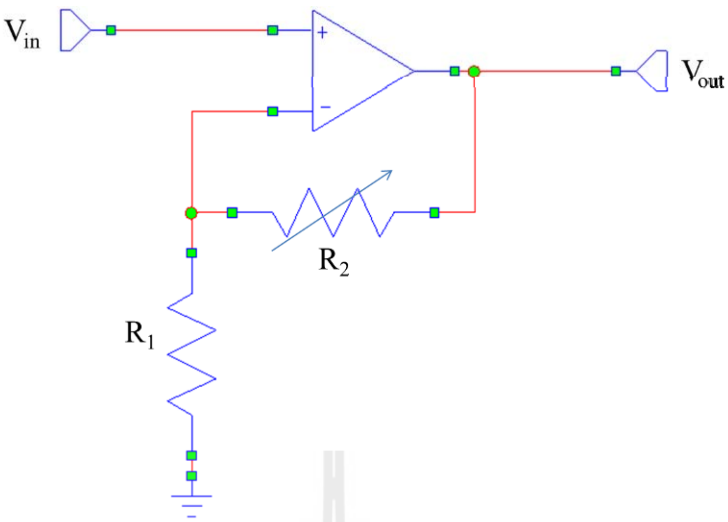


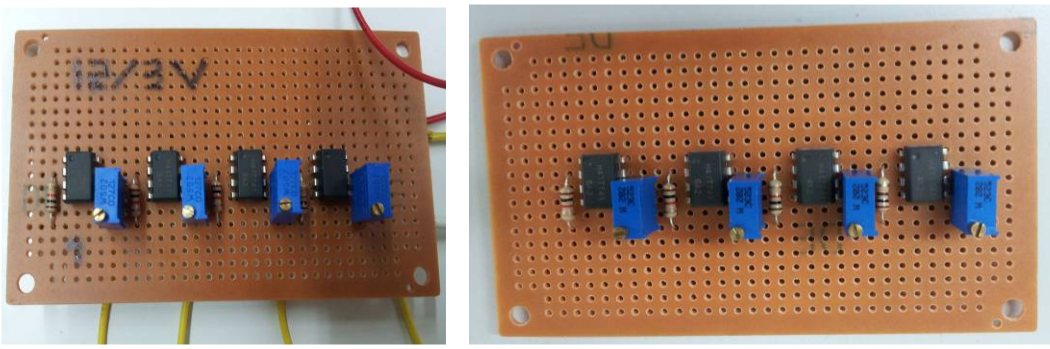
Figure 6.12 Op amp circuit.

while R_2 is adjusted to suit to V_{out} which is input voltage of phase shifter. The phase shift between the antenna elements of the array can be express by (Balanis, 1997)

$$\beta = (n-1)(-kd\cos\theta_0) \tag{6.2}$$

where *n* stands for the order of antenna element and *k* is the propagation constant, with $k = 2\pi/\lambda$. The antenna elements are equally spaced by *d*. The angle represented by θ is measured from the z-axis in spherical coordinate.

From simulation results presented in chapter V, main beam direction of 106° seems to provide the maximum SINR at cell-center area. Then, op amp circuit is designed to control input voltage of phase shifter to shift direction of main beam to



(a) (b)

Figure 6.13 Op amp circuit controlling phase shifter number (a) two to five and (b) six to nine.

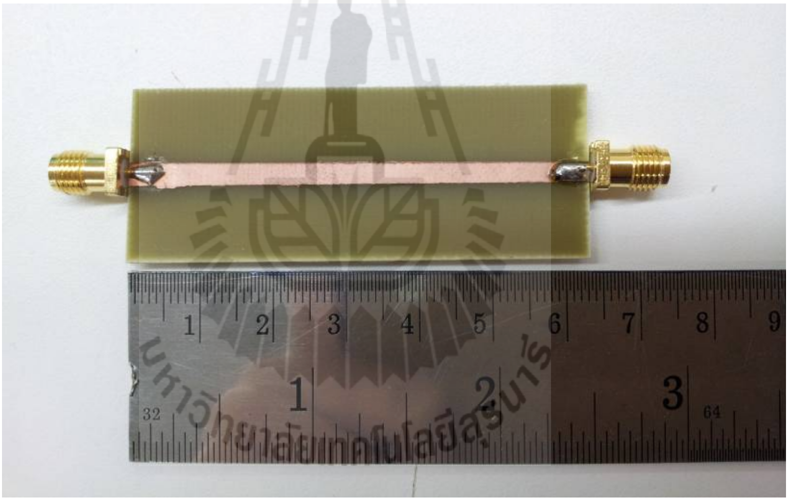


Figure 6.14 180° phase shifter at 900 MHz.

106° as shown in Figure 6.13. One op amp circuit set shown in Figure 6.13 (a) is used for phase shifter number 2 to 5 and another one as shown in Figure 6.13 (b) is used for phase shifter number 6 to 9. For the first phase shifter, 0 V input voltage of phase shifter is designed then op amp circuit is excepted. Please note that nine phase shifters are used to 9-element antenna array. However, the maximum phase shift range of

Mini-Circuits JSPHS-1000 phase shifter is less than 230°. Therefore, phase shifters 180° are created and added to phase shifter number 7 to 9 which have phase shift higher than 230°. The 180° phase shifter is designed by (Pozar, 1998) according to the following equations.

$$\frac{W}{d} = \begin{cases} \dfrac{8e^{A}}{e^{2A}-2} & \text{for } W/d < 2 \\ \dfrac{2}{\pi}\left[B-1-\ln\left(2B-1\right)+\dfrac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln\left(B-1\right)+0.39-\dfrac{0.61}{\varepsilon_r}\right\}\right] & \text{for } W/d > 2 \end{cases} \tag{6.3}$$

where

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}}+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right) \tag{6.4}$$

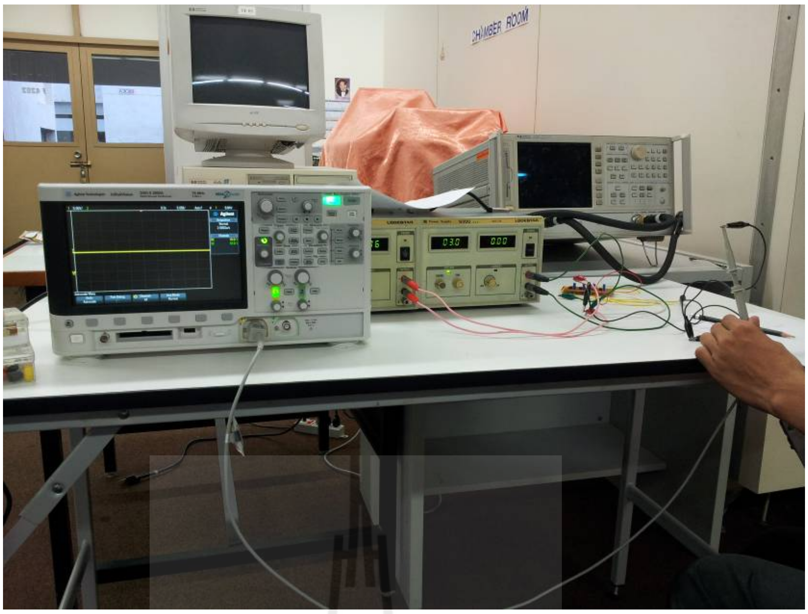
$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \tag{6.5}$$

where W is the width of microstrip line and d is the substrate thickness. Also, Z_0 is characteristic impedance and ε_r is dielectric constant. The line length of phase shifter can be express by

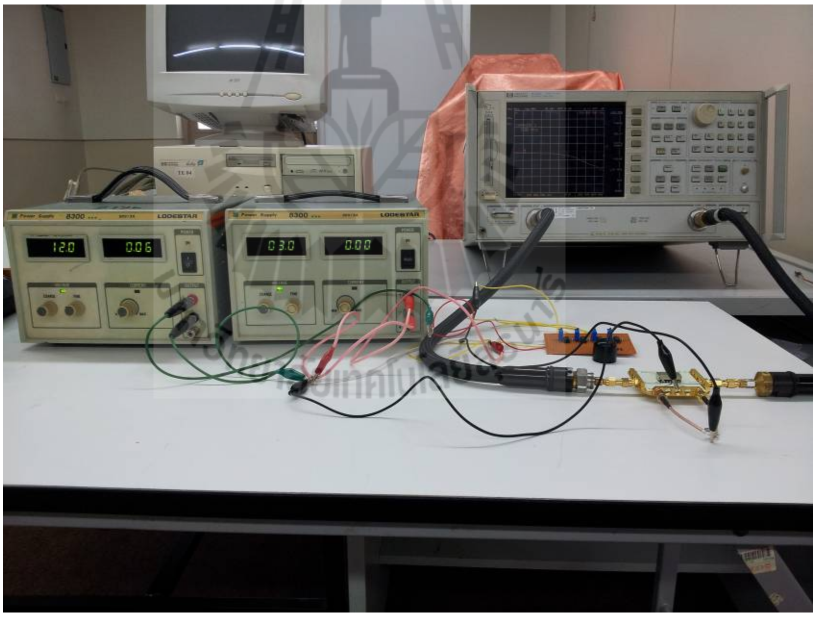
$$l = \frac{\phi}{B} \tag{6.6}$$

where l is the line length of microstrip line and ϕ is the desired phase shift. Please note that phase shifter is created using single-layer printed circuit board using FR4-substrate with dielectric constant of 4.5 and substrate thickness of 1.6 mm. Then, the fabricated phase shifter is measured by Network Analyzer. However, phase shift of phase shifter is not exactly 180° referring to the calculated length. This is due to that dielectric constant is varied with operating frequency. Therefore, the line length of phase shifter is trimmed to make some changes to the line impedance. The 180° phase shifter at 900 MHz is shown in Figure 6.14. Moreover, input voltage and phase shift of phase shifters are measured as shown in Figures 6.15 (a) and (b), respectively. Then, measured results are compared with the one obtained from calculation as shown in Table 6.2. As we can see, the measured results have a good agreement with the ones obtained from calculation.

Next, phase shifters are included with antenna as shown in Figure 6.16. Figure 6.17 shows voltage control of op amp circuit which is input voltage of phase shifter. Afterwards, return loss and impedance of the antenna with phase shifter are measured using network analyzer as shown in Figures 6.18 (a) and (b), respectively. As we can see, the return loss and impedance from antenna with and without phase shifter are similar. The obtained results show -14.729 dB return loss and 47.633 ohm impedance. These results can indicate that this antenna can be used in practical with the equipment having its impedance of 50 ohm. Then, the antenna with phase shifter is tested under same circumstance with the antenna without phase shifter. The results are recorded every 0.5 degree and shown in terms of radiation patterns as shown in Figure 6.19. The Figures 6.19 (a) and (b) show horizontal and vertical patterns of antenna with phase shifter, respectively. In addition, some parameters from experiment are



(a)



(b)

Figure 6.15 Testing of (a) input voltage and (b) phase shift of phase shifters.

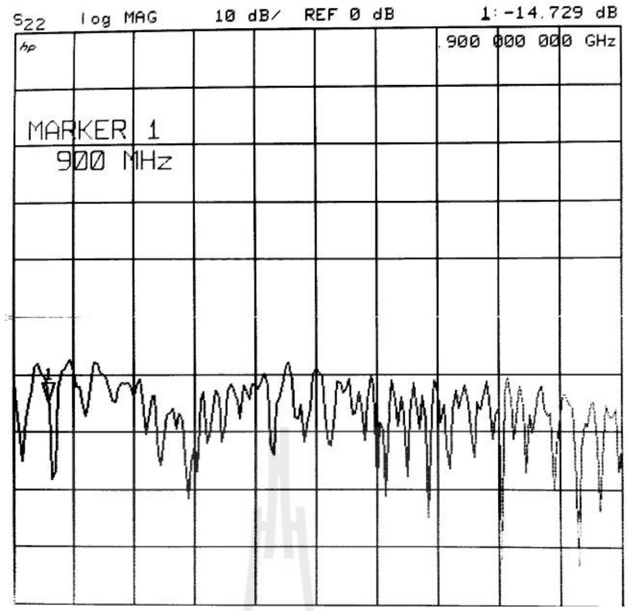
Table 6.2 Calculated results vs. measured results of nine phase shifters.

No. of phase shifter	Calculated results		Measured results	
	Input voltage (V)	Phase shifter (deg.)	Input voltage (V)	Phase shifter (deg.)
1	0	0	0	0
2	3.8	41.58	3.9	41.5
3	5.7	83.16	5.86	82.76
4	7.5	124.74	7.87	125.12
5	9.4	166.32	9.81	166.45
6	17.9	207.9	19.7	208.13
7	5.3	249.48	5.61	249.73
8	6.8	291.06	7.04	292.43
9	8.5	332.64	8.89	332.64

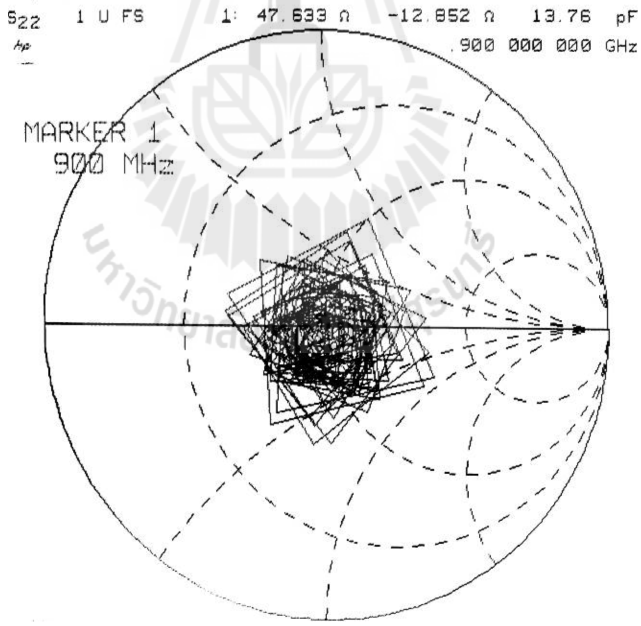
compared with the ones from simulation with and without phase shifter as shown in Table 6.3. As we can see, the experimental results have a good agreement with the ones obtained from simulation results. Also, the obtained half-power beamwidth in vertical plane and also beam tilt are similar. The half- power beamwidth in horizontal plane and front to back ratio of antenna are moderately comparable. However, gain and upper side lobe are slightly different. This may be caused by circumstance under test. However, all experimental results are able to confirm that users at cell-center andcell-edge can utilize two beams separately using this vertical beamforming. Moreover, polarization of antenna with and without phase shifter are measured and compared in Figure 6.20. As we can see, the polarization of two cases have a good agreement. This results are indicated that this antenna is linearly polarized (Balanis, 1997).

Figure 6.16 Photograph of antenna with phase shifters.

Figure 6.17 Input voltage of op amp circuit from power supplies.

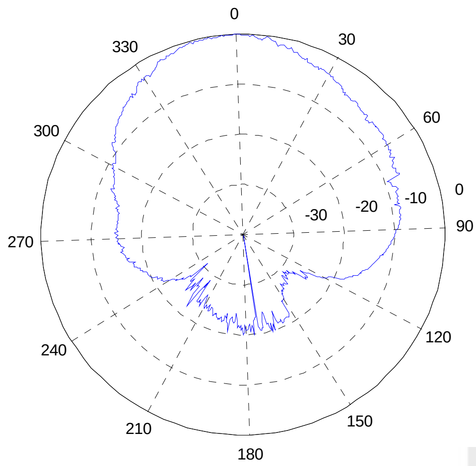


(a)

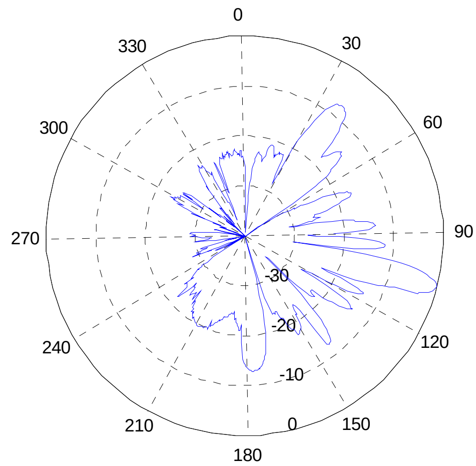


(b)

Figure 6.18 (a) Return loss and (b) impedance of constructed antenna with phase shifters.



(a)



(b)

Figure 6.19 Measured radiation pattern in (a) azimuth and (b) elevation.

Table 6.3 Parameters of antenna with and without phase shifter.

Parameters	**Without phase shifter**		**With phase shifters**	
	Simulation results	**Experimental results**	**Simulation results**	**Experimental results**
Frequency (MHz)	900	900	900	900
Horizontal, half power beamwidth (dBi)	64.1	63	66	65
Gain (dBi)	18.7	18.6	15.1	15.1
Vertical, half power beamwidth (dBi)	7	7	7	7.5
Beam tilt (degree)	6	6	16	16
Upper sidelobe suppression (dB)	13.1	13	14.7	7.4
Front to Back Ratio at 180° (dB)	30.95	32.9	32.8	30.4

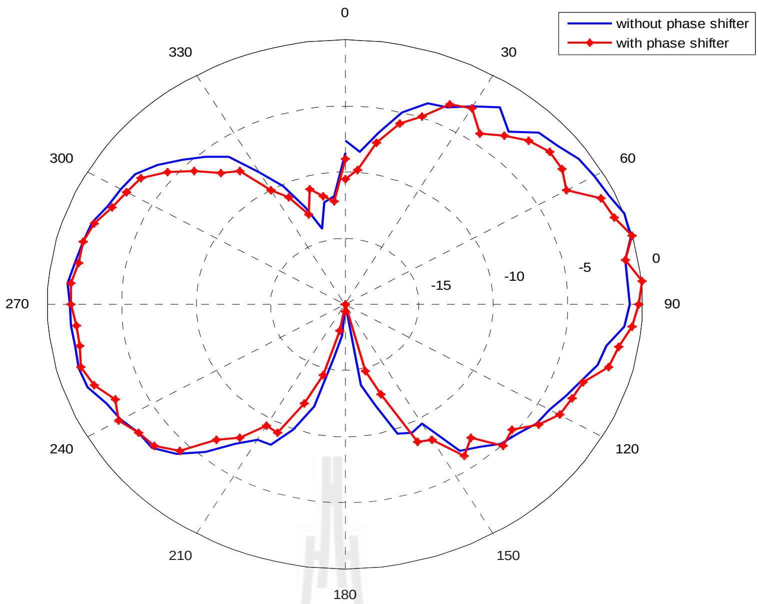


Figure 6.20 Polarization of antenna with and without phase shifter.

6.4 Performance of cellular networks

Latter, the results from experiment are discussed. The performance in terms of SINR and channel capacity using experimental results are shown comparing to the performance obtained from simulation results. The proposed concept is validated comparing with single beam scheme. The obtained comparison is shown in Figure 6.21. Two assumed cases, single beam and vertical beamforming, provide similar performance in the cell-edge region. In addition, the SINR can be improved when applying the proposed concept utilizing vertical beamforming at cell-center like the results obtained from simulation as shown in Figure 5.17.

Next, the channel capacity of two cases is described in Figure 6.22. As we can see, for case of vertical beamforming, two beams separately utilized for cell-center and cell-edge is able to improve the system capacity as a result from simulation in Figure 5.18. Moreover, the SINR throughout the sector is revealed in Figure 6.23. As

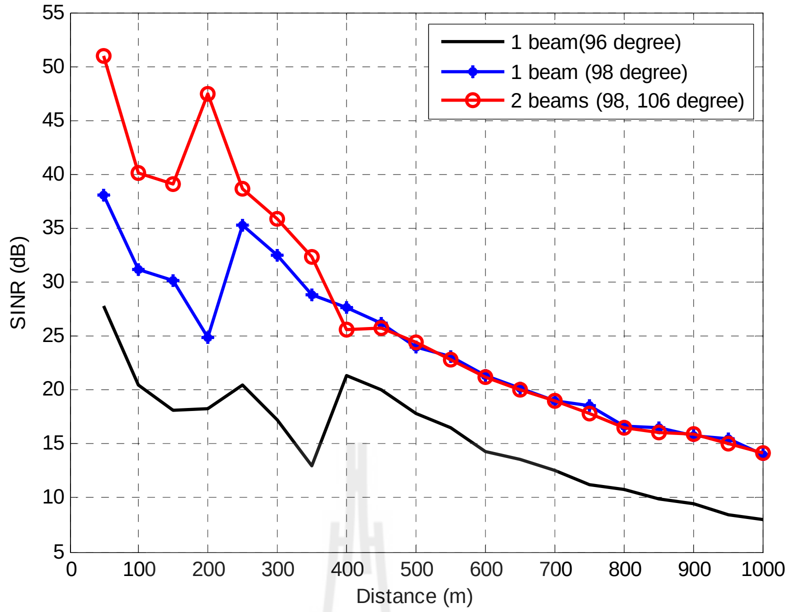


Figure 6.21 SINR vs. distance between BS and user from experimental results for 3 cases, single beam, 1-beam vertical beam and 2-beam vertical beam.

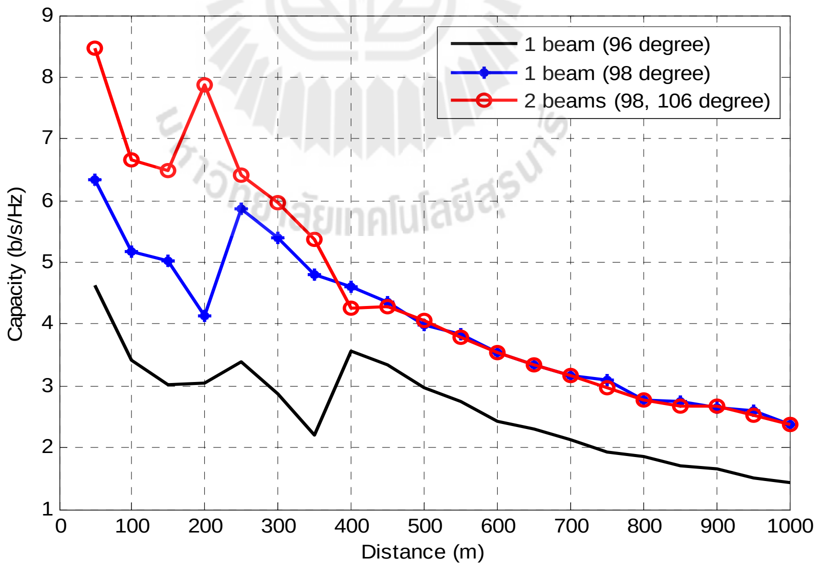
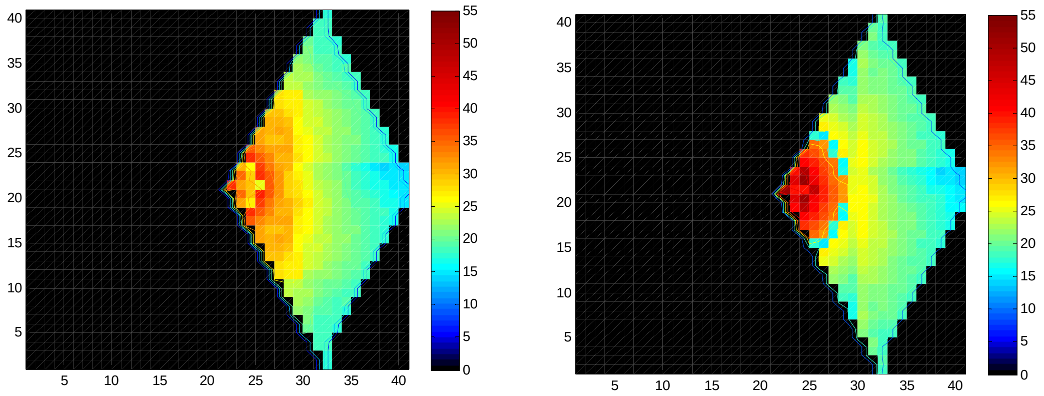


Figure 6.22 Capacity vs. distance between BS and user from experiment results for 3 cases, single beam, 1-beam vertical beam and 2-beam vertical beam.



(a) (b)

Figure 6.23 Contour plot of SINR over the sector from experimental results for (a) single beam and (b) vertical beamforming.

we can see, the area having higher SINR in case of utilizing the proposed concept is wider comparing to the one employing single beam, particularly at the cell-center. From the results, we can confirm that the proposed vertical beamforming enhances performance of cellular networks.

6.5 Chapter summary

The antenna is created based on CST Microwave Studio programming. The radiation patterns are tested under real circumstance for two cases: with and without phase shifter. The radiation pattern from experimental results is compared with the ones from simulation and commercial data. The results are indicated that radiation patterns from experiment, simulation and commercial data have a good agreement. Then, the performance in terms of SINR and channel capacity employing experimental results is revealed. The results from experiment confirm that the proposed vertical beamforming enhances the performance of cellular networks.

CHAPTER VII

THESIS CONCLUSION

7.1 Conclusion

As the demand of cellular networks have been dramatically increased, utilizing the same frequency in every cell for cellular networks can provide full benefit to utilization of frequency bandwidth. However, this can be a cause of ICI from neighboring cells. To tackle the problem, the frequency resource is divided and differently allocated between cell-center and cell-edge areas, so called FFR technique. From literature reviews, there are several forms of subcarrier allocation in FFR technique. Some forms of subcarrier allocation are simulated to compare the performance of cellular networks. From simulated results, form of subcarrier allocation that provides maximum performance is FFR cooperating with cell sectorization. All available subcarriers are separated to two groups, one is called cell-center group employed at cell-center area and another one is called cell-edge group which is divided into three subgroups in which each subgroup is employed at different sectors.

Although, interference signal coming from neighboring cells is reduced using FFR, it cannot cope the problem of ICI. This problem is due to the subcarrier from neighboring cells interferes the one in the cell of interest. To handle this problem, beamforming technique in smart antenna systems have been proposed. Beamforming technique can improve the performance in cellular networks due to this technique are capable of forming beam in desired direction and nulls in the interference directions.

Beamforming technique in smart antenna systems can be classified into two categories: fixed and adaptive beamforming systems. From advantage and disadvantage points of views for fixed and adaptive beamforming systems, fixed beamforming systems are in focus for this thesis as they are not complicated. Moreover, high speed signal processing is not necessary to continually track the desired user in fixed beamforming systems. In addition, beamforming techniques when the beam pattern is steerable in horizontal and vertical planes to reduce interference signal transmitted from the neighboring cells and enhance the signal in desired direction are discussed. The performance comparison of horizontal and vertical beamforming is revealed. The result shows that utilizing vertical beamforming provides higher SINR to the systems. This is because interference from cell-center to the neighboring's cell-center is reduced.

In this thesis, beamforming technique using antenna which is currently employed at cellular BS is considered. From the commercial data, the half power beamwidth in horizontal plane of this array antenna is 120 degree which can cover all of a sector area. However, the half power beamwidth in vertical plane is 7 degree. This beamwidth cannot cover all of users at cell-center or cell-edge area in a sector. Therefore, beamforming technique is used to improve the performance of beam covering at cell-center and cell-edge area. Vertical beamforming which the different beams are separately used for cell-center and cell-edge area is proposed.

Next, beam patterns are simulated according to the BS antenna currently utilized nowadays using CST Microwave Studio. The performance in terms of SINR is considered with radiation pattern of antenna. Two separate beams are utilized for cell-center and cell-edge areas. The results show that when the height of BS antenna is

50 meters mainbeams in directions of 106° and 98° provide the maximum SINR at cell-center and cell-edge areas, respectively. This results is reduction of the inter-cell interference coming from neighboring cells. Moreover, the designed antenna is constructed based on CST Microwave Studio simulation. The radiation patterns are tested under real circumstance in two cases: with and without phase shifter. The radiation pattern from experimental results is compared with the ones from simulation and commercial data. The results are indicated that radiation patterns from experiment, simulation and commercial data have a good agreement. Then, the performance in terms of SINR and channel capacity employing experimental results is revealed. The results from experiment confirm that the proposed vertical beamforming enhances the performance of cellular networks.

The conclusion of this thesis can be summarized from the contributions in Section 1.4 as follows.

7.1.1 The scheme providing the maximum performance which is utilized in thesis work is FFR cooperating with cell sectorization.

7.1.2 Vertical beamforming provides higher SINR to the system comparing to horizontal beamforming.

7.1.3 Beam patterns are simulated according to the BS antenna currently utilized nowadays. The radiation pattern from simulation is compared with the one from commercial data. The result shows that the radiation pattern from simulation and commercial data have a good agreement.

7.1.4 Two separate beams are utilized for cell-center and cell-edge areas. The results show that when the height of BS antenna is 50 meters mainbeams in directions of 106° and 98° provide the maximum SINR at cell-center and cell-edge, respectively.

7.1.5 The antenna is constructed based on CST Microwave Studio simulation. The radiation patterns are tested under real circumstance. The radiation pattern from experiment, simulation and commercial data have a good agreement. The performance employing experimental results confirm that the proposed vertical beamforming enhances the performance of cellular networks.

For future work, some algorithm should be applied to increase half power beamwidth of cell-center beam to cover all of the cell-center area, specifically 350 to 400 meters. However, the experimental results and simulation results from this thesis can be used as a guide line for the performance of the cellular networks, where the benefit of the proposed scheme is still better than the conventional scheme.

REFERENCES

Akma Rhazali, Z., Ismail, M. and Jumari, K. (2002). Simulation of Signal-to-Interference Ratio Performance in GSM System employing switched beam smart antenna system. **Research and Development, SCOReD 2002. Student Conference on**. 422 – 425.

Andrew A CommScope Company; Product Specifications 858DG65T6ESY. www.commscope.com/andrew. 2009.

Balanis, C.A. (1997). **Antenna Theory Analysis and Design.** J. Wiley & Sons.

Boylestad, R.L. and Nashelsky, L. (2002). **Electronic Devices and Circuit Theory.** New Jersey, Upper Saddle River: Prentice Hall International, Inc.

Chaipanya, P., Uthansakul, P. and Uthansakul, M. (2011). Reduction of Inter-Cell Interference Using Vertical Beamforming Scheme for Fractional Frequency Reuse Technique. **IEEE APMC 2011 Asia-Pacific**. 1614-1617, Dec. 2011.

Chaipanya P., Uthansakul P. and Uthansakul, M. (2013). Performance Enhancement employing Vertical Beamforming for FFR Technique. **International Conference on Electrical, Computer and Communication Engineering (ICECCE).** Feb. 2013.

Chang, R.W. (1996). Synthesis of Band-Limited Orthogonal Signals for Multichannel Data Transmission. **Bell Sys. Tech. Journal**. Vol. 45.

Ericsson, Tech. Rep.; Inter-cell interference handling for E-UTRA. 3GPP TSG RAN WG1#42 R1-050764. 2005.

Fakoukakis, F.E., Diamantis, S.G., Orfanides, A.P., and Kyriacou, G.A. (2006). Development of an adaptive and a switched beam smart antenna system for wireless communications. **Journal of Electromagnetic Waves and Applications.** 20(3): 399-408.

Haipeng, L., Lei, Z. and Xin, Z. (2007). A Novel Multi-Cell OFDMA System Structure Using Fractional Frequency Reuse. **IEEE PIMRC int. symp.on.** 1-5, Sept. 2007.

Huawei, Tech. Rep.; Further analysis of soft frequency reuse scheme. 3GPP TSG RAN WG1#42 R1-050841. 2005.

Lei, H., Zhang, L., Zhang, X. and Yang, D. (2007). A Novel Multi-Cell OFDMA System Structure using Fractional Frequency Reuse. **IEEE PIMRC Int. Symp.on.** 1-5.

Lott, M. (2006). Adaptive Random Access with Beam-Forming in 4G Mobile Networks. **IEEE Vehicular Technology Conference.** Vol.1. 435-439.

Morgan, D.R. (2008). Wideband equalization using multiple antennas. **IEEE Wireless Communications and Networking Conference.** 634 – 639.

Naizheng, Z., Per-Henrik, M., Jens, S., Claudio, R. and Jeroen, W. (2008). Antenna Tilt and Interaction with Open Loop Power Control in Homogeneous Uplink LTE Networks. **IEEE Wireless Communication System.** 693-697.

Necker, M.C. (2007). Local Interference Coordination in Cellular OFDMA Networks. **IEEE Vehicular Technology Conference.** 1741 - 1746 .

Pedro, C., Francisco, M.D., Jesus, D. and Luis, O.B. (2008). **Encyclopedia of Wireless and Mobile Communications.** Taylor & Francis. 1131-114, Jan. 2008.

Pozar, D.M. (1998). **Microwave Engineering.** John Wiley & Sons.

Ray, H. (2002). **Communications Systems and Networks.** John Wiley & Sons.

Sajal, K.D. (2010). **Mobile Handset Design.** John Wiley & Sons.

Srikanth, S., Kumaran, V., Manikandan, C. and Murugesapandian. Orthogonal Frequency Division Multiple Access: Is it the Multiple Access System of the Future? **http://comm.au-kbc.org/Docs/Tutorils/OFDMA_BCW_cv6.pdf.**

Sternad, M., Ottosson, T., Ahlen, A. and Svensson, A. (2003). Attaining both coverage and high spectral efficiency with adaptive OFDM downlinks. **IEEE Vehicular Technology Conference (VTC 2003-Fall).** Vol. 4. 2486–2490.

Stutzman, W.L. and Thiele, G.A. (2013). **Antenna Theory and Design.** John Wiley & Sons.

Tianmin, R. and Richard, J.L. (2005). Downlink beamforming algorithms with inter-cell interference in cellular networks. **24th Annual Joint Conference of the IEEE Computer and Communications Societies.** Vol. 1. 47-57, Mar. 2005.

Tianmin, R. and Richard, J.L. (2006). Downlink beamforming algorithms with inter-cell interference in cellular networks. **IEEE Transactions on Wireless Communications.** Vol. 5. No. 10, Oct. 2006.

Tsakalaki, E., Maestro, L.A., Haapala, T., Roman, J.L. and Arauzo, M.A. (2012). Deterministic Beamforming for Enhanced Vertical Sectorization and Array Pattern Compensation. **IEEE 6th European Conference on Antennas and Propagation (EuCAP).** 2789-2793.

Wendy, C.W., Qinghua, L. and Shilpa, T. (2010). A Transmit Beamforming and Nulling Approach with Distributed Scheduling to Improve Cell Edge Throughput. **International Journal of Digital Multimedia Broadcasting.**

WiMAX Forum, Tech. Rep.; Mobile WiMAX – Part I: A technical overview and performance evaluation. 2006.

Wongchompa, P., Uthansakul, M. and Uthansakul, P. (2011). Performance Comparison Between Fractional Frequency Reuse Schemes Employing Beamforming. **ISAP2011.** Oct. 2011.

Yapeng, W., Xu, Y., Ma, A. and Cuthbert, L. (2009). Intelligent Resource Optimisation using Semi-Smart Antennas in LTE OFDMA Systems. **IEEE Communications Technology and Applications.** 173-179.

Yapeng, W., Xu, Y., Ma, A. and Cuthbert, L. (2010). Resource Allocation in LTE OFDMA Systems using Genetic Algorithm and Semi-Smart Antennas. **IEEE Wireless Communications and Networking Conference.** 1-6.

Yilmaz, O.N.C., Hamalainen, S. and Hamalainen, J. (2009). System Level Analysis of Vertical Sectorization for 3GPP LTE. **IEEE 6th Int'l Symp. Wireless Commun. Systems.** 453-457.

Yilmaz, O.N.C. (2010). **Self-Optimization of Coverage and Capacity in LTE Using Adaptive Antenna Systems.** M. Sc. Thesis, Aalto University, Finland.

Yue, Z., Xuming, F., Xiaopeng, H., Zhengguang, Z. and Yan, L. (2009). Fractional Frequency Reuse Scheme and Performance Evaluation for OFDMA Multi-hop Cellular Network. **IEEE Testbeds and Research Infrastructures for the Development of Networks & Communities and Workshops.** 1-5.

Zhu, H. and Ray Lin, K.J. (2008). **Resource Allocation for Wireless Networks: Basics, Techniques, and Applications.** New York: Cambridge.

APPENDIX A

ROTATING PEDESTAL OF ANTENNA

A.1 Rotating pedestal of antenna

Servo motor is combined with pedestal to rotate antenna as shown in Figure A.1. There is a touch screen monitor to control its operation. To set the rotating pedestal, the setting steps are as follows.

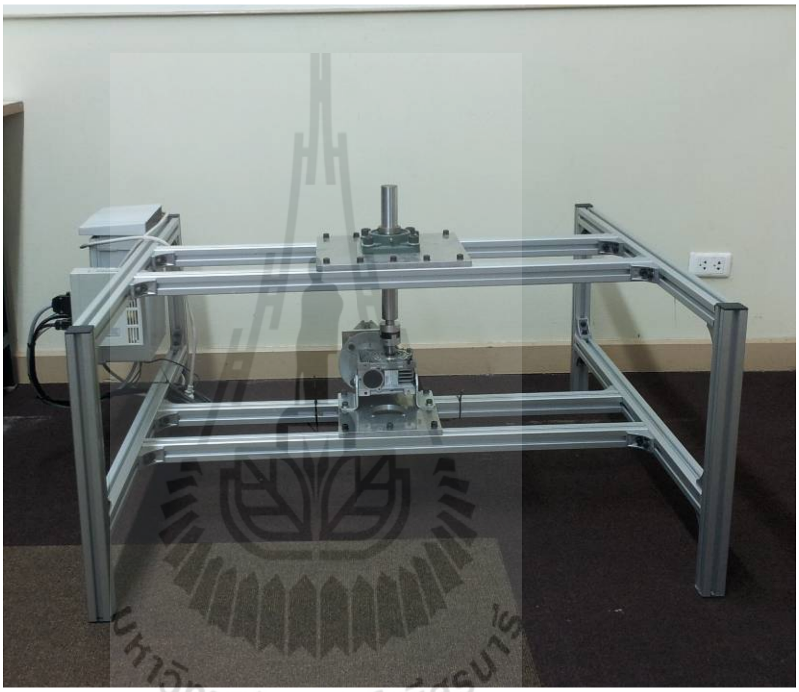


Figure A.1 Rotating pedestal.

A.1.1 Press screen to start as shown in Figure A.1.1.

Figure A.1.1 Starting screen.

A.1.2 The data is shown in monitor. Please note that gray color is appeared at "Home Complete" button as shown in Figure A.1.2.

Figure A.1.2 Home Complete button.

A.1.3. The desired setting is set in this step. First, the step of degree required for rotation is assigned in “Set degree to move step”. Then, press “Enter” when the required degree is set as shown in Figure A.1.3.1. Next, press “Holding time” to assign the waiting time for rotating in next degree. Then, press “Enter” when the holding time is set as shown in Figure A.1.3.2. Later, press “Speed move” to assign the speed moving from one degree to next degree. Then, press “Enter” when the speed move is set as shown in Figure A.1.3.3.

Figure A.1.3.1 Degree setting for moving step.

Figure A.1.3.2 Holding time setting.

Figure A.1.3.3 Speed move setting.

A.1.4 Press  button. Then, press  button. The servo motor is rotated to 0 degree. Green color is appeared at “Home Complete” button.

Figure A.1.4 Home Complete button after setting.

A.1.5 Press “Running” button. Motor is rotated related to the previous setting.

APPENDIX B

TECHNICAL PUBLICATIONS

List of publications

International Journal Paper

Uthansakul, M., Chaipanya, P. and Uthansakul, P. Vertical Beamforming Influence on Cellular Networks. **ECTI Transactions on Electrical Engineering, Electronics and Communications (ECC)**. (revision, Scopus Indexing)

International Conference Paper

Chaipanya P., Uthansakul P. and Uthansakul, M. (2011). Reduction of Inter-Cell Interference Using Vertical Beamforming Scheme for Fractional Frequency Reuse Technique. **Asia-Pacific Microwave Conference (APMC)**.

Chaipanya P., Uthansakul P. and Uthansakul, M. (2013). Performance Enhancement employing Vertical Beamforming for FFR Technique. **International Conference on Electrical, Computer and Communication Engineering (ICECCE).**

Chaipanya P., Uthansakul P. and Uthansakul, M. (2013). Inter-Cell Interference Cancellation for Base Station Antennas. **Wireless and Microwave Technology Conference (WAMICON).**

Vertical Beamforming Influence on Cellular Networks

Pichaya Chaipanya, Monthippa Uthansakul and Peerapong Uthansakul

School of Telecommunication Engineering, Suranaree University of Technology
Muang, Nakhon Ratchasima, Thailand 30000
m5140701@g.sut.ac.th, {mtp,uthansakul}@sut.ac.th

ABSTRACT

This paper proposes a vertical beamforming concept to a cellular network employing fractional frequency reuse technique. The reference antenna utilized in this paper is the one currently employed at base station. The idea of using two different vertical beams is proposed for cell-center and cell-edge regions, separately. The proposed concept is validated through computer simulation in terms of SINR and channel capacity. The obtained results indicate that the proposed concept can improve the performance of the cellular networks comparing with the ones employing horizontal beamforming and one spot beam covering cell sector.

Keywords: Beamforming, Fractional Frequency Reuse, OFDMA, Linear Array, Cellular System

1. INTRODUCTION

Several occurring standards for cellular broadband networks, such as WiMax or Long-Term Evolution (LTE), are based on Orthogonal Frequency Division Multiple Access (OFDMA) [1]. The OFDMA allows the distribution of subcarriers among users thus all users can transmit and receive at the same time within a single channel. Consequently, it can reduce multipath interference. However, the OFDMA technique cannot provide full benefits due to the problem of Inter-Cell Interference (ICI) from neighboring cells. In cellular networks, the users staying in cell-center area exploit high signal strength as they are close to the Base Station (BS). On the other hand, the signal strength is degraded when users are moving close to the cell-edge. Moreover, the users located at cell-edge also experience interference signal coming from neighboring cells. To tackle the problem, the frequency resource is divided and differently allocated between cell-center and cell-edge area, so called Fractional Frequency Reuse (FFR) [2].

From the work presented in [3], a novel FFR scheme for multi-cell OFDMA systems has been proposed. In this scheme, each cell in cellular networks is divided into three sectors. The subcarriers are partitioned into two groups in each cell. One is called super group employed at cell-center and another one is called regular group. The regular group is divided into three parts corresponding to the boundary region of three sectors in the cell-edge. Therefore, the intra-cell interference from cell-edge to cell-center can be decreased and the number of ICIs can be reduced. Furthermore, the concept of beamforming has been proposed to tackle ICI problem. However, the problem still remains when the direction of ICI signal from neighboring cells is the same as the one of desired signal in the cell. Moreover, several antenna types have been proposed to steer their beam to desired direction such as the work presented in [4] which has presented inter-cell interference reduction using vertical beamforming scheme for fractional frequency reuse technique. In this work 7×7 planar array antenna is utilized. This scheme can reduce ICI and improve performance of the cellular networks. Nevertheless, this concept is considerably not practical as there are some difficulties in installation planar array at BS. In addition, system level analysis of vertical sectorization for 3GPP LTE and self-optimization of coverage and capacity in LTE using adaptive antenna systems have been presented [5-6]. In these works, performance with various vertical half-power beamwidths and electrical tilt angles have been observed to obtain the optimized space of the overlap between two vertical sectors and the gain in terms of cell capacity. From these schemes, capacity of the system can be improved. However, the schemes proposed in [5-6] cannot reflect the true performance for cellular network as a real antenna currently employed at BS has not been taken into account. In addition, the work presented in [7] has revealed the performance of vertical beam formation applied to a commercial active antenna. In the mentioned work, a min-norm technique has been proposed to accomplish beam formation which is considerably complicated to be implemented at BS, thus the hardware is costly. Therefore, this paper presents the concept of vertical beamforming suitable for BS antennas as they are currently linearly stacked in vertical manner. This vertical beamforming technique is simple and practical to be installed at BS. The performance of proposed concept is validated through computer simulation comparative with the ones currently utilized at BS.

The rest of this paper is as follows. After brief introduction, the problem formulation of this paper is discussed including an approach to tackle the problem in Section II. Then, the concept of FFR is presented in Section III. Next, both horizontal and vertical beamforming at BS are discussed in Section IV. Afterwards, the proposed concept is properly applied to one commercial antenna currently utilized at BS in

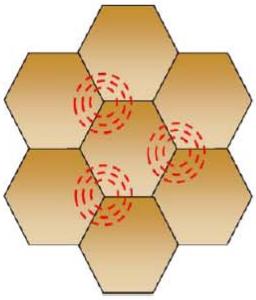
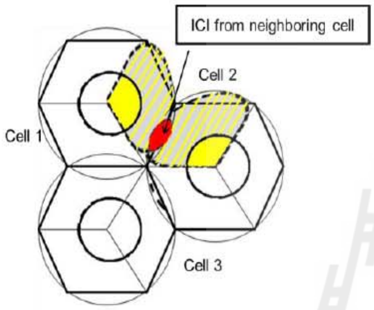
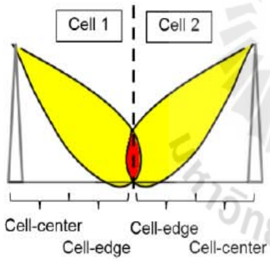


Fig. 1: Interference scenario from neighboring cells.



(a) Top view



(b) Side view

Fig. 2: ICI from neighboring cell viewing at (a) top (b) side.

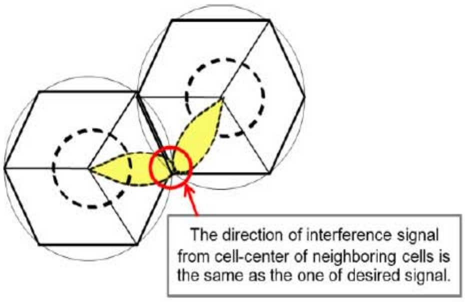


Fig. 3: Interference from neighboring cell when performing horizontal beam formation.

Section V in order to see its real performance. In this section, some simulation results in terms of Signal-to-Interference plus Noise Ratio and channel capacity reveal the performance of vertical beamforming for cellular networks. Finally, Section V concludes the paper.

2. PROBLEM FORMULATION

In cellular networks, all subcarriers are used for full benefits when they are utilized in every cell. However, this causes interference signal between neighboring cells as shown in Fig. 1. To cope this problem, the FFR for OFDMA technique is utilized in cellular networks [8-9]. The users staying in cell-center use different subcarrier from the users located in cell-edge. However, the users in cell-center still suffer from the interference from cell-center of neighboring cells as illustrated in Fig. 2. From literatures [10-13], several ideas when performing beam formation in azimuth have been proposed to tackle the problem. Nevertheless, interference from cell-center of neighboring cells still remains when the direction of interference signal from cell-center of neighboring cells is the same as the one of desired signal in the cell as shown in Fig. 3. In addition, several concepts to form beam towards desired direction using several antenna designs have been proposed for utilizing in cellular networks. Notwithstanding, those concepts are relatively complicated to be set up at BS. Therefore, this paper proposes a simple vertical-beamforming technique to reduce interference signal from neighboring cells. The antenna array commercially utilized at BS is also adopted to see the true performance for cellular systems.

3. FRACTIONAL FREQUENCY REUSE

Fractional Frequency Reuse (FFR) technique can provide full benefit to utilization of frequency bandwidth. Fundamental of FFR technique is the separation of coverage area (or cell) into two parts: cell-center and cell-edge regions. All available subcarriers are used at cell-center region and some of subcarrier groups are used at cell-edge as shown in Fig. 4 (a). Furthermore, FFR technique can be adapted into several allocation subcarrier groups as presented in [14-17]. All available subcarriers are divided into four parts: one part is used at cell-center area while other parts are used at cell-edge area in different cells as shown in Fig. 4 (b). For Fig. 4 (c), all available subcarriers are separated to two groups: cell-center and cell-edge groups. The cell-edge group is separated into three groups employed at cell-edge for different neighboring cells. In addition, to improve its capacity and reduce ICI, FFR technique is utilized including with cell sectorization as shown in Fig. 4 (d) in which each cell is divided into three sectors. All available subcarriers are separated to two groups. One is called cell-center group employed at cell-center area and another one is called cell-edge group. The cell-edge group is divided into three groups where each group is employed at different sectors.

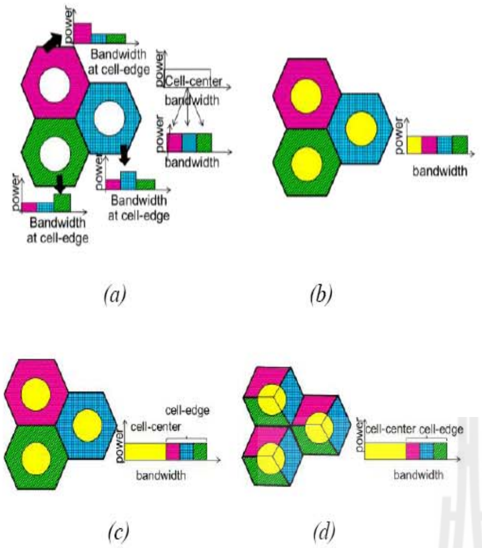


Fig. 4: *Example of FFR technique with different frequency allocation scheme.*

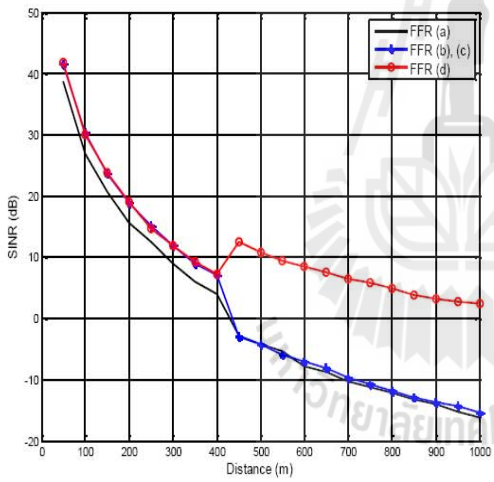


Fig. 5: *SINR vs. distance between BS and MT for different kind of FFR.*

The performance in terms of Signal-to-Interference plus Noise ratio (SINR) employing different FFR techniques is shown in Fig. 5. Please note that FFR technique used in Fig. 5 is referred to the one shown in Fig. 4. As a result, FFR cooperating with cell sectorization provides maximum performance. This is because it provides full benefit of frequency reuse in every cell. Therefore, the concept of FFR plus cell sectorization is adopted for the rest of this paper. Please note that SINR shown in Fig. 5 is rapidly changed at distance of 400 meters as this distance is initially given being a threshold distance between cell-center and cell-edge regions.

Next, beamforming performance when the antennas are vertically and horizontally stacked is discussed. Computer simulation is performed to show the performance in terms of SINR for both scenarios.

4. HORIZONTAL AND VERTICAL BEAMFORMING

Although, interference signal coming from neighboring cells is reduced using FFR, it cannot cope the problem of ICI. This problem is due to the subcarrier from neighboring cells interfering the one in the cell, so called ICI problem. To handle this problem, several researchers have proposed the beamforming techniques when the beam pattern is steerable in horizontal plane as shown in Fig. 6 (a). As we can see that different beams are employed in different azimuth directions. Consequently, it cannot only reduce interference signal transmitted from the neighboring cells but also enhance the signal in desired direction. Nevertheless, the mentioned concept does not work very well for the case having ICI signal coming from the same direction of the desired signal for the cell of interest. In addition, the beam coming from cell-center introduces high level of interference to the neighboring's cell- center. Therefore, this paper proposes an idea to reduce ICI problem using vertical beamforming concept as shown in Fig. 6 (b). As we can see, the FFR technique is utilized along with the concept of different subcarriers in different beams. This is full utilization of parameters in both frequency and space domains. The performance comparison of vertical and horizontal beamforming is shown in Fig. 7. The parameters given in the simulation are listed in TABLE I [3]. As we can see, utilizing vertical beamforming provides higher SINR to the systems. This is because interference from cell-center to the neighboring's cell-center can be reduced.

The vertical beamforming mentioned above can be accomplished using a linear array arranged in vertical lattice [18]. The characteristic of beam steering for linear array is given by [19]

$$AF = \sum_{n=1}^{N} e^{j(n-1)(kd\cos\theta+\beta)} \qquad (1)$$

where N stands for the number of antenna elements and k is the propagation constant, with k=2π/λ. The antenna elements are equally spaced by d. The angle represented by θ is measured from the z-axis in spherical coordinate as shown in Fig. 8. Also, β is the phase shift between adjacent elements which can be expressed by

$$\beta = -kd\cos\theta_0 \qquad (2)$$

where angle represented by θ_0 is the direction of maximum radiation.

For the computer simulation, the hexagonal cellular system is assumed. The wireless channel between BS and users is assumed to experience effects from propagation

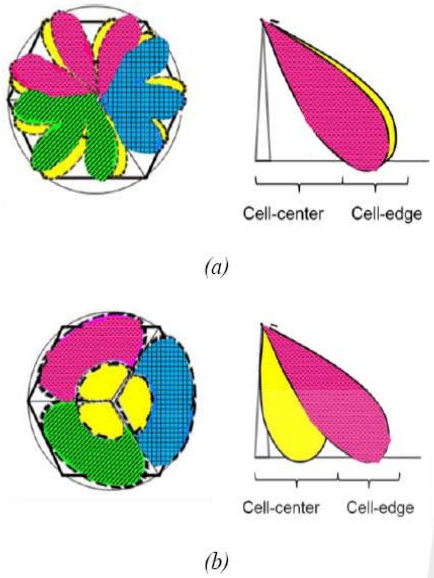


Fig. 6: *(a) Horizontal and (b) vertical beamforming when viewing at top and side.*

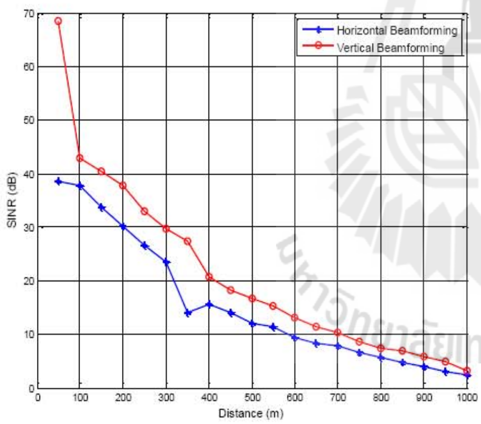


Fig. 7: *SINR vs. distance between BS and MT when performing horizontal and vertical beamforming.*

Table 1: *Parameters given in simulation*

Parameters	Values
subcarrier spacing	15 kHz
white noise power density	-174 dBm/Hz
inter-cell distance	2 km
base station transmit power	43 dBm
carrier frequency	900 MHz
d_{corr}	5 m
standard deviation	8 dB
channel model	Pedestrian B

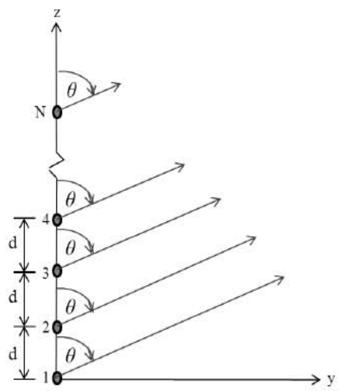


Fig. 8: *Geometry of N-element array positioned along the z-axis.*

path loss and shadowing fading as follows. The propagation path loss can be given by [3]

$$PL = 120.9 + 37.6 \log R \tag{3}$$

where R is the distance between user and BS in kilometers. As the shadowing fading values are assumed to be correlated, then we consider the following correlation model for shadowing [3].

$$S_n = X(d) \cdot S_{n-1} + \sqrt{1 - X(d)^2} \cdot N(0,\sigma) \tag{4}$$

$$X(d) = 2^{-d/d_{corr}} \tag{5}$$

Where $X(d)$ is normalized autocorrelation function, d_{corr} is decorrelation length and d is the moving distance of the mobile station after the last calculation of shadowing. The $N(0,\sigma)$ presented in (4) is a Gaussian random variable with zero mean and standard deviation of σ. The S_n and S_{n-1} are the shadowing values at the two consecutive calculations. The sampled channel frequency response of i^{th} user can be expressed by [3]

$$H_i = \sum_{l=0}^{L-1} h_{i,l}(T_s) e^{-j2\pi k \Delta f \cdot \tau_1} \tag{6}$$

where $h_{i,l}$ is the wide-sense stationary narrow band complex amplitude Gaussian process of the L^{th} path. The T_s stands for the OFDM symbol period and Δf is the neighboring subcarrier spacing, with $\Delta f = 1/T_s$. Also, τ_1 is the corresponding delay. The channel gain between the serving BS and i^{th} user is G_i, which can be expressed by [3]

$$G_i = 10^{\frac{-PL_i}{10}} \cdot S_i \cdot |H_i|^2 \cdot g_i \tag{7}$$

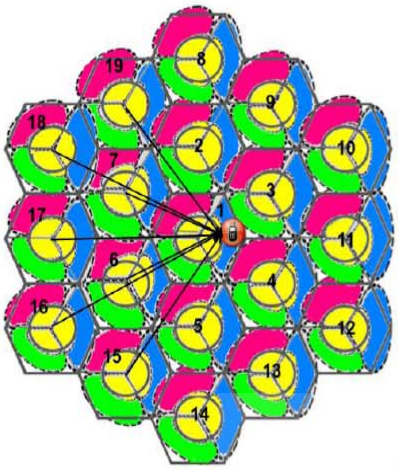


Fig. 9: *Cellular structure of OFDMA systems and interference at cell-edge.*

where g_i is gain of the linear array when transmitting the signal from BS towards the i^{th} user.

The frequency allocation utilized in the computer simulation for this paper is illustrated in Fig. 9. An OFDMA cellular environment with two-tier 19 cells is assumed. When the i^{th} user is located in cell 1, the number of ICI at the cell- center from neighboring cells is 18 (cell 2 to 19). At the cell-edge area, the interference signal is coming from 7 cells. For example, when the i^{th} user is in cell 1, the ICI signal is coming from cell 6, 7, 15, 16, 17, 18, and 19. The received SINR of the i^{th} user can be expressed by [3]

$$SINR_i = \frac{G_i P_i}{N_0 \Delta f + \sum_{j=1}^{q} G_{i,j} P_j} \quad (8)$$

where G_i is gain between i^{th} user and serving cell 1. In addition, $G_{i,j}$ is the gain between i^{th} user and j^{th} cell. The P_i and P_j are transmitted power by serving 1^{st} cell and j^{th} cell, respectively. The parameter q is the number of ICI cells. Also, N_0 is the power spectrum density of AWGN and Δf is the neighboring subcarrier spacing.

The channel capacity of i^{th} user can be expressed by [19]

$$C_i = \left(\frac{m}{M}\right)\log_2\left(1 + SINR_i\right) \quad (9)$$

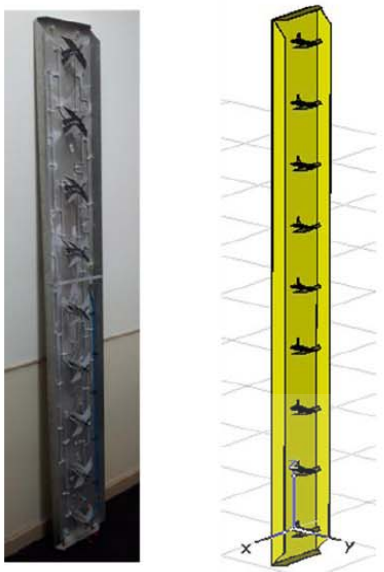
where m is the number of subcarrier groups utilized at desired area and M is all available subcarrier groups. In this paper, the all available subcarriers are separated into two groups.

In next section, simulation results of BS antenna utilized nowadays though CST Microwave Studio are revealed. Then, the performance in terms of SINR and channel capacity using simulation results from CST Microwave Studio through the computer simulation is discussed.

5. VERTICAL BEAMFORMING IN CELLULAR NETWORK

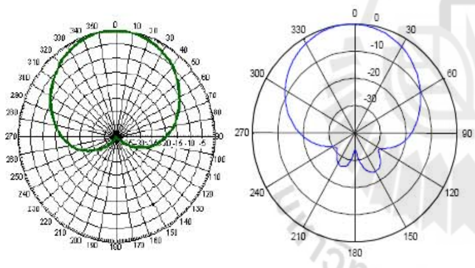
In this paper, the antenna created in simulation according to the one appeared in [20] is currently employed at cellular BS. The photograph of the reference antenna is shown in Fig. 10 (a). It includes 9-elements antenna array where the inter-element spacing is 0.83λ [20]. From simulation results, half power beamwidth in azimuth plane is narrower when the number of array elements decreases. Therefore, it cannot cover all of the sector area. On the other hand, half power beamwidth in azimuth plane is wider than 65° when the number of array elements increases. This may cause an intra-cell interference. In addition, in case of the spacing between adjacent elements is less than 0.83λ, half power beamwidth in azimuth plane is wider than 65° while half power beamwidth in azimuth plane of antenna is less than 65° when the spacing between adjacent element is more than 0.83λ. Moreover, there is large upper sidelobe causing an inter-cell interference to neighboring cells when the spacing between adjacent antennas is more than 0.83λ. The simulation results obtained from CST Microwave Studio are compared with the commercial data from Commscope Company. The photograph of reference antenna is compared with the one created in CST Microwave Studio as shown in Figs. 10 (a) and (b), respectively. The horizontal pattern of commercial data and simulation results are shown in Figs. 11 (a) and (b), respectively. Also, the vertical pattern of commercial data and simulation results are shown in Figs. 12 (a) and (b), respectively. In addition, some parameters given in simulation are compared with the ones from commercial data as shown in Table II. As we can see, the simulation results have a good agreement with the ones from commercial data. Also, the obtained half-power beamwidth in horizontal and vertical planes and also beam tilt are similar. Also, gain and front to back ratio of antenna are moderately comparable.

The performance of cellular networks is shown in terms of SINR and channel capacity using the proposed scheme through the computer simulation. Please note that the parameters given in the simulation are listed in TABLE I [3]. The antenna gain values employed in (7) in case of cell-center and cell-edge are obtained from own developed computer program using CST Microwave studio. Please note that the linear array antenna operating at 900 MHz is employed [20]. The choice of mainbeam direction can be chosen by adjusting the phase shift between the antenna elements of the array. In the cell-center area, the inference signal is assumed to be coming from 18 cells. At the cell-edge area, the interference signal is coming from 7 cells (cell 6, 7, 15, 16, 17, 18 and



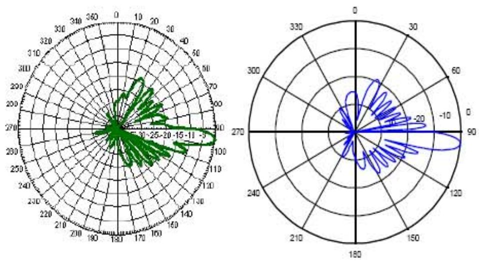
(a) (b)

Fig. 10: *Photograph of reference antenna (a) and the one created in simulation (b).*



(a) (b)

Fig. 11: *Radiation pattern in azimuth of reference antenna [20] obtained from (a) commercial data and (b) simulation.*



(a) (b)

Fig. 12: *Radiation pattern in elevation of reference antenna [20] obtained from (a) commercial data and (b) simulation.*

Table 2: *Parameters of antenna*

Parameters	Commercial data	Simulation results
Frequency (MHz)	870 – 960	900
Horizontal, Half power beamwidth (degree)	65	64.1
Gain (dBi)	17.8	18.7
Vertical, Half power beamwidth (degree)	7	7
Beam tilt (degree)	6	6
Upper sidelobe suppression (dB)	18	13.1
Front to Back Ratio at 180° (dB)	30	30.95

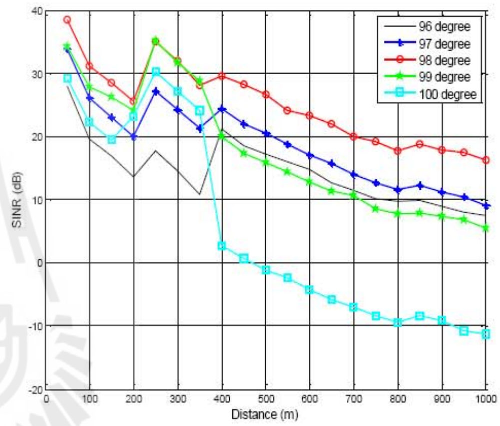


Fig. 13: *SINR vs. distance between BS and MT when varying tilted-angle of mainbeam for cell-edge area.*

19) as demonstrated in Fig. 9. The threshold distance is assumed to be 400 meters. This distance is the criteria to switch the utilized beam. The beam at cell-center is utilized when the distance between user and serving BS is less than 400 meters, otherwise the beam at the cell-edge is exploited.

In case of one spot beam, the coverage area is all over the sector hence the cell-center and cell-edge utilize the same beam pattern. The different mainbeam directions are assumed in order to give various of simulation cases. From simulation, mainbeam direction of 98° seems to provide the maximum SINR to the systems as shown in Fig. 13. However, SINR is relatively low in the cell-center region (0 to 400 meters) when mainbeam direction is small from 96, 97 to 100 degrees. This is due to that the half-power beamwidth in vertical plane of antenna cannot cover all of the sector area. However, the SINR can be improved when applying the proposed concept utilizing vertical beamforming, two beams for cell-center and cell-edge.

Next, an appropriate angle of mainbeam direction covering cell-center area is discussed. Some different

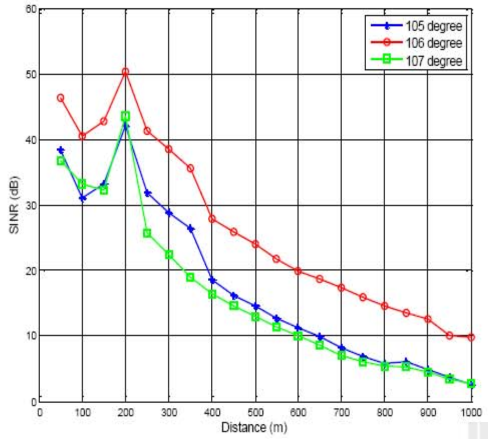


Fig. 14: *SINR vs. distance between BS and MT when varying tilted-angle of mainbeam for cell-center area.*

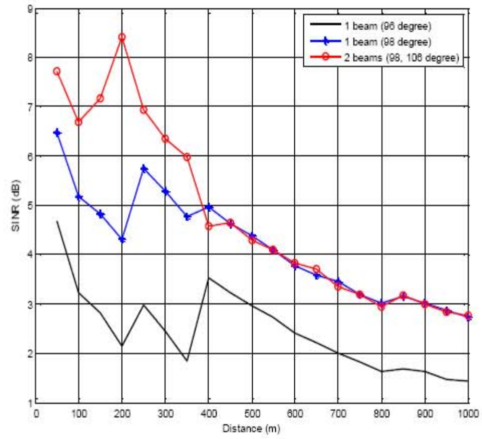


Fig. 15: *SINR vs. distance between BS and MT for 3 cases: single beam, 1-beam vertical beam and 2-beam vertical beam.*

angles of mainbeam directions have been utilized in simulation to improve performance of cell-center area as its outcome is shown in Fig. 14. As we can see, mainbeam direction of 106° seems to provide the maximum SINR at cell-center area. Nevertheless, it cannot provide maximum performance in the cell-edge region (from 400 to 1000 meters) comparing with utilizing main beam direction of 98°. This is because the half-power beamwidth in vertical plane of antenna cannot cover the cell-edge area. Furthermore, the users at the cell-edge area suffer from high level of interference coming from neighboring cells. Therefore, this paper proposes utilization the different beams in cell-center and cell-edge area separately. The mainbeam direction of 106° is used for covering cell-center area and 98°is used for covering cell-edge area.

Latter, the proposed concept is validated comparing with single beam scheme providing one spot beam covering all over the sector, hence the cell-center and cell-edge utilize the same beam pattern. The obtained comparison is shown in Fig. 15. Two assumed cases provide similar performance in the cell-edge region (after 400 meters). In addition, SINR is relatively low in the cell-center region (0 to 400 meters) when applying single beam scheme. However, in this area, the SINR can be improved when applying the proposed concept utilizing vertical beamforming, two separate beams for cell-center and cell-edge.

Next, the channel capacity of two cases is described in Fig. 16. As we can see, case of vertical beamforming, two beams utilized for cell-center and cell-edge separate can improve the capacity system. However at 350 meters, the capacity of proposed scheme is lower than the capacity of one spot beam scheme. This may be caused by changing beam from cell-center to cell-edge. However, the proposed vertical beamforming enhances performance of cellular networks.

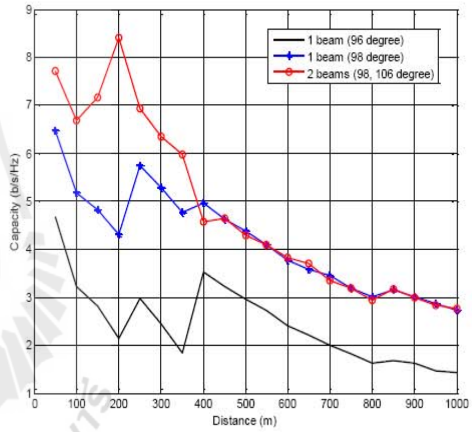
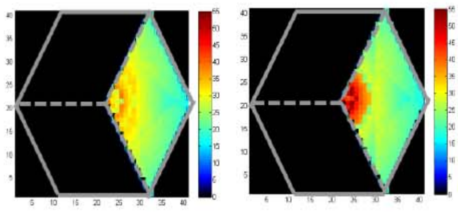


Fig. 16: *Capacity vs. distance between BS and MT for 3 cases: single beam, 1-beam vertical beam and 2-beam vertical beam.*



(a) *(b)*

Fig. 17: *Contour plot of SINR over the sector for (a) single beam and (b) vertical beamforming.*

The results discussed earlier have been obtained by assuming the region in one-dimensional from 0 to 1000 meters. Anyway it cannot illustrate the overall performance throughout the sector. Therefore, the SINR throughout the sector is revealed in Fig. 17. As we can see, the area having higher SINR in case of utilizing the proposed concept is wider comparing to the one employing single beam, particularly at the cell-center. This means that the vertical beamforming enhances the performance of cellular networks.

6. CONCLUSION

This paper has investigated into a vertical beamforming concept for the cellular networks utilizing fractional frequency reuse. Beam patterns are simulated according to the BS antenna currently utilized nowadays. Two separate beams are utilized for cell-center and cell-edge. The proposed concept is validated using computer simulation in terms of SINR and channel capacity comparing with single beam concept. The results show that mainbeam directions of 106° and 98° provide the maximum SINR at cell-center and cell-edge, respectively. This results in reduction of the inter-cell interference coming from neighboring cells. The obtained results have indicated that the vertical beamforming concept can improve the performance of the cellular networks comparing with the one employing one spot beam.

7. ACKNOWLEDGEMENT

The authors acknowledge the financial support from Telecommunications Research and Industrial Development Institute (TRIDI) and Suranaree University of Technology, Thailand.

8. REFERENCES

[1] I. C. Wong, S. Zukang, B. L. Evans and J. G. Andrews, "A Low Complexity Algorithm for Proportional Resource Allocation in OFDMA System," SIPS IEEE Workshop on, pp. 1-6, Oct. 2004.

[2] K. Farooq, LTE for 4G Mobile Broadband Air interface Technologies and Performance, Cambridge University Press, 2009.

[3] L. Haipeng, Z. Lei and Z. Xin, "A Novel Multi-Cell OFDMA System Structure Using Fractional Frequency Reuse," IEEE PIMRC int. symp.on, pp. 1-5, Sept. 2007.

[4] P. Chaipanya, P. Uthansakul and M. Uthansakul, "Reduction of Inter-Cell Interference Using Vertical Beamforming Scheme for Fractional Frequency Reuse Technique," IEEE APMC 2011 Asia-Pacific, pp. 1614-1617, Dec. 2011.

[5] O. N. C. Yilmaz, S. Hamalainen and J. Hamalainen, "System Level Analysis of Vertical Sectorization for 3GPP LTE," IEEE 6th Int'l Symp. Wireless Commun. Systems, pp. 453-457, 2009.

[6] O. N. C. Yilmaz, Self-Optimization of Coverage and Capacity in LTE Using Adaptive Antenna Systems, M. Sc. Thesis, Aalto University, Finland, 2010.

[7] E. Tsakalaki, L. A. Maestro, T. Haapala, J. L. Roman and M. A. Arauzo, "Deterministic Beamforming for Enhanced Vertical Sectorization and Array Pattern Compensation," IEEE 6th European Conference on Antennas and Propagation (EuCAP), pp. 2789-2793, 2012.

[8] M. Sternad, T. Ottosson, A. Ahlen and A. Svensson, "Attaining Both Coverage and High Spectral Efficiency with Adaptive OFDM Downlinks," IEEE Vehicular Technology Conference, Vol. 4, pp. 2486–2490, 2003.

[9] M. C. Necker, "Local Interference Coordination in Cellular OFDMA Networks," IEEE Vehicular Technology Conference, pp. 1741 - 1746, 2007.

[10] W. Yapeng, Y. Xu, A. Ma and L. Cuthbert, "Resource Allocation in LTE OFDMA Systems Using Genetic Algorithm and Semi-Smart Antennas," IEEE Wireless Communications and Networking Conference, pp. 1-6, 2010.

[11] W. Yapeng, Y. Xu, A. Ma and L. Cuthbert, "Intelligent Resource Optimisation Using Semi-Smart Antennas in LTE OFDMA Systems," IEEE Communications Technology and Applications, pp. 173-179, 2009.

[12] C. W. Wendy, L. Qinghua and T. Shilpa, "A Transmit Beamforming and Nulling Approach with Distributed Scheduling to Improve Cell Edge Throughput," International Journal of Digital Multimedia Broadcasting, Vol.2010, pp. 1-10, 2010.

[13] M. Lott, "Adaptive Random Access with Beam-Forming in 4G Mobile Networks," IEEE Vehicular Technology Conference, Vol.1, pp. 435-439, 2006.

[14] Huawei, Tech. Rep., "Further Analysis of Soft Frequency Reuse Scheme," 3GPP TSG RAN WG1#42 R1-050841, 2005.

[15] Ericsson, Tech. Rep., "Inter-Cell Interference Handling for E-UTRA," 3GPP TSG RAN WG1#42 R1-050764, 2005.

[16] Z. Yue, F. Xuming, H. Xiaopeng, Z. Zhengguang and L. Yan, "Fractional Frequency Reuse Scheme and Performance Evaluation for OFDMA Multi-hop Cellular Network," IEEE Testbeds and Research Infrastructures for the Development of Networks & Communities and Workshops, pp. 1-5, 2009.

[17] H. Lei, L. Zhang, X. Zhang and D. Yang, "A Novel Multi-Cell OFDMA System Structure Using Fractional Frequency Reuse," IEEE PIMRC Int. Symp.on., pp. 1-5, 2007.

[18] C. A. Balanis, *Antenna* Theory Analysis and Design, J. Wiley & Sons, 1997.

[19] B. G. Frank, Smart Antenna for Wireless Communications with MATLAB, McGraw-Hill, 2005.

[20] Andrew A CommScope Company, "Product Specifications 858DG65T6ESY," www.commscope.com/andrew, 2009.

Pichaya Chaipanya, received the B. Eng. and M. Eng degree in telecommunication engineering from Suranaree University of Technology, Nakhon Ratchasima, Thailand, in 2008 and 2010. At present, she is working towards her Ph.D. degree in telecommunication engineering at Suranaree University of Technology, Nakhon Ratchasima, Thailand. Her current research interests concern the design, simulation, and testing of vertical beamforming antenna which is based on antenna currently employed at cellular base station.

Monthippa Uthansakul, received the B.Eng degree (1997) in Telecommunication Engineering from Suranaree University of Technology, Thailand, M.Eng degree (1999) in Electrical Engineering from Chulalongkorn University, Thailand, and Ph.D. degree (2007) in Information Technology and Electrical Engineering from The University of Queensland, Australia. She received 2nd prize Young Scientist Award from 16th International Conference on Microwaves, Radar and Wireless Communications, Poland, in 2006. At present, she is lecturer in School of Telecommunication Engineering, Suranaree University of Technology, Thailand. Her research interests include wideband/narrowband smart antennas, automatic switch beam antenna, DOA finder, microwave components, application of smart antenna on WLANs.

Peerapong Uthansakul, received the B.Eng and M.Eng of Electrical Engineering from Chulalongkorn University, Thailand, in 1996 and 1998 respectively, and Ph.D. degree (2007) in Information Technology and Electrical Engineering from The University of Queensland, Australia. From 1998 to 2001, he was employed as a telecommunication engineer at the Telephone Organization of Thailand. At present, he is a lecturer in School of Telecommunication Engineering, Suranaree University of Technology, Thailand. His research interests include wave propagation modelling, MIMO, OFDM and advance wireless communications.

Proceedings of the Asia-Pacific Microwave Conference 2011

Reduction of Inter-Cell Interference Using Vertical Beamforming Scheme for Fractional Frequency Reuse Technique

P.Chaipanya [#1], P.Uthansakul [#2], M.Uthansakul [#3]

[#] *School of Telecommunication Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand 30000*
[1]M5140701@g.sut.ac.th
[2]uthansakul@sut.ac.th
[3]mtp@sut.ac.th

Abstract — **This paper proposes a vertical beamforming scheme for fractional frequency reuse to reduce the effect of inter-cell interference. Two difference beams are employed in cell-center and cell-edge. The proposed concept is validated through computer simulation in term of SINR and channel capacity. The obtained results show that the proposed concept provides higher performance over the one using a single spot beam.**

Index Terms — **Beamforming, fractional frequency reuse, OFDMA, planar array, cellular systems.**

I. Introduction

Several occurring standards for cellular broadband networks, such as WiMax or Long-Term Evolution (LTE) are based on Orthogonal Frequency Division Multiple Access (OFDMA) [1]. The OFDMA distributes subcarriers among users thus all users can transmit and receive at the same time within a single channel. Consequently, it can reduce multipath interference. However, OFDMA cannot provide full benefits due to the problem of Inter-Cell Interference (ICI) at the cell-edge. In cellular networks, the users staying in cell-center area exploit high signal strength as they are close to the base station (BS). On the other hand, the signal strength is dropped when users are moving close to the cell-edge. As a result, the co-channel interference from neighbor cells becomes more pronounced. To tackle the problem, the frequency resource is divided and differently allocated between cell-center and cell-edge areas, this technique is called Fractional Frequency Reuse (FFR).

From the work presented in [3], a novel FFR scheme for multi-cell OFDMA systems is proposed. In this scheme, each cell of cellular system is divided into three sectors. The subcarriers are partitioned into two groups in each cell. One is called super group employed cell-center and another one is called regular group. The regular group is divided into three paths corresponding to the boundary region of three sectors in the cell-edge. Therefore, the intra-cell interference can be avoided. However, this scheme neglects ICI from cell-center to the cell-edge of neighbor cells, which can degrade the system performance. From literatures, the concept of beamforming has been proposed to tackle the problem. However, the problem is still remained when the direction of ICI signal from neighbor cell is the same as the one of desired signal in the cell-center. Therefore, this paper proposes a beamforming technique to reduce ICI from cell-center to the cell-edge of neighbor cells. The beamforming concept proposed in this paper is vertically located in different areas with respect to the cell-center. This concept can be simply applied to the BS antennas utilized nowadays as it is already stacked in vertical lattice.

The rest of this paper is as follows. After brief introduction, the concept of FFR is discussed along with the vision of vertical beamforming in cellular network in Section II. Then, computer simulation is performed to show the performance of proposed concept in Section III. The results obtained using the proposed concept are also compared with the ones employing one spot beam pattern. Finally, Section IV concludes the paper.

II. Fractional Frequency Reuse and Vertical Beamforming

The concept of FFR utilized in this paper is depicted in Fig. 1. As we can see, each cell is divided to three sectors and the available subcarriers are separated into three groups (f1, f2, and f3). The users at cell-center use the remaining subcarrier groups from the cell-edge. The subcarrier from cell-center becomes an interferer to the one at cell-edge of neighbor cell as shown in Fig. 2, so called ICI problem. This impairment is due to the omni-directional beam pattern radiated from the cell-center. To handle this problem, several researchers have proposed the beamforming technique when the beam patterns are steerable in horizontal plane. Hence, it cannot only enhance the desired signal but also reduces interference transmitted from the cell-center of neighbor cell. Nevertheless, the mentioned concept does not work very well for the case having ICI signal coming from the same direction of the desired signal at the cell-center. Therefore, this paper proposes the idea to reduce ICI problem using vertical beamforming concept as shown in Fig. 3. As we can see, the FFR technique is utilized along with the concept of different subcarriers in different beams. This is full utilization of frequency and space domains. According to this, the users at cell-edge receive higher signal strength while the ICI signal from neighbor cells is decreased. As a result, the overall signal quality can be improved.

The vertical beamforming mentioned above can be accomplished using a planar array [4]. The reason is that the

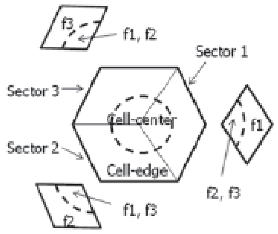


Fig. 1. Cell structure utilizing FFR technique.

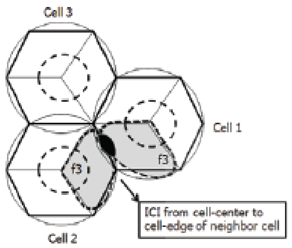


Fig. 2. ICI from cell-center to cell-edge of neighbor cell.

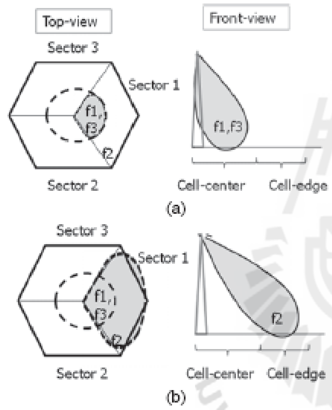


Fig. 3. Beam formation located to (a) cell-center and (b) cell-edge.

planar array is able to provide several variables which can be used to control the pattern shape. The characteristic of beam steering for planar array [5] is given in (1)

$$AF = \sum_{m=1}^{M}\sum_{n=1}^{N} w_{mn} e^{j\left[(m-1)(kd_x \sin\theta\cos\phi+\beta_x)+(n-1)(kd_y \sin\theta\sin\phi+\beta_y)\right]} \qquad (1)$$

where $w = a_m b_m$ in which the weights a_m and b_n can be uniform or can be in any form according to the designer. In addition, M and N stand for a number of antenna elements in the x and y directions, respectively. The antenna elements along the x-axis equally spaced by d_x and also d_y in y-axis. Also, β_x and β_y are phase delays in antenna elements along x and y axes, respectively. The angles represented by and ϕ are directions of incoming/outgoing signal in elevation and azimuth, respectively. The phase delays β_x and β_y can be given by

$$\beta_x = -kd_x \sin\theta_0 \cos\phi_0 \qquad (2)$$

$$\beta_y = -kd_y \sin\theta_0 \sin\phi_0 \qquad (3)$$

In computer simulation for this paper, the hexagonal cellular system is assumed. The wireless channel between the base station and the user is assumed to have effects from propagation path loss and shadowing fading as follows. The propagation path loss can be given by

$$PL = 128.1 + 37.6\log R \qquad (4)$$

where R is the distance between the user and the BS in kilometers. As the shadowing fading values are assumed to be correlated, then we consider the following correlation model for shadowing

$$S_n = X(d)\cdot S_{n-1} + \sqrt{1-X(d)^2}\cdot N(0,\sigma) \qquad (5)$$

$$X(d) = 2^{-d/d_{corr}} \qquad (6)$$

where d_{corr} is decorrelation length and d is the moving distance of the mobile station after the last calculation of shadowing. The $N(0,)$ presented in (5) is a Gaussian random variable with zero mean and standard deviation of σ. The S_n and S_{n-1} are the shadowing values at the two consecutive calculations. The sampled channel frequency response of i^{th} user can be expressed by

$$H_i = \sum_{l=0}^{L-1} h_{i,l}(nT_s)e^{-j2\pi k\Delta f\cdot\tau_1} \qquad (7)$$

where $h_{i,l}$ is the wide-sense stationary narrow band complex amplitude Gaussian process of the L^{th} path. The T_s stands for the OFDM symbol period and •f is the neighbor subcarrier spacing, with •$f = 1/T_s$. Also, $_1$ is the corresponding delay. The channel gain between the serving BS and i^{th} user is G_i, which can be expressed by

$$G_i = 10^{\frac{-PL_i}{10}}\cdot S_i \cdot |H_i|^2 \cdot g_i \qquad (8)$$

where g_i is gain of the planar array when transmitting the signal from BS toward the i^{th} user.

The structure allocation utilized in the computer simulation for this paper is illustrated in Fig. 4. An OFDMA cellular environment with two-tier 19 cells is assumed. When the i^{th} user is located in cell 1, the number of ICI from the cell-center of neighbor cells is 7. For example, when the i^{th} user is in cell 1, the ICI signal is coming from cell 6, 7, 15, 16, 17, 18, and 19. The received SINR of the i^{th} user can be expressed by

$$SINR_i = \frac{G_i P_i}{N_0 \Delta f + \sum_j G_{i,j} P_j} \qquad (9)$$

where G_i is gain between i^{th} user and serving cell 1. In addition, G_{ij} is the gain between i^{th} user and j^{th} cell j. The P_i and P_j are the transmitted power by serving 1^{st} cell and j^{th} cell respectively. Where j is the cell index and equal to 6, 7, 15, 16, 17, 18 and 19. Also, N_0 is the power spectrum density of AWGN, and •f is the neighbor subcarrier spacing.

Next section, simulation results including with the discussion of cellular system using vertical beamforming technique are revealed.

III. Simulation Results and Discussion

This section shows the performance of proposed scheme through the computer simulation. The parameters given in the simulation are listed in TABLE I. The antenna gain values employed in (8) in case of cell-center and cell-edge is obtained from own development in CST Microwave studio. The obtained beam patterns for both cases are shown in Fig. 5. Please note that 7×7 dipole array operating at 2 GHz is employed [3]. Also, the antenna elements are spaced by half-wavelength. The choice of mainbeam's direction can be chosen by adjusting the phase shift between the antenna elements of the array. In the cell-center area, the inference signal is assumed to be coming from 18 cells (cell 2 to 19) and the neighbor sectors are in the cell. At the cell-edge area, the interference signal is coming from 7 cells as demonstrated in Fig. 4. The threshold distance is assumed to be 600 meters. This distance is the criteria to switch the utilizing beam. The beam at cell-center is utilized when the distance between user and serving BS is less than 600 meters, on the other hands beam at the cell-edge is exploited.

With the criteria mentioned before, the simulation is paid to the system performance in term of Signal-to-Interference plus Noise Ratio (SINR) for 4 cases of mainbeam's directions. Fig. 6 shows the obtained results when 7×7 dipole array operating at 2 GHz is employed. As we can see, SINR decreases when the users are moving away from the cell-center. When meeting threshold distance, the utilizing beam is vertically switched to the cell-edge beam. This gives rise to the SINR in the cell-edge region. As a result, the effect of ICI from neighbor cells can be eased. Moreover, a number of mainbeam's directions is assumed. As revealed in Fig. 6, mainbeam's direction of 155° seems to provide the maximum SINR to the systems.

Next, an appropriate number of antenna elements is discussed. Some different number of antenna elements have been utilized in simulation as the outcome is shown in Fig. 7. It is revealed that the more number of antenna elements are

TABLE I
SIMULATION PARAMETERS

Parameters	Values
subcarrier spacing	15 kHz
white noise power density	-174 dBm/Hz
inter-cell distance	2 km
base station transmit power	43 dBm
carrier frequency	2 GHz
d_{corr}	5 m
standard deviation	8 dB

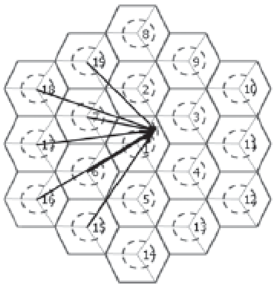


Fig. 4. Cellular structure of OFDMA systems.

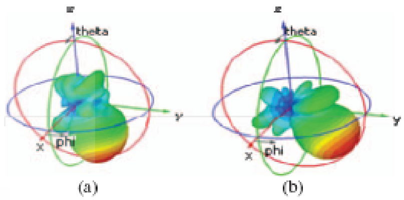


Fig. 5. Simulated patterns of 7×7 dipole array at 2 GHz for (a) cell-center and (b) cell-edge.

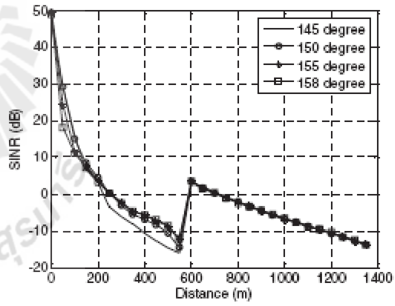


Fig. 6. SINR vs. distance between BS and mobile terminal (MT) when various mainbeam's directons are given.

employed the higher SINR can be obtained. This is because the array gain is increased.

Next, the proposed concept is validated comparing with two other schemes: excluding antenna gain and one spot beam. For the first one, the antenna gain is assumed to be unity all over the sector. However, the effect of path loss

World Academy of Science, Engineering and Technology 74 2013

Performance Enhancement Employing Vertical Beamforming for FFR Technique

P. Chaipanya, P. Uthansakul, and M. Uthansakul

Abstract**—**This paper proposes a vertical beamforming concept to a cellular network employing Fractional Frequency Reuse technique including with cell sectorization. Two different beams are utilized in cell-center and cell-edge, separately. The proposed concept is validated through computer simulation in term of SINR and channel capacity. Also, comparison when utilizing horizontal and vertical beam formation is in focus. The obtained results indicate that the proposed concept can improve the performance of the cellular networks comparing with the one using horizontal beamforming.

Keywords**—**Beamforming, Fractional Frequency Reuse, Inter-Cell Interference, cell sectorization.

I. Introduction

NOWADAYS, the Orthogonal Frequency Division Multiple Access (OFDMA) [1] technique has been utilized in several standards for cellular broadband networks, such as Long-Term Evolution (LTE) or WiMax. The OFDMA deployed the OFDM technology for multiple user access. The OFDMA allows the distribution of subcarriers among users thus all users can transmit and receive simultaneous time within a single channel. Therefore, it can reduce multipath interference. However, all subcarriers are utilized for full benefits when they are used in every cell. This is because of the problem of Inter-Cell Interference (ICI) from neighbor cells. In cellular networks, the users staying in cell-center area exploit high signal strength as they are nearby to the base station (BS). On the other hand, the signal strength is degraded when users are moving close to the cell-edge. Moreover, the users located at cell-edge also suffering inferring signal coming from neighboring cells. To tackle the problem, the frequency resource is divided and differently allocated between cell-center and cell-edge area, this technique is called Fractional Frequency Reuse (FFR) [2].

Fundament of FFR technique is division of the cell area into two regions: cell-center and cell-edge region. All available subcarriers are separated into two groups. One is used for cell-center region and another one is used for cell-edge region. Therefore, the intra-cell interference from cell-edge to cell-center can be ease and the number of ICI can be reduced. Furthermore, the concept of horizontal beamforming has been proposed to improve performance of FFR technique. However, it cannot provide full benefit due to the direction of ICI signal from neighboring cells is the same as the one of desired signal in the cell. Therefore, this paper proposes a vertical beamforming technique to reduce ICI from neighboring cells. The vertical beamforming concept proposed in this paper is two difference beams are utilized in cell-center and cell-edge separately. The horizontal and vertical beamforming are simulation to comparative performance when utilized different FFR technique.

The rest of this paper is as follows. After brief introduction, the concept of FFR is presented in Section II. Then, horizontal and vertical beamforming are discussed along with computer simulation results to show the performance of proposed concept in Section III. The results obtained using the proposed concept are also compared with the ones employing horizontal beamforming utilized different FFR technique. Finally, Section IV concludes the paper.

II. Fractional Frequency Reuse

FFR is a technology that splits coverage cell into two regions: cell-center and cell-edge region. All available subcarriers are divided into two groups to allocate for cell-center and cell-edge region separately as shown in Fig. 1. Moreover, FFR technique can be remodeled into several type by allocation subcarrier groups [3]–[6]. All available subcarriers are used at cell-center area. At cell-edge area, all available subcarriers are divided into three groups to use at each cell-edge area in different cell as shown in Fig. 2 (a). For Fig. 2 (b), all available subcarriers are separated to four groups. Users at cell-center region use one subcarrier group while users at cell-edge region use the other subcarrier group. Furthermore, all available subcarriers are divided into two groups. One is called cell-center group and another one is called cell-edge group. The cell-center group is used at cell-center area. The cell-edge group is separated to three subgroups, each subgroup is utilized at cell-edge for different neighboring cells as shown in Fig. 2 (c). For Fig. 2 (d), the cell-edge area is separated to three sectors to reduce ICI and improve its capacity. All available subcarriers are divided into two groups. One is cell-center group employed at cell-center area. Another one is cell-edge group which is divided into three subgroups, each subgroup is employed at each sector.

The authors are with School of Telecommunication Engineering, Suranaree University of Technology, Nakhon Ratchasima, 30000 Thailand (phone: 66-4422-4351; fax: 66-4422-4603; e-mail: m5140701@g.sut.ac.th, mtp@sut.ac.th, Uthansakul@sut.ac.th).

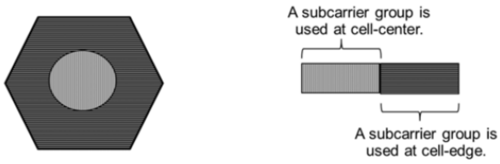


Fig. 1 Fundament of FFR technique

Next, each type of FFR (FFR (a) to FFR (d)) technique is discussed along with horizontal and vertical beamforming. Computer simulation is performed to show the performance in term of SINR and channel capacity for both beamforming with different FFR technique.

III. Horizontal And Vertical Beamforming

The intra-cell interference from cell-edge to cell-center can be ease and the number of ICI can be reduced by using FFR technique. However, the problem of subcarrier from neighboring cells interferer to the one in the cell still remains. This impairment is due to radiation pattern of antenna is used to covering all of a sector area. To handle this problem, several researchers have proposed the beamforming technique when the beam pattern is steerable in horizontal plane. Consequently, it cannot only reduce interference signal transmitted from the neighboring cells but also enhance the desired signal. Nevertheless, the mentioned concept does not work very well for the case having ICI signal coming from the same direction of the desired signal at the cell. Therefore, this paper proposes an idea to reduce ICI problem using vertical beamforming concept as shown in Fig. 3. As we can see, the FFR technique is utilized along with the concept of different subcarriers in different beams. This is full utilization of parameters in both frequency and space domains. According to this, the users at cell-center receive higher signal strength while the ICI signal from neighboring cells is decreased. As a result, the overall signal quality can be improved.

The vertical beamforming mentioned above can be accomplished using a linear array [7]. The characteristic of beam steering for linear array is given by [8].

(1)

where N stands for a number of antenna elements and k is the propagation constant, with $k=2\pi/\lambda$. The antenna elements are equally spaced by d. Also, β is the phase shift between adjacent elements. The angle represented by θ is measured from the z-axis in spherical coordinates.

For the computer simulation in this paper, the hexagonal cellular system is assumed. The wireless channel between the base station and the user is assumed to have effects from

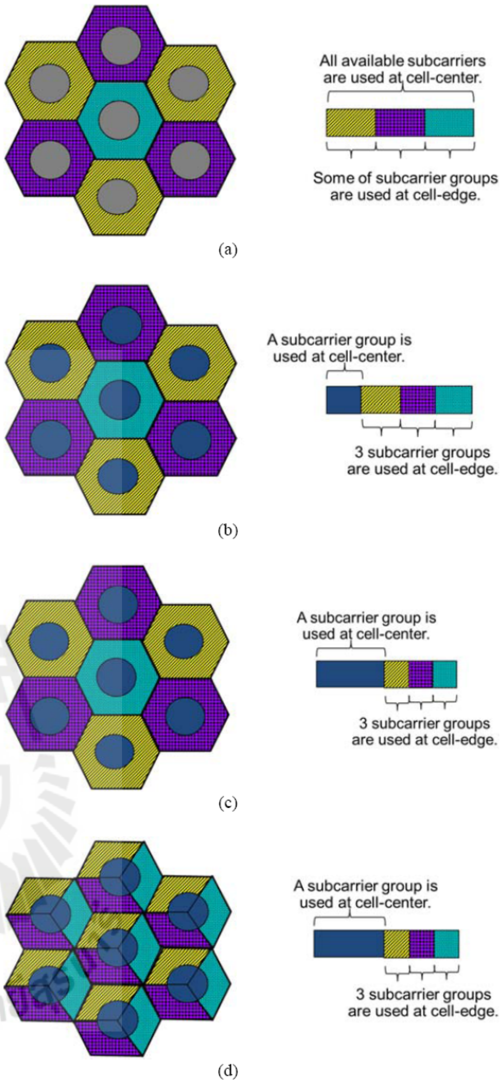


Fig. 2 Cell structure utilizing FFR technique

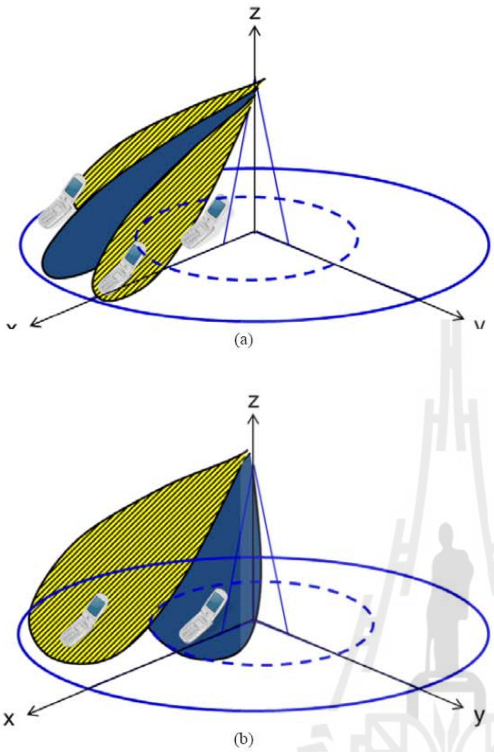


Fig. 3 (a) Horizontal and (b) vertical beamforming

propagation path loss and shadowing fading as follows. The propagation path loss can be given by

$$PL = 120.9 + 37.6 \log R \tag{2}$$

where R is the distance between the user and the BS in kilometers. As the shadowing fading values are assumed to be correlated, then we consider the following correlation model for shadowing

$$S_n = X(d) \cdot S_{n-1} + \sqrt{1 - X(d)^2} \cdot N(0,\sigma) \tag{3}$$

$$X(d) = 2^{-d/d_{corr}} \tag{4}$$

where d_{corr} is decorrelation length and d is the moving distance of the mobile station after the last calculation of shadowing. The $N(0,\sigma)$ presented in (3) is a Gaussian random variable with zero mean and standard deviation of σ. The S_n and S_{n-1} are the shadowing values at the two consecutive calculations.

The sampled channel frequency response of i^{th} user can be expressed by

$$H_i = \sum_{l=0}^{L-1} h_{i,l}(nT_s) e^{-j2\pi k \Delta f \cdot \tau_1} \tag{5}$$

where $h_{i,l}$ is the wide-sense stationary narrow band complex amplitude Gaussian process of the L^{th} path. The T_s stands for the OFDM symbol period and Δf is the neighbor subcarrier spacing, with $\Delta f = 1/T_s$. Also, τ_1 is the corresponding delay. The channel gain between the serving BS and i^{th} user is G_i, which can be expressed by

$$G_i = 10^{\frac{-PL_i}{10}} \cdot S_i \cdot |H_i|^2 \cdot g_i \tag{6}$$

where g_i is gain of the linear array when transmitting the signal from BS toward the i^{th} user.

The structure allocation utilized in the computer simulation for this paper is illustrated in Fig. 4. An OFDMA cellular environment with two-tier 19 cells is assumed. When the i^{th} user is located in cell 1, the number of ICI at the cell- center from neighbor cells is 18. At the cell-edge area, the interference signal is coming from 7 cells as shown in Fig. 4. The received SINR of the i^{th} user can be expressed by

(7)

where G_i is gain between i^{th} user and serving cell 1. In addition, $G_{i,j}$ is the gain between i^{th} user and j^{th} cell j. The P_i and P_j are the transmitted power by serving 1st cell and j^{th} cell respectively. The parameter q is the number of ICI cells. Also, N_0 is the power spectrum density of AWGN, and Δf is the neighbor subcarrier spacing.

The performance in term of SINR using horizontal and vertical beamforming with different FFR technique through the computer simulation is shown in Fig.5. The parameters given in the simulation are listed in TABLE I [6]. Please note that, a threshold distance between cell-center and cell-edge area is 400 meters. As we can see, when FFR technique including with cell sectorization (FFR (d)) is utilized, it can provide higher SINR to the system. Furthermore, case of vertical beamforming with FFR (d) technique can be provided the maximum SINR of the system due to interference from cell-center to neighboring's cell-center is reduced. Moreover, the average channel capacity is calculated [2] as shown in TABLE II. This result can confirm that the vertical beamforming with FFR (d) enhances performance of cellular network.

World Academy of Science, Engineering and Technology 74 2013

TABLE I
SIMULATION PARAMETERS

Parameters	Values
subcarrier spacing	15 kHz
white noise power density	-174 dBm/Hz
inter-cell distance	2 km
base station transmit power	43 dBm
carrier frequency	900 MHz
d_{corr}	5 m
standard deviation	8 dB
channel model	Pedestrian B

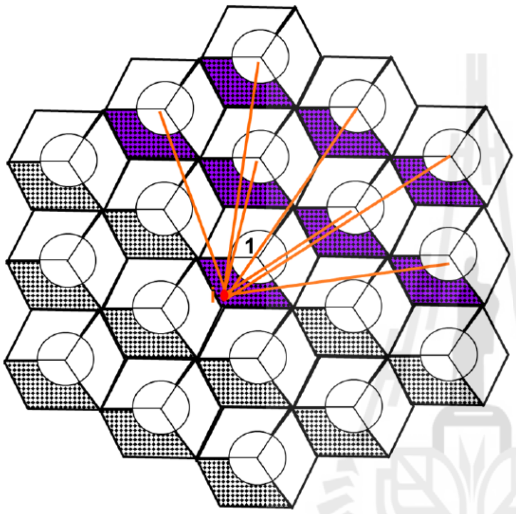


Fig. 4 Cellular structure of OFDMA system and interference at cell-edge

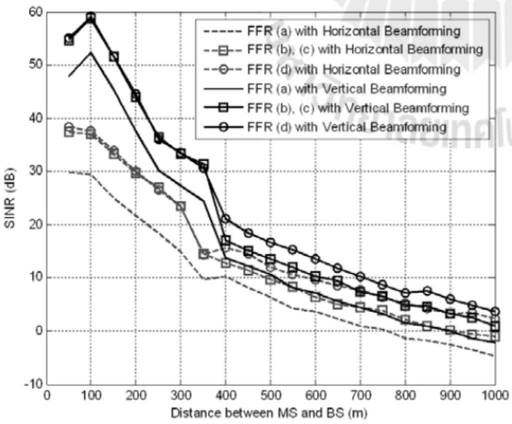


Fig. 5 SINR vs. distance between base station and mobile terminal

TABLE II
CHANNEL CAPACITY

Type of FFR	Channel Capacity (b/s/Hz)	
	Horizontal Beamforming	Vertical Beamforming
a	2.0374	3.4905
b	1.1913	1.7837
c	1.9880	3.0009
d	2.6542	3.8388

IV. Conclusion

This paper has proposed a vertical beamforming concept for the cellular networks utilizing fractional frequency reuse including with cell sectorization. Two beams are utilized for cell-center and cell-edge separately. According to this, the inter-cell interference from neighboring cell can be ease by utilizing vertical beamforming. Moreover, the capacity can be improved when FFR technique is used including with cell sectorization. The proposed concept is validated using computer simulation in term of SINR and channel capacity. The obtained results have indicated that the vertical beamforming with cell sectorization FFR concept can improve the performance of the cellular networks comparing with the one using horizontal beamforming concept.

Acknowledgment

The authors acknowledge the financial support from Telecommunications Research and Industrial Development Institute (TRIDI) and Suranaree University of Technology, Thailand.

References

[1] I. C. Wong, S. Zukang, B. L. Evans, J. G. Andrews, "A Low Complexity Algorithm for Proportional Resource Allocation in OFDMA System," SIPS IEEE Workshop on, pp. 1-6, Oct. 2004.

[2] K. Farooq, LTE for 4G Mobile Broadband Air interface Technologies and Performance, New York: Cambridge University Press, 2009.

[3] Huawei, Tech. Rep., "Further analysis of soft frequency reuse scheme,"3GPP TSG RAN WG1#42 R1-050841, 2005.

[4] Ericsson, Tech. Rep., "Inter-cell interference handling for E-UTRA,"3GPP TSG RAN WG1#42 R1-050764, 2005.

[5] Z. Yue, F. Xuming, H. Xiaopeng, Z. Zhengguang, L. Yan, "Fractional Frequency Reuse Scheme and Performance Evaluation for OFDMA Multi-hop Cellular Network," IEEE Testbeds and Research Infrastructures for the Development of Networks & Communities and Workshops, 2009, pp. 1-5.

[6] H. Lei, L. Zhang, X. Zhang, D. Yang, "A Novel Multi-Cell OFDMA System Structure using Fractional Frequency Reuse," IEEE PIMRC Int. Symp.on., 2007, pp. 1-5.

[7] C. A. Balanis, Antenna Theory Analysis and Design, J. Wiley & Sons, 1997.

[8] B. G. Frank, Smart Antenna for Wireless Communications with MATLAB,, McGraw-Hill, 2005.

Inter-Cell Interference Cancellation for Base Station Antennas

P.Chaipanya, P.Uthansakul and M.Uthansakul

School of Telecommunication Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand
m5140701@g.sut.ac.th, uthansakul@sut.ac.th and mtp@sut.ac.th

***Abstract*—This paper proposes a concept of null steering to the antennas currently utilized at Base Station (BS) in cellular systems. As a result, interference from neighboring cells can be avoided. The proposed null steering is chosen in vertical plane. This is because the current BS antennas are at present stacked in vertical lattice. From simulation results, the proposed concept enhances the system performance in term of SINR and channel capacity comparing to the one without null steering.**

Keywords-Base station antenna; null steering; linear array; inter-cell interference; cellular systems

I. INTRODUCTION

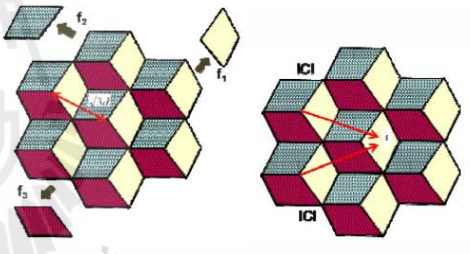
Nowadays, mobile communication is a part of daily life for the most people. A Cellular system is one typical type of mobile communications which is extremely popular. A technique to gain plentiful users for cellular system is frequency reuse [1]. One severe impairment for this system is interference coming from some adjacent cells operating at the same subcarrier group, so call Inter-Cell Interference (ICI). However, the frequency reuse technique cannot provide full benefits as users still face high interference level from the other Base Stations (BS) operating at the same subcarrier group. To taken this problem into account, several antenna types have been proposed to steer beam in a desired direction while placing null to interference directions [2-3]. These schemes can reduce ICI, hence an improved performance of the cellular networks. Nevertheless, those concepts are considerably not practical as there are some difficulties to install those complex computing systems to BS. Therefore, this paper proposes a low complex null-steering concept in which it can directly apply to the antennas currently utilized at BS.

The rest of this paper is as follows. After brief introduction, the problem formulation in term of ICI in cellular system is discussed in Section II. Then, BS-antennas from commercial data are considered and also a low complex null steering concept is proposed in Section III. Then, an enhanced performance employing the proposed concept is shown in Section IV via computer simulation. Finally, Section V concludes the paper.

II. PROBLEM FORMULATION

The concept of frequency reuse in sectorization cellular systems utilized in this paper is depicted in Fig. 1 (a). As we can see, each cell is divided to three sectors and available subcarriers are separated into three groups (f_1, f_2, and f_3). The subcarrier from the other cells operating at the same subcarrier group becomes interferers to the cell of interest, so called ICI as shown in Fig. 1 (b). This impairment is due to the radiation pattern of antenna in interference direction has high gain level as shown in Fig. 2. Therefore, this paper proposes the idea to reduce ICI problem using BS antenna with null steering concept by fixed main beam and interference direction. From Fig. 2, the direction of interference signal can be calculated using Pythagoras theorem. The interference direction is varied by changing the height of antenna and distance between adjacent cell. In this paper, the height of BS antenna is assumed to be 50 meters and the distance between adjacent cell is 1000 to 3000 meters. According to this, the directions of interference signal are approximately 90 to 91.5 degrees. Then, ICI can be reduced by placing null in the calculated directions.

The vertical beamforming mentioned above can be accomplished using a linear array stacked in vertical [4].



(a) (b)

Figure 1. (a) Cell structure utilizing frequency reuse in sectorization cellular and (b) interference from adjacent cells.

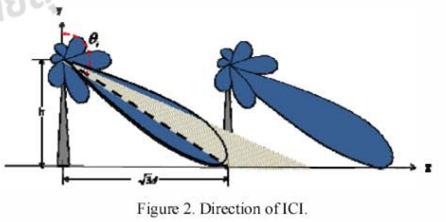


Figure 2. Direction of ICI.

978-1-4673-5537-7/13/$31.00 ©2013 IEEE

The characteristic of beam steering for linear array is given by [5]

$$AF = \sum_{n=1}^{N} w_n e^{j(n-1)(kd\cos\theta + \beta)} \tag{1}$$

where w_n is a weighting coefficients at n^{th} antenna element, N stands for a number of antenna elements and k is propagation constant where $k = 2\pi/\lambda$. The antenna elements are equally spaced by d. Also, β is the phase shift between adjacent antenna elements. The angle represented by θ is direction of incoming/outgoing signal in elevation plane. The phase delay β can be expressed by

$$\beta = -kd\cos\theta_0 \tag{2}$$

where θ_0 is the direction of desired signal in elevation plane. In computer simulation, path loss effect in wireless channel between users and BS is also taken into account as follows [6]:

$$PL = 128.1 + 37.6\log R \tag{3}$$

where R is the distance between user and BS in kilometers.

The problem configuration utilized in the computer simulation for this paper is illustrated in Fig. 1. A cellular environment with one-tier 7 cells is assumed. When the i^{th} user is located in center-tier cell, the number of ICI from the neighboring cells is 2. The received SINR at i^{th} user can be expressed by

$$SINR_i = \frac{P_i g_i \left(10^{\frac{PL_i}{10}}\right)}{N_0 W + \sum_j P_j g_{i,j} \left(10^{\frac{PL_j}{10}}\right)} \tag{4}$$

where the P_i and P_j are transmitted power serving i^{th} cell and j^{th} cell, respectively. The g_i is gain of linear array when transmitting the signal from BS toward the i^{th} user. In addition, $g_{i,j}$ is gain between i^{th} user and j^{th} BS. Also, N_0W is background noise. The PL_i and PL_j are propagation path loss from i^{th} BS and j^{th} to i^{th} user, respectively.

Next, the antennas currently utilized at BS are discussed followed by the proposed null-steering concept.

III. Proposed Null-Steering Concept for Base Station Antennas

From commercial data from Commscope Company [7], a BS employed 9-elements antenna array stacked in vertical with inter-element spacing of 0.83λ. The antennas operate in 900-MHz band. From the information provided by Commscope Company [7], its radiation patterns both in horizontal and vertical planes are shown in Fig. 3. Then, the antennas were re-created in CST Microwave Studio as its simulated patterns for both cases are shown in Fig. 4. The outcome obtained from simulation has a good agreement with the ones from commercial data. From those figures, the vertical mainbeam's direction is obtained at 96 degrees and half power beamwidth in vertical data is 7 degrees. In horizontal plane, half power beamwidth obtained from simulation result is comparable with the one from commercial data, 64.1 and 65 degrees respectively.

From last section, the antennas need to steer nulls to the direction between 90 and 91.5 degrees such that ICI from neighboring cells can be eased. In this paper, a null-steering scheme based on fixed sidelobe cancellation is adopted. The basic of the mentioned concept is to choose array weights such that a null can be placed in the interference direction while maintaining the maximum gain at mainbeam's direction. The array weights can be accomplished using the Godara method [8]. The characteristic of null steering for Godara method is given by [5]

$$\overline{w}^H = \overline{u}_1^T \cdot \overline{A}^H \left(\overline{A} \cdot \overline{A}^H + \sigma_n^2 \overline{I}\right)^{-1} \tag{5}$$

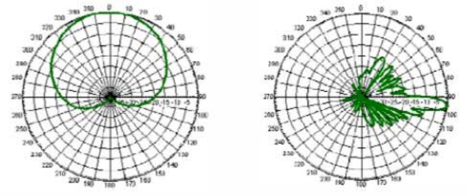
where $\overline{u}_1^T$ is the Cartesian basis vector whose length equals the total number of source. The $\overline{A}$ is a matrix of steering vectors which must be $N \times N$ matrix with N-array elements and N-arriving signal. In addition, σ_n^2 is noise variance.

Next, the system performance when applying the above null-steering concept is discussed. For this case, the main beam direction is 96 degree referring to the commercial data. In addition, interference direction is given at 91 degree calculated from last section. The horizontal and vertical patterns of BS antenna after applying null-steering technique are shown in Fig. 5. In vertical plane, the main beam direction and half power beamwidth are 97 and 6.5 degrees which are similar to the ones obtained without null steering. This means that some significant parameters after performing null steering still remain. Moreover, the back lobe level in horizontal plane with null steering is moderately comparable with the one without null steering. However, the obtained half power beamwidth in horizontal plane is slightly lower than the current one (without null steering). This does not affect the overall performance as half-power beamwidth still covers the same area. Also seen in figure, higher level of sidelobe (at 85 degree) is slightly higher comparing with the one without null steering. This does not affect the system quality as it was not given rise in the direction of interference.

In Next section, simulation results of cellular system in term of SINR is revealed comparing between with and without null steering.

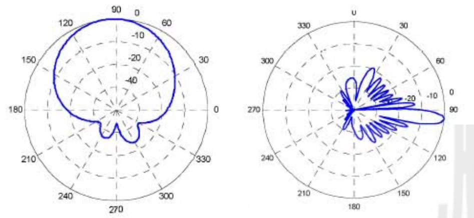
IV. Simulation Result

This section shows the performance of proposed concept through the computer simulation. In this paper, the total background noise of -174 dBm/Hz is assumed. The BS transmits power of 43 dBm and the distance between adjacent cells are 2 kilometers, respectively [6]. The antenna gain values employed in (4) is obtained from own developed



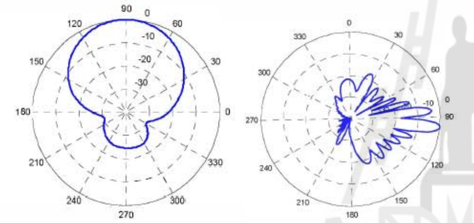
(a) (b)

Figure 3. (a) Horizontal and (b) vertical pattern from commercial data.



(a) (b)

Figure 4. (a) Horizontal and (b) vertical pattern from simulation.



(a) (b)

Figure 5. (a) Horizontal and (b) vertical pattern with null steering.

simulation in CST Microwave studio. In this paper, inference signal is assumed to be coming from 2 cells as demonstrated in Fig. 1 (b). The performance in term of SINR using BS antenna without null steering and the one with null steering through the computer simulation are shown in Fig. 6. As a result, the SINR can be clearly enhanced when utilizing null steering at BS antenna. This is because the interference signals can be eased when placing nulls to their directions. From Fig. 6, the average SINR is 51.4178 and 59.4503 dB for the cases without and with null steering, respectively. Moreover, the channel capacity for both cases is calculated [6]. The average channel capacity is 5.4877 and 6.4142 b/s/Hz for the cases without and with null steering, respectively.

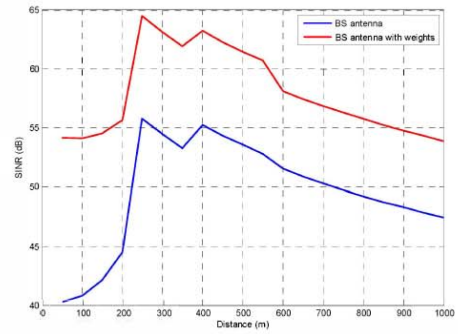


Figure 6. SINR vs. distance between BS and users for the BS antenna without and with null steering.

V. CONCLUSION

This paper has proposed the BS antenna with null steering to enhance performance of cellular system. The reason is that a null can be placed in the direction of interference while maintaining its maximum gain at direction of interest. The proposed concept has been applied to the commercial BS antennas. The obtained simulation results have revealed that the cellular system gain SINR and channel capacity when applying a simple null-steering scheme to BS antennas.

ACKNOWLEDGMENT

The authors acknowledge the financial support from Telecommunications Research and Industrial Development Institute (TRIDI) and Suranaree University of Technology, Thailand.

REFERENCES

[1] A. Goldsmith, Wiress Communications, Cambridge University Press, 2007.

[2] D. E. N. Davies and M. S. A. S. Rizk, “A Broadband Experimental Null-Steering Antenna System for Mobile Communications,” IET Journals and Maxgazines, vol 48, Issure 10, pp. 509-517, 1978.

[3] Y. Kishiyama, T. Nishimura, T. Ohgane, Y. Ogawa, Y. Doi, “Weight Estimation for Downlink Null Steering in a TDD/SDMA System,” Vehicular Technology Conference Proceedingvol. 1, pp. 346-350, 2000.

[4] C. A. Balanis, Antenna Theory Analysis and Design, J. Wiley & Sons. 1997.

[5] B. G. Frank, Smart Antenna for Wireless Communications with MATLAB, McGraw-Hill, 2005.

[6] K. Farooq, LTE for 4G Mobile Broadband Air interface Technologies and Performance, Cambridge University Press, 2009.

[7] Andrew A CommScope Company, “Product Specifications 858DG65T6ESY,” www.commscope.com/andrew, 2009.

[8] L. Godara, “Application of Antenna Arrays to Mobile Communications, Part II: Beamforming and Direction-of-Arrival Considerations,” Proceedings of the IEEE, vol. 85, No. 8, pp. 1995-1245, Aug. 1997.

BIOGRAPHY

Miss Pichaya Chaipanya was born in Chiang Mai, Thailand, in 1985. She graduated with the Bachelor Degree and Master Degree of Engineering in Telecommunication Engineering in 2007 and 2009 respectively from Suranaree University of Technology, Nakorn Ratchasima, Thailand. Then she is currently pursuing her Ph.D program in Telecommunication Engineering, School of Telecommunication Engineering, Suranaree University of Technology. Her current research interests concern the design, simulation, and testing of vertical beamforming antenna which is based on antenna currently employed at cellular base station.