國立交通大學

電子工程學系電子研究所碩士班

碩 士 論 文

行動全球互通微波存取中多重輸入與輸出系統的下行傳輸效能分析

Downlink Performance Analysis of MIMO System in Mobile WiMAX

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中 華 民 國 九十七年一月

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摘 要

在這篇論文中，將介紹多根天線的技術，還有**WiMAX**的媒介接取控制層如何控制多根天線，我們也發展了一個行動**WiMAX**模擬平台，並且建立了包含基礎無線資源管理以及可以支援多根天線運作的媒介接取控制層，藉由此模擬平台，透過四種不同的排程方法（循環排程、最大訊雜比排程、比例公平式排程、**Early Deadline First**）搭配兩種不同的資料形式（網路語音傳遞、檔案傳輸協定），分析多根天線在各種不同情形下能改善多少系統效能（傳輸速率、服務品質控制、系統容量），並且更進一步分析各種多根天線技術在系統效能上的差異，了解各種不同技術（空間多工、發射分送）在不同的排程方式和不同的資料形式下的使用的時機。除此之外，我們也就單根天線和多跟天線討論有關於在每個封包最後填不滿一個**slot**時所造成的浪費，以及用簡單的方法調整**PDU**的大小並觀察所能改善的效能

Downlink Performance Analysis of MIMO System in Mobile WiMAX

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Abstract

In the thesis, we introduce multiple-input and multiple-output (MIMO) Antenna techniques and how to control multiple antennas in media access control (MAC) layer in mobile WiMAX. We build a simulation platform for mobile WiMAX with basic Radio Resource Management (RRM) and MIMO-enabled MAC layer. We analyze the system performance, including throughput, quality of service (QoS), and system throughput, different scheduling algorithms (round robin (RR), Maximum Carrier to Interference-plus-Noise Ratio (MaxCINR), proportional fair (PF), early deadline first (EDF)) and different traffic types (VOIP, FTP). Furthermore, we discuss system performance in different MIMO techniques (spatial multiplexing and transmit diversity). Finally, we investigate the influence of padding of a burst and attempt to improve performance by adapting a PDU size.

誌　謝

光陰似箭，碩士班的求學歷程即將畫下句點。在這一段過程中，認識許多好夥伴，其中更是有許多在我在專業領域研究上的貴人，很慶幸有你們的陪伴與幫助，在此我願意將我小小的成果分享給在這兩年陪伴我的你們。

先，我要感謝我的指導教授 黃經堯老師，除了在專業上授了我許多關於無線通訊的知識外，也讓我在這一段求學的過程中埱養如何去找出問題、分析問題、解決問題的能，除此之外，在表達能力上的川練，藉由老師紮實的要求與指正下，讓我獲益良多。另久詭要感謝交大電信系 伍紹勳老師的指導，給了我在研究上所需的基礎知識，不厭其煩的協助我解決在一個未知領域上的瓶頸，有你們在百忙之中抽空指導，我才能順利的完成碩士論文。

初入學之時，感謝老師 黃經堯教授的收容，才能開啟了自己對於無線通訊領域的摸索，雖然不知日後的發展會否繼續摸索下去，但是可以慶幸的是，學習的路至此為止雖然走的長了點，卻沒有走偏。從學習什麼是研究開始，直到現在，過程中一直有著不少的盲點。至此，最重要的除了感謝 黃經堯老師平日的指導之外，也要感謝老師能夠撥冗參加我的報告，點破我思考上的盲點，也讓我的研究內容能更趨完整與豐富。除了鄭重的感謝老師們的指導外，更想要跟一起過日子的朋友們說聲感謝。

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2008 年 蕭世璞撰

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Chapter 1 Introduction

In modern communication, voice, data, and multimedia provided by wireless system are necessary, so reliable and high data rate transmission is required for different applications. When people stay in various geographical locations, wired communication is inconvenient, costly, or unavailable, so they need that wireless broadband brings high-speed data. Worldwide Interoperability for Microwave Access (WiMAX) is a technology based on the IEEE 802.16d [1] specification and IEEE 802.16e [2] specification to commercialize broadband wireless for mass market. The IEEE 802.16d standard is proposed to stationary transmission and the IEEE 802.16e is intended for both stationary and mobile deployments.

The multiple-input and multiple-output (MIMO) system has recently emerged as one of significantly techniques and manifests a chance of overcoming the bottleneck of traffic throughput. MIMO system can be defined as an arbitrary wireless communication system which transmits information between transmitter and receiver with multiple antennas. The idea behind MIMO is that the signals at receive antennas are combined in a certain way to improve the bit-error rate (BER) and the data rate. The core technology of MIMO is how to combine signals by space-time signal processing. The important feature of MIMO is the ability to change multipath propagation, traditionally a tough problem of wireless transmission, into a benefit for users. MIMO can take the advantage of random fading [3], [4], [5] for transmission quality and multipath delay spread [6] and [7] for data rate. Hence, WiMAX supports several multiple-antenna options including Space-Time Code (STC) system, and Adaptive Antenna System (AAS).

The performance analysis of Scheduling Algorithm in WiMAX has been investigated [8]. The author only focuses on single-input and single-output (SISO) system. In [9], MIMO system (two transmit antennas and two receive) is applied in hypertext transfer protocol (HTTP) traffic scenario but Scheduling algorithm only adopts proportional fair (PF) method. In the thesis, we focus on the performance analysis of downlink transmission with 4-by-4 MIMO to address the capability in Mobile WiMAX and investigate the performance of different receivers and different scheduling methods. Besides, we also discuss the effect of fragmentation and packing in a MIMO system. In the simulation, we employ four scheduling algorithms to analyze the system performance.

The rest of the thesis is organized as follows: In Chapter 2, the MIMO technique overview is introduced. In Chapter 3, a proposed PDU segmentation method is introduced. In Chapter 4, the simulation setup is addressed. In Chapter 5, it shows the simulation results. Finally the conclusion and future works are provided in Chapter 6.

Chapter 2 Overview of MIMO System

The use of multiple antennas at the transmitter and receiver in a wireless system, popularly known as MIMO system, has rapidly gained in popularity due to its powerful performance-enhancing capabilities.

2.1 Benefits of MIMO Technology

The benefits of MIMO technology are array gain, spatial diversity gain, spatial multiplexing gain and interference reduction that can significantly improve performance. In general, it may not be possible to exploit simultaneously all the benefits described above due to conflicting demands on the spatial degrees of freedom. However, using some combination of the benefits across a wireless network will result in improving throughput, coverage and reliability. These gains are described in following.

2.1.1 Array Gain

Array gain can increase the strength of the receive SNR as a result of coherent combining effect of the wireless signals at a receiver. The coherent combining may be realized through spatial processing at the receive antenna array or spatial pre-processing at the transmit antenna array. Array gain improves resistance to noise, thereby improving the coverage of a wireless network.

2.1.2 Spatial Diversity Gain

The signal level at a receiver in a wireless system fluctuates or fades. Spatial diversity gain mitigates fading and is realized by providing the receiver with multiple (ideally independent) copies of the transmitted signal in space, time or frequency. With an increasing number of independent copies (the number of copies is often referred to as the diversity order), at least one of the copies is not experiencing a deep fade increases and integrating all copies can promote the signal level, so the quality and reliability of reception are improved. A MIMO channel with M_T transmit antennas and M_R receive antennas potentially offers $M_T \cdot M_R$ independently fading links, that means $M_T \cdot M_R$ being the maximum spatial diversity order

2.1.3 Spatial Multiplexing Gain

MIMO systems offer a linear increasing in data rate through spatial multiplexing independent data streams within the same bandwidth of operation. Under suitable channel conditions, such as rich scattering in the environment, the receiver can separate the data streams. In general, the number of data streams that can be reliably supported by MIMO channel equals the minimum number of transmit antennas and receive antennas. The spatial multiplexing gain increases the throughput of a wireless network.

2.1.4 Interference Reduction and Avoidance

Interference in wireless networks results from multiple users sharing time and frequency resources. Interference may be mitigated in MIMO systems by employing the spatial dimension to increase the distance between users. Additionally, the spatial dimension may be leveraged for the purposes of interference avoidance. Interference reduction and avoidance improve the coverage and range of a wireless network.

2.2 Principle of MIMO System

Figure 2-1 shows the basic block diagram that constitutes a MIMO communication system. A digital source in the form of a binary data stream is sent into the coding and interleaving block. The source are encoded (in the thesis, using a convolutional encoder) and interleaved. Then, the interleaved codeword is mapped to complex modulation symbols by symbol mapper. These symbols are input to a space-time encoder that outputs one or more spatial symbol streams. The spatial symbol streams are mapped to the transmit antennas by the space-time precoding block. After upward frequency conversion, filtering and amplification, the signals launched from the transmit antennas propagate through the channel and arrive at the receive antennas. At the receiver, the signals are collected by possibly multiple antennas and space-time processing, space-time decoding, symbol demapping, deinterleaving and decoding operations are performed in sequence to recover the message. The level of intelligence, complexity and a priori channel knowledge used in selecting the coding and antenna mapping algorithms can be a deal depending on the application. This determines the class and performance of the multiple antenna solution that is implemented.

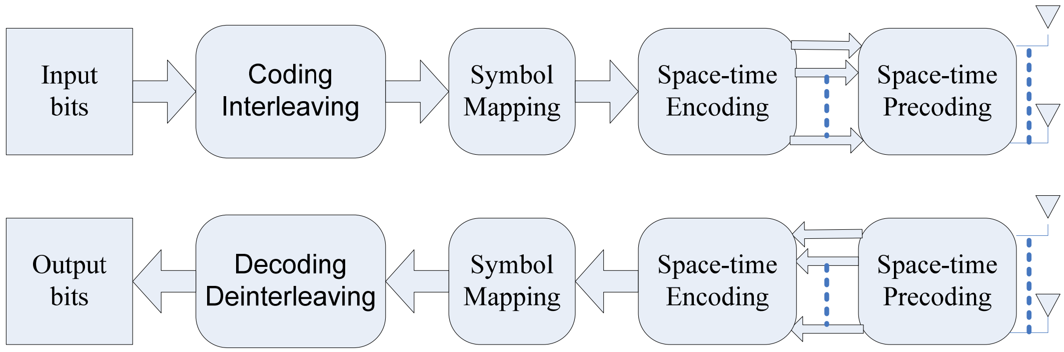

Figure 2-1 Basic Block of MIMO System

In a multiple antennas system, information can be transmitted by various transmission techniques. One way is to adjust the weights of all transmit antennas, which transmit the same signal, to compensate for the distortion caused by channel on transmitted signals. This method is called transmit beamforming [10]. Another way is to use antenna selection where only a signal antenna is used for transmission at any particular instant [11]. These two schemes both require feedback. Transmit beamforming needs to the receiver feeds back the channel estimation to the transmitter from time to time, but antenna selection only needs a little feedback that is which subset of available antennas should be use for transmission [12] and [13]. Furthermore, providing feedback not only makes the protocol elaborate but also increases the receiver complexity.

The transmission scheme which does not require feedback of channel estimation is referred as open loop transmit technique. Therefore, the total transmit power is usually distributed equally among all antennas. The open loop scheme makes the protocol easier, so STC is exploited in the simulation.

2.3 Space-Time Code

The set of schemes aimed at realizing joint encoding of multiple transmit antennas are called STC which is an open loop transmission scheme. In these schemes, a number of code symbols equal to the number of transmit antennas are generated and transmitted simultaneously. These symbols are generated by the space-time encoder such that by using the appropriate signal processing and decoding procedure at the receiver to maximize the diversity gain and the coding gain.

The first attempt to develop STC was presented in [14] and was inspired by the delay diversity scheme of Wittnebn [15]. However, the key development of the STC concept was originally revealed in [16] in the form of trellis codes, which is called space-time trellis code (STTC). At the receiver, it requires a multidimensional (vector) Viterbi algorithm for decoding STTC. The codes can provide a diversity benefit equal the number of transmit antennas in addition to a coding gain that depends on the complexity of the code (number of states in the trellis) without any loss in bandwidth efficiency.

Then, another STC, space-time block code (STBC), is developed due to the fact that STBC can be decoding utilizing simple linear processing at the receiver in contrast to the STTC. Although STBC codes can provide the same diversity gain as the STTC for the same number of transmit antennas, they have zero or minimal coding gain. In the thesis, only STBCs is considered which currently dominate the literature rather than on trellis-based approaches due to decoding complexity.

2.3.1 Transmit Diversity

When the number of antennas is fixed, the decoding complexity of space-time trellis coding increases exponentially as a function of the diversity level and transmission rate [17]. In addressing the issue of decoding complexity, [18] discovered a remarkable space-time block coding scheme for transmission with two antennas. This scheme supports maximum-likelihood (ML) detection based only on linear processing at the receiver, since symbols from each antenna are orthogonal. This could make the receiver to decode the transmission information with less complexity even if it only has single antenna. The scheme was later generalized in [19] to an arbitrary number of antennas.

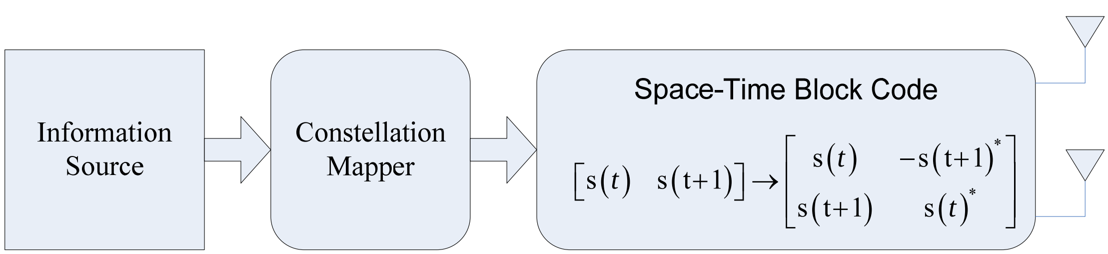

Figure 2-2 Transmit Diversity Transmitter

Figure 2-2 shows the baseband which is represented for STBC with two transmit antennas and two receive antennas. The input symbols to the space-time block encoder are divided into groups of two symbols each. At a given symbol period, the two symbols in each group $\{\mathrm{s}(t),\ \mathrm{s}(t+1)\}$ are transmitted simultaneously from the two antennas. The signal transmitted from antenna 1 is $\mathrm{s}(t)$ and the signal transmitted from antenna 2 is $\mathrm{s}(t+1)$. In the next symbol period, the signal $-\mathrm{s}^*(t+1)$ is transmitted from antenna 1 and the signal $\mathrm{s}^*(t)$ is transmitted from antenna 2. Let h_1 and h_2 be the channels from the first and second transmit antenna to the receive antenna, respectively. Here, the important assumption is that h_1 and h_2 are scalar and constant over two successive symbol periods, that is

$$h_i(2nT) \approx h_i((2n+1)T), \quad i = 1,2.$$

Here, a receiver has a single antenna. We also denote the received signal over two

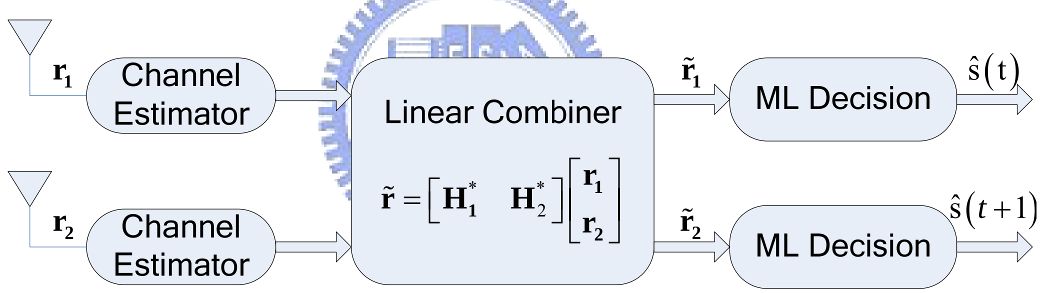

Figure 2-3 Transmit Diversity Receiver

consecutive symbol periods as $\mathrm{r}(t)$ and $\mathrm{r}(t+1)$. The received signals can be expressed as

$$\mathrm{r}(t) = h_1\,\mathrm{s}(t) + h_2\,\mathrm{s}(t+1) + \mathrm{n}(t) \tag{1}$$

$$\mathrm{r}(t+1) = -h_1\,\mathrm{s}^*(t+1) + h_2\,\mathrm{s}^*(t) + \mathrm{n}(t+1) \tag{2}$$

Where $\mathrm{n}(t)$ and $\mathrm{n}(t+1)$ represent the additive white Gaussian noise (AWGN) which is independent and identically-distributed (i.i.d.) complex Gaussian random variables with zero mean and power spectral density $N_0/2$ per dimension. The received signal vector is defined as $\mathbf{r}=\left[\mathrm{r}(t) \quad \mathrm{r}^*(t+1)\right]^T$, the coded symbol vector is defined as $\mathbf{s}=\left[\mathrm{s}(t) \quad \mathrm{s}(t+1)\right]^T$, and the noise vector is defined as $\mathbf{n}=\left[\mathrm{n}(t) \quad \mathrm{n}^*(t+1)\right]^T$. Equations (1) and (2) can be rewritten in

$$\mathbf{r}=\mathbf{Hs}+\mathbf{n}$$

(3)

Where the channel matrix $\mathbf{H}$ is

$$\mathbf{H}=\begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}$$

(4)

$\mathbf{H}$ is only a virtual MIMO matrix with space (columns) and time (rows). The set of all possible symbol pairs $\mathbf{s}=\left\{\mathrm{s}(t),\mathrm{s}(t+1)\right\}$ is defined as $\mathbf{S}$. It assumes that all symbol pairs are equiprobable and noise vector $\mathbf{n}$ is a multivariate AWGN, so the optimum maximum likelihood (ML) decoder can be simplified as

$$\hat{\mathbf{s}}=\arg\min_{\hat{\mathbf{s}}\in\mathbf{S}}\left\|\mathbf{r}-\mathbf{Hs}\right\|^2$$

(5)

The ML decoding rule in (5) can be further simplified by realizing that the channel matrix $\mathbf{H}$ is always orthogonal regardless of the channel coefficients. Hence, $\mathbf{H}^*\mathbf{H}=\alpha\mathbf{I}_2$ where $\alpha=\left|h_1\right|^2+\left|h_2\right|^2$. Consider the modified signal vector $\tilde{\mathbf{r}}$ given by

$$\tilde{\mathbf{r}}=\mathbf{H}^*\mathbf{r}=\alpha\mathbf{s}+\tilde{\mathbf{n}}$$

(6)

Where $\tilde{\mathbf{n}}=\mathbf{H}^*\mathbf{n}$. In this case, the decoding rule becomes

$$\hat{\mathbf{s}} = \arg\min_{\hat{\mathbf{s}}\in\mathbf{S}} \left\| \tilde{\mathbf{r}} - \alpha\hat{\mathbf{s}} \right\|^2$$

(7)

Since $\mathbf{H}$ is orthogonal, it can be easily verified that the noise vector $\tilde{\mathbf{n}}$ will have a zero mean and covariance $\alpha N_0 \mathbf{I}_2$. Therefore, it follows immediately that by using this simple linear combining, the decoding rule in (7) reduces to two separate, and much simpler decoding rules for $s(t)$ and $s(t+1)$.

Initially developed to provide transmit diversity in the MISO case, STCs are easily extended to the MIMO case. When the receiver has two antennas, such as figure 2-3, the received signal vector $\mathbf{r_m}$ at receive antenna *m* is

$$\mathbf{r_m} = \mathbf{H_m} \cdot \mathbf{s} + \mathbf{n_m}, \quad m = 1,2$$

(8)

$$\mathbf{H}_m = \begin{bmatrix} h_{1m} & h_{2m} \\ h_{2m}^* & -h_{1m}^* \end{bmatrix}, \quad m = 1,2$$

(9)

Where $\mathbf{n_m}$ is the noise vector at the two time instants and $\mathbf{H_m}$ is the channel matrix from the two transmit antennas to the *m*th receive antenna. The optimum ML decoder can be represented by

$$\hat{\mathbf{s}} = \arg\min_{\hat{\mathbf{s}}\in\mathbf{S}} \sum_{m=1}^{2} \left\| \mathbf{r}_m - \mathbf{H}_m\hat{\mathbf{s}} \right\|^2 \qquad (10)$$

The decision rule in (7) and (10) is applied a hard decision on $\tilde{\mathbf{r}} = \mathbf{H}^* \cdot \mathbf{r}$ and $\tilde{\mathbf{r}}_\mathbf{m} = \sum_{m=1}^{2} \mathbf{H}_\mathbf{m}^* \mathbf{r}_\mathbf{m}$, respectively. Therefore, as shown in figure 2-3, the received vector after linear combining, $\hat{\mathbf{r}}_\mathbf{m}$, can be made soft decision for $s(t)$ and $s(t+1)$. If the STBC is concatenated with an outer conventional channel code, such as convolutional code, the soft decisions can be fed to the outer channel decoder to yield a better performance. The extension of the above STBC to more than two transmit antennas was studied in [17], [19], [20], and [21]. A technique was developed for constructing STBCs that provide the maximum diversity promised by the number of transmit and receive antennas. These codes keep the simple ML decoding algorithm in use based on only linear processing at the receiver [18]. However, for general constellation mapper like M-QAM or M-PSK there is not a STBC with transmission rate one and simple linear processing that will give the maximum diversity gain with more than two transmit antennas. Moreover, it was also shown that such a code where the number of transmit antennas equal the number of both the number of information symbols transmitted and the number of the slot is needed to transmit the code block does not exist. However, for rates less than one, such codes can be found and it is also possible to sacrifice orthogonality in an effort to maintain full rate or one code with more than two transmit antennas. In [22], quasi-orthogonal STBC could preserve the full diversity and full rate at the cost of a small loss BER and some extra decoding complexity relative to truly orthogonal schemes.

2.3.2 Spatial Multiplexing

Spatial multiplexing can maximize the average data rate over the MIMO system due to each stream of independent data are transmitted over different antennas. Assuming a block of independent data $\mathbf{s}$ with size $M \times L$ is transmitted over the $M \times N$ MIMO system and the receiver will obtain $\mathbf{r} = \mathbf{hs} + \mathbf{n}$ where size of $\mathbf{r}$ is $N \times L$, where L is the length of a block, M is the number of transmit antennas, and N is the number of receive antennas. The optimum decoding method is ML decoder where the receiver compares all possible combination s of symbols which could have been transmitted with what is observed

$$\hat{\mathbf{s}} = \arg\min_{\hat{\mathbf{s}}} \left\| \mathbf{r} - \mathbf{h}\hat{\mathbf{s}} \right\| \tag{11}$$

The complexity of ML decoder is very high when many antennas or high-order modulations are adopted. Enhanced variants of this like sphere decoding [23] have been proposed. Another popular decoding strategy, BLAST (Bell Laboratories Layered Space-Time) or D-BLAST (Diagonal-BLAST), proposed by [3]. D-BLAST employs a diagonally layered coding structure in which code blocks are dispersed across diagonals in space-time. However, the diagonal approach suffers from certain implementation complexity which makes it inappropriate for initial implementation. Some space-time is wasted at the start and the end of a burst that would be significant when the burst length is short and the complication of the careful avoidance of catastrophic error propagation is a concern.

In [24], vertical BLAST (V-BLAST) was addressed to be implemented in practice. Space is the M points discrete space defined by the M transmit antennas. V stands for vertical, referring to layering space-time with consecutive transmitted vector signals, a sequence of successive vertical columns in space-time.

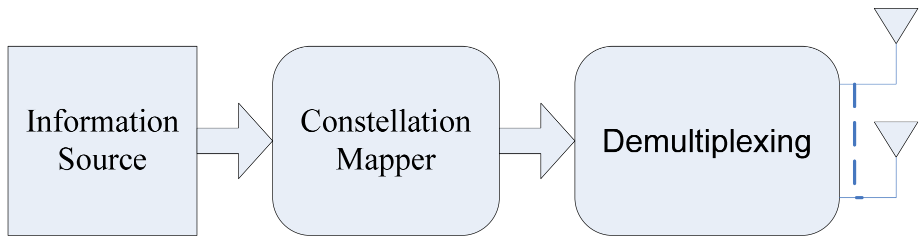

Figure 2-4 Spatial Multiplexing Transmitter

A high –level block diagram of V-BLAST system is shown in figure 2-4. A single data stream is demultiplex into M substreams and fed to its respective transmitter. Each transmitter is an ordinary QAM transmitter. The collection of transmitters comprises, in effect, a vector-valued transmitter, where components of each transmitted M-vector are symbols drawn from a QAM constellation. Here, the same constellation is employed for each substream, and that transmissions are organized into burst of L symbols. The power launched by each transmit antenna is proportional to $1/M$ so that the total radiated power is constant. Inter-substream coding is not required, though conventional coding of the individual substreams is certainly applied.

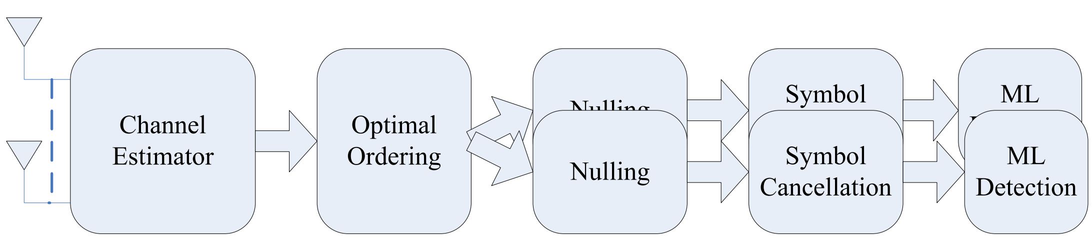

Figure 2-5 Spatial Multiplexing Receiver

Letting $\mathbf{a} = \begin{bmatrix} a_1 & a_2 & \cdots & a_M \end{bmatrix}^T$ denote the vector of transmit symbols, then the corresponding received vector is

$$\mathbf{r}_1 = \mathbf{Ha} + \mathbf{n}$$

Where $\mathbf{n}$ is a noise vector with components drawn from i.i.d. wide-sense stationary processes with variance σ^2. Each substream in turn is considered to be the desired signal and the remainder is considered as interferers. Nulling is performed by linearly weighting the received signals so as to satisfy some performance-related criterion, such as minimum-mean-squared error (MMSE) or zero-forcing (ZF). The linear nulling approach is viable, but nonlinear techniques can achieve better performance. Using symbol cancellation, interference from already-detected components of $\mathbf{a}$ is subtracted out from the received signal vector. As the result effectively fewer interferers are present in a modified received vector. This is somewhat analogous to decision feed back equalization. When symbol cancellation is used, the order in which the components of $\mathbf{a}$ are detected becomes important to overall performance of the system, but it doesn't have influence when pure nulling is used. Under the assumption that components of $\mathbf{a}$ are employ the same modulation constellation, the component with the smallest receive SNR will dominate the error performance of the system. Choosing the best receive SNR at each stage in the detection in the detection process leads to the optimum ordering. The full V-BLAST detection algorithm can be described compactly as a recursive procedure shown in Figure 2-5.

2.4 Introduction of MIMO in WiMAX

In WiMAX , multiple antennas technique is optional, but MIMO will become main stream due to high throughput and low BER. In this section, how WiMAX supports MIMO with STC will be introduced.

2.4.1 STBC in WiMAX

In WiMAX, two, three, and four antennas can be employed and matrix A, matrix B, and matrix C are defined to support STBC as shown in Table 2-1. In two transmit antennas system, matrix A is applied for transmit diversity and matrix B is applied for spatial multiplexing. In three and four transmit antennas systems, matrix A and matrix B is applied for transmit diversity and matrix C is applied for spatial multiplexing.

Table 2-1 STBC Types in WiMAX

	2X2	3X3	4X4
Matrix A	$\begin{bmatrix} S_i & -S_{i+1}^* \\ S_{i+1} & S_i^* \end{bmatrix}$	$\begin{bmatrix} \tilde{S}_1 & -\tilde{S}_2^* & 0 & 0 \\ \tilde{S}_2 & \tilde{S}_1 & \tilde{S}_3 & -\tilde{S}_4^* \\ 0 & 0 & \tilde{S}_4 & \tilde{S}_3 \end{bmatrix}$	$\begin{bmatrix} S_1 & -S_2^* & 0 & 0 \\ S_2 & S_1^* & 0 & 0 \\ 0 & 0 & S_3 & -S_4^* \\ 0 & 0 & S_4 & S_3^* \end{bmatrix}$
Matrix B	X	$\begin{bmatrix} \sqrt{\frac{3}{4}} & 0 & 0 \\ 0 & \sqrt{\frac{3}{4}} & 0 \\ 0 & 0 & \sqrt{\frac{3}{4}} \end{bmatrix} \begin{bmatrix} \tilde{S}_1 & -\tilde{S}_2^* & \tilde{S}_5 & -\tilde{S}_6^* \\ \tilde{S}_2 & \tilde{S}_1^* & \tilde{S}_6 & \tilde{S}_5^* \\ \tilde{S}_7 & -\tilde{S}_8^* & \tilde{S}_3 & -\tilde{S}_4^* \end{bmatrix}$	$\begin{bmatrix} S_1 & -S_2^* & S_5 & -S_7^* \\ S_2 & S_1^* & S_6 & -S_8^* \\ S_3 & -S_4^* & S_7 & S_5^* \\ S_4 & S_3^* & S_8 & S_6^* \end{bmatrix}$
Matrix C	$\begin{bmatrix} S_i \\ S_{i+1} \end{bmatrix}$	$\begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix}$	$\begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{bmatrix}$

Where the complex symbols to be transmitted be x_1, x_2, x_3, x_4 which take values from a square QAM constellation. Let $S_i = x_i e^{j\theta} = S_{iI} + jS_{iQ}$ for $i = 1, 2, ..., 8$, where $\theta = \tan^{-1}\left(\frac{1}{3}\right)$ and $\tilde{S}_1 = S_{1I} + jS_{3Q}$; $\tilde{S}_2 = S_{2I} + jS_{4Q}$; $\tilde{S}_3 = S_{3I} + jS_{1Q}$; $\tilde{S}_4 = S_{4I} + jS_{2Q}$; $\tilde{S}_5 = S_{5I} + j\tilde{S}_{7Q}$; $\tilde{S}_6 = S_{6I} + jS_{8Q}$; $\tilde{S}_7 = S_{7I} + jS_{5Q}$; $\tilde{S}_8 = S_{8I} + S_{6Q}$. This space-time-frequency code can be decoded by ML method.

Antennas selection and antennas grouping can used for spatial multiplexing and transmit diversity, respectively. In matrix B and matrix C, the MIMO system can select coding method between vertical coding and horizontal coding. Vertical coding indicates transmitting a single FEC encoded stream over multiple antennas, so the number of encoded stream is always 1, such as Figure 2-6 and Figure 2-8. Transmitting multiple separately FEC encoded stream over multiple antennas is horizontal encoding and the number of encoded stream is more than 1, such as Fig 2-7 and Fig 2-9. A stream is defined as each information path encoded by STC encoder that is passed to subcarrier mapping and send through one antenna. A layer is defined as an information path fed in STC encoder as an input, hence the number of layers in a system with vertical encoding is one but in case of horizontal coding it depends on the number of encoding and modulation path. It means that only horizontal encoding can support multi-user transmission. Table 2-2 defines the mode of downlink operation which describes all transmission methods in IEEE 802.16e.

Table 2-2 Downlink MIMO Operation Mode

Number of transmit antennas	Matrix indicator	Num of layers	Number of users	Encoding type	Rate
2	A	1	1	STTD	1
2	B	1	1	Vertical encoding	2
2	B	2	1	Horizontal encoding	2
2	B	2	2	Horizontal encoding	2
4	A	1	1	STTD	1

4	B	1	1	Vertical encoding	2
4	B	2	1	Horizontal encoding	2
4	B	2	2	Horizontal encoding	2
4	C	1	1	Vertical encoding	4
4	C	4	1	Horizontal encoding	2
4	C	4	>1	Horizontal encoding	4

Table 2-3 defines the mode of uplink operation which describes all transmission methods in IEEE 802.16e. During up transmission, a MS uses most two antennas.

Table 2-3 Uplink MIMO Operation Mode

Number of transmit antennas	Matrix indicator	Num of layers	Number of users	Encoding type	Rate
1	B	2	2	Collaborative	1 per users
2	B	1	1	Vertical encoding	2
2	A	1	1	STTD	1

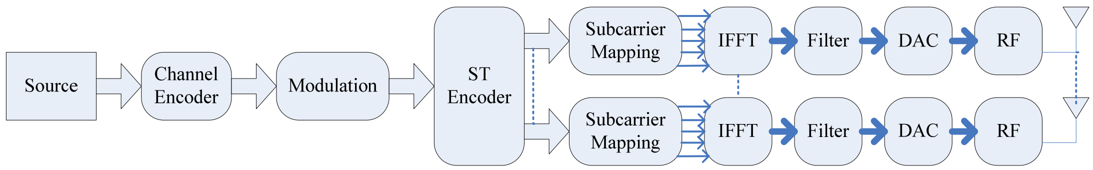

Figure 2-6 Transmitter of Matrix A for 2, 3, or 4 Transmit Antennas and Matrix B for 3 or 4 Transmit Antennas

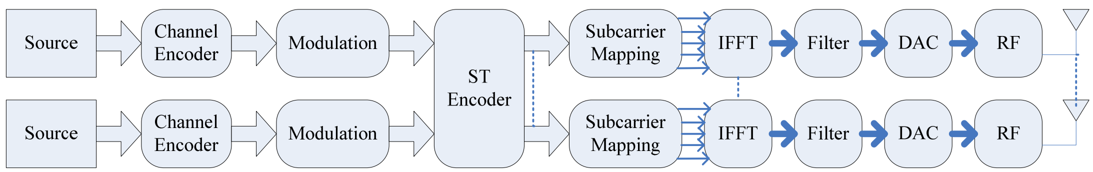

Figure 2-7 Transmitter of Matrix B with Horizontal Encoding for 3 or 4 Transmit Antennas

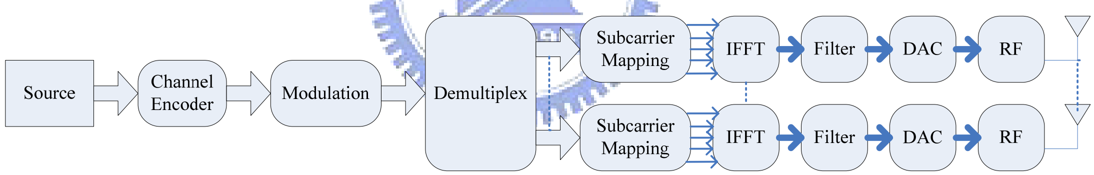

Figure 2-8 Transmitter of Matrix C with Vertical Encoding for 2, 3, or 4 Transmit Antennas

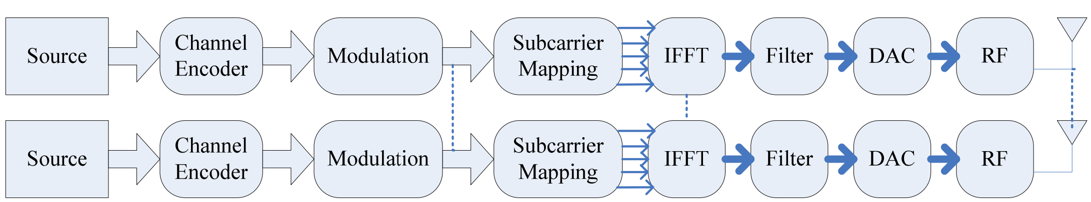

Figure 2-9 Transmitter of Matrix C with Horizontal Encoding for 2, 3 or 4 Transmit Antennas

2.4.2 MIMO Coefficient

The STC scheme for two antennas may be enhanced by using four antennas at the transmission site like combination of STC and AAS as shown in Fig 2-10. Two first antennas, Antenna 0 and Antenna 1, transmit the signal as defined in transmit diversity or in spatial multiplexing and the two second antennas, Antenna 0' and Antenna 1', transmit two first antennas signal with a complex multiplication factor. The BS may change the antennas weights using feedback from the user. The transmitter can get the MIMO coefficient which be represented by Fig 2-11 from feedback.

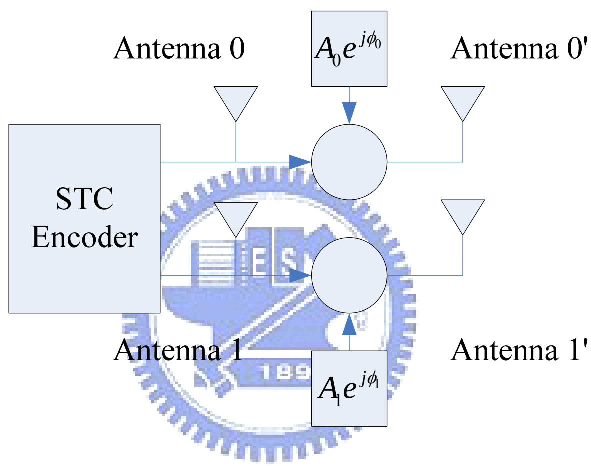

Figure 2-10 The STC Scheme for Two Antennas Enhanced by Using Four Antennas

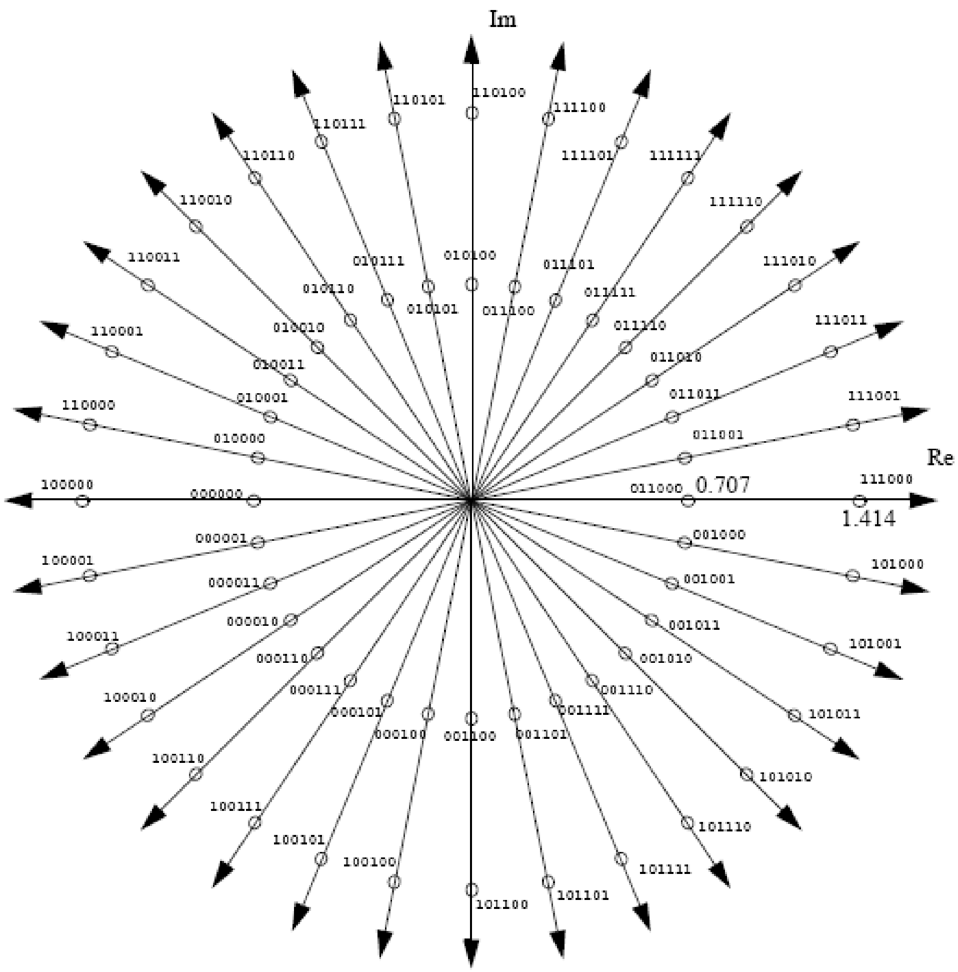

Figure 2-11 Mapping of MIMO Coefficients for Quantized Precoding Weights for Enhanced Fast MIMO Feedback Payload Bits

This method does not change the channel estimation process of the user. Therefore, this scheme could be implemented without any changes made to the STC users.

2.4.3 MIMO Feedback in WiMAX

In WiMAX system, all transmission setup is decided by the BS. A BS needs information and control signals to maintain transmission. A MS can send feedbacks either as a response to feedback requests of a BS or as an unsolicited feedback. Feedbacks and feedback requests can be sent through the MAC layer and the PHY layer. The MIMO system need more information and control signals, because of more complex transceiver of MIMO system.

MIMO Feedback requests are sent by a BS to ask MS reporting the information about MIMO parameters. In the MAC layer, they can be brought in feedback request extended subheader and fast feedback allocation subheader. In the PHY layer, the feedback-polling information element (IE), CQICH allocation IE, and CQICH allocation enhanced IE in the uplink map can trigger off feedback of MSs.

In the MIMO system, there are three important parameters, MIMO mode, MIMO coefficients, and SNR, which need to be fed by users. MSs can report information in the MAC layer, and employ fast feedback channel or fast feedback enhanced channel to feed parameters in the PHY layer. Feedback in MAC layer is allocated by feedback polling IE and feedback request extended subheader and in PHY layer is allociated in fast feedback channel and enhanced fast feedback channel which include fast MIMO feedback (MIMO coefficient), mode selection feedback, and effective CINR feedback indicated in fast feedback allocation subheader, CQICH allocation IE, CQICH allocation enhanced IE.

2.4.4 MIMO Control in WiMAX

In the MIMO transmission, a BS control MIMO setup including number of antennas, midamble presence, matrix indicator, number of layers, and pilot pattern indicator. A BS sets MIMO transmission through STC downlink zone IE, MIMO downlink basic IE, MIMO downlink enhanced IE, MIMO uplink basic IE, and MIMO uplink enhanced IE. The MIMO control information elements is shown in Table 2-4.

Table 2-4 MIMO Control Information Elements

	function
STC downlink zone IE	Number of antennas Midamble presence Matrix indicator
MIMO downlink basic IE	Matrix indicator Number of layers
MIMO downlink enhanced IE	Matrix indicator Number of layers
MIMO uplink basic IE	Matrix indicator Collaborative indicator
MIMO uplink enhanced IE	Matrix indicator pilot pattern indicator

Chapter 3 Simulation Setup

In this chapter, the IEEE 802.16e system level simulation platform with MIMO technologies will be described. The details of system architecture and simulation parameters are going to be presented. Then, the link budget, such as path loss and shadow fading, in the platform is suitable for IEEE 802.16e standard. The setting of basic radio resource managements will be described in this chapter. Finally, the traffic models of simulation are introduced. The setting and the structure of the simulation platform is referred from [25].

3.1 Simulation architecture

In the simulation of a mobile system, the interference from other cells is an important element that would affect the overall performance. Hence, the effect needs to be considered into the simulation. When the number of simulation cells increase, it causes high load of computation and needs long simulation time. Considering the tradeoff between accurate simulation and computing cost, two-tier interference is appropriate. According to approximate the cell coverage with a hexagon, we consider nineteen cells in our simulation as shown in Figure 3-1 in which only the central cell completely has two-tier interference cells and the other cells can not find out the symmetric two-tier interference cells. Even if nineteen cells are simulated, only one statistic simulation value of the central cell can be referred, that is lower simulated efficiency. Therefore, a wrap around technique as shown in Figure 3-2 is adopted to make any of nineteen cells owns complete two-tier interference cells. The main ideal is the lacks of any two-tier interference cells of a specific cell are copies from the simulated cells which are besides the two-tier interference cells of the specific cell. Through the clever arrangement, every cell has complete and symmetric, two-tier interference cells. Because the cell owns whole interference after wrap around, the statistic simulation value of nineteen cells would be meaningful.

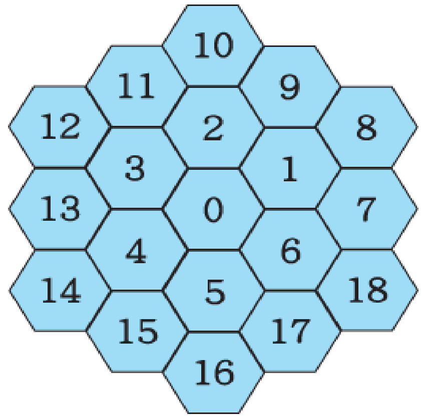

Figure 3-1 Cell Structure of System

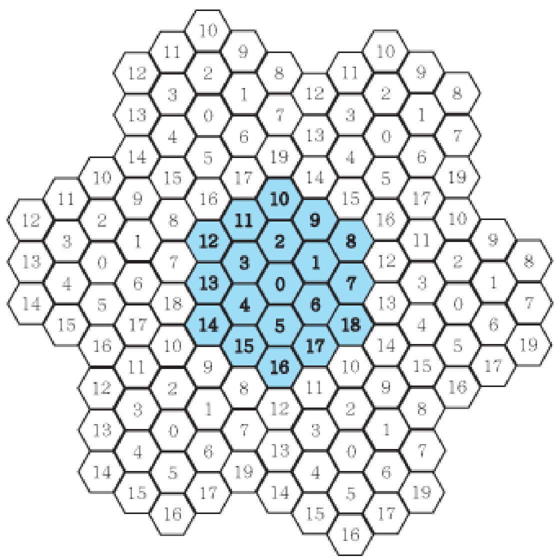

Figure 3-2 Wrap Around

The cell radius is 1 km and the total cell bandwidth is 10 MHz. This approximate cell coverage is a result from a plan of Link Budget. In the simulation platform, a cell is divided into three sectors as shown in Figure 3-3. Each sector has the different antenna direction and a regular pattern of deployment. The sector architecture in 802.16e system can reduce the transmission power of BS antenna and intercell interference. Furthermore, there is a small part of intercell interference in different sectors of distinct BSs due to subcarrier permutation. This characteristic is very difficult to simulate, so instead of it, a sector would only produce interference to other sectors which have the same direction due to sectors of the same direction have the same subchannel. The cell's frequency reuse factor in our simulation platform will be set to 1 as shown in Figure 3-3 and needs 10 MHz bandwidth.

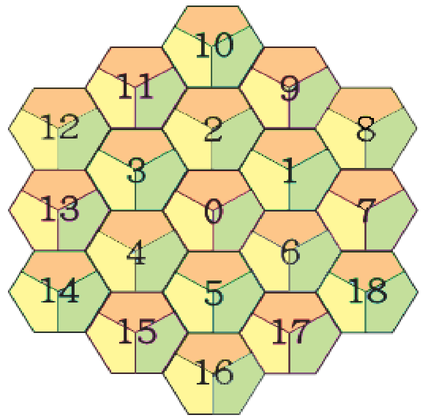

Figure 3-3 Sector Deployment and Frequency Reuse Factor

In our simulation platform, the setting of antenna pattern uses the 3GPP's model [3GPP] as shown in Figure 3-4

$$A(\theta) = -\min\left[12 \times \left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right] \tag{12}$$

Where $-180^\circ \le \theta \le 180^\circ$, $\theta_{3dB} = 70^\circ$, and $A_m = 20dB$

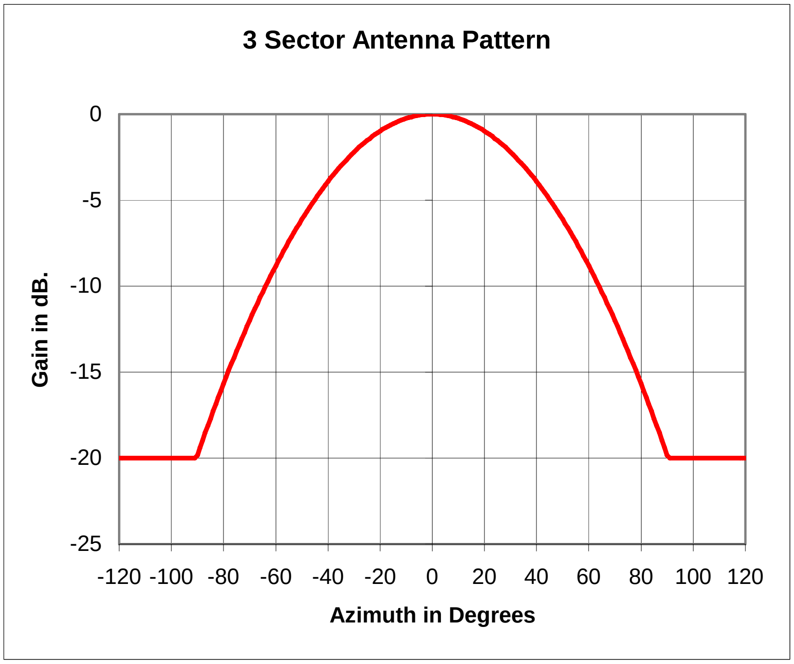

Figure 3-4 Antenna Pattern for 3-sector Cells

3.2 The Architecture of Frame Transmission

In the thesis, the downlink transmission is focused and the OFDMA technique with TDD mode is adopted. The IEEE 802.16 standard can support an asymmetric downlink and uplink transmission of TDD mode, which adjusts the ratio according to the traffic loading of downlink and uplink transmission. In the simulation, the ratio of downlink to uplink transmission is29 to 18 and the frame length is 5 ms. The frame structure is 1024-FFT OFDMA downlink carrier allocations -PUSC mode defined in the standard and the carrier distribution is shown in Table 3-1. In the 1024 subcarriers, only 720 subcarriers carry data information and other subcarriers are used for guard band, pilot and dc subcarrier.

Table 3-1 OFDMA Downlink Parameter

Parameter	Value
System Channel Bandwidth	10 MHz
Sampling Frequency	11.2 MHz
FFT Size	1024
Subcarrier Frequency Spacing	10.94 kHz
Useful Symbol Time	91.4 microseconds
Guard Time	11.4 microseconds
OFDMA Symbol Duration	102.9 microseconds
Frame duration	5 milliseconds
Number of OFDMA Symbols	48
DL PUSC Null Subcarriers	184
DL PUSC Pilot Subcarriers	120
DL PUSC Data Subcarriers	720
DL PUSC Subchannels	30

The length and number of OFDMA symbols are defined according to WiMAX Forum [25] and [26]. For 10MHz bandwidth and 1024 FFT sizes, the symbol period should be 102.9 μs and there will be 47 OFDMA symbols per frame. According to the ratio of downlink to uplink transmission, there are 24 symbols per downlink frame. Due to the definition of PUSC in IEEE802.16e, two symbols with one subchannel form one slot. There are 12 slots in a downlink frame and 10 subchannels per sector (30/3 = 10). Hence, there are 120 slots per downlink frame to transmit data.

3.3 Link Budget

The link budget settings of downlink transmission in our simulation are as far as possible to match the Mobile WiMAX [25] environment. In [25], it makes deployment scenario assumptions for 802.16e, such as Table 3-2. In the simulation, the outdoor vehicular scenario is adopted, which the BS transmitted power is 43 dBm, the BS antenna gain is 15 dBi, the MS antenna gain is -1dBi on the downlink transmission. The common usage value of thermal noise density is -173.93 dB / Hz. The receiver noise figure of MSs is 7 dB [25]

Table 3-2 Link Budget Parameter of Mobile WiMAX

Scenario / Parameter	Indoor	Outdoor to indoor	Outdoor vehicular
BS Tx power	27 dBm (0.5 W)	36 dBm (4 W)	43 dBm
MS Tx power	17 dBm	17 dBm	23 dBm
BS ant gain	6 dBi	17 dBi	15 dBi
MS ant gain	0 dBi	0 dBi	-1 dBi
BS ant height		15 m	30 m

In wireless channel, the transmitted signals will suffer the fading effect, which can change the original signals. The fading can be divided into two types: large scale and small scale. Large scale fading which contains pathloss and shadow fading would affect SINR and small scale fading which is composed of multipath effect, Doppler effect, and spatial correlation, frequency correlation) has not influence of SINR because average of the small scale during a frame time is zero. In the simulation, slow fading without spatial correlation and Doppler effect is adopted. The pathloss model is used to present the signal strength decreases with increasing distance between transmitter and receiver. In 3GPP spatial correlation channel (SCM) [27], it provides several pathloss models, such as Table 3-3. Suburban macro scenario is adopted in the simulation.

Table 3-3 Environment Parameters in SCM

Channel Scenario	Suburban Macro	Urban Macro	Urban Micro
Lognormal shadowing standard deviation, σ_{SF}	8dB	8dB	NLOS: 10dB LOS: 4dB
Pathloss model (dB), *d* is in meters	$31.5 + 35\log_{10}(d)$	$34.5 + 35\log_{10}(d)$	NLOS: $34.53 + 38\log_{10}(d)$ LOS: $30.18 + 26*\log_{10}(d)$

The main reason forms shadow fading is from the shelters, like buildings, or mountain, on the signal transmitted path. According to the test result of the real wireless environment, we can know the variant of shadow fading is a log-normal distribution statistically. Hence, we can use the log-normal distribution to produce the shadow fading effect. The standard deviation of this distribution is based on the simulation environment. In the simulation, the standard deviation is 8 dB due to SCM model [27]. When the user is fixed, the shadow fading effect will not alter. On the other hand, the shadow fading changes in different locations of the mobile user. In the different simulation points, we can use the log-normal distribution to produce a value for the shadow fading. However, the time between two neighbor simulation points is very small so that the mobile user location will not change very obvious even at high mobile speed. It means the variance the shadow fading will not be large and have a correlated relationship between two neighbor time points. Hence, we use the concept of a correlation model, called Gudmundson's correlation model [28]

$$\rho\left(\triangle x\right) = \exp(-\frac{\left|\triangle x\right|}{d_{cor}}\ln 2) \tag{13}$$

where ρ is the auto-correlation constant between two simulation sample points, $\triangle x$ is the distance of two sample points and is a function of sampling times between them, sampling duration, and user speed. The d_{cor} is de-correlation distance and the values in the suburban macro, urban macro, and urban micro environments are 200m, 50m, and 5m, respectively. In the simulation, we use 50m as our parameter. Using log-normal distribution and correlation model, the simulation can get more actual shadow fading.

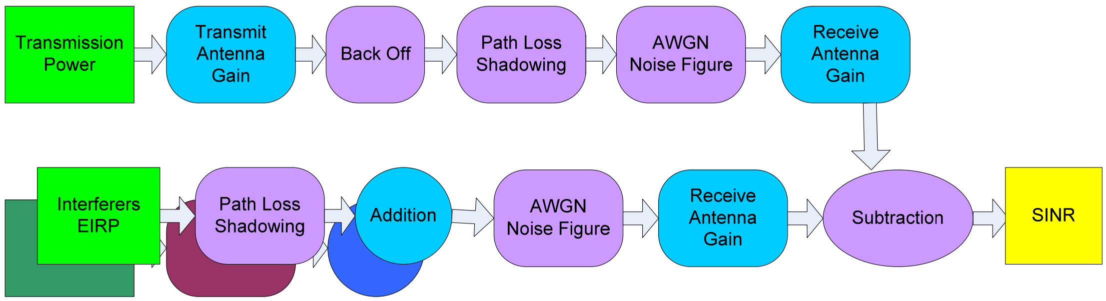

Figure 3-5 SINR Computation Flow

In Figure 3-5, we present the flow of signal-to-interference and noise ratio (SINR) computation. The OFDMA technique uses the multiple carriers to transmit signal and we should compute carrier-to-interference and noise ratio (CINR), not SINR. But the MSs of 802.16 system with PUSC or FUSC mode only compute and report the sum of received CINR per carrier to BS, not individual CINR. Hence, the SINR and CINR are the same under these conditions. Finally, the mobility model we use is like below. The MS speed is 30 km/hr. Probability to change direction is 0.2 when position update and maximum angle for direction update is 45^{o}.

3.4 Performance Curve

After CINR calculation, modulation and coding scheme need to be decided. How to select modulation and coding scheme is based on BER or PER which is calculated in physical layer as shown in Figure 3-6. Performance curve can map received to BER or PER and includes small scale fading. In the simulation, small scale fading contains multipath effect, frequency correlation and performance curve is produced based on IEEE 802.16e standard as shown in Figure 3-7 and Figure3-8 from Prof. Wu.

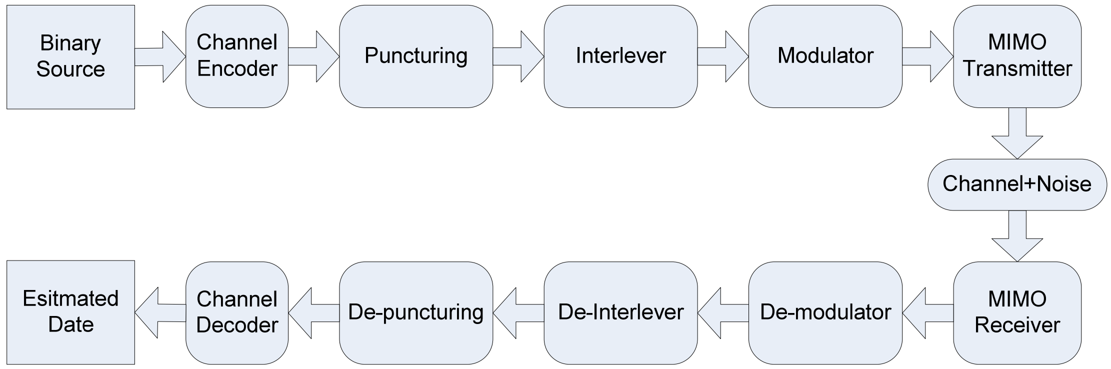

Figure 3-6 Physical Layer Block Diagram

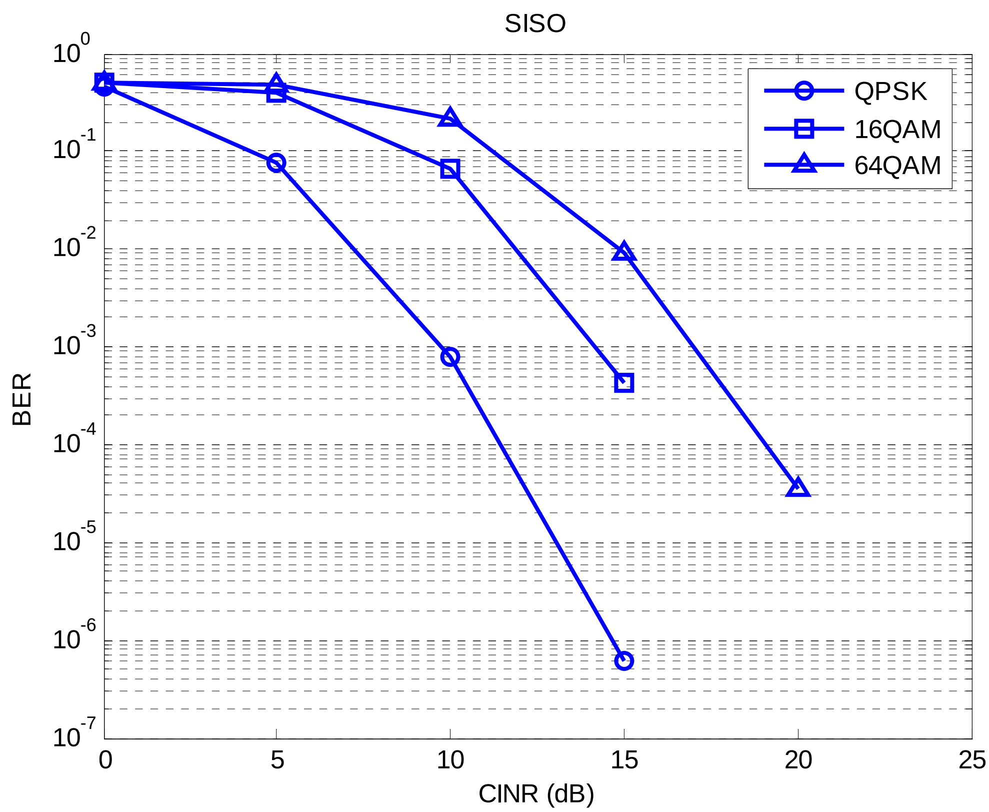

Figure 3-7 SISO Performance Curve

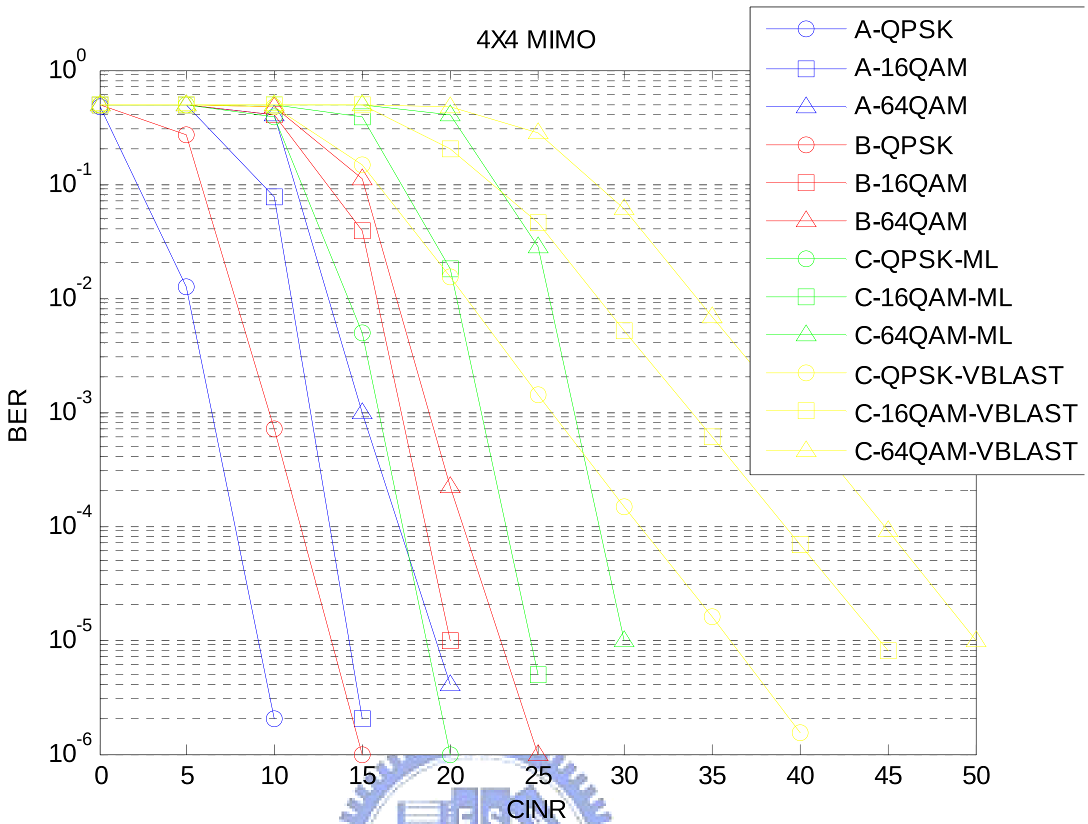

Figure 3-8 4X4 MIMO Performance Curve

3.5 Basic Radio Resource Management

The purpose of radio resource managements is to raise the efficiency and reliability of wireless transmission. In the performance analysis, the basic radio resource management is constructed and described as following.

3.5.1 Rate Control

The adaptive modulation and coding scheme is a major method to keep the quality of wireless transmission. Due to trade off between efficiency and robustness, IEEE802.16e system can dynamically adjust modulation coding scheme depends on the carrier to interference plus noise ratio (CINR) condition of the radio link. It supports multiple modulation methods: Quadrature Phase Shift Keying (QPSK), 16-state Quadrature Amplitude modulation (16-QAM), and 16-state Quadrature Amplitude modulation (64-QAM) and several coding schemes, like Convolution

Code (CC), Low Density Parity Check Code (LDPC), Block Turbo Code (BTC), and Convolution Turbo Code (CTC). In the simulation, the coding scheme is used to correct errors in the receiver and only convolution code (CC) with 1/2 code rate is applied. From 4.2, one slot carries 48, 96, and 144 bits by using QPSK, 16-QAM, and 64-QAM, respectively.

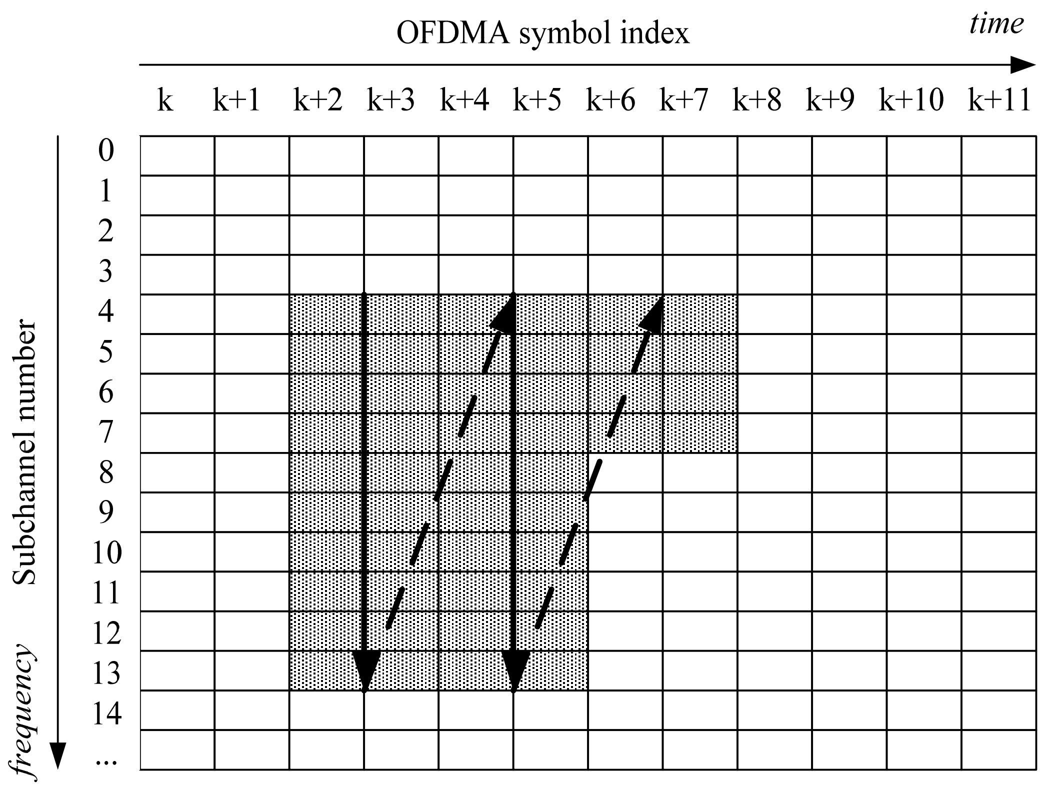

Figure 3-9 Example of Mapping OFDMA Slots toSsubchannels and Symbols in The Downlink PUSC Mode

Data Region is a two-dimensional allocation which contents a group of contiguous subchannels and OFDMA symbols. All the allocation refers to logical subchannels. The minimum unit of data mapping is an OFDMA slot. Based on standard, how many and which slots should be assigned to a transmission is decided by BS and there are different mechanisms in downlink and uplink transmission. In downlink resource allocation, the system according to the data size tries to fulfill the slots first in frequency domain. After the frequency domain is fulfilled, then it changes to the next time domain to continuously fulfill slots. In other words, the data mapping method is frequency first as shown in Figure 3-9.

Figure 4-7 Example o mapping OFDMA slots to subchannels and symbols in the downlink PUSC mode

3.5.2 Subcarrier Permutation

Subcarrier permutation is a method to assign frequency subcarriers into subchannels. The allocation of subcarriers to subchannels is accomplished via permutation rule.

Partial Usage of Subchannels (PUSC) which is the distributed subcarrier permutation is applied in the simulation. Distributed permutation means the subcarriers belonged to a subchannel are selected pseudo randomly from all subcarriers. It can average intercell interference and avoid fading effect. PUSC can be used both in downlink and uplink. It will group subcarriers first then choose subcarriers per group and each group only provides one subcarriers to form a subchannel. It also use distributed permutation mode. Hence, the interference of one slot produced by the other cells will be dispersed to all subframe.

3.5.3 Scheduling Methods

Based on the information mentioned before, BS will do the scheduling decision and form DL-MAP and UL-MAP to indicate the scheduling result. System could consider the QoS requirement of different service and their channel condition to do the scheduling decision and a good scheduling algorithm shall utilize the resource well and meet the different users' requirement. In the IEEE802.16e standard, it doesn't define the scheduling information and this part is left for design. And a proposed scheduling algorithm will be discussed in detail in this thesis.

Some scheduling algorithms proposed by [29], [30], [31], [32], and [33] are applied in the simulation. Different scheduling algorithms have different targets to achieve. Some of them want to achieve fairness and some of them hope to maximize throughput or maintain the QoS. These algorithms have their own advantages. However, they have disadvantages in some aspects too.

3.5.3.1 Round-Robin (RR)

In the round-robin scheduling algorithm, a system schedules packets by users in a fixed sequence irrespective of the channel condition and services requirement. This algorithm provides fairness but ignore the channel condition and QoS requirement. It is hard to be used in mix-traffic system due to different QoS requirement.

3.5.3.2 MaxCINR

MaxCINR scheduling algorithm schedules packets which belonged to the user with better CINR, much better channel condition. The kind of scheduling algorithm takes channel condition into consideration and may provide good multiuser diversity to enhance system throughput and decrease transmission time due to efficient transmission. However, it is less fairness. If the power control doesn't implement well, some users might never get opportunity to transmit data. Besides, it can't provide QoS guarantee especially to real-time service, which QoS definition is usually delay bound consideration. System will select user *m** that fulfill:

$$\mathrm{m}^*(t) = \arg\max_m \mathrm{CINR}_m(t) \tag{14}$$

3.5.3.3 Proportional Fair (PF)

This algorithm considers channel condition and fairness across users. It provides a tradeoff between system throughput and user fairness. The scheduling decision will follow a ratio which is instantaneous data-rate over average data-rate and pick larger user *m**:

$$\mathrm{m}^*(t) = \arg\max_m \frac{\mathrm{R}_m(t)}{\mathrm{S}_m(t)} \tag{15}$$

$$\mathrm{S}_m(t) = \left(1 - \frac{1}{W}\right)\mathrm{S}_m(t-1) + \frac{1}{W}\mathrm{R}_m(t)\delta(t-m) \tag{16}$$

where $\mathrm{R}_m(t)$ denotes the achievable instantaneous data rate for user *m*, $\mathrm{S}_m(t)$ denotes the moving average of data-rate at user *m*, and *W* donates the length of moving average. This algorithm provides both fairness and channel condition concerns, but it lacks QoS guarantee, especially for real-time service.

3.5.3.4 Early Deadline First (EDF)

This algorithm considers completely the delay constraint. It ignores the channel quality so it might not use bandwidth efficiently. However, it can provide strict QoS guarantee for delay-sensitive service because it will transmit packet first which is much closer to their delay bound. System will transmit packet belonged to user m^* if

$$m^* = \arg\min_m \left(DB - Age - T_m \right) \tag{17}$$

where *DB* means delay bound, *Age* is the time that the packet stayed in MAC, and T_m is the transmission time for users in the current frame.

In non-real-time service, there is no delay bound requirement but they have the minimum reserved rate requirement. Although non-real-time service can tolerate delay, it still must be transmitted in an acceptable rate. A new QoS criterion is called "soft delay bound" defined by [34]. Soft delay bound is not only still related to the definition of minimum reserved rate, but it translates the minimum reserved rate concept into time concept. With the common definition for both real-time and non-real-time services, it will be much easier to do the scheduler design.

The minimum reserved rate means how many data should be transmitted in a certain period to meet the QoS requirement. In another aspect of the definition, how many time before should system transmit the known size packet will meet the QoS requirement. And that time will be the soft delay bound for non-real-time service

$$soft\_delay\_bound = \frac{packet\_size}{\min imum\_reserved\_traffic\_rate} \tag{18}$$

The soft delay bound will be an indication of the minimum performance that the non-real-time service should achieve. If the packet be transmitted successfully before the soft delay bound, it means the packet meets the QoS requirement. However, it doesn't mean that the non-real-time service can only achieve the defined performance. If there are still resource could be used, the non-real-time service can have better performance. Maybe the packet can be transmitted much earlier before the soft delay bound.

It is called "soft delay bound" because the different characteristic between real-time and non-real-time service. If the real-time service exceeds the delay bound, the packet will be dropped because it is useless even. However, non-real-time service must focus on the correctness. It can tolerate delay but doesn't like data loss. Therefore system will still transmit the non-real-time service packet even if it exceeds the soft delay bound.

Besides the drop and transmit issue, the soft delay bound of non-real-time service will be accumulated across the packets belonged to the same user. It can be expressed in the following formula, P denotes the packet size:

$$minimum\_reserved\_rate \geq \frac{(P_1 + P_2 + \cdots + P_n)}{t} \tag{19}$$

$$soft\_delay\_bound \leq \frac{(P_1 + P_2 + \cdots + P_n)}{minimum\_reserved\_rate} \tag{20}$$

It means, a single user might have several packets to be transmitted. The soft delay bound will accumulate across packets. If the first packet is transmitted much earlier before its' soft delay bound. The second packet of the user will have much longer soft delay bound because it take benefit from the first packet's fast transmission. However, if the first packet is transmitted really late even after the required soft delay bound, it means the packet doesn't meet the QoS requirement. Besides this, it will influence the next packet because the next packet will have shorter delay bound than normal because the former packet takes much longer time.

3.5.4 Segmentation and Packing

The MAC PDU is a data exchanged unit between the MAC layer of the BS and MSs. A MAC PDU consists of a 48bit MAC header, a variable length data payload, and an optional 32 bits Cyclic Redundancy Check (CRC). Sometimes some MAC PDU will not include payload and CRC bits. These kinds of PDUs are used only in the uplink to transmit control message. Those MAC signaling headers include bandwidth request, uplink transmit power report, CINR report, CQICH allocation request, PHY channel report, uplink sleep control, SN report, and feedback functionalities. MAC PDUs also include some subheaders. Those subheaders will be inserted in

MAC PDUs following the generic MAC header. Those subheaders help system perform grant management, packing, ARQ feedback, etc…

In IEEE 802.16e system, MAC SDUs coming from CS will be formatted according to the MAC PDU format in the CPS, possibly with fragmentation and packing. That's due to the precious radio resources and system hopes to utilize the resources efficiently.

Fragmentation process means to divide a SDU into different PDUs payload areas. That is because the MAC PDU size is limited by standard, 2048 bytes. Besides, larger PDU size may causes error occurs more easily. Therefore, divide SDU properly according to the channel condition will avoid transmission errors and save the resource used for retransmission. Figure 3-10 shows the process of fragmentation.

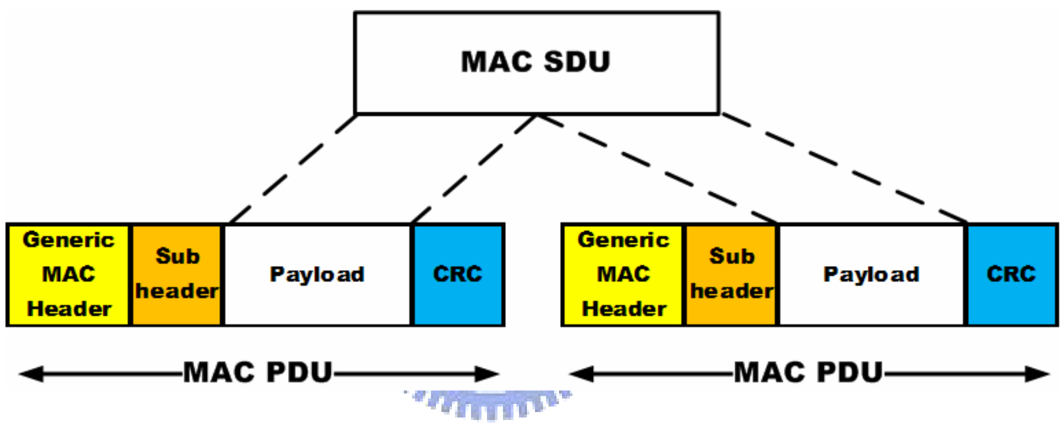

Figure 3-10 Segmentation

Packing process is to pack several SDUs into a single PDU payload. In this way, system may avoid resource waste due to the overhead caused by MAC header and CRC. Figure 3-11 shows the process of packing.

Both processes may be initiated by either a BS for a downlink connection or a MS for and uplink connection.

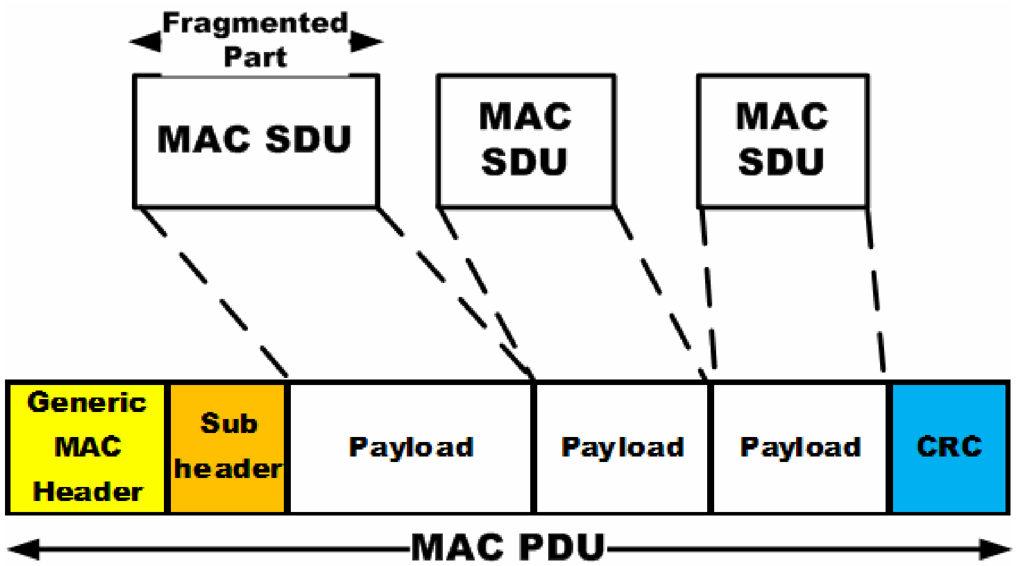

Figure 3-11 Packing

In the simulation, a MAC SDU is generated according to traffic model. Then, system will segment a SDU into PDUs or pack SDUs into a PDU to satisfy a fixed PDU size, 180 Bytes, which is decided by slot size and performance curve. Then, PER can be calculated by

$$PER = 1 - (1 - BER)^{bits} \tag{21}$$

BER is available by channel condition feedback and performance curve mapping. The rate control is used to satisfy the target PER which is could different in each application

In the simulation, packing is not applied because there are not so small packets which need to be packed. The segmentation method wants to use last slots to transmit a packet. First, it calculates how many slots should be occupied when a packet is not segmented and size of padding in a burst. Then, it exploits the padding of a burst to decided number of PDU and PDU size. For example in Figure 3-12, a packet can be segmented into two PDUs occupies the same slots as a packet without segmentation but have smaller size of each PDU. However, it needs three slots to transmit when a packet is segmented into three PDUs so that throughput or throughput could decrease.

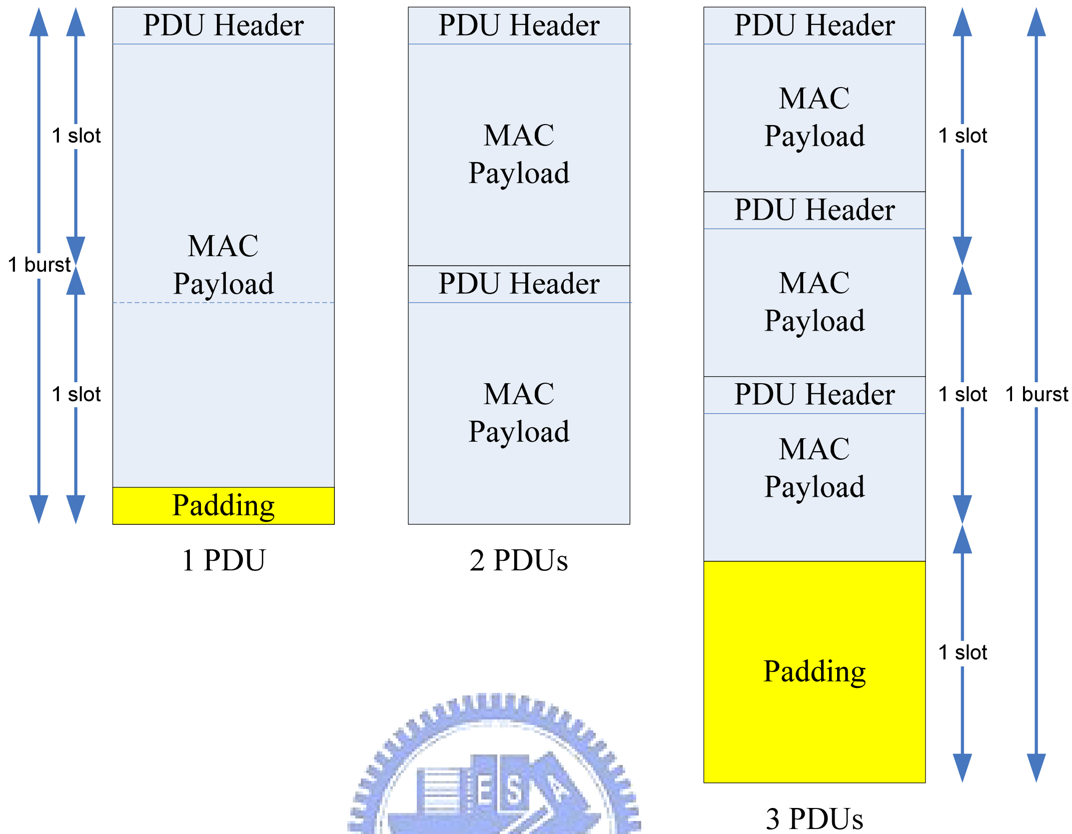

Figure 3-12 Segmentation Comparison

3.5.5 Others

3.5.5.1 Power Control

The BS launches signals with maximum and fixed power. The power of each subcarrier is equal.

3.5.5.2 Handoff method

In the thesis, hard handoff which is "Break-Before-Make" is applied, since handoff is not a weight-bearing point in the simulation.

3.5.5.3 ARQ retransmission

In the simulation, we only implement the ARQ retransmission and don't use the HARQ. When the PDU comes about error, the ARQ retransmission will work. However, if system finds out that the retransmission exceeds packet's delay bound of the service, it will drop the packet because it is meaningless to retransmit the PDU. The number of retransmission times is decided based on the type of applications. For streaming service and non-real-time service, the retransmission times are three and for voice service, the retransmission time is one. That's because the delay is core factor in QoS for voice service and the error rate is the core factor in QoS for streaming and non-real-time servicel.

3.6 Traffic Model

In IEEE 802.16e standard, the downlink data traffics are divided into four QoS classes, such as real-time CBR, real-time VBR, delay-tolerant VBR, and BE. The details are described in [25]. In the simulation, we build FTP service to stand for delay-tolerant VBR service, voice and streaming service for real-time VBR. The FTP traffic model adopts 3GPP2 model [35] as shown in Table 3-4. Both of the non-real-time services' minimum reserved rate will be set to 60kbps according to [36]. The VoIP traffic model uses G729 codec [37] as shown in Table 3-5. The FTP services use TCP/IP protocol to transmit, so the FTP packet needs to add 20 bytes TCP header and 20 bytes IP header. The VoIP services user RTP/UDP/IP protocol to transmit. The VoIP packet must add 12 bytes RTP header, 8 bytes UDP header, and 20 bytes IP header.

Table 3-4 FTP Traffic Model

File Size	Truncated Lognormal	Mean = 2 Mbytes Std. Dev. = 0.722 Mbytes Maximum = 5 Mbytes
Reading Time	exponential	Mean = 180 sec

Table 3-5 VOIP Traffic Model

codec	Framesize(byte)	Interval(ms)	Rate(bps)	Delay bound(ms)
G729-1	20.0	20.0	8k	20.0

Mobile WiMAX supports VOIP and FTP service with varied QoS requirements as described in Table 3-6.

Table 3-6 Applications and Quality of Service

Table 3-6 QoS Class	Applications	QoS Specifications
UnSolicited Grant Service (UGS)	VoIP	Maximum sustained rate Maximum latency tolerance Jitter tolerance
Non-Real-Time Polling Service	FTP	Minimum Reserved Rate Maximum Sustained Rate Traffic Priority

3.7 Simulation Parameters

Finally, we use Table X to summarize this chapter and present the arrangement of the parameter setting in our simulation platform

Table 3-7 The Parameter Setting in Simulation Platform

Parameters	Value
Number of 3-Sector Cells	19
Operating Frequency	2.5 GHz
Duplex	TDD

Subcarrier Permutation	PUSC
Channel Bandwidth	10 MHz
BS-to-BS Distance	2 kilometers
Minimum Mobile-to-BS Distance	36 meters
Antenna Pattern	70° (-3 dB) with 20 dB front-to-back ratio
BS Height	32 meters
MS Height	1.5 meters
BS Antenna Gain	15 dBi
MS Antenna Gain	-1 dBi
BS Maximum PowerAmplifier Power	43 dBm
MS Maximum Power Amplifier Power	23 dBm
Number of BS Tx/Rx Antenna	Tx: 4; Rx: 4
Number of MS Tx/Rx Antenna	Tx: 4; Rx: 4
BS Noise Figure	7 dB
MS Noise Figure	4 dB
Modulation Scheme	QPSK, 16QAM, 64QAM
Channel Coding	Convolutional Code
Interference Model	average interference model for PUSC
Link adaptation	CQI Feedback Error free
Path Loss Model	Loss (dB) =35.0log(R)+31.5 (R in m)

Lognormal Shadowing Standard Deviation	8 dB
Correlation distance for shadowing	50m
MS Mobility	30 km/hr
Spatial Channel Model	Slow fading with Uncorrelated
Cell Configuration	3 Sectors/Cell
Frequency Reuse	1X3X3
Traffic Type	Full Buffer
Scheduler	RR, MaxCINR, PR, EDF
Antenna Configuration	1X1, 4X4
DL MIMO Support	TD, SM
MIMO Switch	Adaptive MIMO switch
Coding	CC
Frame Overhead	9 OFDMA symbols (5DL, 3UL, 1TTG)
Data Symbols per Frame	39
DL/UL Partition	24:15

Chapter 4 Simulation Result

In this chapter, we show the system level simulation results of MIMO systems in different downlink scheduling algorithms. The scheduling algorithms include Early Dead First, Proportional Fair, Maximum CINR, and Round Robin. We investigate the throughput performance and some QoS-associated factors such as minimum reserved rate for non-real-time services and packet loss rate for real-time services.

4.1 Spatial Multiplexing in Different Scheduling Methods

In the simulation, there are two types of receivers, ML and VBLAST, which car support Spatial Multiplexing. In this section, the spatial multiplexing utilization in different scheduling will be discussed. The utilization is defined as

4.1.1 VOIP Traffic Service

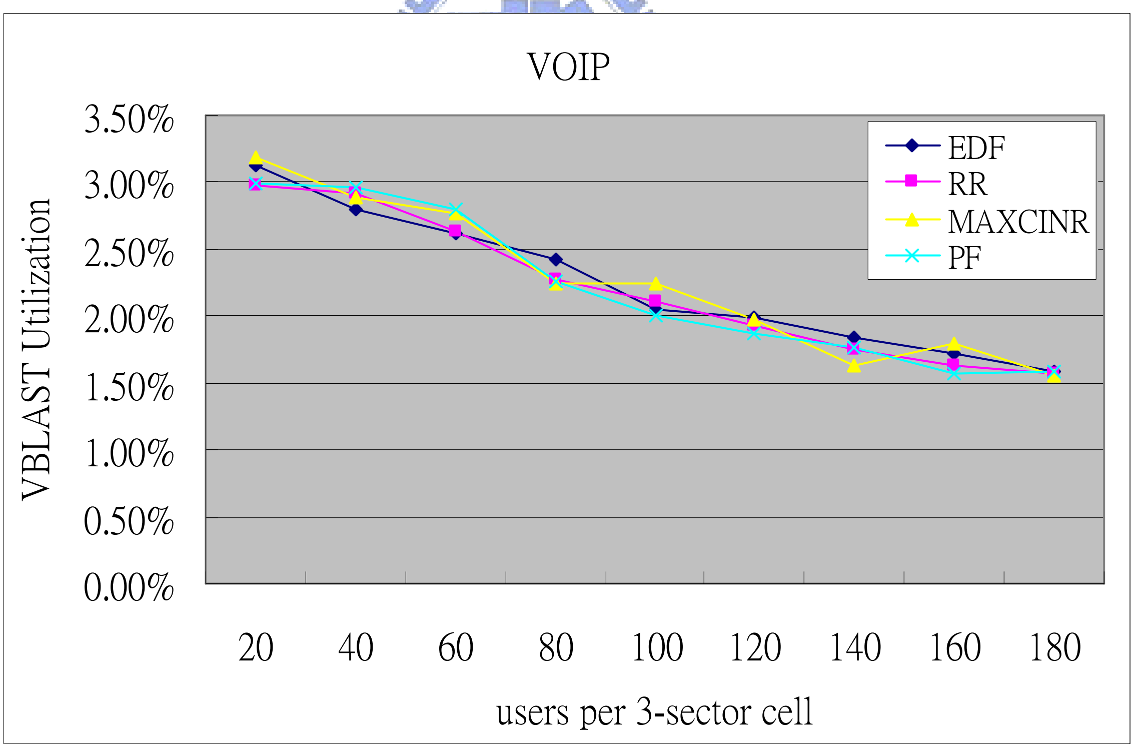

Figure 4-1 VBLAST Utilization for Real Time Service

In VOIP traffic service, Figure 4-1 shows spatial multiplexing utilization with VBLAST in different scheduling is almost the same. The spatial multiplexing utilization is defined as following

$$U_{SM} = \frac{SM\_transmission\_times}{total\_transmission\_times} \tag{22}$$

There is the same result when a ML receiver is employed as shown in Figure 4-2, because a frame can not be filled to the full when average packet-loss rate achieves upper bound. When approximately 180 users per cell make average packet-loss rate arrive upper bound, channel utilization of each scheduling method is around 77% as shown in Figure 4-3. The channel utilization is defined as following

$$U_{ch} = \frac{occupied\_slots}{total\_slots} \tag{23}$$

The packet size of VOIP traffic service is small, so the channel utilization is dominated by number of users in a BS. In the simulation users are randomly deployed, hence each BS doesn't have the same users. When the channel is full in some BSs, the packet-loss rate is the proportion of full channel BSs.

In the simulation, Spatial multiplexing Utilization with ML receivers is much higher than spatial multiplexing utilization with VBLAST receivers. It means that the ML receiver is more complex, but more efficient.

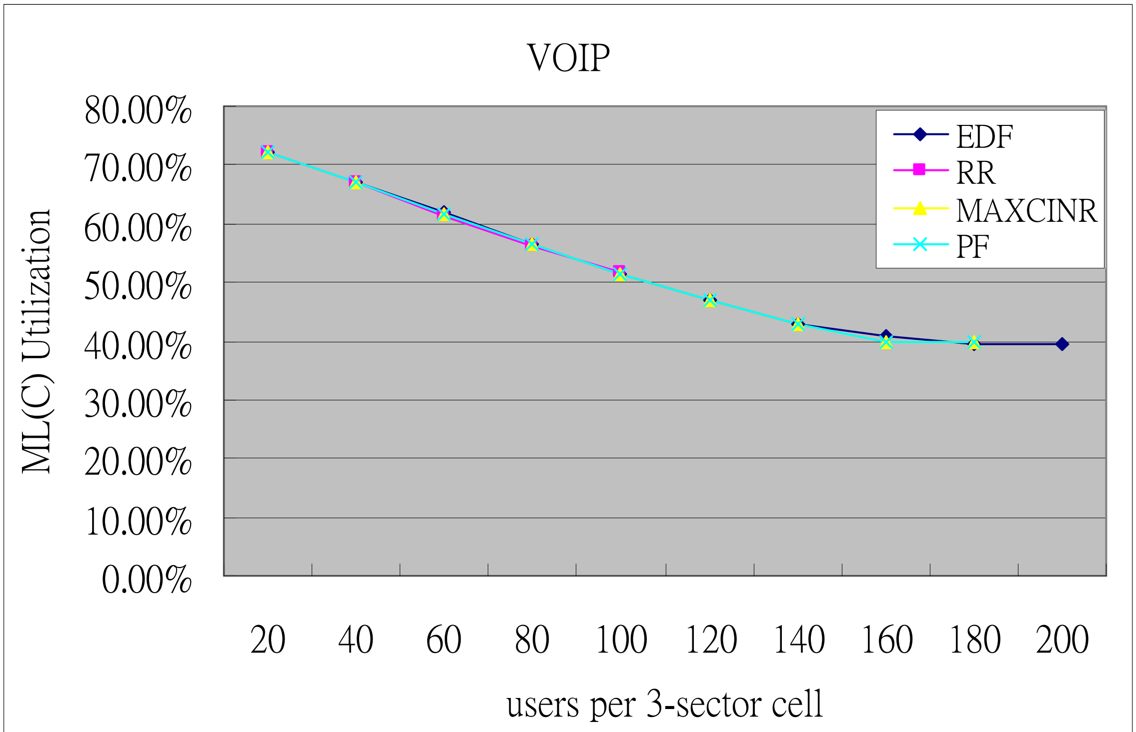

Figure 4-2 Utilization of Spatial Multiplexing with ML Receiver for Real Time Service

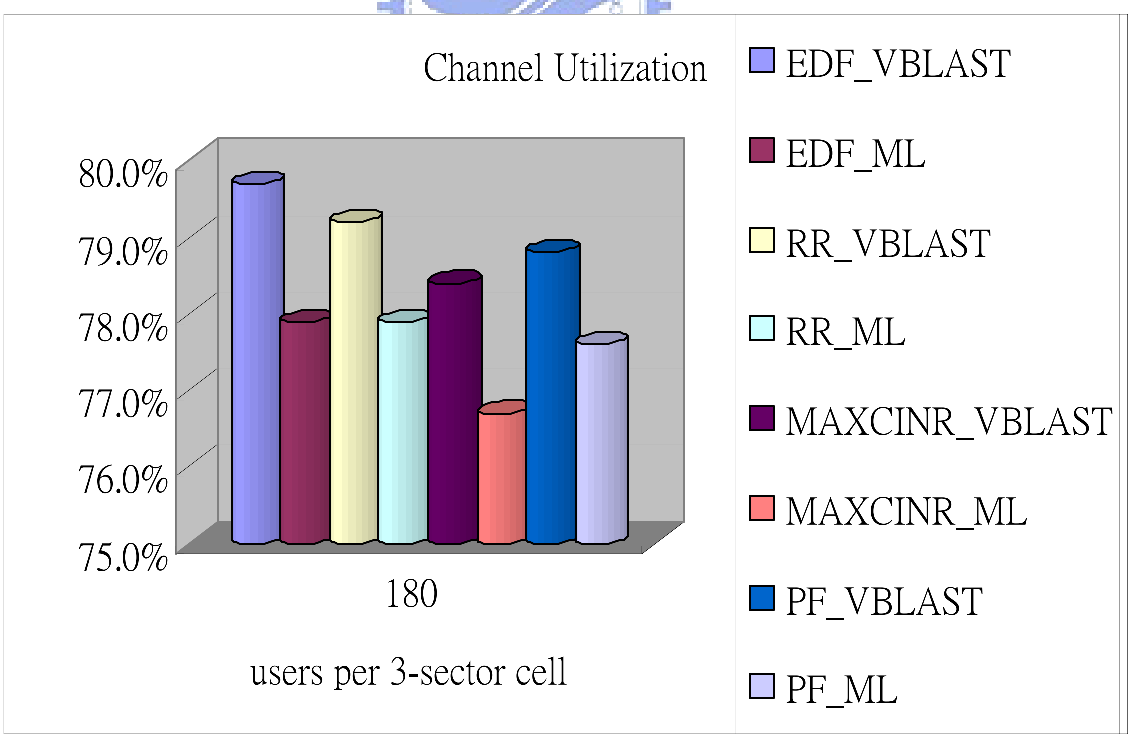

Figure 4-3 Channel Utilization for Real Time Service

4.1.2 FTP Traffic Service

The packet size is large in the FTP traffic service, hence about 20 user per cell can almost fill every frame with data as shown in Figure 4-4. The spatial multiplexing utilization obviously relates to the characteristic of each scheduling method as shown in Figure 4-5 and Figure4-6. Spatial multiplexing utilization of EDF method decrease when users per BS increases, since users with bad RF condition have higher transmission priority. The MAXCINR method has the highest spatial multiplexing utilization because spatial multiplexing is employed by high CINR users. The PF method considers both CINR and average data rate, hence the spatial multiplexing utilization lightly decreases when number of users increases. Every user has the same transmission priority when the BS adopts RR scheduling method. Therefore, all users transmit data in sequence and spatial multiplexing utilization is almost at any user per cell. Spatial multiplexing utilization of FTP traffic service is higher spatial multiplexing utilization of VOIP traffic service in every scheduling method. A VOIP packet arrives during fixed time, hence the user with high CINR spends more time than the user the low CINR to wait the next packet after the packet has transmitted. The user with high CINR may not successively transmit data in every frame. However, the user with FTP traffic service can continuously transmit data in every frame because the next packet arrives after the packet has transmitted.

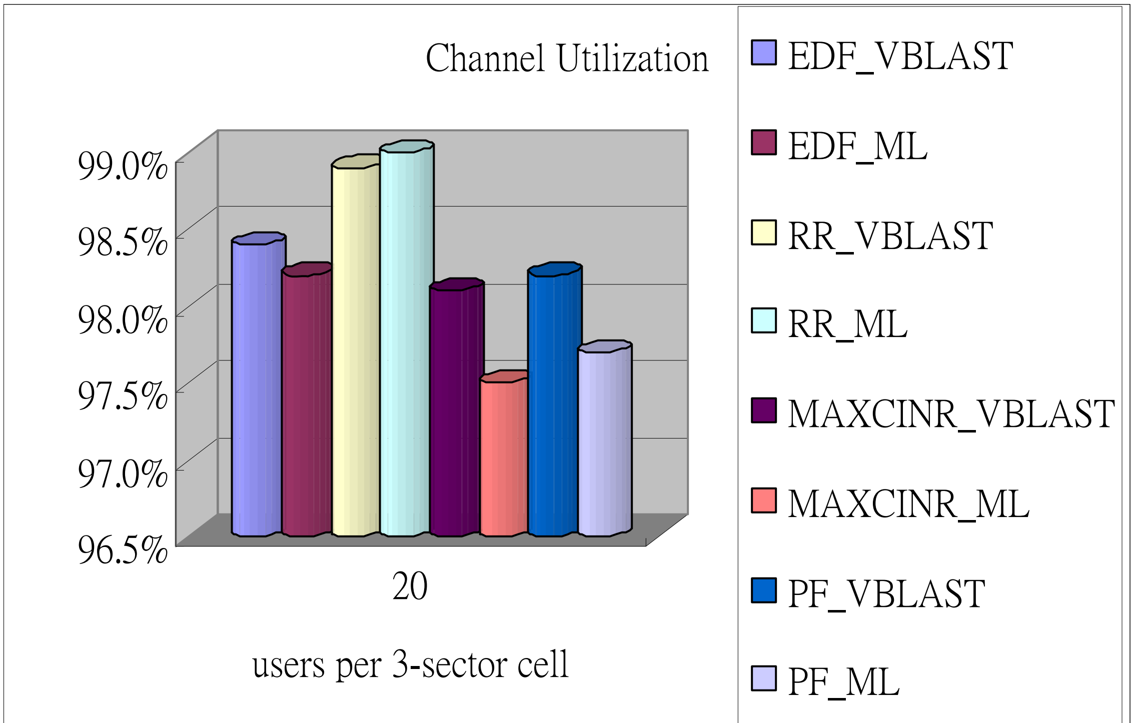

Figure 4-4 Channel Utilization for Non-real Time Service

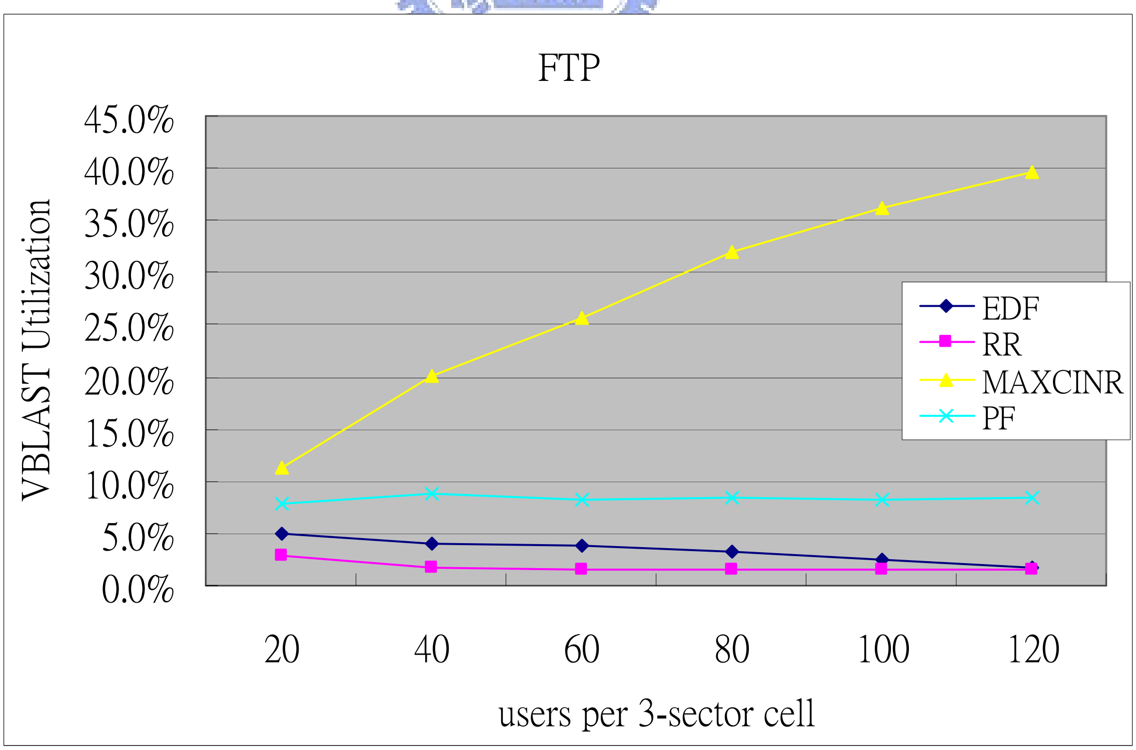

Figure 4-5 VBLAST Utilization for FTP Traffic Service

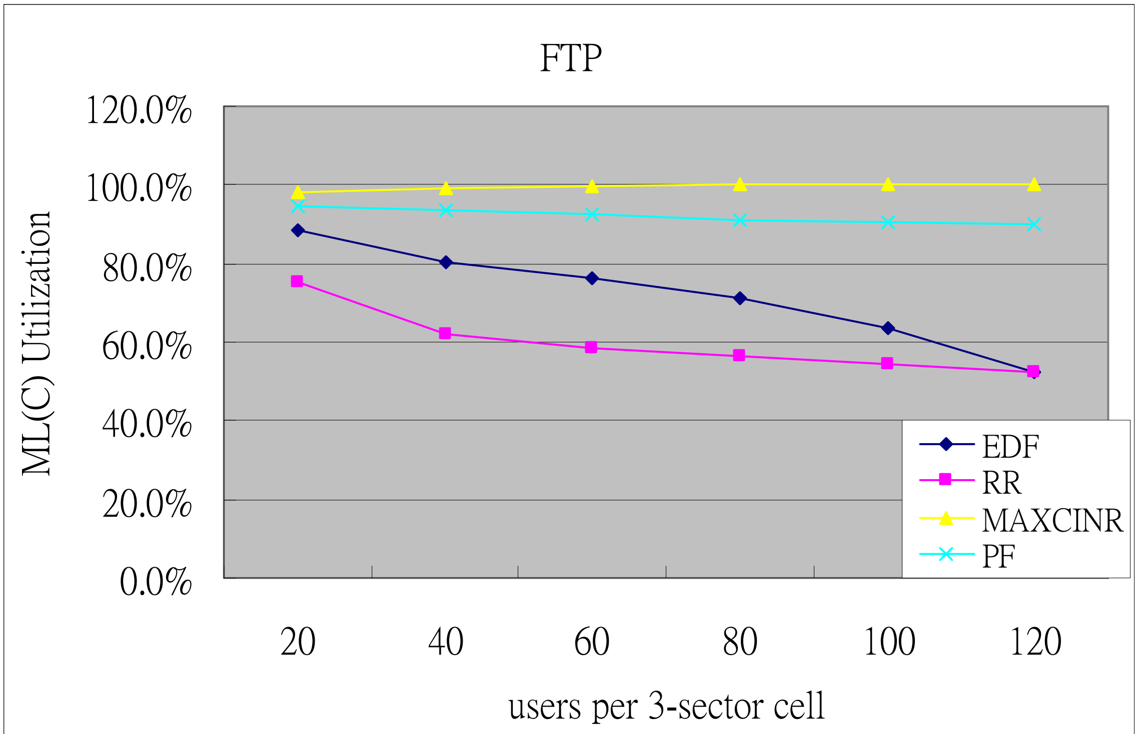

Figure 4-6 Utilization of Spatial Multiplexing with ML Receiver for FTP Traffic Service

4.2 QoS of Different Receivers

In the thesis, the downlink performance of Mobile WiMAX with MIMO technique which includes three different receivers is investigated in terms of VoIP and FTP and we also compare their QoS in different scheduling methods. The indication of QoS is defined as minimum reserved rate for non-real-time service (FTP) and packet loss rate for real-time service (VoIP). Minimum reserved rate is the percentage of users who don't meet the QoS requirements. Packet loss rate indicates the percentage of packets exceeding its delay bound.

4.2.1 VOIP Traffic Service

Figure4 -7, Figure4-8, Figure 4-9, and Figure 4-10 show the results in EDF, RR, MAXCINR, and PF scheduling methods, respectively. The results in EDF and RR scheduling methods are that throughput can be improved about 42% by using MIMO technique. The throughput can increase

46% by employing MIMO technique in MAXCINR and PF scheduling methods. The performance of MAXCINR and PF scheduling methods can be improved lightly more than in EDF and RR scheduling methods, because the transmission rate is considered in MAXCINR and PF scheduling methods.

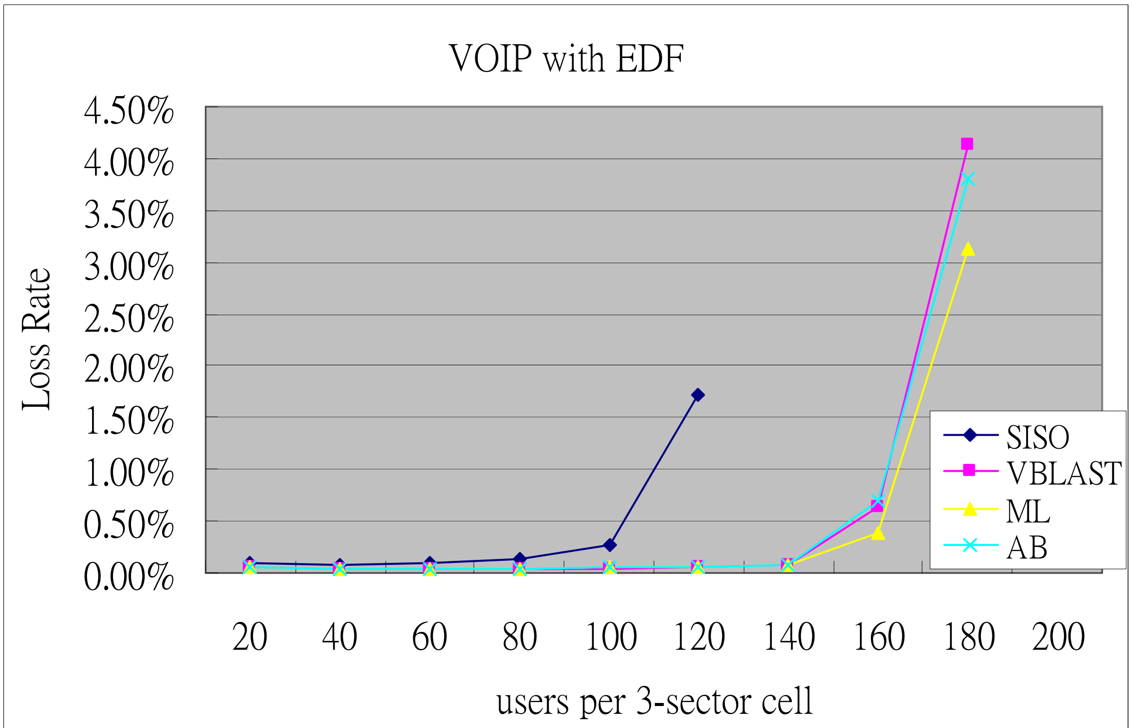

Figure 4-7 Packet Loss Rate with EDF for Real Time Service

In each scheduling method, different receivers in MIMO transmission almost have the same capacity. The MIMO transmission which only employs transmit diversity has lightly better throughput than which employs transmit diversity and spatial multiplexing with VBLAST in high packet loss rate, since users using VBLAST have higher PER than using transmit diversity in high CINR condition. Using spatial multiplexing can not significantly increase throughput even if the ML receiver is employed. It is because the channel utilization is not full when packet loss rate achieves upper bound as specified in 4.1.1 and low CINR users dominate the throughput. A packet of QPSK and matrix A needs to occupy 13 slots but a packet of 64QAM and matrix B occupies 3 slots. Spatial multiplexing can only increase transmission in high CINR condition but can not improve in low CIRN condition.

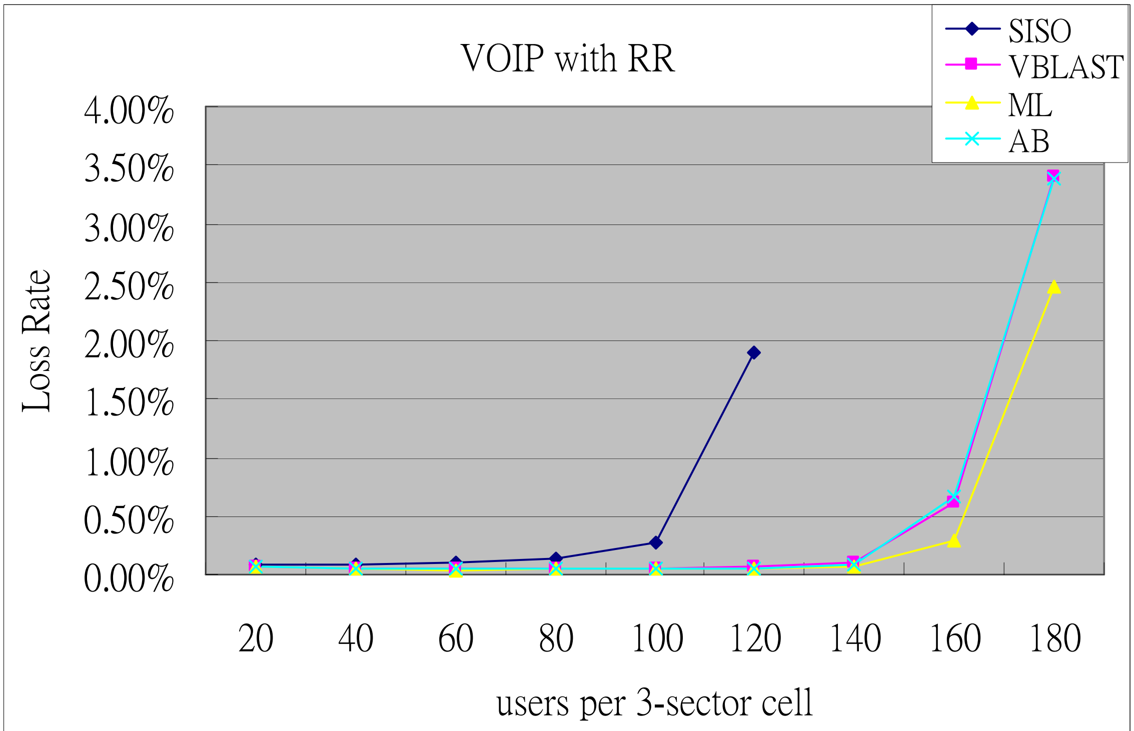

Figure 4-8 Packet Loss Rate with RR for Real Time Service

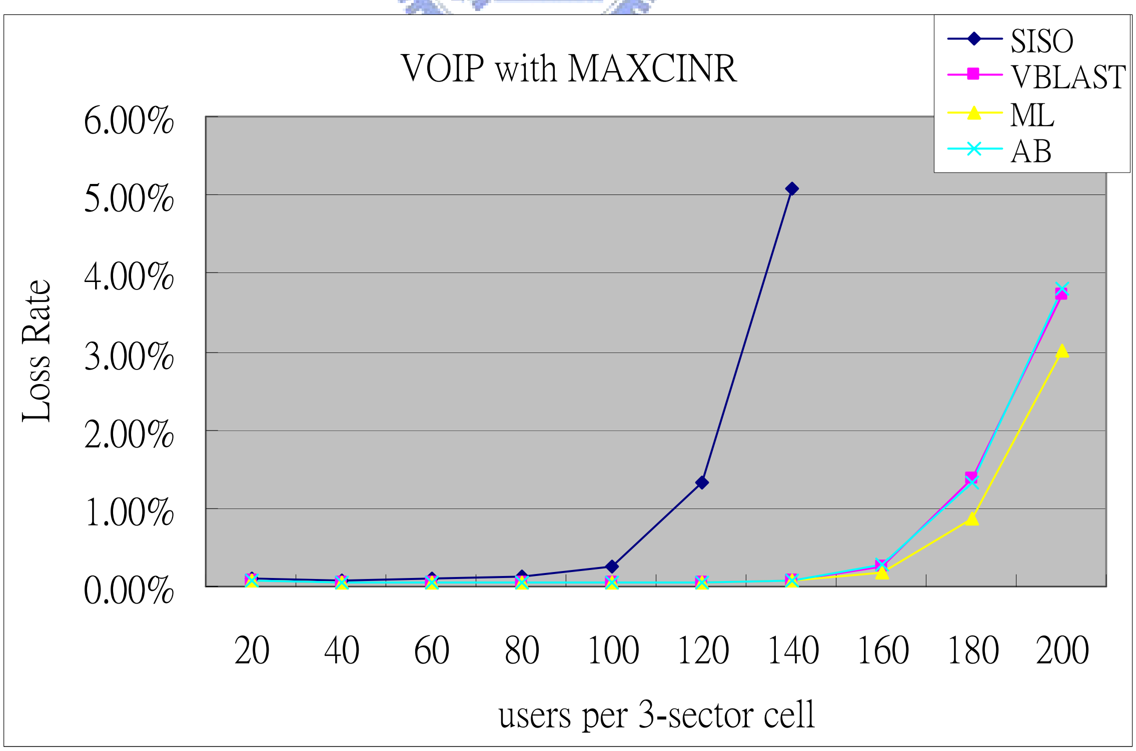

Figure 4-9 Packet Loss Rate with MAXCINR for Real Time Service

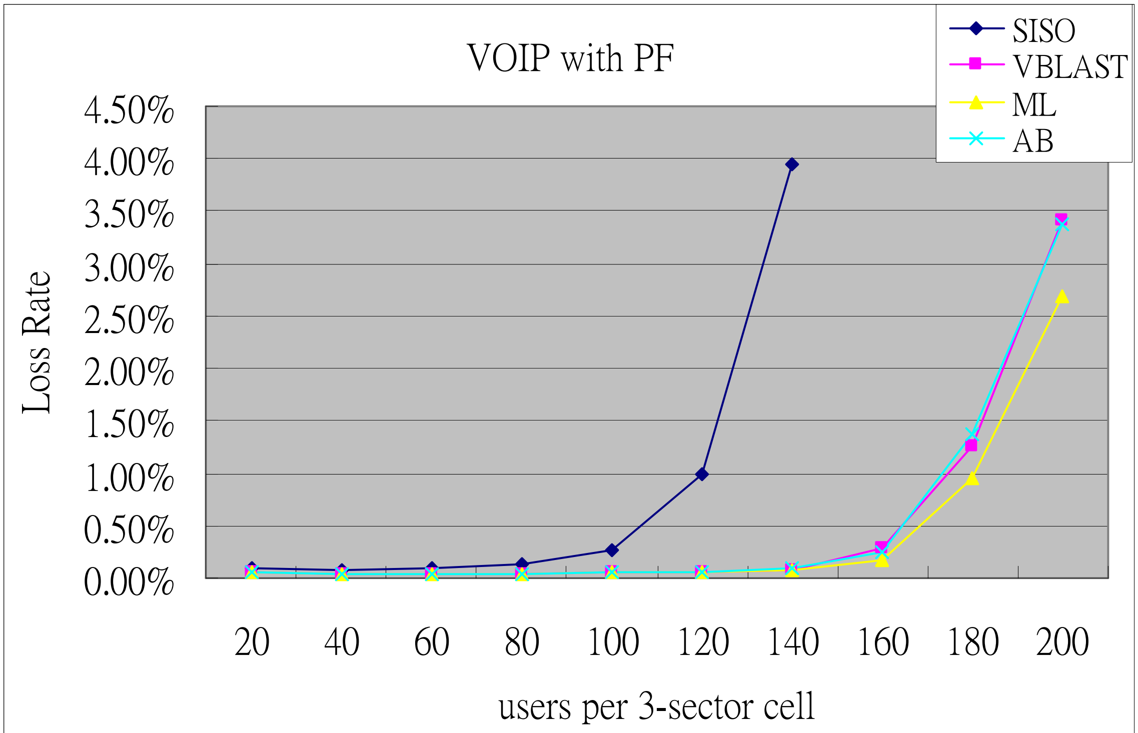

Figure 4-10 Packet Loss Rate with PF for Real Time Service

4.2.2 FTP Traffic Service

Figure 4 -11, Figure 4-12, Figure 4-13, and Figure 4-14 show the results in EDF, RR, MAXCINR, and PF scheduling methods, respectively. MIMO transmission with different receivers in FTP traffic service is not like in VOIP traffic service which has almost the same throughput.

In EDF scheduling method as shown in Figure 4-11, the throughput of MIMO transmission with ML receiver is 15% better than the throughput of MIMO transmission with VBLAST receiver. The MIMO transmission with the VBALST receiver has more 50% throughput than SISO transmission. The MIMO transmission without spatial multiplexing almost has the same throughput with the MIMO transmission with VBLAST due to low VBLAST utilization as shown in Figure 4-5.

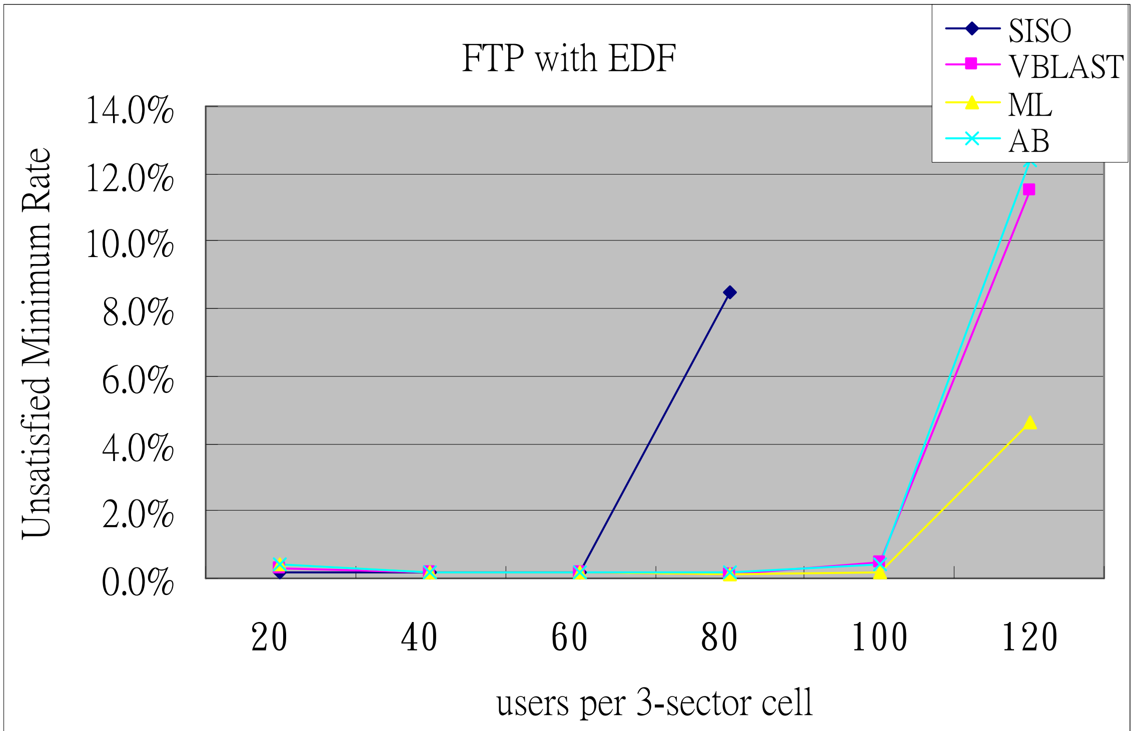

Figure 4-11 Unsatisfied Minimum Rate with EDF for Non-real Time Service

In RR scheduling method as shown in Figure 4-12, the throughput of MIMO transmission with ML receiver is 10% better than the throughput of MIMO transmission with VBLAST receiver. The MIMO transmission with the VBALST receiver has more 60% throughput than SISO transmission. The MIMO transmission without spatial multiplexing almost has the same throughput with the MIMO transmission with VBLAST due to low VBLAST utilization as shown in Figure 4-5.

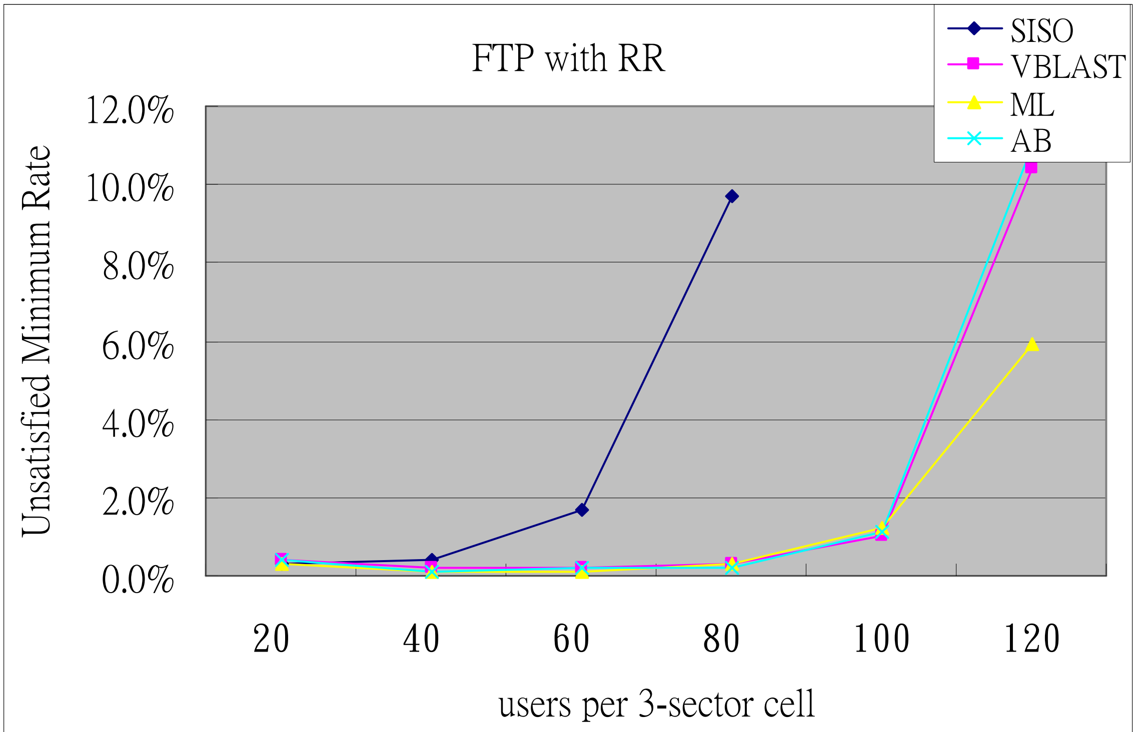

Figure 4-12 Unsatisfied Minimum Rate with RR for Non-real Time Service

In the MAXCINR scheduling method, even MIMO transmission with the ML receiver can not satisfy the QoS of FTP traffic service as shown in Figure 4-13. High CINR uses have high priority to be served, hence low CINR users don't have a lot of probability to transmit data.

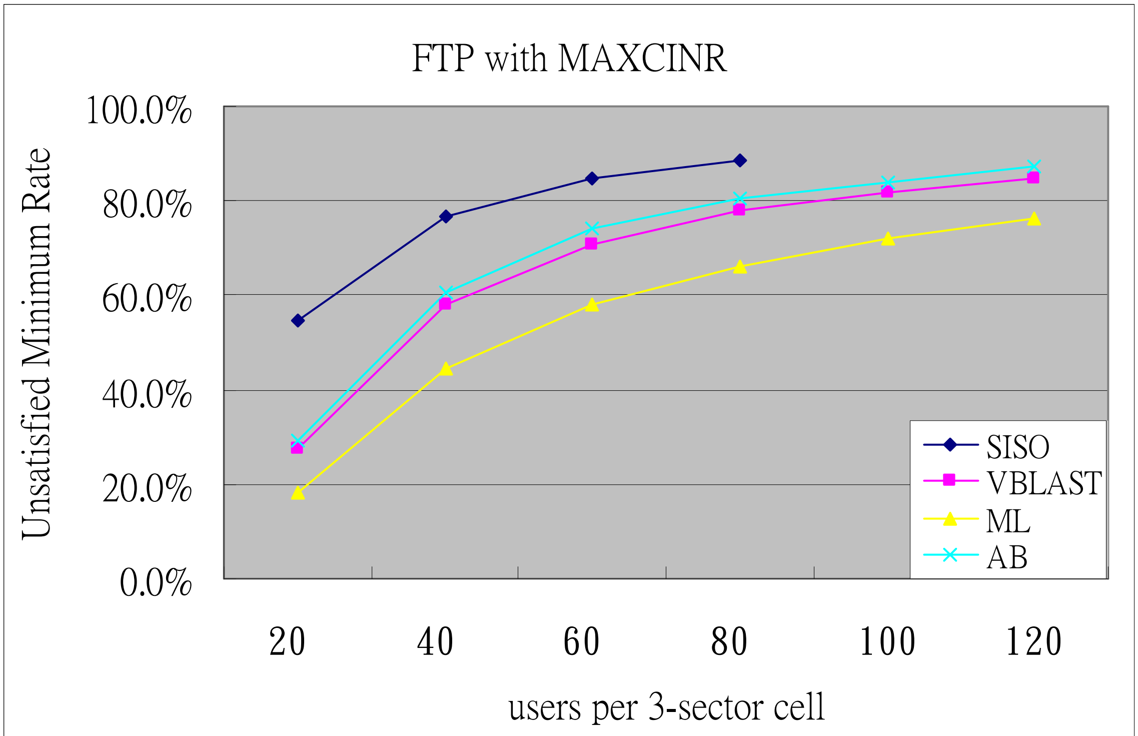

Figure 4-13 Unsatisfied Minimum Rate with MAXCINR for Non-real Time Service

In PF scheduling method as shown in Figure 4-14, the throughput of MIMO transmission with ML receiver is 40% better than the throughput of MIMO transmission with VBLAST receiver. The MIMO transmission with the VBALST receiver has more 100% capacity than SISO transmission. The MIMO transmission without spatial multiplexing has less 10% throughput than the MIMO transmission with VBLAST.

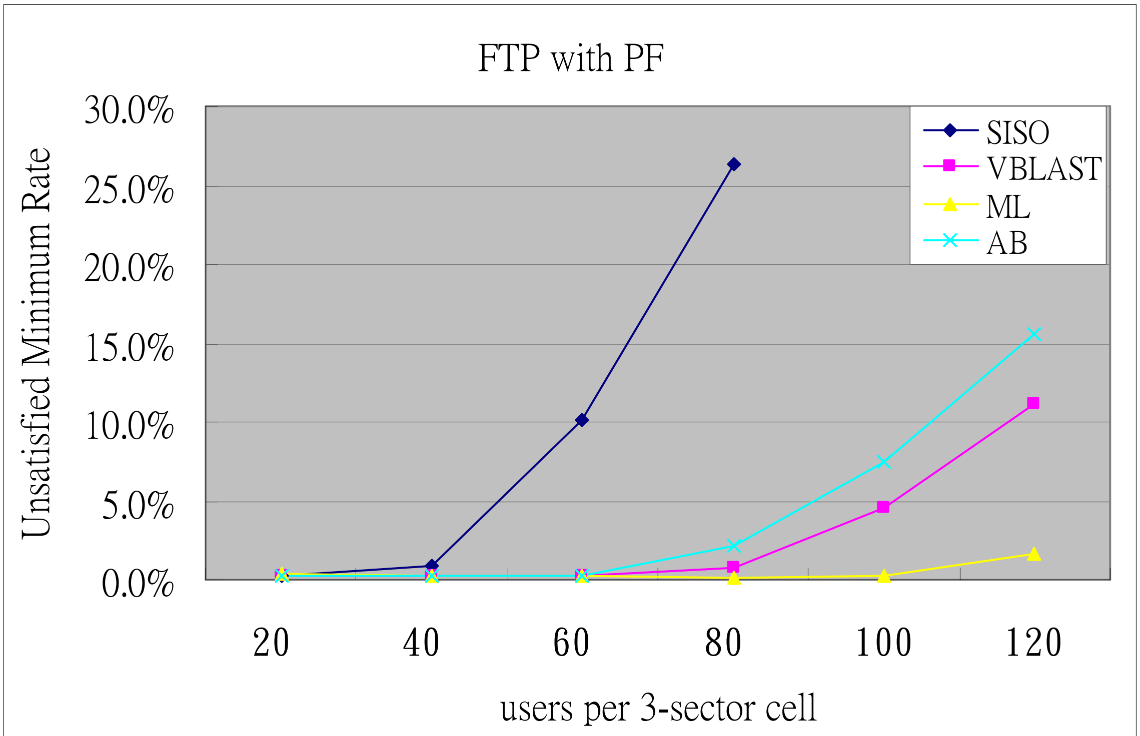

Figure 4-14 Unsatisfied Minimum Rate with PF for Non-real Time Service

The capacity in the PF scheduling method can be improved more than in EDF and RR scheduling methods, because the transmission rate is considered in the PF scheduling method.

4.3 Throughput of FTP Traffic Service

In the section, the MAC throughput performance in downlink transmission with MIMO technique is discussed in terms of different scheduling algorithms and different receiver technique. MAC throughput indicates the real data that have been transmitted. It ignores the header and the retransmitted data and reflects the real data which is really useful.

In EDF scheduling method as shown in Figure 4-11, the throughput of MIMO transmission with ML receiver is 15% better than the throughput of MIMO transmission with VBLAST receiver. The MIMO transmission with the VBALST receiver has more 50% throughput than SISO transmission. The MIMO transmission without spatial multiplexing almost has the same throughput with the MIMO transmission with VBLAST due to low VBLAST utilization as shown in Figure 4-5.

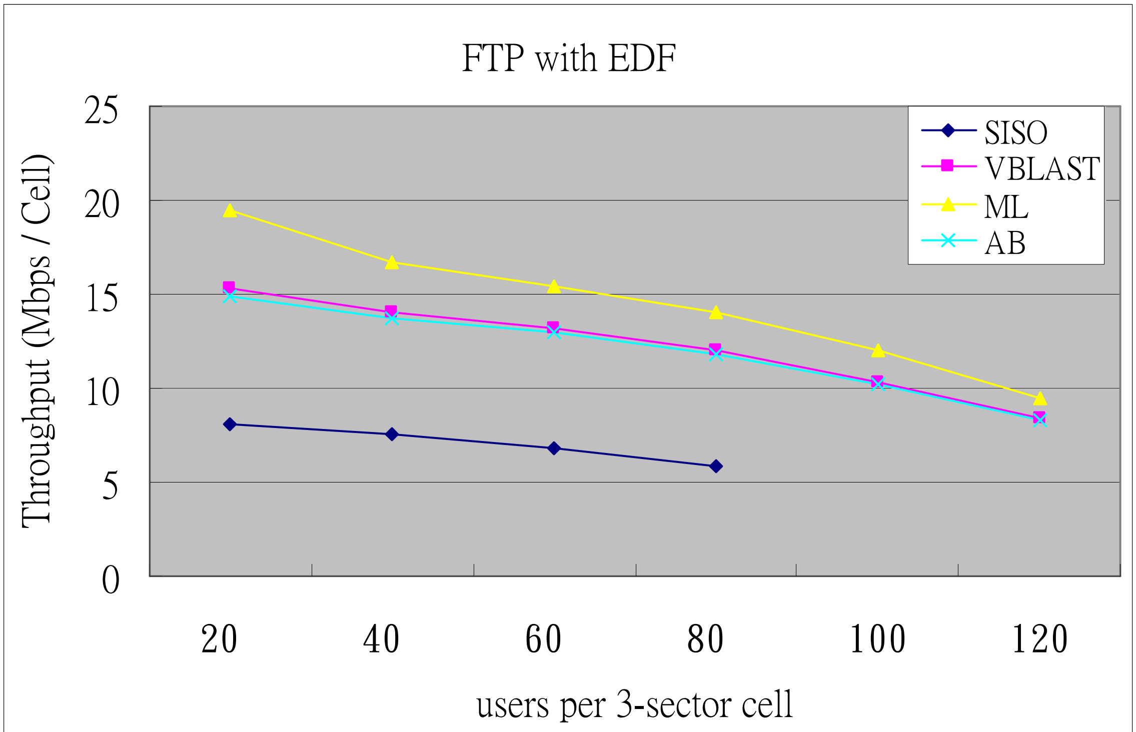

Figure 4-15 Throughput with EDF

In RR scheduling method as shown in Figure 4-12, the throughput of MIMO transmission with ML receiver is 6% better than the throughput of MIMO transmission with VBLAST receiver. The MIMO transmission with the VBALST receiver has more 40% throughput than SISO transmission. The MIMO transmission without spatial multiplexing almost has the same throughput with the MIMO transmission with VBLAST due to low VBLAST utilization as shown in Figure 4-5.

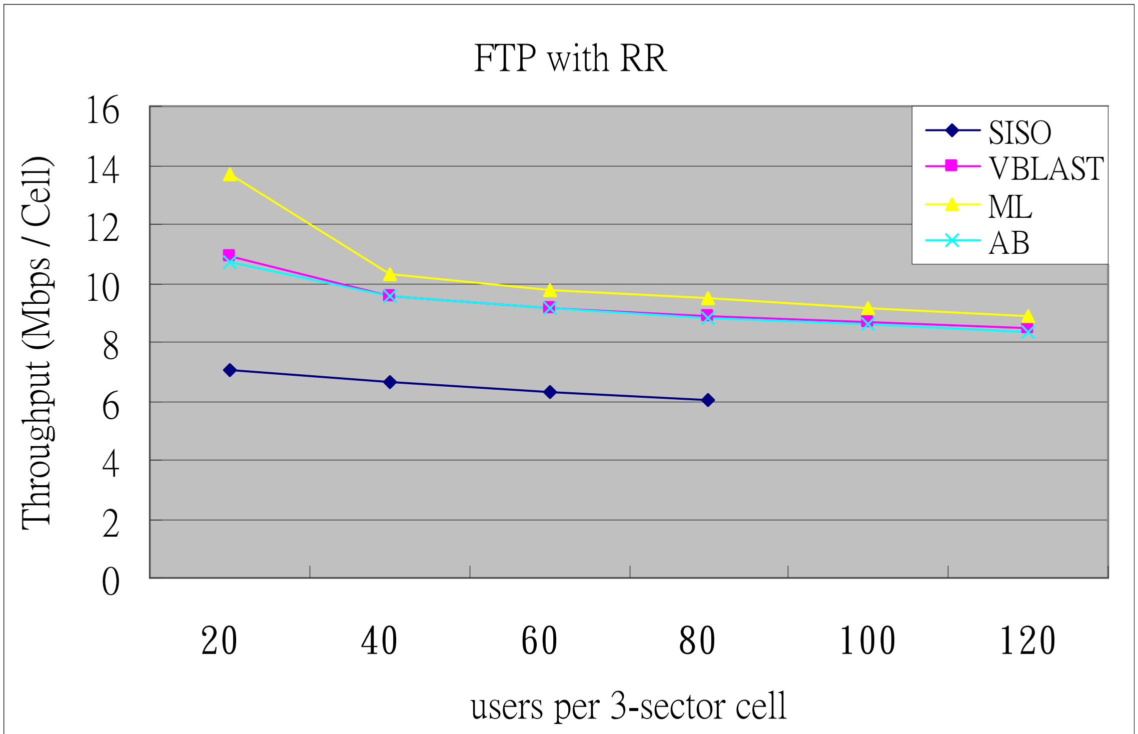

Figure 4-16 Throughput with RR

In MAXCINR scheduling method as shown in Figure 4-17, the throughput of MIMO transmission with ML receiver is 55% better than the throughput of MIMO transmission with VBLAST receiver. The MIMO transmission with the VBALST receiver has more 100% throughput than SISO transmission. The MIMO transmission without spatial multiplexing has less 20% throughput than the MIMO transmission with VBLAST.

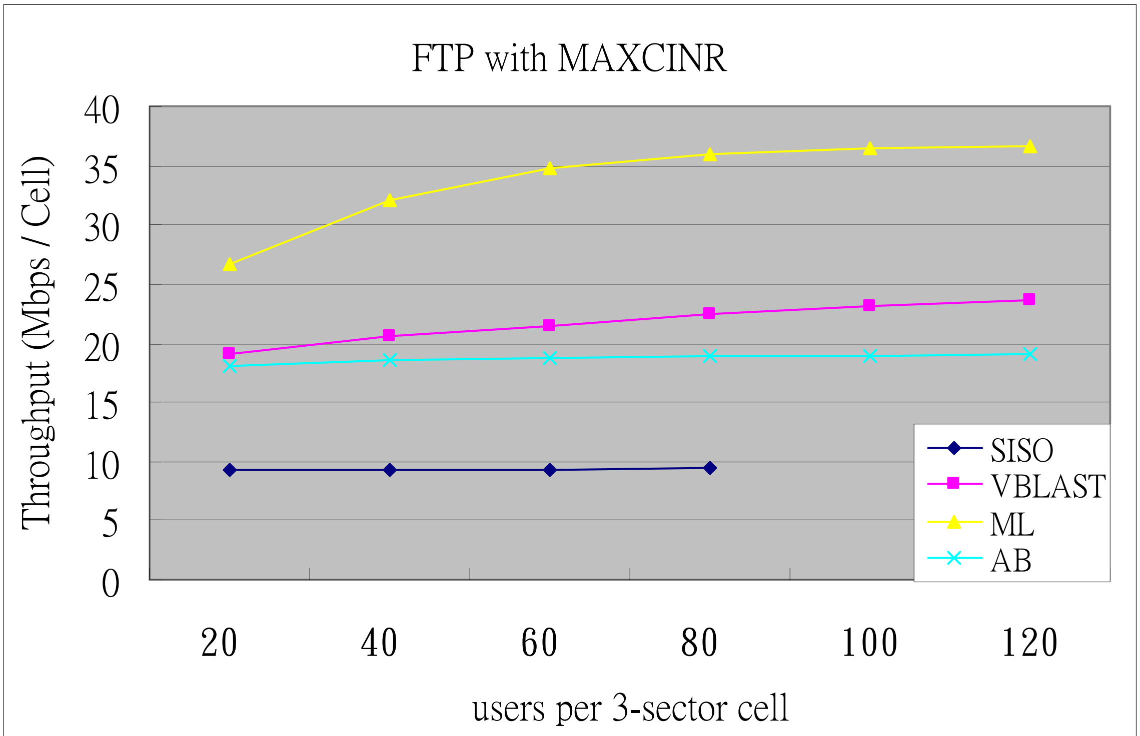

Figure 4-17 Throughput with MAXCINR

In PF scheduling method as shown in Figure 4-18, the throughput of MIMO transmission with ML receiver is 45% better than the throughput of MIMO transmission with VBLAST receiver. The MIMO transmission with the VBALST receiver has more 100% throughput than SISO transmission. The MIMO transmission without spatial multiplexing has less 5% throughput than the MIMO transmission with VBLAST.

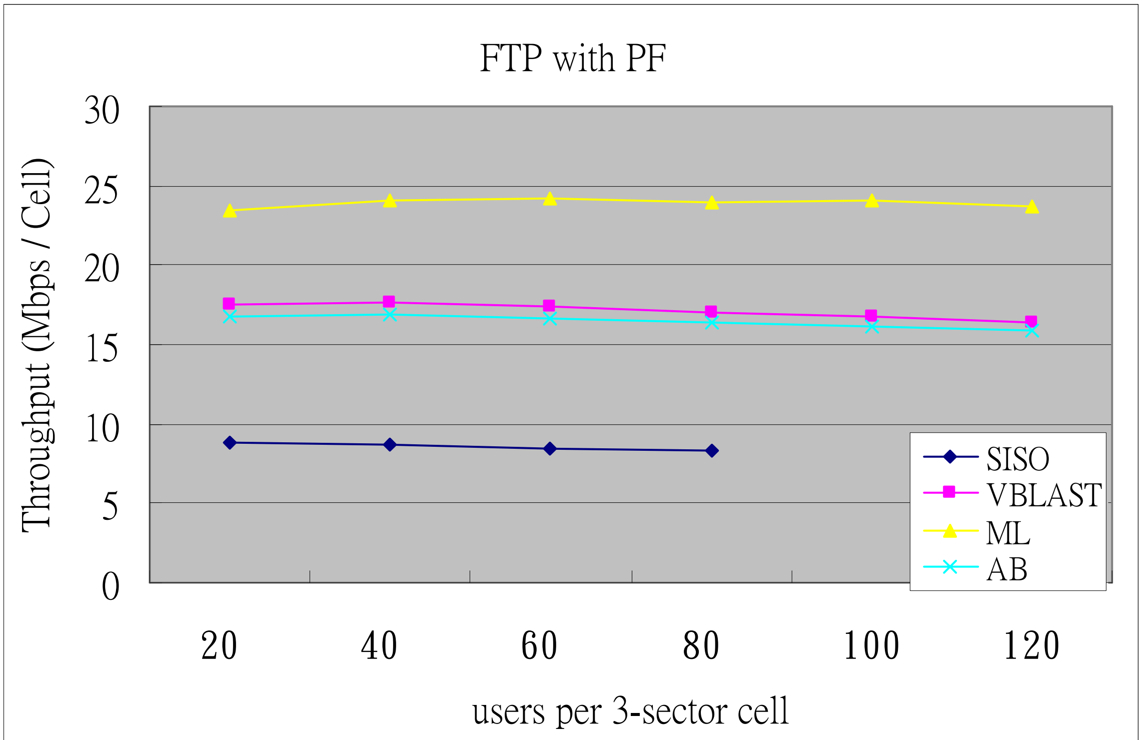

Figure 4-18 Throughput with PF

The throughput in MAXCINR and PF scheduling methods can be improved more than in EDF and RR scheduling methods, because the transmission rate is considered in MAXCINR and PF scheduling methods.

4.4 Fragmentation

In Figure 4-19, the channel utilization decreases when users increase in a cell, since high transmission rate may causes large padding of a burst. A VOIP packet is much smaller than a FTP packet, hence the padding is more serious in VOIP traffic. Exploiting padding of a burst to adapt PDU size can reduce loss rate as shown in Figure 4-20. When users per cell increase, more loss rate can be improved. There is ARQ in the simulation, so PDU can be retransmitted to reduce PER. When more users stay in a cell, a PDU may not be retransmitted before its delay bound, loss rate be improved obviously.

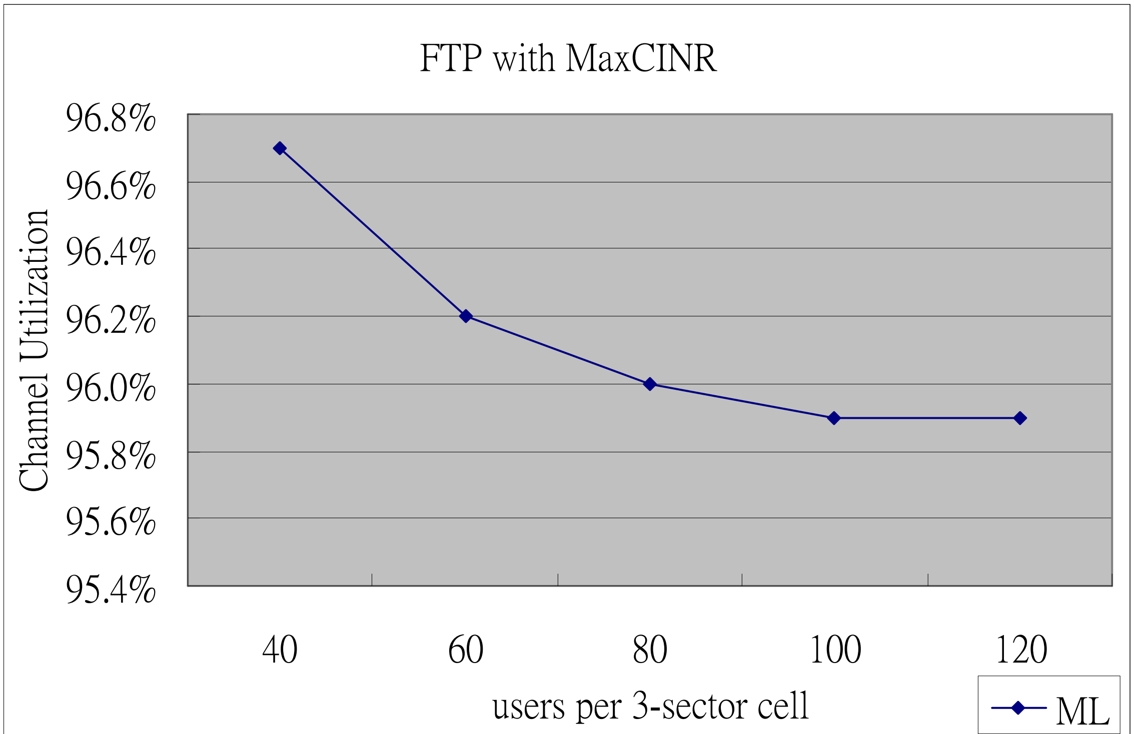

Figure 4-19 Channel Utilization for FTP Traffic Service

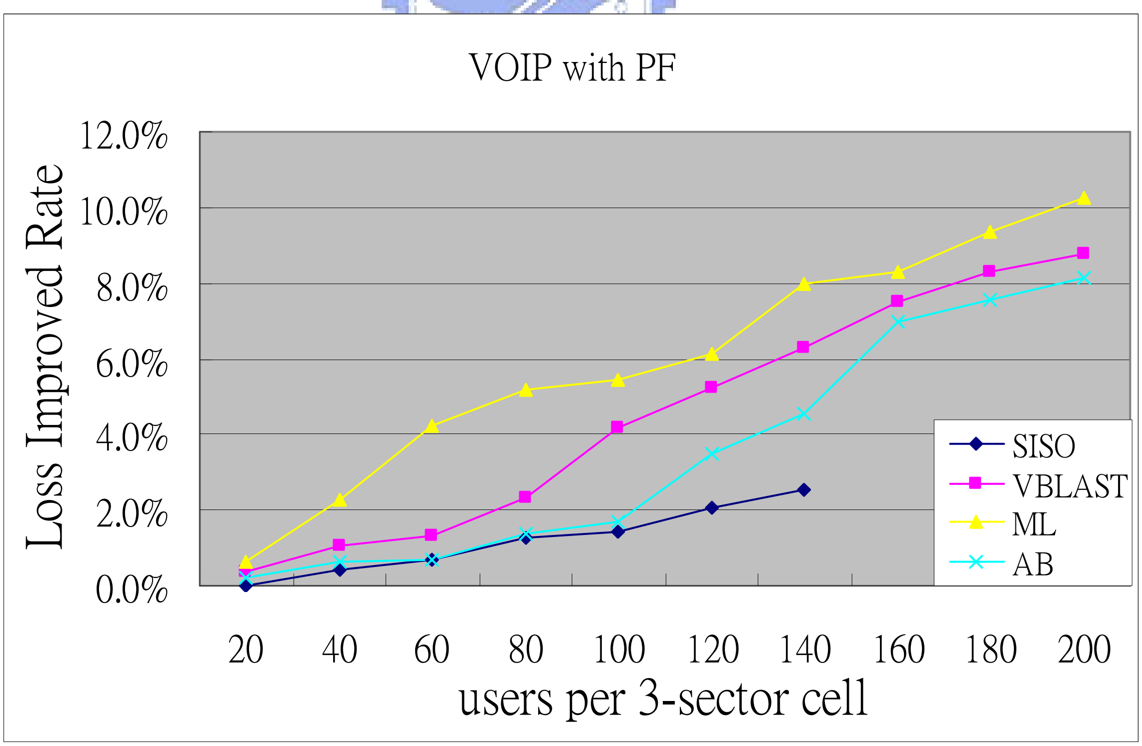

Figure 4-20 Improved Loss Rate in PF Scheduling Method for VOIP Traffic Service

Chapter 5 Conclusion and Future Work

In the thesis, our contributions are the system level platform establishment of MAC layer with MIMO technique in WiMAX standard and the performance study of MIMO transmission system. First, the MAC layer with MIMO technique in IEEE 802.16e system is implemented in our study. The platform is used for preliminary understanding of MIMO system. Secondly, utilization of different receivers of spatial multiplexing technique in different scheduling methods is studied. Then, QoS of the MIMO System with different receivers in different scheduling methods is studied. Finally, the characteristic of MIMO transmission is studied and a simple fragmentation method is applied for improving the PER.

From the performance simulation, we can get the conclusion as below. For real time service, the VBLAST utilization of different scheduling methods is the same and the spatial multiplexing with the ML receiver utilization of different scheduling methods is also the same. Furthermore, MAXCINR and PF scheduling methods can improve more QoS than RR and EDF scheduling methods but it is not obvious. It means that there is not a scheduling method with MIMO technique which is more appropriate than others for real time service. For non-real time service, the MAXCINR scheduling method has the highest spatial multiplexing utilization and the PF scheduling method is better than EDF and RR scheduling methods. However, MAXCINR is not the most appropriate scheduling method for non-real time service because MAXCINR can not satisfy QoS. The PF scheduling method can improve more QoS and provide higher throughput than EDF and RR scheduling methods because it considers the transmission rate. Therefore, the PF is most appropriate scheduling method for non-real time service. When the transmission rate is higher, the influence of the padding of a burst is more serious.

The MIMO system with mixed transmit diversity and spatial multiplexing almost has the same capacity as the MIMO system only with transmit diversity for VOIP traffic service. It means that spatial multiplexing can provide high transmission rate, but is not suitable for VOIP traffic service.

In the future work, we can update to the channel model, the other simple radio resource management control algorithm in the platform, which is referred to power control, ARQ, and handoff algorithm. With more advance radio resource management control algorithms, the performance can be upgraded more and QoS of can be guarantee further.

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