國 立 交 通 大 學

電信工程學系

碩 士 論 文

以 IP 為基礎之 OFDMA 系統在 FFR 架構下適用於即時性服務之快速基地台切換技術

Fast Base Station Switching for Real-time Services in IP-based OFDMA Systems with Fractional Frequency Reuse

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摘要

以網際網路協定(Internet Protocol, IP) 為基礎的正交分頻多重接取(Orthogonal Frequency Division Multiple Access, OFDMA)系統憑藉著與網際網路良好的互連能力以及在多路徑(Multi-path)傳播環境下可提供更高的資料傳輸率而被視為下一世代重要的無線通訊傳輸技術。 本篇論文研究在以 IP 為基礎的 OFDMA 系統下實際的換手方法。部份頻率重複使用(Fractional Frequency Reuse, FFR)細胞架構藉由規劃一個細胞的內外區域使用不同的頻率重複係數(Frequency Reuse Factor)來提高頻譜的使用效率(Spectrum Efficiency)。 在 OFDMA 系統中，快速基地台切換技術已是目前受歡迎的換手方法，此技術可以減少換手所造成的服務中段時間，也被 IEEE 802.16e-2005 標準所採用。 然而在換手的過程中，訊號品質不佳以及乒乓效應(Ping-pong Effect)的問題依然存在。 本篇論文提出一套換手方法,利用 FFR 細胞架構的優點與快速調距(Fast Ranging)的方式來改善訊號品質不佳的問題，也降低乒乓效應的發生率。模擬結果顯示本方法可大幅減少換手的過程中封包遺漏率同時減低乒乓效應。

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Abstract

IP (Internet Protocol)-based OFDMA (Orthogonal Frequency Division Multiple Access) is regarded as one of the key technologies for the next generation wireless communication due to its capability to inter-work with Internet and to achieve high transmission rate in a multi-path environment. In this thesis, the issue of effective hand-off over IP-based OFDMA systems is investigated. Fractional Frequency Reuse (FFR) cell structure is employed to achieve high spectrum efficiency by allowing different reuse factors to be used in the inner and outer areas of a cell. Fast base station switching (FBSS) has been a popular hand-off method for OFDMA systems and was adopted in the IEEE 802.16e-2005 standard to reduce service disruption time. Nevertheless, it may suffer from poor signal quality and the ping-pong effect during hand-off. This thesis proposes a hand-off method with the benefits of FFR cell structure and fast ranging so as to increase the signal quality and reduce the occurrence of the ping-pong rate. Simulation results show that the proposed method can significantly reduce the packet loss rate and ping-pong rate during handoff.

誌謝

本篇論文得以順利完成，首先要特別感謝我的指導教授 沈文和博士，在兩年研究過程中給予非常多的指導與建議，並教導我進行研究的方法與態度，尤其沈文和教授做研究謹慎小心的態度，讓我印象深刻，對我不僅在課業上甚至是做人處事上都有莫大的影響。在本篇論文中，有許多的觀念及推導方式都是經由沈教授的指點和教導，才能讓研究工作如此順利進行。另外，要感謝口試委員 蔡育仁教授和 黃經堯教授的指正與建議，使我的碩士論文更加完善。

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研究生邱相榮謹識於交通大學

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Chapter 1 Introduction

With the rapid development of mobile communication technologies and the customers' needs, mobile phones have been developed from the first generation-analog system to the second one-digital mobile communication, which is the cellular mobile phone we use in present. Besides the voice communication, the mobile phones are taken as a communication tool in which people can transmit images, send and receive e-mail, and have mobile Internet. In order to develop the mobile phones into multi-media and data communications, its third generation has been produced. With the growth of mobile Interne, moreover, the fourth generation of the mobile communication is being developed to provide high-speed data rate transmission under the high speed motion. The following section explores the development of mobile communication technologies [1].

The first generation (1G) of mobile communication technologies is analog frequency modulation among which American's Advanced Mobile Phone System (AMPS) is regarded as the most successful. However, AMPS has defects, such as poor secrecy, limited system capacity, no data information transmission and higher volumes. The second generation (2G) adopts digital modulation technique, speech coding, and digital signal processing to provide higher secrecy, system capacity, spectrum efficiency, and the transmission of the low-speed data information. In order to offer more various services to customers, International Telecommunication Union (ITU) enacted the concept of third generation system (3G). Different from voice services provided by the second generation mobile communication systems, the third generation mobile communication systems can provide the data transmission rate up to 2Mbps, and can dynamically adjust the data rate based on the user's demands. Besides, the third generation mobile communication systems can support different types of services including voice, data transmissions, streaming video transmissions, and video phone. Users can get the huge resources from Internet anytime, anywhere through 3G networks. Both circuit-switched and packet-switched modes are supported by 3G systems. Circuit-switched mode is used for real-time service such as voice and video services while packet-switched mode is used for non-real time data transmissions. 3G systems are able to adjust the modes dynamically based on the service quality requirements [1].

Next generation wireless communication systems are moving toward integrating more than two networks, and users can choose the network according to the signal quality of the network and his/her requirements anytime, anywhere [1-3]. Owing to the developments of multimedia, people want to watch favorite programs on the go. Therefore, mobile communication technologies are developing toward high data rate transmissions. Users can not only transmit/receive voice and video but also get services from Internet to obtain useful information and multimedia services. The fourth generation mobile communication is developing toward this direction.

Multi-path fading channel effect is a problem that wireless communication systems must solve. If a modulated signal is transmitted, multiple reflected waves of the transmitted signal will arrive at the receiving antenna from different directions with different propagation delays and different phases. These reflected waves are combined together constructively or destructively giving rise to received signal fading at the receiver site depending on the phases of the reflected waves. Besides, inter-symbol interferences (ISI) might be generated owing to the superposition of reflected signals which have different delays. A equalizer must be used to solve ISI problem in the traditional single carrier systems with high speed transmissions. As the transmission rate increases, equalizer design becomes more complex. Multi-carrier systems like OFDM systems which data are transmitted by orthogonal sub-carriers aim to solve this problem. The symbol duration of the OFDM systems is longer than that of traditional single carrier systems. A cyclic prefix is added to the front of each symbol to reduce inter-block interferences made by multi-path channel effects. Because all sub-carriers in OFDM systems are orthogonal and partially overlapped, the spectrum efficiency is higher than the traditional single carrier systems. Currently, OFDM-based systems are IEEE 802.11a, HyperLAN 2, asymmetric digital subscribe loop (ADSL), and IEEE 802.16-based WiMAX system.

Internet protocol (IP) based Network is mutual in the wire-line networks, and the most popular Internet uses IP-based networks. Because IP-based networks are not related to the radio access techniques, IP network is treated as the most important techniques to integrate heterogeneous networks so that they can inter-network with each other [3]. Compared with circuit-switched networks, IP-based network is more suitable for packet-based applications such as multimedia, data packets transmission, etc [2]. These applications are also the developing trends of future wireless communication systems. Future wireless communications are integrated by IP networks, and users can choose one of the usable networks according to the network conditions at that time.

In the wireless communication environments, the signals on the same frequency band will interfere with each other. Therefore, the spectrum, a very scare resource which should be used efficiently, causes the birth of the cellular wireless communication system. However, the adjacent BSs cause co-channel interferences to the users if they use the same frequency band. Therefore, the concepts of frequency reuse which can reduce co-channel interferences and efficiently reuse the frequency band become very important. Besides, to use scare radio resources more efficiently, fractional frequency reuse (FFR) cell structure [4-7] has been proposed. When the users are cross to the serving BS, the SINR is larger than the SINR of the user in the vicinity of cell border. Thus, under the condition that the required SINR is met, the BS can serve the user using the sub-channels with the smallest frequency reuse factor to increase system capacity. This is the main functionality of the fractional frequency reuse technology.

Handoff technique is one of essential mechanisms to support user mobility in multi-cellular communication systems. The use’s signal quality is influenced by not only the distance between the user and the serving BS but also the obstacles in the signal propagation path. To maintain uninterrupted services, the handoff mechanisms should be initiated at the right moment such that the user can communicate with the BS having better signal quality. Currently, the development of wireless communication is toward IP-based network systems, and both network layer handoff and link layer handoff should be taken into consideration in handoff mechanisms. The network layer handoff processing time depends on the network topology and states. In [8], authors used neighborcasting to achieve low latency handoff. Before link-layer handoff, the MN notifies the old foreign agent (FA) to forward duplicated packets to all neighboring FAs. Network-layer handoff latency can be reduced significantly. In [9], authors introduced mobile initiated tunneling handoff. Before disconnecting from the old AP, a mobile can initiate a handoff by sending the old foreign agent (FA) a handoff request containing the new FA's information got from the mobile pre-trigger. The methods proposed by these two papers are to perform the network layer handoff in advance which handoff users' packets can be forwarded to possible new FAs to reduced the network layer handoff latency. In [10], the authors gave a survey of mobility management techniques in next generation IP-based wireless systems. Hierarchical network architecture is introduced in this paper. This network structures can avoid any signaling traffic to Home Agent (HA) as long as the mobile is within a regional network. An explicit proactive handoff scheme with motion prediction is introduced by [11]. A mobile can anticipate a handoff from the link layer trigger, and use locally stored movement patterns to dynamically predict the next subnet. As a result, handoff latency and packet loss rate is reduced.

Link layer handoff aims to adjust mobile's transmit power, timing, and carrier frequency in OFDMA systems. To reduce the service disruption time, the concepts of scanning with association have been proposed in IEEE 802.16e-2005 [12]. During the normal operation, the serving BS may allocate time intervals to MS for the purpose of MS seeking and monitoring suitability of neighbor BSs as targets for handoff. The time during which the MS scans for available BS will be referred to as a scanning interval. MS can perform initial ranging with neighboring BSs in the scanning interval. Association is an optional initial ranging procedure occurring during scanning interval with respect to one of neighbor BSs. The function of association is to enable the MS to acquire and record ranging parameters and service availability information for the purpose of proper selection of HO target and/or expediting a potential future handover to a target BS. Consequently, the time required to perform link layer handoff can be reduced, and the service disruption time is also reduced.

Next generation wireless systems are envisioned to have an IP-based infrastructure with the support of heterogeneous access technologies. Next generation wireless systems also call for the integration and interoperation of heterogeneous networks. To achieve high data rate transmission and high spectrum efficiency, OFDM seems to be one of important technologies.

Fractional frequency reuse (FFR) cell structure can be used to improve scare radio resources utilization. For this reason, IP-based OFDMA system with factional frequency reuse cell structure is chosen as the system model in this thesis. The network layer handoff effect and link layer signal quality are jointly considered in designing handoff mechanisms in this thesis. How the fast base station mechanism gets the benefits of fractional frequency reuse cell structure to improve performances is introduced in this thesis.

The rest of this thesis is organized as follows. In Chapter 2, we describe the system models. Chapter 3 describes the different kinds of handoff mechanisms. Chapter 4 presents the signaling procedures. Fast base station switching with factional frequency reuse is presented in Chapter 5. Chapter 6 describes the simulation environments and results. Finally, conclusions are presented.

Chapter 2 System Model

2-1 OFDM Technology

In wireless communications, the channel imposes a limit on data rates in the system. One way to increase the overall data rate is to split the data stream into a number of parallel channels and use different sub-carriers for each channel. This is the multi-carrier transmission technology and is shown in Fig. 1. Using the multiple sub-carriers to transmit data, the symbol duration will be longer. Compared with the single carrier system, therefore, multi-carrier systems can have higher tolerance on inter-symbol interferences (ISI) [13-15].

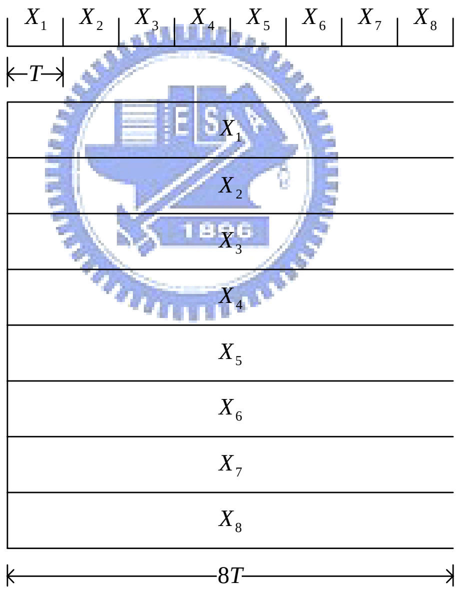

Fig. 1 Single carrier and multi-carrier transmissions

Orthogonal frequency division multiplexing (OFDM) [16-17] is a multi-carrier technique by using the orthogonal sub-carriers to transmit data. In the time domain, sub-carriers are orthogonal with each other, but in the frequency domain, the sub-carriers are partially overlapped.

If we want to distinct two signals with length T_{FFT} but with different frequencies in the frequency domain, and the two signals do not interfere with each other, the minimum frequency spacing of the two signals is $\Delta f = {}^{1}\!/\!_{T_{FFT}}$.

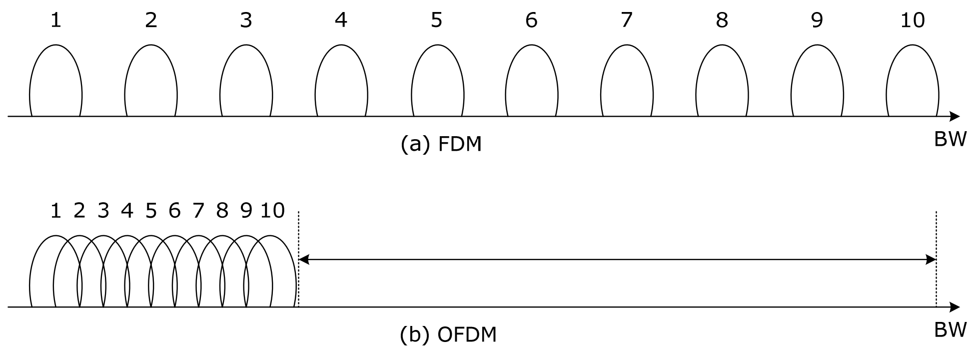

Fig. 2 Spectrum of FDM and OFDM systems

We compare the spectrum efficiency of the traditional single carrier system and OFDM system. The bandwidth and data rate of single carrier systems can be represented as

$$W = \frac{(1+\beta)}{T}, \quad \beta: \text{Roll-off Factor} \tag{1}$$

$$R = \frac{\log_2 M}{T}, \quad M: \text{ Alphabet Size} \tag{2}$$

The spectrum efficiency can be represented as

$$\frac{R}{W} = \frac{\log_2 M}{(1+\beta)} \quad \text{(bits/s/Hz)} \tag{3}$$

The bandwidth and data rate of OFDM system is

$$W = \frac{B+1}{NT} \tag{4}$$

$$R = \frac{\log_2 M}{T}, \quad M: \text{ Alphabet Size} \tag{5}$$

The spectrum efficiency of OFDM system can be written as

$$\frac{R}{W} = \log_2 M \quad \text{(bits/s/Hz)} \tag{6}$$

We can know the spectrum efficiency of OFDM systems is larger than the traditional FDM system by $(1+\beta)$. Fig. 2 is the spectrum diagrams of traditional FDM system and OFDM system.

OFDM signal can be written as

$$s(t) = \mathrm{Re}\left\{ \sum_{l=-\infty}^{\infty} \left(\sum_{k=-K}^{K} X_{l,k} e^{j2\pi\left(f_c + \frac{k}{T_{FFT}}\right)t} \right) \cdot U_{T_{FFT}}\left(t - lT_{FFT}\right) \right\} \tag{7}$$

Total number of sub-carriers is (2K+1). $X_{l,k}$ is the transmitted signal of the k th sub-carriers in the l th OFDM symbol.

The $U_{T_{FFT}}$ can be written as

$$U_{T_{FFT}}(t) = \begin{cases} 1, & 0 \le t \le T_{FFT} \\ 0, & \text{otherwise.} \end{cases} \tag{8}$$

The $\tilde{s}(t)$ is the equivalent low pass representation, and can be written as

$$\tilde{s}(t) = \sum_{l=-\infty}^{\infty} \left(\sum_{k=-K}^{K} X_{l,k} e^{j\frac{2\pi k}{T_{FFT}}t} \right) \cdot U_{T_{FFT}}\left(t - lT_{FFT}\right) \tag{9}$$

The $\tilde{s}_l(t)$ is the l th OFDM symbol with infinite expansion in time domain from $-\infty$ to ∞ without truncation by T_{FFT}. The signal can be represented as

$$\tilde{s}_l(t) = \sum_{k=-K}^{K} X_{l,k} e^{j\frac{2\pi k}{T_{FFT}}t} \tag{10}$$

By observing $\tilde{s}_l(t)$, we can find it is a periodic signal with period T_{FFT}.

$$\tilde{s}_l(t + mT_{FFT}) = \sum_{k=-K}^{K} X_{l,k} e^{j\frac{2\pi k}{T_{FFT}}(t+mT_{FFT})} = \sum_{k=-K}^{K} X_{l,k} e^{j\frac{2\pi k}{T_{FFT}}t} \cdot e^{j2\pi km} = \sum_{k=-K}^{K} X_{l,k} e^{j\frac{2\pi k}{T_{FFT}}t} = \tilde{s}_l(t) \tag{11}$$

The spectrum of $\tilde{s}_l(t)$ can be written as

$$S_{\tilde{s}_l(t)}(f) = \sum_{k=-K}^{K} X_{l,k} \delta(f - k\Delta f), \qquad \Delta f = \frac{1}{T_{FFT}} \tag{12}$$

It is a line spectrum as shown in Fig. 3.

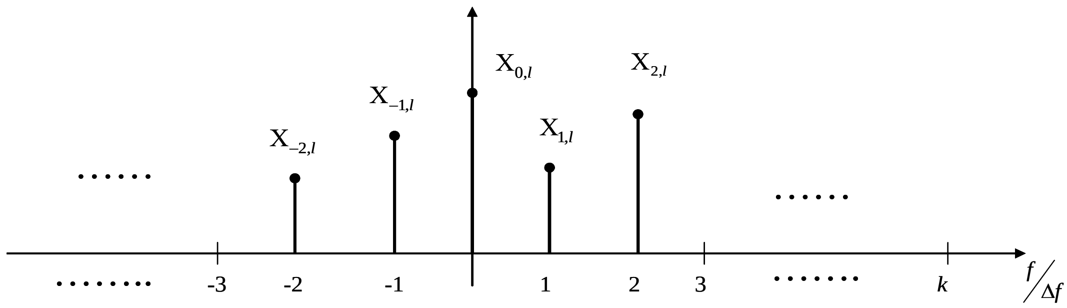

Fig. 3 The spectrum of $\tilde{s}_l(t)$

The practical transmitted signal of $\tilde{s}_l(t)$ is truncated in time domain by T_{FFT}, and we represent this truncated signal as $\tilde{s}_{l,u}(t)$.

$$\tilde{s}_{l,u}(t) \doteq \tilde{s}_l(t) U_{T_{FFT}}(t - lT_{FFT}) \tag{13}$$

If we truncate a signal in time domain by T_{FFT}, the frequency response of the signal will convolute with the sinc function in the frequency domain. Thus, the spectrum of $\tilde{s}_{l,u}(t)$ is

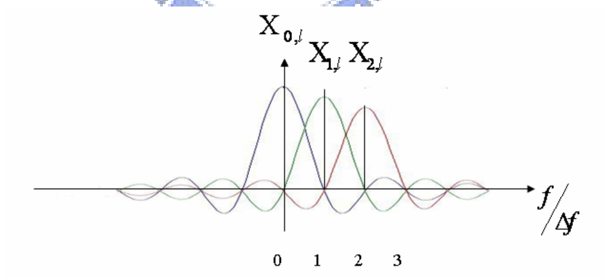

Fig. 4 The spectrum of $\tilde{s}_{l,u}(t)$

We can represent the modulator of OFDM system as

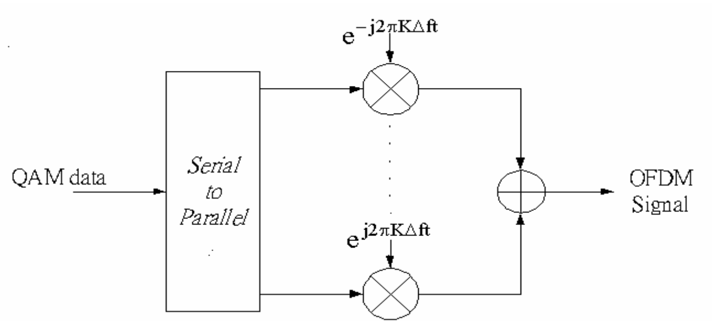

Fig. 5 OFDM modulator

How to decode the received signals is described as follows. Without loss of generality, we consider the situation with l=0. Take the Fourier transform of the received signal with l=0, and the signal can be written as

$$S_{\tilde{s}_{0,u}}(f)=\int_{-\infty}^{\infty}\tilde{s}_{0,u}(t)e^{-j2\pi ft}dt=\int_{0}^{T_{FFT}}\sum_{k=-K}^{K}X_{0,k}e^{j2\pi k\Delta ft}e^{-j2\pi ft}dt \tag{14}$$

Observing the signal of the K th sub-carrier, we will get original transmitted signal as shown in equation (15)

$$S_{\tilde{s}_{0,u}}(f)|_{f=k\Delta f}=\sum_{m=-K}^{K}X_{0,m}\int_{0}^{T_{FFT}}e^{-j2\pi(k-m)\Delta ft}dt=X_{0,k} \tag{15}$$

The OFDM demodulator is

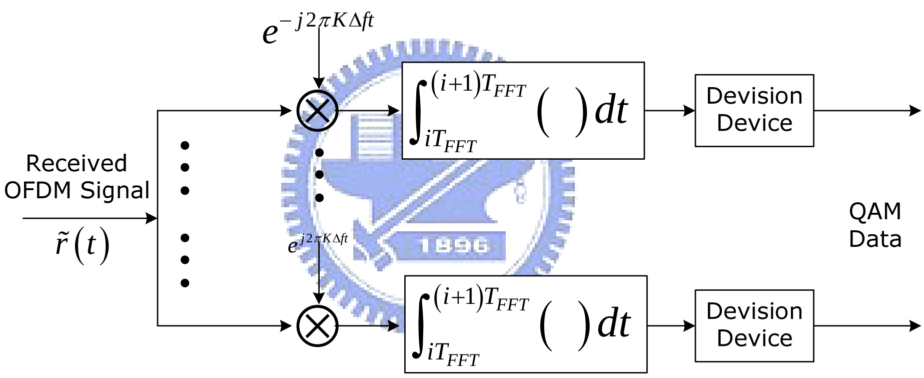

Fig. 6 OFDM demodulator

Fig. 7 shows that when the carrier frequency is not correct, the point of zero crossing will be shifted, and this causes inter-carrier interferences (ICI).

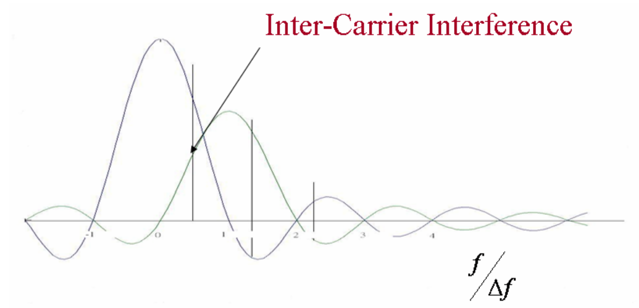

Fig. 7 Inter-carrier interference caused by frequency error

Fig. 8 shows that when the clock is incorrect, the orthogonality of sub-carriers will be destroyed and the inter-block interference (IBI) is generated.

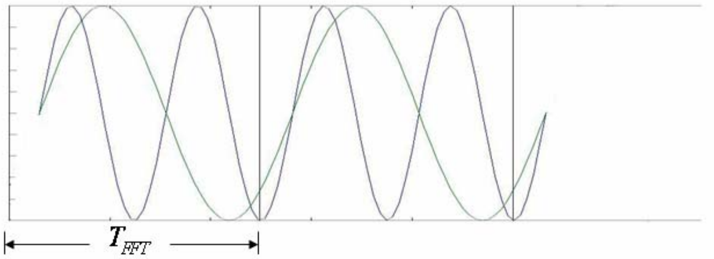

Fig. 8 Inter-block interference caused by clock error

We consider how the OFDM system resists the multi-path fading under the frequency selective channel.

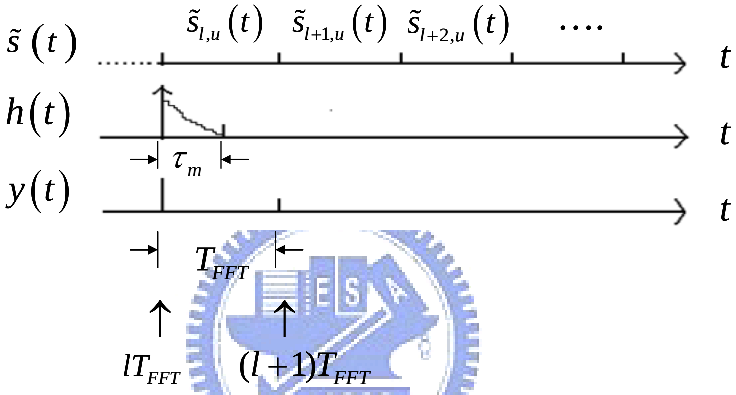

Fig. 9 Frequency selective channel

As shown in Fig. 9, *h(t)* is the channel impulse response, and τ_m represents the maximum delay spread. The received signals can be expressed as

$$y(t)=\begin{cases} \tilde{s}_{l,u}(t)\otimes h(t), & lT_{FFT}+\tau_m \le t < (l+1)T_{FFT} \\ \left[\tilde{s}_{l,u}(t)+\tilde{s}_{l-1,u}(t)\right]\otimes h(t), & lT_{FFT} \le t < lT_{FFT}+\tau_m \end{cases} \tag{16}$$

According to equation (16), the frequency selective channel causes inter-block interferences (IBI). Even if we do not consider the IBI effect, set $\tilde{s}_{l-1,u}(t)=0$, the spectrum of received signals is

$$S_{y_{l,u}}(f)=\left[S_{\tilde{s}_{l,u}}(f)\cdot H(f)\right]\otimes \mathrm{sinc}(T_{FFT}f)\cdot T_{FFT} \tag{17}$$

According to equation (17), because the frequency response of the signal convolutes with sinc function, the point of zero crossing will not be zero anymore, and this results in inter-carrier interferences (ICI). To solve this problem, OFDM systems will add the guard interval, T_g, in front of the each symbol. Define $T_{OFDM} = T_g + T_{FFT}$ as the symbol duration. Due to the change of symbol duration, we redefined the transmitted signals as

$$\begin{aligned} v(t) &= \sum_{l=-\infty}^{\infty} v_{l,u}(t - lT_{OFDM}) \\ v_{l,u}(t) &= \tilde{s}_l(t) \cdot U_{OFDM}(t - lT_{OFDM} + T_g) \end{aligned} \tag{18}$$

According to equation (11), $\tilde{s}_l(t)$ is a periodic signal, and equation (18) shows that $v_{l,u}(t)$ is truncated from $\tilde{s}_l(t)$ with length T_{OFDM}. As shown in Fig. 10, in each OFDM symbol, the forefront and last signals of $v_{l,u}(t)$ are the same.

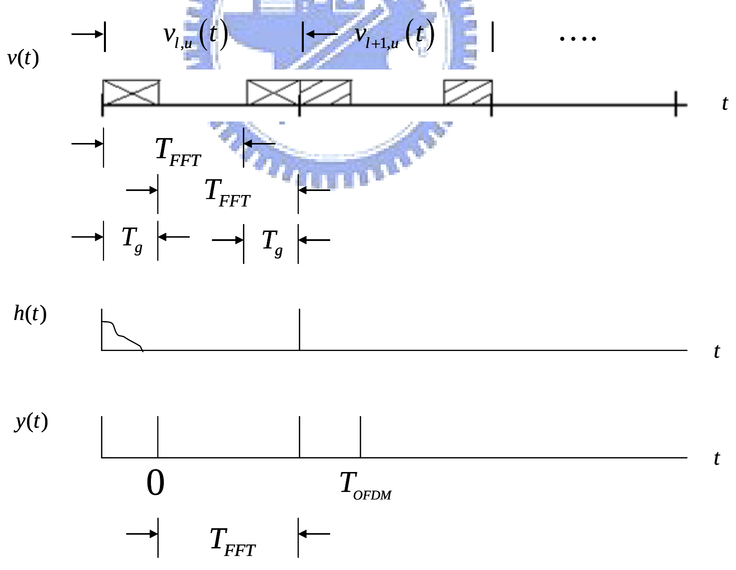

Fig. 10 Cyclic prefix for OFDM signals

The received signals can be expressed as

$$y(t) = \begin{cases} \left[\tilde{s}_l(t) \otimes h(t)\right] \cdot U_{T_{FFT}}(t - lT_{OFDM}), & (lT_{OFDM} \le t < (l+1)T_{OFDM} - T_g) \\ T_{l-1,u}(t) \otimes h(t) + T_{l,u}(t) \otimes h(t), & (lT_{OFDM} - T_g \le t < lT_{OFDM}) \end{cases} \tag{19}$$

The spectrum of received signals $y_{l,u}(t)$ can be written as

$$\begin{aligned} S_{y_{l,u}(t)}(f) &= \left[\sum_{k=-K}^{K} X_{l,k} H(k\Delta f)\cdot\delta(f-k\Delta f)\right]\otimes \operatorname{sinc}(T_{FFT} f) T_{FFT} \\ &= \sum_{k=-K}^{K} X_{l,k} H(k\Delta f)\operatorname{sinc}(T_{FFT} f) T_{FFT} \end{aligned} \tag{20}$$

According to equation (20), the point of zero crossing is not destroyed, and the orthogonality between sub-carriers still exists. The inter-block interferences and inter-carrier interferences will not be introduced through this kind of setting.

Now, we consider how the OFDM systems perform the multiple access, which is the OFDMA (Orthogonal Frequency Division Multiple Access) systems. OFDMA systems not only have the capabilities to resist the multi-path fading and inter-symbol interferences but also have the abilities to let multiple users transmit data at the same time by using the characteristic of orthogonality of OFDM sub-carriers. Consequently, the BS can dynamically adjust the number of sub-channels for each user according to the number of data needed to be transmitted to utilize the radio resources more efficiently. Besides, for the downlink, if the BS knows the channel conditions for each user, the BS can serve the users with better sub-channels, and the system capacity is increased by this kind of arrangement.

The benefits of OFDMA technology can be concluded as follows:

1. This technology can resist multi-path fading efficiently without complex time-domain equalizer, which increases the complexity of the receiver. It is very suitable to work in the non-light sight transmission environments. When the maximum delay spread is known, OFDM can combat the inter-symbol interference owing to the delay spread of the channel while the single carrier system needs a highly complex equalizer to eliminate the inter-symbol interference due to delay spread of the channel.
2. In the slowly time-variant channels, the BS can dynamically adjust the data rate of each sub-carrier according to the received SINR of that sub-carrier to increase system capacity.
3. Compared with single carrier systems, OFDMA systems have the frequency diversity to

combat the narrow band interference.

4. Using the orthogonality of sub-carriers, multiple users can transmit/receive data at the same symbol duration. By obtaining the channel state information, the BS can schedule better sub-channels for each user to transmit/receive data.

Compared with the single carrier systems, the disadvantages of OFDMA systems are

1. OFDM system is very sensitive to the frequency offset and phase noise which destroy the orthogonality of sub-carriers to cause inter-carrier interferences.
2. Peak to average power ratio (PAPR) problem which causes non-linear distortion is large. This problem increases the complexities of power amplifier.

2-2 Fractional Frequency Reuse

In the wireless communication environments, the signals on the same frequency band will interfere with each other. Therefore, the spectrum, a very scare resource which should be used efficiently, causes the birth of the cellular wireless communication systems. The BS transmit signals with high power to cover larger coverage in the traditional wireless communication systems, while in the cellular wireless communication systems, the large coverage will be divided into several smaller areas, each of which is served by BS with smaller power. However, the adjacent BSs cause co-channel interferences to the users if they use the same frequency band. Therefore, the concepts of frequency reuse which can reduce co-channel interferences and efficiently reuse the frequency band become very important. Frequency reuse technology is to divide the usable frequency bands into smaller ones which are used by the adjacent BSs to serve users. When the receiver’s co-channel interferences are controlled in an acceptable range, the transmission will be able to operate normally. However, the co-channel interferences decrease nonlinearly with the increase of the distance. In other words, the same frequency band can be reused if the distance between the BSs using the same frequency band is far enough. By reusing the frequency band, the spectrum can be used more efficiently.

In the cell planning, the most important parameter, the reuse distance, represents the minimum space of two BSs with the same frequency band under the condition that SINR requirement is met [14-15]. Another parameter related to the reuse distance is frequency reuse factor, K, which suggests that the usable frequency bands will be divided into K small bands. The K value refers to the number of the adjacent K BSs, all of which use different frequency bands as shown in Fig. 11. The higher value K represents the further the distance of the BSs with the same frequency band, which results in lessening the co-channel interference. According to the principle, however, the bandwidth allocated to one BS is lessening, causing the decrease of the trunking efficiency.

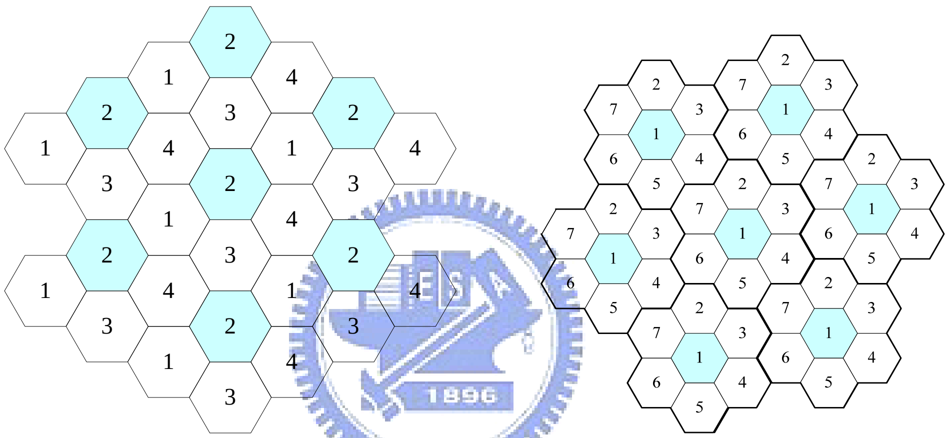

Fig. 11Cell structure for different frequency reuse factor

Fractional frequency reuse cell structure [4-7] is to divide one cell into some concentric sub-cells as shown in Fig. 12. One BS can have many kinds of frequency reuse sub-channels, and each sub-cell will use the sub-channels of different frequency reuse factor to serve users. When the users are cross to the serving BS, the SINR is larger than the SINR of the user in the vicinity of cell border. Thus, under the condition that the required SINR is met, the BS can serve the user using the sub-channels with the smallest reuse factor to increase system capacity. This is the main functionality of the fractional frequency reuse technology.

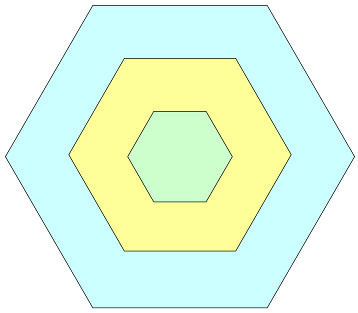

Fig. 12 Fractional frequency reuse cell structure

As mentions above, when the users are cross to the serving BS, the SINR is larger than the SINR of the users in cell boundary. For this reason, the sub-channels with smaller reuse factor can be used to server the users in the inner area of a cell. The inner cell coverage planning aims to maximize the inner cell coverage under the condition that user's SINR requirement is met.

The inner cell coverage planning is as follows:

1. If we know the user's location which is relative to the serving BS, the distance, d_0, between the serving BS and the user can be calculated. The distance, d_k, between the user and the co-channel BS with number k is also obtained.
2. By calculating the link budget, the minimum reuse factor (K), cell coverage (R), and maximum transmit power (P_{MAX}) can be obtained.
3. Solve the non-linear equation with downlink power constraint $P \le P_{MAX}$. The inner cell coverage is

$$\text{Coverage} = \max\left\{d_0 : SINR\left(d_0\right) \ge \text{Required } SINR\right\} \tag{21}$$

Where

$$SINR\left(d\right) = P - PathLoss\left(d\right) - \text{Shadow Margin} - \text{Co-channel Interferences (dB)}$$

$$\text{Co-channel Interferences} = 10 \cdot \log_{10}\left(\sum_{k=1}^{19} 10^{\left(\frac{P - PathLoss\left(d_k\right)}{10}\right)}\right) \text{(dB)}$$

2-3 IP-based Mobile Communication Networks

The wire-line routing technology has been developed mutually, and the most successful one is IP technology. Currently, the most popular Internet is IP-based network systems. The home-used asymmetric digital subscriber loop (ADSL), wireless local area network IEEE 802.11 a/b/g, and the networks in the school and business are all IP-based networks. Currently, wireless communication systems are developing toward high data rate transmissions, and IP networks can provide good integrations. Besides, IP networks does not depend on the radio access technologies, so different kinds of systems can inter-work with each other using the IP networks. For this reason, wireless communication systems are developing toward IP-based network systems in present.

Compared with circuit-switched network systems, IP-based networks are more suitable to transmit packet-based applications like multimedia, data packets, etc. IP-based networks are also the trends of developing future wireless communication systems [3]. Therefore, as shown in Fig. 13, through IP networks, users can get the huge resources on the Internet anytime, anywhere, and all the services of future wireless communication systems are integrated through IP networks. Besides, users can use better networks according to the network conditions at that moment.

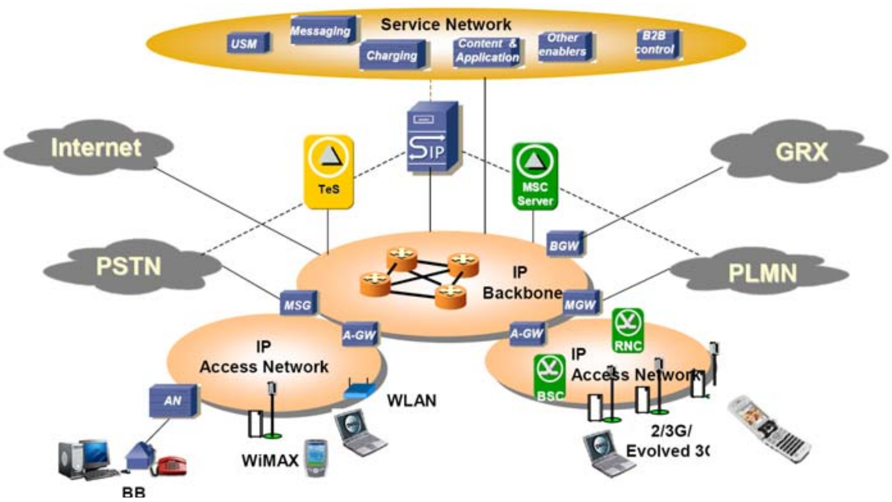

Fig. 13 IP-based network architecture [18]

Because wire-line networks users don't move, packets can be transmitted to the receiver side correctly through routers. Currently, IP address is used to be the destinations for packet transmission in IP networks, and therefore, when users are moving, routers can not deliver packets to the destinations correctly in the wireless communication systems. To solve this problem, Internet Engineering Task Force (IETF) is developing new standard which is called Mobile IP to enable the capability such that packets can be transmitted to the destination correctly without changing the IP address even if uses are moving. The detailed signaling procedures will be introduced in Chapter 4.

The currently developing WiMAX system is an IP-based wireless system, and WiMAX forum [5,6,19] are developing the network architecture, which is shown in Fig. 14. BSs connect to an access service network gateway (ASN-GW) directly, and ASN-GW connects with the Internet directly. Besides, ASN-GW is also responsible for executing the jobs of foreign agent (FA), controlling all the BSs connected to it, and letting users to handover between BSs smoothly. Compared with 3G systems, the functionalities of ASN-GW is similar to radio network controller (RNC), and the only difference is that ASN-GW connects to Internet directly while RNC connects to Internet through gateway GPRS support node (GGSN)[20].

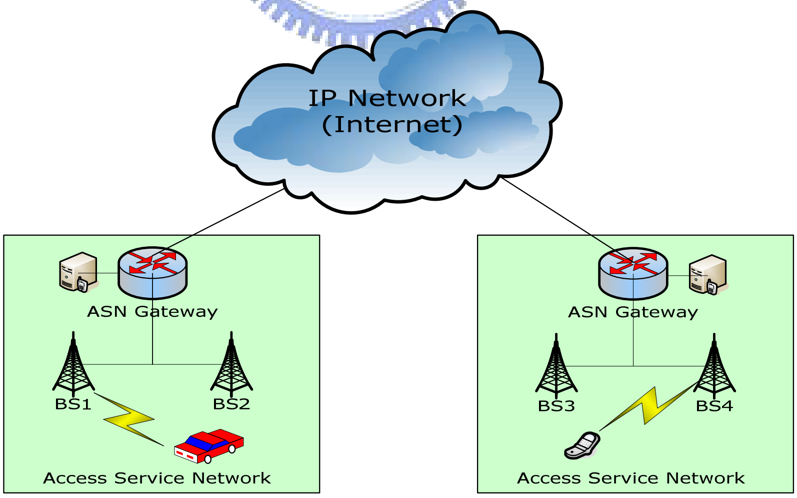

Fig. 14 WiMAX network reference model

The frame structure of IEEE 802.16e-2005 is introduced in the following parts. IEEE 802.16e-2005 system adopts the OFDMA technology, which can let multiple users transmit/receive data at the same time. This system has two modes called TDD and FDD, and we introduce the point to multipoint (PMP) frame structure based on the TDD mode.

According to the IEEE 802.16e-2005 standard, the frame durations can be 2, 2.5, 4, 5, 8, 10, 12.5, and 20 milliseconds. In compliance with Fig. 15, each frame can be further divided into downlink sub-frame and uplink sub-frame. The downlink sub-frame consists of preamble, frame control header (FCH), downlink (DL) Map, uplink (UL) Map, and DL burst. DL Map and UP Map provide the locations of user's data in the downlink and uplink sub-frame for each user. Uplink sub-frame is composed of UL bursts and ranging sub-channels.

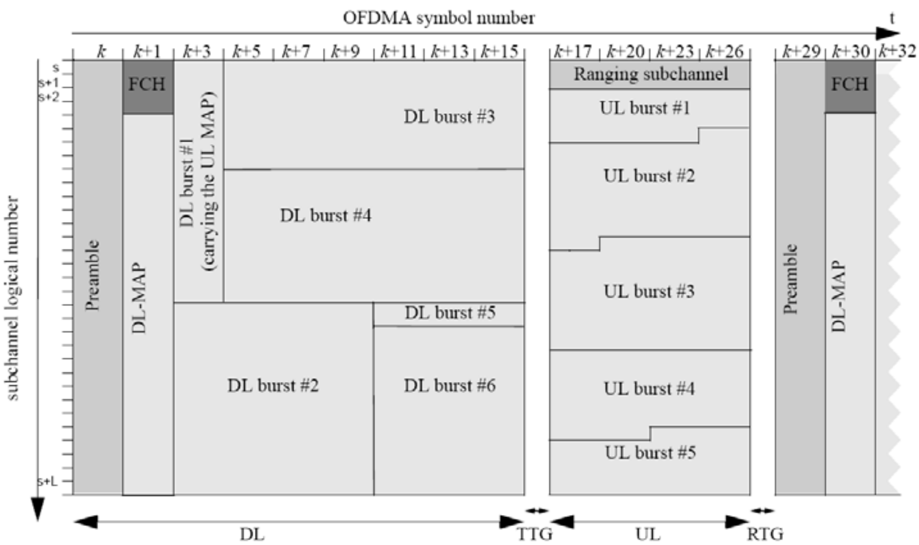

Fig. 15 IEEE 802.16e-2005 frame structure

In the IEEE 802.16e-2005 system, the basic unit is a sub-channel in the frequency domain. The process to pick up sub-carriers to form sub-channels is called sub-channelization process. There are two kinds of sub-channelization processes as follows:

1. Adjacent (Localized) sub-carrier sub-channelization
2. Distributed (Interleaved) sub-carrier sub-channelization.

As shown in Fig. 16 and Fig. 17, the difference of these two sub-channelization processes is the relative location of the sub-carriers when they are chosen to form a sub-channel.

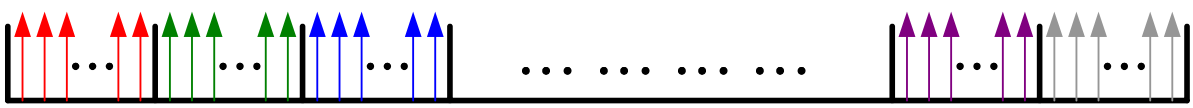

Fig. 16 Adjacent sub-carrier sub-channelization method

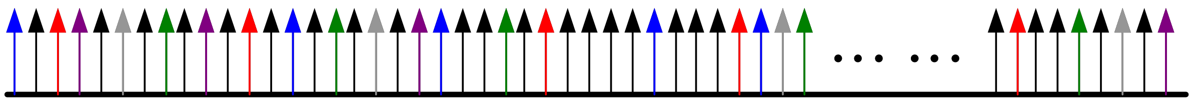

Fig. 17 Distributed sub-carrier sub-channelization method

As shown in Fig. 16 and Fig. 17, adjacent sub-carrier sub-channelization process is picking up successive sub-carriers to form a sub-channel while distributed sub-carrier sub-channelization process is picking up non-continuous sub-carriers to form a sub-channel. These two sub-channelization processes lead to different channel gain of a sub-channel.

In the wireless communication, multi-path fading channel effect is unavoidable. To observe this phenomenon in the frequency domain, the adjacent sub-carriers will have similar channel gains. From the viewpoint of statistics, coherence bandwidth is a statistical measure of the range of frequencies over which the channel passes all spectral components with approximately equal gain and linear phase. Thus, the coherence bandwidth represents a frequency range over which a signal's frequency components have a strong potential for amplitude correlation. Owing to the movement of users, the Doppler Effect is being come into existence. Therefore, the frequency will be shifted. Observing this phenomenon in the time domain, the successive time samples have the same channel gains. From the viewpoint of statistics, the coherence time is a measure of the expected time duration over which the channel's response is essentially invariant. The larger moving speed of the user, the larger the Doppler Shift, and the coherence time is shorter.

According to the characteristics of wireless communication environments, if we pick up the adjacent sub-carriers to form a sub-channel, the channel gains of sub-carriers in this sub-channel will be similar, but the differences of channel gains of different sub-channels can be great. If users report their channel gains of sub-channels at the right moment, cooperating with resource allocation algorithm, BSs can serve users with better channel quality for transmissions. This kind of method can improve system capacity. The time that users report their channel state information and BS executes calculation causes delay, and therefore, this kind of sub-channelization process is more suitable for fixed users or for users with low velocity which have longer coherence time.

Interleaved sub-carriers sub-channelization process picks up sub-carriers distributed over entire frequency band, and sub-carriers in a sub-channel have different channel gains. Therefore, the channel gain of each sub-channel is similar. The benefit of this kind of method is that the resource allocation algorithm is low complex, and as performing the allocation, the BS can decide required number of sub-channels based on the amount of user’s data. Because the channel gains of high speed moving users vary rapidly, and the reporting delay will cause the correlation of channel gain uncorrelated. Consequently, this kind of sub-channelization process is more suitable for high speed users.

The comparison of interleaved and adjacent sub-carrier sub-channelization is listed in Table 1.

	Adjacent Sub-carrier Permutation	Distributed Sub-carrier Permutation
Benefits	Sub-channelization Gain	1. Inter-cell interference averaging. 2. Frequency diversity.
Scheduling	Advanced frequency scheduler to explore frequency selective gain	1. Simple scheduler. 2. Rely on frequency diversity to achieve robust transmission
Channel Condition	Stationary channel	Fast-changing channel

Table 1 Comparison of different kinds of sub-carrier permutation rules

We introduce the adjacent sub-channelization process as follows. In IEEE 802.16e-2005, a bin contains 9 successive sub-carriers within a symbol, as shown in Fig. 18. The fifth sub-carrier is the pilot. A sub-channel is composed of six bins. As shown in Fig. 18, the possible combination is that

1. six bins within a symbol
2. three bins with two symbols
3. two bins with three symbols
4. one bins with six symbols

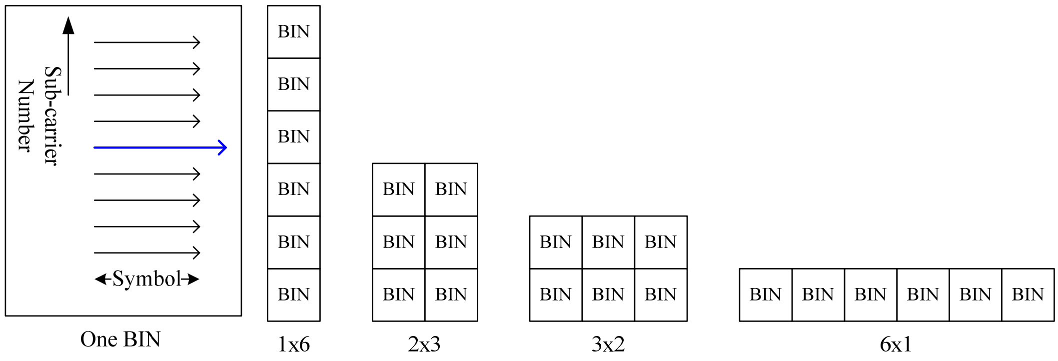

Fig. 18 Band AMC sub-channelization method

The interleaved sub-carrier sub-channelization method is also suitable for cell with sectors, and one of these kinds of methods is called partial usage sub-channelization (PUSC).

The carrier allocation to sub-channels is performed as the following procedure:

1. Dividing the sub-carriers into 120 physical clusters containing 14 adjacent sub-carriers each (starting from carrier 0).
2. Renumbering the physical clusters into logical clusters using the following formula:

$$LogicalClusters = \begin{cases} \text{RenumberingSequence}(PhysicalClusters)\text{ , First DL zone} \\ \text{RenumberingSequence}(PhysicalClusters + 13 \cdot DL\_PermBase) \bmod N_{clusters}\text{ , otherwise} \end{cases}$$

3. Allocate logical clusters to groups. For FFT size=2048, dividing the clusters into six major group. Group 0 includes clusters 0-23, group 1 includes clusters 24-39, group 2 includes clusters 40-63, group 3 includes 65-79, group 4 includes clusters 80-103, and group 5 includes 104-119. The even number of groups contains 24 clusters, and the odd number of groups contains 16 clusters.
4. Allocate the pilot location as shown in the figure below.

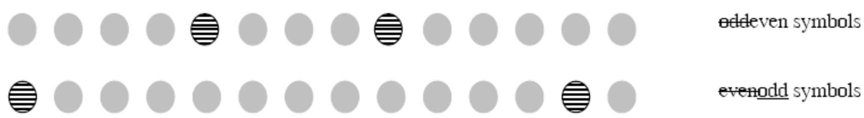

Fig. 19 Pilot location for PUSC

5. Taking all the remaining data sub-carriers within the symbol and using the following formula to form sub-channels

$$subcarrier(k,s) = N_{subchannels} \cdot n_k + \{ p_s [n_k \bmod N_{subchannels}] + DL\_PermBase \} \bmod N_{subchannels} \quad (21)$$

where

$subcarrier(k,s)$ is the sub-carrier index of subcarrier k in subchannel s

$n_k = (k + 13 \cdot s) \bmod N_{subcarriers}$

$p_s[j]$ is the series obtained by rotating basic permutation sequence cyclically to the left s times

$N_{subchannels}$ is the number of subchannels

$N_{subcarriers}$ is the number of data subcarriers allocated to a subchannel in each OFDM symbol

The distributed sub-carrier sub-channelization formulation is shown in Fig. 20.

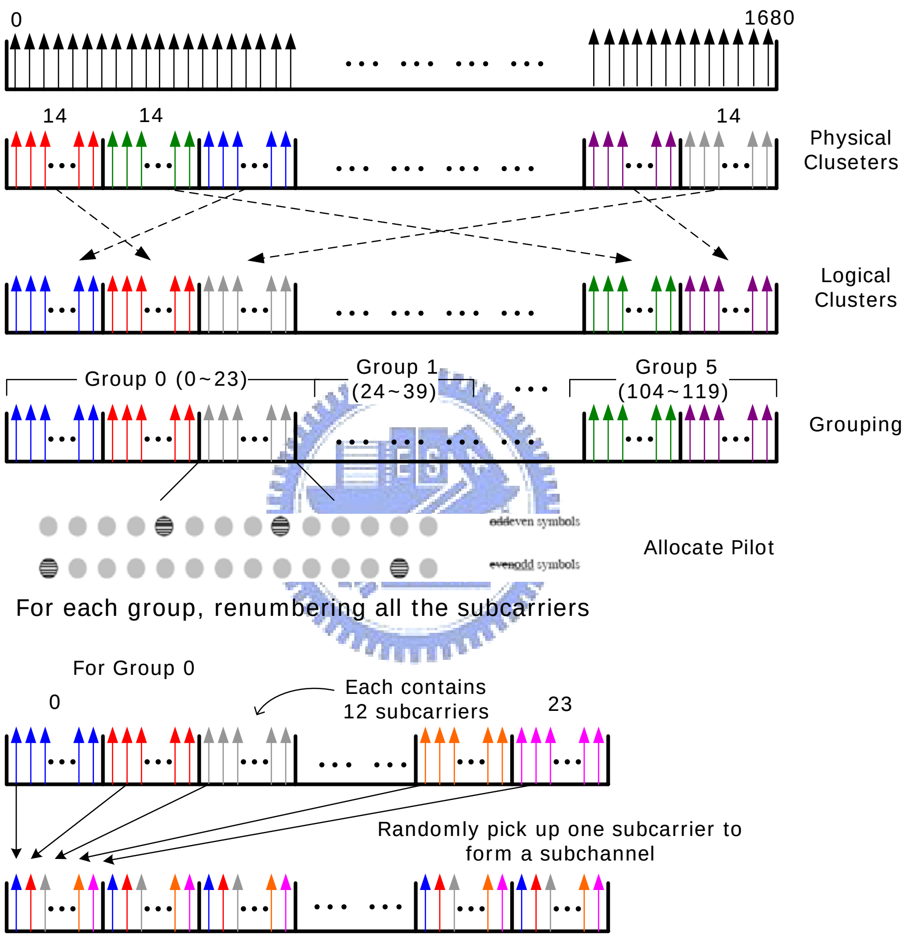

Fig. 20 PUSC sub-channelization process

In the WiMAX system, the moving speed of each user is different. Consequently, the required sub-channelization formulations are also different. To let the two kinds of methods coexist within one frame, the possible way is to form different kinds of sub-channels at different time instants. To achieve this goal, IEEE 802.16e-2005 specification defines STC_DL_Zone_IE() information element, and the BS can inform users the sub-channelization rules of the DL burst through this information element.

Chapter 3 Handoff in OFDMA Systems

In the cellular mobile communication systems, the movement of users causes the variations of channel quality so that the service quality may become worse. In order to provide the users with better communication qualities and uninterrupted services, the handoff mechanisms should be initiated to switch them to other BSs with better channel quality. The goals to perform handoff are presented as follows: [4, 21, 22]

1. When users are in the vicinity of cell border, the handoff mechanisms should be initiated to keep the services uninterrupted.
2. Users can choose the BSs with better channel quality for communications to reduce the power consumption and the interferences to other users.
3. Performing handoff can achieve the load balancing of the systems.
4. Performing handoff maintains the Quality-of-Services (QoS) of the users.

The initiation of the handoff mechanisms may result from the changes of the connection quality, the service requirement, the users' moving speed, the network conditions, and so on. In the IP-based OFDMA system, like WiMAX system based on IEEE 802.16e-2005, both of the network and the link layer handoffs should be considered in designing handoff mechanisms. The service disruption caused by the handoff depends on the processing time of the two layers handoff. To achieve seamless handoff, therefore, it would be better to shorten the processing time.

In the WiMAX system, there are three kinds of the handoff mechanisms, the hard handoff, the macro diversity handoff (MDHO), and the fast base station switching (FBSS).

3-1 Hard Handover

As shown in Fig. 21, the user periodically scans the signal qualities of the serving and the neighboring BSs for determining the requirement of handoff when being served. If the signal quality of the neighboring BS is better than that of the serving BS by a threshold Th_change, the user can inform the serving BS to initiate the handoff mechanism. The user would first perform the link layer handoff for the initial ranging including the clock adjustment, the power adjustment, and the carrier frequency adjustment. After completed, the network reentry process will be initiated. However, the network and the link layer handoffs cause service interruption because they take time.

Referring to the hard handoff mechanism, it has to disconnect the old connection and then reestablish the new one, which is called break-before-make (BBM) mechanism. The benefits of the hard handoff include that it does not occupy the network and the link layer resources, and the signaling procedure is simpler. However, the user's packets are not correctly delivered to the new BS before the network layer handoff completion. Consequently, the service is interrupted which may not satisfy the quality-of-service (QoS) of real-time services when the users perform the handoff. Moreover, the hand handoff has the ping-pong effect which is related to the setting of the value of Th_change. If the setting value of Th_change is too low, it might leads to wrong handoff decisions which make the user be switched between the new and old BSs back and forth, and cause the resource waste and the service interruption. If the value is higher, it can avoid the problem of making the wrong handoff decision and reduce the occurrence of the ping-pong effect, but the signal quality of the user might become worse.

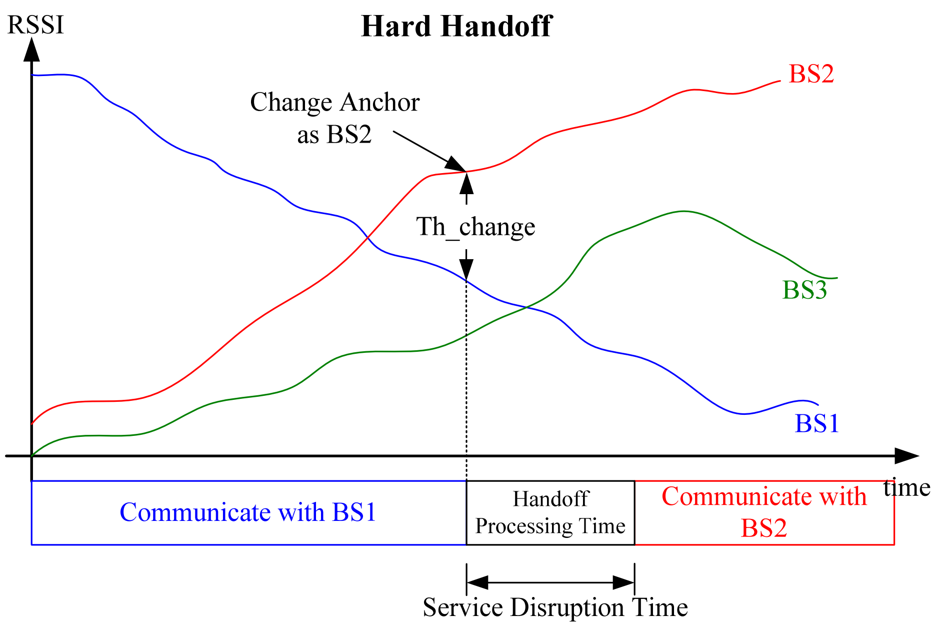

Fig. 21 Hard handoff initiation algorithm

3-2 Macro Diversity Handover

Different from hard handoff, soft handoff [21-22] allows users to establish connections with multiple BSs. As shown in Fig. 22, the user periodically scans the signal qualities of the serving and the neighboring BSs for determining the requirement of handoff when being served. If the signal quality of the neighbor BS has the trend to become better, and when the differential value of signal quality between the serving BS and the neighboring BS is smaller than the threshold Th_add , as shown in Fig. 22, the user informs the serving BS to add this neighbor BS into the diversity and establish the network layer data path through signaling exchanges such that the user's packets can be forwarded to the new BS in advance. After this operation is completed, the user can communicate with all the BSs in the diversity set. When the user receives data from all the BSs in the diversity set, it can perform the combining to get the diversity gain.

There are two kinds of combining methods [23]. One is called radio frequency combining (RFC) and the other one is called maximum ratio combining (MRC). Without loss of generality, we assume that there are two BSs in the diversity set. As RFC is performed, the two BSs transmit the same data on the same sub-carriers to the user. There is a delay between the two signals from the two BSs, but the user treats this delay as the results of multi-path channel effect. Consequently, the user doesn't experience that there are two BSs transmitting the data to him/her and decodes packets as communicating with only one BS. When the MRC is performed, the two BSs send the same data on their own sub-channels to the user, and the user combines the soft bits to decode the data.

Different from the hard handoff, macro diversity handoff allows the user to communicate will multiple BSs, and the problems of ping-pong effect and the long service disruption time are solved. In macro diversity handoff mechanism, the serving BS forwards the user's data to all the BSs in the diversity set, and the user communicates all of them to get the better signal quality. However, the macro diversity handoff consumes not only the network layer resources but also the link layer resources.

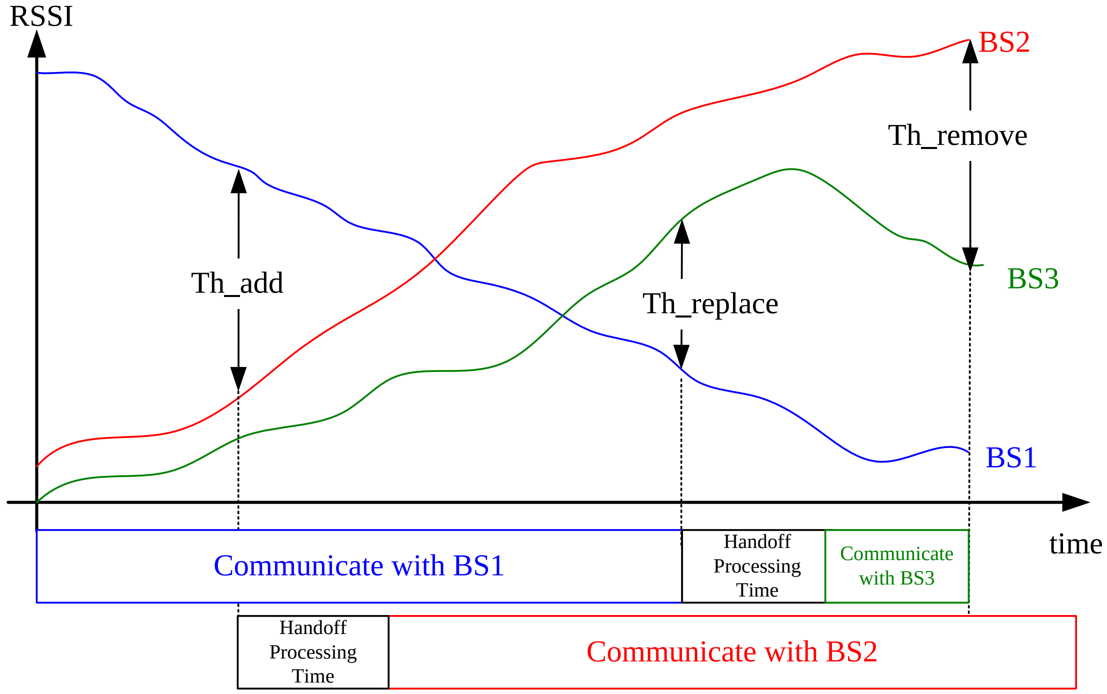

Fig. 22 Macro diversity handover initiation algorithm

3-3 Fast Base Station Switching

For the hard handoff, the service disruption takes too long so that its QoS can not be guaranteed. On the contrary, the macro diversity handoff can solve this problem, but it occupies the radio resources of the link layer. Therefore, fast base station switching (FBSS) in IEEE 802.16e-2005 [12] adopts the same network layer handoff with MDHO in which the user's packets will be early forwarded to all BSs in the diversity set. On the other hand, FBSS utilizes the same link layer handoff with the hard handoff in which the user can only communicate with one BS at a time. In so doing, the radio resources of FBSS can be saved, and the QoS can be guaranteed as well.

When the differential value of signal quality between the serving BS and the neighboring BS is smaller than the threshold Th_add, as shown in Fig. 23, the mobile adds the neighboring BS into the diversity set, initiates the network layer handoff, and establishes the data path between the serving BS and the newly-added BS. Therefore, the user's packets belonging to MS can be transferred to BS2. Different from the time of network reestablishment for the hard handoff, the FBSS would establish the network connections in advance which can help solve the problem of packet loss for the network disconnection. When communicating with the BS, besides, the user can request the serving BS to allocate the scanning intervals in order to let it perform initial ranging with the neighboring BSs which can adjust the power, the timing, and the carrier frequency in advance to reduce the time required for the link layer handoff. The more detailed signaling procedure in this part will be explored in Chapter 4.

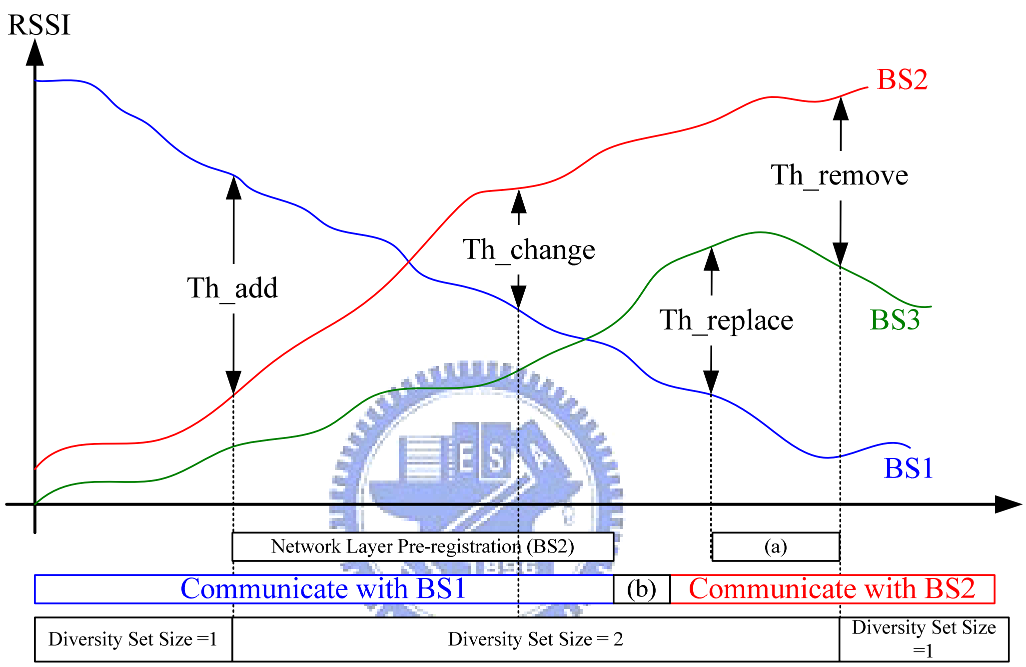

Fig. 23 Fast Base Station Switching initiation algorithm

Chapter 4 Signaling Procedure for FBSS

4-1 Signaling Procedure for Network Layer Handoff

4-1.1 Data Path Set up

In the handoff signaling procedure proposed by WiMAX Forum [19], the access service network gateway (ASN-GW) performs the functionality of foreign agent (FA). If we switch the serving BS between the BSs controlled by the same ASN-GW, we only need to update the data path without performing the layer 3 handoff, which needs to change the care-of address if Mobile IP is used. If we change the serving BS between the BSs controlled by different ASN-GWs, the data path needs to be established between the new BS and ASN-GW first so that the user's packets can be forwarded to the new BS correctly. Then, the Mobile IP handoff signaling might be initiated such that the correspondent can forward packets directly to the mobile's care-of address. In so doing, the time to execute Mobile IP signaling which causes service disruption can be reduced. The Mobile IP signaling procedure is explored in next section.

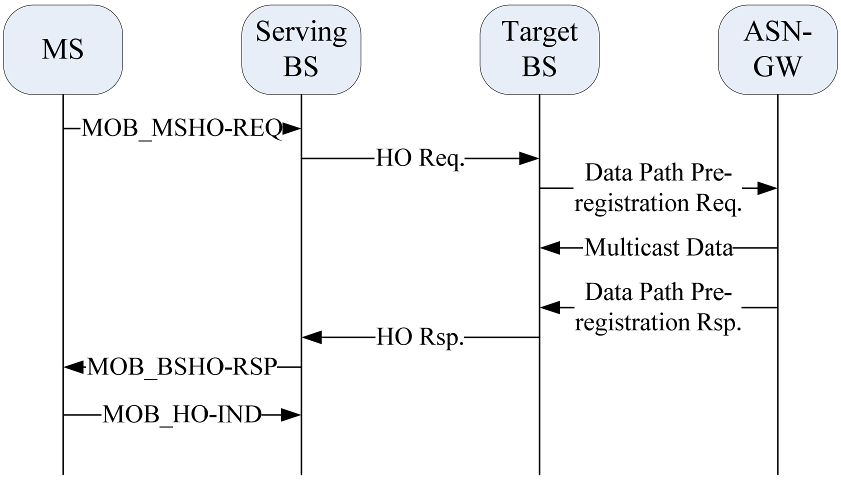

Fig. 24 Signaling procedure for establishing data path

Fig. 24 is the signaling procedure for establishing data path. The user can decide to add the target BS into the diversity set based on the scanning results. The user transmits MOB_MSHO-REQ message to the serving BS for adding the target BS into the diversity set and the target BS performs the signaling exchanges with the ASN-GW to set up the data path. As the completion of establishing data path, the target BS will transmit handoff response to the serving BS, and the serving BS will inform the user that the data path has been established. Then the user will transmit confirm message MOB_HO-IND to the serving BS.

4-1.2 Mobile IP

Before introducing the Mobile IP signaling procedure [24], define the following network elements:

- Home address: When the user is in its home network, the packet can be delivered to the user correctly through this IP address.
- Care-of Address (CoA): When the user is in the foreign networks, the user will obtain a Care-of Address. The user can use this CoA as its IP address such that the packets can be transmitted/received correctly.
- Home Agent (HA): A router located at the home network. When the user is in foreign networks, HA intercepts the packets belong to the user and forwards these packets to the current CoA of the user through IP-in-IP tunneling method.
- Foreign Agent (FA): A router located at the foreign network. FA receives the packets tunneled from the HA and de-tunnels these packets. According to the IP address of the IP header, the packets can be correctly sent to the user.
- Authentication, Authorization, Accounting (AAA) server: A server for authentication, authorization, and accounting. This server will verify if the user is a legal one. As performing the signal exchanges, this server is also used to verify the factuality of the signals.
- Mobile Node (MN): the user.
- Correspondent Node (CN): the user who is communicating with the MN currently.

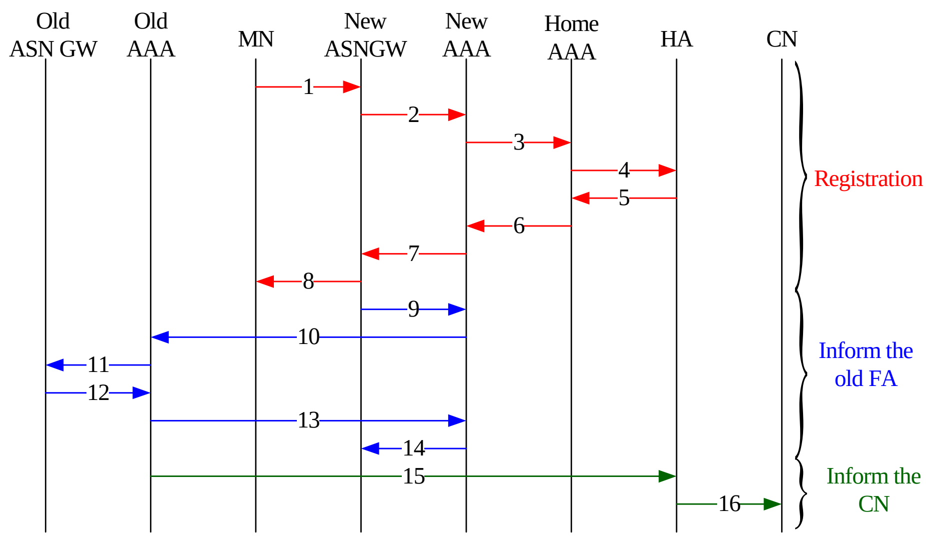

Fig. 25 Mobile IP signaling procedure

When the user receives the advertisement of the FA, he/she knows that he/she is in the foreign network. Therefore, the user needs to perform the Mobile IP signaling procedure to maintain the network connection such that packets can be transmitted/received correctly.

Fig. 25 is the detail signaling procedure for Mobile IP, and the signaling procedure is produced base on the WiMAX network reference model and Mobile IPv4 signaling procedure proposed by IETF. In WiMAX networks, the ASN-GW performs the functionality of the FA. Message 1 represents that the user registers with the new ASN-GW and provides its home address and Network Access Identifier (NAI) to the ASN-GW. Next, the ASN-GW verifies if the user is a legal one through AAA servers using the message 2, 3, and 4 to transmit the user's information to the HA for registration. If so, the HA will transmit messages back to the ASN-GW through AAA servers. Then the ASN-GW informs the old ASN-GW to let the old ASN_GW forward packets belong to the user to the new ASN-GW. Message 15 and 16 is to inform the correspondent node about the changing of the IP address such that the packets can be routed directly to the new ASN-GW without being routed to the old ASN-GW to reduce the consumption of network layer resources.

4-2 Signaling Procedure for Link Layer Handoff

4-2.1 Scanning and Association

The BS periodically broadcasts MOB_NBR-ADV message to all users in order to provide them with the information about neighboring cells so that users can synchronize with neighboring BSs quickly. Moreover, the users can utilize the information to determine the targets for handoff. Users can also decide if they need to perform scanning. If so, the users will be arranged to do initial ranging with the neighboring BSs to adjust timing, transmit power, and carrier frequency.

A MOB_SCN-REQ message may be transmitted by an MS to request scanning intervals for the purpose of seeking available BSs and determining their suitability as targets for handoff. This information might also contain the base station id (BSID) and scanning types. In the message, the following items may also be included.

1. Scan duration: Duration (in units of frames) of the requested scanning period.
2. Interleaving interval: The period of MS's normal operation which is interleaved between scanning durations.
3. Scan iteration: The requested number of iterating scanning interval by an MS.

A MOB_SCN-RSP message shall be transmitted by the BS either unsolicited or in response to an MOB_SCN-REQ message sent by an MS. MOB_SCN-RSP message consists of scanning durations (in units of frames), the report modes, the report periods, start frame, interleaving interval, scan iterations, BSID, and scanning types.

In the scanning procedure, if the users support association function, they would acquire and record the scanning results and service availability information which can become the basis of determining the targets for handoff and reducing its processing time. If the BSs can support coordination, the serving BS may coordinate the association procedure with the requested neighboring BSs through the backbone network, arranging a contention-free initial rang code and ranging slots to the users. In so doing, the fast ranging can be achieved. The scanning procedure is shown in Fig. 26 [12]:

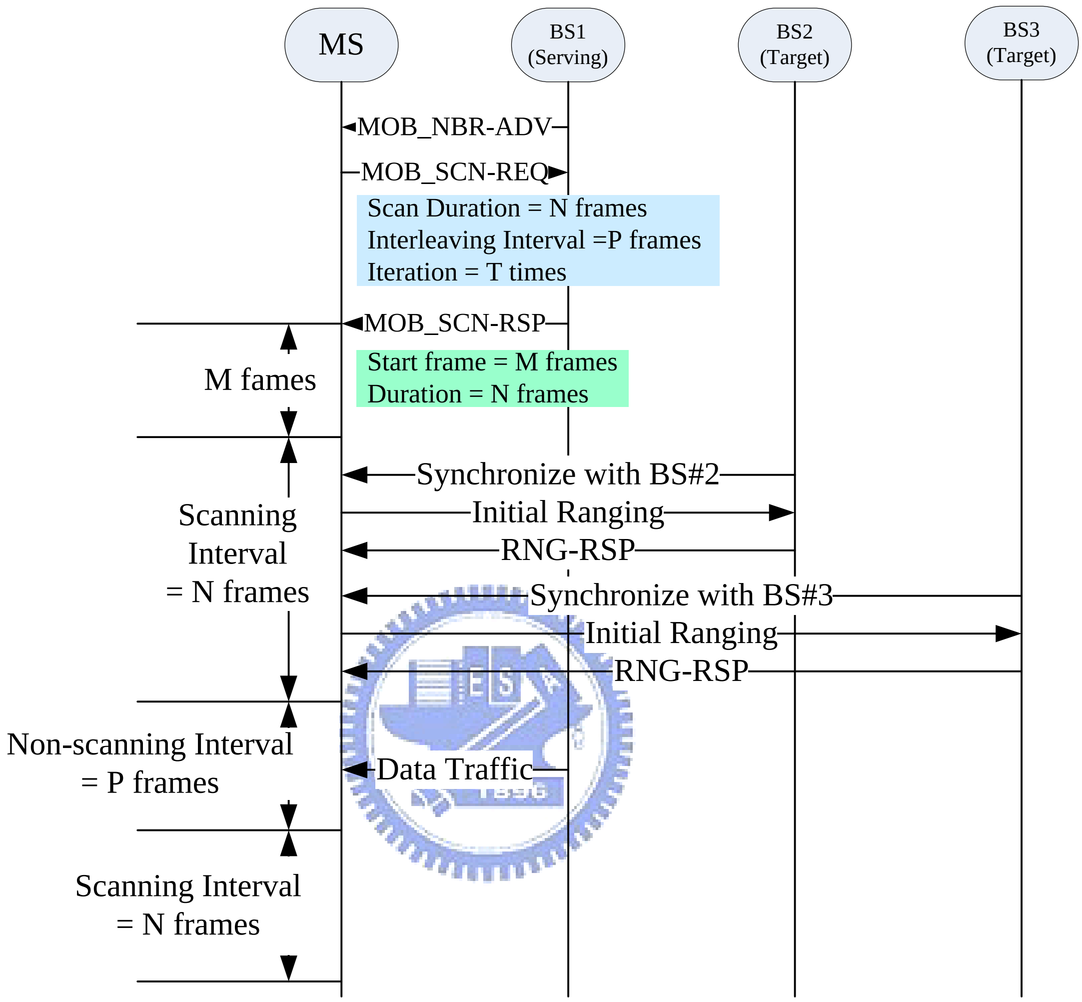

Fig. 26 Signaling procedure for scanning

As shown in Fig. 26 in which N frames is meant for the scan duration, P frames for the interleaving interval, and T times for the iteration, the MS sends MOB_SCN-REQ message to the serving BS to request scanning the neighboring BS1 and BS2. When the BS receives the MS's request, it will use the MOB_SCN-RSP message to reply back to MS with the same information receiving from it. Besides, the serving BS also informs the MS that the scanning will be start M frame later. If the serving BS requests the MS to report the scanning results, the MS can use MOB_SCN-REP message to report them back.

4-2.2 Initial Ranging and Fast Handover Ranging

In the IEEE 802.16e-2005 system [12], the uplink sub-frame allocates the ranging sub-channels under the OFDMA mode to let users perform ranging which can adjust timing, transmit power, and carrier frequency. For different purposes, ranging processes can be divided as follows:

1. Initial ranging
2. periodic ranging
3. bandwidth request
4. handover ranging

There are 256 pseudo-noise ranging codes (0~255) divided into four groups. The first N codes produced are for initial ranging, the next M codes produced are for periodic ranging, the next L codes produced are for bandwidth request, and the next O codes produced are for handover ranging. As shown in Fig. 27, MS can randomly choose a code from its group according to what the MS would like to perform. When the BS receives the message, it can recognize which operation MS would like to execute through the code.

N (Initial Ranging)	M (Periodic Ranging)	L (Bandwidth Request)	O (Handover Ranging)

Fig. 27 Ranging Codes

Fig. 28 is the initial ranging procedure. The brief description of ranging procedure is as follows:

1. When the user receives the UL_MAP, it will find out the location of ranging channels (slots). The user transmits randomly selected code in a randomly selected ranging slot to the BS.
2. The BS will reply the power, timing, and carrier frequency corrections with ranging code and ranging slot to the user using RNG-RSP.
3. Receiving RNG-RSP, the user will adjust its power, timing and carrier frequency.
4. The process is performed iteratively to adjust parameters. Until the signal quality of the

uplink is satisfied, the BS will inform the user that the state is success and the connection is established. The user can transmit/receive data at this moment.

When the connection has been set up and the data have been transmitted, the user needs to perform ranging periodically to maintain the connection quality owing to the movement of the user which causes the change of the connection quality. The periodic ranging procedure is similar with the initial ranging one, and the difference is that it is a contention-free ranging.

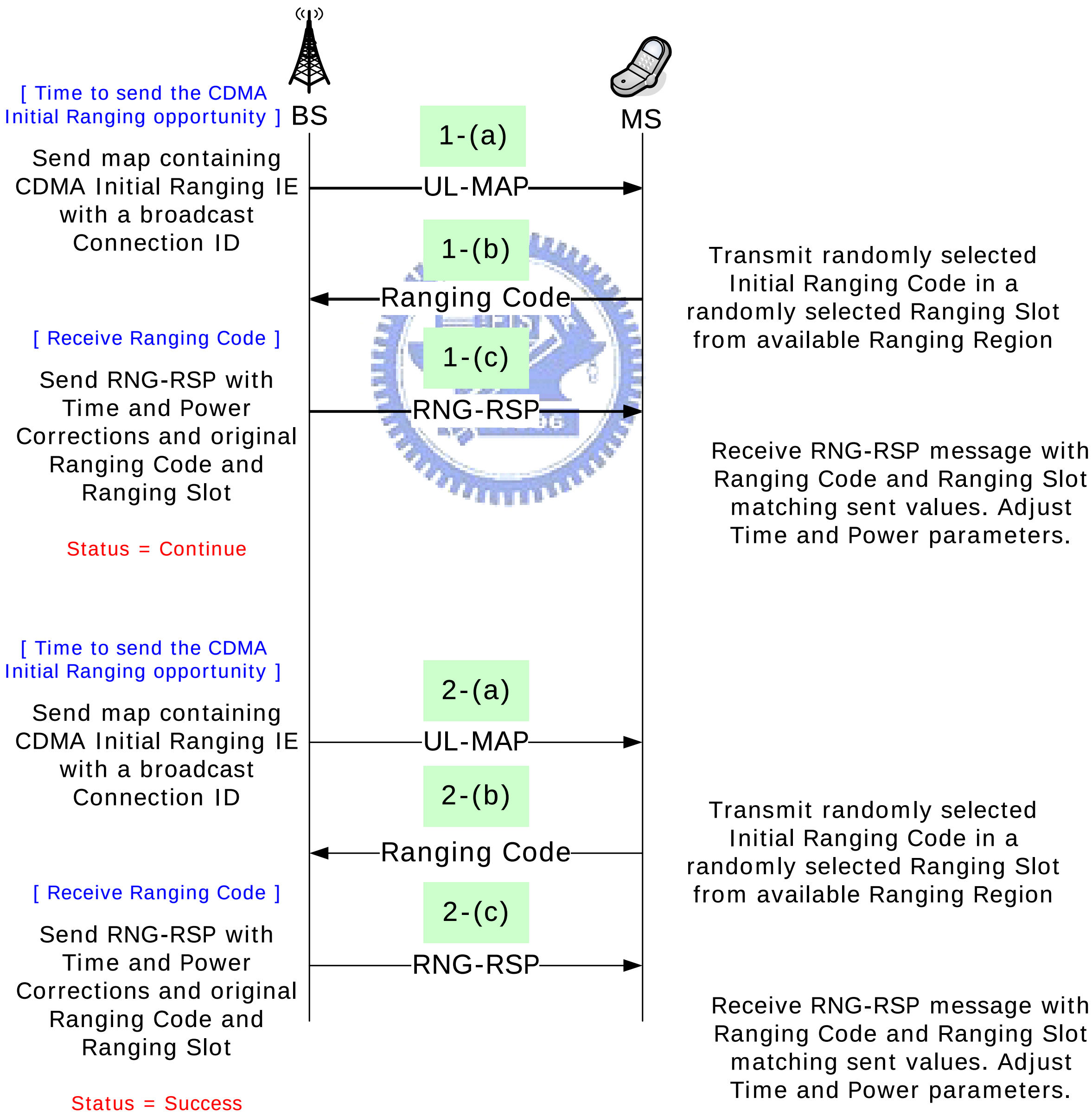

Fig. 28 Initial ranging signaling procedure

We explain how to use the scanning results to expedite the link layer handoff such that the service disruption time can be reduced. In IEEE 802.16e-2005, it proposed the association functionality which records the scanning results for fast handoff. We assume that as performing the association, MS has performed the following actions:

1. For the neighbor BSs, the user's timing and carrier frequency have been adjusted correctly through association. So, as performing handover ranging, only the power needs to be adjusted.
2. The possible handoff targets have already reserved a dedicated ranging slot and a dedicated ranging code to the user, so the user doesn't have to perform the contention ranging.

For the power correction, our assumption is presented as follows:

1. The user transmits the dedicated ranging code using the maximum transmit power.
2. When the BS receives the ranging code and estimates it, the margin users need to adjust would be replied back by using the defined "TLV" (type/length/value) with 8 bites appended to UL_MAP_Fast_tracking_IE to complete adjusting only once instead of "step size" adjustment.
3. The operation speed of power amplifier is very fast, and the power can be corrected about 5 microseconds.

We will transmit the information by further merging 1-(c) into 2-(A), so that we can shorten the processing time required for ranging.

The modified ranging procedure is shown in Fig. 29. Because uplink power can be oriented by the power amplifier in one time, the strength receiving from the users in 2-(b) can meet the basic communication needs. After handover ranging (2 frame time), the MS can return to the normal operation with the new BS.

Owing to the establishment of data path, the MS's packets have been forwarded to the new BSs. Therefore, the time required for performing link layer ranging becomes the main factor which causes the service disruption. In IEEE 802.16e-2005, the frame durations are from 2 to 20 milliseconds; in the handoff process, thus, the maximum time of service disruption caused by handover ranging is 40 milliseconds which is counted by 20 milliseconds for 2 frames. In so doing, the requirement for service disruption can satisfy real time services.

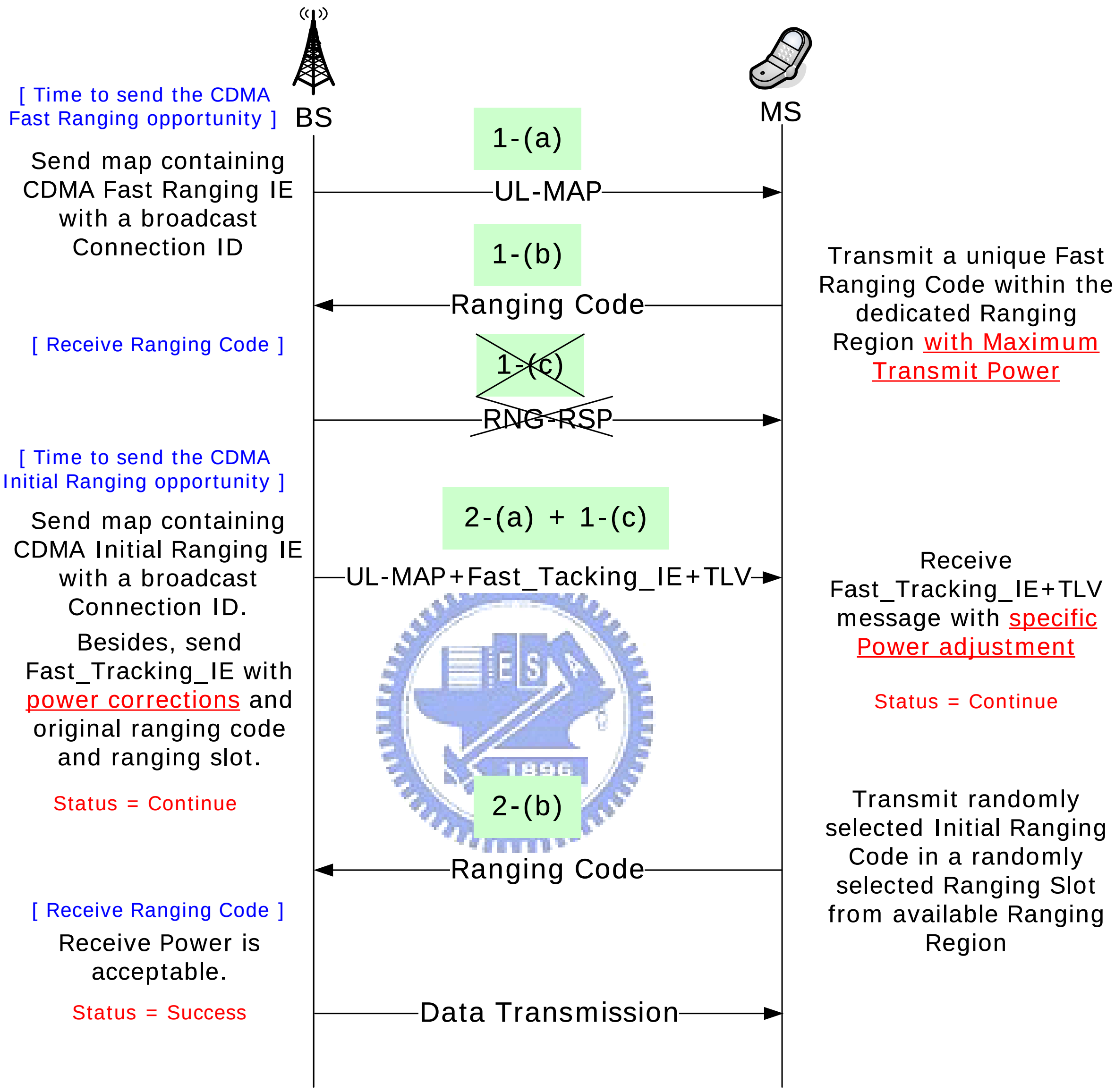

Fig. 29 Modified fast handoff ranging signaling procedure

Chapter 5 FBSS with FFR Cell Structure

5-1 Zone Concept Sub-channelization Method

Fractional frequency reuse (FFR) cell structure and two kinds of sub-channelization processes in WiMAX system have been introduced in Chapter 2. To implement FFR cell structure, the BS must arrange different frequency reuse sub-channels for data transmissions within a frame. We consider that FFR is applied and all BSs have the same carrier frequency. The process of forming different sub-carrier sub-channelizations is explained as follows:

1. The distributed sub-carrier sub-channelization process is to divide all usable sub-carriers into 120 physical clusters, and renumbers all of the physical clusters into logical clusters based on DL_PermBase which is provided by the serving BS. Afterwards, the logical clusters are grouped, assigned pilot location, and then take all remaining sub-carriers to form a sub-channel based on DL_PermBase. Owing to the different values of DL_PermBase for each BS, we cannot segment on the frequency for allocating different sub-channels to different BSs. As shown in Fig. 30, the possible way is to segment a frame into many time zones in which the different time zones are allocated to the different BSs for data transmission to achieve FFR.

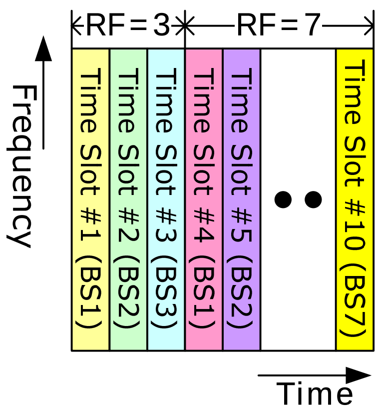

Fig. 30 Frame structure for fractional frequency reuse

2. The adjacent sub-carrier sub-channelization is formed in the same way for all BSs; therefore, it can be segmented either by the time domain or the frequency domain to complete FFR cell structure.

5-2 FBSS Initiation Algorithm for FFR Cell Structure

This section explores how the fast handoff mechanism implements the special FFR cell structure to achieve seamless handoff. In the traditional cell planning for meeting SINR's need at the cell border, the minimum frequency reuse factor is regarded as K. Under the system structure of the factional frequency reuse, a BS contains a variety of sub-channels with different frequency reuse factor within a cell's coverage. When close to the BS, the user can use the sub-channels with the reuse factor smaller than K to increase the system capacity. Besides, planning a small portion of sub-channels with reuse factor larger than K is called handoff sub-channels that can improve the poor signal quality during the handoff. The concept of cell planning is shown in Fig. 31.

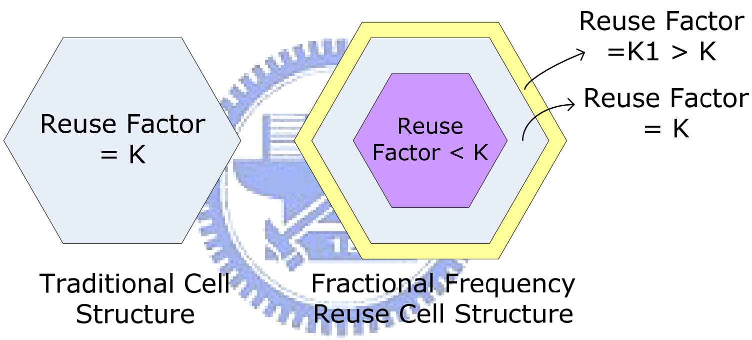

Fig. 31 Cell planning for fractional frequency reuse cell

Three kinds of handoff mechanisms have been introduced in Chapter 3. To design the fast base station switching algorithms suitable for the fractional frequency reuse cell structure, we redefine the following parameters for the proposed handoff algorithms by referring to FBSS in IEEE 802.16e-2005, the previous hard and soft handoff mechanisms, and the white paper proposed by WiMAX Forum.

1. Candidate set: the set of the neighboring BSs in which its preamble can be received by the MS.
2. Active BS: An active BS is informed of the mobile station capabilities, security parameters, service flows, and full MAC context information.
3. Diversity Set: The diversity set contains a list of active BSs to the MS. The diversity set is managed by the mobile station and base station. The diversity set is applicable to

macro diversity handover (MDHO) and fast BS switching (FBSS).

4. Serving BS: For any mobile station, the serving base station is the base station with which the mobile station has most recently completed registration at initial network entry or during a handover.
5. Target BS: The base station that a mobile station intends to be registered with at the end of a handover.
6. Maximum Diversity Set Size: The maximum allowable number of BSs in the diversity set.

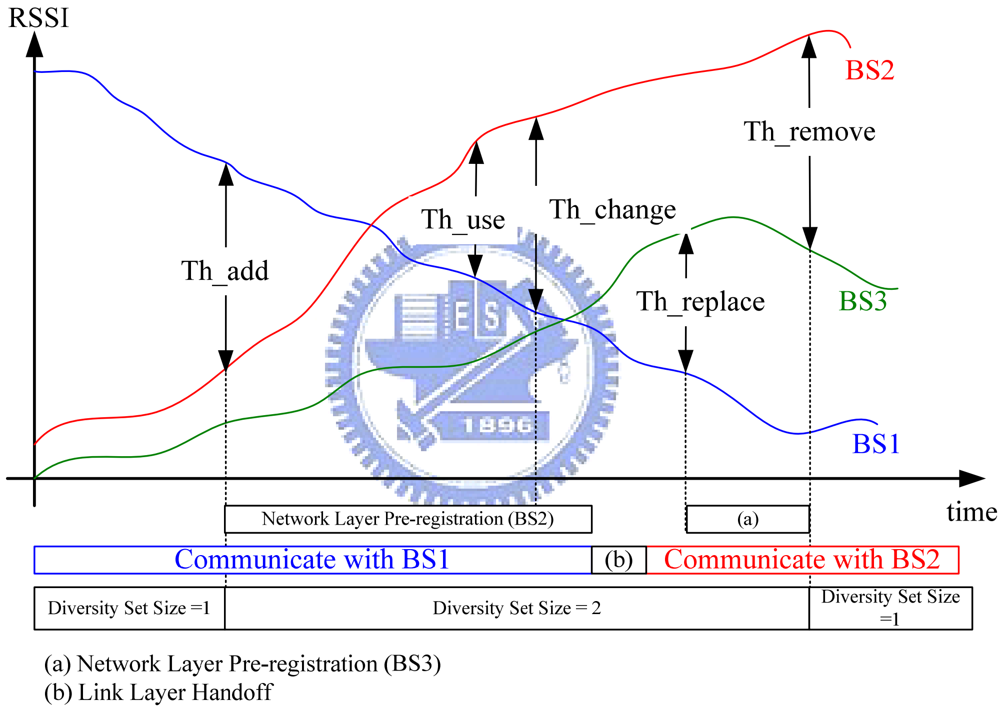

Fig. 32 Modified FBSS initiation algorithm under FFR cell structure

Fig. 32 is the modified FBSS initiation algorithms under the FFR cell structure. To implement the algorithm, we define the following parameters and initiate some actions based on the received signal strength indicator (RSSI) of the preamble.

1. Th_add: If (RSSI of Serving BS) – (RSSI of Best Candidate Set BS) < Th_add, the network pre-registration process will be started. This process adds the Best Candidate BS into the diversity set and set up the data path, so that the user’s packets can be delivered to the new BS correctly.
2. Th_change: If (RSSI of Best Diversity Set BS) – (RSSI of Serving BS) > Th_change and

the data path of the network layer has been completely established, the link layer handoff will be launched to turn the Best Diversity Set BS into the new Serving BS.

3. Th_replace: If the Diversity Set size is equal to the Maximum Diversity Set size and (RSSI of Best Candidate BS) – (RSSI of Worst Diversity Set BS) > Th_replace, the BS Candidate BS replaces Worst Diversity Set BS to become one of the diversity set and to start the establishment of the data path.
4. Th_remove: If (RSSI of Serving BS) – (RSSI of Worst Diversity Set BS) > Th_remove, the Worst Diversity BS is removed from the Diversity Set to reduce the waste of the network resources.
5. Th_use: If (RSSI of any Diversity BS) – (RSSI of Serving BS) > Th_use, the Serving BS serves the users so as to improve their signal quality by using the pre-arranged handoff sub-channels.

Shown by a random distribution, the time for establishing data path depends on the network state, network topology, and routing path. Besides, when the Th_add and Th_change is fixed, as shown in Fig. 33, we define it into Tc the time change from Th_add to Th_change which is caused by RSSI's differential values between the Serving BS and the Best Candidate Set BS. The value of Tc is also a random distribution which depends on the moving speed of the user and the shadow fading.

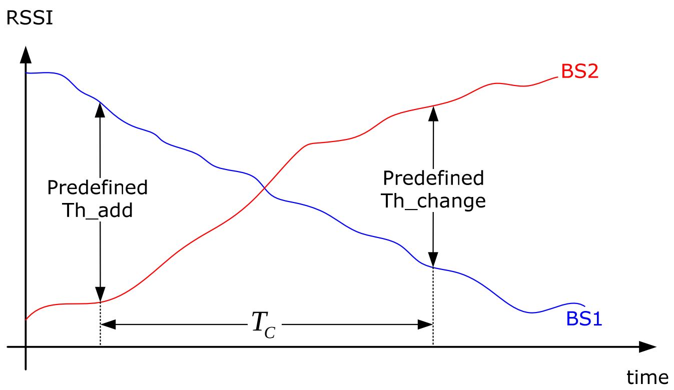

Fig. 33 The definition of Tc

5-3 Signaling Procedure

The signaling procedures of network layer handoff, scanning, initial ranging, fast handover ranging have been introduced in Chapter 4. We describe signaling procedure for fast base station switching under fractional frequency reuse cell structure in this section.

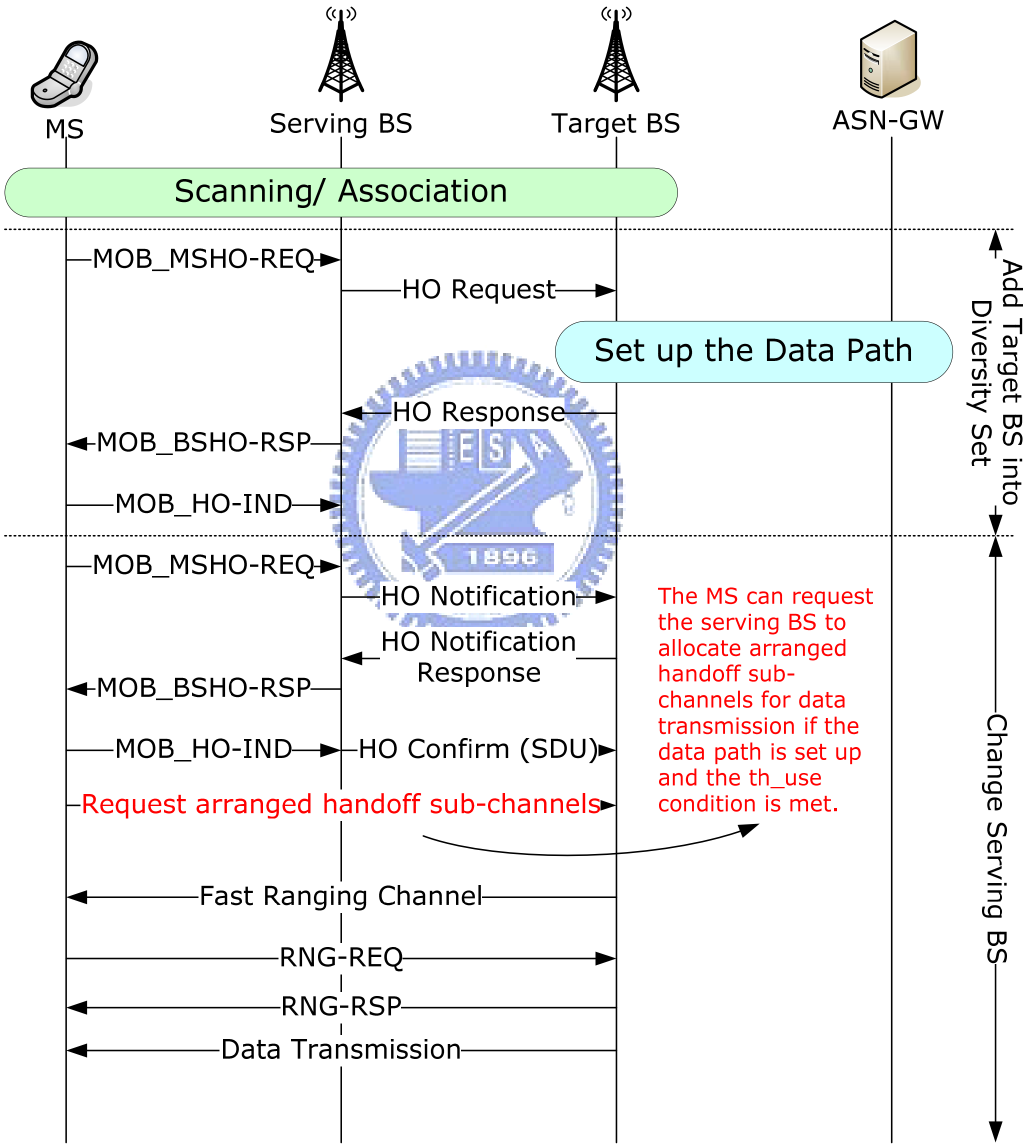

Fig. 34 FBSS signaling procedure

Fig. 34 is the signaling procedure for FBSS. It can be divided into two parts. The first part is the signaling procedure to add the target BS into the diversity set. As the serving BS receives

MOB_MSHO-REQ message from the MS to add the neighboring BS into the diversity set, it negotiates with the target BS through backbone networks message exchanges such that the user's information can be delivered to the target BS. The other part is to change the serving BS. As the serving BS receives MOB_MSHO-REQ message from the MS to change serving BS, the serving BS can inform the target BS to allocate a dedicated ranging code and slot to the handoff user. The handoff user can perform contention-free fast handover ranging to expedite the handoff such that service disruption time is minimized. On the other hand, the serving BS might be requested by the MS to serve him/her with especially-arranged handoff sub-channels to increase the signal quality if the Th_use condition is met.

Chapter 6 Simulation Results

Building up a simulation environment which fit in with real situations simulates the operations of the systems correctly. In section 6-1, the simulation environment setting and simulation techniques are introduced. Simulation results and discussions are presented in section 6-2.

6-1 Simulation Environment and System Parameters

In the wireless communication environment, two types of fading effects that characterize mobile communication: large-scale fading and small-scale fading. Large-scale fading represents the average signal power attenuation or the path loss due to motion over large areas. This phenomenon is affected by prominent terrain contours (e.g., hills, forests, clumps of buildings, etc.) between the transmitter and receiver. The receiver is often said to be shadowed by such prominences. The statistics of large-scale fading provide a way of computing an estimate of path loss as a function of distance between the transmitter and receiver. Large-scale fading is often described in terms of path loss and shadow fading. On the other hand, small-scale fading characterizes the rapid fluctuations of the received signal strength over very short travel distances or short time durations. These three kinds of fading models are described in the following sections.

Path Loss Model

Path loss describes the mean signal strength attenuation versus distance. In this thesis, we adopt the WINNER C2 model proposed by IST-WINNER project [25]. This model is obtained from the measurement in the urban environment. The mathematical description of the model is as follows:

$$PathLoss(d) = 35 \cdot \log 10(d) + 38.4 + 20 * \log 10\left(\frac{f_{carrier}}{5}\right) \tag{23}$$

$f_{carrier}$: Carrier Frequency (GHz)

d : Distance between the mobile and the BS (meter).

Shadow Fading Model

When there are obstacles in the propagation path between the BS and the mobile, the received signal quality is fluctuated. Owing to user's movement, signal propagation path will be changed, and thus, the receiver is not shadowed by such obstacles anymore. Shadow fading describes this kind of phenomenon which is the variations about the mean signal strength. According to the measurements from real wireless propagation surroundings, the shadow fading is log-normal distributed. Therefore, if we do not consider special terrain, we would model the shadow effect as a log-normal random variable to generate the shadow fading effects in the simulations. The standard deviation of this random variable depends on the simulation surroundings. According to the measurement results proposed by WINNER C2 model, the standard deviation is 8 dB [25].

The most popular autocorrelation model of the shadow fading is the model proposed by Gudmundson [26]. Based on the measurement results, Gudmundson proposed the decreasing correlation function as follows:

$$R(k) = \sigma^2 a^{|k|}$$
$$a = \varepsilon_D^{vT/D} \tag{24}$$

Where

$R(k)$: the correlation of two points.

σ : the standard deviation of shadow fading.

k : the samples between two points.

a : the correlation factor which represents the autocorrelation coefficient between adjacent samples.

v : the mobile velocity.

T : the sampling period.

D : the de-correlation distance obtained by measuring the environments

ε_D : the correlation between two points separated by distance D.

If the correlation factor is equal to 0.5, the decreasing correlation function proposed by Gudmundson can be expressed as:

$$\rho(\Delta x) = e^{-\frac{|\Delta x|}{D}\ln 2} \tag{25}$$

Where

$\rho(\Delta x)$: autocorrelation coefficient between two samples

Δx: the distance between two samples which is equal to $|k \cdot T \cdot v|$

D: the de-correlation distance

Small-scale fading

In a cellular mobile radio environment, the surrounding objects, such as houses, building or trees, act as reflectors of radio waves. These obstacles produce reflected waves with attenuated amplitudes and phases. If a modulated signal is transmitted, multiple reflected waves of the transmitted signal will arrive at the receiving antenna from different directions with different propagation delays. These reflected waves are called multi-path waves. Due to the different arrival angle and times, the multi-path waves at the receiver site have different phases. These reflected waves are combined together constructively or destructively giving rise to received signal fading at the receiver site depending on the phases of the reflected waves. This is called multi-path channel effect.

To simulate the effects of multi-path channels, the most important thing is to simulate the scattering effects. One of the effective channel simulators has been suggested by Jake. Jake's model [15,28] assumes that reflector close to the mobile are finite and uniformly distributed over two-dimension plane. As the mobile moves toward a specific direction, the Doppler frequency offset of each reflected signals can be obtained. Because the antenna of the cell phone is usually omni-directional, the received signal is the sum of all reflected signals. The scattering environment considered by Jake is shown in Fig. 35.

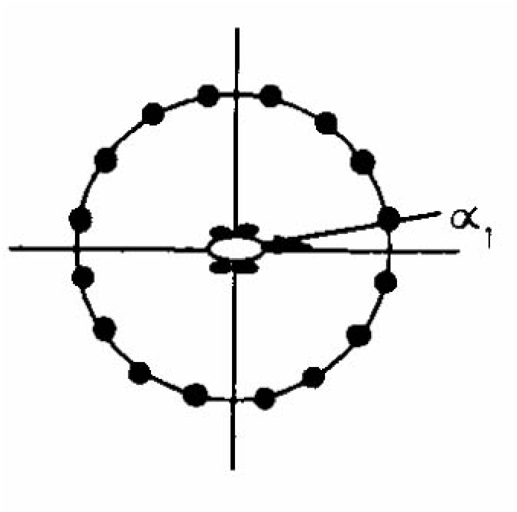

Fig. 35 The angle of incidence considered by Jake's model

The mathematical description of the Jake's model is

$$r(t) = \sum_{n=1}^{N} e^{-j\left(\hat{\phi}_n + 2\pi f_m t \cos\theta_n\right)}$$
$$where \quad \hat{\phi}_n = 2\pi\left(f_c + f_m\right)\tau_n \qquad (26)$$
$$\theta_n = \frac{2\pi n}{N}, \quad n = 1, \ 2, ...N$$

$r(t)$ is the received signal, which can be represented as

$$r_I(t) = 2\sum_{n=1}^{M} \cos\beta_n \cos 2\pi f_n t + \sqrt{2}\cos\alpha \cos 2\pi f_m t$$
$$r_Q(t) = 2\sum_{n=1}^{M} \sin\beta_n \cos 2\pi f_n t + \sqrt{2}\sin\alpha \cos 2\pi f_m t \qquad (27)$$
$$\alpha = \frac{\hat{\phi}_N - \hat{\phi}_{-N}}{2}$$

$$r_I(t) : I - Part$$
$$r_Q(t) : Q - Part$$

Traffic model

In the simulation, we choose voice over IP (VoIP) as the real-time application. The VoIP model G.728 proposed by International Telecommunication Union (ITU) is adopted in the simulation. G.728 codec is low delay speech coder standard, for compressing toll quality speech (8000 samples/second). G.728 coders are widely used for applications that require very low algorithmic delay. The typical application of this speech coder is in telephony over packet networks. G. 728 codec are based on the principle of Low Delay-Code Excited Linear Prediction (LD-CELP).

The VoIP packet arrivals every 20ms, which is equal the frame length. For G. 728 Codec, the data rate is 16 kbits/sec, and therefore, voice IP data in a packet is 320 bits. Besides, the RTP header requires 12 bytes, UDP header requires 8 bytes, and IP header requires 20 bytes, so each VoIP packet contains 640 bits in our simulation.

Wrap Around Technique

Co-channel interference is one of the important factors in the wireless communication systems, and must be considered in the simulation. According to the analyses proposed by Lee and Miller [28], if two-tier interference sources are considered, the co-channel interference can be simulated approximately equal to infinite interference sources. Therefore, only two-tier interference sources are simulated in our simulation. At the borders of the defined coverage area cell wrapping is applied in order to provide a realistic inter-cell interference and the possibility of handover in the border cells.

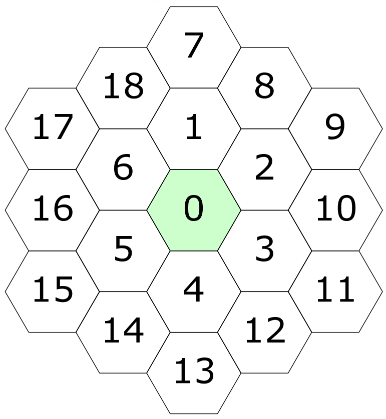

Fig. 36 Simulation environments with 19 cells

As shown in Fig. 36, if frequency reuse factor equal to one is applied, only the center BS, BS #0, suffers two-tier interferences. All the other BSs cannot suffer entire two-tier interferences. For this reason, only the center BS has useful statistical information, and this kind of simulation is non-efficient. We adopt wrap around technique which lets all BSs suffer entire two-tier interferences. Wrap around means when the user leave from one edge, the user will enter the cell on the opposite edge. As shown in Fig. 37, if the user leaves from cell #13, he/she will enter the cell #17 to avoid boundary effect such that handoff can be achieved. Besides, if the serving cell is BS #7, the two-tier interfering BSs are mark by the green color. Therefore, wrap around technique can not only avoid boundary effect but also generate two-tier interferences.

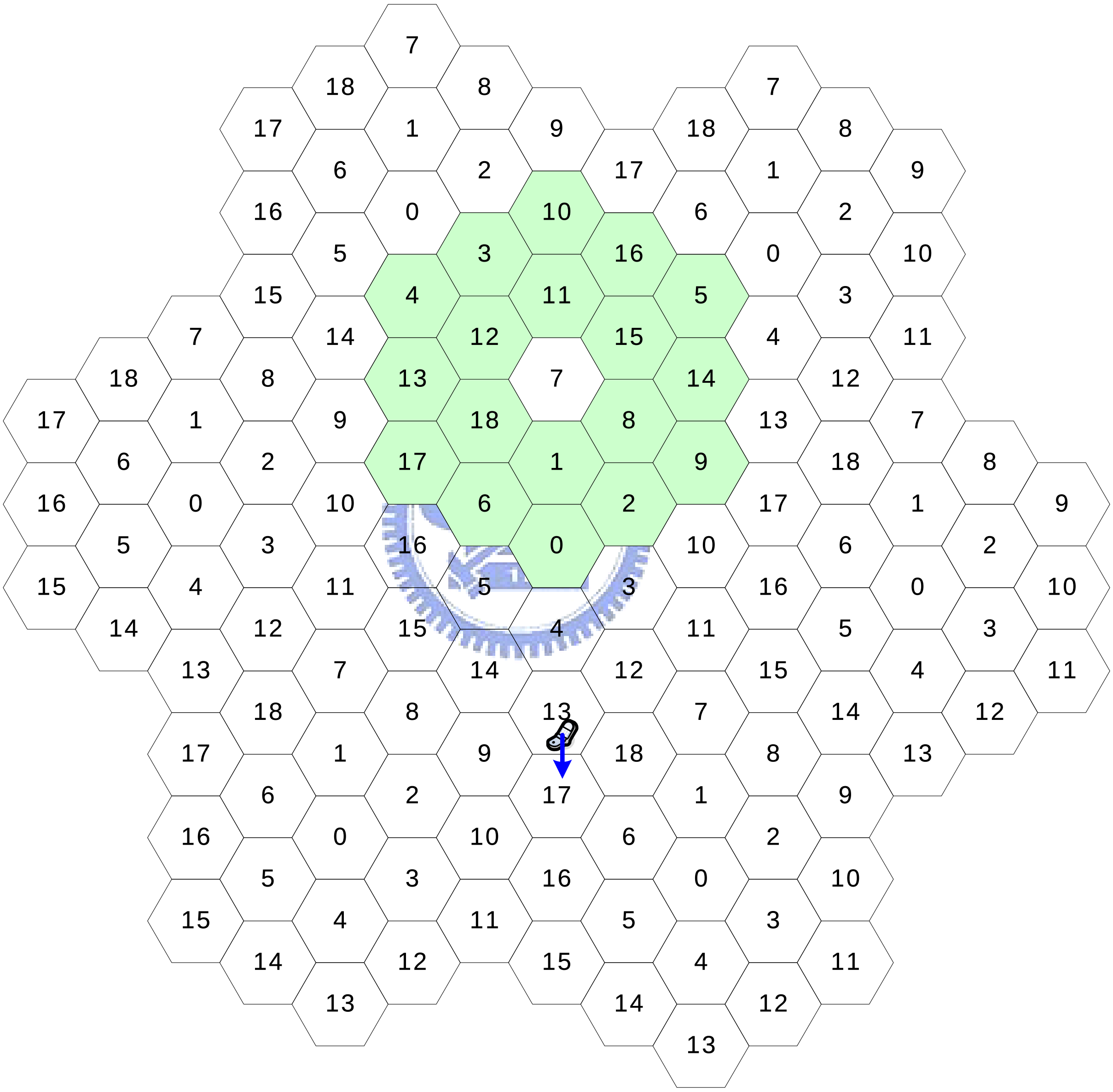

Fig. 37 Simulation environments when the wrap around technique is applied

Link Budget

The link budget consider that the total bandwidth is 6 MHz, the environment temperature is 293K, the frequency reuse factor is 4, FFT size is 2048, carrier frequency is 2.5 GHz, and PUSC with 3 sectors is used.

Modulation Scheme	QPSK	
Coding Rate	1/2	
Transmitter(BS)		
Max. Transmit Power for each BS [dBm]	46.0206 (40W)	
Max. Transmit Power for each Sector [dBm]	41.2494 (13.3333W)	
Max. Transmit Power for each Subchannel [dBm]	28.2391 (0.6667W)	a
BS Antenna Gain [dBi]	18	b
Back Off [dB]	5	c
EIRP Per Sub-channel [dBm]	41.2391	d=a+b-c
Receiver (MS)		
Thermal Noise Density [dBm/Hz]=KT	-173.9325	e
Noise Figure [dB]	6	f
Receiver Noise Density [dBm/Hz]	-167.9325	g=e+f
Receiver Noise Power[dBm]	-118.8828	h
Received Interference Power [dBm]	-113.1265	i
Total Received Noise and Interference Power [dBm]	-112.1032	
Required Eb/ (No+Io) [dB]	6	j
Mobile Antenna Gain [dBi]	0	l
Required Received Signal Power[dBm]	-106.1032	m
Max. Allowable Propagation Loss [dB]	147.3423	n=d-m
Coverage Probability [%]	90	
Log Normal Fading Constant [dB]	8	o
Log Normal Fading Margin [dB]	10	p
Allowed Path Loss for Cell Range [dB]	137.3423	r=n-p
Corresponding Cell Radius [m]	1000	

Table 2 Link budget for PUSC

6-2 Simulation Results

Simulation results are presented in this section. Both distributed and adjacent sub-carrier sub-channelization methods are taken into consideration. Different moving speed of users is also considered in the simulation. We first analyze that different threshold setting influences the performances and resource consumption without using the FFR cell structure. After that, the performances under the FFR cell structure are presented.

We simulated the average packet loss rate, ping-pong rate, and average diversity set size for FBSS and MDHO with and without fractional frequency reuse. In the average packet loss rate calculation, we assume that the packet is loss if any bit within this packet is not received correctly by the mobile. Average diversity set size can be treated as the network layer resource consumption because the data need to be forwarded to all the BSs in the diversity set through backhaul network. The ping-pong effect causes the MS to switch the serving BS between the new and old BSs back and forth, and therefore, the MS need to perform handoff ranging with the new BS. Moreover, the radio link resource is wasted if unnecessary ping-pong effect occurs. The average ping-pong rate is defined as

$$R_{ping-pong} = \frac{number\ of\ link\ layer\ handoff\ events\ with\ ping\ pong\ effect}{total\ number\ of\ link\ layer\ handoff\ event} \qquad (28)$$

Fig. 38 shows the average packet loss rate during handoff without using the FFR cell structure under the PUSC mode. Th_add is the threshold to decide the initiation of network layer handoff. The time required for the network layer handoff and the variation speed of link layer signal quality should be considered altogether into the threshold setting. The higher value of Th_add, the more easily Best Candidate Set BS can be added into the diversity in which the data path of the network layer will be established. Under this circumstance, it will be much easier to finish the data path before Th_change condition is met but relatively consume network resources which is shown in Fig. 39. Besides, Th_change is the threshold to change serving BS. If the value of Th_change is too low, it would influence the decision of the link layer handoff and make the users switched between the new and the old BSs back and forth which cause the ping-pong effect to waste resources. If the value is too high, it helps increase the accuracy of deciding the handoff but decrease the users' link and service quality. So, Fig. 38 shows that as the Th_change increases, the average packet loss rate decreases. But low Th_change might cause high ping-pong effect which is shown in Fig. 40.

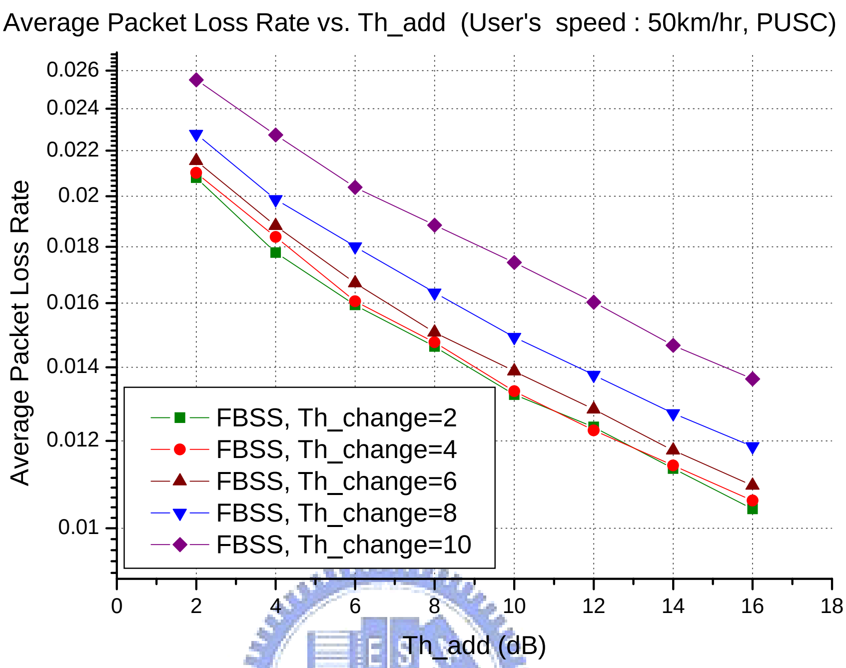

Fig. 38 Average packet loss rate vs. Th_add (50km/hr, PUSC)

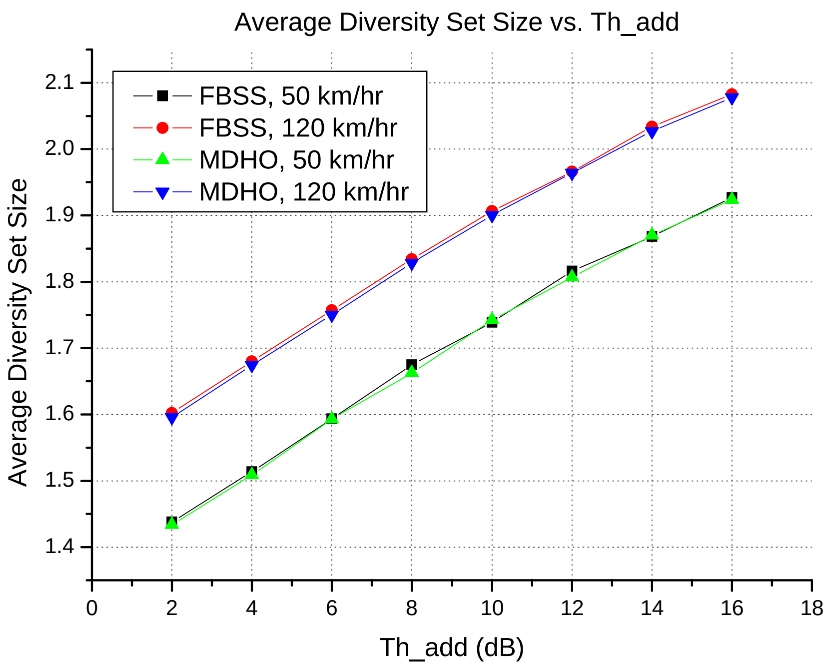

Fig. 39 Average diversity set size vs. Th_add

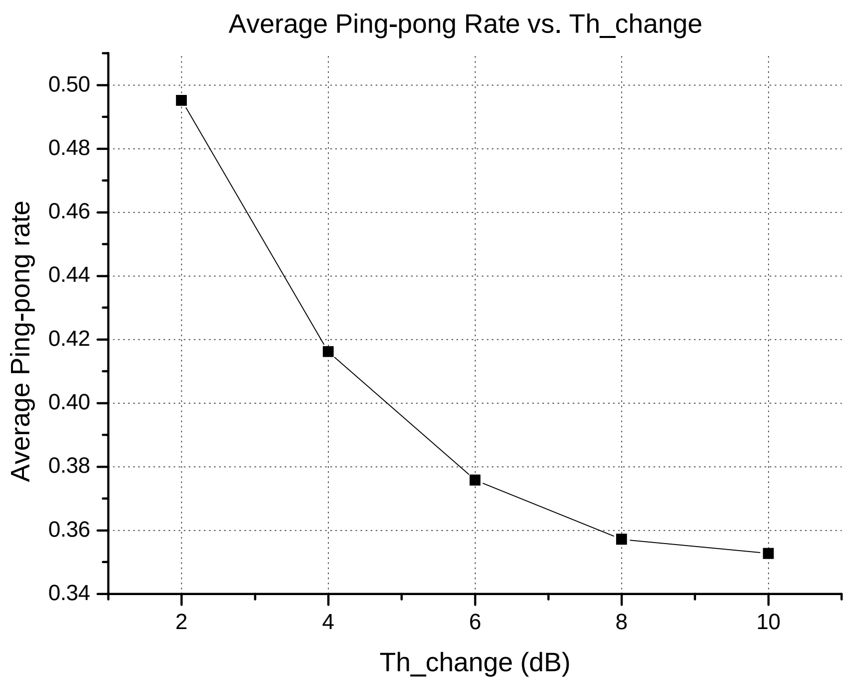

Fig. 40 Average ping-pong rate vs. Th_change

Fig. 41, 40, and 41 show the average packet loss rate under the FFR cell structure when the users' moving speed is 50km/hr and the PUSC is applied. If the Th_use is set to be smaller, the average packet loss rate decreases because the handoff user is more easily served by the arranged handoff sub-channels. On the other hand, the smaller value of Th_use will lead to larger radio resource consumption which is shown in Table 3. Table 3 shows average portion of time that handoff sub-channel is used. In this table, we can observe that if Th_use is set to be larger, the smaller portion of time needs to be allocated for handoff sub-channel. Besides, as the Th_use is fixed, if the Th_change value is set to be larger, the user is harder to change the serving BS to the BS with better channel quality. This case causes the handoff sub-channel usage rate increase.

According to what is mentioned above, the value of Th_change can be set higher to make the correct decision for the handoff and to reduce the occurrence of the ping-pong effect if the user is served with the sub-channels. If the Th_change condition is met but the network data path is not completely established yet, on the other hand, the problem of the poor signal quality with the serving BS which could also lower service quality can be solved by using the sub-channels.

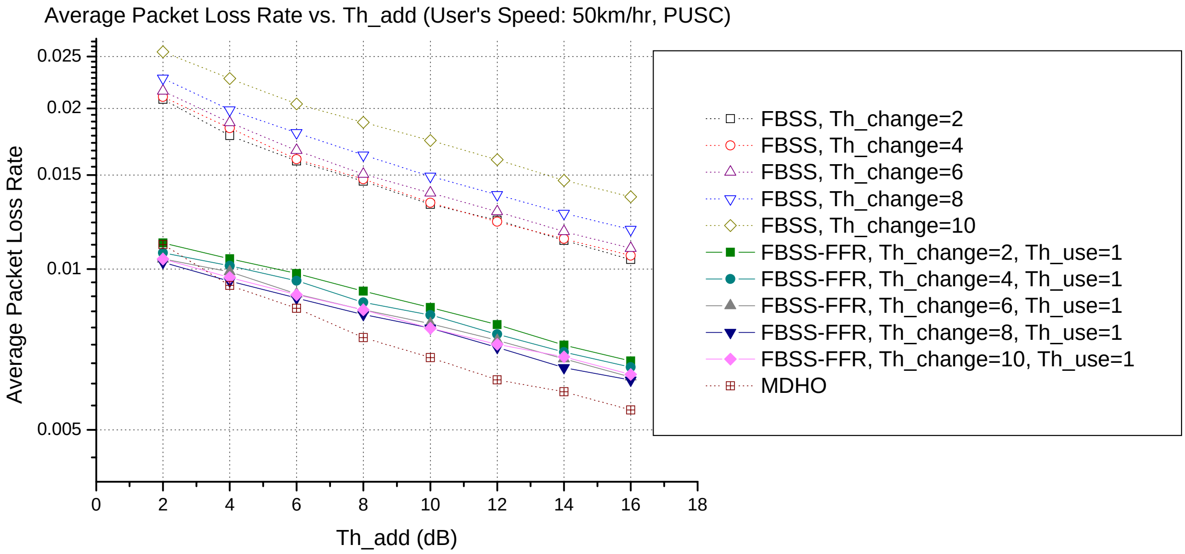

Fig. 41 Average Packet Loss Rate vs. Th_add with Th_use=1 (50km/hr, PUSC)

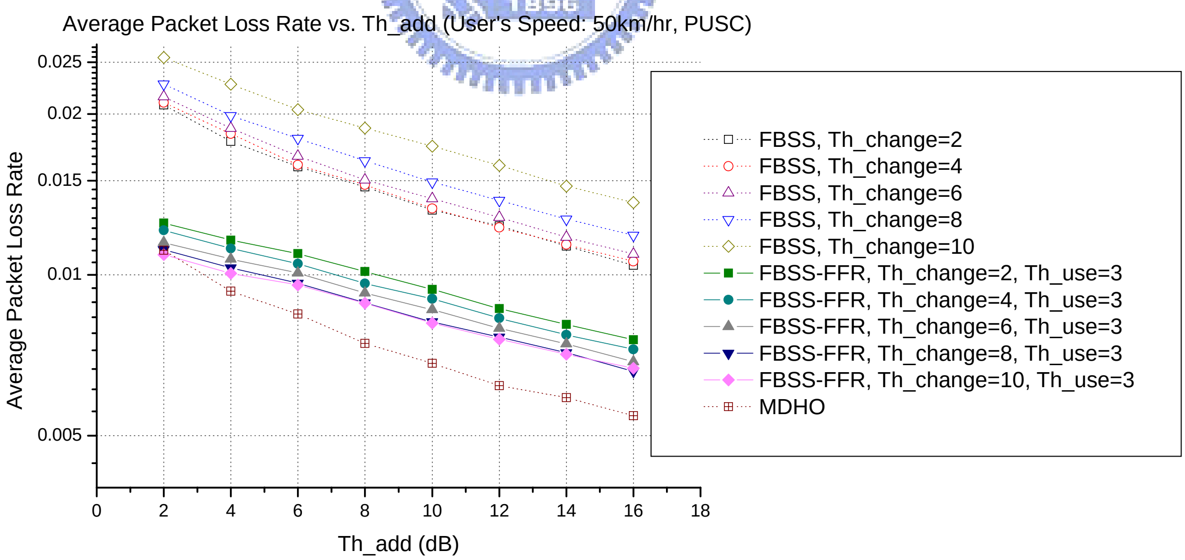

Fig. 42 Average Packet Loss Rate vs. Th_add with Th_use=3 (50km/hr, PUSC)

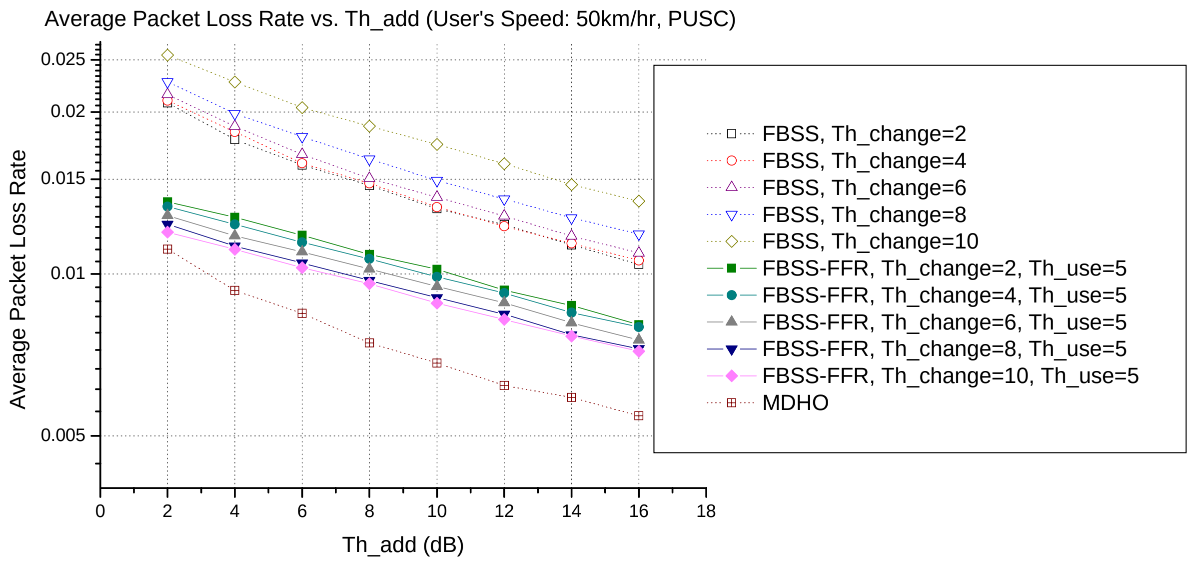

Fig. 43 Average Packet Loss Rate vs. Th_add with Th_use=5 (50km/hr, PUSC)

Th_change / Th_use	2	4	6	8	10
1	0.085	0.099	0.116	0.133	0.15
3	0.044	0.055	0.070	0.086	0.1
5	0.023	0.027	0.036	0.050	0.065

Table 3 Portion of time that RF=7 sub-channels is used (User’s speed: 50km/hr)

According to the mentions above, we can use the network and radio resource consumption to determine which combination of thresholds should be used. For example, if the average diversity set size has to be smaller than 1.8, the usable Th_add range is 0~12. Moreover, if the portion of time allocated to handoff sub-channels has to be smaller than 0.1, the possible combinations are Th_use=3~5 with Th_change=0~10 and Th_use=1 with Th_change=2~4. Besides, if the ping-pong rate is constraint to be smaller than 0.4, the Th_change should be set to be larger than 4. Using the resource constraint and performance requirement, the optimal threshold setting can be obtained.

Fig. 44 43, 44 are the average packet loss rate performance with different Th_use values under the FFR cell structure when the moving speed of users is 120km/hr and PUSC is applied. Table 4 shows the portion of time need to be allocated to handoff sub-channels. The same phenomenon can be obtained. The difference is that when the user velocity is 120km/hr, the average packer loss rate under FBSS with FFR is better than that under MDHO mode. Because the MDHO can improve the signal quality only when the network layer data path establishment which requires time to process is completed. As the user's moving speed increases, the connection quality also change rapidly. Therefore, the FBSS with FFR can rescue the user whose connection quality is bad without any processing time while MDHO can rescue the user only when the data path establishment is completed. When the user's velocity is not very fast, MDHO has beer average packet loss rate performances because the user's signal quality does not change rapidly, and the data path establishment can be completed before the connection quality of the user becomes poor.

Th_use \ Th_change	2	4	6	8	10
1	0.179	0.187	0.197	0.208	0.219
3	0.126	0.132	0.142	0.153	0.162
5	0.086	0.090	0.096	0.106	0.116

Table 4 Portion of time that RF=7 sub-channels is used (User's speed: 120km/hr)

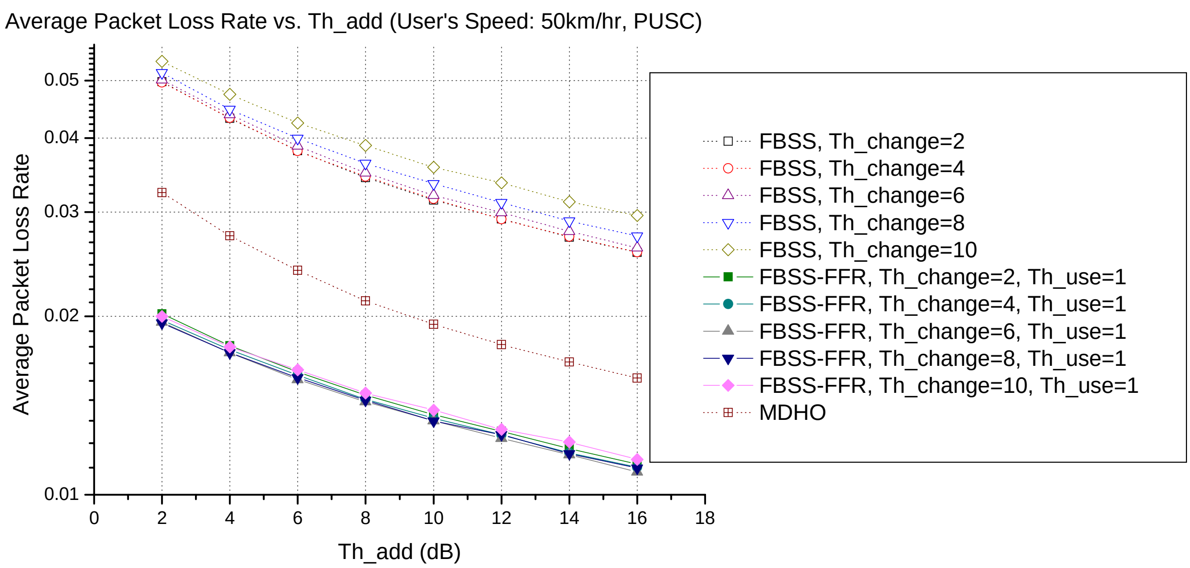

Fig. 44 Average Packet Loss Rate vs. Th_add with Th_use=1 (120km/hr, PUSC)

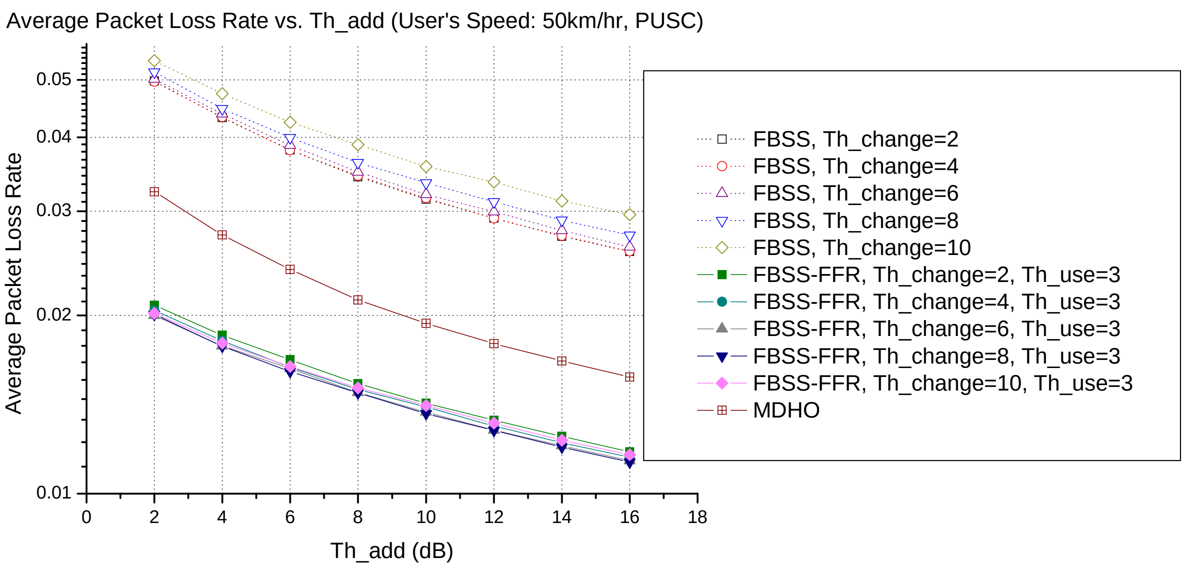

Fig. 45 Average Packet Loss Rate vs. Th_add with Th_use=3 (120km/hr, PUSC)

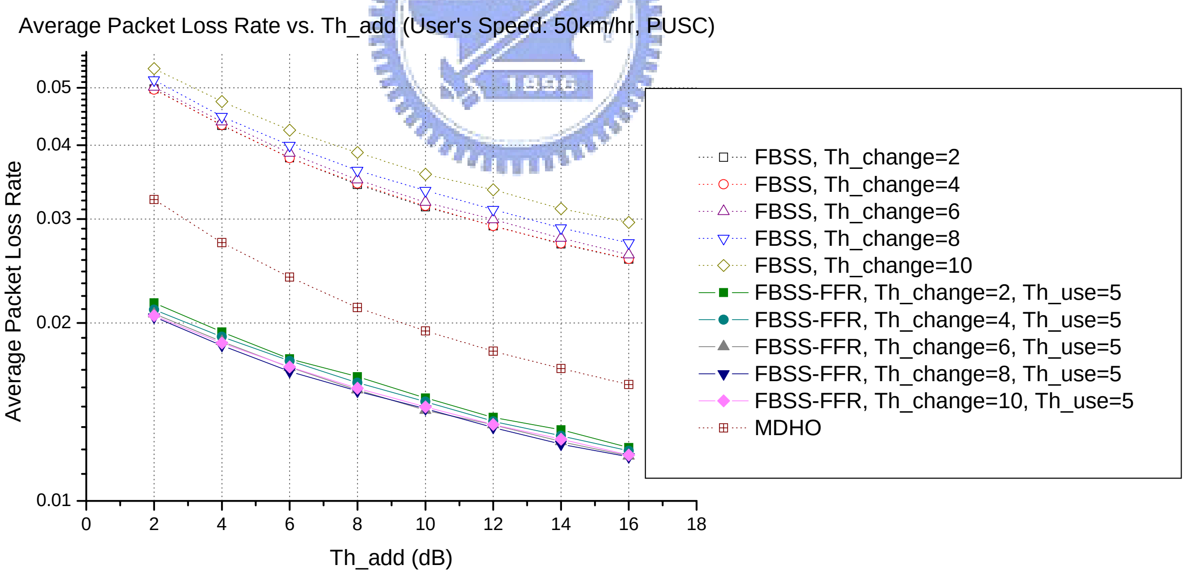

Fig. 46 Average Packet Loss Rate vs. Th_add with Th_use=5 (120km/hr, PUSC)

Fig. 47~50 show the average packet loss rate when the band AMC sub-carrier sub-channelization is performed. Impact on average packet loss rate for different threshold setting and user's velocity is also shown in these figures. In the simulation, we assume that the serving BS will schedule the handoff user's using the sub-channels with the best channel condition from the user's perspective. The user need to report the channel gains of each sub-channel to the serving BS, and the reporting delay is 20 milliseconds which is equal to the frame length.

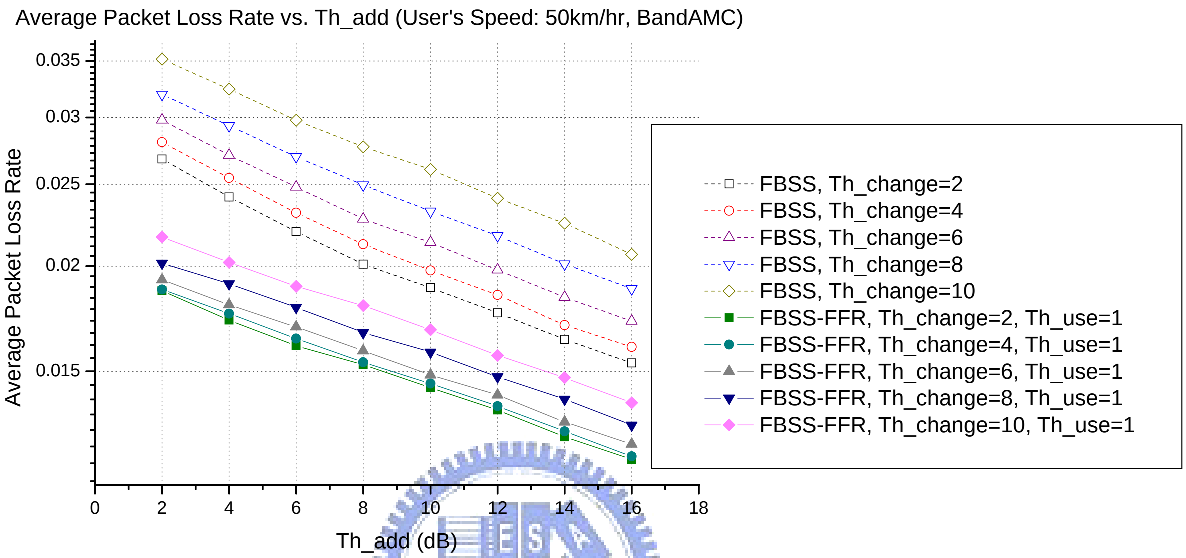

Fig. 47 Average Packet Loss Rate vs. Th_add with Th_use=1 (50km/hr, BandAMC)

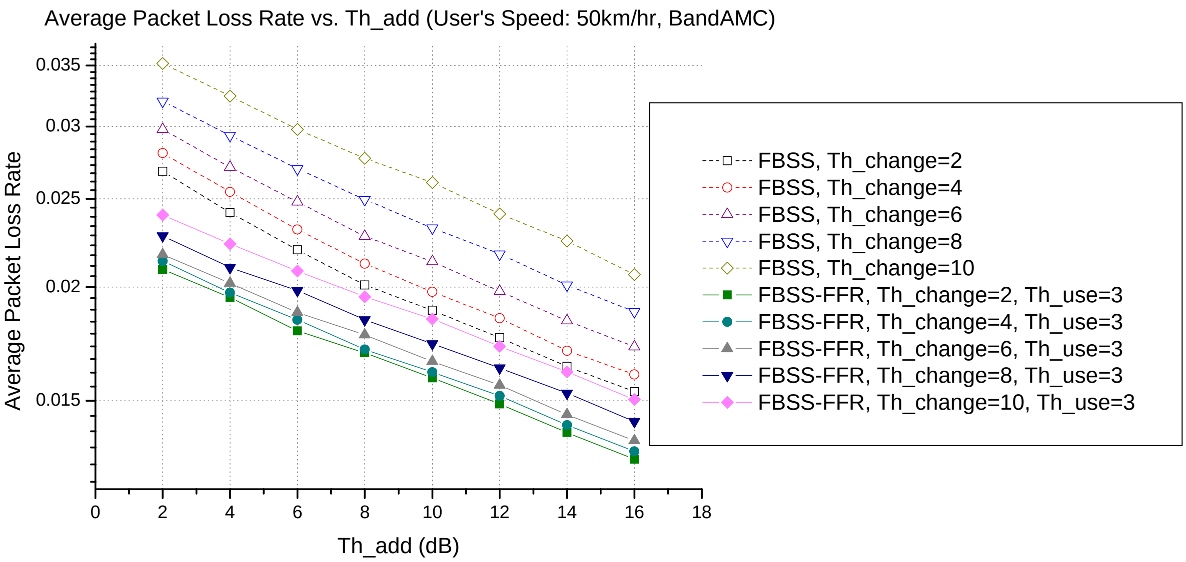

Fig. 48 Average Packet Loss Rate vs. Th_add with Th_use=3 (50km/hr, BandAMC)

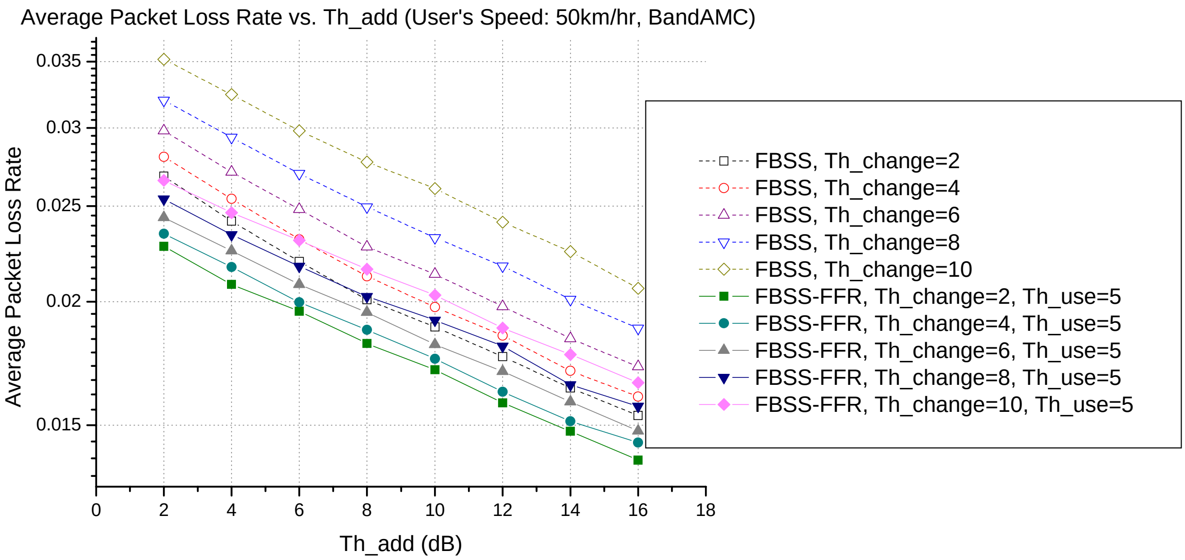

Fig. 49 Average Packet Loss Rate vs. Th_add with Th_use=5 (50km/hr, BandAMC)

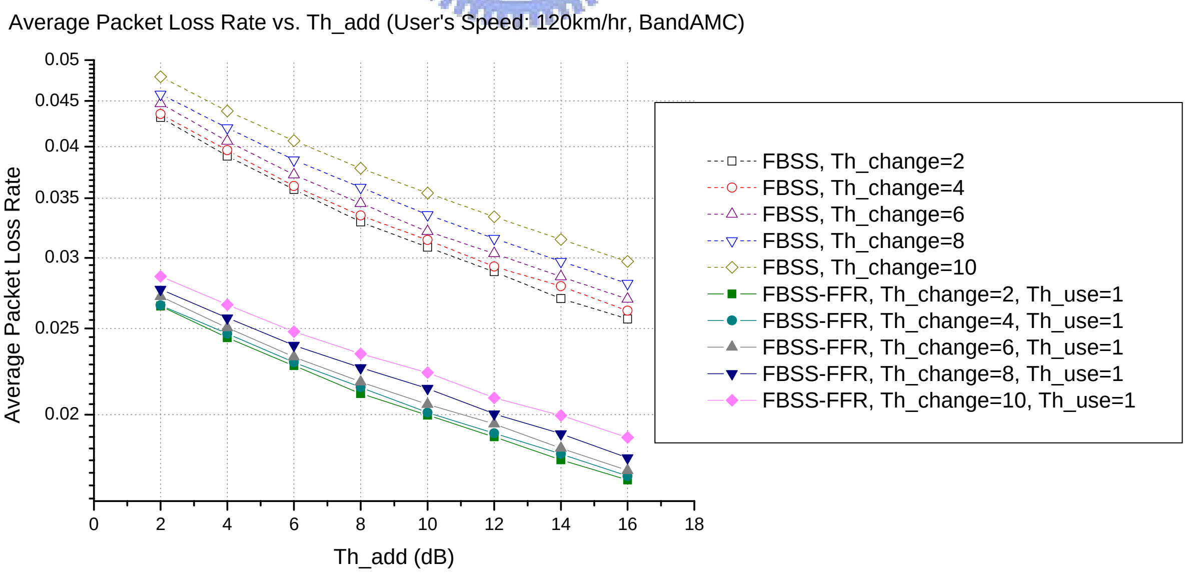

Fig. 50 Average Packet Loss Rate vs. Th_add with Th_use=1 (120km/hr, BandAMC)

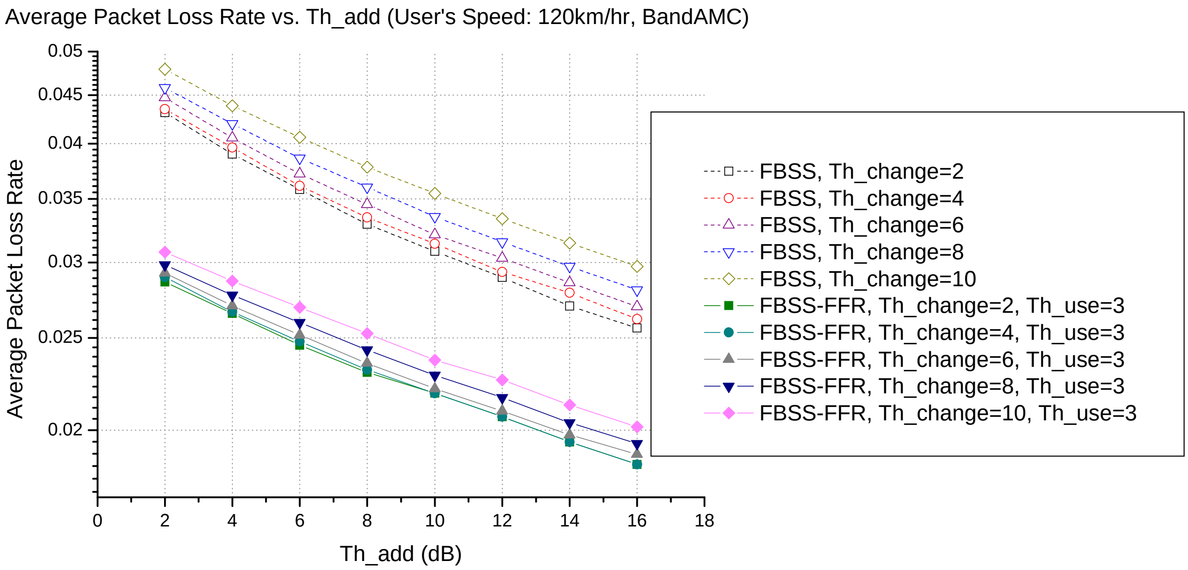

Fig. 51 Average Packet Loss Rate vs. Th_add with Th_use=3 (120km/hr, BandAMC)

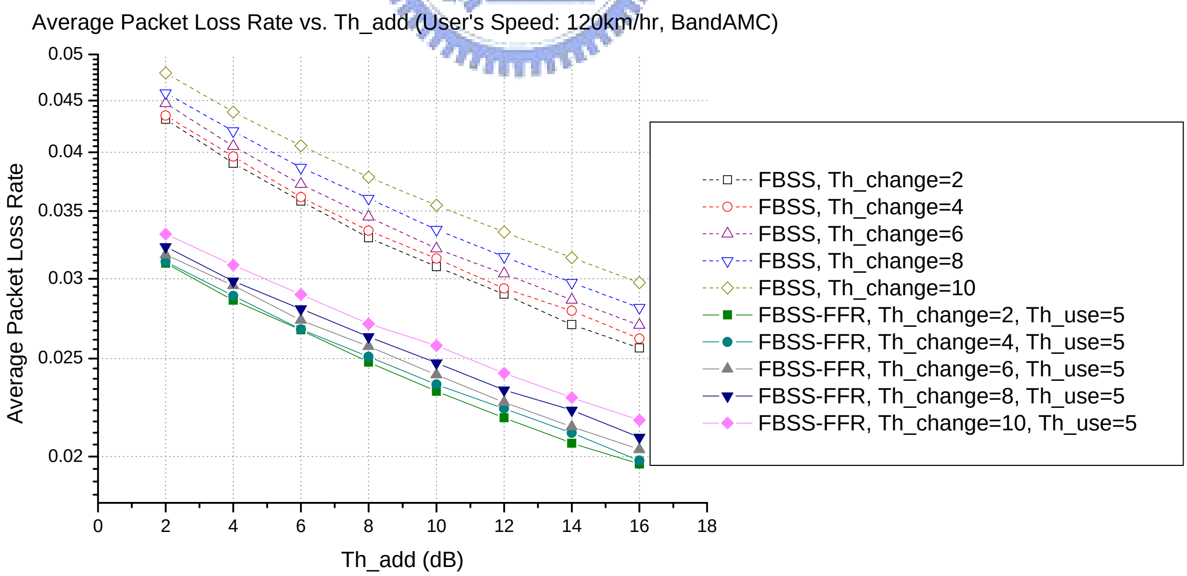

Fig. 52 Average Packet Loss Rate vs. Th_add with Th_use=5 (120km/hr, BandAMC)

Conclusions

In this thesis, at first, we introduce the system architectures of IEEE 802.16e-2005, including frame structure, sub-channelization process, and handoff mechanisms. We also introduce the cell planning and frame structure design for fractional frequency reuse cell structure. Based on the IEEE 802.16e-2005, we modified FBSS initiation algorithm such that it can take advantages on FFR cell structure. The signaling procedures for the modified FBSS algorithm are also presented in this thesis.

The proposed fast handover ranging requires only two frames to complete link layer handoff, which can meet the real-time services requirements. Besides, network layer handoff effect on the link quality can be easily alleviated by using the arranged handoff sub-channels at the right moment. Furthermore, the value of Th_change can be set higher to make the correct decision for the handoff and to reduce the occurrence of the ping-pong effect if the user is served with the arranged handoff sub-channels. If the Th_change condition is met but the network data path is not completely established yet, on the other hand, the problem of the poor signal quality with the serving BS which could also lower service quality can be solved by using the arranged handoff sub-channels.

Simulation results show that handoff performance can be improved if the serving BS serves its handoff users using the arranged handoff sub-channels. Without any resource constraint, the average packer loss rate can be improved up to 60%. If the user’s moving speed is very high, ex. 120 km/hr, the average packet loss rate of FBSS with FFR is better than that of MDHO.

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