國 立 交 通 大 學

電 信 工 程 學 系

碩 士 論 文

IEEE 802.16e 系統中頻寬請求機制之研究

A Study on
Bandwidth Request Mechanisms in
IEEE 802.16e Systems

研 究 生： 吳其珍

指導教授： 黃家齊 博士

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研 究 生：吳其珍　　　　Student：Chi-Chen Wu

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摘　　要

IEEE 802.16e 規格中為了支援不同服務之不同服務品質要求，定義了多種頻寬請求機制，透過頻寬請求機制，需要額外頻寬的用戶可以向基地台要求額外的頻寬。其中一種頻寬請求機制是基於競爭的方式，基地台分配額外的資源給用戶端們傳送競爭訊號，用戶們隨意挑選傳輸機會傳送頻寬請求訊號，這些訊號有可能會發生碰撞。為了降低碰撞所發生的 overhead，在 IEEE 802.16e OFDMA 模式中特別設計了展頻碼供頻寬請求機制使用，基地台所分配之頻寬請求資源會先切割成多個傳輸機會, 需要請求頻寬的用戶端們會在隨意選擇的傳輸機會中傳送隨意挑選的展頻碼給基地台, 一個傳輸機會中允許不同的用戶傳送不同的展頻碼，一旦展頻碼被偵測出，該用戶會被安排到特定的資源位置進行 bandwidth request header 之訊號交換。本論文針對 OFDMA 模式下基於展頻碼的頻寬請求機制提出偵測方法，而此偵測方法之計算複雜度會隨著展頻碼的個數增加。為了減少計算複雜度，本論文基於上行通道化提出另一個較為簡單的頻寬請求機制。此機制中一個傳輸機會所需的子載波個數少於展頻碼方法中所需的個數，並且基地台會事先指定傳輸機會給每個用戶。此外，每個細胞有一組獨特碼，屬於同一個細胞的用戶就在基地台所指定的傳輸機會傳送這組碼，基地台只需要偵測傳輸機會是否有用戶使用, 而不需要偵測一個傳輸機會中有哪些碼有被用戶使用，此方法在不犧牲偵測率的情況下，大大降低了基地台所需之偵測複雜度。

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Student：Chi-Chen Wu　　　　Advisor：Dr. Chia-Chi Huang

Department of Communication Engineering
National Chiao Tung University

ABSTRACT

To support different levels of QoS services, IEEE 802.16e specifies some bandwidth request mechanisms. Using these bandwidth request mechanisms, the Subscriber Stations (SSs) which need some other bandwidth can request bandwidth from the Base Station (BS). One of these mechanisms is contention-based. For contention-based bandwidth request mechanism, the BS allocates resources in the uplink subframe for SSs to send contention signals. The allocation is divided into transmission opportunities (TOs). Each SS randomly select a TO and send contention signals which may result in collision. To reduce overhead, IEEE 802.16e specifies a CDMA-based bandwidth request mechanism for OFDMA-PHY. SSs which want to request bandwidth send CDMA codes as contention signals in their selected TOs to the BS. More than one CDMA code are allowed in a TO. In this thesis, a detection method is proposed for this CDMA-based bandwidth mechanism. To reduce computation complexity, we also propose a simpler bandwidth request mechanism. In the proposed method, the number of subcarriers in a TO is less than that in the CDMA-based method and each SS is pre-assigned a TO by the BS. Besides, each cell has a unique code. SSs from a cell transmit the code in the pre-assigned TO. Thus the BS does not need to detect all the codes for a TO. Without sacrificing detection probability, this method greatly reduces computation complexity.

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吳其珍

2007 年 8 月於新竹交大工四館 717 室

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Chapter 1
Introduction to IEEE 802.16e Systems

IEEE 802.16 defines the WirelessMAN air interface specification for Wireless Metropolitan Area Networks. The standard provides alternatives to wireline broadband access and enables rapid deployment of cost-effective interoperable multivendor BWA products and encourages worldwide spectrum allocation.

1.1 Physical Layer

The 802.16 physical layer supports Line-of-sight (LOS) and non-LOS wireless operation. The primary bands are as follows: 10-66GHz licensed bands, frequencies below 11 GHz and license-exempt frequencies below 11 GHz. IEEE 802.16 supports four kinds of physical layers including single-carrier (SC), SCa, OFDM, and OFDMA. SC is applied for line-of-sight operation in the 10-66GHz licensed bands. SCa is designed for licensed bands below 11 GHz in conjunction with frequency domain equalization. OFDM supports operation below 11 GHz licensed bands and mobility up to portable. OFDMA is developed for operation below 11 GHz and supports full mobility.

1.2 MAC Layer

The MAC comprises three sublayers— Service-Specific Convergence sublayers (CS), MAC Common Part Sublayer (MAC CPS) and Security Sublayer. The CS classfies external network service data units (SDUs) and associates them to the proper service flows. Thus the MAC CPS (common part sublayer) is not required to understand the format of any information from the CS payload. The MAC CPS performs the core MAC functionality such as system access, bandwidth allocation, connection establishment, etc. Quality of Service (QoS) is also charged by the MAC CPS. The security sublayer provides authentication, secure key exchange and encryption. The IEEE 802.16 MAC layer supports PMP (point-to-multiple point), PtP (point-to-point) and mesh networks. Here we focus on the PMP networks. For the downlink, from the BS to the subscriber, operates on a PMP basis. A wireless link operates with a central BS and a sectorized antenna that can handle multiple independent sectors simultaneously. The downlink is generally broadcast. For the uplink, access and bandwidth allocation is shared by subscriber stations. Services required by users are varied such as legacy-tolerance. To support different kinds of services, the MAC must accommodate both continuous and bursty traffic.

1.3 Motivation of This Thesis

Several kinds of QoS services are supported in IEEE 802.16e and different kind of QoS has different request for bandwidth. In IEEE 802.16e, there are several methods for SSs to request bandwidth from a BS. In this thesis, bandwidth request mechanisms for OFDMA systems are aimed at. The OFDMA system specified in IEEE 802.16e will be introduced in chapter 2. In chapter 3, some bandwidth request mechanisms in IEEE 802.16 will be introduced first and then the proposed method is illustrated. Simulation results and discussions are shown in chapter 4. Conclusions are made in chapter 5.

Chapter 2

WirelesslessMAN-OFDMA (Orthogonal Frequency Division Multiple Access) PHY and MAC Overview

In this chapter, the OFDMA PHY and MAC specified in IEEE 802.16e will be introduced.

2.1 OFDMA PHY Overview

In the OFDMA PHY, resources are divided into slots both time and frequency dimension. Thus, many users can simultaneously transmit data in the same OFDMA symbol and one user can transmit data across several OFDMA symbols.

2.1.1 OFDM Symbol Description

The OFDMA PHY mode based on at least one of the FFT sizes 2048, 1024,512, and 128 shall be supported. This facilitates scalable bandwidth. The MS should scan the DL signal when performing initial network entry to detect the FFT size employed by the BS. After data is modulated onto the subcarriers, Inverse-Fourier-transform is applied to create time domain signal and the time duration is referred to as the useful symbol time T_b. In order to maintain the orthogonality of the subcarriers, a cyclic prefix is inserted before the actual data samples. The cyclic prefix is the replication of the last Np samples of the OFDM symbols. The ratio of CP time to useful time shall be 1/32, 1/16, 1/8, or 1/4. As long as the delay spread is shorter than the cyclic prefix duration, ISI is eliminated. Figure 2.1 illustrates this structure.

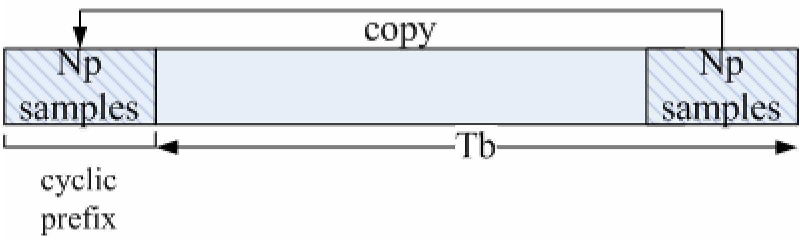

Figure 2.1 Structure for an OFDM symbol

An OFDMA symbol is made up of subcarriers, and the number of which determines the FFT size. There are three types of subcarriers:

—Data subcarriers for data transmission

—Pilot subcarriers for coherent detection

—Null carriers for guard bands and DC carrier.

In the OFDMA mode, the active subcarriers including data subcarriers and pilot subcarreirs are divided into several subchannels. There are different ways to divide active subcarriers for the downlink and the uplink. The symbol is divided into logical subchannels to support scalability, multiple access, and advanced antenna array processing capabilities. The subcarriers in a subchannel may, but not need to be adjacent.

2.1.2 OFDMA Subcarrier Permutation

Subcarriers of an OFDMA symbol are divided into subchannels. Permutations are applied to do subchannelization. And there are two main categories of subcarrier permutations in IEEE 802.16e: distributed and adjacent permutation. Distributed subcarrier permutation means that subcarrier indices in a subchannel are spread out across the whole band. Distributed subcarrier permutation performs well for mobile applications because it makes use of frequency diversity. Distributed subcarrier permutation is used in PUSC (partial usage of subchannels), FUSC (full usage of subchannels), OPUSC (optional PUSC), OFUSC (optional FUSC), TUSC1 (tile usage of subchannels) and TUSC2. For PUSC and OPUSC, some of the subchannels are allocated to the transmitter; for FUSC and OFUSC, all subchannels are allocated to the transmitter. TUSC1 and TUSC2 shall be only used within AAS (Adaptive Antenna System) zone. Adjacent subcarrier permutation means that subcarrier indices in a subchannel are contiguous. Adjacent permutation is used in Band AMC (Adaptive Modulation and Coding) because it is simpler to feedback the channel quality.

2.1.3 OFDMA Zones

A permutation zone is a number of contiguous OFDMA symbols that use the same permutation formula. The OFDMA frame may contain multiple zones. The transition between zones is indicated in the DL-MAP. The PHY parameters may be different from one zone to the next one. The following figure illustrates an OFDMA frame with multiple zones:

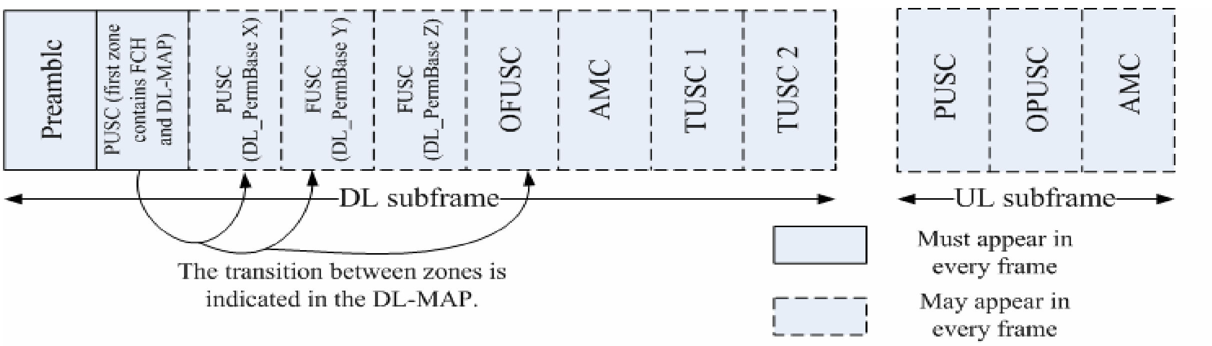

Figure 2.2 OFDMA frame with multiple zones

2.1.4 Frame Structure

In licensed bands, the duplex method should be either FDD (Frequency Division Duplex) or TDD (Time Division Duplex). In license-exempt bands, the duplex method shall be TDD.

In TDD, a frame contains DL and UL bursts. The allowed frame durations are 2, 2.5, 4, 5, 8, 10, 12.5, and 20 ms. The frame duration is defined in the DL-MAP. Each frame in the downlink transmission begins with a preamble followed by a DL transmission period and then an UL transmission period. In each frame, the TTG (transmit/receive transition gap) and RTG (receive/transmit transition gap) shall be inserted between the downlink and uplink and at the end of each frame, respectively, to allow the BS to turn around. The following figure is an example of an OFDMA frame in TDD mode:

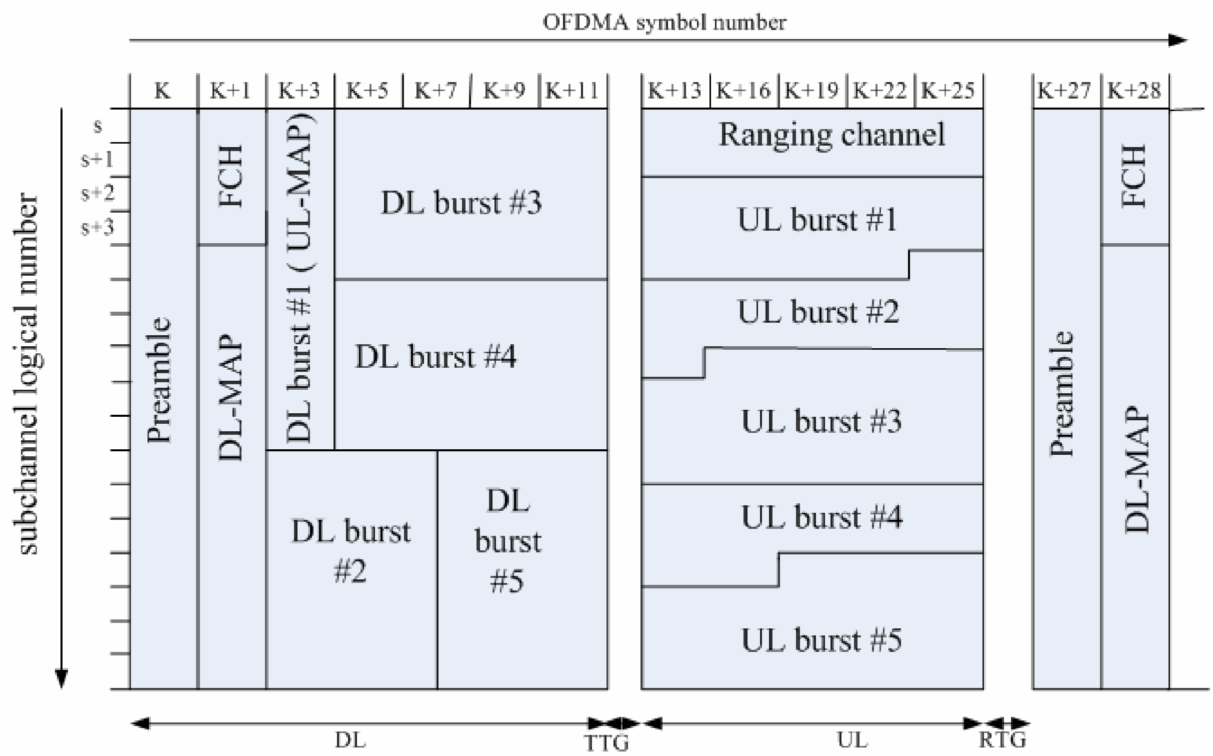

Figure 2.3 An example of one TDD time frame

DL subframe begins with a preamble and the following 4 subchannels called Frame Control Header (FCH). The FCH carries Downlink Frame Prefix (DLFP) which provides the decoding information for decoding the DL-MAP. The DLFP format is shown in table 2.1. The Preamble is BPSK modulated by a PN code which is determined by the IDcell which is assigned by the management entity and the sector number. Preamble enables MS to synchronize with the system, maintain the synchronization and do channel estimation. Preamble also enables MS to measure the received power for channel quality reporting and handover. The DL-MAP following the FCH specifies the downlink allocations for MSs ; The UL-MAP following the DL-MAP specifies the uplink allocations for MSs. In the DL subframe, Downlink Channel Descriptor (DCD) and Uplink Channel Descriptor are transmitted periodically to broadcast DL and UL system information respectively. The UL subframe contains user-data bursts and ranging channel. The ranging channel is used by the MS to gain access, maintain connection with BS and to request bandwidth.

Syntax	Size	Notes
Used subchannel bitmap	6 bits	Indicate which groups of subchannel are used on the first PUSC zone
Reserved	1 bits	Shall be set to zero
Repetition Coding Indication	2 bits	Indicate 2,4,6 or no repetition coding is used on DL-MAP
Coding Indication	3 bits	Indicate which kind of FEC encoding is used on DL-MAP
DL-MAP Length	8 bits	Defines the length of the DL-MAP message
Reserved	4 bits	Shall be set to zero

Table 2.1 DLFP format

2.1.5 Channel Descriptor Message

A Downlink Channel Descriptor (DCD) and an Uplink Channel Descriptor (UCD) shall be broadcast by the BS at a periodic interval to define the characteristics of a downlink and uplink physical channel respectively. Both the DCD and the UCD message include Configuration Change Count which is incremented by one (modulo 256) by the BS whenever any of the values of this channel descriptor change. If the value of this count in a subsequent DCD remains the same, the MS can quickly decide that the remaining fields have not changed and may be able to disregard the remainder of the message. Downlink and Uplink Burst Profile are also defined in DCD and UCD messages. In UCD, Ranging Backoff Start, Ranging Backoff End, Request Backoff Start and Request Backoff End are also included. Ranging Backoff Start and End define the initial and final backoff window size for initial ranging contention; Request Backoff Start and End define the initial and final backoff window size for contention bandwidth requests.

2.1.6 Downlink Map (DL-MAP) Message

The DL-MAP is QPSK modulated at 1/2 code rate by FEC specified in DLFP. DL-MAP enables subscriber stations to decode the downlink subframe. The DL-MAP corresponds to the PHY characteristics as defined by the DCD. The DL-MAP provides the Burst Profile of each allocation using a Downlink Interval Usage Code (DIUC) in DL-MAP IEs (Information Elements). Each allocation is assigned by providing the subchannels and the OFDMA-symbol offset from the preamble. The table 2.2 defines the DIUC encoding that should be used in the DL-MAP IEs and table 2.3 shows the DL-MAP format. The content of IEs is different from kind to kind depending on which kind of information the IE refers to (DIUC).

DIUC	Usage
0-12	Different burst profiles
13	Gap/PAPR reduction
14	Extended-2 DIUC IE
15	Extended DIUC

Table 2.2 OFDMA DIUC values

Syntax	Size	Notes
Management Message Type=2	8 bits	
PHY Synchronization	variable	for synchronization 、PHY specific
DCD Count	8 bits	The configuration change count of the DCD
Base Station ID	48 bits	The most significant 24 bits shall be operator ID
DL-MAP IEs	variable	PHY specific
Padding	0 or 4 bits	Padding to reach byte boundary

Table 2.3 DL-MAP format

2.1.7 Uplink Map (UL-MAP) message

The UL-MAP defines the uplink bandwidth allocations. The allocations are defined by UL-MAP IEs which shall indicate the allocated number of OFDMA symbols and subchannels, the OFDMA symbol and subchannel offset, etc. The UL-MAP is sent in the first DL burst whose subcarrier permutation, modulation and coding parameters are specified by the DL-MAP. As same as the DL-MAP, Uplink Interval Usage Code (UIUC) is used in the UL-MAP. The table 2.4 defines the OFDMA UIUC encoding and table 2.5 shows the UL-MAP.

UIUC	Usage
0	Fast-Feedback Channel
1-10	Different Burst Profile
11	Extended UIUC 2 IE
12	CDMA Bandwidth Request, CDMA Ranging
13	PAPR reduction allocation, Safety Zone
14	CDMA Allocation IE
15	Extended UIUC

Table 2.4 OFDMA UIUC values

Syntax	Size	Notes
Management Message Type=3	8 bits	
Reserved	8 bits	Shall be set to zero
UCD Count	8 bits	Matches the value of the Configuration Change Count of the UCD
Allocation Start Time	32 bits	Effective start time of the uplink allocation defined by the UL-MAP
UL-MAP IEs	variable	PHY specific
Padding	4 bits	Padding to reach byte boundary

Table 2.5 UL-MAP format

UL-MAP IEs with different UIUC values contain different content. For example, UL-MAP IE with UIUC=12 allocates resources for CDMA ranging and bandwidth request. OFDMA symbol offset, subchannel offset, number of OFDMA symbols, number of subchannels and ranging methods are defined in this UL-MAP IE. UL-MAP IE with UIUC=14 allocates bandwidth to a user that requested bandwidth using a CDMA request code. In this IE, duration of the allocation, repetition code used inside the allocated burst, the CDMA code sent by the SS, the ranging code, OFDMA symbol and ranging subchannel used by the SS are indicated.

2.2 MAC Overview

The MAC is connection-oriented and supports various levels of QoS. All services are mapped to a connection based on the associated QoS levels. Each service flow is associated with a single CID (connection identifier). A scheduling service is determined by a set of QoS parameters which are managed using DSA (Dynamic Service Addition) and DSC (Dynamic Service Change). Five services are supported: Unsolicited Grant Service (UGS), Real-time

Polling Service (rtPS), Extended rtPS (ertPS), Non-real-time Polling Service (nrtPS), and Best Effort (BE).

The UGS is designed to support real-time data streams that generate fixed-sized data packets on a periodic basis, such as Voice over IP (VoIP) without silence suppression.

The rtPS is designed to support real-time data streams that generate variable-sized packets at periodic intervals, such as MPEG video.

The Extended rtPS (ertPS) is a scheduling mechanism which builds on the efficiency of both UGS and rtPS. The BS provides unicast grants in an unsolicited manner like in UGS, which saves the latency of a bandwidth request. The allocations for ertPS are dynamic instead of fixed for UGS allocations. ertPS is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as VoIP services with silence suppression.

The nrtPS is designed to support delay-tolerant data streams consisting of variable-sized data packets for which minimum data rate is required, such as FTP.

The BE (Best Effort) service is to provide a scheduling service to support data streams for which no minimum service level is required and may be handled on a space-available basis.

The mandatory QoS service parameters such as Maximum Sustained Traffic Rate, Maximum Latency, Minimum Reserved Traffic Rate, Tolerated Jitter, etc, are defined according to different kind of scheduling service.

Besides, many other techniques are applied in IEEE 802.16 MAC. Mobility is support via hard handover (HO), fast base station switching (FBSS) and macro diversity handover (MDHO), etc. Idle mode and sleep mode are allowed for MSs. The MAC layer also supports ARQ scheme, transport protocols, physical layer HARQ (Hybrid ARQ), adaptive modulation and coding, etc.

Chapter 3
Bandwidth Request Mechanisms in IEEE 802.16e systems

To support different levels of QoS services, changing bandwidth requirements is necessary for all services except incompressible constant bit rate UGS connections. Demand Assigned Multiple Access (DAMA) services are given resources on a demand assignment basis. There are numerous methods by which SSs can request bandwidth in IEEE 802.16e systems. In this chapter, some existed bandwidth request mechanisms are introduced and the proposed bandwidth request method is illustrated.

3.1 Requests

Because the uplink burst profile can change dynamically, all requests for bandwidth shall be made in terms of bytes needed to carry the MAC header and payload, but not the PHY header. The Bandwidth request message may be transmitted during any uplink allocation, except during any initial ranging interval. Bandwidth request may be incremental or aggregate. A request may come as a stand-alone bandwidth request header or a Piggyback Request (optional) which is carried in the Grant Management subheader. The following figure shows the bandwidth request header.

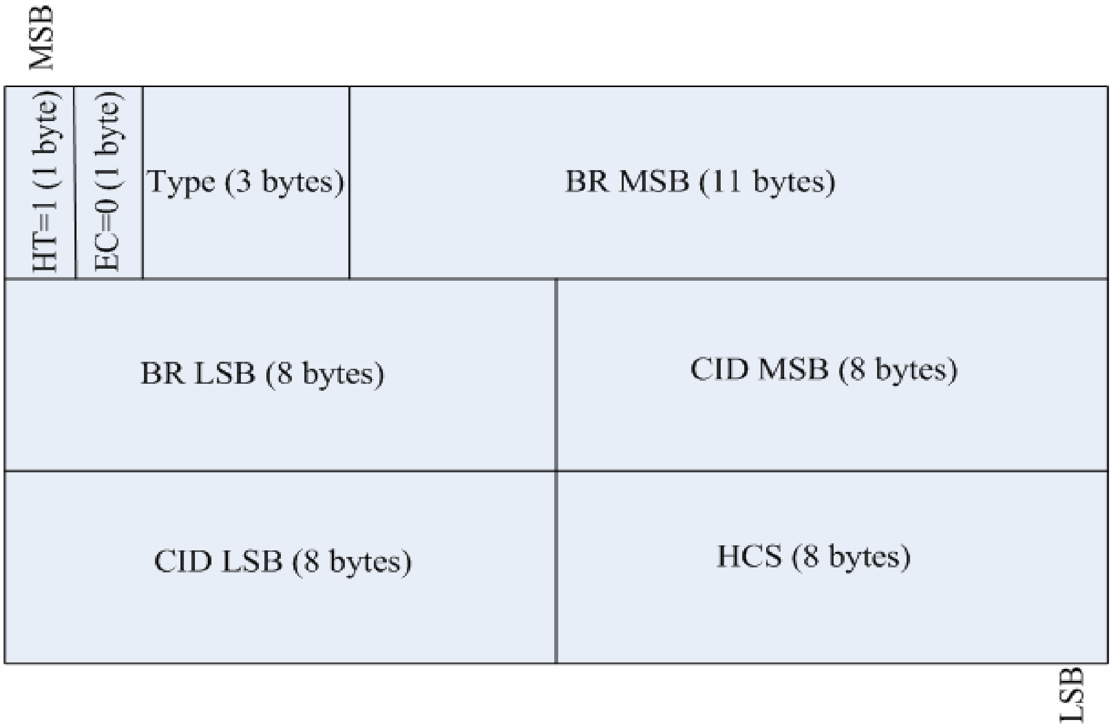

Figure 3.1 Bandwidth request header format

The length of the bandwidth request header shall always be 48 bytes. The EC field shall be set to 0, which means no encryption. The type field indicates whether the request is incremental or aggregate. The CID (Connection Identifier) indicates the connection which the bandwidth is requested for. The Bandwidth Request (BR) indicates the number of bytes requested.

3.2 Polling

Polling is activated by the BS which allocates bandwidth for SSs to make bandwidth requests. These allocations may be to individual SS or to groups of SSs. The allocations are not in the form of explicit message, but are in the form of IEs within the UL_MAP. Polling may be performed by unicast, multicast, broadcast or PM (Poll Me) bit.

For unicast, each SS is polled individually and allocated with sufficient bandwidth to request bandwidth within the UL-MAP. If the SS does not need bandwidth, the allocation shall be padded.

If no sufficient bandwidth is available to poll each SS individually, some SSs may be polled in multicast groups or a broadcast poll may be issued. As with individual polling, the bandwidth is indicated by IEs within the UL-MAP. For multicast or broadcast polling, the allocation is to a multicast or broadcast CID (connection identifier). To reduce the collision probability, only SSs needing bandwidth reply by Request IEs and contention resolution algorithm is applied. The SS shall assume that the transmission has been unsuccessful if no response has been received before timeout.

SSs with active UGS connections may set the PM bit in the Grant Management subheader in a MAC packet of the UGS connection to tell the BS that they need to be polled. When the BS detects the polling request, it performs the polling process to satisfy the request.

3.3 Contention-based Bandwidth Requests

IEEE 802.16e also supports contention-based bandwidth requests for OFDM-PHY and OFDMA-PHY. The BS may allocate some resource which is defined in the UL-MAP for SSs to send contention signal. For the UGS and the rtPS, the SS is prohibited from using any contention request opportunities for the connection. The allocation is divided into several transmission opportunities (TOs) and SSs shall send their contention signals in their selected TOs. TO is the basic allocation for a SS to transmit contention signal. These contention signals are allowed to collide. When the BS detects the signals, it will allocate another resource for those SSs to send message to tell the BS the amount of bandwidth they needs. The detail of contention-based bandwidth requests mechanisms will be illustrated as follows.

3.3.1 Contention-based Focused Bandwidth Requests for WirelessMAN-OFDM

The WirelessMAN-OFDM PHY supports two contention-based Bandwidth Request mechanisms. The first one allows the SS to send bandwidth request header shown in figure 3.1 during a REQ Region-Full. The other one is that the SS may send a Focused Contention Transmission during a REQ Region-Focused.

In a REQ Region-Full, when subchannelization is not active, the SS shall transmit a short preamble followed by the bandwidth request MAC header shown in figure 3.1.

When subchannelization is active, the allocation is partitioned in to Transmission Opportunities (TOs) both in time and frequency. The width (in subchannels) and length (in OFDM symbols) of each TO is specified in the UCD message. The transmission of an SS shall contain a subchannelization preamble corresponding to the TO chosen, followed by data OFDM symbols using the most robust mandatory coding method (BPSK-1/2).

In a REQ Region-Focused, a SS shall transmit a 4-bit Contention Code over a TO that consists of 4 subcarriers by two OFDM symbols. An OFDM symbol can be divided into 48 contention channels. The selection of the Contention Code and Contention Channel is done with equal probability among the eight possible codes which is shown in table 3.1. Upton detection, the BS shall provide an uplink allocation for the SS to transmit a Bandwidth Request MAC PDU by transmitting an OFDM Focused_Contention_IE, which specifies the Contention Channel, Contention Code, and Transmission Opportunity that were used by the SS. The OFDM Focused_Contention_IE is shown in table 3.2. This allows an SS to determine whether it has been given an allocation by matching these parameters with those it used. During the first OFDM symbol of the TO, the phase of the four subcarriers is not specified. During the second OFDM symbol of the TO, the phases shall depend on the corresponding bit in the chosen contention code, and the phase transmitted during the first OFDM symbol on the same subcarrier. If the code bit is +1, the phase shall be the same as that transmitted during the first OFDM symbol. If the code bit is -1, the phase shall be inverted 180 degrees with respect to the phase transmitted during the first OFDM symbol. If $b_0(m,k)$ represents the *k*th subcarrier of the *m*th contention channel in the first OFDM symbol, then the corresponding value during the second OFDM symbol is $b_1(m,k) = C_n(k) \cdot b_0(m,k)$ where n is the index of the selected contention code.

Code index	Bit 0	Bit 1	Bit 2	Bit 3
0	1	1	1	1
1	1	-1	1	-1
2	1	1	-1	-1
3	1	-1	-1	1
4	-1	-1	-1	-1
5	-1	1	-1	1
6	-1	-1	1	1
7	-1	1	1	-1

Table 3.1 OFDM Contention codes

Syntax	Size
Frame Number Index	4 bits
Transmit Opportunity Index	3 bits
Contention Channel Index	6 bits
Contention Code Index	3 bits

Table 3.2 OFDM focused contention IE format

3.3.2 Contention-based CDMA Bandwidth Requests for WirelessMAN-OFDMA

3.3.2.1 Transmission Opportunity

For OFDMA systems, the BS will allocate some resources to SSs to perform bandwidth requests. The allocation is called ranging channel. These resources are indicated within the UL-MAP IE with UIUC=12. OFDMA symbol offset, number of OFDMA symbols, subchannel offset, number of subchannels and ranging method are defined in the UL-MAP IE. Figure 3.2 illustrates the frame structure and the allocation.

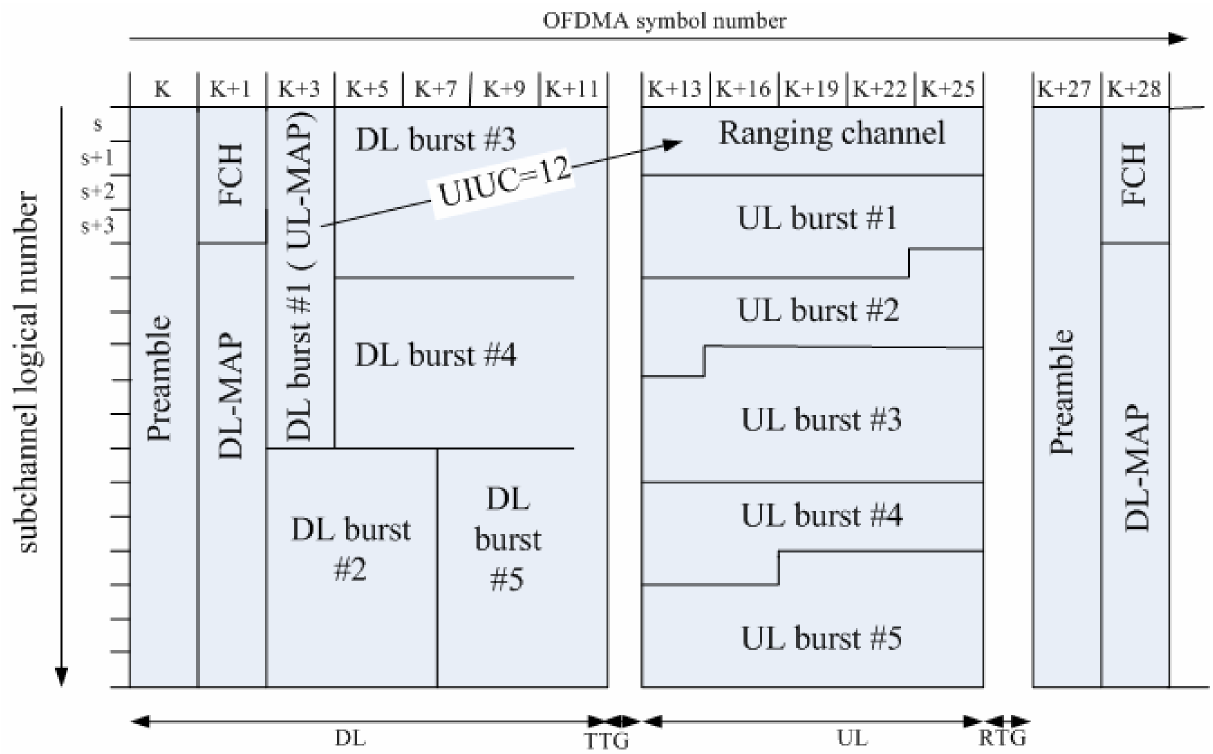

Figure 3.2 Frame structure and the allocation of ranging subchannels

The Bandwidth Request allocation is subdivided into transmission opportunities (TOs) of N_1 OFDMA symbols by N_2 subchannels. The allocation may not be a whole multiple of N_1 symbols, so a gap may be formed. This is illustrated in figure 3.3. The SS can send a transmission in two ways. The first one is to modulate one ranging code on the ranging subchannel for a period of one OFDMA symbol. The other one is to modulate three consecutive ranging codes on the ranging subchannel for a period of three OFDMA symbols (one code per symbol). Thus, N_1 is either 1 or 3. Which of these two methods is used is specified in the UL-MAP. The time domain illustration is shown in figure 3.4 and 3.5. N_2 is the number of subchannels needed to form a ranging subchannel. The value of N_2 depends on which kind of subchannelization is used. Table 3.3 shows the values of N_1 and N_2 corresponding to PUSC and OPUSC.

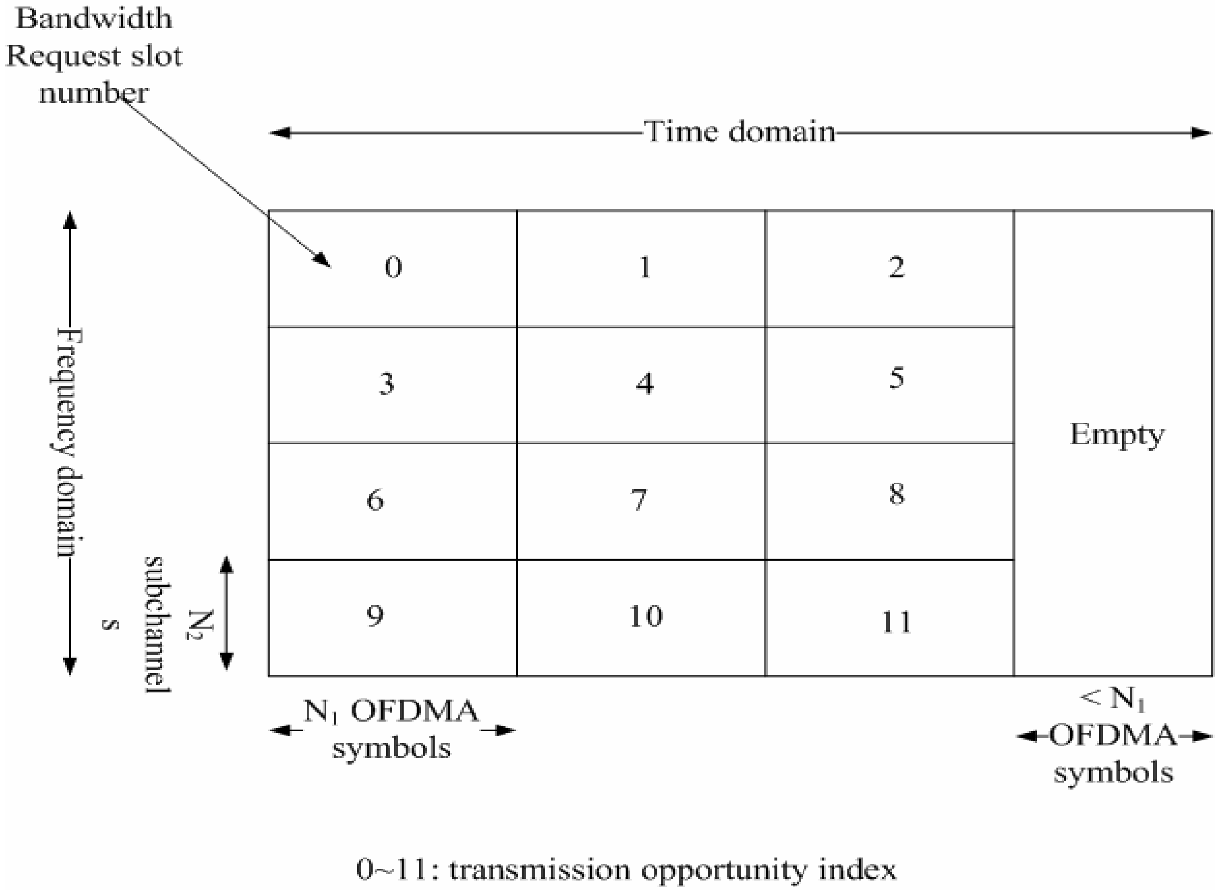

Figure 3.3 Bandwidth request opportunities

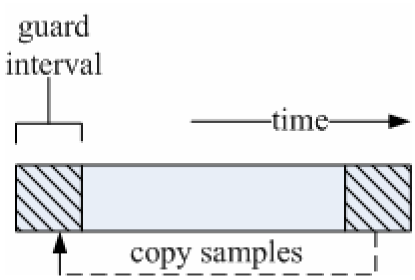

Figure 3.4 Bandwidth request transmission for OFDMA using one code

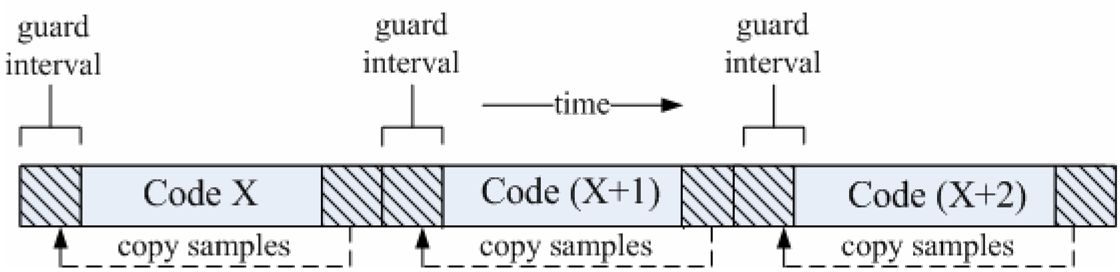

Figure 3.5 Bandwidth request transmission for OFDMA using three consecutive codes

	N_1 (OFDMA symbols)	N_2 (subchannels)
UL-PUSC	1 or 3	6
UL-OPUSC	1 or 3	8

Table 3.3 Values of N_1 and N_2 corresponding to different kind of subchannelization

Each SS which wants to request bandwidth shall randomly select a ranging subchannel and a ranging code from the code subset and a ranging code from the code subset. For UL-PUSC, a ranging subchannel is composed of six logically adjacent subchannels; for UL-OPUSC, a ranging subchannel is composed of eight logically adjacent subchannels. One subchannel consists of six tiles. The tile structures for UL-PUSC and UL_OPUSC are shown in figure 3.6 and 3.7. For UL-PUSC, each tile is constructed from four successive active subcarriers; for UL-OPUSC, each tile is constructed from three successive active subcarriers. Therefore, one subchannel consists of 24 subcarriers and one ranging subchannel consists of 144 subcarriers. The relationship between one tile, one subchannel and one ranging subchannel for UL-PUSC is illustrated in figure 3.8.

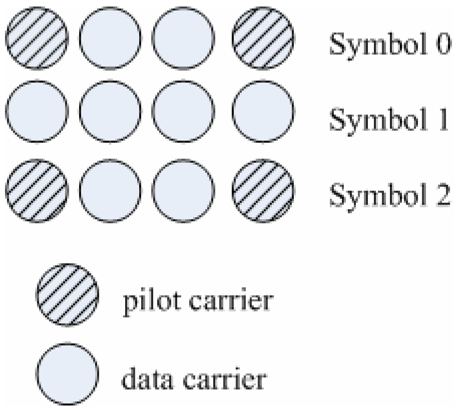

Figure 3.6 Tile structure for UL-PUSC

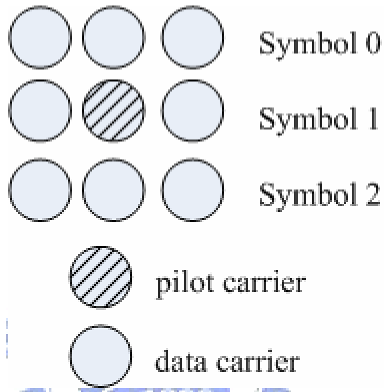

Figure 3.7 Tile structure for UL-OPUSC

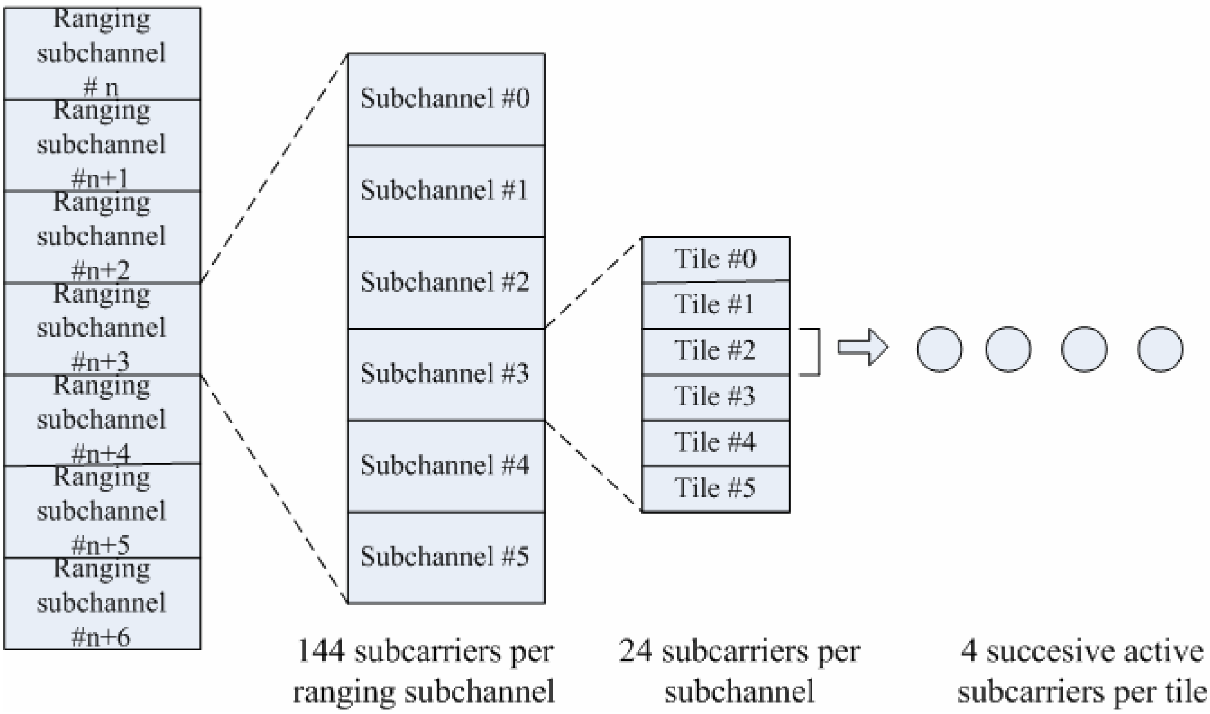

Figure 3.8 Relationships among tiles, subchannels and ranging subchannels for UL-PUSC

The used subcarriers in an OFDMA symbol excluding the dc subcarrier are first divided into tiles and each tile contains four successive active subcarriers. Tiles in each group are physically adjacent and are numbered from 0 to N_{tiles}-1 where N_{tiles} denotes the number of tiles in one OFDMA symbol. Then the following formula is used to select tiles that construct a subchannel:

$$Tiles(s,n)=N_{subchannels}*n+(Pt[(s+n) \bmod N_{subchannels}]+UL\_PermBase) \bmod N_{subchannels} \quad (3.1)$$

where

Tiles(s,n) is the tile index starting from 0 to N_{tiles}-1

n is the tile index 0…5 in a subchannel

Pt is the tile permutation

s is the subchannel index in the range 0….$N_{subchannels}$-1

UL_PermBase is an integer value in the range 0…69, which is assigned by a management entity

$N_{subchannels}$ is the number of subchannels in one OFDMA symbol.

The first term of equation 3.1 means that the total tiles are first divided into 6 groups. For a specific subchannel, the 6 tiles are selected from these 6 groups respectively. The second term of equation 3.1 means the offset of a tile in its group. These values are different according to different FFT sizes. Table 3.4 shows the parameters for 2048-FFT OFDMA uplink subcarrier allocations for PUSC.

Parameter	Value	Notes
Number of DC subcarriers	1	
N_{used}	1681	Number of all subcarriers used within a symbol
Guard subcarriers: Left, Right	184, 183	

Tile Permutation	6,48,58,57,50,1,13,26,46,44, 30,3,27,53,22,18,61,7,55,36, 45,37,52,15,40,2,20,4,34,31, 10,5,41,9,69,63,21,11,12,19, 68,56,43,23,25,39,66,42,16, 47,51,8,62,14,33,24,32,17, 54,29,67,49,65,35,38,59,64, 28,60,0	Used to allocate tiles to subchannels
$N_{subchannels}$	70	
N_{tiles}	420	
Number of subcarriers per tile	4	
Tiles per subchannel	6	

Table 3.4 2048-FFT OFDAM uplink subcarrier allocations for PUSC

For example, the tiles used for subchannel s=3 in UL_PermBase=2 are computed and the FFT size is 2048. The parameters are shown in table 3.4. First, active subcarriers are divided into tiles and each tile composes of four consecutive active subcarriers. These tiles are indexed from 0 to 419 and divided into 6 groups, which is shown in figure 3.9.

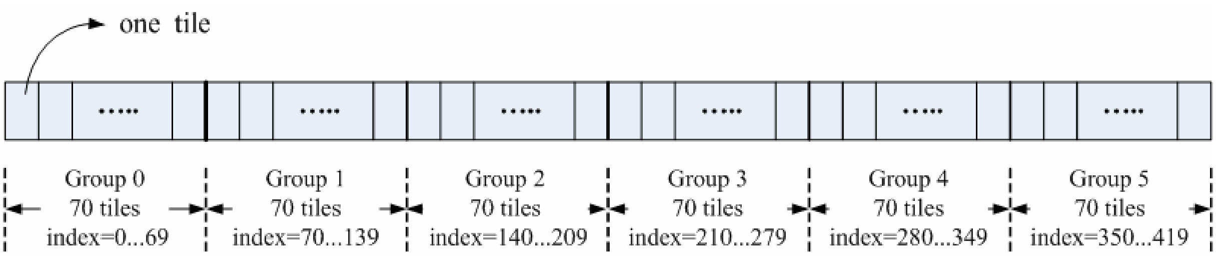

Figure 3.9 Division of tiles into six groups

According to equation 3.1 and table 3.4, Tile(3,0)=70*0+(Pt[(3+0)mod 70]+2)mod 70=0+(Pt[3]+2)mod 70=(57+2)mod 70=59, which means that the first tile for subchannel 3 is the tile indexed as 60. The remaining 5 tiles are indexed as follows:

Tile(3,1)=70*1+(Pt[(3+1)mod 70]+2)mod 70=70+(Pt[4]+2) mod 70=122

Tile(3,2)=70*2+(Pt[(3+2)mod 70]+2)mod 70=140+(Pt[5]+2) mod 70=143

Tile(3,3)=70*3+(Pt[(3+3)mod 70]+2)mod 70=210+(Pt[6]+2) mod 70=225

Tile(3,4)=70*4+(Pt[(3+4)mod 70]+2)mod 70=280+(Pt[7]+2) mod 70=308

Tile(3,5)=70*5+(Pt[(3+5)mod 70]+2)mod 70=350+(Pt[8]+2) mod 70=398

Thus subchannel 3 is composed of tiles with index=59, 122, 143, 225, 308 and 398.

3.3.2.2 Ranging Code

Ranging codes are generated by the PRBS (pseudo-random binary sequence) generator which is shown in figure 3.10. The PRBS generator shall be initialized by the seed b15…b1= 0, 0, 1, 0, 1, 0, 1, 1, s0, s1, s2, s3, s4, s5, s6 where s6 is the LSB of the PRBS seed and s6:s0=UL_PermBase. s6 is the MSB of the UL_PermBase. The UL_Permbase is assigned by a management entity. The binary ranging codes are sequences of the pseudonoise sequence appearing at its output C_k. The length of each ranging code is 144 bits. The first code is produced by taking the output of the first to 144th clock of the PRBS generator, the second code is produced by taking the output of the 145th to 288th clock of the PRBS generator, etc. There are 256 available ranging codes. These 256 available codes are partitioned into four subgroups for initial-ranging, periodic-ranging, bandwidth-requests and handover-ranging. Each SS which wants to request bandwidth randomly select a ranging code and BPSK modulates the selected ranging code onto the selected ranging subchannel. The bits are mapped to the subcarriers in increasing frequency order of the subcarriers, such that the lowest indexed bit modulates the subcarrier with the lowest frequency index and the highest indexed bit modulates the subcarrier with the highest frequency index.

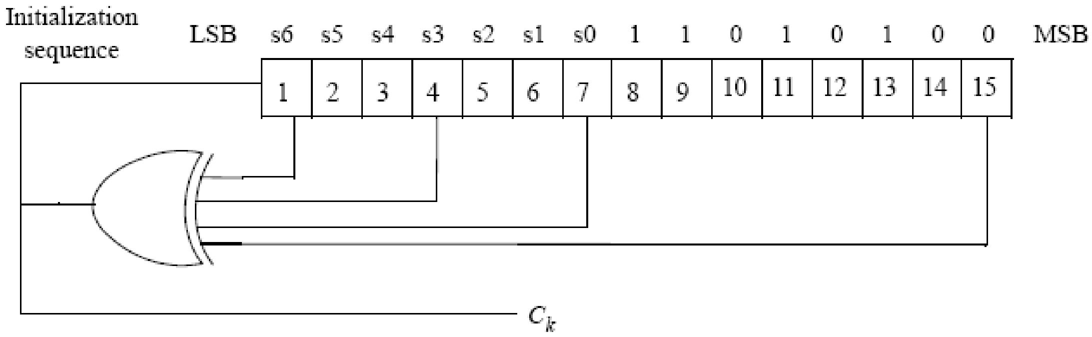

Figure 3.10 PRBS generator for ranging code generation

3.3.2.3 Bandwidth Request Mechanism

Assume that there are N_c ranging codes and Ns ranging subchannels available for SSs to select. Each SS which wants to request bandwidth randomly select a ranging channel and a ranging code. After modulating the selected ranging code onto the selected ranging channel, the SS transmits a complete OFDMA symbol. The BS will receive a signal which contains many SSs' bandwidth request signals. Each SS's bandwidth request signal would experience different channel. The system model is shown in figure 3.11.

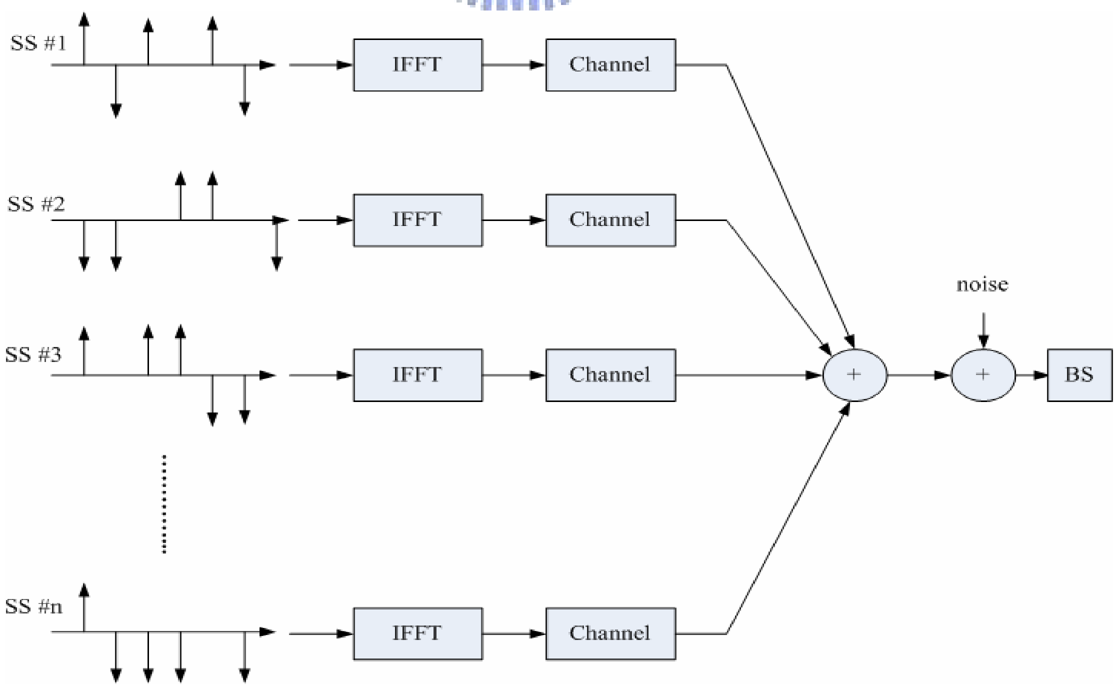

Figure 3.11 System model

3.3.2.4 Proposed Detection Method

Assume that the synchronization and power control are done during initial ranging or periodic ranging. The detection method is based on the correlation between codes. When the code matches the received signal, the correlation will be large. Otherwise, the correlation will not be large if the code does not match the received signal. After receiving the bandwidth request signal $\mathbf{Y_t}$, the BS performs FFT to transform $\mathbf{Y_t}$ to frequency domain and derives $\mathbf{Y_f}$. For each ranging subchannel, there are N_c ranging codes to be checked. For each ranging subchannel, the signal is multiplied by each of these N_c ranging codes ,$\mathbf{C_1}$, $\mathbf{C}_2$,…, $\mathbf{C}_{Nc-1}$, and $\mathbf{C}_{Nc}$, which will derive $\mathbf{d_1}$, $\mathbf{d_2}$, …, $\mathbf{d_{Nc-1}}$ and $\mathbf{d_{Nc}}$. Then transform these resulted vectors to time domain by IFFT. In time domain, calculate the power of each tap and select the maximum value among those taps. After selecting the maximum values, $Y_{k,1}, Y_{k,2}, ..., Y_{k,Nc-1}$ and $Y_{k,Nc}$ where k is the ranging subchannel index, average these Nc values and derive a constant A . Compare each of these Nc values with the average value A. If $Y_{k,i} - A > threshold$, where i =1,2,… Nc and k=1,2,…Ns, the *ith* ranging code is considered received by the BS in the *kth* ranging subchannel. This may be either detection, false alarm or undesired collision false alarm. Instead, if $Y_{k,i} - A \le threshold$, the ranging code is not seen by the BS in the ranging subchannel. This may be either miss detection or no SS transmitting the ranging code in this ranging subchannel. The threshold is chosen according to a desired performance criterion. The value $Y_{k,i}$ can be large if the *ith* ranging code is transmitted by some SS. If the *ith* ranging code is not transmitted by any SS, $Y_{k,i}$ can be small. Thus the average of these *Nc* values lies between these two case. The detection procedure is illustrated in figure 3.12.

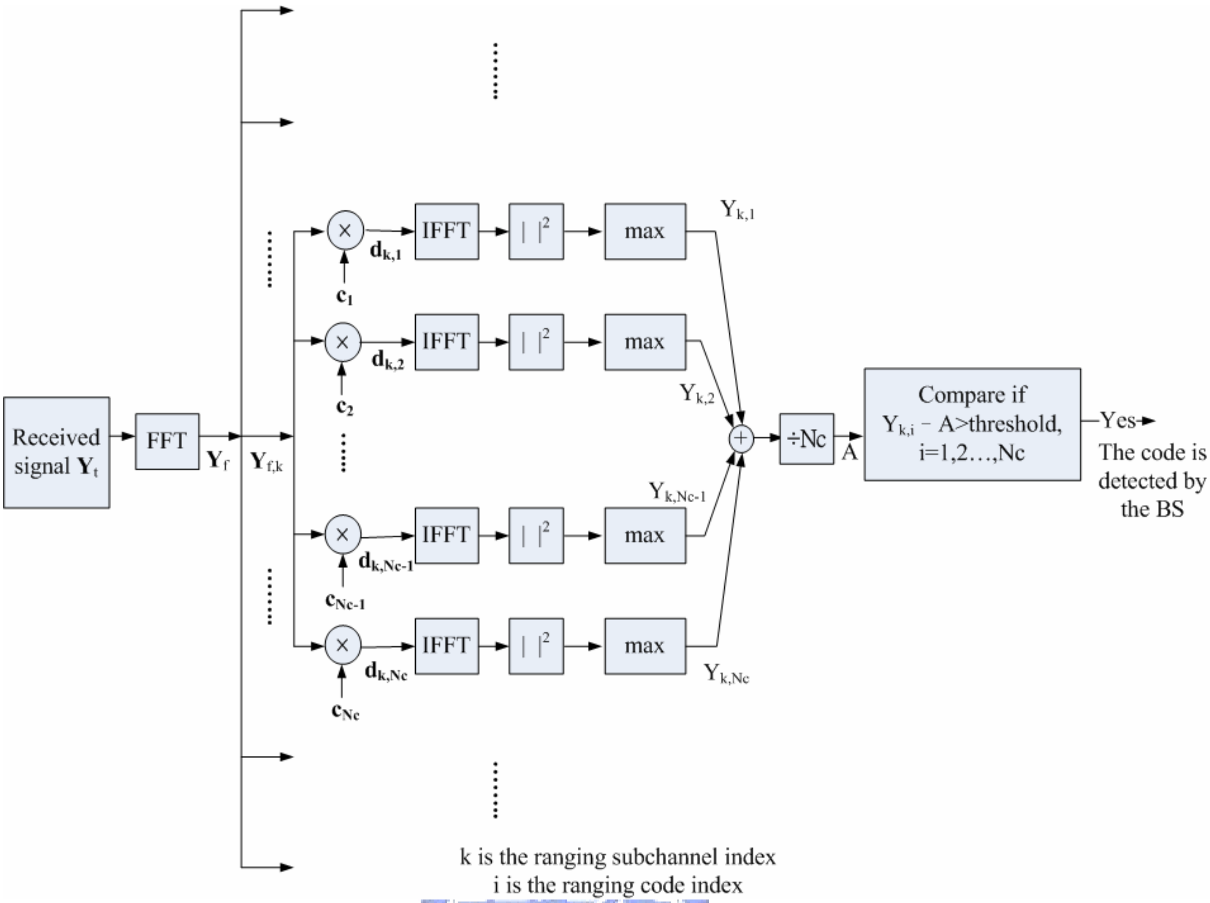

Figure 3.12 Proposed detection method for CDMA-based bandwidth request mechanism

3.4 Proposed Bandwidth Request Method

3.4.1 Proposed Method

In the proposed method, a ranging subchannel consists of one subchannel instead of six subchannels in the CDMA-based method. Each subchannel consists of six tiles and each tile consists of four consecutive active subcarriers. Thus, for the same allocations, the number of ranging subchannels in the proposed method is six times more than that in the CDMA-based method. Each SS which wants to request bandwidth randomly selects a ranging subchannel and energizes every subcarrier in the selected ranging subchannel and then transmits a complete OFDMA symbol to the BS.

3.4.2 Detection Method

Because subcarriers in a tile are physically adjacent, we assume the channel response for each subcarrier in the same tile is nearly the same. Assume that synchronization and power control are done during initial ranging or periodic ranging. After the BS receives the bandwidth request signal, the signal is transformed to frequency domain by FFT. The following detection procedure is described as follows:

Step 1— for the jth tile of the ith ranging subchannel, calculate the inner product of the subcarriers of $\mathbf{Y}_{i,j}$ and vector $\mathbf{V}=[1,1,1,1]$ and get $S_{1,i,j}=\sum_{k=0}^{3} Y_{i,j,k}$ where $Y_{i,j,k}$ is the kth subcarrier of the jth tile of the ith ranging subchannel. Then add the square of $S_{1,i,j}$ and get $S_{1,i}=\sum_{j=0}^{Nt-1}\left|S_{1,i,j}\right|^2$ where Nt is the number of tiles in a ranging subchannel. The mathematical description is as follows:

$$S_{1,i}=\sum_{j=0}^{Nt-1}\left|S_{1,i,j}\right|^2=\sum_{j=0}^{Nt-1}\Big|\underbrace{\mathbf{Y}_{i,j}\cdot\mathbf{V}}_{S_{1,i,j}}\Big|^2=\sum_{j=0}^{Nt-1}\Big|\underbrace{\sum_{k=0}^{3}Y_{i,j,k}}_{S_{1,i,j}}\Big|^2$$

$$=\sum_{j=0}^{Nt-1}\left|\sum_{k=0}^{3}\left(H_{i,j,k}X_{i,j,k}+\underbrace{I_{i,j,k}+N_{i,j,k}}_{N'_{i,j,k}}\right)\right|^2$$

$$\approx\sum_{j=0}^{Nt-1}\left|4H_{i,j,0}\underbrace{X_{i,j,0}}_{=1}+\sum_{k=0}^{3}N'_{i,j,k}\right|^2$$

$$=\sum_{j=0}^{Nt-1}\left|4H_{i,j,0}+\sum_{k=0}^{3}N'_{i,j,k}\right|^2$$

where $H_{i,j,k}$ is the channel response for the kth subcarrier of the jth tile of the ith ranging subchannel, $I_{i,j,k}$ and $N_{i,j,k}$ means interference and noise respectively.

Step 2—for the jth tile of the ith ranging subchannel, calculate the inner product of $\mathbf{Y}_{i,j}$ and vector $\mathbf{U}=[1,1,1,-1]$ and get $S_{2,i,j}=\sum_{k=0}^{2}Y_{i,j,k}-Y_{i,3}$. Then add the square of $S_{2,i,j}$ and get $S_{2,i}=\sum_{j=0}^{Nt-1}\left|S_{2,i,j}\right|^{2}$. The mathematical description is as follows:

$$S_{2,i}=\sum_{j=0}^{Nt-1}\left|S_{2,i,j}\right|^{2}=\sum_{j=0}^{Nt-1}\left|\underbrace{\mathbf{Y}_{i,j}\cdot\mathbf{U}}_{S_{2,i,j}}\right|^{2}=\sum_{j=0}^{Nt-1}\left|\underbrace{\sum_{k=0}^{2}Y_{i,j,k}-Y_{i,j,3}}_{S_{2,i,j}}\right|^{2}$$

$$=\sum_{j=0}^{Nt-1}\left|\left(H_{i,j,0}X_{i,j,0}+H_{i,j,1}X_{i,j,1}+H_{i,j,2}X_{i,j,2}-H_{i,j,3}X_{i,j,3}\right)+\left(N'_{i,j,0}+N'_{i,j,1}+N'_{i,j,2}-N'_{i,j,3}\right)\right|^{2}$$

$$\approx\sum_{j=0}^{Nt-1}\left|2H_{i,j,0}\underbrace{X_{i,j,0}}_{=1}+\sum_{k=0}^{2}N'_{i,j,k}-N'_{i,j,3}\right|^{2}$$

$$=\sum_{j=0}^{Nt-1}\left|2H_{i,j,0}+\sum_{k=0}^{2}N'_{i,j,k}-N'_{i,j,3}\right|^{2}$$

Step 3— calculate the ratio of $S_{1,i,j}$ and $S_{2,i,j}$ where j=0… $Nt-1$. If $4-\delta<\frac{S_{1,i,j}}{S_{2,i,j}}<4+\delta$, the counter is added by 1 and assume the final counter value is b.

Step 4— calculate the ratio of $S_{1,i}$ and $S_{2,i}$ where i=1,2,…Ns-1 and Ns is the number of ranging subchannels. The mathematical description is as follows:

If ranging signal is transmitted:

$$\frac{S_{1,i}}{S_{2,i}} \approx \frac{\sum_{j=0}^{Nt-1}\left|4H_{i,j,0}+\sum_{k=0}^{3}N'_{i,j,k}\right|^2}{\sum_{j=0}^{Nt-1}\left|2H_{i,j,0}+\sum_{k=0}^{2}N'_{i,j,k}-N'_{i,j,3}\right|^2}$$

$$\approx \frac{16\sum_{j=0}^{Nt-1}\left|H_{i,j,0}+\frac{1}{4}\sum_{k=0}^{3}N'_{i,j,k}\right|^2}{4\sum_{j=0}^{Nt-1}\left|H_{i,j,0}+\frac{1}{2}\left(\sum_{k=0}^{2}N'_{i,j,k}-N'_{i,j,3}\right)\right|^2} \approx 4$$

If ranging signal is not transmitted:

$$\frac{S_{1,i}}{S_{2,i}} = \frac{\sum_{j=0}^{Nt-1}\left|\sum_{k=0}^{3}N'_{i,j,k}\right|^2}{\sum_{j=0}^{Nt-1}\left|\sum_{k=0}^{2}N'_{i,j,k}-N'_{i,j,3}\right|^2} \approx 1$$

If $4-\delta<\frac{S_{1,i}}{S_{2,i}}<4+\delta$, $S_{1,i}>\mu$ and b>=2, the ranging subchannel is considered to be used by some SS. This may be either detection, false alarm or undesired collision false alarm. Instead, the ranging subchannel is considered not to be used by any SS. This may result from either miss detection or that the ranging subchannel not used by any SS. δ and μ are adjusted according to the desired performance criterion. Figure 3.13 and 3.14 illustrate step1 and step2 and Nrc denotes the number of ranging subchannels.

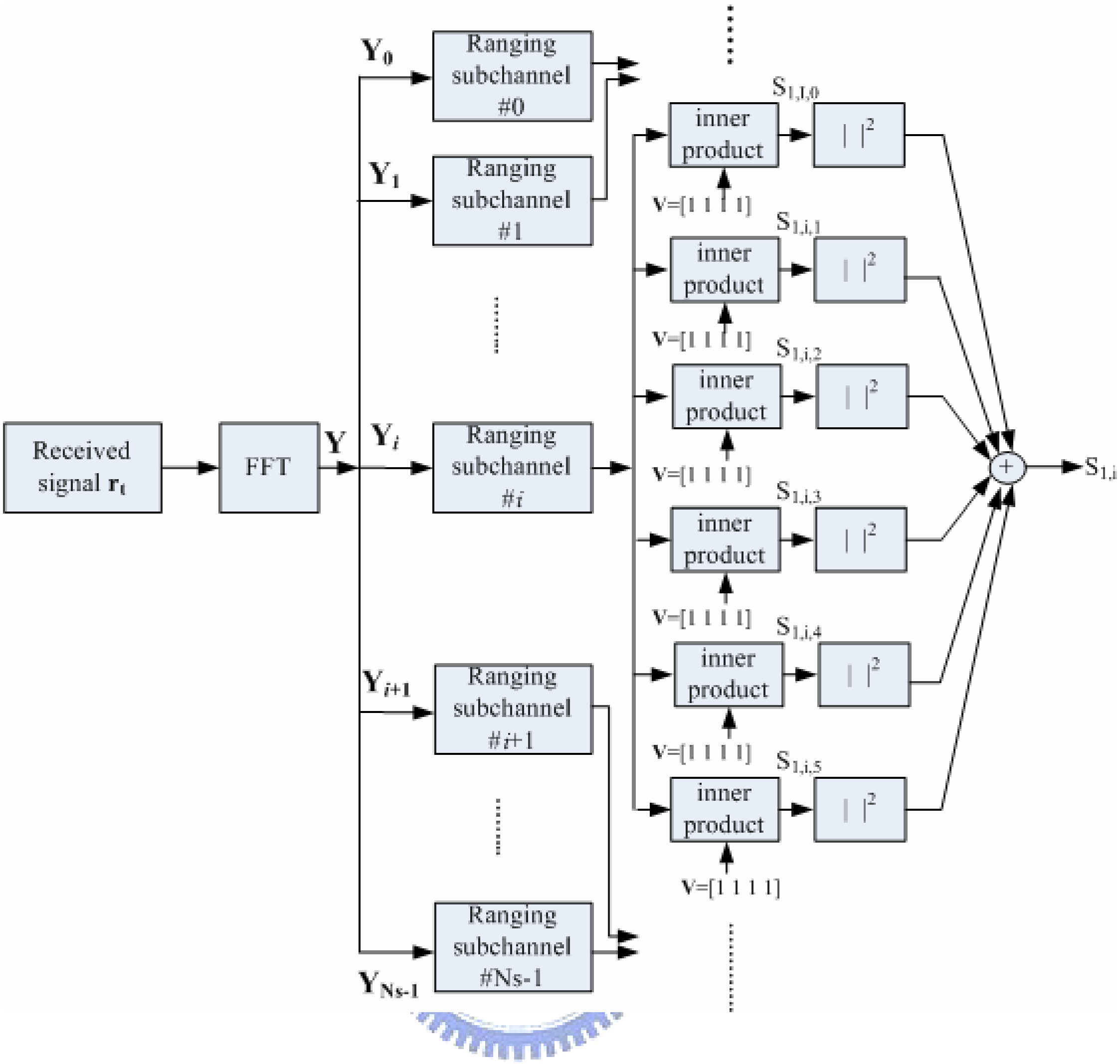

Figure 3.13 Step 1 of the detection procedure for the proposed method

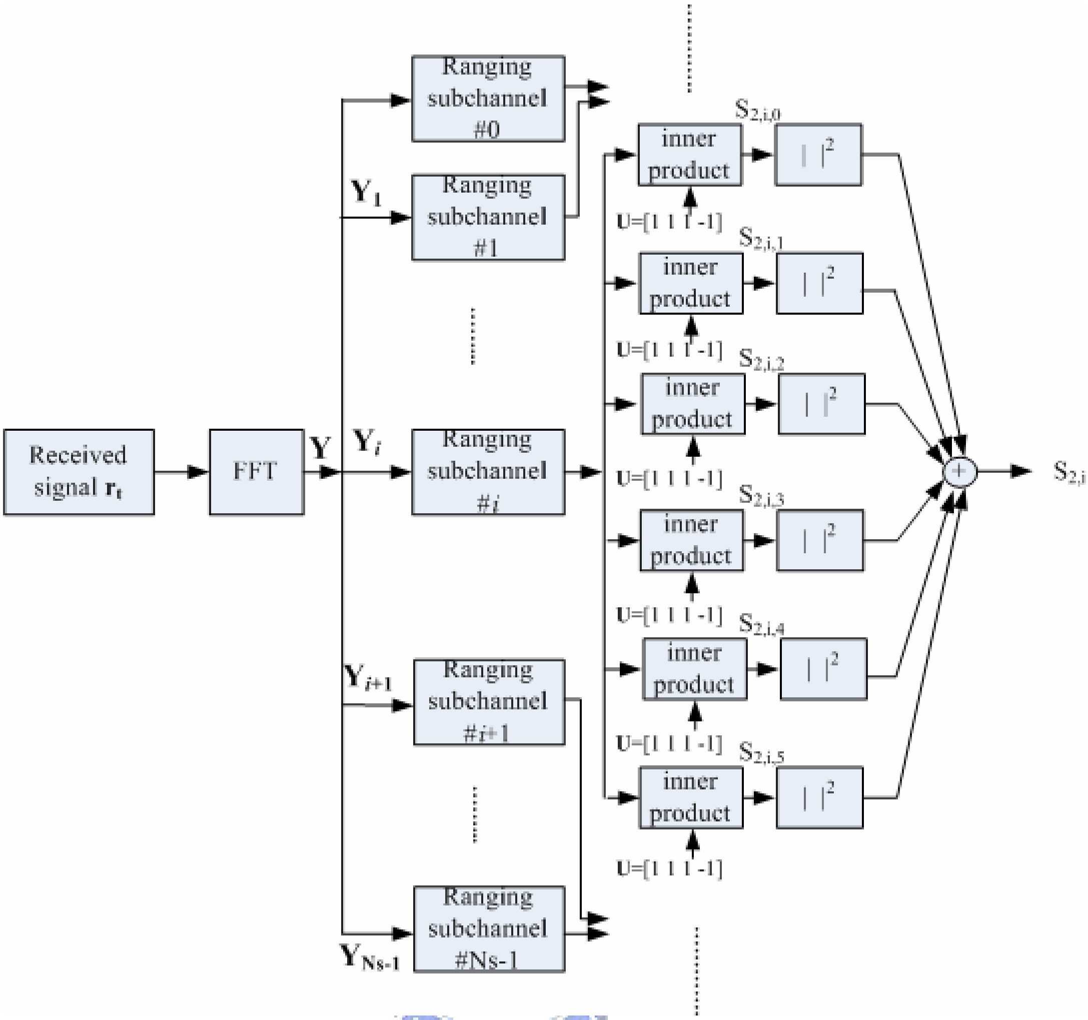

Figure 3.14 Step 2 of the detection procedure for the proposed method

3.4.3 Modify the Proposed Method

In the proposed method, each SS which wants to request bandwidth will select a ranging subchannel and energize the subcarriers within the selected ranging subchannel. In the modified method, some codes are used to help the BS to differentiate SSs from different cells. Each user in one cell uses the same code and binary modulates the code in the selected ranging subchannel. The code length is 4 bits. Since a ranging subchannel is composed of 6 tiles and each tile consists of 4 subcarriers, the 4-bit code is 6 times repeatedly modulated onto the 6 tiles. This is shown in figure 3.15 and the 4-bit codes are shown in table 3.5. The codes are not completely orthogonal, for example, the code with index=0 and the code with index=4 or the code with index=1 and the code with index=5, etc.

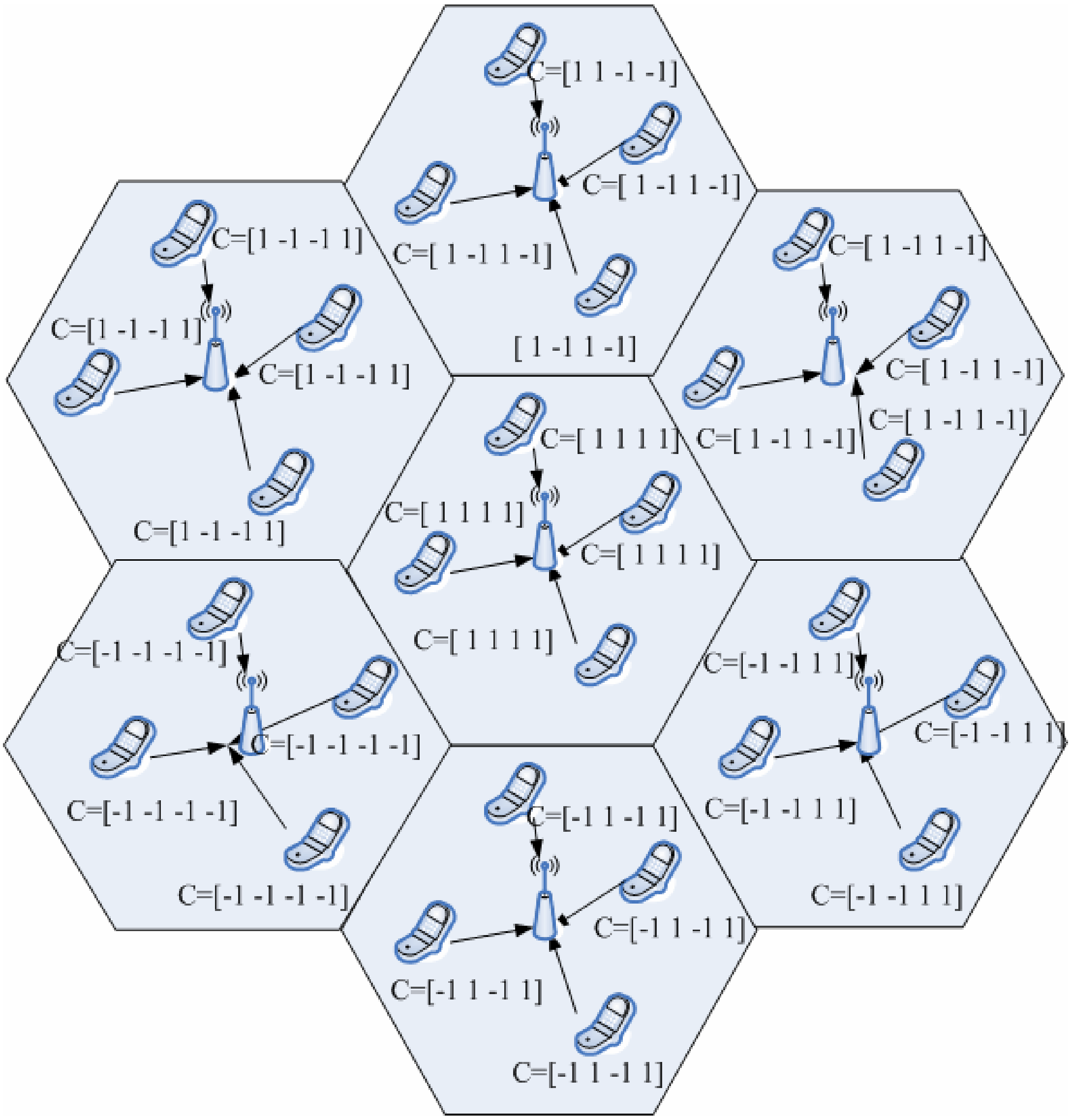

Figure 3.15 Codes are used to differentiate SSs from different cells

Code index	Bit 0	Bit 1	Bit 2	Bit 3
0	1	1	1	1
1	1	-1	1	-1
2	1	1	-1	-1
3	1	-1	-1	1
4	-1	-1	-1	-1
5	-1	1	-1	1
6	-1	-1	1	1

Table 3.5 Codes used for SSs in different cells

3.4.4 Detection for the Modified Method

The detection procedure of this modified method is almost the same as that of the proposed method. But before entering the detection procedure as described as above, the signal of tiles in each ranging subchanel is first multiplied by the used code corresponding to the cell. Each ranging subchannel is detected following the procedure described in 3.4.2. Figure 3.16 and 3.17 illustrate step 1 and step 2 of the detection procedure where **C** means the code used by the SSs in the observed cell.

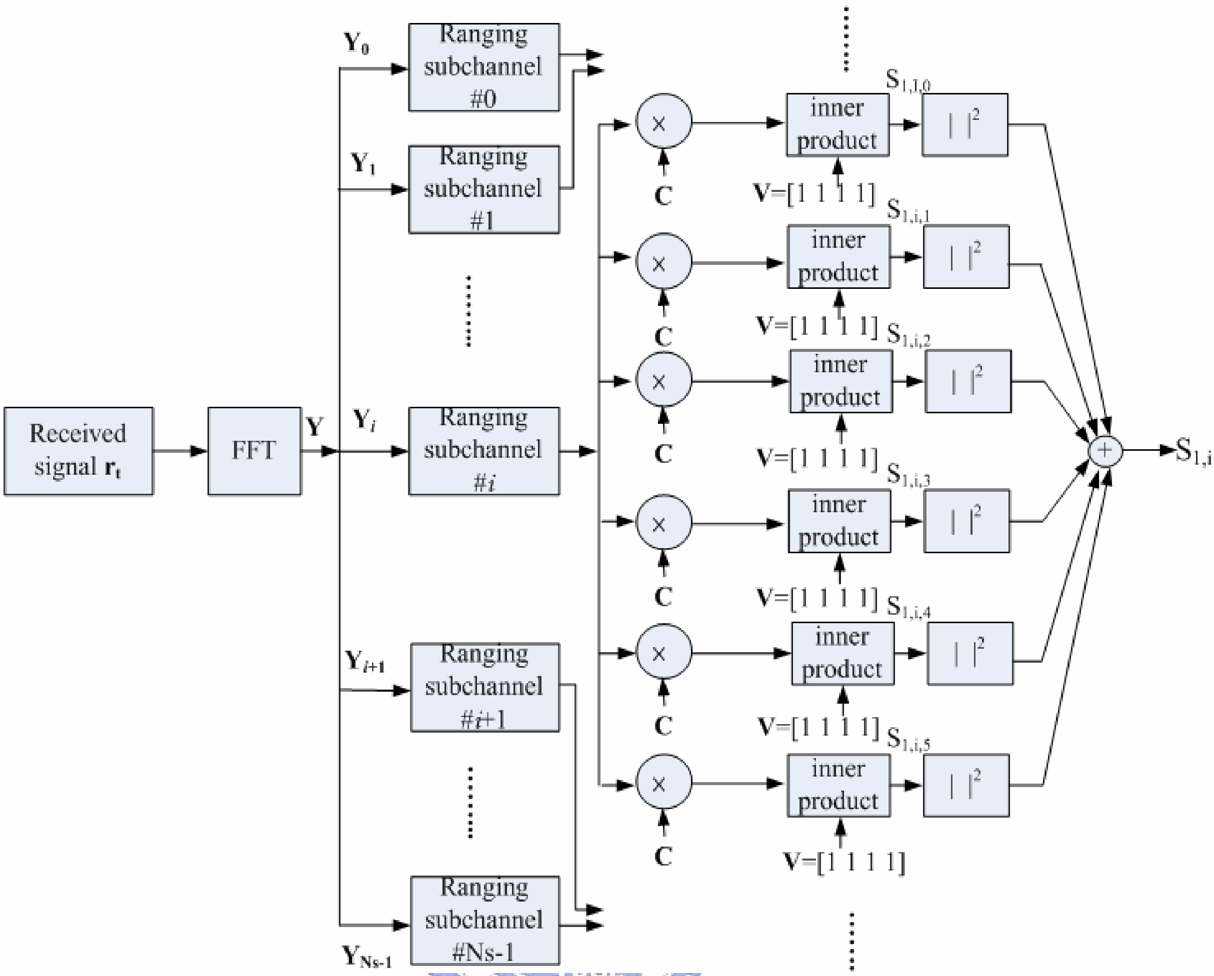

Figure 3.16 Step 1 of the detection procedure for the modified method

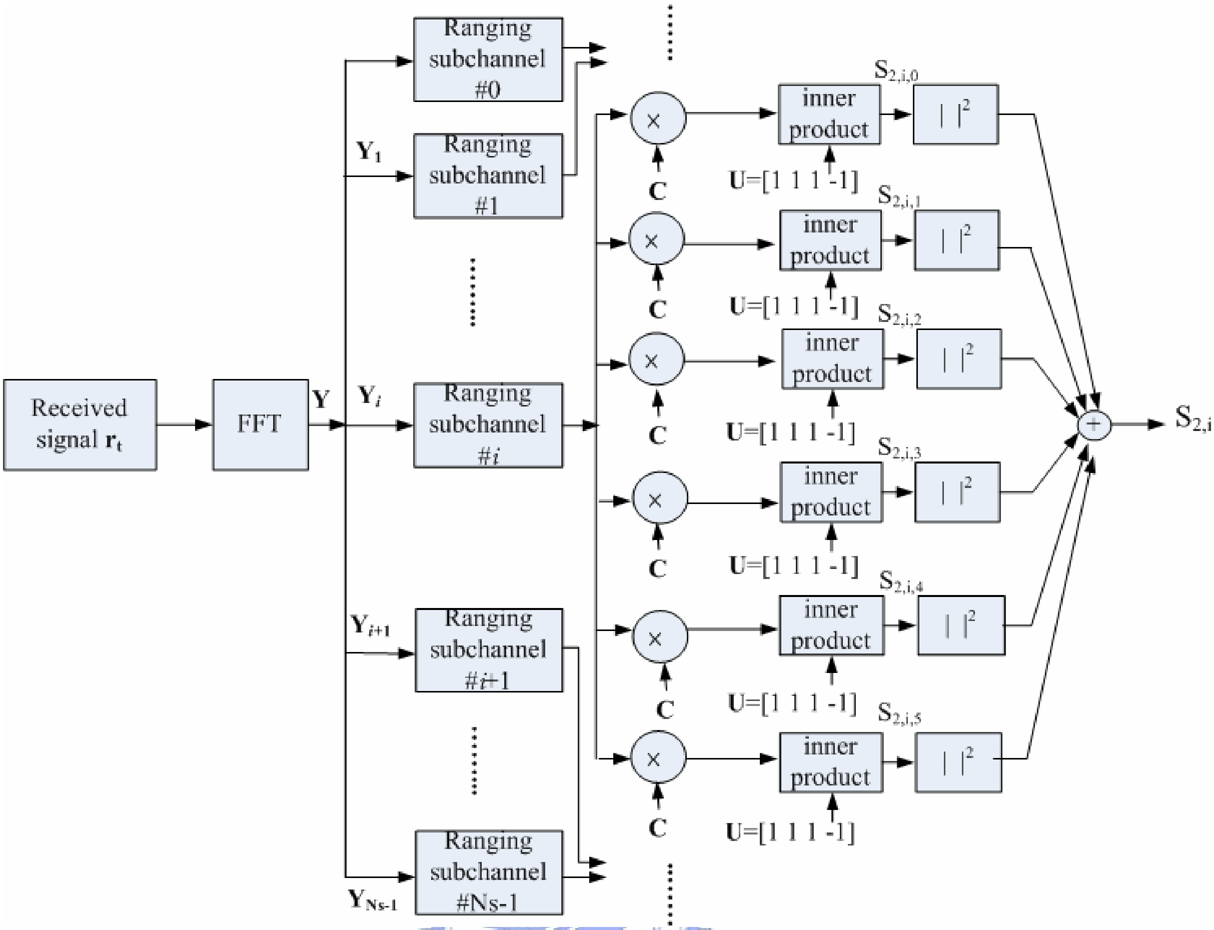

Figure 3.17 Step 2 of the detection procedure for the modified method

3.5 Contention Resolution

As same as the 802.11 CSMA/CA MAC protocol, the mandatory method of contention resolution that shall be supported is based on a truncated binary exponential backoff, with the initial backoff window and the maximum backoff window controlled by the BS. The values are specified in the UCD message and represent as a power-of-two value. When an SS enters the contention resolution process, it sets its internal backoff window equal to the Request Backoff Start defined in the UCD message. The SS shall randomly select a number within its backoff window. This number means the number of transmission opportunity the SS shall defer before transmitting. For an example, consider an SS whose initial backoff window is 15. When entering the contention resolution process, the SS first randomly select a number between 0 and 15. Assume the SS selects the number 11. The SS must defer a total of 11 contention transmission opportunities. If the first allocation is for 6 TOs, the SS shall not use this and has 5 more Tos to defer. If the next allocation contains 3 TOs, the SS has 2 more to defer. If the following allocation is for 5 TOs, the SS transmits on the third transmission opportunity after deferring for 2 more opportunities. The SS shall consider the contention transmission lost or collided if no data grant has been received in the number of subsequent UL-MAP messages before timeout. Under this condition, the SS shall increase its backoff window by a factor of two, as long as it is less than the maximum backoff window defined in the UCD messages. Once the data grant is received, the contention resolution is complete.

Chapter 4
Simulation Results and Discussions

In this chapter, simulation environment and some definitions are given. Then simulation results are shown and followed by the discussions.

4.1 Simulation Environment

4.1.1 Multicell Structure and Antenna Pattern

The simulation is run under a multicell structure which is shown in figure 4.1. There are 7 cells and each cell consists of three sectors.

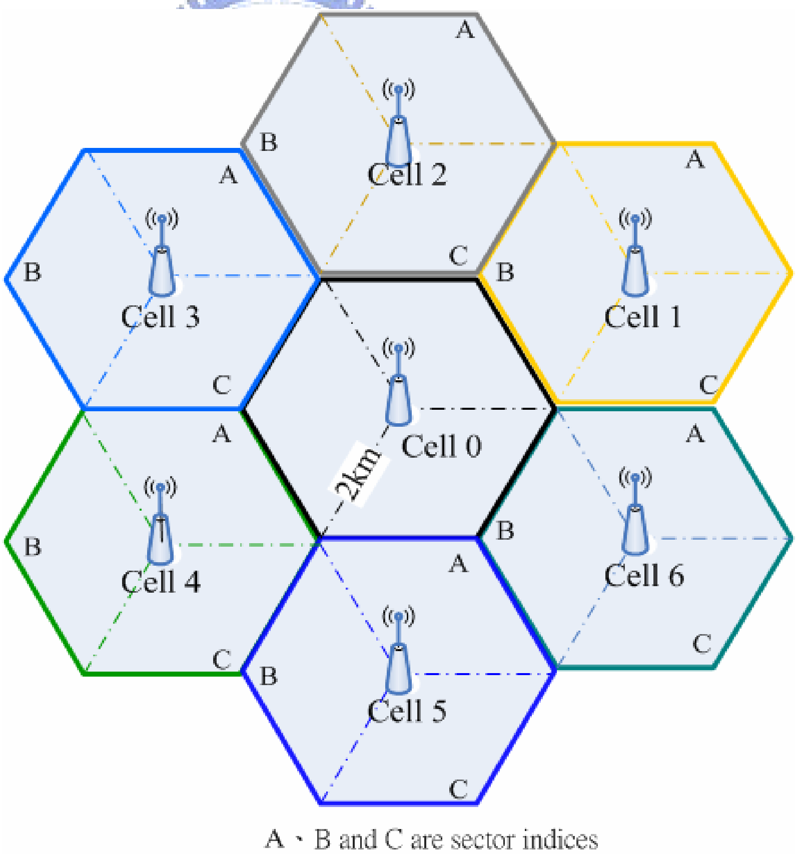

Figure 4.1 Multicell structure

Cell 0 is the observed cell and the other cells (cell 1 to cell 7) are cells introducing intercell interference. The cell radius is 2 kilometers. The BS antenna is 3-sector antenna. The antenna pattern for the BS is specified as

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

where $-180^\circ < \theta \le 180^\circ$, θ is the angle between the direction of interest and the steering direction of the antenna. $\theta_{3dB} = 70^\circ$ is the 3dB beam width and $A_m = 20dB$ is the maximum attenuation. Figure 4.2 shows this 3-sector antenna pattern.

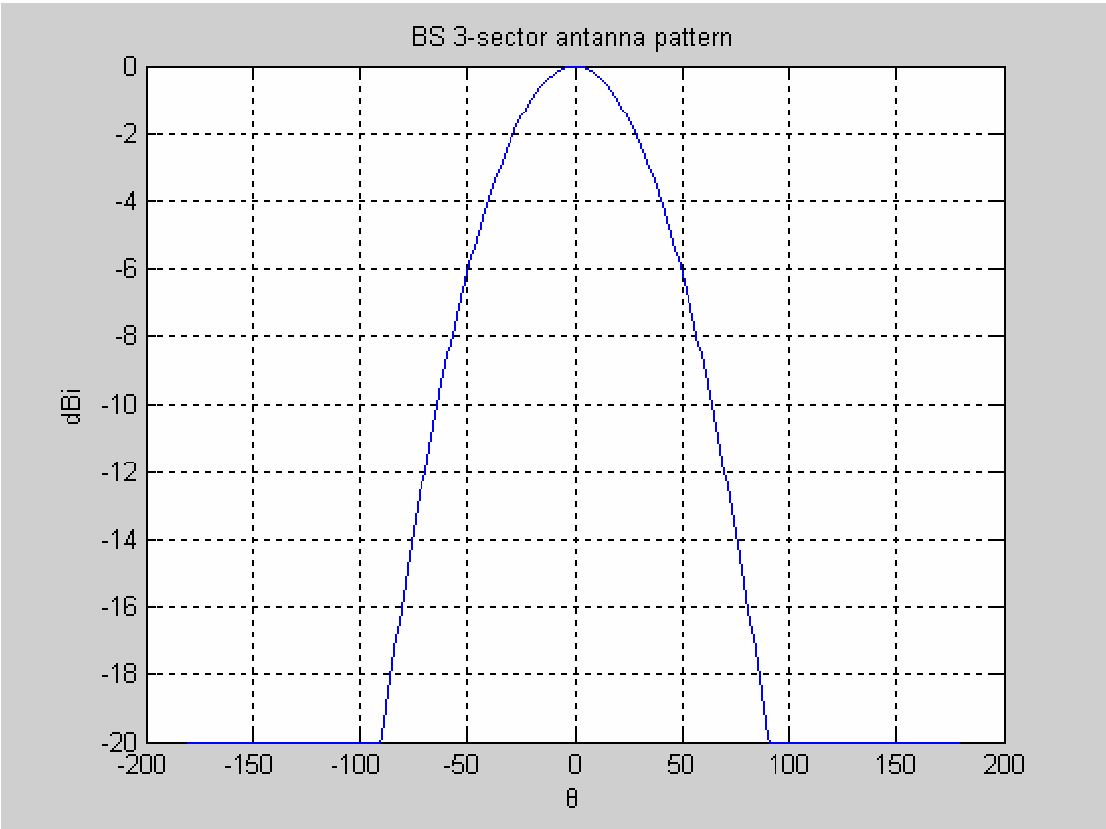

Figure 4.2 3-sector antenna pattern

When θ>90.3696°, the attenuation is 20 dBi. Omni antenna is assumed for SS.

Assume that subscriber stations (SSs) are uniformly distributed in 7 cells.

4.1.2 Channel Model [3] [4]

There are three path loss categories in [4]. Type A is the maximum path loss category which is hilly terrain with moderate-to-heavy tree densities. Type C is the minimum path loss category which is mostly flat terrain with light tree densities. Type B has the intermediate path loss between Type A and C. For a given reference distance d_0, the path loss (in dB) is given by

$$PL=A+10\gamma\log_{10}(d/d_0)+ s +\Delta PL_f+\Delta PL_h \quad \text{for } d > d_0,$$

where $A=20 \log_{10}(4\pi d_0/\lambda)$ (λ is the wavelength in meters), γ is the path loss exponent with $\gamma= a-b*h_b+c/ h_b$ for h_b between 10 meters and 80 meters (h_b is the height of the BS), d_0=100 meters and a=4, b=0.0065, c=17.1 for Type B. The shadowing effect is represented by s, which is a lognormal random variable with standard deviation value=9.6 for Type B. ΔPL_f and ΔPL_h are the correction term for carrier frequency and receive antenna height. $\Delta PL_f = 6 \log_{10}(f/2000)$ dB where f is the carrier frequency in MHz. $\Delta PL_h = -10.8 \log_{10}(h/2)$ where h is the SS antenna height between 2 meters and 10 meters. Due to reciprocity property, the transmssion power of each SS can be calculated.

For multipath fading channel, SUI-4 is applied for Type B channel and NLOS situation. Table 4.1 shows the parameters for SUI-4 channel model.

Terrain Type B: Intermediate path-loss condition: SUI-4				
	Tap1	Tap2	Tap3	Unit
Delay	0	1.5	4.0	μs
Power	0	-4	-8	dB
K factor	0	0	0	
Doppler	0.2	0.15	0.25	Hz

Table 4.1 Parameters for SUI-4 channel model

K factor is the ratio of the power between the constant part and the Rayleigh (variable) part.

For a Ricean distribution (LOS), a constant path component has to be added to the Rayleigh part. For a Rayleigh distribution (NLOS), the K factor is zero since no constant part is needed. Simulation parameters are listed in table 4.2.

System bandwidth	20 MHz
Carrier frequency	5 GHz
Cell radius	2 km
BS antenna height	30 m
SS antenna height	2 m
FFT size	2048
Guard subcarriers: Left, Right	184, 183
Number of dc subcarrier	1
Subcarrier used (N_{used})	1680
Number of subcarriers allocated for bandwidth request	1296
Number of null subcarriers	384
Cyclic prefix	512
Modulation	BPSK
Path loss model	Type B (intermediate path loss [3] [4])
Multipath fading model	SUI-4 (table 4.1)
SNR	6.4 dB
Average number of transmissions per cell within an OFDMA symbol	3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 54

Table 4.2 Simulation parameters

The number of used subcarriers for 2048-FFT OFDMA in the uplink is 1680. Since a ranging subchannel consists of 144 subcarriers for CDMA-based method, there are 11 available ranging subchannels in an OFDMA symbol and the number of the remaining subcarriers is 96 (1680-11*144=96). If these 11 ranging subchannels are all allocated for bandwidth request, the allocation to each sector will not be fair since 11 is not a multiple of 3. To prevent that the performance is dominated by the sector which is allocated with the least number of ranging subchannels, the first 9 ranging subchannels out of the 11 ranging subchannels are allocated for bandwidth request. Thus, each sector of a cell is allocated with 3 ranging subchannels (432 subcarriers).

The number of subcarriers used for bandwidth request is 1296. For the proposed method, a ranging subchannel is composed of one subchannel which consists of 24 subcarriers. Therefore, there are 54 ranging subchannels for the proposed method. Each sector in a cell is allocated with 18 ranging subchannels. This is summarized in table 4.3.

	Number of subcarriers	Number of subcarriers per ranging subchannel	Number of ranging subchannels
CDMA-based method	1296	144	9
Proposed method	1296	24	54

Table 4.3 Summary of the usage of the subcarriers for CDMA-based and the proposed method

4.2 Some Definitions

There are some terms to be defined:

1. when there is only one SS transmitting some code or energizing subcarriers in some ranging subchannel and the detector output is positive, this is termed detection;

2. when there is some transmission that is not detected by the detector, this is termed miss

detection. In this case, the BS does not allocate resource for bandwidth request and these SSs have to backoff and retry in a subsequent frame.

3. when more than two SSs transmit the same code or energize in the same ranging subchannel, collision happens. In this case, the BS may or may not allocate resource for bandwidth request depending on if the detector output is positive or negative. If the detector output is positive, the allocated resource will cause more than one SSs to respond and collide. If the detector output is negative, the missed SSs will backoff and retry in a subsequent frame. The later case is termed undesired collision false alarm in [9]. The summary of the definitions are shown in table 4.4.

According to previous paragraph, the detection probability is the ratio of the number of successful detection to the total number of transmissions. The miss detection probability is the ratio of the number of missed transmissions to the total number of transmissions. The undesired collision false alarm probability is the ratio of the number of transmissions that result in undesired collision false alarm to the total number of transmissions.

Number of transmissions \ detector output	Positive	Negative
0	False Alarm	
1	Successful Detection	Miss Detection
2 or more	Undesired Collision False Alarm	

Table 4.4 Summary of the definitions

4.3 Simulation Results

The simulations are run under several conditions:

1. CDMA-based method and the number of ranging code is 6 (Nrc=6);

2. CDMA-based method and the number of ranging code is 9 (Nrc=9);

3. the proposed method without codes to differentiate SSs from different cells and each SS randomly selects a ranging subchannel and energizes its randomly selected subcarriers;

4. the proposed method without codes to differentiate SSs from different cells and each SS energizes the ranging subchannel which is assigned by the BS;

5. the proposed method with codes to differentiate SSs frome different cells and each SS sends the specified code onto its randomly selected ranging subchannel;

6. the proposed method with codes to differentiate SSs frome different cells and each SS sends the specified code onto the ranging subchannel which is assigned by the BS.

For 3, 4, 5 and 6, the simulations are also run under the condition that the counter in the detection procedure is not included. The number of trials is 1000 and the system parameters, threshold, δ and μ, are chosen such that the number of false alarm is around 100.

Detection Probability

$$= \frac{\text{number of detected transmissions excluding the collided ones}}{\text{number of total transmissions}}$$

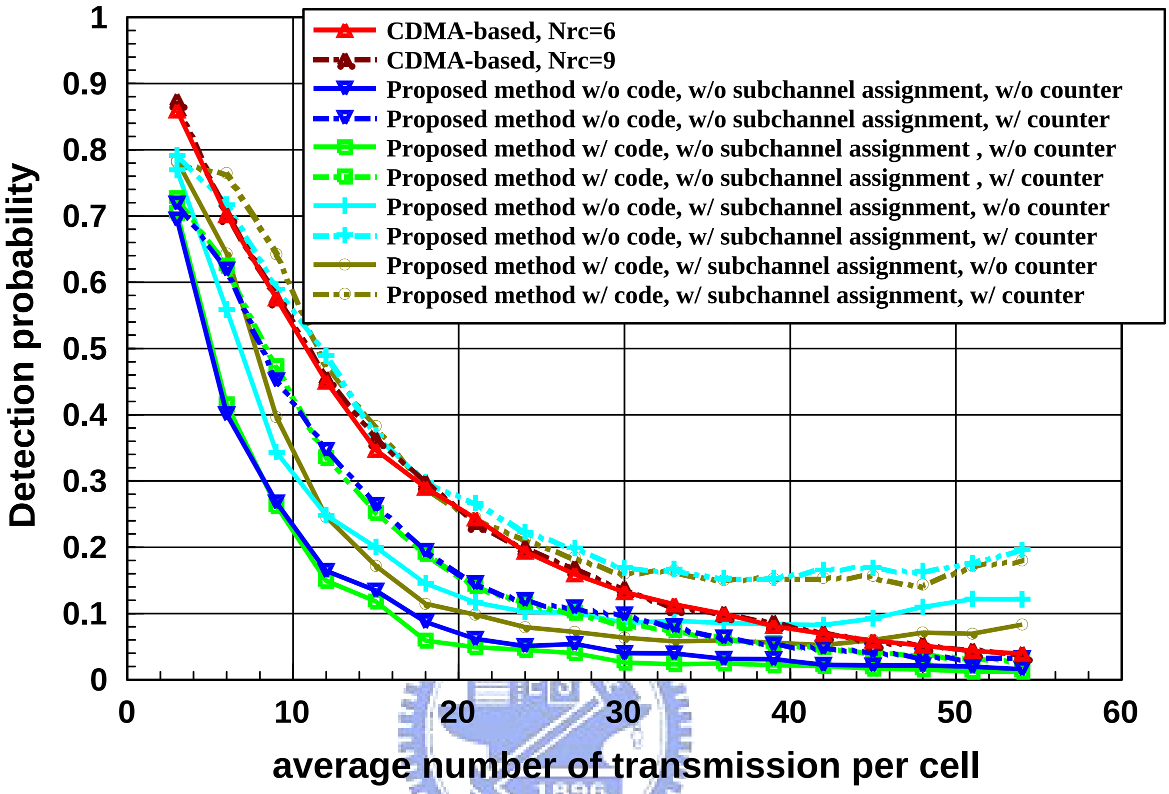

Figure 4.3 Detection probability

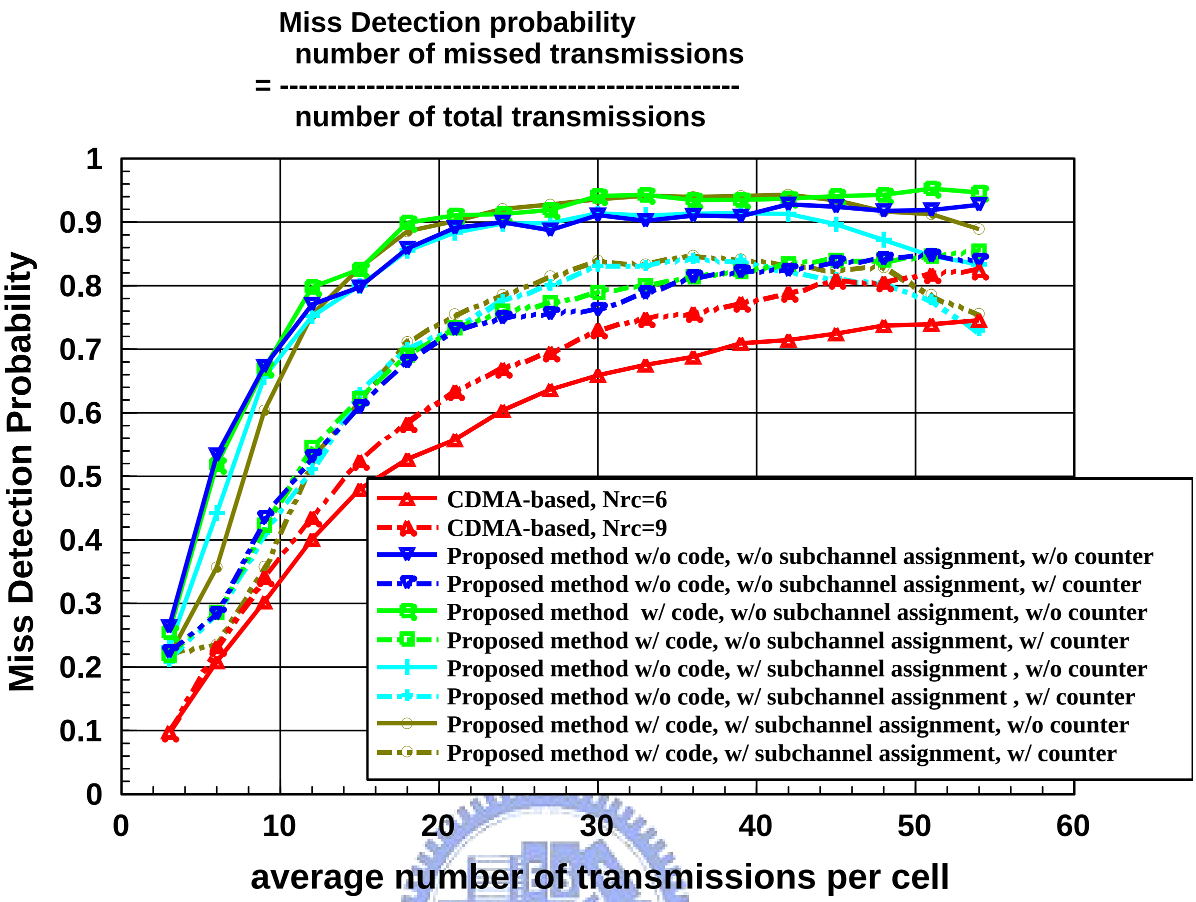

Figure 4.4 Miss Detection probability

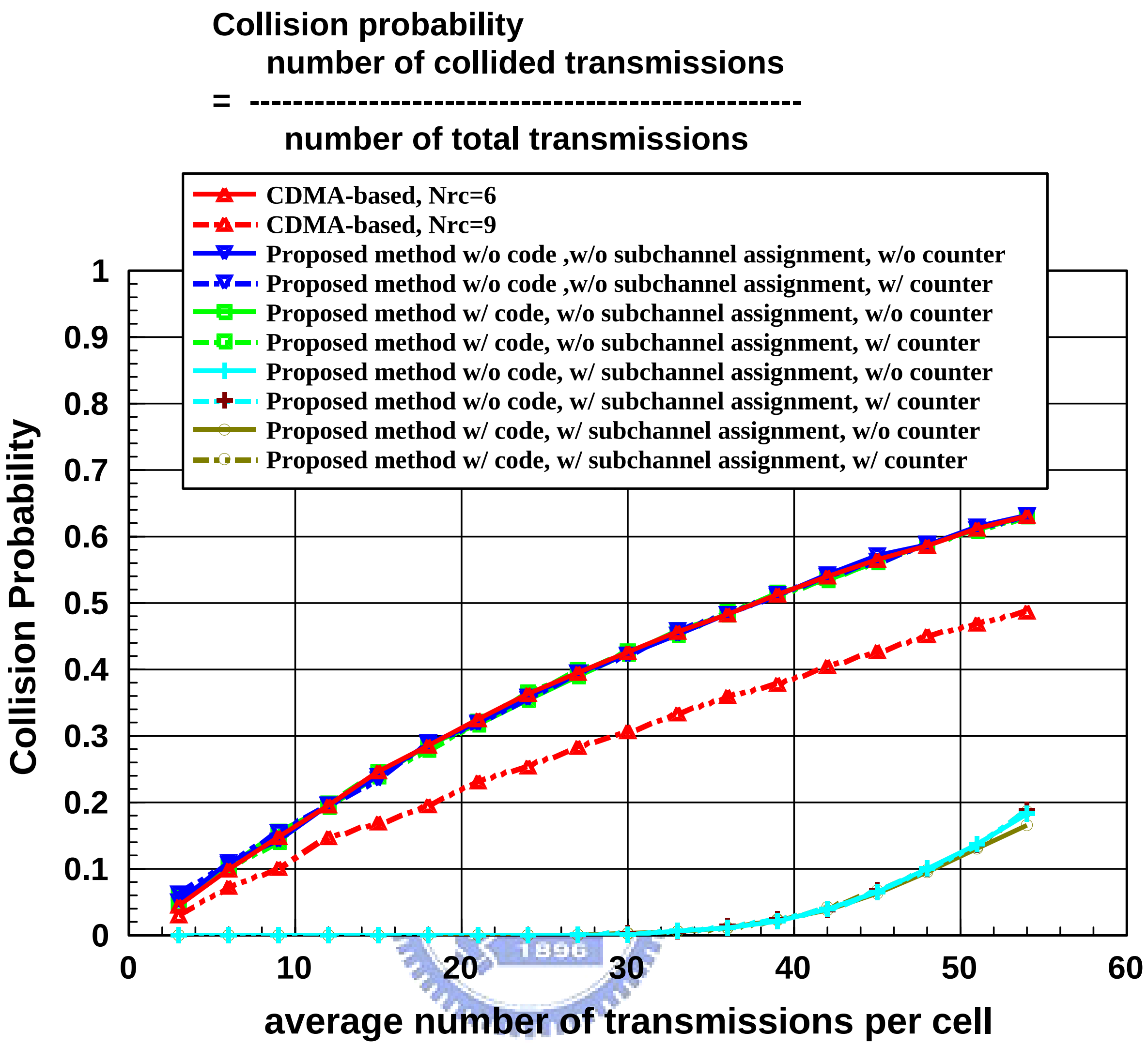

Figure 4.5 Collision probability

Undesired Collision False Alarm Probability

$$= \frac{\text{number of collided transmissions that result in positive detection}}{\text{number of total transmissions}}$$

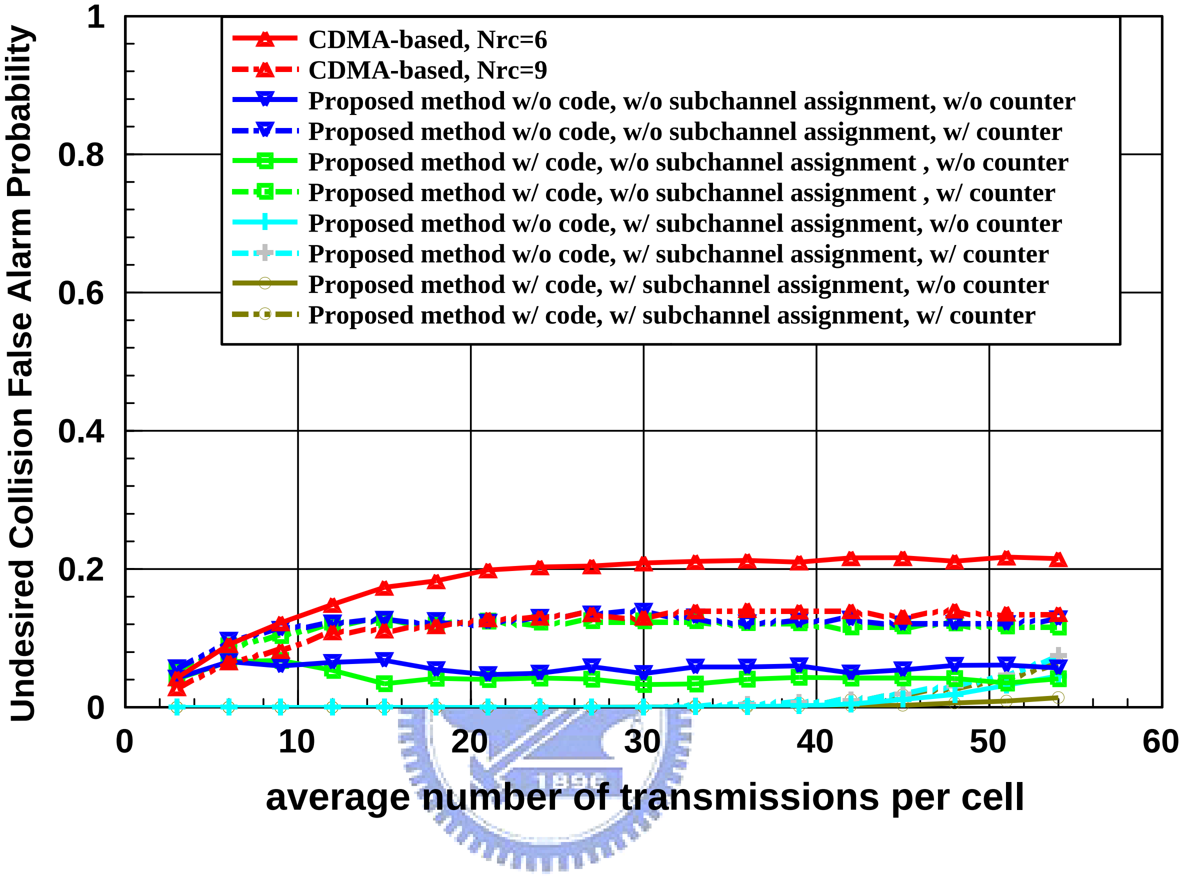

Figure 4.6 Undesired collision false alarm probability

$$\text{total detection probability} = \frac{\text{number of detected transmissions}}{\text{total number of transmissions}}$$

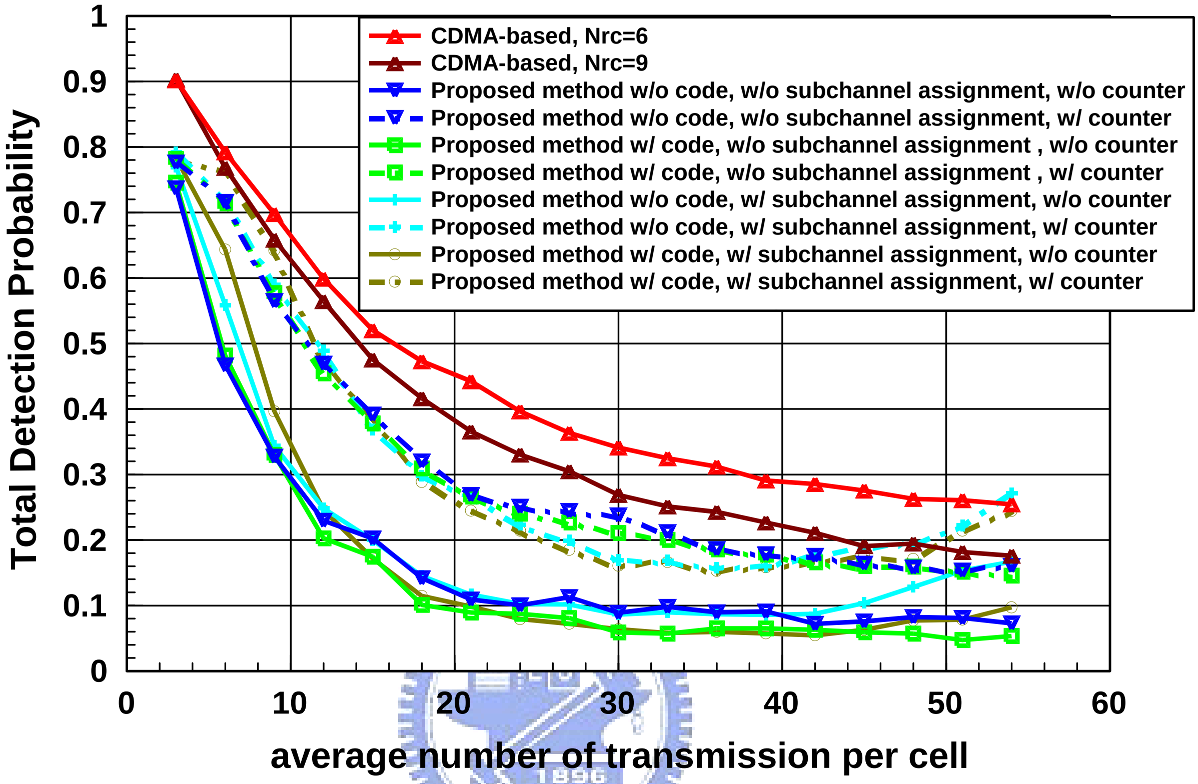

Figure 4.7 Total detection probability

4.4 Discussions

In Figure 4.3, the detection probability for CDMA-based method is better than the proposed method except the proposed method with ranging subchannel assignment whether the code is used or not. The addition of the codes does not provide much gain. Instead, the counter in the detection procedure improves the detection probability. For CDMA-based method, the detection probability is nearly the same when the number of ranging codes is 6 or 9.

Figure 4.4 shows the miss detection probability which is defined as the ratio of the number of missed transmissions and the number of total number of transmissions. The miss detection is the worst (highest miss detection probability) for the proposed method whether the ranging subchannel assignment and codes are applied or not when the counter is not included in the detection procedure. The CDMA-based method with 6 ranging codes has lower miss detection probability than that with 9 ranging codes. Because the ranging codes generated by the generator shown in figure 3.10 are not completely orthogonal, the CDMA-based method with 9 ranging codes will introduce more false alarms than that with 6 ranging codes. If there are 3 SSs send 3 different CDMA codes in a ranging subchannel for CDMA-based method with 6 ranging codes and 9 ranging codes, there will be 3 and 6 CDMA codes that may potentially introduce false alarms. Thus, to reduce false alarms, the miss detection probability will be high. The cost of miss detection is that the missed SSs shall perform contention resolution algorithm and retry in some of the following allocation. Miss detection may include collided transmissions.

Figure 4.5 shows the collision probability which is defined as the ratio of the number of collided transmissions and number of total transmissions. The collision probability increases as the number of transmissions increases. The proposed method with ranging subchannel assignment has the lowest collision probability because SSs do not select ranging subchannels randomly. For CDMA-based method, collision happens when two or more SSs transmit the same CDMA code in the same ranging subchannel. The collision probability of the CDMA-based method with 9 ranging codes is lower than that with 6 ranging codes since there are 81 combinations of the ranging subchannels and ranging codes for the former and 54 combinations for the later.

Figure 4.6 shows the undesired collision false alarm probability which means the ratio of the number of collided transmissions that result in detection positive and the number of total transmissions. When there is a signal that results in positive detector output, the BS can not tell if it comes from one SS or many SSs. If the signal comes from several SSs, the BS will allocate resources and more than one SS will respond, which leads to the following collisions.

Therefore, miss detection is preferred when collision happens. From figure 4.5 and 4.6, we can see that the detector without the counter for the proposed method can filter out more collided signals than the detector with the counter. The detector for the CDMA-based method filters out less collided signals than that for the proposed method.

Figure 4.7 shows the overall detection probability which means the ratio of the number of detected transmissions including the collided ones and the total number of transmissions.

The selection of the threshold for the detector is an important issue. To suppress false alarms, the detection probability will be lowered and miss detection probability will increase. The addition of codes for the proposed method does not provide extra gain.

Chapter 5
Conclusions and Future Work

In this thesis, a simpler bandwidth request method is proposed. The detection procedure is more complex for the CDMA-based method since an extra IFFT computation and maximum value search are needed. Increasing the number of ranging codes will reduce collision probability but will increase the computation complexity. Thus, the tradeoff between complexity and collision reduction has to be made.

The proposed bandwidth request method can achieve similar performance and it introduces much less computation complexity. Besides, for the same allocated resources, the number of ranging subchannels is more in the proposed method than that in the CDMA-based method. Accordingly, the proposed method can be applied to the OFDM or OFDMA systems whose bandwidth or number of subcarriers is not sufficient.

There may be some skills to reduce the detection complexity for the CDMA-based method and accelerate the speed of detection. In this thesis, the simulations are run under SUI-4 model which is a channel model for fixed wireless applications. Therefore, the performance of the CDMA-based method and the proposed method can be investigated further under high mobility channels in the future work.

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