國 立 交 通 大 學
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碩 士 論 文

中繼站 WiMAX 系統以混合功率和頻寬為基礎之選擇

Hybrid Power and Bandwidth Based Selection in Relay WiMAX Systems

研 究 生: 楊宗耿

指導教授: 黃經堯 教授

中華民國九十七年七月

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學生：楊宗耿　　　　　　　　　　　　指導教授：黃經堯博士

國立交通大學電子工程學系電子研究所碩士班

中文摘要

802.16j 的規格已制定完成起即將被應用於未來的無線通訊系統中。點對點的中繼站傳輸來自於在封包無線和無線點對點傳輸的網路下，電信訊號根據源頭節點和目的節點之間的距離來透過一個或多個居中的節點來傳輸。爲了符合未來應用服務之趨勢，假設在手機用戶密集度不低的情況下，必須有一個方法去處理中繼站的選擇以用來處理 MR-BS 和 MS 之間資料的傳輸。選擇一個好的中繼站路徑以及 RS 的部署是很重要去加強系統的效能。此篇論文中，探討一個特殊的 weighted ERRI 演算法，利用舊有的 Effective Radio Resource Index (ERRI)的觀念，來選擇 MS 傳輸的路徑而且和另外一個特殊的 weighted CINR 演算法來做比較。除此之外，我們也探討了端對端之間的延遲、MS 的傳送功率、吞吐量和最後一哩權重的關聯性。利用這個演算法，在這關聯性中，我們會發現一個很重要的權衡。以至於此演算法的概念，未來可以再繼續加強來應用在 802.16j 系統中。

Hybrid Power and Bandwidth Based Selection in Relay WiMAX Systems

Student : Tsung-Keng Yang Advisor : Dr. Ching-Yao Huang

Department of Electronics Engineering

Institute of Electronics

National Chiao Tung University

Abstract

The 802.16j standard is standardized and soon be one of the popular technique which will be used in the future wireless communication environment. Peer-to-peer relaying transmission stems from pack radio and ad-hoc networks where the traffic signals have to be relayed through one or more intermediate node(s), depending on the distance between the source and the destination nodes. To meet the future trend, there must be some way to deal with the relaying node selection which is used to deal with the data transmission between MR-BS and MS provided that the subscriber density is not very low. Having good selection of the relay path and RS deployment are important to enhance system performance. In this thesis, a specific algorithm, weighted ERRI algorithm uses the old ideal of the Effective Radio Resource Index (ERRI) to select the better transmission route of MS and compares with another specific algorithm, weighted CINR algorithm. Besides, we also discuss the relationship between the weight of the last mile and end-to-end delay, the transmit power of MS, and throughput. Using this relationship of the algorithm, we would discover a tradeoff. As for the concept of the algorithm, it would be continuously enhanced and implemented in 802.16j system in the future.

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碩士班的時光流逝飛快，在新竹的兩年求學時光將劃下句點。在碩士班的這兩年中，不僅僅專業知識上的學習，更遇到了因緣分相遇需要感謝的貴人，非常感謝緣分讓我們能夠相遇，以及讓我自己更加的成長茁壯，是一段難忘且自我成長的好時光。

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楊宗耿　　謹誌

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目錄

List of Tables

List of Figures

Chapter 1 Introduction

The standard 802.16e [1] has been standardized in 2006. The version provides the possibility of MSs with mobility that is greatly different from 802.16d [2] only provides fixed broadband wireless access. With the mobility, the system is not only the last mile solution for the end users. The system will be mode like cellular system but with higher transmission rate and bandwidth than 3G or even 3.5G system.

Therefore, on the completion of IEEE802.16-2004 [2] and IEEE 802.16-2005 [1] standards for WMAN (Wireless Metropolitan Area Network), nowadays, WiMAX reaches maturity as a serious alternative for mobile broadband access deployment. As a continuous effort to enhance WiMAX system, 802.16j MR task group [3] has been charted in March 2006. The objective of 802.16j is to adapt the promising advantages of multi-hop access in terms of capacity, throughput, and coverage to WiMAX systems. Low-cost RSs are allocated between the 802.16 compliant MS/SS (Subscriber Station) and Base Station (MR-BS) because RSs do not require the wired backhaul and are much cheaper than MR-BS. Multi-hop networks provide the increased deployment flexibility and improve the economic viability of 802.16WiMAX system due to the cheaper cost.

Therefore, RSs are provided to be allocated in the transparent and non-transparent MR network during the transmission between BS to MS/SS. Because a RS relays the user data and control information between BS and MS, it is a significant issue to let the system throughput and performance increase under the influence of RS. According to good channel conditions in MR network, deploying RSs in excellent location to relay user data and choosing the best transmission route for MS are keys to influence the throughput of communication.

Therefore, having a good deployment for RS to transmit data efficiently and using a great method for MS to select transmission route can achieve the services' wanted throughputs and enhance the system performance is really crucial in the future wireless communication system. In this thesis, we will discuss these two issues and propose two algorithms of the transmission route selection for comparison.

The rest of this thesis is organized as follows: In chapter2, the review to Mobile WiMAX system and the review to WiMAX Relay System. In chapter3, we briefly introduce the network simulator because we use the network simulator to run the simulation. In chapter4, the proposed algorithms are discussed detailed. In chapter5, we describe the setting of simulation parameter and show the simulation results. Finally in chapter6, the conclusion and future works will be provided.

Chapter 2 Review to WiMAX System

The IEEE Standard 802.16 Family specifics the air interface of fixed and mobile WIMAX systems. The standard scope includes two layers: the MAC layer and the PHY layer. Specification of the MAC layer includes the security and convergence sublayer and common part sublayer. The system architecture, optimizations and algorithms is not in the defined scope. A reference model of IEEE 802.16 PHY/MAC is shown in Figure 2-1.

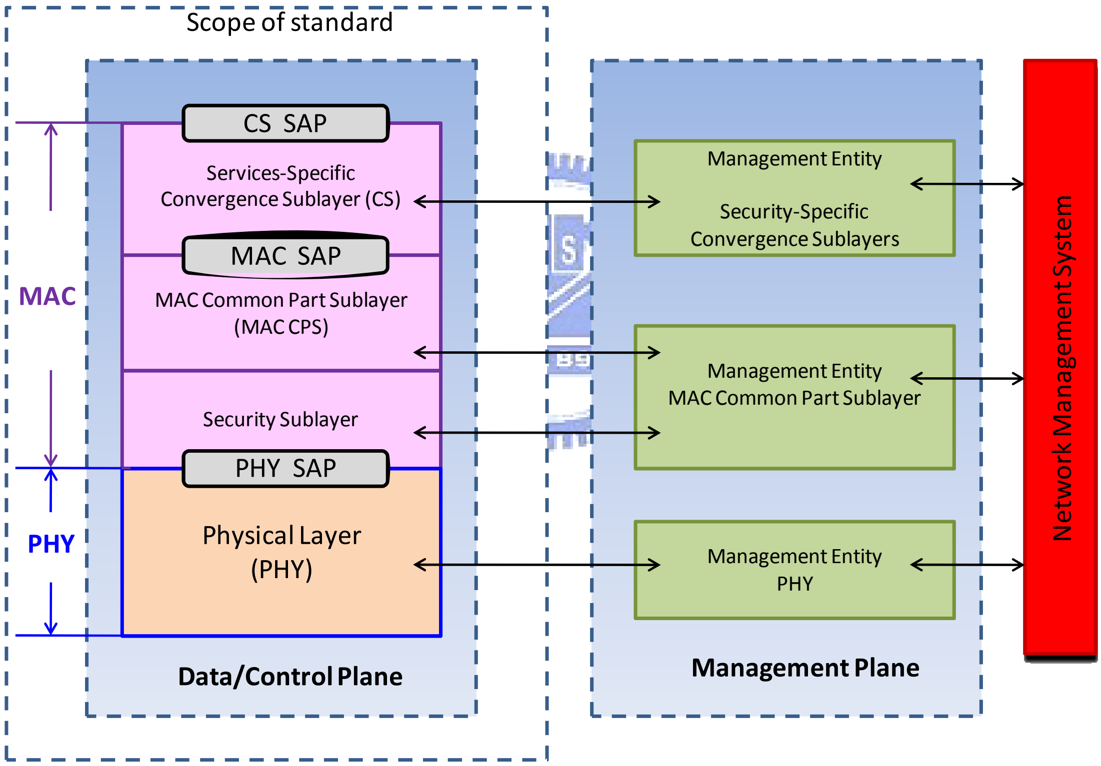

Figure2.1 IEEE 802.16 PHY/MAC Reference Model[1][2]

We briefly review the operations of MAC layer and PHY layer in the IEEE 802.16 standard. In Figure2.2, it illustrate the system architecture of the IEEE 802.16e.The CS provides any transformations or mapping of external network data which are received through the CS service access point (SAP), into MAC service data units (MSDU) that are received by the MAC layer through the MAC SAP [4].This sublayer contains several functions which are classifying external network SDUs and associating them to the proper MAC service flow identifier (SFID) and connection ID (CID). It also contains such the functions of payload header suppression (PHS).

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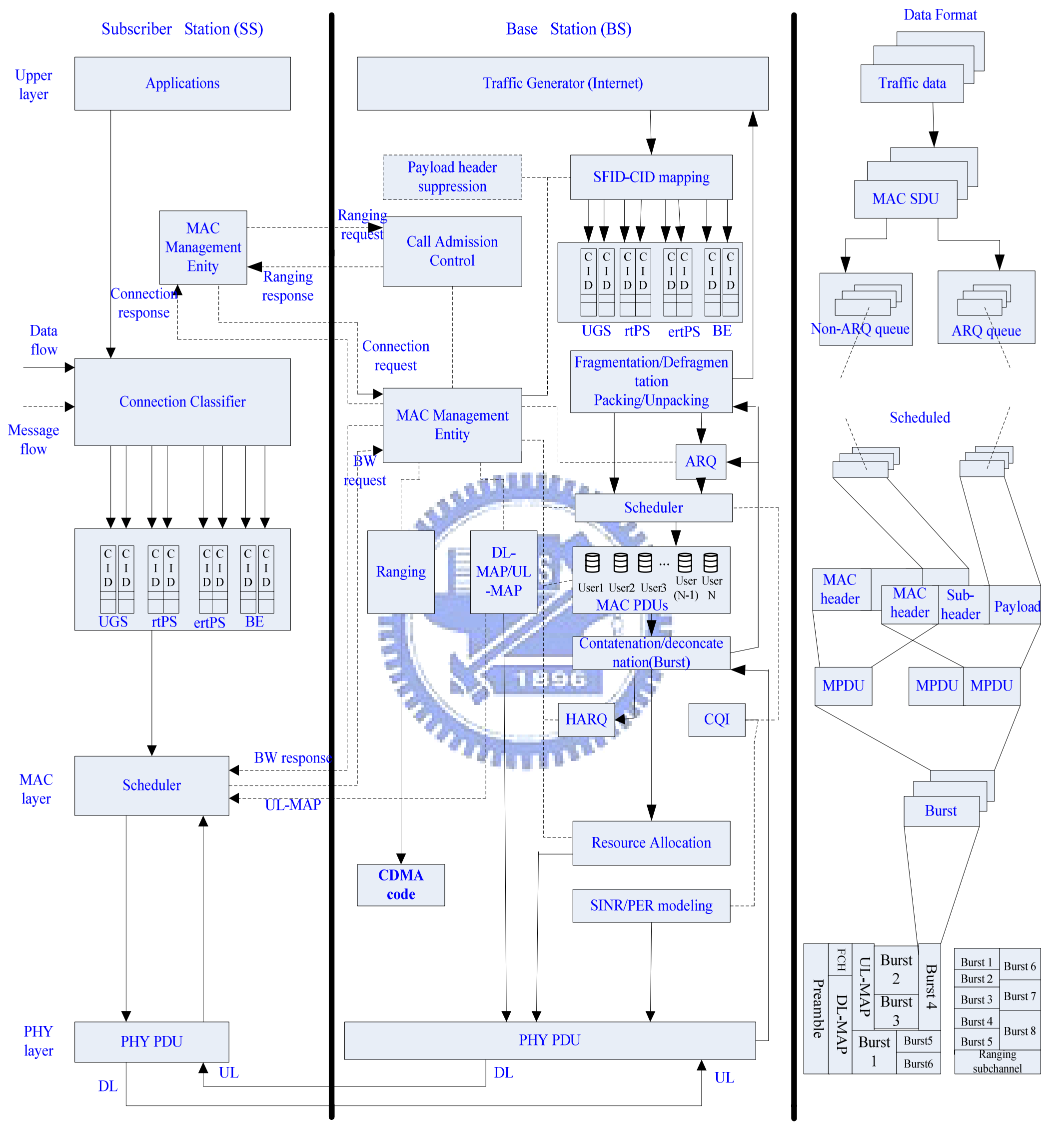


Figure2.2 The MAC simulation architecture of IEEE 802.16[4]

The MAC CPS provides the core MAC functionality of system access such as bandwidth allocation, scheduling, contention mechanism, connection establishment, and connection maintenance. It receives data from vary kind of CSs, through the MAC SAP, classified to particular MAC connection. And, in scheduling types side, the IEEE 802.16-2004 standard specially supports five quality-of-service scheduling types: unsolicited grant service(UGS) for the constant bit rate(CBR) service and real-time VoIP, real-time polling service(rtPS) for the variable rate (VBR) service, non-real-time polling service(nrtPS) for non-real-time VBR, and best effort service(BE) for service with no rate or delay requirements. Especially, there is an additional service type called extended real-time polling service (ertPS) for voice over IP (VoIP) service in 802.16e standard.

These quality-of-service classes are correlated with certain predefined sets of QoS-related service flow parameters. The MAC scheduler provides the appropriate data handling mechanisms for data transmission according to each QoS classes. After finishing the SFID-CID mapping, the upper-layer protocol data units (PDUs) with an assigned individual CID are passed into different level queues in the MAC layer. And then, these data packets in these queues are regards as MSDUs and will be fragmented or packed into various sizes according to the MAC scheduling operation, and be processed by a selective repeat automatic repeat request (ARQ) block mechanism if the ARQ-enabled function is opened.

For the UL traffic, each SS should perform ranging to the BS before SS entering the system. When SS performs the initial ranging, the SS will ask a request to be served in the DL via the burst profile by BS transmitting its choice of DL interval usage code (DIUC) to the SS. And then, the BS will command the SS to use an uplink burst profile with the allocated UL interval usage code (UIUC) with the grand of the SS in UL-MAP message. The DL-MAP and UL-MAP contain the channel ID and the MAP information elements (IEs), the functions of IEs are which describes the PHY specification mapping in the DL and UL specifically. The burst profile includes the DIUC, UIUC, and the type-length-value (TLV) encoded information. The TLV encoded information will report different PHY layer of the modulation type, FEC code type, and encoding parameters. The MAC data payload is packed according to these encoding types.

Radio link control (RLC) that the PHY layer requires equally, which is the capability of the PHY layer to transition from one burst profile to another. The RLC starts with the periodical BS broadcasting of the burst profiles which have been chosen for the downlink and uplink connections. After determining the downlink and uplink burst profiles between the BS and a particular SS, RLC will monitor the burst profile and set control to the burst profiles. The SS will do the ranging with the RNG-REQ message to request a change in downlink burst profile. The BS will use channel measurements reporting request (REP-REQ) message to request signal-to-noise ratio (SNR) channel measurements reports. And then, the SS uses the channel measurement report response (REP-RSP) message to respond the channel measurements listed in the received REP-REQ.

In the IEEE 802.16 system, the system uses the frame-based transmission architecture where the frame length is variable. Every frame is separated into two subframes: the DL subframe and UL subframe. Here, we pay attention to the frame structure on OFDMA-PHY in time division duplex (TDD) mode. A DL subframe consists of DL subframe prefix to specify the modulation and coding (in PHY mode), the length of the first DL burst, and the broadcast MAC control message. The DCD (Downlink channel descriptor) and UCD (Uplink channel descriptor) comprise of the detail information of the DL burst profile and the UL burst profile. It does not define the admission control process although IEEE 802.16 defines the connection signaling between SS and BS. By the connection classifier based on CID, all packets from the application layer are classified and are passed to the appropriate queue. At the SS, the scheduler will get the packets from the queues and forward them to the network in the appropriate time slots as defined by the UL-MAP sent by the BS. By the scheduler module based on the BW-request message that reports the current queue size of each connection in SS, the UL-MAP is determined. So, in the following article of this chapter 2 in my thesis, I will separate MAC layer and PHY layer structure of IEEE 802.16e WiMAX into discussion.

2.1 WiMAX Physical Layer

The physical (PHY) layer of WiMAX is based on IEEE 802.16-2004 and IEEE 802.16e-2005 standards and was designed getting much influence from Wi-Fi, especially IEEE 802.11a. Although many aspects of the two technologies are different because of the inherent difference in each of their purpose and applications, some of their basic constructs are very similar. The IEEE 802.16 suite of standards (IEEE 802.16-2004/IEEE 802.16E-2005) defines within its scope four PHY layers, any of which can be used to develop a broadband wireless system with the media access control (MAC) layer. The PHY layers defined in IEEE 802.16e are divided into several parts:

- WirelessMAN SCa, a single-carrier PHY for frequencies between 2GHZ and 11GHZ for point-to-multipoint operations.
- WirelessMAN OFDM, a 256-point FFT-based OFDM PHY layer for point-to-multipoint operations in non-LOS conditions at frequencies between 2GHz and 11GHz. This PHY layer, finalized in the IEEE 802.16-2004 specifications, has been accepted by WiMAX for fixed operations and is often referred to as fixed WiMAX. The OFDM PHY transmission chains are illustrated in Figure 2.3.

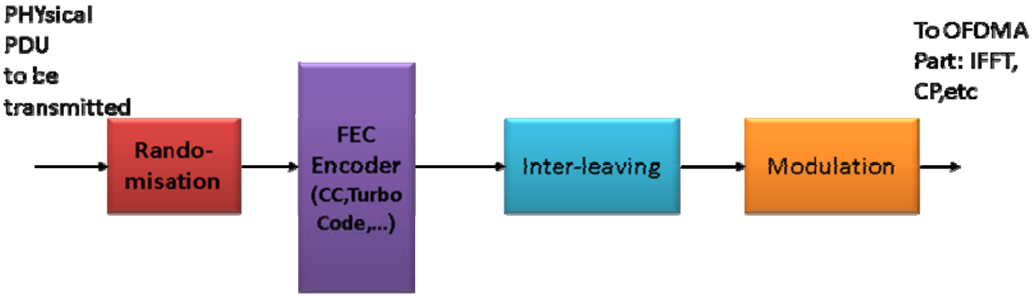


Figure2.3 OFDM PHY transmission chain[5]

- WirelessMAN OFDMA, a 2,048-point FFT-based OFDMA PHY for point-to multipoint operations in NLOS conditions at frequencies between 2GHz and 11 GHz. In the IEEE 802.16e-2005 specifications, this PHY layer has been modified to SOFDMA (scalable OFDMA), where the FFT size is variable and can take any one of the following values: 128, 512, 1024, and 2048. The variable FFT size allows for optimum operation/implementation of the system over a wide range of channel bandwidths and radio conditions. The PHY layer has been accepted by WiMAX for mobile and portable operations and is also referred to as mobile WiMAX. The OFDMA PHY transmission chains are illustrated in Figure 2.4.

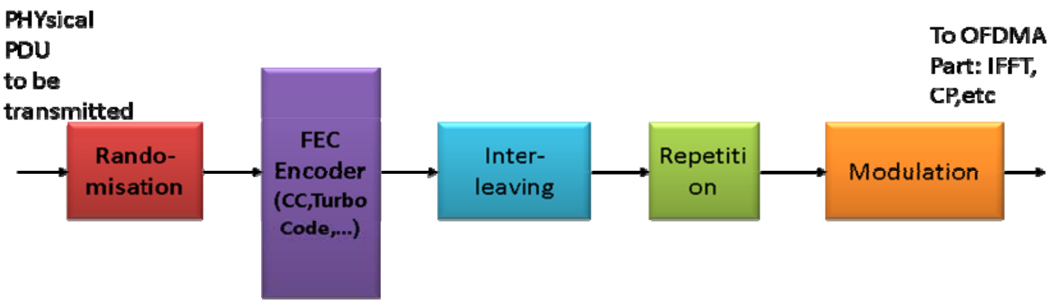


Figure2.4 OFDMA PHY transmission chain[5]

Figure2.5 illustrates the evident functional stage of a WiMAX PHY layer. The first functional stages have relation to many functions such as forward error correction (FEC), channel encoding, rate matching, interleaving, and symbol mapping. The next set of functional stages is connected to the construction of the OFDM symbol in the frequency domain. During this stage period, data is individually mapped onto the appropriate subchannels and subcarriers. Pilot symbols are inserted into the pilot subcarriers allowing the receiver to estimate and get track of the channel state information. This stage is also responsible for any space/time encoding for transmit diversity or MIMO. The final functions are related to the conversion of the OFDM symbol from the frequency domain to the time domain and finally to an analog signal so we can use analog signal to transmit over the air. Although Figure2.5 shows only the logical components of a transmitter, similar components also exist at the receiver, to reconstruct the transmitted information sequence in reverse order.

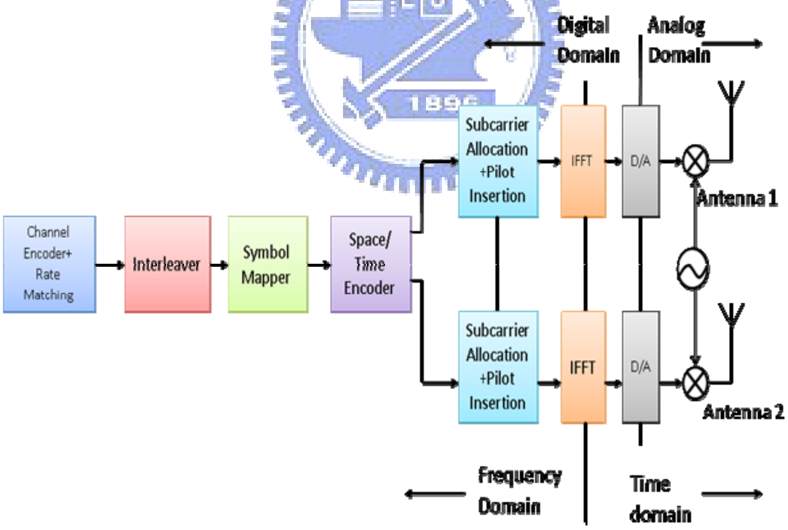


Figure2.5 Functional stages of WiMAX PHY[5]

In the first of this 2.1 chapter, I describe the various components of modulation scheme and channel-coding as defined in the IEEE802.16e-2005 standard. Next, we will introduce the burst profile that is the basic tool in the 802.16 standard MAC Layer.

2.1.1 Digital Modulation

About the recent modern communication systems, IEEE 802.16e WiMAX uses digital modulation. Now, the famous rule of a digital modulation is to modulate an analogous signal with a digital sequence in order to transport this digital sequence. It shows in Figure 2.6 [6].

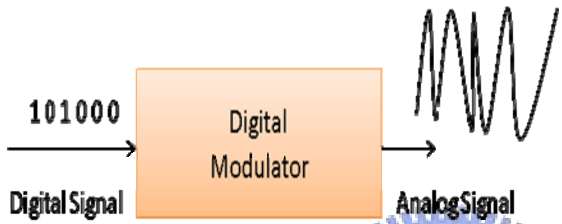


Figure2.6 Digital modulation rule[6]

There are many advantages with regard to classical analogue modulation: better resistance to noise, use of high-performance digital communication and coding algorithms, etc. By adjusting the physical characteristics of a sinusoidal carrier, either the frequency, phase or amplitude, or a combination of some of these, the variants are retrieved. The IEEE 802.16 standard supports four modulations – BPSK, QPSK, 16-QAM, 64-QAM. I will give a short explanation for these modulations used in OFDM and OFDMA PHYsical layers in this section.

- Quadrature Phase Shift Keying(QPSK)

  If we need a higher spectral efficiency modulation, greater modulation symbol can be used. For instance, QPSK considers two-bit symbols of modulation. Table 2.1 illustrates the possible phase values as a function of the modulation symbol. QPSK can be used many variants but QPSK always has a four-point constellation. Figure 2.7 shows the constellation. The decision at the receiver, e.g. between symbol‘00’ and symbol’01’, is less easy than a decision between ‘0’ and‘1’. So, compared to BPSK, the QPSK modulation is less noise-resistant as it has a smaller immunity against interference.

Even bits	Odd bits	Modulation symbol	Φ_K
0	0	00	$\pi/4$
1	0	01	$3\pi/4$
1	1	11	$5\pi/4$
0	1	10	$7\pi/4$

Table2.1 Possible phase values for QPSK modulation [6]

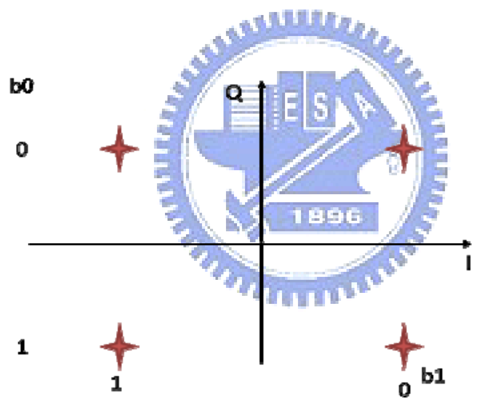


Figure2.7 Example of a QPSK constellation[6]

- Quadrature Amplitude Modulation(QAM): 16-QAM and 64-QAM

The QAM changes the amplitudes of two sinusoidal carriers depending on the digital sequence that must be transmitted; the two carriers being out of phase of $+\pi/2$. So, this modulation is called quadrature. Both 16-QAM which are 4bits modulation symbols and 64-QAM which are 6bits modulation symbol modulation are included in the IEEE 802.16standard. The 64-QAM is shown in Figure 2.8. Evidently, 6 bits are transmitted with each modulation symbol. The 64-QAM modulation is optional in some cases:

- when the OFDM PHYsical Layer is used, License-exempt bands
- for OFDMA PHY, yet the Mobile WiMAX profiles indicates that 64-QAM is mandatory in the downlink

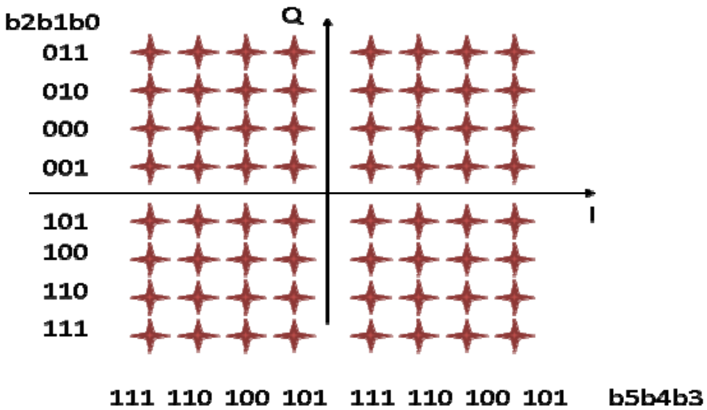


Figure2.8 Example of 64-QAM constellation[6]

2.1.2 Channel Coding

The radio link varies very fast, it often suffering from great interference. Channel coding are mainly used to prevent and to correct the transmission errors of wireless systems, must have a very excellent performance in order to maintain high data rates. The channel coding chain in 802.16 is composed of three steps:

- Randomizer
- Forward Error Correction
- Interleaving

They are implemented in the order in transmission. So, in 2.1.2 section, I will talk about the above three function in brief.

2.1.2.1 Randomisation

Randomisation introduces protection from information-theoretic uncertainty, to avoid long sequences of constructive ones or consecutive zeros, and it is also useful for avoiding non-centered data sequences. Data randomisation is performed on each downlink and uplink burst of data. If the situation is that the amount of data to transmit does not fit exactly the amount of data allocated, it must add padding of 0xFF to the end of the transmission block. In Figure 2.9, the Pseudo-Random Binary Sequence (PRBS) generator used for randomisation is shown. Each data byte to be transmitted enters sequentially into the randomizer, with the Most-Significant Byte (MSB) first. For Preambles, they are not randomized because the randomizer sequence is used only to information bits.

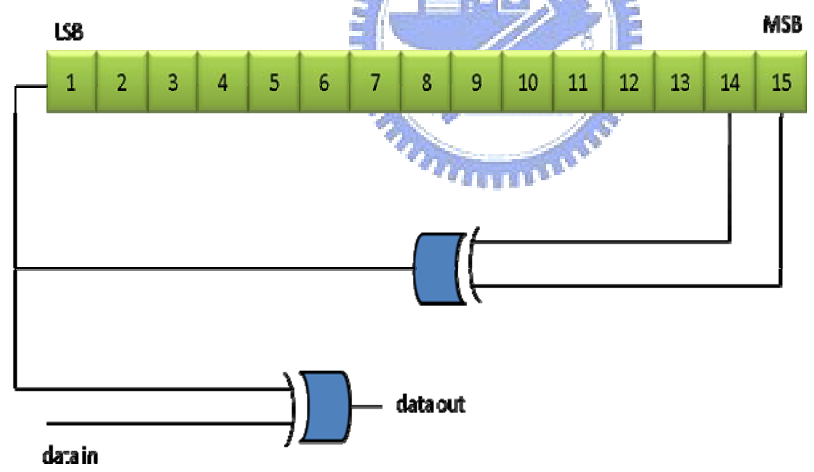


Figure2.9 PRBS generator used for data transmission in OFDM and OFDMA PHY[6]

2.1.2.2 Forward Error Correction (FEC) Codes

For OFDM PHY, the types of FEC encodings are listed below:

- Concatenated Reed-Solomon Convolutional Code (RS-CC). It includes the concatenation of a Reed-Solomon outer code and a rate-compatible Convolutional inner code. The code is mandatory on both uplink and downlink.
- Convolutional Turbo Codes(optional)
- Block Turbo Coding(BTC)(optional)

When requesting access to the network, the most robust burst profile must be used. For OFDMA PHY, the FEC encodings are:

- (Tail-biting) Convolutional Turbo Codes (CC). This code is mandatory according to the 802.16 standard. Based on WiMAX profiles, only the Zero-Tailing Convolutional Code is mandatory.
- Convolutional Turbo Codes (CTC). This code is optional according to the 802.16 standards. Yet, according to the mobile WiMAX profiles, the CTC is mandatory.
- Block Turbo Coding (BTC) (optional)
- Low Density Parity Check (LDPC) codes (optional)

2.1.2.3 Interleaving

Interleaving is a method used to protect the transmission against long sequences of consecutive errors. These long sequences of error may affect many bits in a row and can then result in many losses of transmitted burst. Interleaving can facilitate error correction. The encoded data bits are interleaved by a block interleaver with a block size corresponding to the number of bits per allocated subchannels per OFDM symbol [1]. The function of interleaver is made of two steps:

- Distribute the coded bits over subcarriers. A first permutation makes sure that adjacent coded bits are mapped onto nonadjacent subcarriers.

- The second permutation makes sure that adjacent coded bits are mapped alternately on to less or more significant bits of the constellation, thus avoiding long runs of bits of low reliability.

2.1.2.4 Repetition

The standard indicates that repetition for the OFDMA PHY can be used to increase the signal margin further over the modulation and FEC mechanisms.

As for repetition coding, R=2, 4, 6, the number of allocated slots will be a whole multiple of the repetition factor R for the uplink. On the other hand, for the downlink, the number of the allocated slots will be in the range of $R\times K$, $R\times K+(R-1)$, when K is the number of required slots if we want to apply the repetition scheme.

The binary data that fits into a region which is repetition coded is reduced by a factor R compared to a nonrepeated region of the slots with the same size and FEC code type. After finishing FEC and bit-interleaving, these data are segmented into slots, and then, each group of bits designated to fit in a slot is repeated R times to form R continuous slots following the normal slot ordering that is used for data mapping. This repetition scheme applies only to QPSK modulation, and it can be applied in all coding schemes, but it cannot be used in HARQ with CTC.

2.1.3 Burst Profile

The burst profile is a basic tool and useful function in the 802.16 standard MAC Layer. The function of burst profile allocation, which changes dynamically and possibly very fast, is mainly about physical transmission. The parameters of the burst profiles of WiMAX are summarized. And, the burst profiles are used for the link adaption procedure.

2.1.3.1 Downlink Burst Profile Parameters

The burst profile parameters of a downlink transmission for OFDM and OFDMA PHYsical layers are proposed in Table 2.2. The parameters called FEC code is the Modulation and Coding Scheme (MCS). For OFDMA PHY, there are totally 20 MCS combinations of modulation (BPSK, QPSK, 16-QAM, 64-QAM), coding (CC, RS-CC, CTC or BTC) and coding rate (1/2, 2/3, 3/4 and 5/6). The most frequency-use efficient MCS among all MCS is 64-QAM (BTC) 5/6. For OFDMA PHY, there are 34 MCS combinations of modulation (BPSK, QPSK, 16-QAM, 64-QAM), coding rate (1/2, 2/3, 3/4, 5/6). The Downlink Interval Usage Code (DIUC) is the burst usage descriptor, which includes the burst profile.

Burst profile parameter	Description
Frequency (in kHZ)	Downlink Frequency
FEC code type	Modulation and Coding Scheme(MCS); there are 20 MCSs in OFDM PHY and 34 MCSs in OFDMA PHY
DIUC mandatory exit threshold	The CINR at or below where this burst profile can no longer be used and where a change to a more robust burst profile is Required. Expressed in 0.25 dB units.
DIUC mandatory exit threshold	The minimum CINR required to start using this burst profile when changing from a more robust burst profile. Expressed in 0.25 dB units
TCS_enable (OFDM PHY only)	Enables or disables TCS

Table2.2 Downlink burst profile parameters for OFDM and OFDMA PHYsical layers [6]

2.1.3.2 Uplink Burst Profile Parameters

In Table 2.3, I list the burst profile parameters of an uplink transmission for an

OFDM PHT, and in Table 2.4, I list the burst profile parameters of an uplink transmission for an OFDMA PHY respectively.

Burst profile parameter	Description
FEC type and modulation type	There are 20 MCSs in OFDM PHY
Focused contention power boost	The power boost in dB of focused contention carriers
TCS_enable	Enables or disable TCS

Table2.3 Uplink burst profile parameters for the OFDM PHYsical Layer [6]

Burst profile parameter	Description
FEC type and modulation type	There are 52MCSs in OFDM PHY
Ranging data ratio	Reducing factor, in units of 1dB, between the power used for this burst and the power used for CDMA Ranging; encoded as a signed integer

Table2.4 Uplink burst profile parameters for the OFDMA PHYsical Layer [6]

2.1.3.3 MCS Link Adaptation

The choice between different burst profiles or between different MCSs is a useful tool because choosing the MCS most suitable for the state of the radio channel leads to an optimal (highest) average data rate. This procedure is the so-called link adaptation procedure. The order of magnitudes of SNR thresholds can be obtained from Table 2.5, proposed in the 802.16 standard for some test conditions.

Modulation	Coding rate	Receiver SNR threshold(dB)
BPSK	1/2	6.4
QPSK	1/2	9.4
QPSK	3/4	11.2
QAM-16	1/2	16.4
QAM-16	3/4	18.2
QAM-64	1/2	22.7
QAM-64	3/4	24.4

Table2.5 Received SNR threshold assumptions [1]

2.2 WiMAX MAC Layer

In a network, the PHY layer use the physical medium, such as radio frequency, light waves, or copper wires to reliably deliver information bits from the transmitter to receiver. However, the PHY layer is not informed of quality of service (QoS) requirements and is not aware of the nature of the application, such as VoIP, HTTP, or FTP. So, the Media Access Control (MAC) layer, which resides above the PHY layer, plays an important role in the network [5]. MAC layer is responsible for controlling and multiplexing various links over the same physical medium. Some important functions of the MAC layer in WiMAX are to

- Segment or concatenate the service data units (SDUs) received from higher layers into the MAC PDUs (protocol data units), the basic building block of MAC-layer payload
- Select the appropriate burst profile and power level to be used for the transmission of MAC PDUs
- Retransmission of MAC PDUs that were received erroneously by the receiver when auto-mated repeat request (ARQ) is used
- Offer QoS control and priority handling of MAC PDUs belonging to

different data and signaling bearers

- Schedule MAC PDUs over the PHY resources
- Offer support to the higher layers for mobility management
- Offer security and key management
- Offer power-saving mode and idle-mode operation

The MAC layer of WiMAX, as shown in Figure2.10, is separated into three distinct components: the service-specific convergence (CS), the common-part sublayer, and the security sublayer. The CS is the interface between the MAC layer and layer 3 of the network, and receives data packets from the higher layer. These higher-layer packets are also known as MAC service data units. The CS takes responsibility for performing all operations that are dependent on the nature of the higher-layer protocol and its requirements from the rest of the MAC and PHY layers of a WiMAX network.

As for the common-part sublayer of the MAC layer, it performs all the packet operations that are independent of the higher layers, such as fragmentation and concatenation of SDUs into MAC PDUs, QoS control, and ARQ. The functions of security sublayer are encryption, authorization, and power exchange of encryption keys between the BS and the MS.

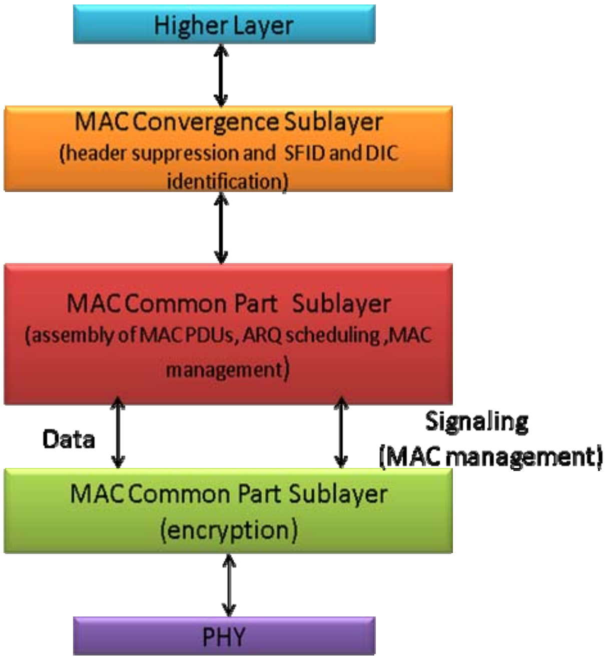


Figure2.10 The WiMAX MAC layer[5]

In this section, I will briefly introduce the MAC layer. First, I will describe the MAC frames format. And then, I describe the network work entry and quality of service (QoS) management that are the important part of the MAC layer, such as ranging, the five scheduling service or QoS Classes. Finally, I talk about Radio Resource Management (RRM) that is an important part for maximizing the efficiency of radio resource ultizilation.

2.2.1 MAC Frames

A MAC PDU is known as a MAC frame and is illustrated in Figure2.11. Each MAC frames starts with a fixed-length MAC header which be followed by the payload of the MAC PDU (that is MPDU). A MPDU may includes a CRC (Cyclic Redundancy Check). If present, the MPDU payload contains one or more components of the following:

- zero or more subheaders included in the payload;

- zero or more MAC SDUs;
- fragment of a MAC SDU.

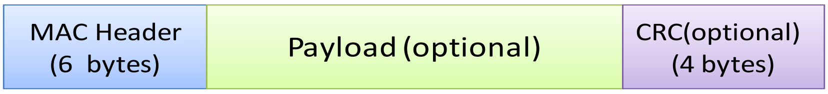


Figure2.11 General format of a MAC frame or MAC PDU[6]

The payload information may have various lengths. Hence, a MAC frame length is a variable number of bytes. The MAC based on this format is allowed to tunnel various higher-layer traffic types without knowledge of the formats or bit patterns of those messages.

2.2.2 Network Entry

Systems must follow sequences of procedures for entering and registering a new SS or, more generally, a new node to the network. When an MS acquires the network after being powered up a WiMAX network undergoes various steps. An overview of this process is briefly illustrated in Figure2.12.

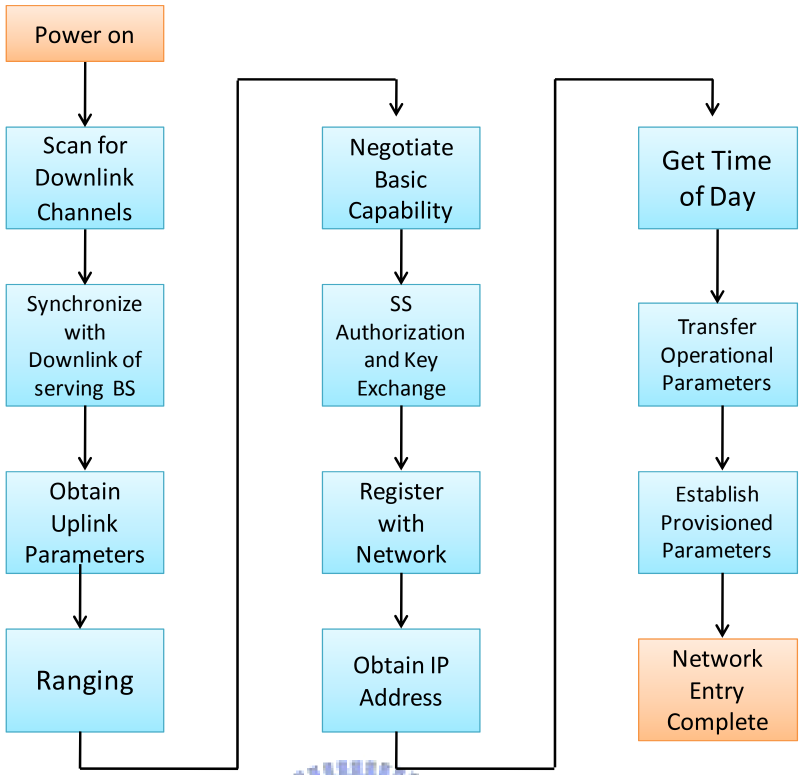


Figure2.12 Brief sequences of functional block of network entry[5]

The network entry procedure for Mech is described in the standard. Figure2.13 shows an illustration in detail of the network entry procedures. And then, I briefly introduce the sequence of the procedures for network entry.

- 1. Scan for a downlink channel and establish synchronization with the BS: While the system is initializing or after signal loss, the SS must acquire a downlink channel. First, it tries to reacquire this downlink channel. If this fails, the SS begins to scan the possible channels of the downlink frequency band of operation continuously until it finds a valid downlink signal.

- 2. Synchronization:

  The SS MAC searches for the DL-MAP message. Once it has received at least one DL-MAP message, the SS achieves MAC synchronization. An SS MAC remains in synchronization if only it still successfully receives continuously DL-MAP and DCD messages of the downlink channel.

- 3. Perform initial ranging:

  Initial ranging happens while an SS wants to enter a network. The main objective of initial ranging is the adjustment of each SS timing offset and power parameters in the initialization phase.

- 4. Negotiate basic capabilities:

  This is SS and BS exchanging their supported parameters. After finish of ranging, the SS transmits an SBC-REQ message with its capabilities to inform the BS of its basic capabilities. And then, the BS responds with an SBC-RSP message with the intersection of the SS and BS capabilities.

- 5. Authorize the SS and process keys exchange:

  At this phase, the SS has to do the authentication mechanism. It is to exchange secure keys. While the SS sends a PKM-REQ message to the BS, the BS responds with a PKM-RSP message.

- 6. Perform registration:

  Registration is the process that the SS is allowed entry into the network. And, a managed SS receives its secondary management CID and thus becomes a manageable SS.

- 7. Establish IP connectivity:

  In order to obtain IP address, the SS makes use of the Dynamic Host Configuration Protocol (DHCP) mechanisms, from the DHCP server and any other parameters needed to establish IP connectivity.

- 8. Establish the time of day:

  The SS needs to have the current date and time from the BS. The protocol by which the SS retrieves the time of day from a time server through the BS is defined in IETF RFC 868, which gives the number of seconds starting from year 1900, on 4 bytes. The request and response are transferred using the User Datagram Protocol (UDP).

- 9. Transfer operational parameters
- 10. Set up connections:

The BS sends DSA-REQ messages to the SS to set up connections for preprovisioned service flows belonging to the SS after the transfer of operational parameters for a managed SS or after registration for an unmanaged SS.

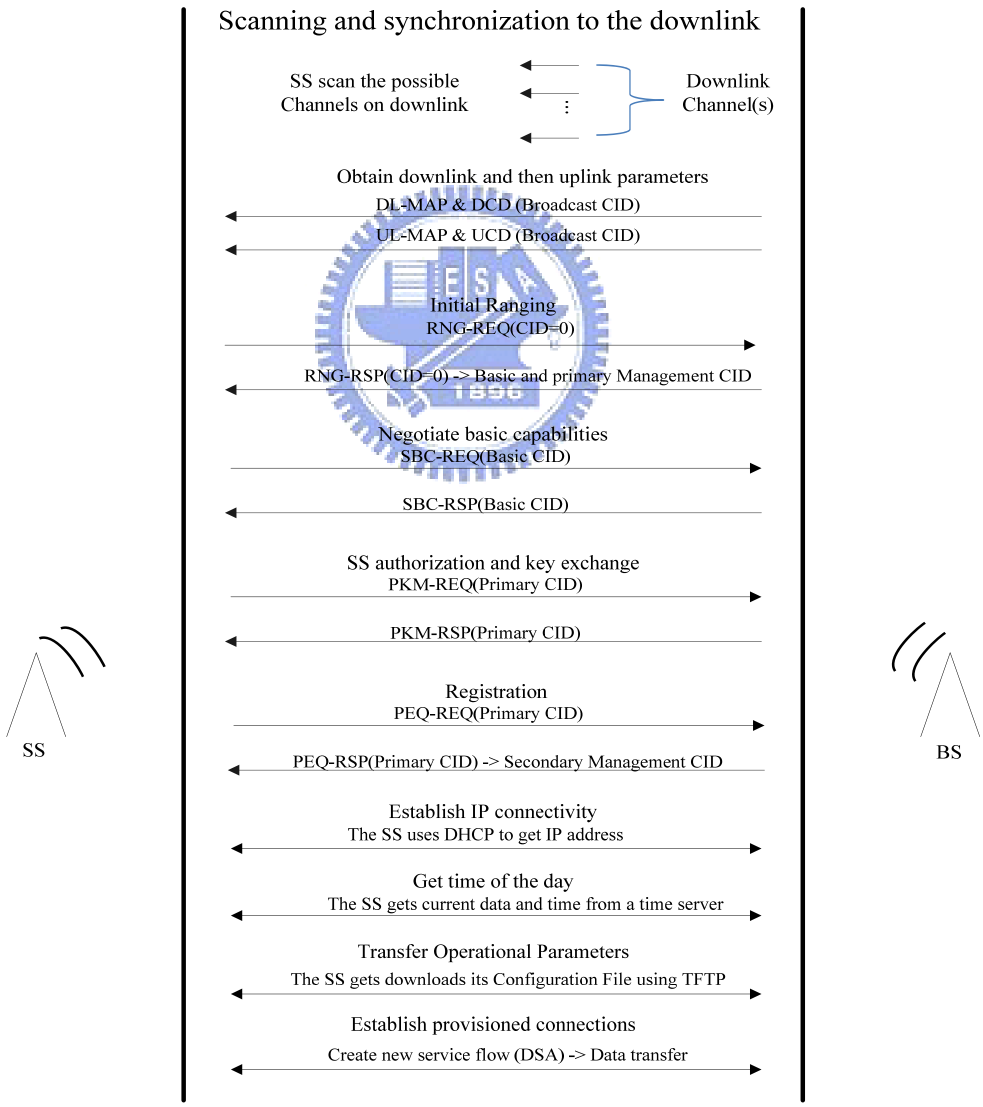


Figure2.13 SS Network Entry procedures[6]

2.2.2.1 Ranging

The sequence of the ranging process is defined in the WiMAX 802.16 standard [1] that allows the SSs to do the following:

- Acquire the correct timing offset of the network. The SS can then be aligned with the frame received from the BS for OFDM and OFDMA PHYsical layers.
- Request power adjustments or downlink burst profile change. So, within the appropriate reception thresholds, the SS can be received.

The SS performs ranging by transmitting the RNG-REQ MAC management message. The RNG-REQ message may be transmitted in the initial ranging uplink contention slots or in data grant intervals allocated by the BS to the SS. SS performs ranging at initialization and periodically. Two types ranging processes are performed:

- The initial ranging:

  If an SS want to communicate with the BS, initial ranging is an important step for the SS. Initial ranging allows an SS to join the network to get the correct transmission parameters which are time offset, frequency and transmitted power level, so that the SS can communicate with the BS.

- Periodic Ranging:

  After the initial ranging where physical parameters are adjusted, the periodic ranging allows the SSs adjusting transmission parameters so that the SSs can maintain communication quality with the BS. For the managing the data of uplink and downlink, distinct processes are used. Some PHY modes support ranging mechanisms unique to their abilities.

2.2.3 The Scheduling Services or QoS Classes

The WiMAX 802.16e standard supports several QoS classes for system supports different kinds of service. For different classes, system sets different parameters and transmission/request methods to let system maintain the QoS requirement for different kinds of service. Here will introduce those classes:

In downlink, it defines four kinds of QoS classes.

a. **Real-time CBR data streams**

These kinds of service are designed to support real-time service flows that generate fixed-size data packets on a periodic basis, such as T1/E1 and VoIP without silence suppression. For maintaining the QoS, there are several kinds of parameters used: Maximum Sustained Traffic Rate, Maximum Latency, Tolerated Jitter, and the Request/Transmission Policy.

b. **Real-time VBR data streams**

These kinds of service are designed to support real-time service flows that generate variable size data packets on a periodic basis, such as moving pictures experts group (MPEG) video. For this service, there are several kinds of parameters used: Maximum Sustained Traffic Rate, Minimum Reserved Traffic Rate, Maximum Latency, and the Request/Transmission Policy.

c. **Delay-tolerant VBR data streams**

These kinds of service are designed to support delay-tolerant data streams consisting of variable-sized data packets for which a minimum data rate is required, such as FTP. For this service, there are several kinds of parameters used: Maximum Sustained Traffic Rate, Minimum Reserved Traffic Rate, Traffic Priority, and the Request/Transmission Policy.

d. **Best effort data streams**

These kinds of service are designed to support data streams for which no minimum service level is required and therefore may be used on a space-available basis. The mandatory QoS service flow parameters for this scheduling service are Maximum Sustained Traffic Rate, and Request/Transmission Policy.

In uplink, it defines five kinds of QoS classes.

a. **Unsolicited Grant Service (UGS)**

The UGS is designed to support real-time service flows that generate fixed-size data packets on a periodic basis, such as T1/E1 and VoIP without silence suppression. There are several kinds of parameters used for this service: Maximum Sustained Traffic Rate, Maximum Latency, Tolerated Jitter, Uplink Grant Scheduling Type and the Request/Transmission Policy.

b. **Real-time Polling Service (rtPS)**

The rtPS is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as moving pictures experts group (MPEG) video. It is used for VBR service. There are several kinds of parameters used for this service: Maximum Sustained Traffic Rate, Minimum Reserved Traffic Rate, Maximum Latency, Uplink Grant Scheduling Type, and the Request/Transmission Policy.

c. **Extended Real-time Polling Service (ertPS)**

Extended rtPS is a scheduling mechanism which builds on the efficiency of both of the UGS and rtPS. The Extended rtPS is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as Voice over IP services with silence suppression. The parameters are Maximum Sustained Traffic Rate, Minimum Reserved Traffic Rate, Maximum Latency, and the

Request/Transmission Policy.

d. **Non-real-time Polling Service (nrtPS)**

The nrtPS is designed for non-real-time service which can tolerate more delay, such as FTP, web-browsing, etc… There are several kinds of parameters used for this service: Maximum Sustained Traffic Rate, Minimum Reserved Traffic Rate, Maximum Latency, and the Request/Transmission Policy.

e. **Best Effort Service (BE)**

BE service is with the lowest QoS level. These kinds of service are designed to support data streams for which no minimum service level is required and therefore may be handled on a space-available basis. The mandatory QoS service flow parameters for this scheduling service are Maximum Sustained Traffic Rate, and Request/Transmission Policy.

2.3 Review to WiMAX Relay System

IEEE 802.16j is an amendment and enhancements to the IEEE 802.16broadband wireless access standard to enable the operation of multi-hop relay stations (RS). Its aim is to enhance the coverage, per user throughput and system capacity of IEEE 802.16e by specifying the 802.16 multi-hop relay capacities functionalities relay stations and base stations. Compared with base station (BS), RS has two advantages: the first, it does not need a wire-line backhaul, and the second, it has much lower hardware complexity. Due to the above two advantages, using RSs can significantly reduce the deployment cost of the system. In this section, I will briefly talk about the function of IEEE 802.16j system, PHY layer and the MAC layer.

2.3.1 Introduction

Advances in wireless communication technologies in last decade have dramatically and largely changed human's lives. From wireless telephony to wireless internet, people can access much information anytime and anywhere. Such an enhancement further triggers people's expectation for higher transmission rate and better quality of services [7].

However, when system operators try to upgrade their cellular networks to supports a much higher transmission rate, it will result in a transmit power issue. For instance, ten times in transmission rate will result in more than ten times in transmit power in order to achieve the required signal to interference plus noise ratio (SINR). Because of the hardware cost or battery life of a mobile station (MS) since the transmit power cannot be increased unlimitedly, the station holes may exists between adjacent base stations (BS) [8].

Traditional solution to this problem is to deploy additional BSs or repeaters to serve the coverage holes. However, the deployment cost of BS is very high and the wire-line backhaul may not be available and set everywhere. On the other hand, repeater has two problems: it amplifies interference and has no intelligence of signal control and processing. For relay station (RS), it could receive and forward signals from source to destination through radio, so the deployment of RS has been developed as a more cost-effective solution. Since RSs do not need a wire-line backhaul, the deployment cost of RSs will be much lower than that of BSs. Meanwhile, RS can decode the signal from the source and forward it to the destination. And, both of the intelligent resource scheduling mechanism and cooperative transmission can be applied to obtain better system performance.

Hence, multi-hop relays (MR) have been proposed to enhance cell coverage and user throughput to the traditional cellular systems that have BS and MS exist. Within

IEEE 802.16 Working Group, IEEE 802.16j Relay Task Group has been devoted to standardize an MR network with the objectives to enhance the system coverage, per-user throughput and capacity of the IEEE 802.16broadband wireless system. IEEE 802.16j is the only standard body that is currently standardizing a multi-hop relay network, so I will briefly talk about the followings that are the some functions of IEEE 802.16j.

2.3.1.1 Some Basic Definitions about Relay

Before I introduce the 802.16j architecture, I first talk about the some basic definitions about relay [3].

- **MR-BS frame**: Frame structure for DL/UL reception by MR-BS
- **RS frame**: Frame structure for DL/UL transmission/reception by RS
- **DL access zone**: A portion of the DL sub-frame in the MR-BS/RS frame used for MS or transparent RS transmission. The DL access zone may consist of the entire downlink subframe, depending on the method used to separate the transmission on the access and relay zone
- **UL access zone:** A portion of the UL sub-frame in the MR-BS/RS frame used for MS to MR-BS/RS transmission. A frame may have no UL access zone, or the UL access zone may consist of the entire uplink subframe, depending on the method used to separate the transmissions on the access and relay links.
- **DL relay zone:** A portion of the DL sub-frame in the MR-BS/RS frame used for MR-BS/RS to RS transmission. A frame may have no DL relay zone, depending on the method used to separate the transmissions the access and relay links.

- **UL relay zone:** A portion of the UL sub-frame in the MR-BS/RS frame used for RS to MR-BS/RS transmission. A frame may have no UL relay zone, or the UL relay zone may consist of the entire uplink subframe, depending on the method used to separate the transmissions on the access and relay links.
- **Tunnel CID (T-CID):** An identifier taken from the connection identifier (CID) space that uniquely identifies a transport tunnel connection.
- **Management tunnel CID (MT-CID):** An identifier taken from the connection identifier (CID) space managed by an MR-BS that uniquely identifies a management tunnel connection between the MR-BS and an access RS.
- **Access link:** A radio link between an MR-BS or RS and an MS, or between an MR-BS or RS and a subordinate RS during network entry. The access link is either an uplink or downlink.
- **Relay link (R-link):** A radio link between an MR-BS and an RS or between a pair of RSs. This can be a relay uplink or downlink.
- **RS transmit/receive transition gap (RSTTG):** The minimum transmit-to-receive turnaround gap required at an RS. RSTTG is measured from the time of the last sample of the transmitted burst to the first sample of the received burst at the antenna port of the RS.
- **RS receive/transmit transition gap (RSRTG):** The minimum receive-to-transmit turnaround gap required at an RS. RSRTG is measured from the time of the last sample of the received burst to the first sample of the transmitted burst at the antenna port of the RS.
- **Relay receive/transmit transition gap (R-RTG):** Receive/transmit transition gap between a received mode access zone or relay zone and a

transmit mode access or relay zone in an RS frame that provides for the required RSRTG. It shall be an integer number of OFDMA symbols. The R-RTG shall be calculated by following equation: Where RTD is the round trip delay between the RS and its superordinate station and OFDMASymbolUnit is the integer number of OFDMA symbols.

- **Relay transmit/receive transition gap (R-TTG):** Transmit/receive transition gap between a transmit mode access or relay zone and a receive mode access or relay zone in an RS frame that provides for the required RSTTG. It shall be an integer number of OFDMA symbols. The R-TTG shall be calculated by following equation:

$$\text{R-TTG}=\begin{cases} 0 & \text{if } RTD/2 \geq RSTTG \\ \text{OFDMASymbolUnit}(RSTTG-RTD/2) & \text{if } RTD/2 \leq RSTTG \end{cases}$$

  Where RTD is the round trip delay between the RS and its superordinate station and OFDMASymbolUnit is the integer number of OFDMA symbols.
- **Non-transparent RS:** A non-transparent RS transmits DL frame-start preamble, FCH, MAP message(s) and channel descriptor (DCD/UCD) messages.
- **Transparent RS:** A transparent RS does not transmit DL frame-start preamble, FCH, MAP message(s) or channel descriptor (DCD/UCD) messages.
- **Multihop relay base station (MR-BS):** A generalized equipment set providing connectivity, management, and control of relay stations and subscriber stations.
- **Security zone key (SZK)**: A group key shared by the MR-BS and a group of RS within the same security zone. The SZK is a head of key hierarchy used to satisfy the security requirements such as integrity protection for

relay MAC PDUs within a defined security zone.

- **Relay station (RS):** A generalized equipment set, dependent of a multihop relay base station (MRBS), providing connectivity, to other RSs or subscriber stations (SS). An RS may also provide management and control of subordtinate RSs or SSs. The air interface between an RS and an SS is identical to the air interface between a BS and an SS.
- **Centralized scheduling:** A mode of operation applicable to multihop relay where an MR-BS determines the bandwidth allocations and generates the corresponding MAPs (or dictates the information used by RSs to generate their MAPs) for all access and relay links in the MR-cell.
- **Distributed scheduling:** A mode of operation applicable to multihop relay where the MR-BS and each RS in the MR-cell (with or without information from the MR-BS) determine the bandwidth allocations and generate the corresponding MAPs for the access link to/from their subordinate SSs and/or relay links to/from their subordinate RSs.
- **Relay zone:** A portion of frame used for the Relay link.
- **Transparent zone:** A portion of the DL sub-frame in the MR-BS/RS frame for an RS operating in the transparent mode used for MR-BS/RS to MS transmission. A DL sub-frame may, or may not, have a transparent zone.
- **Access station:** A station that provides a point of access into the network for an MS or RS. An access station can be a BS, RS, or MR-BS.
- **Access RS:** A relay station which serves as an access station.
- **Intermediate RS:** A relay station that is located on a path between an MR-BS and an access RS.

- **Round trip delay (RTD):** The round trip delay time between communicating stations
- **Security zone (SZ):** a group consisting of one or more RSs and the MR-BS that share key material for the protection of MAC management messages produced and processed by members of the group.
- **In-band relay:** A non-transparent relay where the access links and relay links use the same carrier frequency and are separated in time.
- **Out-of-band relay:** A non-transparent relay where the access links and relay links use different carrier frequencies and may not be time separated.
- **Infrastructure station**: an MR-BS or RS

2.3.2 IEEE 802.16j System Architecture

In this section, the key system features of the IEEE 802.16j MR architecture are overviewed. The basic system architecture of IEEE 802.16j is illustrated in Figure2.14, where two kinds of radio links are defined: access link and relay link. BS that is capable of supporting multi-hop relay is called MR-BS. For the radio link that originates or terminates at an MS, which is either a downlink (DL) or an uplink (UL), defined in IEEE802.16-2004, we call it the access link. For the radio link between an MR-BS and an RS or between a pair of RSs, which also can be either uplink or downlink, we call it the relay link.

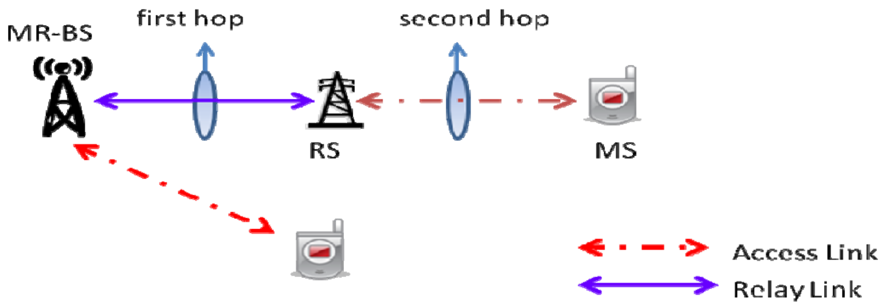


Figure2.14 The system architecture[8]

Following the basic architecture in Figure2.14, a new frame structure is shown in Figure 2.15, where each DL sub-frame and UL sub-frame comprise access zone and relay zone. The DL/UL access zone is a portion of DL/UL sub-frame used for access links transmission, and the DL/UL relay zone is a portion of DL/UL sub-frame used for relay links transmission. Note that each DL/UL sub-frame may have not only one relay zone, it may have more than one.

Two types of RSs have been defined in IEEE 802.16j: non-transparent RS and transparent RS in order to enable RS operations with no change on the legacy MS specification. The non-transparent RS acts as a BS sector [9], therefore the MR-BS has to assign a preamble index to each RS, and the RS will transmit its own preamble, FCH and MAP over the access zone. The frame structure for the non-transparent RS is shown Figure2.15.

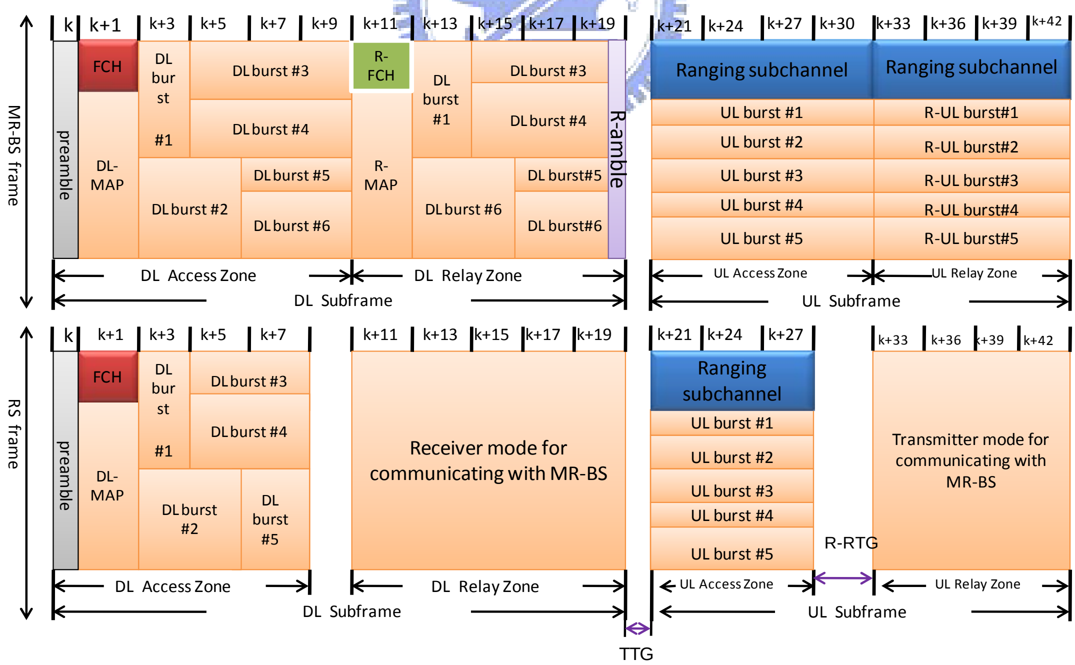


Figure2.15 configuration for an non-transparent relay frame structure[3]

Because they need to transmit their own preamble at the start of a frame and cannot receive the preamble transmitted from the MR-BS or other RSs, it is not possible for non-transparent RSs to scan and synchronize with each other by the preamble. In Figure2.15, the relay amble (R-amble) located at the end of downlink sub-frame is designed for many purposes, such as measurement, synchronization and neighborhood discovery over relay links. Note that the R-amble may not be transmitted in each frame for overhead reduction.

As for the transparent RS, it doesn't have its own preamble, FCH, and MAP. The transparent RS looks transparent to each MS and only relays each MS's data. The transparent RS will be in receiving mode while the MR-BS transmits its preamble, FCH, and MAP to them.

When an MS communicates with a non-transparent RS, it will receive the preamble, FCH, MAP and data burst transmitted from the RS. On the other hand, if an MS communicates with a transparent RS, it will receive the data burst from the RS but receive the preamble, FCH and MAP transmitted from the MR-BS. Therefore, MR-BS controls the transparent RS centralized that transmits/receives the data burst over the designated sub-channels and symbol times. It is very important that the MR-RS and multiple RSs can serve a particular MS simultaneously so as to increase the signal quality and accrue cooperative diversity gain.

As for the non-transparent RS, without the instruction from the MR-BS, it can generate its own FCH and MAP, so that the de-centralized control can be performed to reduce the delay of transmitting message and the messaging overhead over relay links. Meanwhile, a group of RSs may transmit the same preamble, FCH, MAP and data burst and act as a single virtual station from MS's point of view. In this case, the handover procedure will not be initiated by the MS when MS move between the grouped RSs and the cooperative diversity gain will be obtained.

2.3.3 MAC Layer

2.3.3.1 Scheduling Services

In MR systems with RSs operating in distributed scheduling mode, using RS scheduling information (RS-SCH management message) to ensure QoS requirements for UGS, ertPS, rtPS are met [3].

- **UGS:** In an MR system with RSs operating in distributed scheduling mode. To meet a UGS service flow's need, the MR-BS and RSs along the path shall grant fixed size bandwidth to its subordinate station on a real-time periodic basis. The MR-BS or RS may send RS scheduling information (RS-SCH) in advance to its subordinate RS to indicate when and how much bandwidth it will schedule for the service in the future.
- **rtPS:** In an MR system with RSs operating in distributed scheduling mode. To meet an rtPS service flow's need, the MR-BS and RSs along the path shall poll its subordinate station on a real-time periodic basis. The MRBS or an RS may send RS scheduling information (RS-SCH management message) to its subordinate RS to indicate when it will schedule a poll in the future.
- **Extended rtPS:** In an MR system with RSs operating in distributed scheduling mode. To meet an Extended rtPS service's need, the MR-BS and RSs along the path shall grant dynamic size bandwidth to its subordinate station on a real-time periodic basis. The MR-BS or RS may send RS scheduling information (RS-SCH management message) to its subordinate RS to indicate when and how much bandwidth it will schedule for the service in the future.

2.3.3.2 MAC Support of PHY

- **DL-MAP:** The DL-MAP message defines the usage of the downlink intervals on the access links for a burst mode PHY. It may also be used for relay links for transparent RS.
- **UL-MAP:** The UL-MAP message defines the uplink usage on the access link in terms of the offset of the burst relative to the Allocation Start Time.
- **R-MAP:** The R-MAP message defines both of the usage of downlink and uplink intervals on the relay link for the OFDMA-PHY.

2.3.3.3 Network Entry and Initialization

Network systems shall support the list of sequence procedures for entering and registering a new SS or RS to the network.

The procedure for initialization of an SS is known in IEEE 802.16e. Here, the procedure for initialization of an RS is shown in Figure2.16 respectively. In the sequence blocks of the Figure2.16 show the overall flow between the stages of initialization in an RS. In the Figure2.16, it shows no error paths simply to provide an overview of the process of the initialization.

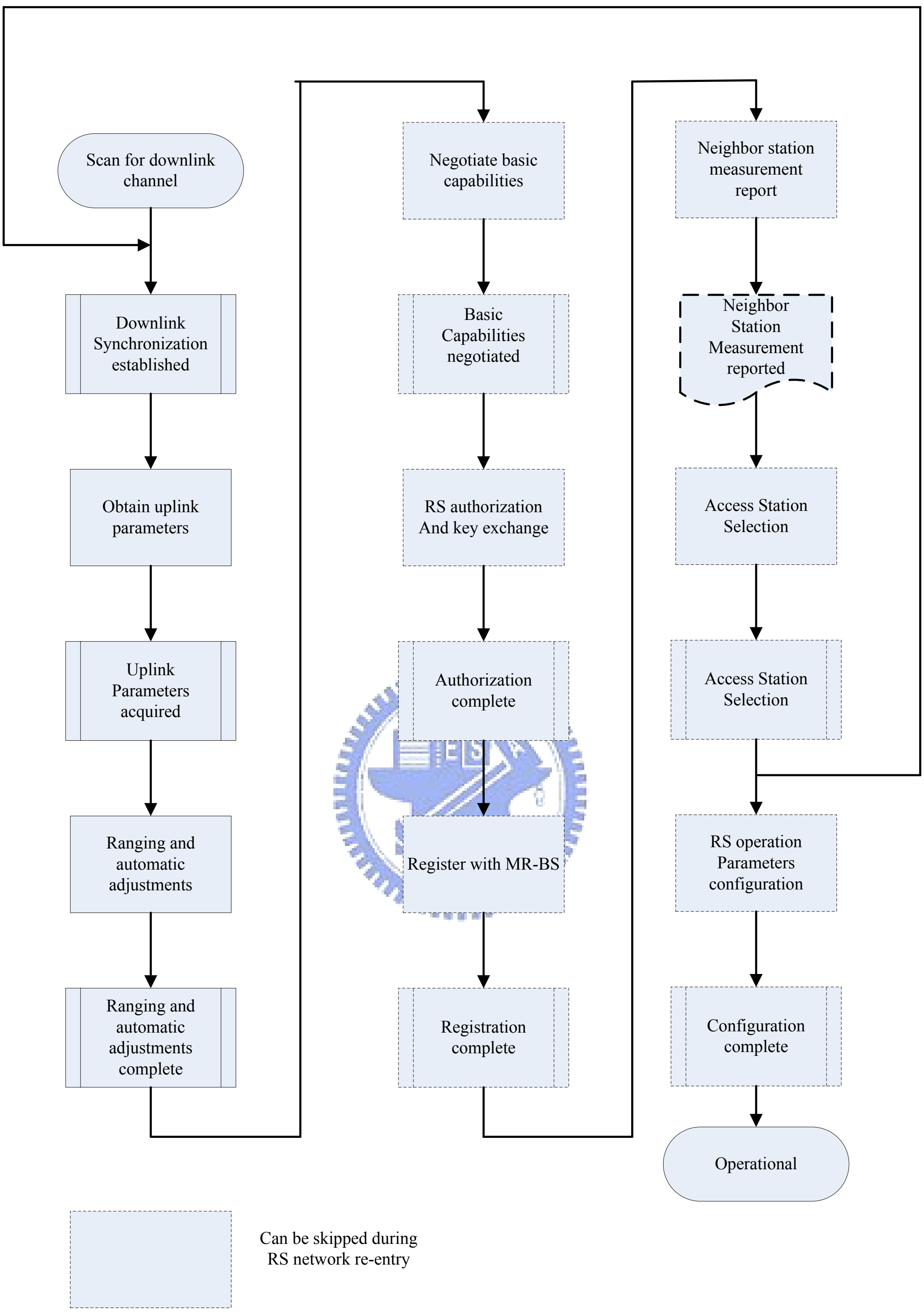


Figure2.16 RS initialization overview[3]

The procedure can be separated into the following phases:

a) Scan for DL channel and establish synchronization with the BS

a1) Perform the first stage access station selection (RS only)

b) Obtain Tx parameters (from UCD message)

c) Perform ranging

d) Negotiate basic capabilities

e) Authorize SS/RS and perform key exchange

f) Perform registration

f1) Obtain R-link Parameters (RS only)

g) Establish IP connectivity (SS only)

h) Establish time of day (SS only)

i) Transfer operational parameters (SS only)

j) Set up connections (SS only)

k) Obtain neighbor station measurement report (RS only)

l) Perform the second stage access station selection (RS only)

m) Configure operation parameters (RS only)

Phase e) of the above implementation is optional. This phase shall be performed if both SS/RS and BS support Authorization Policy. Phases g), h), and i) of the above implementation at the SS is optional. These phases will only be performed if the SS has indicated in the REG-REQ message that it is a managed SS.

Phase a1), k), l) of the implementation are optional. The MR-BS may instruct the RS to omit phases a1), k), l), m) by the RS network entry optimization TLV in the RNG-RSP message.

2.3.3.4 Relay Path Management and Routing

MR-BS does centralized calculation for the path between the MR-BS and an access RS for both the uplink and downlink direction based on the topology information obtained from topology discovery or update process. The path creation is subject to the limitations of tree topology and other limitations such as the availability of radio resource, radio quality of the link, load condition of an RS, etc.

There are two path management may be used:

- **Embedded path management for relay**

  The method of embedded path management is that the MR-BS shall organizationally assign CIDs to its subordinate stations such that the CIDs allocated to all subordinate RSs of any given station is a subset of the allocated CIDs for that station. Embed the network topology into a systematic CID structure in order to help RSs to find routing paths without storing all CIDs of subordinate RSs in the routing table.

- **Explicit path management for relay**

  After MR-BS discovers the topology between a newly attached MS or RS and itself, or detects a topology update due to events such as mobility, MR-BS would remove an old path, and establish a new path and inform the new path information to all the RSs on the path.

  While some connections are established or removed, MR-BS would distribute the information of mapping between the connection and the path to all the RSs on the path. The connection could be a regular connection established for an MS or for an RS.

2.3.4 PHY Layer

2.3.4.2 Frame Structure of MR-BS and RS

In this section, I describes the minimal requirements for a frame structure an MR-BS and its subordinate RS.

- **Transparent frame structure- MR-BS frame structure**

An example the transparent frame structure is illustrated in Figure2.17. See Figure2.17, each frame in the downlink transmission starts with a preamble followed by an FCH, DL-MAP, and possibly UL-MAP. As for R-MAP, it is located following MAP and is defined as an extension of MAP. The frame structure is divided into both periods of DL sub-frame period and UL sub-frame period. In each frame, the TTG shall be inserted between the DL sub-frame and the UL sub-frame, and the RTG shall be inserted at the end of each frame.

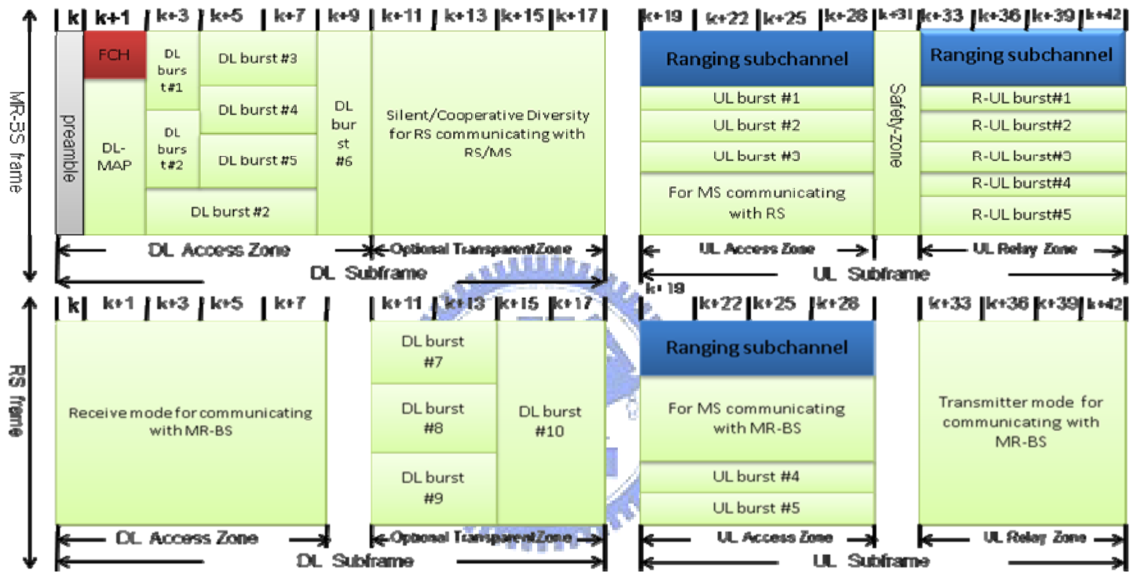


Figure2.17 configuration for an in-band transparent relay frame structure[3]

RSs performing initial ranging and MSs for all ranging operations to use the ranging subchannel in the access zone. RSs use the ranging subchannel in the relay zone for ranging operations other than initial ranging. For the DL sub-frame, it shall include one access zone and one transparent zone for RS to MS transmissions. The MR-BS may also transmit in the transparent zone. For the UL sub-frame may include a UL access zone and a UL relay zone.

- **Transparent frame structure- Relay frame structure**

See Figure2.17, an RS frame structure is also illustrated. Differing from MR-BS frame structure, a transparent RS does not transmit the preamble, FCH and MAP at the beginning of the frame. It receives the preamble, FCH and MAP and optional R-MAP transmission from MR-BS instead. The detailed allocation for an RS in the access zone is indicated by a MAP message and in the relay zone by an R-MAP message. In each frame, a TTG shall be inserted in the middle of the DL sub-frame and the UL sub-frame and an RTG shall be inserted at the end of each frame. The DL sub-frame shall include one access zone for MR-BS to RS and MS transmissions and may include one transparent zone for RS to subordinate station transmissions. The UL sub-frame may include one access zone and one relay zone for RS to superordinate station transmissions. STC DL Zone IE() message may indicate additional power adjustment to be applied to transparent zone in order to reduce the absolute received signal level difference experienced by the MSs served in that zone from different paths of MR-BS and RS. The ranging subchannel in the access zone is used by RSs performing initial ranging and MSs for all ranging operations. For the purpose of monitoring, the relay link amble, when present, should be allocated at the end of the DL subframe.

- **Non-transparent frame structure - MR-BS frame structure**

  An example of the non-transparent frame structure of MR-BS frame structure is shown Figure2.18. Each MR-BS frame begins with a preamble followed by an FCH and the DL MAP and possibly UL MAP. The DL sub-frame shall be composed of at least one DL access zone and one or more DL relay zones especially. The UL sub-frame may be composed of one or more UL access zones and one or more UL relay zones especially. An MR-BS would make use of a relay zone for transmission, reception or idle but the MR-BS shall not be required to support multiple modes of operation within the same zone. In each frame, the TTG shall be put in the middle of the DL sub-frame and the UL sub-frame, and the RTG shall be set at the end of each frame.

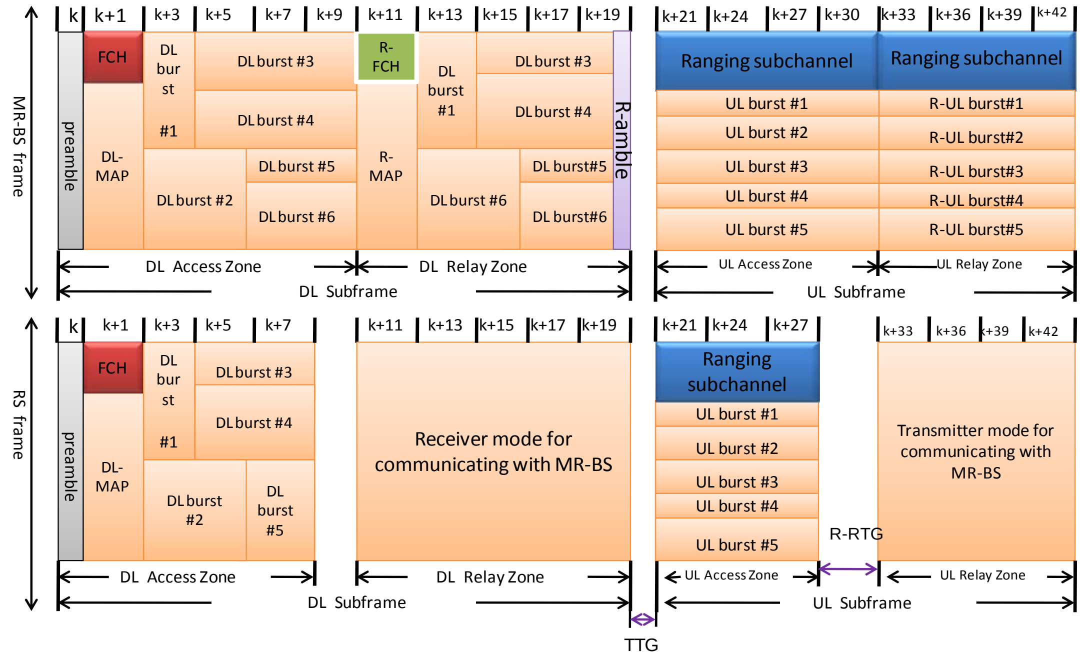


Figure2.18 configuration for an in-band non-transparent relay frame structure[3]

- **Non-transparent frame structure - Relay frame structure**

See Figure2.18, an RS frame structure is also illustrated. The RS transmits its frame start time aligned with frame start preamble of its superordinate station. The UL sub-frame of the RS is aligned to the UL sub-frame of the MR-BS. The DL sub-frame shall be composed of at least one DL access zone and one or more relay zones. The UL sub-frame may be composed of one or more UL access zones and one or more relay zones. RS would use a relay for either transmission, reception, or idle but the RS shall not be required to support both modes of operation within the same zone. In each frame, for the TTG, it shall be put between the DL sub-frame and the UL sub-frame. For the RTG shall be set at the end of each frame. Each RS frame starts with a preamble followed by an FCH and the DL-MAP and possibly a UL-MAP. The R-FCH and the R-DL-MAP shall be transmitted in the first DL Relay zone in transmission mode. By utilizing the RCD message of its MR-BS, the frame structure of an RS can be configured.

2.3.4.3 OFDMA Ranging Codes

The number of available codes is 256 which range from the number 0 to the number 255. A subgroup of these ranging codes where the subgroup is defined by a number S, 0 <= S <= 255 are used by each BS. The group of codes will be between S and ((S+O+N+M+L+P+Q) mod 256). The following is about the N codes, M codes, L codes, O codes, P codes, Q codes individually.

- The main function of the first N codes produced is initial-ranging. Clock the PRBS generator $144 \times (S \bmod 256)$ times to $144 \times ((S + N) \bmod 256) - 1$ times.
- The main function of the next M codes produced is periodic-ranging. Clock the PRBS generator $144 \times ((N + S) \bmod 256)$ times to $144 \times ((N + M + S) \bmod 256) - 1$ times.
- The main function of the next L codes produced is bandwidth-requests. Clock the PRBS generator $144 \times ((N + M + S) \bmod 256)$ times to $144 \times ((N + M + L + S) \bmod 256) - 1$ times.
- The main function of the next O codes produced is handover-ranging. Clock the PRBS generator $144 \times ((N + M + L + S) \bmod 256)$ times to $144 \times ((N + M + L + O + S) \bmod 256) - 1$ times.
- The main function of the next P codes produced is RS initial-ranging. Clock the PRBS generator $144 \times ((N + M + L + O + S) \bmod 256)$ times to $144 \times ((P + N + M + L + O + S) \bmod 256) - 1$ times
- The main function of the next Q codes produced is RS dedicated codes. Clock the PRBS generator $144 \times ((P + N + M + L + O + S) \bmod 256)$ times to $144 \times ((Q + P + N + M + L + O + S) \bmod 256) - 1$ times

The ranging codes used in the relay zone and them used in the access zone are the same.

Chapter 3 Network Simulator

The 802.16_based WiMAX module is named as Mac802_16 class according to the IEEE 802.16-2004 standard [1]. And the simulation platform is based on the ns-2 version 2.29. The whole WiMAX modules are all written by using object-oriented programming language C++ and module and ns-2 modules. So, the platform of the ns-2 plays an important role in the IEEE 802.16 WIMAX module, even the 802.16j relay module is added on based on the forward module. So, in this chapter of the first issue, I will introduce the whole network simulation in detail. In the chapter, I first introduce the NS-2 briefly, and then I brief talk about the IEEE 802.16e WIMAX module and add-on IEEE 802.16j module and simulation steps and notices. The following I first talk about is network simulator.

In the network simulators, we can achieve specific purposes like ATM , wireless , TCP/IP and general purposes like modifiable modules and modules extensibilities. So NS-2 functionalities include functions which are wired and Wireless. Wired functions as transportation aspect, includes TCP , UDP , RTP , SRM. As traffics sources aspect , includes web , ftp , telnet , cbr , stochastic. As Queuing disciplines aspect , includes drop-tail, RED, FQ, SFQ , DRR. Wireless functions as ad hoc routing , mobile IP , directed diffusion , and sensor-MAC. The network simulators have the two purposes:

- Specific Purposes
  - ATM
  - Wireless
  - TCP/IP
- General Purposes
  - Modifiable modules

- Modules extensibility

and a simulator can provides many features:

- Easy network topology setup
- Protocols and application implementation
    - TCP, UDP
    - FTP , Telnet , Web , CBR , VBR
    - Routing protocols
    - Queue management protocols
- Configurability
- Extensibility

The Method for network research is the following:

- Analytical
    - Model
    - General expression or close form
- Emulation
    - Network testbed
    - Lab environment
    - Real code
- Simulation
    - Virtual network testbed

Why do we want to do the simulation? The following list is the reason why we do the simulation requiring much time and work.

- Study of implemented protocols and algorithms
    - Behavior
    - Performance
- Test of unimplemented new protocols and algorithms

➢ Comparison of results across research efforts

but the network simulation will have the advantages and disadvantages actually

Advantages	Disadvantages
◆Inexpensive, Flexible , and Reconfigurable ◆Network phenomena interested can be reproduced ◆Opportunity to study large-scale network ◆Easier comparison of results across research efforts	◆Important network details may be missed ◆Protocols or algorithms must be "added" before simulation can be done ◆High start-up cost ◆Have to be carefully verified before the test results can be used

Figure3.1 The advantage and disadvantage of network simulator

3.1 NS2 architecture overview

NS is an event driven network simulator developed at UC Berkeley that simulates variety of IP networks. The changing history of the NS is NEST (Network Simulation Testbed) , and REAL (Realistic and Large) , and NS-1 and NS-2 finally [11]. It implements network protocols such as TCP and UPD, traffic source behavior such as FTP, Telnet, Web, CBR and VBR, router queue management mechanism such as Drop Tail, RED and CBQ, routing algorithms such as Dijkstra, and others. It is important for us that NS also implements multicasting and some of the MAC layer protocols for LAN simulations. The NS project is now a part of the VINT project that develops tools for simulation results display, analysis and converters that convert network topologies generated by well-known generators to NS formats. Currently, NS (version 2) written in C++ and OTcl (Tcl script language with Object-oriented extensions developed at MIT) is available.

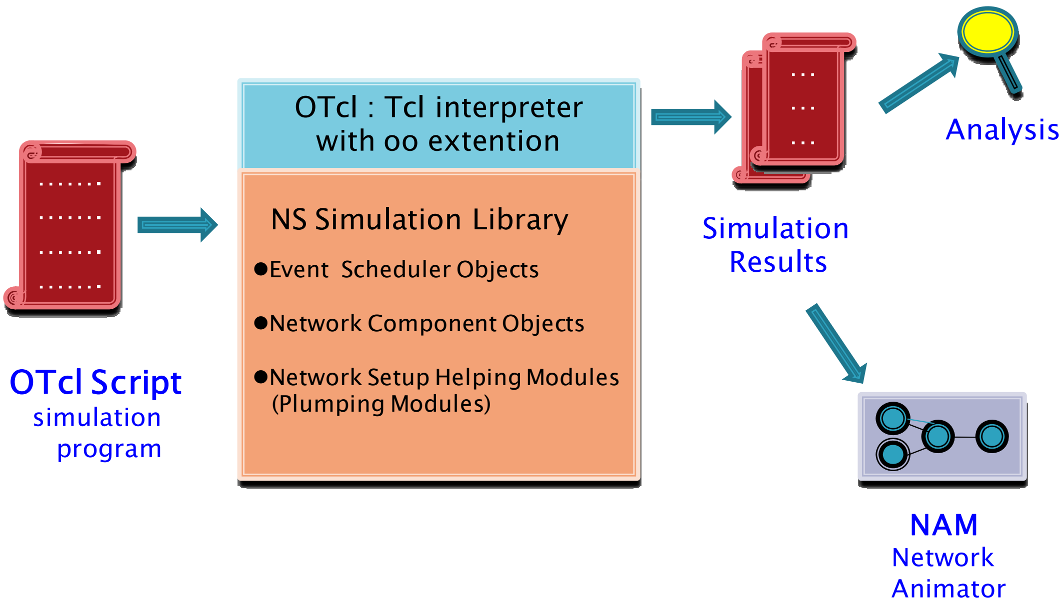


Figure3.2 User's view of NS[10]

As shown in Figure3.2, in a simplified user's view, NS is Object-oriented Tcl (OTcl) script interpreter that has a simulation event scheduler and network component object libraries, and network setup (plumbing) module libraries (actually, plumbing modules are implemented as member functions of the base simulator object). In other words, to use NS, you program in OTcl script language. To setup and run a simulation network, a user should write an OTcl script that initiates an event scheduler, and sets up the network topology using the network objects and the plumbing functions in the library, and tells traffic sources when to start and stop transmitting packets through the event scheduler. The term "plumbing" is used for a network setup, because setting up a network is plumbing possible data paths among network objects by setting the "neighbor" pointer of an object to the address of an appropriate object. When a user wants to make a new network object, he can easily make an object either by writing a new object or by making a compound object from the object library, and plumb the data path through the object. The plumbing OTcl modules actually make the job very easy. The power of NS comes from this plumbing. Another major component of NS beside network objects is the event scheduler. An event in NS is a packet ID that is unique for a packet with scheduled time and the pointer to an object that handles the event. In NS, an event scheduler keeps track of simulation time and fires all the events in the event queue scheduled for the current time by invoking appropriate network components, which usually are the ones who issued the events, and let them do the appropriate action associated with packet pointed by the event. Network components communicate with one another passing packet, however this does not consume actual simulation time. All the network components needing to spend some simulation time handling a packet use the event scheduler by issuing an event for the packet and waiting for the event to be fired to itself before doing further action handling the packet. For example, a network switch component that simulates a switch with 40 microseconds of switching delay issues an event for a packet to be switched to the scheduler as an event 40 microsecond later. The scheduler after 40 microseconds dequeues the event and fires it to the switch component, which then passes the packet to an appropriate output link component. Another use of an event scheduler is timer. Timers use event schedulers in a similar manner that delay does. The only difference is that timer measures a time value associated with a packet and does an appropriate action related to that packet after a certain time goes by, and does not simulate a delay.

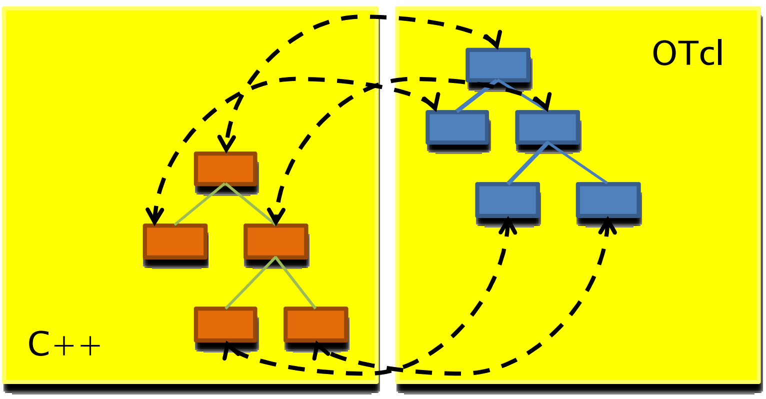


Figure3.3 C++ and OTcl : The Duality[11]

NS is written not only in OTcl but also in C++. Figure3.3 shows an object hierarchy example in C++ and OTcl. For efficiency reason, NS is comprised with the data path implementation and control path implementations. In order to reduce packet and event processing time, the event scheduler and the basic network component objects in the data path are written and compiled using C++. These compiled objects are made available to the OTcl interpreter through an OTcl linkage that creates a matching OTcl object for each of the C++ objects and makes the control functions and the configurable variables specified by the C++ object act as member functions and member variables of the corresponding OTcl object. In this way, the controls of the C++ objects are given to OTcl. It is also possible to add member functions and variables to a C++ linked OTcl object. The objects in C++ that do not need to be controlled in a simulation or internally used by another object do not need to be linked to OTcl. Likewise, an object (not in the data path) can be entirely implemented in OTcl. One thing to note in the Figure3.3 is that for C++ objects that have an OTcl linkage forming a hierarchy, there is a matching OTcl object hierarchy very similar to that of C++.

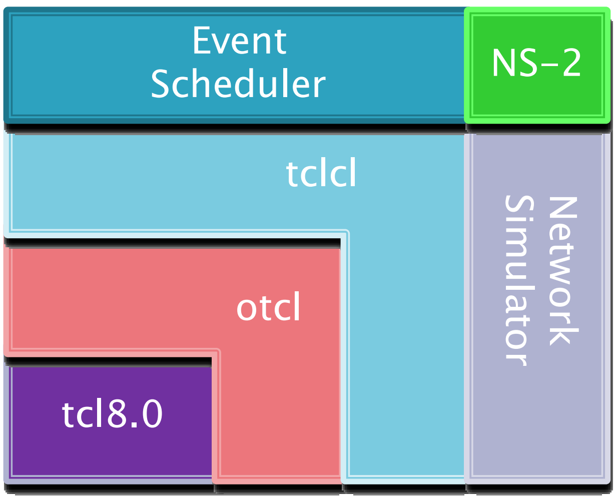


Figure3.4 Architecture view of NS[11]

Figure3.4 shows the general architecture of NS. In this figure, a general user can be thought of standing at the left bottom corner, designing and running simulations in Tcl using the simulator objects in the OTcl library. The event schedulers and most of the network components are implemented in C++ and available to OTcl through an OTcl linkage that is implemented using tclcl. The whole thing together makes NS, which is a extended Tcl interpreter with network simulator libraries.

If we want to obtain the simulation results, as Figure3.2, when a simulation is finished, NS produces one or more text-based output files that contain detailed simulation data, if specified to do so in the input Tcl (or more specifically, OTcl) script. The data can be used for simulation analysis or as an input to a graphical simulation display tool called Network Animator (NAM) that is developed as a part of VINT project. NAM has a nice graphical user interface similar to that of a CD player (play, fast forward, rewind, pause and so on), and also has a display speed controller. Furthermore, it can graphically present information such as throughput and number of packet drops at each link, although the graphical information cannot be used for accurate simulation analysis.

In a word, ns is the simulator itself. Nam is the network animator which can visualize ns output and use GUI interface to generate ns scripts. The pre-processing are traffic and topology generators. The post-processing are simple trace analysis, often in Awk , Perl , or Tcl. Then I will briefly introduce some function of the ns platform.

PART I. Interface to the Interpreter

3.2 OTcl Linkage

Ns-2 is an object oriented simulator, written in C++, with an OTcl interpreter as a frontend. The simulator supports a class hierarchy in C++, and a similar class hierarchy within the OTcl interpreter. The two hierarchies are closely related to each other; from the user's perspective, there is a one-to-one correspondence between a class in the interpreted hierarchy and one in the compiled hierarchy [12]. Users create new simulator objects through the interpreter; these objects are instantiated within the interpreter, and are closely mirrored by a corresponding object in the compiled hierarchy.

The interpreted class hierarchy is automatically established through methods defined in the class TclClass. User instantiated objects are mirrored through methods defined in the class TclObject. The ns-2 directory structure is illustrated in Figure3.5.

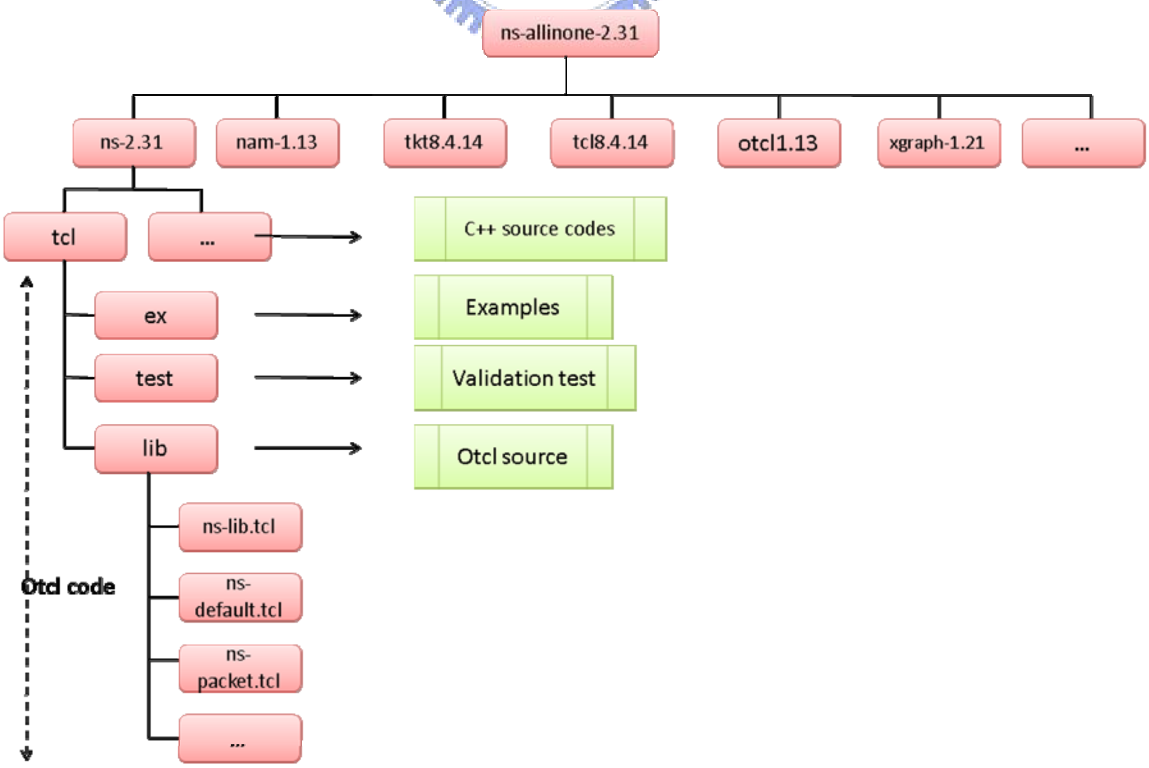


Figure3.5 NS-2 Directory Structure

3.2.1 Concept overview

Ns uses two languages because simulator has two different kinds of things it needs to do. On one hand, detailed simulations of protocols require a systems programming language which can efficiently manipulate bytes, packet headers, and implement algorithms that run over large data sets. For these tasks run-time speed is important and turn-around time (run simulation, find bug, fix bug, recompile, re-run) is less important. On the other hand, a large part of network research involves slightly varying parameters or configurations, or quickly exploring a number of scenarios. In these cases, iteration time (change the model and re-run) is more important. Since configuration runs once (at the beginning of the simulation), run-time of this part of the task is less important.

Ns meets both of these needs with two languages, C++ and OTcl. C++ is fast to run but slower to change, making it suitable for detailed protocol implementation. OTcl runs much slower but can be changed very interactively, making it ideal for simulation configuration.

3.2.2 Class Tcl

The class Tcl encapsulates the actual instance of the OTcl interpreter and provides the methods to access and communicate with that interpreter. The class provides methods for the following operations：

• Obtain a reference to the Tcl instance;

• Invoke OTcl procedures through the interpreter;

• Retrieve, or pass back results to the interpreter;

• Report error situations and exit in an uniform manner;

• Store and lookup “TclObjects”.

• Acquire direct access to the interpreter.

3.2.3 Class TclObject

Class TclObject is the base class for most of the other classes in the interpreted and compiled hierarchies. Every object in the class TclObject is created by the user from the interpreter. An equivalent shadow object is created in the compiled hierarchy. The two objects are closely associated with each other. The following example illustrates the configuration of an SRM agent (class Agent/SRM/Adaptive).

```
set srm [new Agent/SRM/Adaptive]
$srm set packetSize_ 1024
$srm traffic-source $s0
```

By convention in ns, the class Agent/SRM/Adaptive is a subclass of Agent/SRM, is a subclass of Agent, is a subclass of TclObject. The corresponding compiled class hierarchy is the ASRMAgent, derived from SRMAgent, derived from Agent, derived from TclObject respectively. The first line of the above example shows how a TclObject is created; the next line configures a bound variable; and finally, the last line illustrates the interpreted object invoking a C++ method as if they were an instance procedure.

3.2.4 Class TclClass

This compiled class (class TclClass) is a pure virtual class. Classes derived from this base class provide two functions:

- Construct the interpreted class hierarchy to mirror the compiled class hierarchy
- Provide methods to instantiate new TclObjects.

Each such derived class is associated with a particular compiled class in the compiled class hierarchy, and can instantiate new objects in the associated class.

PART II. Simulator Basics

3.3 The Class Simulators

The overall simulator is described by a Tcl class Simulator and especially provides a set of interfaces for configuring a simulation and for choosing the type of event scheduler used to drive the simulation. A simulation script generally starts by creating an instance of this class and calling various methods to create nodes, topologies, and configure other aspects of the simulation.

3.3.1 Simulator Initialization

When a new simulation object is created in tcl, the initialization procedure performs the following operations:

• initialize the packet format (calls create_packetformat)

• create a scheduler (defaults to a calendar scheduler)

• create a "null agent" (a discard sink used in various places)

The field offsets within packets used by the entire simulation are set up by the packet format. The scheduler runs the simulation in an event-driven manner and may be replaced by alternative schedulers which provide somewhat different semantics.

3.3.2 Schedulers and Events

The simulator is an event-driven simulator. There are now four schedulers available in the simulator, each of which is implemented using a different data structure: a simple linked-list, heap, calendar queue (default), and a special type called "real-time". The scheduler runs by selecting the next earliest event, executing it to completion, and returning to execute the next event. Unit of time used by scheduler is seconds. Presently, the simulator is single-threaded, and only one event in execution at any specific time.

3.4 Nodes and Packet Forwarding

Nodes and Packet Forwarding is creating the nodes.

The procedures and functions described can be found in ~*ns*/tcl/lib/ns-lib.tcl, ~*ns*/tcl/lib/ns-node.tcl,~*ns*/tcl/lib/ns-rtmodule.tcl,~*ns*/rtmodule.{cc,h},~*ns*/classifier.{cc,h},~*ns*/classifier-addr.cc,~*ns*/classifier-mcast.cc,~*ns*/classifiermpath.cc,and,~*ns*/replicator.cc.

3.4.1 Node Basics

The basic primitive for creating a node is

set ns [new Simulator]

$ns **node**

Most of the components of the node are themselves TclObjects. The typical structure of a (unicast) node is as shown in Figure3.6. The function of these classifiers is to distribute incoming packets to the correct agent or outgoing link.

All nodes include in any case the following components:

- an address or id_, monotonically increasing by 1 (from initial value 0) across the simulation namespace as nodes are created
- a list of neighbors (neighbor_)
- a list of agents (agent_)
- a node type identifier (nodetype_)
- a routing module

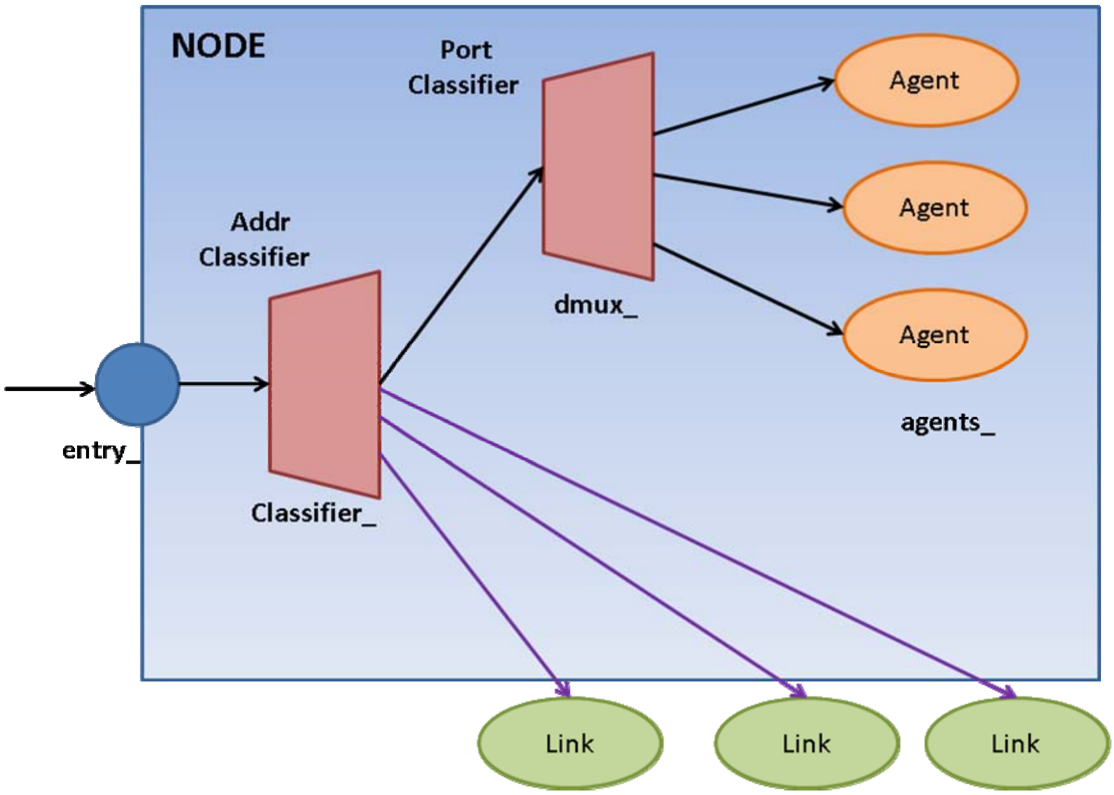


Figure3.6 Structure of an Unicast Node. Notice that entry_ is simply a label variable instead of a real object[12]

On the other hand, the overall structure of a typical multicast node is shown in Figure3.7. When a simulation uses multicast routing, the highest bit of the address indicates whether the particular address is a multicast address or an unicast address. If the bit is 0, the address represents a unicast address, the address represents a multicast address when the bit is 1.

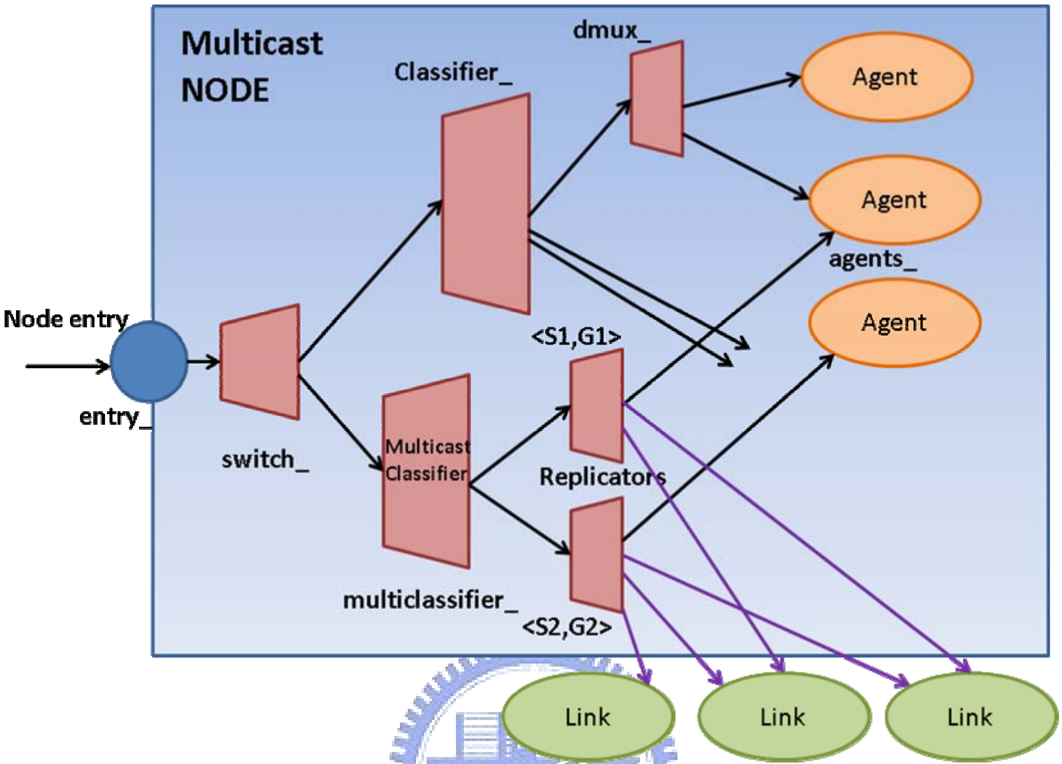


Figure3.7 Internal Structure of a Multicast Node[12]

3.5 Routing Module and Classifier Organization

As we have seen, a ns node is composed of many classifier. The simplest unicast node contains only one address classifier and one port classifier. If we want to extend the functionality of the node, more classifiers are added into the base nodes. Then, it makes the multicast node. As more function blocks is added, and each of these blocks requires its own classifier(s), it becomes important for the node to provide a *uniform* interface to organize these classifiers and to bridge these classifiers to the route computation blocks.

The classical method to handle this case is through class inheritance. For instance, if we wants a node that supports hierarchical routing, owe simply derive a Node/Hier from the base node and override the classifier setup methods to insert hierarchical classifiers. This method works well when the new function blocks are independent and cannot be "arbitrarily" mixed. For instance, both hierarchical routing and ad hoc routing use their own set of classifiers. Inheritance would require that we have Node/Hier that supports the former and Node/Mobile for the latter. This becomes slightly problematic when we want an ad hoc routing node that supports hierarchical routing. In this case, we may use multiple inheritance to solve the problem, but this quickly becomes infeasible when the total number of such function blocks increases.

3.5.1 Routing Modul

Generally to speak, the routing implementation in ns includes three basic function block:

- *Routing agent* exchanges routing packet with neighbors.
- *Route logic* uses the information gathered by routing agents (or the global topology database in the case of static routing) to perform the actual route computation.
- *Classifiers* sit inside a Node. They use the computed routing table to perform packet forwarding.

Implementing a new routing protocol, we do not always implement all of the three blocks.

When a new routing protocol implementation includes more than one function blocks, especially it contain its own classifier, it is desirable to have another object, which we call *routing module* managing all these function blocks and to interface with node to organize its classifier. In Figure3.8, it illustrates functional relation among these objects. It is important to know that routing modules may have direct relationship with route computation blocks, including route logic and/or routing agents, but route computation may not install through a routing module because there are maybe other modules that are interested in learning about the new modules.

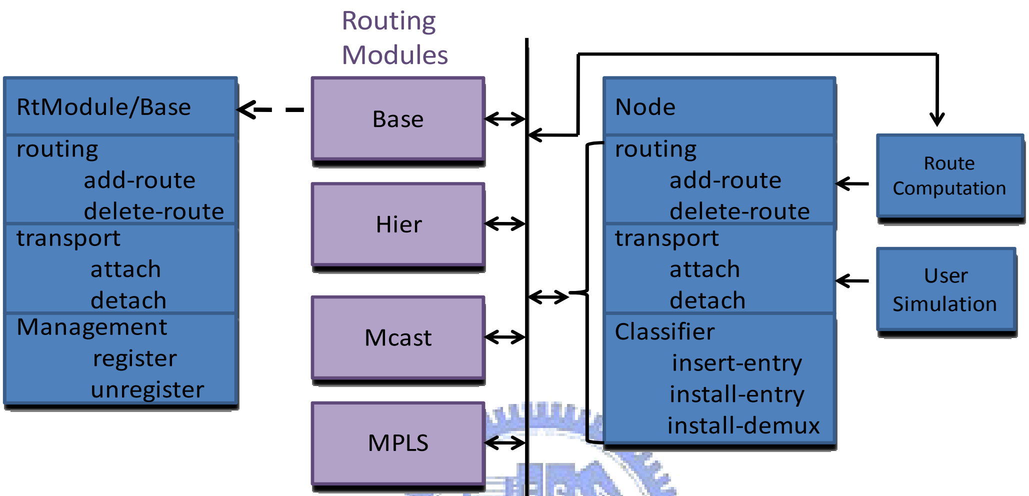


Figure3.8 Interaction among node, routing module, and routing. The dashed line shows the details of one routing module[12]

A routing module contains three major functionalities:

1. A routing module initializes its connection to a node.
2. If a routing module is interested in knowing routing updates, the node will inform the module.
3. If a routing module is interested in learning about transport agent attachment and detachment in a node, the node will inform the module.

3.6 WiMAX NS-2 Module and 802.16j Add-On

The Mac802_16 is a subclass of the Mac class. It is an abstract class including the functions of the BS and MS. So, it is added with the elements of 802.16j based on the original module. Here, I briefly introduce the relation the class of each module and relations with other module. The module is illustrated in Figure3.9.

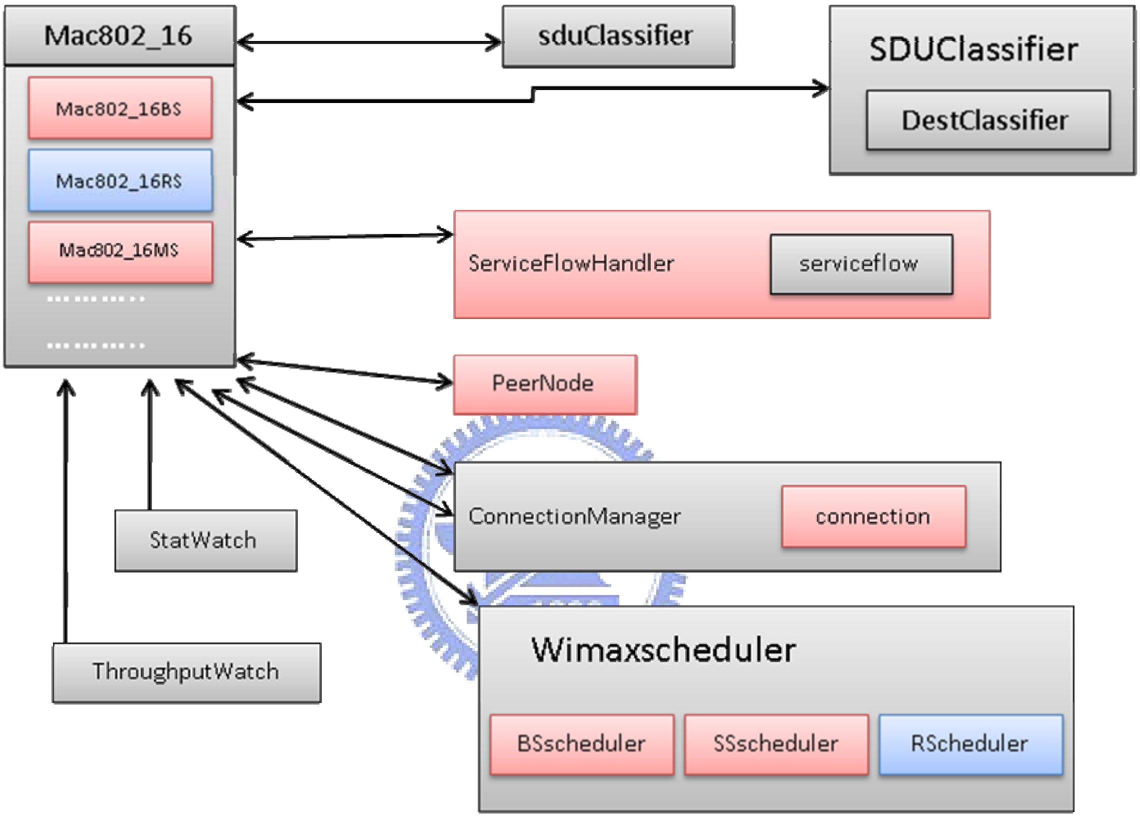


Figure3.9 Mac 802.16 class and 802.16j add-on diagram

- **MAC802_16**

  A class containing the common elements of the base station, and mobile station.

- **Ssuclassifier**

  Map each outgoing packet with the proper connection identifier (CID)

- **ServiceFlowHandler**

  Handle flow request/responses

- **Peernode**

Contain the peer's connection and status

- **WimaxScheduler**

  Create with an interface with MAC, for BS, RS, and SS
- **StatWatch , ThroughputWatch**

  Compute statistics for packet and traffic & Trigger events

3.6.1 Installation Steps

Before running simulation, I must correctly construct the simulation environments to do my wanted simulation. The overview of the sequence construction of the simulation is illustrated in Figure3.10.

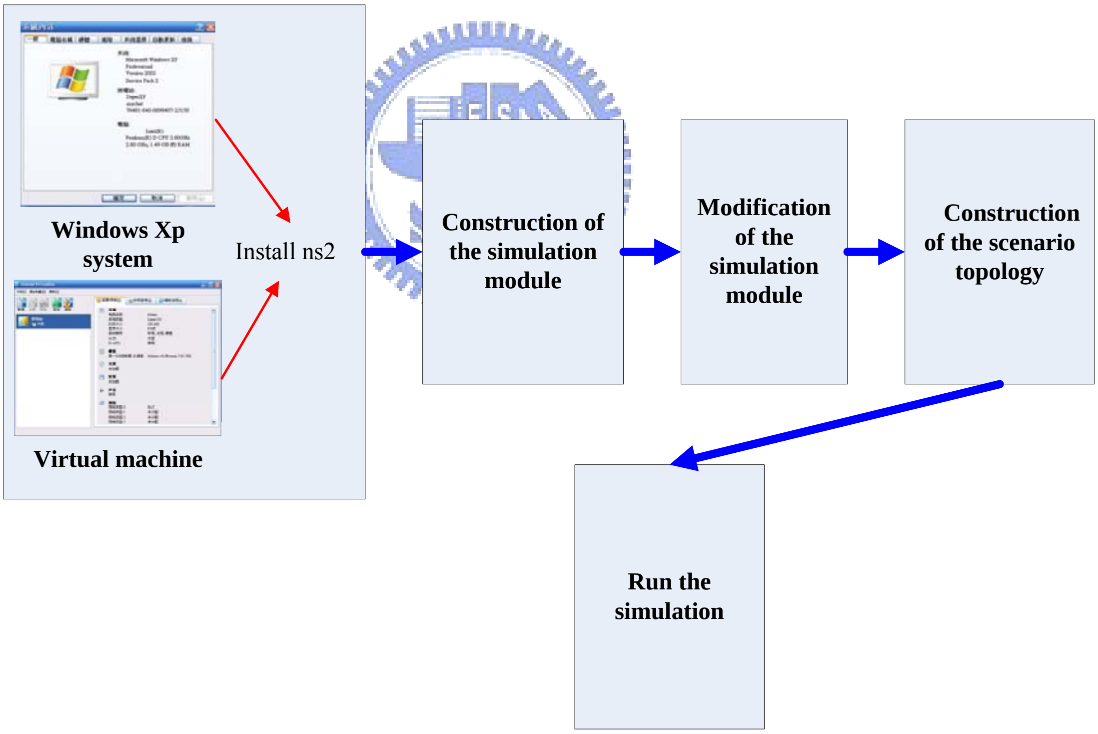


Figure3.10 The overview of the sequence construction of the simulation

The steps of the simulation including the construction of the tool environment are separate into five parts: the ns2 installation, construction of the simulation module, modification of the simulation module, construction of the scenario topology, and run the simulation.

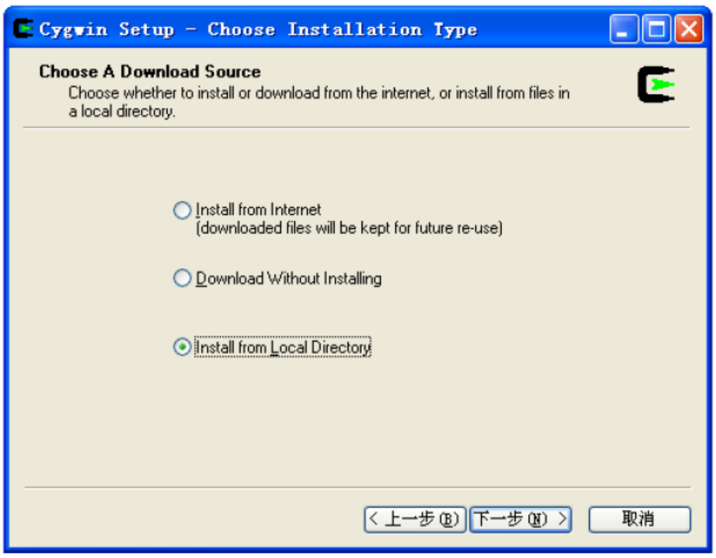
- The ns2 installation
  - Install ns2 in Windows XP system

1. Install cygwin

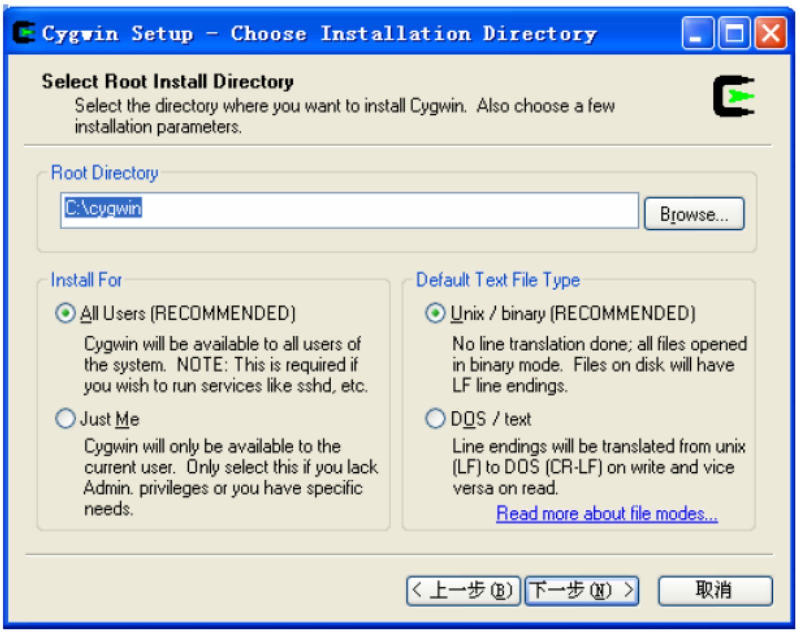
   1) Download cygwin steup.exe from website:www.cygwin.com.

   2) Click on “cygwin.exe”.

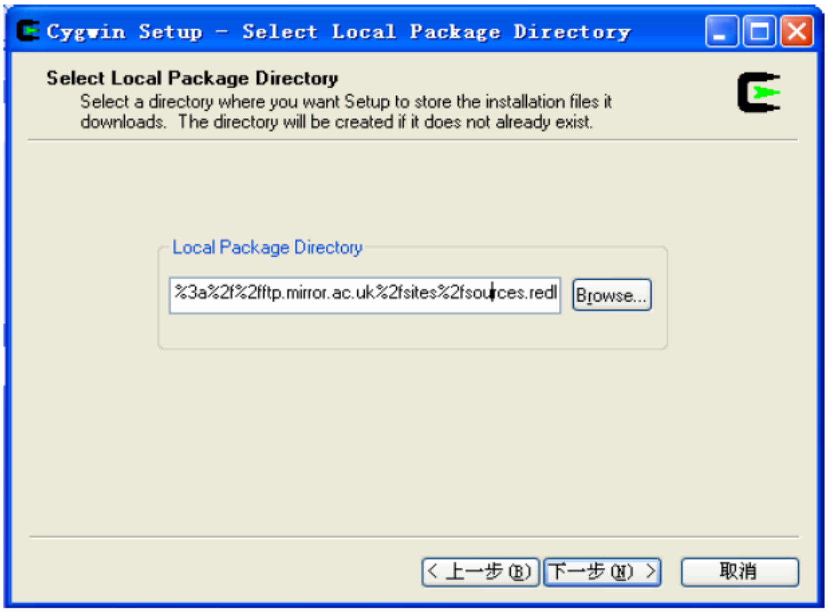
   3) Select “install local directory”



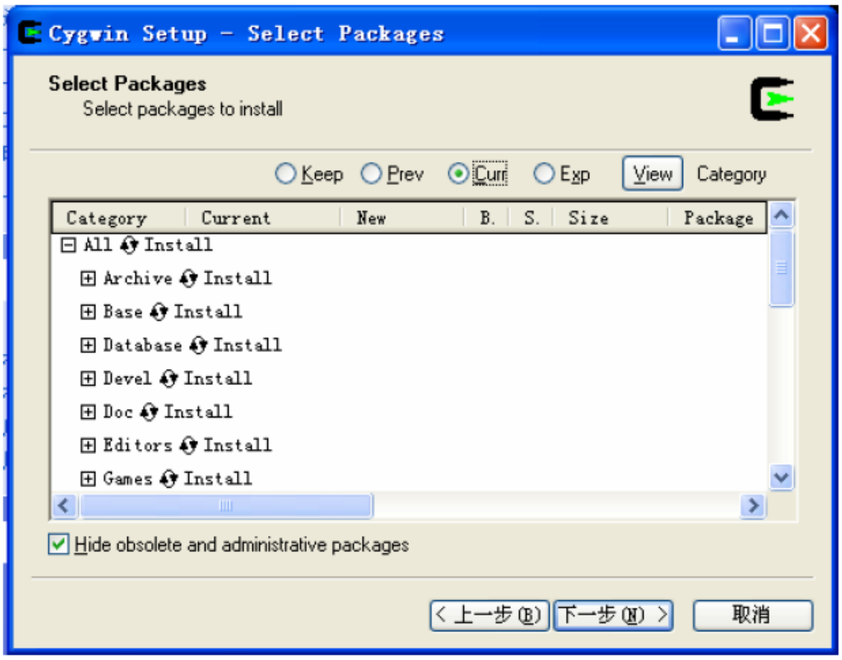
   4) Select browse for ”cygwin” file



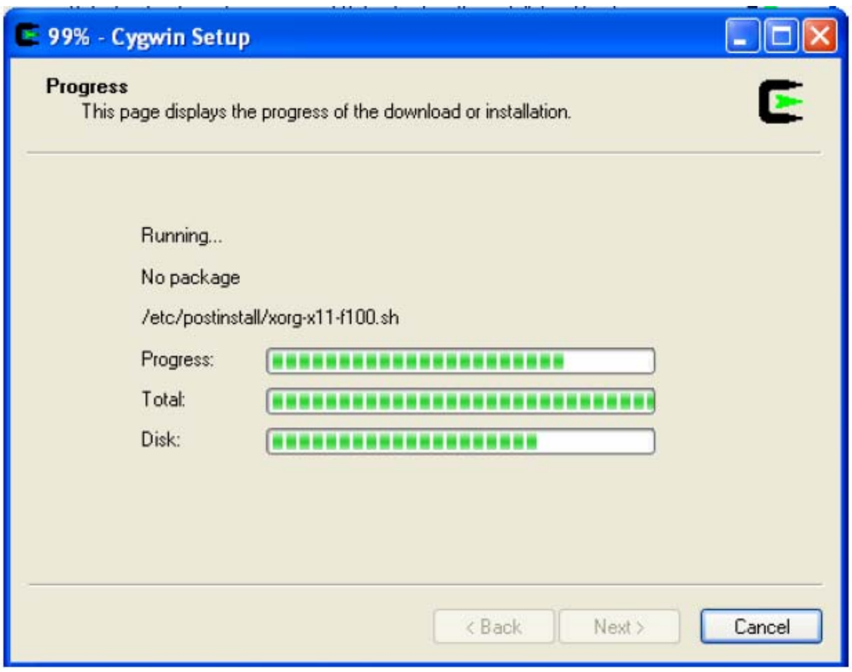
5) Install “C:\NS2\NS-2.31Installfiles\Cygwin files\ftp%3a%2f%2f%2fftp.mirror.ac.uk%2fsites%2fsources.redhat.com%2fftp%2fcygwin”



6) Select to install all



7) Installing



8) Finishing

installing"ftp%3a%2f%2fftp.is.co.za%2fmirrors%2fcygwin"

2. Install NS2

9) Copy ns-allinone-2.31.2.tar to directory c:/cygwin/usr/local

10) Unzip "ns-allinone-2.31.2.tar"

11) Click on desktop icon"cygwin"

12) Type “cd ..” to go to the upper folder(“cd” must be low case. And there is one space between”d” and “.”

13) Type “cd ..” again

14) “cd usr”, go to folder “usr”

15) “cd local”, go to folder “local”

16) Find the “install.exe ” file

17) Start to run the installation “./install”

18) Installing & Done

◆ Install ns2 in virtual machine

Because the operation interface is almost the same as the Windows XP system and I could have freedom to add many tools on the virtual machine unlike the limitation of Windows XP system that I could not add some tools freely, I prefer to use virtual machine to operate ns2 to run simulation for the reasons. The steps of ns2 installation are the same as them in Windows XP systems.

- Construction of the simulation module

After finishing the NS2 install, the simulation platform is done. And then, I could construct the simulation module such as WiMAX module or WiFi module, etc, based on someone’s objective. Here, I use the NIST WiMAX module as my simulation module. So, according the following listed steps, I could construct the WiMAX environment on the NS2 simulation platform:

1) Download the NIST WiMAX released module from the website

2) Unzip the folder of the NIST WiMAX module

3) Cope the patch file in the folder into the ns-2.31/ directory and install the patch by running "patch -p0 <patch-ns-2.31-041707" from the ns-allinone-2.31 directory.

4) Re-run "./configure ; make clean ; make" in the ns-2.31 directory.

5) Now WiMAX Scripts are ready to run.

- Modification of the simulation module

  In this part, it means both of the advancement and changing of the core module. Definitely, that is to add and modify the [*.cc,*.h] file. Based on my experience, this part is the most difficult and scaring for me and everyone because I spend much time to fine my needed data and trace data in one hand, and I must have much courage to face the breakdown of the platform in a blink of eye. So, in this part, it needs patient for everyone to implement and is separated into several step:

  1) Prepare modules (ie. a.h, a.cc).

  2) Modify ns-default.tcl file if the beginning setting of the simulation is needed to set.

  3) Compile afresh.

  4) Test the module.

- Construction of the scenario topology

  In this part, that is to use TCL (Tool Command Language) to script the simulation module. Definitely, it is to set the simulated network environment and parameter setting.

- Run the simulation

3.6.2 Throughput and Delay Measurement

The Figure3.11 shows the simulation flow using ns. When I have done the simulation and produce the output file such as out.nam and out.tr in Figure3.12, I can use some tools to show and analyze the result. About the part of result analysis, it includes the measurements of end-to-end delay and jitter and throughput and packet loss and uses method of the analysis of the traffic trace file. Results analysis has two methods. First method is not needed for user to modify the core module of the ns. Second method is needed for user to modify the core module of the ns instead. For the first method, it has two advantages:

- This method is simple and easy.
- Users don't modify the complicated core module of the ns2 because it is very time-consuming.

But it also has two disadvantages based on my experience and many users:

- If the amount of data is too much, it will results in the time of simulation increasing largely.
- If the amount of data is too much, it will results in the amount of traffic trace file too much and overload of the computers because the ram of the computer is not big enough.

For the second method, it has one advantage:

- It should modify the core module of the ns2 to add and change some files in order to record directly the testing parameters which is needed for user. While the simulation is done, the records have been recorded.

But using this method also has one the same disadvantage:

- It is very consuming for user to modify and trace the complicated core module of the ns2.

Here, I introduce the first method because I make use of the first method to analyze results.

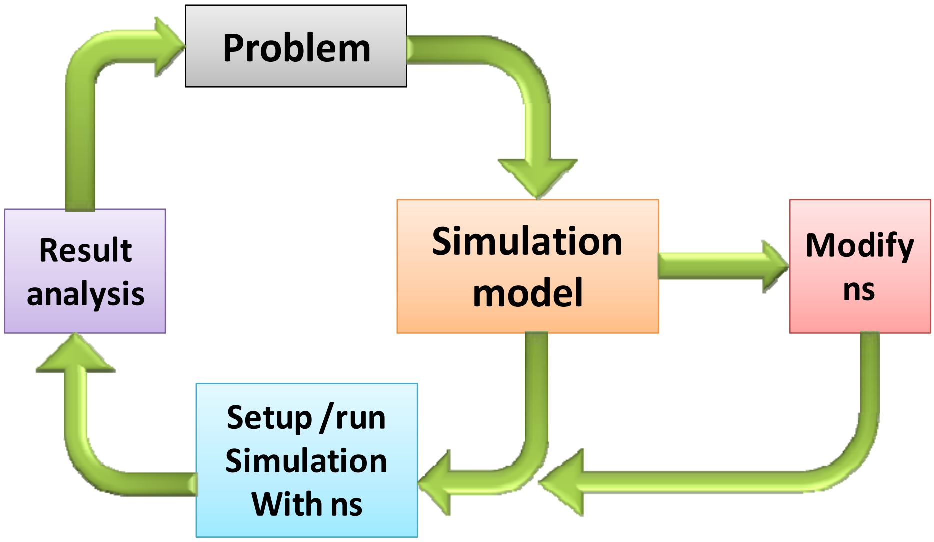


Figure3.11 The simulation flow using ns

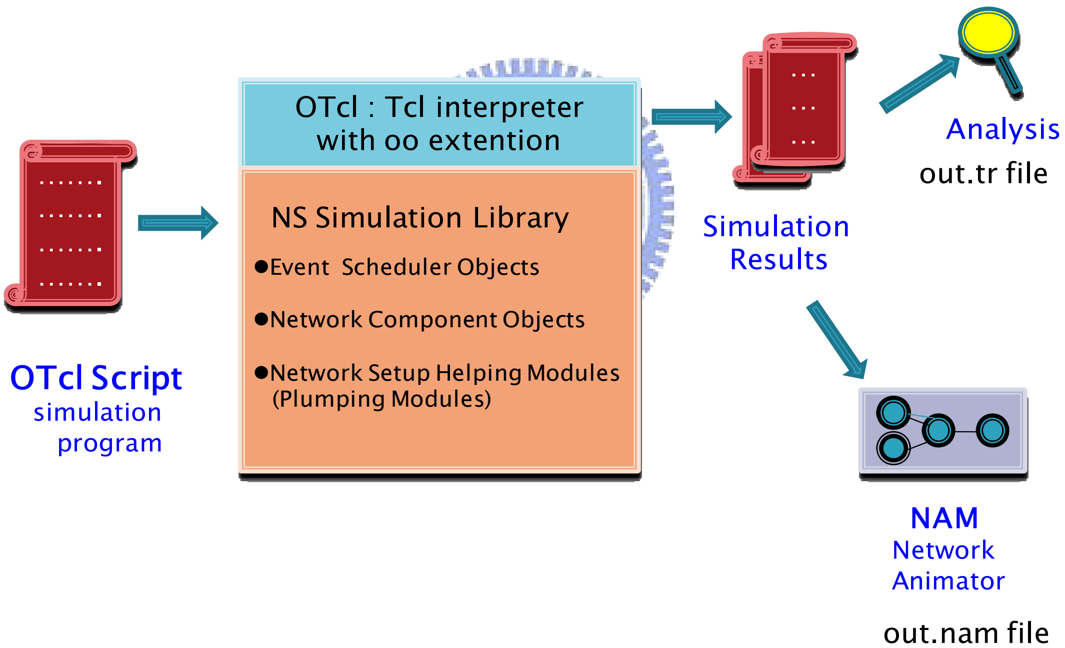


Figure3.12 User's view of ns[11]

After finishing the simulation, the platform will output two files which are out.tr and out.nam. Out.nam is so used to show the simulation process in visual form that users could understand the packets transmitted form the source node to the receiver node by seeing. Out.tr records all of the events of the process of the packets transmitted, so this file is very important for users to analyze system performance such as end-to-end delay, throughput. In Figure3.13, it shows the detail flow of analyzing system performance. So, first I introduce the trace raw data format in Figure and then take an example of my own in my platform. Finally, I talk about the .awk file that can analyze the trace raw data and calculate the different system performances.

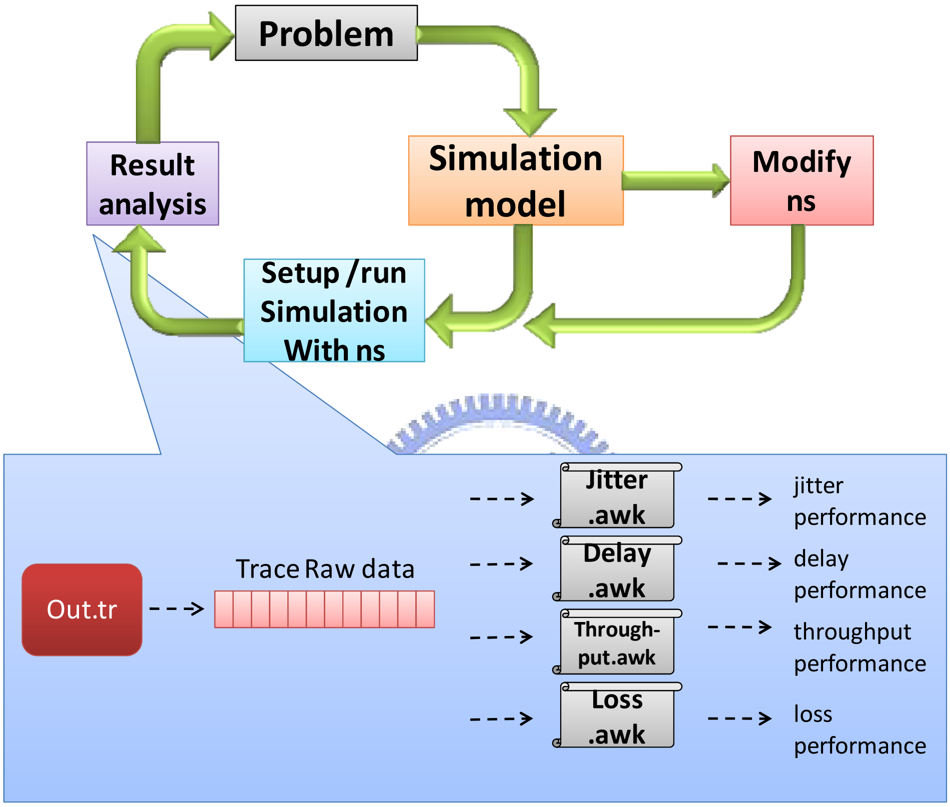


Figure3.13 The detail flow of analyzing system performance

The trace raw data format is illustrated in Figure. Each column represents different mean.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Event	Time	From node	To node	Pkt type	Pkt size	Flags	Fid	Src addr	Dst addr	Seq num	Pkd id

Figure3.14 The trace raw data format

- Column 1: The happening cause of the packet event. If the first column equals “r”, it represents the packet is received by some node. If the first column equals “d”, it represents the packet is dropped by some queue. If the first column equals “+”, it represents the packet enters some queue. If the first column equals “–”, it represents the packet enters some queue.

- Column 2: The time that the packet event happens.
- Column 3 & Column 4: The location that the event happens from some node to some node.
- Column 5: The type of the packet
- Column 6: The capacity of the packet
- Column 7: The flag mark of the packet
- Column 8: The stream which the packet belongs to.
- Column 9& Column 10: The source and destination node of the packet
- Column 11: The serial number of packets.
- Column 12: The id of the packet

Finally, I introduce the awk file to analyze the trace raw data and get the throughput and endto-end delay. Here, I don’t introduce the loss and jitter calculation because I don’t need them later. Awk is a program language and has many functions of general program languages. Because awk program language have some features: 1) it uses interpreter not compile first, 2) the variable is typeless, 3) it can use words to be associative array, so using awk program language to write program for users is time-conserving and compact. In Figure , taking an example in my simulation. The first data row that awk reads is “+ 20.185502 1 0 cbr 1520 ------- 1 1.0.10.0 0.0.0.0.8 0 46”, The second data row that awk reads is “- 20.185502 1 0 cbr 1520 ------- 1 1.0.10.0 0.0.0.0.8 0 46”. The third data row that awk reads is “r 20.186624 1 0 cbr 1520 ------- 1 1.0.10.0 0.0.0.0.8 0 46”.

```
+ 20.185502 1 0 cbr 1520 ------- 1 1.0.10.0 0.0.0.8 0 46
- 20.185502 1 0 cbr 1520 ------- 1 1.0.10.0 0.0.0.8 0 46
r 20.186624 1 0 cbr 1520 ------- 1 1.0.10.0 0.0.0.8 0 46
```

Figure3.15 The example of trace raw data format

In my simulation platform, the following is the awk file of end-to-end delay and throughput.

- Awk file for measuring End-to-end delay

```
BEGIN {
    highest_packet_id=0;
}
{

    if($12>highest_packet_id)
        highest_packet_id=$12;
    if(start_time[$12]==0)
        end_time[$12]=$2

    if($8==1&&$1!="d")
    {
        if($1=="r")
        {
            end_time[$12]=$2;
        }
        else
        {
            end_time[$12]=-1;
        }
    }
}
END{
    for($12=0;$12<=highest_packet_id;$12++)
    {

        packet_duration=end_time[$12+1]-end_time[$12];
        printf("%f\n",packet_duration);

    }
}
```

Figure3.16 Awk file for measuring End-to-end delay

In Figure3.16, Each $(number) means the data in the number column. The "BEGIN" part means the awk reads the trace raw data row by row and records them. The “END” means the program begins to calculate the end-to-end delay according to the program writing in the “END” part.

- Awk file for measuring throughput

```
BEGIN{
    init=0;
    i=0;
}
{

    packet_size_number=$6;

    if( $1=="r"&& $4==0 ) {
        packet_size[i+1]=packet_size[i]+packet_size_number;

        if(init==0){
                start_time=$2;
                init=1;
        }

        end_time[i]=$2;
        i=i+1;
    }

}
END{
            printf("%f\t%f\n",end_time[0],0);

            for(j=1;j<i;j++){

                th=packet_size[j]/(end_time[j]-start_time)*8/1000;

                printf("%f\t%f\n",end_time[j],th);

            }
            printf("%f\t%f\n",end_time[j-1],0);
}
```

Figure3.17 Awk file for measuring throughput

In Figure3.17, the awk file for measuring throughput belongs to the average throughput.

Chapter 4 The Issue of Multi-hop relays

Multi-hop relays (MR) have been proposed to enhance cell coverage and user throughput to traditional cellular systems as well with appropriate deployment of RSs [8].

4.1 Deployment in IEEE 802.16j Multi-hop Relay Network

According the previous argument, in the Manhattan-like environment, the shadow fading due to the managed street layout can be adopted to lower the multiple access interference. In the traditional cellular deployment, shadow fading in the environment of the time is regarded as a negative effect.

So, RS is deployed to avoid the effect of the shadow fading as illustrated in Figure4.1. Firstly, RS is deployed to have LOS (line of sight) with the signal source. Secondly, shadow fading is adopted to interfering signal. Take an example in Figure4.2, RS_1 has LOS with its subordinate station MS_1. At the same time, RS_1 has NLOS with MS_2. Therefore, the radio link $RS_1 \leftrightarrow MS_1$ can reuse the radio resource allocated the radio link $RS_2 \leftrightarrow MS_2$, and the interference from RS_1 to MS_2 is avoided largely by the shadow fading.

According the anterior argument, the RS deployment can be summarized in two stages:

1. Deploy RS at the location where it can have LOS to its signal source and to its transmission destination. If LOS is not always guaranteed, select the location where it can have highest LOS probability.
2. After finishing initial stage, adjust the location of each RS to have NLOS to

its interference sources or its interfering targets.

The first stage of deployment aims to improve the received strength of the desired signal because avoiding the shadow fading properly, and the second stage is mainly used to reduce the interference largely. Therefore, the received signal quality can be consequently and largely improved, and the shadow fading can greatly isolate the interfering signals transmitted from the interference sources. So, following the aforementioned and the anterior RS deployment method, within the area surrounded by objects such as building, hill, etc, the radio resources can be reused by different relay stations without significantly interfering with each other.

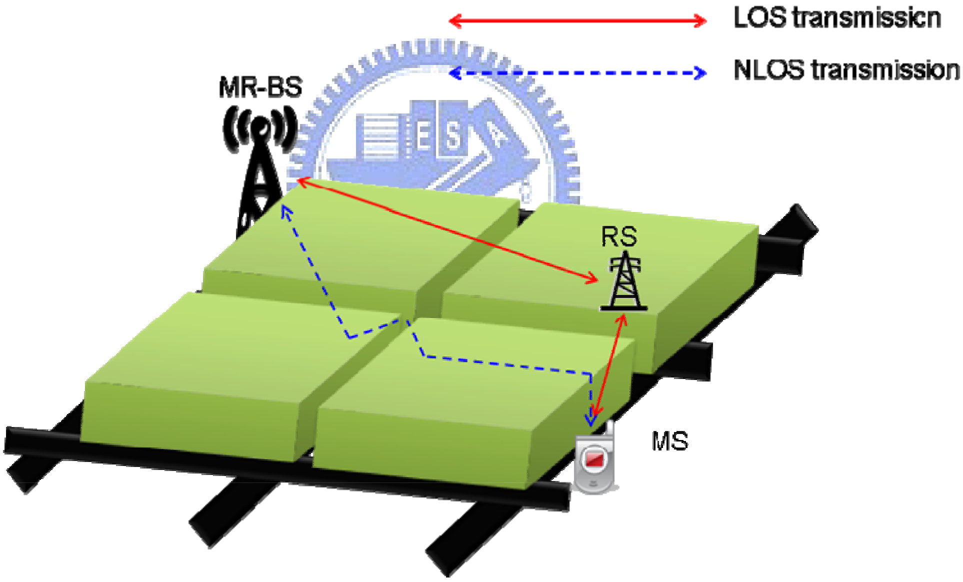


Figure4.1 RS to have LOS with signal source[8]

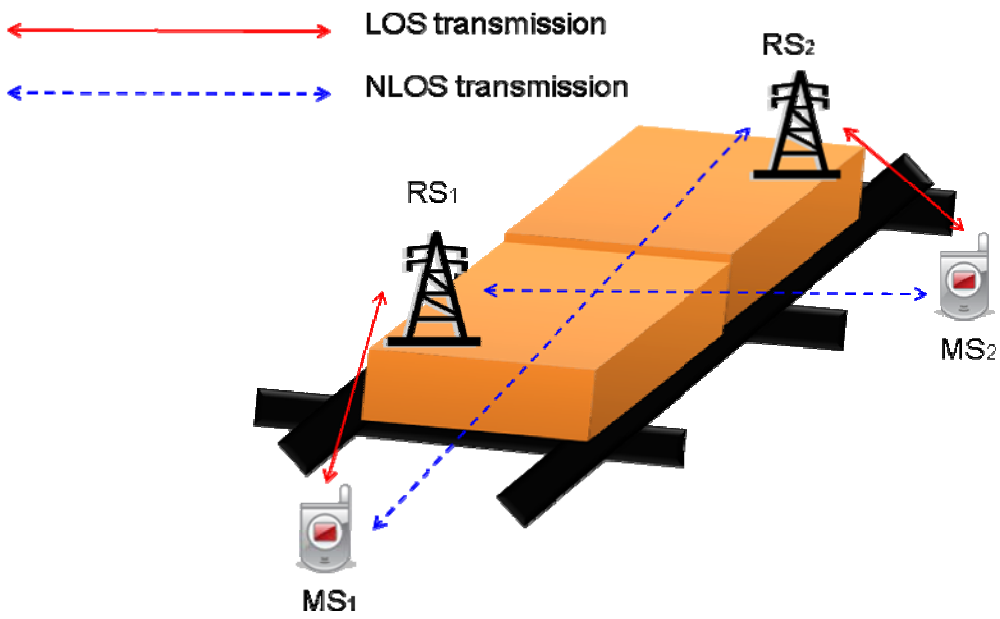


Figure4.2 RS to have NLOS with interference source[8]

But if we want to deploy RS to the location based on the above stages, is it possible that everything in every aspect is very well. Because of the first stage, it is not enough to only consider RS have the LOS condition to MS, it must also consider the modulation and code rate of MS. Because the modulation and coding the WiMAX systems uses affects the system throughput mainly. The basic idea is quite simple: Transmit as high a data rate as possible when the channel is good, and transmit at a lower rate when the channel is poor, in order to avoid excessive dropped packets. Lower data rates are achieved by using a small constellation, such as QPSK, and low-rate error-correcting codes. On the other hand, the higher data rates are achieved with large constellations, such as 64QAM, and less robust error correcting codes. A block diagram of an adaptive modulation and coding scheme is illustrated in Figure4.3. The objective of the transmitter is to transmit data from its queue as quickly as possible, subject to the data being demodulated and decoded reliably at the receiver.

Using common WiMAX burst profiles, it is possible to achieve a large range of spectral efficiencies and allows the throughput to increase as the CINR increases following the trend promised by Shannon's formula $C = \log_2(1 + CINR)$. In this case, the lowest offered data rate of the AMC is QPSK and rate 1/2 turbo codes; the highest data-rate burst profile is with 64 QAM and rate 3/4 turbo codes. Because the reached throughput is normalized by the bandwidth, 64QAM with rate 3/4 codes achieves a maximum throughput and QPSK with rate 1/2 codes achieves a best-case throughput.

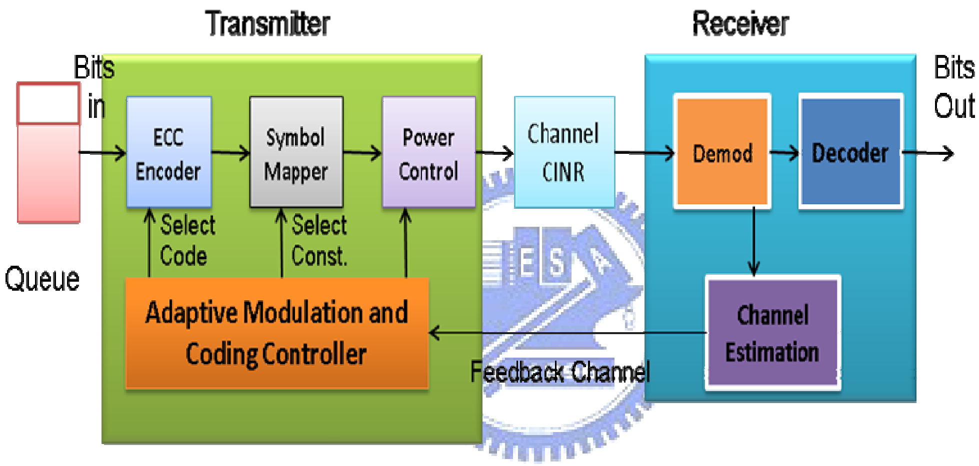


Figure4.3 Adaptive modulation and coding scheme[5]

The throughput in some cases may be affected by AMC largely and it results in the low quality of communication performance of users. Maybe RS is deployed based on the second stage that RS has NLOS condition to MS, so that it does not use the better AMC such as 64QAM and rate 3/4 turbo codes and uses the 16QAM and rate 3/4 turbo codes instead. So, RS deployment should focus on the AMC to enhance the system throughput.

4.1.1 Basis of RS deployment

If the locations where we deploy RS are based to the received signal from AWGN channel, I can allocate RS to the better location in the environment where uses the better burst profile. So, the first step is to get the CINR value of different bit error rate and burst profiles.

The probability of error at the detector for phase modulation in an AWGN channel may be found in any textbook that treats digital communications [13]. Since binary phase modulation is identical to binary PAM, the probability of error is

$$P_2 = Q\left(\sqrt{\frac{2E_b}{N_O}}\right) \qquad (1)$$

where E_b is the energy bit. Four-phase modulation may be regarded as two binary phase-modulation systems on orthogonal carriers. Consequently, the probability of a bit error is identical to that for binary phase modulation. For M>4, there is no simple closed-form expression for the probability of a symbol error. A good approximation for P_M is

$$\begin{aligned} P_M &\approx 2Q\left(\sqrt{\frac{2E_s}{N_O}}\sin\frac{\pi}{M}\right) \\ &\approx 2Q\left(\sqrt{\frac{2kE_b}{N_O}}\sin\frac{\pi}{M}\right) \qquad (2) \end{aligned}$$

where $k = \log_2 M$ bits per symbol. The equivalent probability of bit error for M-ary modulation is also difficult to derive due to the dependence of the mapping of k-bit symbols into the corresponding signal phases. When a Gray code is used in the mapping, two k-bit symbols corresponding to adjacent signal phases differ in only a single bit. Because the most probable errors due to noise result in the erroneous selection of an adjacent phase to the true phase, most k-bit symbol errors contain a single bit error. So, the equivalent probability of bit error for M-ary phase modulation is approximated as

$$P_b \approx \frac{1}{k} P_M \qquad (3)$$

Therefore, perform a Monte Carlo simulation of QPSK communication system that models the detector as the one that computes the correlation metrics. The model for the system to be simulated is illustrated in Figure4.4.

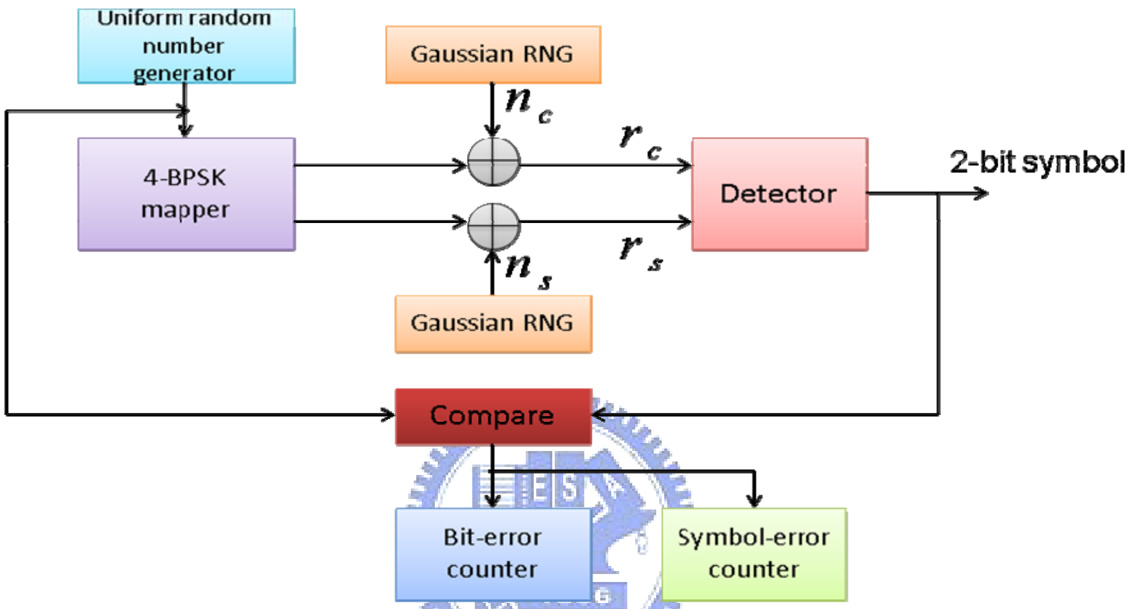


Figure4.4 Block diagram of an M=4 PSK system for a Monte Carlo simulation[13]

I start simulation for computing performance of a QPSK system by generating a sequence of quaternary symbols that are mapped into the corresponding four-phase signal points. I make use of a random number generator that generates a uniform number in the range (0, 1). This range is divided into four equal intervals, (0, 0.25), (0.25, 0.5), (0.5, 0.75), and (0.75, 1.0), where the subintervals correspond to the pairs of information bits 00, 01, 11, and 10. The additive noise components n_c and n_s are statistically independent, zero-mean Gaussian random variables with variance σ^2. According to the above simulation preparation, I could get the simulation performance shown in Figure4.5.

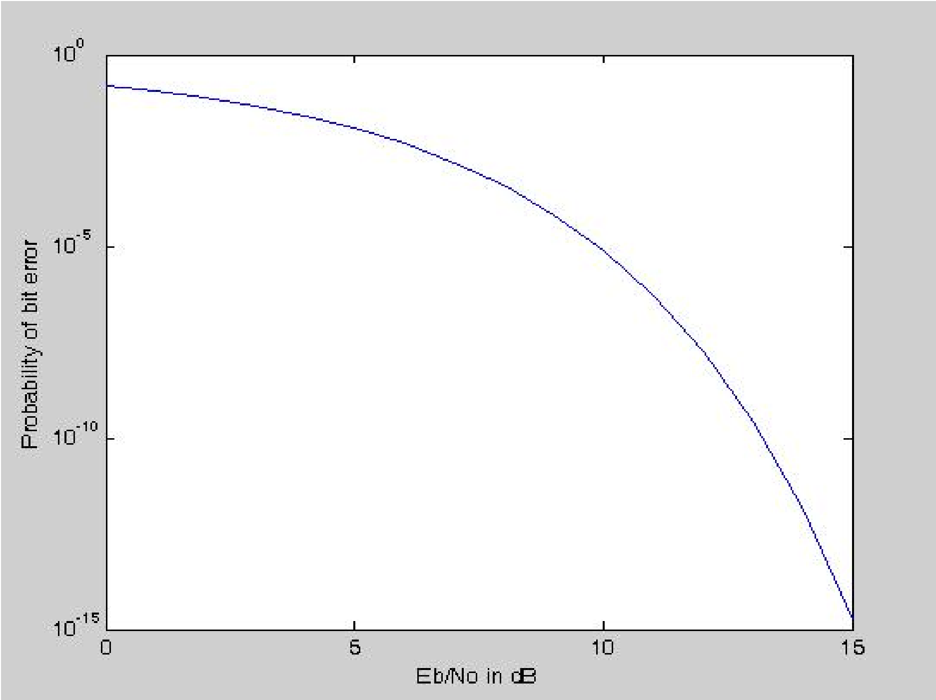


Figure4.5 Performance of a 4-phase PSK system from the Monte Carlo simulation [13]

As for the performance of QAM systems that employ rectangular signal constellation, rectangular signal constellations in which M= 2^k, where k is even, the QAM signal constellation is equivalent to two PAM signals on quadrature carriers, each having $\sqrt{M} = 2^{\frac{k}{2}}$. Because the coherent detection greatly separates the signals in the phase quadrature components, the probability of error for QAM is easily determined from the probability of error for PAM. The probability of a correct decision for the M-ary QAM system is

$$P_c = (1 - P_{\sqrt{M}})^2 \qquad (4)$$

where $P_{\sqrt{M}}$ is the error probability of a $\sqrt{M}$ -ary PAM with one-half the average power. By modifying the error probability for M-ary PAM, we get

$$P_{\sqrt{M}} = 2(1 - \tfrac{1}{\sqrt{M}})Q(\sqrt{\tfrac{3}{M-1}\tfrac{E_{av}}{N_O}}) \qquad (5)$$

where $\frac{E_{av}}{N_O}$ is the average SNR per symbol. The error probability of a symbol for the

M-ary QAM is

$$P_M = 1-(1-P_{\sqrt{M}})^2 \qquad (6)$$

When k is even, the result is exact. When k is odd, no equivalent $\sqrt{M}$ -ary PAM system. If we employ the optimum detector which bases its decisions on the optimum distance metrics, it is straightforward that the symbol-error probability is tightly upper-bounded as

$$P_M \le [1-2Q(\sqrt{\tfrac{3E_{av}}{(M-1)N_O}})]^2$$

$$\le 4Q(\sqrt{\tfrac{3kE_{av}}{(M-1)N_O}}) \qquad (7)$$

Where $\frac{E_{av}}{N_O}$ is the average SNR per bit for $k \ge 1$.

So, we perform a Monte Carlo simulation of an M=16-QAM communication system using a rectangular signal constellation. See the Figure4.6. We use the uniform random generator (RNG) to generate the sequence of information symbols corresponding to the 16 possible 4-bit combinations of b_1, b_2, b_3, b_4. The information symbols are mapped into the corresponding signal points which have the coordinates $[A_{mc}, A_{ms}]$. For the noise components $[n_c, n_s]$, they are generated by two Gaussian RNG. As a result, the received signal-plus-noise is

$$\gamma = [A_{mc} + n_c, A_{ms} + n_s] \quad (8)$$

The functional block of the error counter counts the symbol errors in the detected sequence. So, for the transmission of N=10000 symbols at different value of the SNR parameter $\frac{E_b}{N_O}$, where $E_b = \frac{E_s}{4}$ is the energy bit, the results of the Monte Carlo simulation is illustrated in Figure4.7.

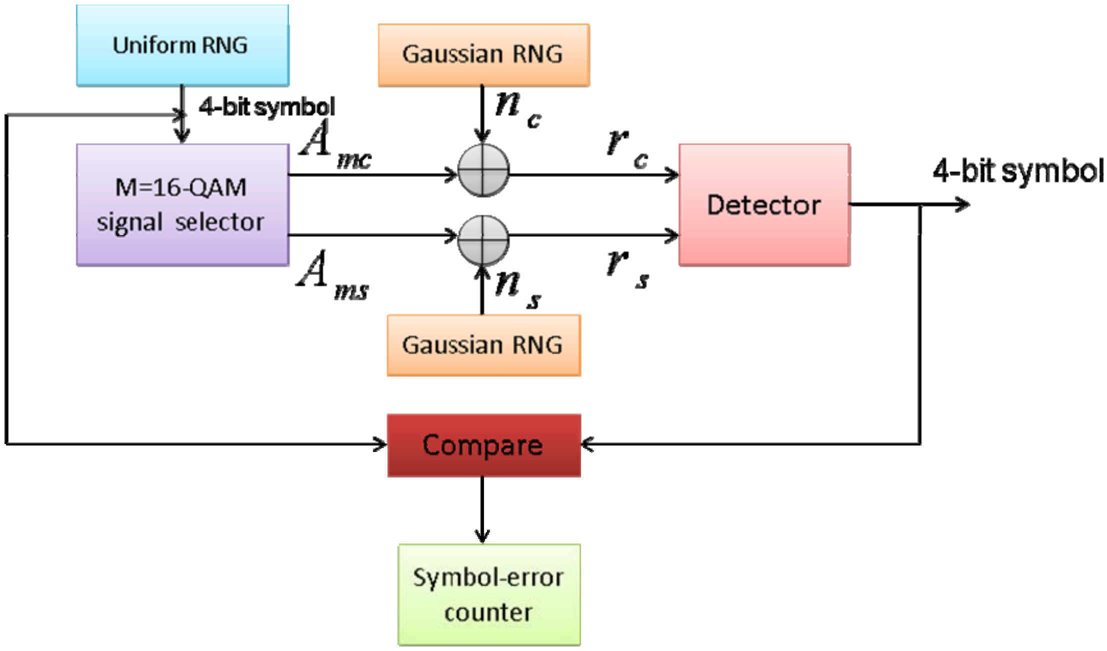


Figure4.6 Block diagram of an M=16-QAM system for a Monte Carlo simulation [13]

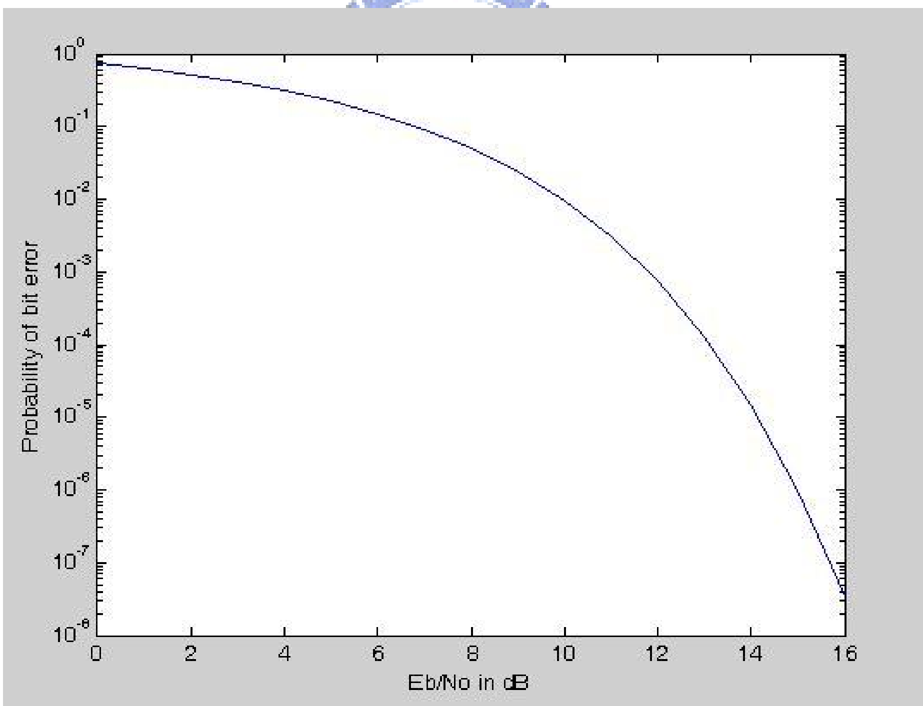


Figure4.7 Performance of M=16-QAM system from the Monte Carlo simulation

We perform a Monte Carlo simulation of an M=64-QAM communication system using a rectangular signal constellation. See the Figure4.8. For the transmission of N=10000 symbols at different value of the SNR parameter $\frac{E_b}{N_O}$, where $E_b = \frac{E_s}{4}$ is the energy bit, the results of the Monte Carlo simulation is illustrated in Figure4.9.

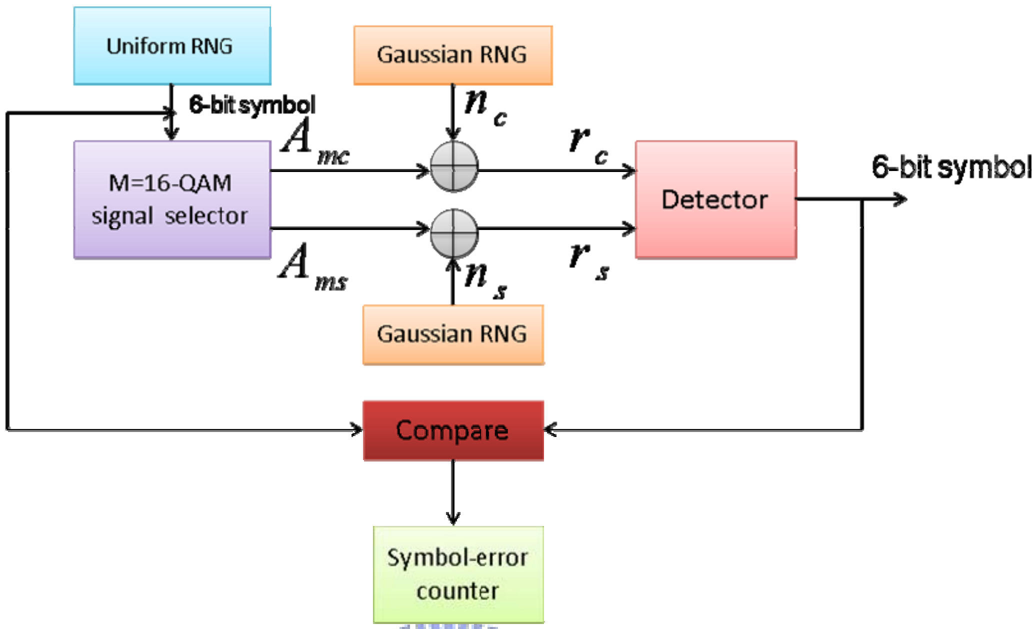


Figure4.8 Block diagram of an M=64-QAM system for a Monte Carlo simulation[13]

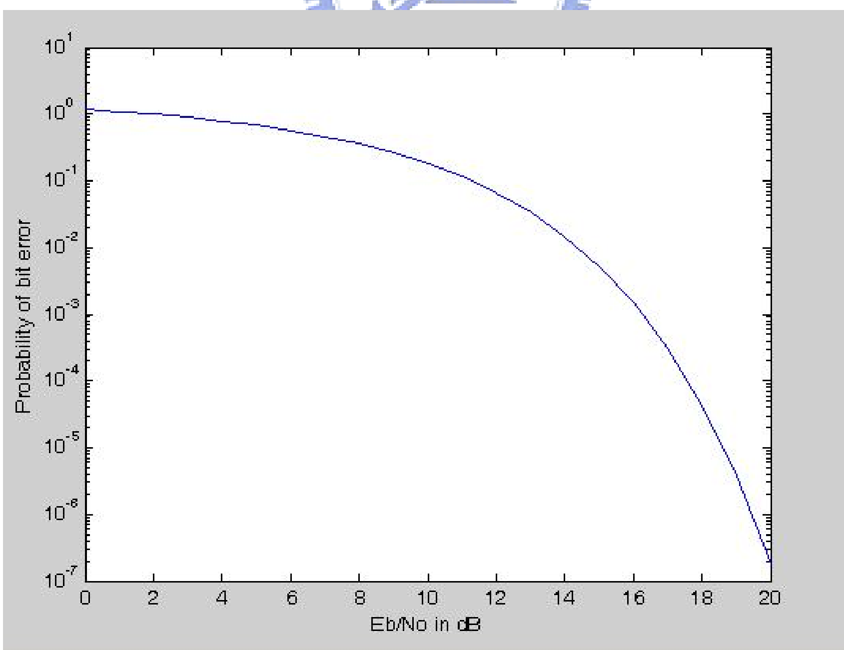


Figure4.9 Performance of M=64-QAM system from the Monte Carlo simulation

Therefore, following the above results of AWGN channel, I can compute the CINR in different bit error rate (BER) and code rate of QPSK, 16QAM, and64QAM.

And I get the range of CINR between different modulation and code rate in Figure4.10.

	BER 1e-5 Code rate 1/2	BER 1e-6 Code rate 1/2	BER 1e-5 Code rate 2/3	BER 1e-6 Code rate 2/3	BER 1e-5 Code rate 3/4	BER 1e-6 Code rate 3/4
QPSK	9.794	10.795	9.878	10.865	9.906	10.89
16QAM	13.764	14.926	13.799	14.962	13.81	14.975
64QAM	18.594	19.53	18.718	19.636	18.76	19.681

Figure4.10 CINR rahge of different modulation and code rate

After the calculation of CINR, I can allocate RS to different location according to different radio propagation model which are used to predict the received signal power of each packet. And most importeant is that I can use the radio propagation model to get the distance between two stations and the location wherer I shuold allocate any station. At the physical layer of each wireless node, there is a receiving threshold. When a packet is received, if its signal power is below the receiving threshold, it is marked as error and dropped by the MAC layer. There are three propagation model in ns In my simulation, which are the free space model, two-ray ground reflection model and the shadowing model. Here, I use the two-ray ground reflection model because a single line-of sight path between two mobile nodes is seldom the means of propagation. In the following , I introduce the free space model, and two-ray ground reflection model because two-ray ground reflection model also contains the free space model in some cases [12].

- Free space model

The free space propagation model assumes the ideal propagation condition that there is only one line-of-sight path between the transmitter and receiver.

H.T.Friis presented the following equation to calculate the received signal power in free space at distance d from the transmitter[12].

$$\Pr(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \qquad (9)$$

P_t is the transmitted signal power. G_t and G_r are the transmitter and the receiver respectivelly. In ns simulation, it is common to set $G_t = 1$ and $G_r = 1$. L is the system loss and λ is the wavelength.The original equation in [15] assumes $L = 1$. The free space model is used to represent the communication range as a circle around the transmitter. If the receiver is within the circle, packets will be received successfully. But the receiver is outside the circle, packets will be dropped.

- Two-ray ground reflection model

Actually, we use the type of the propagation model. Two-ray ground reflection model consists of the free space model in some cases, and considers both the direct path and a ground reflection path. The received power at distance d is predicted by

$$\Pr(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L} \qquad (10)$$

The h_r and h_t individually represent the heights of transmit and receive antennas. The above received power equation show the faster power loss than the equation of the free space model as distance increase. Because of the bad results for a shorter distance due to the oscillation caused by the constructive and destructive combination of two rays, the free space model is used when d is small. Hence, a cross-over distance d_c is calculated is this model.When $d < d_c$, the equation of free space model is used. When $d > d_c$, the equation of two-ray ground reflection model is used. Because two equations of different model have the same result at the cross-over distanve, d_c may be calculated as

$$d_c = \frac{(4\pi h_t h_r)}{\lambda} \qquad (11)$$

So, accoring to the two-ray ground reflection equation and CINR, we can allocate different d which is shown in Figure4.11 between RS and MS or RS and MR-BS . Make the link between RS ans MS and between RS and MR-BS have the better modulation and code rate.

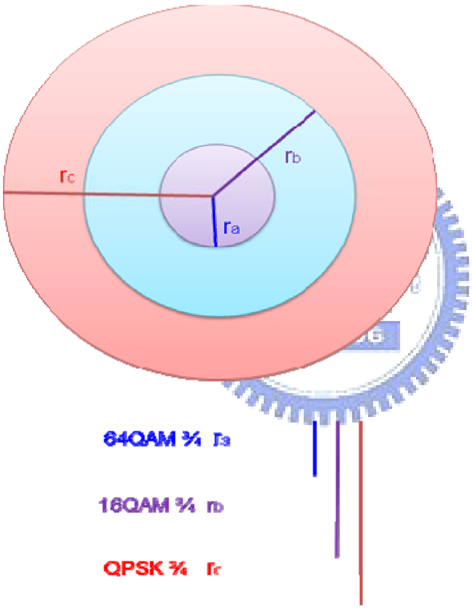


Figure4.11 The circle scenario of defferent modulation and code rate using two-ray groung reflectoon model

4.2 Transmission route selection

After we deploy RS to the better location where uses the better burst profile according to the aforementioned propagation model, the following question is to select the best transmission route for MS while the subscriber density is not very low.

Multi-hop Relay network architecture is considered to support MSs with MR-BS by using the multi-hop relaying technique with the aid of relay stations [16]. The main function of an RS is basically to support data transmission between RS and MS, between RS and MR-BS to complete the original communications between MR-BS and MS via the multi-hop relay path [17]. There, routing is very crucial and challenging in ad hoc networks. Routing in cellular multi-hop network, is likely to be much more manageable due to the presence of the central node, base station [18]. Routing (relaying node selection) is a still non-trivial issue in cellular multi-hop networks since there are often many candidate relaying nodes for a node that require relaying assistance and not choosing the optimal relaying node can have the potential impacts on the overall performance improvements. Therefore, a MS in the Multi-hop Relay network selecting which RS to enable data transmission among many transmission routes is very important to achieve the maximized network throughput, a relay path from MR-BS to MS or vice versa should be efficiently selected [19].

In recent years, routing in the context of MCNs (multi-hop cellular net-works) has become a research issue, and a few algorithms have been proposed so far, e.g., location-based routing [20], path-loss-based routing [21], transmission-power-routing [22], and congestion-based routing [23]. For Location-based routing, it has been continuous enhanced to optimistic algorithms, such as Shortest Total Distance (STD) Selection, Least Longest Hop Selection, and Shortest Relaying Hop Distance (SRD) Selection [21]. For path-loss-based routing, it contains Minimum Total Pathloss (MTP) selection, Least Maximum Pathloss (LMP) Selection (used in [24]), Minimum Relaying Hop Pathloss (MRP) Selection. Generally, radio resource, hop distance, latency, and delay jitter, can be used to select relay path for multi-hop relay networks [25]. A metric is defined in [26], efficiency system spectral efficiency normalized by the downlink/uplink (UL/DL) ratio of a TDD system acts as a system-wise performance parameter. But the metric lacks of the granularity of the multi-hop path and cannot be a good evaluation for relay path selection.

A metric is proposed in [27], Effective Radio Resource Index (ERRI) is to stand for the cost a link. ERRI is a normalized and defined measurement in terms of the number of OFDMA slots needed to send 30 bytes in a Sub-Carrier Utilization Index (SCUI) defined as the number of 64-sub-carriers used to transmit an OFDMA slot of user data [28]. And the cost function proposed in [27], the path cost between MR-BS and MS is defined as the summation of the products of ERRIs and weights of all links of the path. The less the cost is, the better path is. But the weights of all links are not defined definitely. It is not well to set the weight of different leap all the same. Instead, the cost function is needed to consider some aspects about the weight. In the following, firstly, I introduce ERRI clearly in order to use ERRI to create the new algorithm. Secondly, we create two new weighted ERRI algorithm and weighted CINR algorithm to focus on the different weight of different leap.

4.2.1 Effective Radio Resource Index (ERRI) Introduction

In MR networks, radio resource is one of the factors to be serious taken into account in relay path selection. So the ERRI is elaborately designed. An OFDMA frame proposed in [28] may include multiple zones, such as PUSC (partial usage of sub-channels), FUSC (full usage of sub-channels), PUSC with all sub-channels, optional FUSC, AMC (adaptive modulation and coding), TUSC1 (title usage of subcarriers 1), and TUSC2 (title usage of subcarriers 2). Each zone is defined by the sub-channel permutation used which is a method of mapping physical subcarriers to logical subchannels. The relationships between the subcarrier utilization in a specific OFDMA zone, the OFDMA slot, the OFDMA symbol, and FFT size is shown in

Table4.1 And the OFDMA Zones of 1 to 9 are individually for DL FUSC, DL optional FUSC, DL TUSC2, UL optional FUSC, DL TUSC2, UL optional PUSC, AMC 2×3, AMC 1×6, DL PUSC, DL TUSC1, and UL PUSC. In Table, each column is a two-couple with the format (N_{slot}, N_{symbol}). N_{slot} and N_{symbol} represents the numbers of slots and OFDMA symbols related to the specific FFT size under a specific OFDMA zone. Specially, the value of $\frac{N_{slot}}{N_{symbol}}$ is very important to indicate the number of slots required for transmitting an OFDMA symbol. For instance, 16 slots are required for transmitting an OFDMA symbol if the FFT size is 1024 in the DL FUSC zone.

OFDMA ZONE	FFT Size			
	2048	1024	512	128
1	(32,1)	(16,1)	(8,1)	(2,1)
2	(32,1)	(16,1)	(8,1)	(2,1)
3	(96,3)	(48,3)	(24,3)	(6,3)
4	(96,3)	(48,3)	(24,3)	(6,3)
5	(96,3)	(48,3)	(24,3)	(6,3)
6	(192,6)	(96,6)	(48,6)	(12,6)
7	(60,2)	(30,2)	(15,2)	(3,2)
8	(70,3)	(35,3)	(17,3)	(4,3)
9	(70.3)	(35,3)	(17,3)	(4,3)

Table4.1 Relationships between the sub-carrier utilization in a specific OFDMA zone [27]

A sub-carrier utilization index is based on Table4.1 and defined as the number of 64-sub-carriers used to transmit an OFDMA zone of user data. Calculate the value of SCUI of each OFDMA zone and list in Table4.2. The value of sub-carrier utilization index (SCUI) in each field is dependent on both of the sub-carrier allocation in the OFDMA zone and the FFT size. In Table4.2, 1 to 9 of the OFDMA Zones represent DL FUSC, DL optional FUSC, DL TUSC2, UL optional PUSC, AMC2×3, AMC1×6, DL PUSC, DL TUSC1, and UL PUSC. Definitely, the Table4.2 is converted according to the Table4.1. For example, in Table4.2, 30 slots are required to transmitting an OFDMA symbol if the FFT size is 1024 in the DL PUSC zone. In Table, the same column of the same field is $\frac{16}{15}=\frac{2}{30}\times\frac{16}{1}$ that has the meaning of normalization based on different FFT size.

OFDMA ZONE	FFT Size			
	2048	1024	512	128
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	16/15	16/15	16/15	4/3
8	48/35	48/35	24/17	3/2
9	48/35	48/35	24/17	3/2

Table4.2 SCIs of possible OFDMA zones [27]

According to the SCUIs, effective radio resource index is defined to represent the productive degree of radio resource of a link and is normalized by the bandwidth unit for the transmitting a fixed amount of data using 64-QAM CC 5/6 with repetition 1.So, that is, ERRI points the numbers of OFDMA slots required to transmit 30 bytes.

Take 64QAM 5/6 for example and the figure is illustrated in Figure4.12.

30(subchannels) x 16(subcarriers) x6 (bit)x(5/6)=2400 bits

2400/(30x8)= 30(byte/symbol)

10x3=30(byte/slot)

So, using burst profile, 64QAM 5/6 to transmit data of 30 bytes needs 30 OFDMA slots.

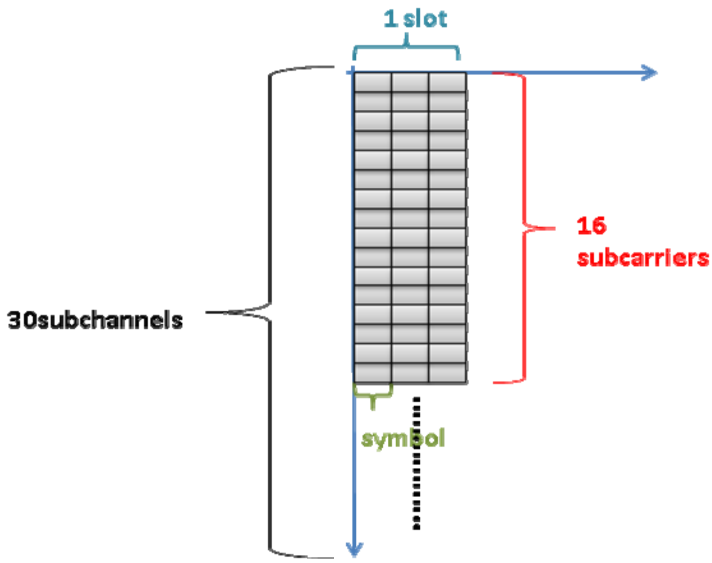


Figure4.12 example of OFDMA slots to subchannels and symbols

The Table4.3 for ERRIs related to various FFT sizes for OFDMA burst profiles is listed.

Burst profiles	Bytes per OFDMA slot	ERRI Value(slot)
QPSK,CC/BTC/CTC½,6	1	30
QPSK,CC/BTC/CTC½,4	3/2	20
QPSK,CC/BTC/CTC½,2	3	10
QPSK,CC/BTC/CTC½,1	6	5
QPSK,CC/BTC/CTC¾,1	9	10/3
16-QAM,CC/CTC½,1	12	5/2
16-QAM,BTC½,1	16	15/8
16-QAM,CC/CTC¾,1	18	5/3
16-QAM,BTC¾ ,1	20	3/2
64-QAM,CC/CTC 2/3,1	24	5/4
64-QAM,BTC¾,1	25	6/5
64-QAM,CC/CTC¾,1	27	10/9
64-QAM,CC 5/6,1	30	1

Table4.3 ERRIs of different types of OFDMA burst profiles [27]

4.2.2 New Proposed Algorithm of Transmission Route Selection

In the multi-hop relay networks, it exists one MR-BS and numerous MSs in the environment. Whether in transparent or nontransparent relay system, an MS of user data could be able to transmit data to MR-BS or BS, or via a number of RS and vice versa. But there are many paths that an MS want to choose to transmit data, it must make a rule to let MS to do path selection. Therefore, firstly, we will define variables used later.

- N_{MS} represents the total numbers of MS, and MS_i means the i th MS , i = 1,2,…. N_{MS}.
- MS_i has multiform diverse transmission routes between the MR-BS and itself. The various routes of MS_i are denoted as r_i^m .
- N_{P_i} represents the total numbers of diverse route between MR-BS and MS_i. The variable m =1, 2,….. N_{P_i} .
- h_i^m is the hop numbers in the m diverse path of MS_i. k =1,2,3…. h_i^m.

In Figure4.13, it illustrates an MR network, comprising one MR-BS, one MS (i.e.MS1), and three RSs including RS1, RS2, and RS3. There are three diverse DL/UL relay routes between MR-BS and MS1. In this Figure4.13, N_{P_i} =3, N_{MS} =1, and MS_i is MS1 because there is only one MS. And it could represent three routes in each variable, respectively. Three routes are denoted as r_1^1, r_1^2, and r_1^3. In the route of r_1^1, there are two hops that $h_1^1 = 2$.

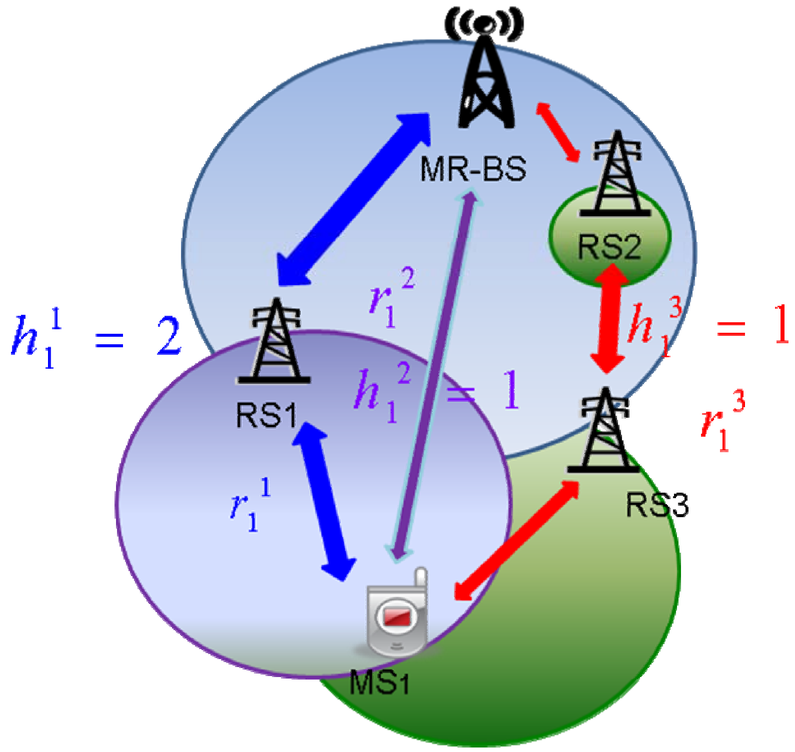


Figure4.13 Illustration of an MR network composing three transmission route

The leap between MR-BS and RS1 is the first hop, and the leap between RS1 and MS1 is the second hop. As for the route of r_1^2, there is only one hop that MS1 transmit data to MR-BS directly and $h_1^2 = 1$. The only leap between MR-BS and MS1 is the first hop. As for the route of r_1^3, there are three hops that $h_1^3 = 3$. The leap between MR-BS and RS2 is the first hop, the leap between RS2 and RS3 is the second hop, and the leap between RS3 and MS1 is the third hop.

Each link is assigned a weighted value by the traffic or link quality to reflect the various scenarios [36]. For example, in Figure 4.13, each leap of three transmission route individually is assigned the same weighted value 1. That is, the cost function in one transmission route is just the summation of ERRI of each leap not to consider other aspects. Generally, the job that calculates the cost of the possible path for an MS belongs to MR-BS. MR-BS always takes care of the modulation and coding rate between itself and neighbors MS but don't take care of the leap information between RSs and between the access RS and MS. So, RSs are assumed to report the leap information such as the modulation and coding rate of leap between RSs and between the access and MS. Therefore, MR-BS could calculate the summation of ERRI of all transmission routes. After t MR-BS has the cost of each path between itself and any MS, it can make the MS to select the relay path having the smallest cost because using a smaller number of OFDMA slots to transmit a fixed amount of data is beneficial for system capacity, the MR-BS prefers to select the path with less cost for routing if there are multiple relay paths that could be selected. But the problem is coming. As in Figure4.13, the weighted value of the link of all transmission routes are set to 1, it may happen the special case that there are many routes having the same cost. Take two special examples that two relay paths have the same cost if the weighted value of each link is set to 1 shown in Figure4.14 and Figure4.15.

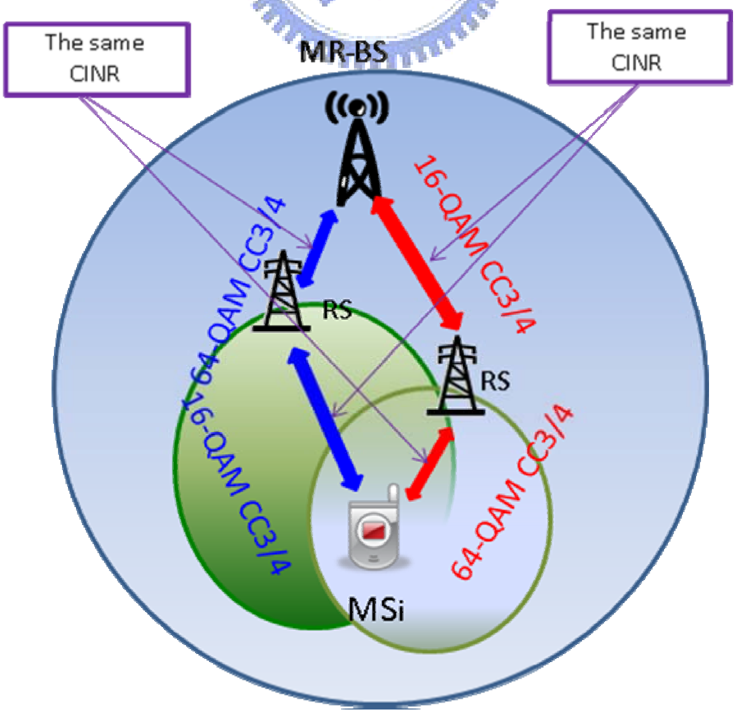


Figure4.14 Special example1

In Figure 4.14, there are two transmission routes that MSi is in the signal coverage of MR-BS and two RSs. And two transmission routes have the same hop numbers equal to two. The burst profile of the first hop of the left route is that modulation is 64QAM and coding rate is 3/4 and it of the second hop is that modulation is 16QAM and coding rate is 3/4. The cost function equals to $\frac{25}{9}$ which $\frac{10}{9}$ adds $\frac{5}{3}$. As for the burst profile of the first hop of the right hop is that modulation is 16QAM and coding rate is 3/4 and it of the second hop is that modulation is 64QAM and coding rate is 3/4. The cost function equals to $\frac{25}{9}$ which $\frac{5}{3}$ adds $\frac{10}{9}$. The problem we are critically faced with is the same cost value so that we don't know which path we should choose. Therefore, this is the problem existing in the first special case.

In Figure4.15, it is the second special example. There are also two transmission route. This scenario is another condition that the CINR of the first hop of each transmission route is the same but the CINR of the second hop is different. The CINR of the second hop of the left transmission route is bigger than the CINR of hop of the right transmission route. Apparently, we should choose the left transmission route because the MS cost less power to transmit data to the access RS compared to the right transmission route. In the MR network, MS power is a big significant problem we should think about carefully. If MS can achieve the same modulation and coding rate during data transmission, it would rather cost less power than much power. But if we calculate the cost function and we discover that the cost values of two transmission route are the same. Therefore, we are also faced with the same significant problem that we still don't know which relay path we should select.

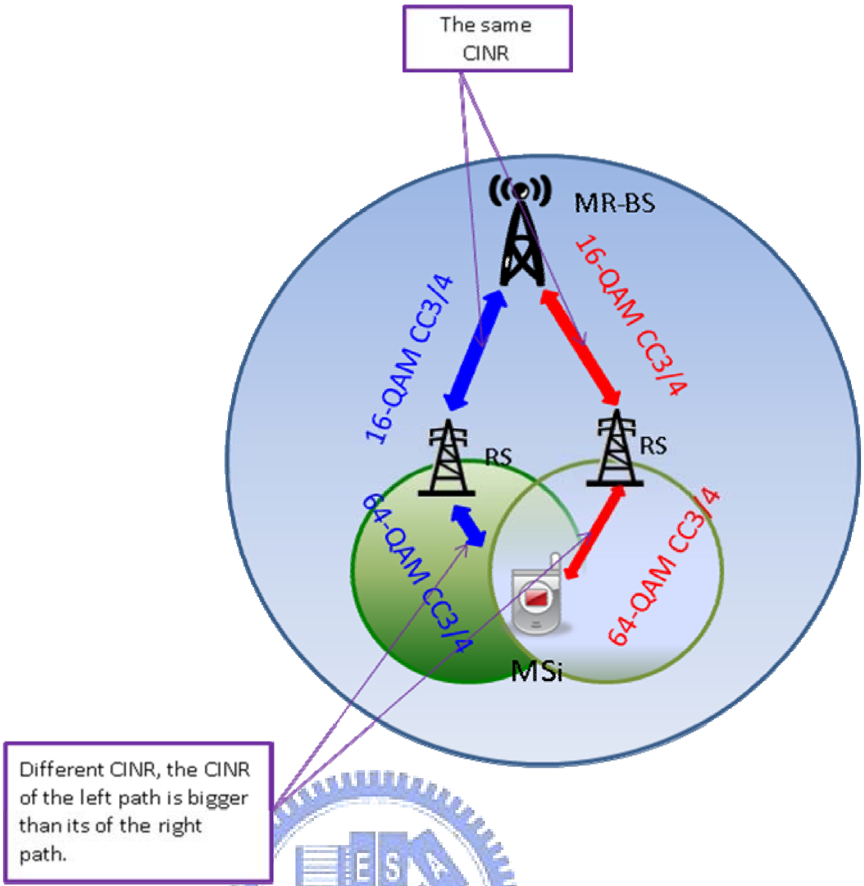


Figure4.15 Special example2

The above two examples are just the tips of the iceberg. If the environment exists more than the data transmission of two hops, it may exist the data transmission of three hops or four hops, etc. The duplicate problem will happen more often with the hop numbers increasing. We list the duplicate problem of only four hop in Table4.4. In Table4.4, it shows that the problem is serious that we don't know how to let MS to choose which relay path according to the summation of the ERRI if the weighted values of all links are set to 1 and only calculating the summation of the ERRI.

PATH	Burst Profile & ERRI Value				Total ERRI
PATH 1	1st hop	--	--	--	10/3
	QPSK,CC½ 10/3	--	--	--	
PATH 2	1st hop	2nd hop	--	--	10/3
	16QAM,CC½ 5/3	16QAM,CC½ 5/3	--	--	
PATH 3	1st hop	2nd hop	3rd hop	--	10/3
	16QAM,CC¾ 10/9	16QAM,CC¾ 10/9	16QAM,CC¾ 10/9	--	
PATH 4	1st hop	2nd hop	3rd hop	--	10/3
	16QAM,CC½ 5/3	64QAM,CC2/3 5/6	64QAM,CC2/3 5/6	--	
PATH 5	1st hop	2nd hop	3rd hop	4th hop	10/3
	64QAM,CC2/3 5/6	64QAM,CC2/3 5/6	64QAM,CC2/3 5/6	64QAM,CC2/3 5/6	

Table4.4 The duplicate transmission conditions of the summation of ERRI in four hop system

According to the above special examples, it is known that we should consider the transmission power of MS in the final hop because the transmission power is very important for MS to transmit data using less power. If MS using the same burst profiles such as modulation64QAM and coding rate 3/4 could rather use less power to transmit data than more power, it is the best choice for MS. In order to observe the influence of the last mile, I will propose two algorithms. I list the two formulas in the following:

$$f\gamma_i = \min_{m\in 1,2,3\ldots N_{P_i}} \{(1-p_{h_i^m}^m)\times \sum_{k=1}^{h_i^m-1} ERRI_k^m + p_{h_i^m}^m \times ERRI_{h_i^m}^m\} \quad (12)$$

$$f\gamma_i = \max_{m\in 1,2,3\ldots N_{P_i}} \{(1-p_{h_i^m}^m)\times \sum_{k=1}^{h_i^m-1} CINR_k^m + p_{h_i^m}^m \times CINR_{h_i^m}^m\} \quad (13)$$

Firstly, I introduce the first formula called weighted ERRI algorithm.

- N_{P_i} represents the total numbers of diverse route between MR-BS and

MS_i. The variable m =1, 2,….. N_{P_i} .

- h_i^m is the hop distance in the m diverse path of MS_i. k =1,2,3…. h_i^m.
- $p^m_{h_i^m}$ represents the weight of the last mile h_i^m in the m diverse path , and $(1-p^m_{h_i^m})$ represents the weight of the leaps other than the last mile. $p^m_{h_i^m}$ ranges from 0.1 to 0.9.
- $ERRI^m_{h_i^m}$ represents the ERRI of the last mile h_i^m in the diverse path m , and the $\sum_{k=1}^{h_i^m-1} ERRI^m_k$ represents the summation of the ERRI of the leaps other than the last mile in the diverse path m .
- $f\gamma_i$ represents the final route chosen by the MS_i finally among many diverse routes.

The objective of weighted ERRI algorithm is to observe the condition of the relay path selection while the weight of the last mile continuously increasing from 0.1 to 0.9. When the weight is 0.1, it means we focus on the leaps other than the last mile, and lower the influence of the last mile. Weight increases continuously. When the weight is 0.5, it represents that the influence of each leap in one diverse path is the same, and not focus on specific leap. When the weight is 0.9, it represents that we focus on the last mile greatly and heavily lower the other leaps except the last mile. So, for uplink relay network, we separate three different cases in the environment using this formula to choose the transmission route:

- Case 1-MS is not in the signal coverage of BS and is in the signal coverage of some RSs, that is, non-transparent relay as shown in Figure4.16.

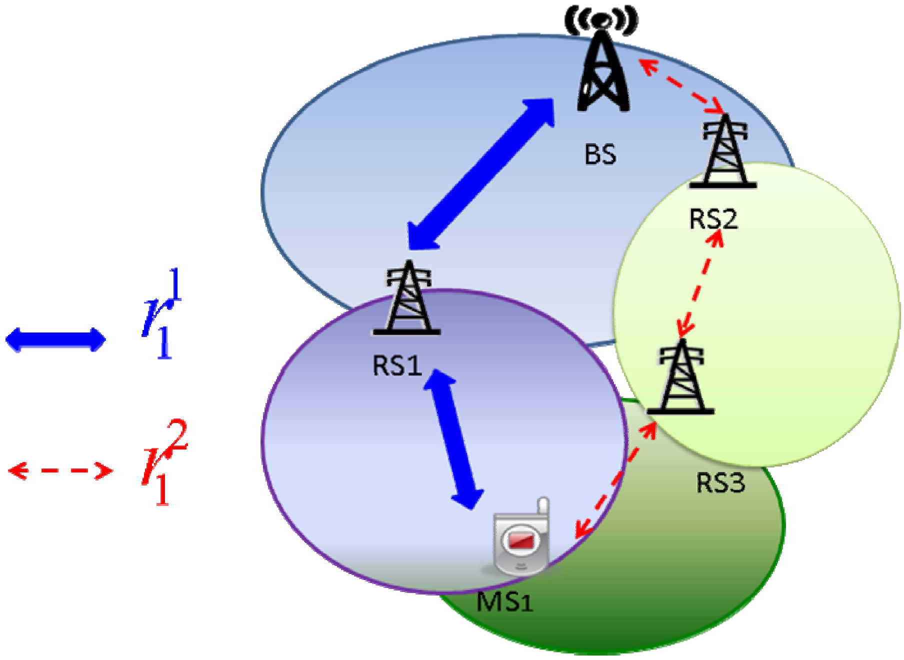


Figure4.16 The scenario of the non-transparent relay

There are two relay paths, r_1^1 and r_1^2. According to the weighted ERRI algorithm, we can derive the each value of weighted ERRI algorithm of two relay path.

$$r_1^1 = \{(1 - P_2^1) \times \sum_{k=1}^{1} ERRI_k^1 + P_2^1 \times ERRI_2^1\} \quad (14)$$

$$r_1^2 = \{(1 - P_3^2) \times \sum_{k=1}^{2} ERRI_k^2 + P_3^2 \times ERRI_3^2\} \quad (15)$$

And then, choose the relay path which the value of weighted ERRI algorithm is minimum while the weight of the last mile continuously increases from 0.1 to 0.9. Therefore, the selection of the relay path changes according different probabilities of the last mile.

- Case 2-MS is in the signal coverage of MR-BS and of several RSs, that is, transparent relay as shown in Figure4.17.

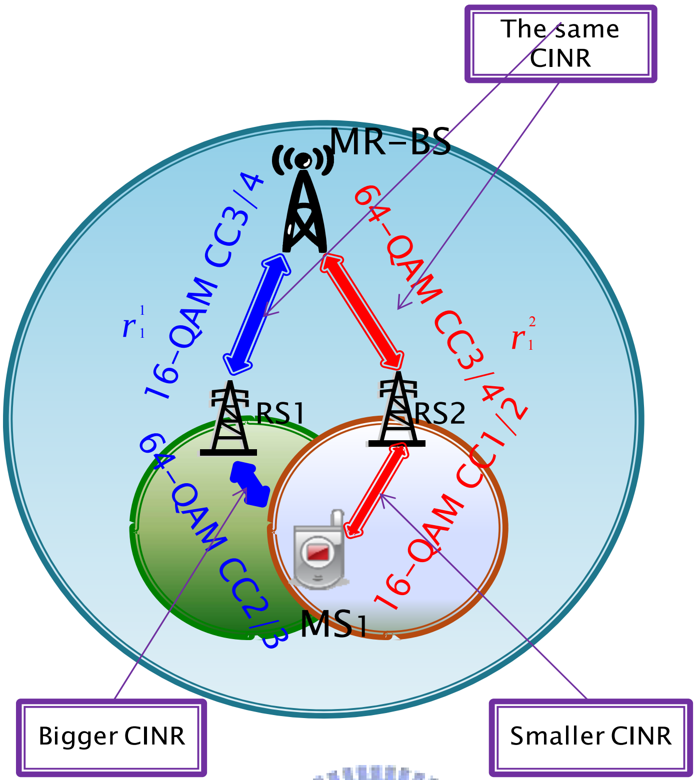


Figure4.17 The scenario of the case2

MR-BS could help MS1 choose the transmission route based on the two values of the weighted ERRI algorithm in the following.

$$r_1^1 = \{(1-P_2^1)\times ERRI_1^1 + P_2^1 \times ERRI_2^1\} = \{(1-P_2^1)\times\frac{5}{3} + P_2^1\times\frac{5}{4}\} \quad (16)$$

$$r_1^2 = \{(1-P_2^2)\times ERRI_1^2 + P_2^2 \times ERRI_2^2\} = \{(1-P_2^2)\times\frac{10}{9} + P_2^2\times\frac{5}{2}\} \quad (17)$$

Where P_2^1 and P_2^2 ranges from 0.1 to 0.9. And the results of the path selection based on the cost calculated by two equations are shown in Table4.5. The priority represents MS1 select the route firstly

Probability p_2^1 , p_2^2	cost	cost	priority
0.1	1.625	1.2500	r_1^2
0.2	1.5833	1.3889	r_1^2
0.3	1.5417	1.5278	r_1^2
0.4	1.5000	1.6667	r_1^1
0.5	1.4583	1.8056	r_1^1
0.6	1.4167	1.9444	r_1^1
0.7	1.3750	2.0833	r_1^1
0.8	1.3333	2.2222	r_1^1
0.9	1.2916	2.3611	r_1^1

Table4.5 The result of the path selection in two-hop network

The result shows that MS select r_1^2 rather than r_1^1 when the weight ranges from 0.1 to 0.3. On the other hand, MS select r_1^1 rather than r_1^2 when the weight ranges from 0.4 to 0.9.

- Case3-MR-BS helps MS decide use RS or not RS to transmit data as shown is Figure4.17.

Similarly, in transparent relay network, MR-BS could help MS decide to use RS or not use MS to transmit data according to weighted ERRI algorithm. There are two routes in Figure4.18. Route r_1^1 is the direct path and route r_1^2 is the multi-hop path.

$$r_1^1 = ERRI_1^1 \quad (18)$$

$$r_1^2 = \{(1-P_2^2)\times ERRI_1^2 + P_2^2 \times ERRI_2^2\} = \{(1-P_2^2)\times\frac{10}{9} + P_2^2\times\frac{5}{3}\}_{P_2^2=0.1,0.2,....0.9}$$

(19)

where P_2^1 are not needed to be used and P_2^2 ranges from 0.1 to 0.9.

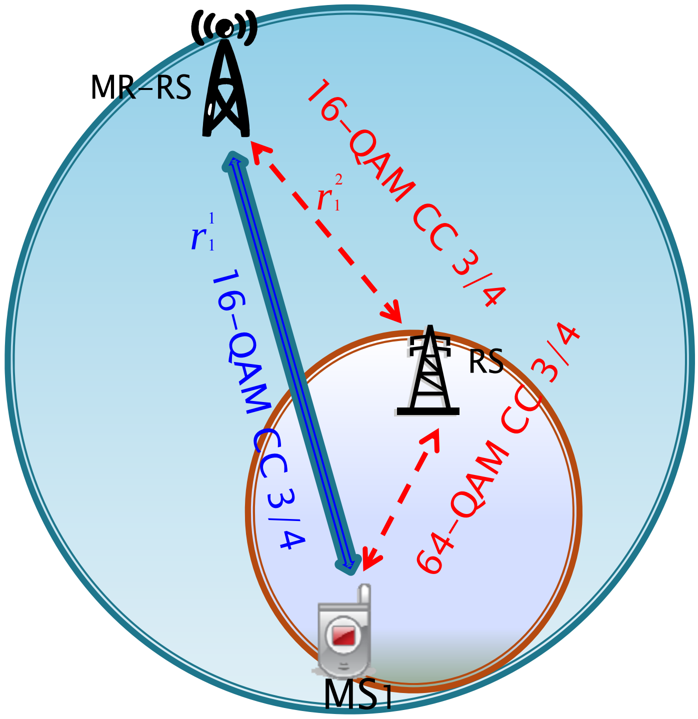


Figure4.18 The scenario of the case3

The results of the path selection based on the cost calculated by two equations are shown in Table4.6 and it shows that MS always chooses the route r_1^2 when MS meets the two transmission routes having these modulations and coding rate in link condition.

Probability p_2^1 , p_2^2	cost	cost	priority
0.1	1.6667	1.6111	r_1^2
0.2	1.6667	1.5556	r_1^2
0.3	1.6667	1.5000	r_1^2
0.4	1.6667	1.4444	r_1^2
0.5	1.6667	1.3889	r_1^2
0.6	1.6667	1.3333	r_1^2
0.7	1.6667	1.2778	r_1^2
0.8	1.6667	1.2222	r_1^2
0.9	1.6667	1.1667	r_1^2

Table4.6 The result of the path selection in two-hop network

Finally, in two-hop network, when weight of the last mile ranges from 0.1 to 0.9,I list the priority of the transmission route of different modulation if I suppose coding rate is 3/4.

- When weight of the last mile=0.1

  64QAM3/4(the first hop) + 64QAM3/4(the last mile) → 16QAM3/4 + 64QAM3/4 → QPSK3/4 + 64QAM3/4 → 64QAM3/4 + 16QAM3/4 → 16QAM3/4 + 16QAM3/4 → QPSK3/4 + 16QAM3/4 → 64QAM3/4 + QPSK3/4 → 16QAM3/4 + QPSK3/4 → QPSK3/4) + QPSK3/4

- When weight of the last mile=0.2

  64QAM3/4(the first hop) + 64QAM3/4(the last mile) → 16QAM3/4 + 64QAM3/4 → QPSK3/4 + 64QAM3/4 or 64QAM3/4 + 16QAM3/4 → 16QAM3/4 + 16QAM3/4 → QPSK3/4 + 16QAM3/4 → 64QAM3/4 + QPSK3/4 → 16QAM3/4 + QPSK3/4 → QPSK3/4 + QPSK3/4

- When weight of the last mile=0.3

  64QAM3/4(the first hop) + 64QAM3/4(the last mile) → 16QAM3/4 + 64QAM3/4 → 64QAM3/4 + 16QAM3/4 → 16QAM3/4 + 16QAM3/4 → QPSK3/4 + 64QAM3/4 → QPSK3/4 + 16QAM3/4 → 64QAM3/4 + QPSK3/4 → 16QAM3/4 + QPSK3/4 → QPSK3/4 + QPSK3/4

- When weight of the last mile=0.4

  64QAM3/4(the first hop) + 64QAM3/4(the last mile) → 16QAM3/4 + 64QAM3/4 → 64QAM3/4 + 16QAM3/4 → 16QAM3/4 + 16QAM3/4 → QPSK3/4 + 64QAM3/4 → QPSK3/4 + 16QAM3/4 → 64QAM3/4 + QPSK3/4 → 16QAM3/4 + QPSK3/4 → QPSK3/4 +

QPSK3/4

- When weight of the last mile=0.5

  64QAM3/4(the first hop) + 64QAM3/4(the last mile) → 16QAM3/4 + 64QAM3/4 or 64QAM3/4 + 16QAM3/4 → 16QAM3/4 + 16QAM3/4 → QPSK3/4 + 64QAM3/4 or 64QAM3/4 + QPSK3/4 → QPSK3/4 + 16QAM3/4 or 16QAM3/4 + QPSK3/4 → QPSK3/4 + QPSK3/4

- When weight of the last mile=0.6

  64QAM3/4(the first hop) + 64QAM3/4(the last mile) → 64QAM3/4 + 16QAM3/4 → 16QAM3/4 + 64QAM3/4 → 16QAM3/4 + 16QAM3/4 → 64QAM3/4 + QPSK3/4 → QPSK3/4 + 64QAM3/4 → 16QAM3/4 + QPSK3/4 → QPSK3/4 + 16QAM3/4 → QPSK3/4 + QPSK3/4

- When weight of the last mile=0.7

  64QAM3/4(the first hop) + 64QAM3/4(the last mile) → 64QAM3/4 + 16QAM3/4 → 16QAM3/4 + 64QAM3/4 → 16QAM3/4 + 16QAM3/4 → 64QAM3/4 + QPSK3/4 → 16QAM3/4 + 64QPSK3/4 → QPSK3/4 + 64QAM,3/4 → QPSK3/4 + 16QAM3/4 → QPSK3/4 + QPSK3/4

- When weight of the last mile=0.8

  64QAM3/4(the first hop) + 64QAM3/4(the last mile) → 64QAM3/4 + 16QAM3/4 → 16QAM3/4 + 64QAM3/4 or 64QAM3/4 + QPSK3/4 → 64QAM3/4 + QPSK3/4 → 16QAM3/4 + 16QAM3/4 → 16QAM3/4 + QPSK3/4 → QPSK3/4 + 64QAM3/4 → QPSK3/4 + QPSK3/4

- When weight of the last mile=0.9

  64QAM3/4(the first hop) + 64QAM3/4(the last mile) → 64QAM3/4 + 16QAM3/4 → 64QAM3/4 + QPSK3/4 → 16QAM3/4 + 64QAM3/4 → 16QAM3/4 + 16QAM3/4 → 16QAM3/4 + 16QAM3/4 → 16QAM3/4 + QPSK3/4 → QPSK3/4 + 64QAM3/4 → QPSK3/4 + QPSK3/4

After finishing the introduction of weighted ERRI algorithm, I make a equation called weighted CINR algorithm for comparison.

$$f\gamma_i = \max_{m\in 1,2,3,\ldots,N_i} \{(1-p_{h_i^m}^m)\times \sum_{k=1}^{h_i^m-1} CINR_k^m + p_{h_i^m}^m \times CINR_{h_i^m}^m\} \ldots\ldots(2)$$

The equation variables of weighted CINR algorithm are the same as those of weighted ERRI algorithm. Carrier to Interference-plus-Noise Ratio (CINR), expressed in decibels (dBs), is a measurement of signal effectiveness. The carrier is the desired signal, and the interference can either be noise or co-channel interference or both. In order for the signal receiver to be able to decode the signal, the signal must fall into an acceptable CINR range. The only different is that it selects the maximum of the equation in diverse path m not as weighted ERRI algorithm selection the minimum of the equation in diverse path m because the bigger CINR means channel condition is better and the received power is more powerful.

Chapter 5 Simulation Results

In this chapter, we will show the simulation results for with different algorithms selecting relay path to see the advantage of the proposed algorithm –weighted ERRI algorithm. We will focus on some factors such as throughput, end-to-end in the simulation environment of single user and multiuser. We use those results to show that the advantages and drawbacks of the proposed algorithm.

The goals of designing the algorithm are to select the better relay path for MS to efficiently transmit data, especially in the complicated network existing multiuser, and to enhance the system performance. In the following simulation results, it will show the proposed algorithm will really perform the throughput and ene-to-end delay and transmit power of MS. Then we will meet the tradeoff if we use the proposed algorithm to select relay path.

5.1 Traffic Models

In IEEE 802.16e standard, the uplink data traffics are divided into five QoS classes, such as Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), extended real-time Polling Service (ertPS), and Best Effort Service (BE). The detailS are described in 2.2.3. In simulation, we build CBR service to stand for BE service. The uplink is basically a round robin priority scheduler. After allocating bandwidth for basic, primary and secondary connections, it allocates bandwidth for data connections of BE. The scheduler implements a Best-Effort scheduler coupled with a Round Robin algorithm to distribute the bandwidth allocations among the users. To support BE, bandwidth requests are generated at the MS indicating the amount of data to transfer.

Finally, we use the Table5.1 to summarize and present the parameter setting in my simulation platform.

Parameters	**Value/Comment**
Packet size	1500 (packet size in bytes at CBR application)
Gap size	0.1(compute gap size between packet)
Client timeout	50(avoid BS disconnecting the MS)
Transmitter/Receiver	Uplink
Channel type	WirelessChannel
Radio-propagation model	Two-ray ground
Network interface type	OFDMA
MAC TYPE	802_16/BS
Interface queue type	DropTail/PriQueue
Link layer type	LL
Antenna model	Omniantenna
Routing protocol	DSDV
Traffic model	CBR
Agent	UDP
FFT	1024
Sub-channels	30
Datas sub-carriers within each subchannel	16
Frequency Bandwidth	10MHZ

AMC	BPSK+CC 1/2, QPSK+CC 1/2, QPSK+CC 3/4, 16-QAM+CC 1/2, 16-QAM+CC 3/4, 64-QAM+CC 2/3, 64-QAM+CC 3/4

Table5.1 The parameter setting in simulation platform

5.2 Simulation Results

Firstly, we want to prove the importance of the RS deployment, so we place the RS in the location that the burst profiles of the last mile are all 64QAM+CC3/4. And, we run multiple users to transmit data using three different burst profiles of the last mile according to different CINR such as QPSK+CC3/4, 16QAM+CC3/4, 64QAM+CC3/4. The following result in Figure5.1 shows apparently that the system has much throughput if the last mile has better burst profile to let more MSs to transmit data. And it proves that the RS deployment for the transmission of MS is great key to make the system throughput more because the load bottleneck of the last mile exists and limit the system throughput.

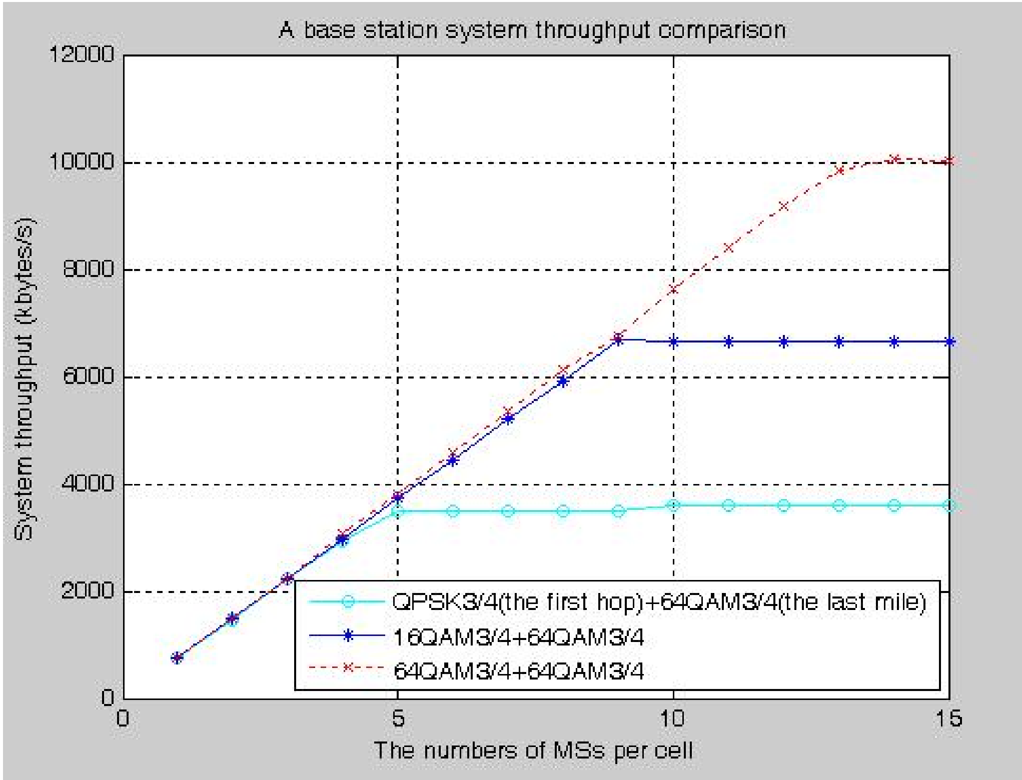


Figure5.1 The simulation throughput that MS use different burst profiles of the last mile to transmit data

In terms of end-to-end delay shown in Figure5.2, three simulations in different burst profile of the last mile maintain each end-to-end delay before the transmission load is not full. But, as for the relay path that the burst profile of the last mile is QPSK+CC3/4 and the burst profile of the first hop is 64QAM+CC3/4, the bottleneck of the transmission data load happens at the earliest. As MSs increase, the delay is more and more important. Compared to the relay path that the burst profile of the first mile is 64QAM+CC3/4 and the burst profile of the last hop is QPSK+CC3/4, the system will let more MSs to transmit data and the bottleneck of the transmission data load happens lately. In terms of the MR network, it absolutely wants to let more MSs to transmit data and get less end-to-end delay, so deploying RS in the location MSs using the better burst profiles to transmit data is important.

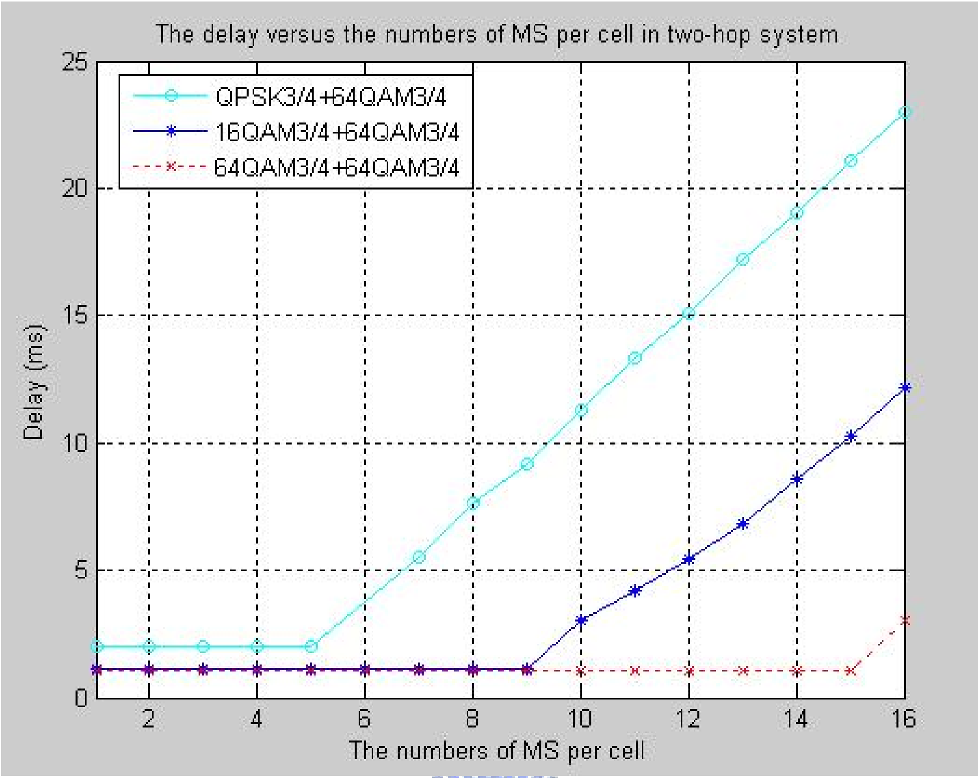


Figure5.2 The simulation delay that MS use different burst profiles of the last mile to transmit data

After proving the importance of RS deployment, I start to compare the weighted ERRI algorithm and weighted CINR algorithm. Firstly, I use single user to run simulation. A MS move around in the environment and select one of relay paths to uplink data in the two-hop system. The results are shown in Figure5.3. We could see that the uplink throughput is almost the same using these two algorithms because the frame is not full with only one user.

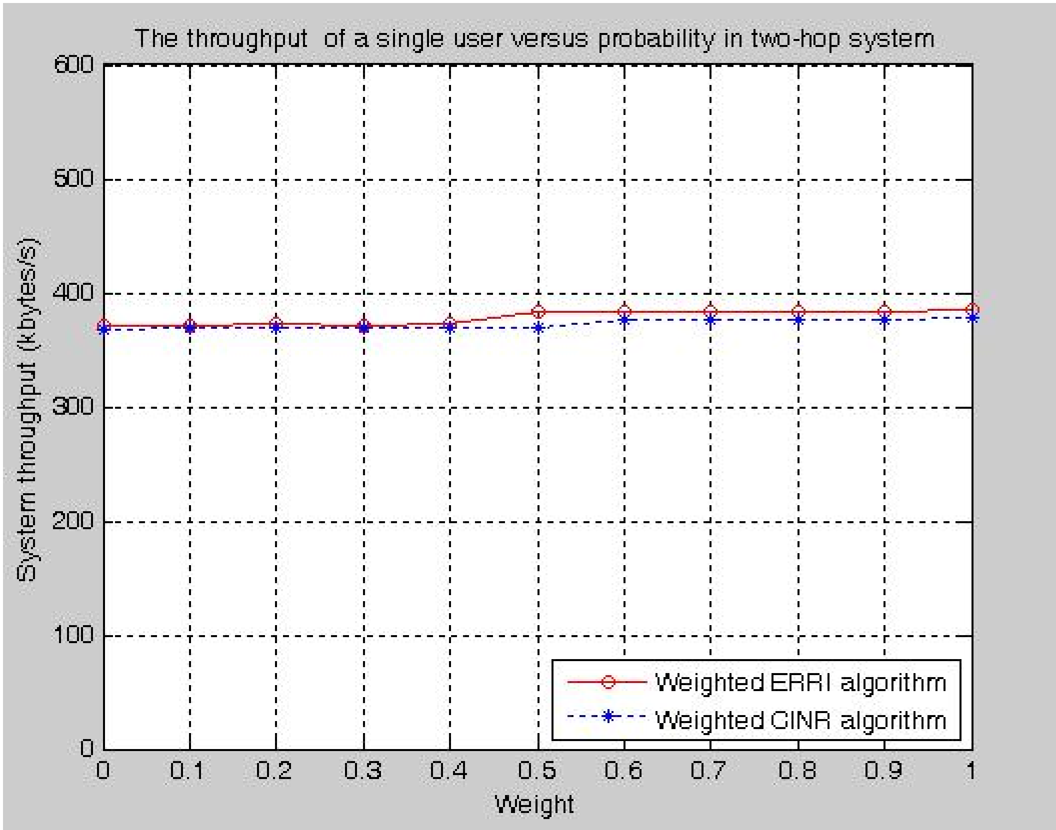


Figure5.3 The simulation throughput using two algorithm of transmission route selection

The simulation delay for single user is shown in Figure5.4. Apparently, the delay of weighted ERRI algorithm is when the weight of the last mile is less than 0.5, the delay is not fluctuated. The selection of transmission route is typical not to be influenced by the weight of the last mile. We don't deploy RS using the modulation of QPSK in the first hop since the modulation of QPSK is not used in practice in real MR nekwork. Because the transmission route may appear the first hop, 64QAM+CC3/4, and the last mile, QPSK+CC3/4 when the weight ranges from 0.1 to 0.4 and the transmission route don't appear the first hop, OPSK+CC3/4, and the last mile, QPSK+CC3/4 when the weight ranges from 0.6 to 0.9, the delay between 0.1 to 0.4 is larger than 0.6 to 0.9. As for the weighted CINR algorithm, the selection of transmission route is easy to be influenced by the weight of the last mile. Since MS may choose the relay path that burst profile of the first hop is QPSK+CC3/4 and the last mile are 64QAM+CC3/4 not to choose the relay path that burst profile of the first hop is 16QAM+CC3/4 and the last mile are 64QAM+CC3/4 under the influence of the range of CINR in the same burst profile, the first hop dominates the selection when the weight equals 0.1. As the weight increases, the ability of domination of the first hop declines. So, the delay also declines. But when the weight of the last mile ranges from 0.6 to 0.9,the delay of weighted CINR algorithm is larger than the delay of weighted ERRI algorithm because Ms using weighted ERRI algorithm can't have chance to select the relay path that the first hop is 16QAM+CC3/4 and the last mile is 64QAM+CC3/4 instead of selecting the path that the first hop is 16QAM+CC3/4 and the last mile is 16QAM+CC3/4 and Ms using weighted CINR algorithm may have chance to select the relay path that the first hop is 16QAM+CC3/4 and the last mile is 16QAM+CC3/4 not to selecting the path that the first hop is 16QAM+CC3/4 and the last mile is 64QAM+CC3/4. The priority of the selected relay path using weighted ERRI algorithm is fix but the priority of the selected relay path using weighted CINR algorithm is not fix. So, it makes the difference results of delay.

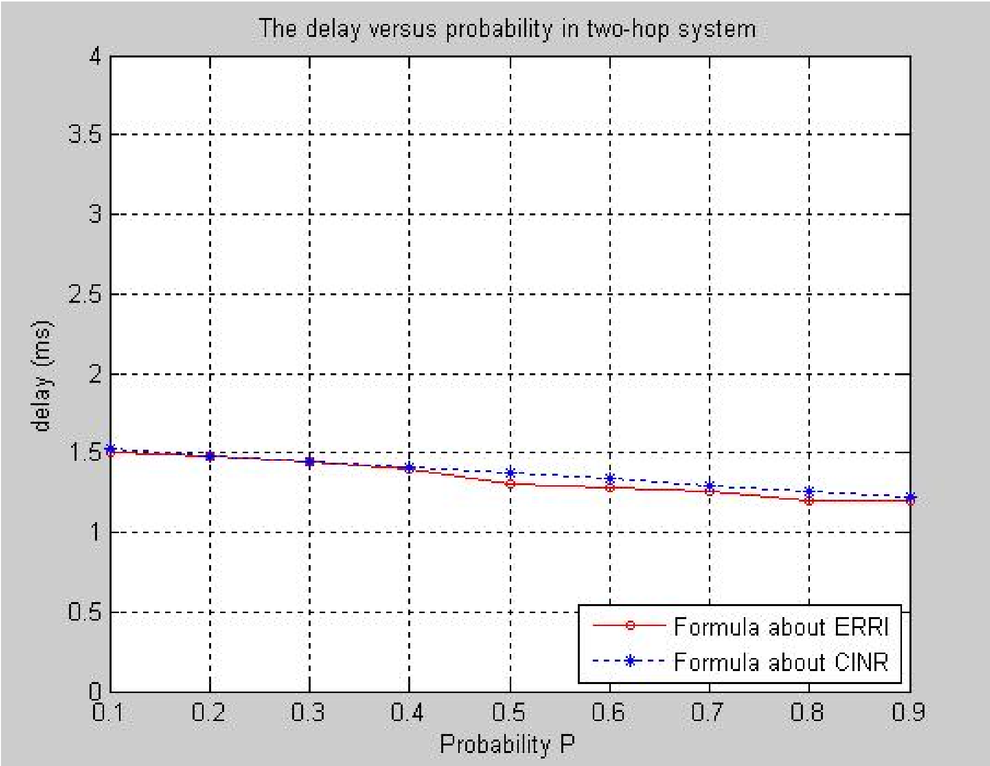


Figure5.4 The simulation delay for single user using two algorithm of transmission route selection

The simulation of transmit power for single user is shown in Figure5.5. The transmit power of MS using weighted ERRI algorithm is larger than the transmit power of weighted CINR algorithm when weight of the last mile ranges from 0.1 to 0.9. But when we focus on the last mile and increase the weight if the last mile, we could see the result that the transmit power of MS using weighted ERRI algorithm is less than the transmit power of MS using weighted CINR algorithm. The reason is that MSs choose the relay path having the worse burst profile of the last mile due to the variation of CINR that the changeable CINR having range is not as the fix ERRI in the same burst profile. Hence, the transmit power using weighted ERRI algorithm begins to be less than the transmit power using weighted CINR algorithm when the weight of the last mile is above 0.9. But in Figure5.5, while the weight equals to 1.0, the transmit power of MS using weighted CINR algorithm is finally less than that using weighted ERRI algorithm. That is because MS only consider the condition of the last mile, MS could use less power to transmit data according to max CINR theorem. Contrarily, MS may choose the relay path using the much power to transmit data due to the same ERRI value of the same burst profile.

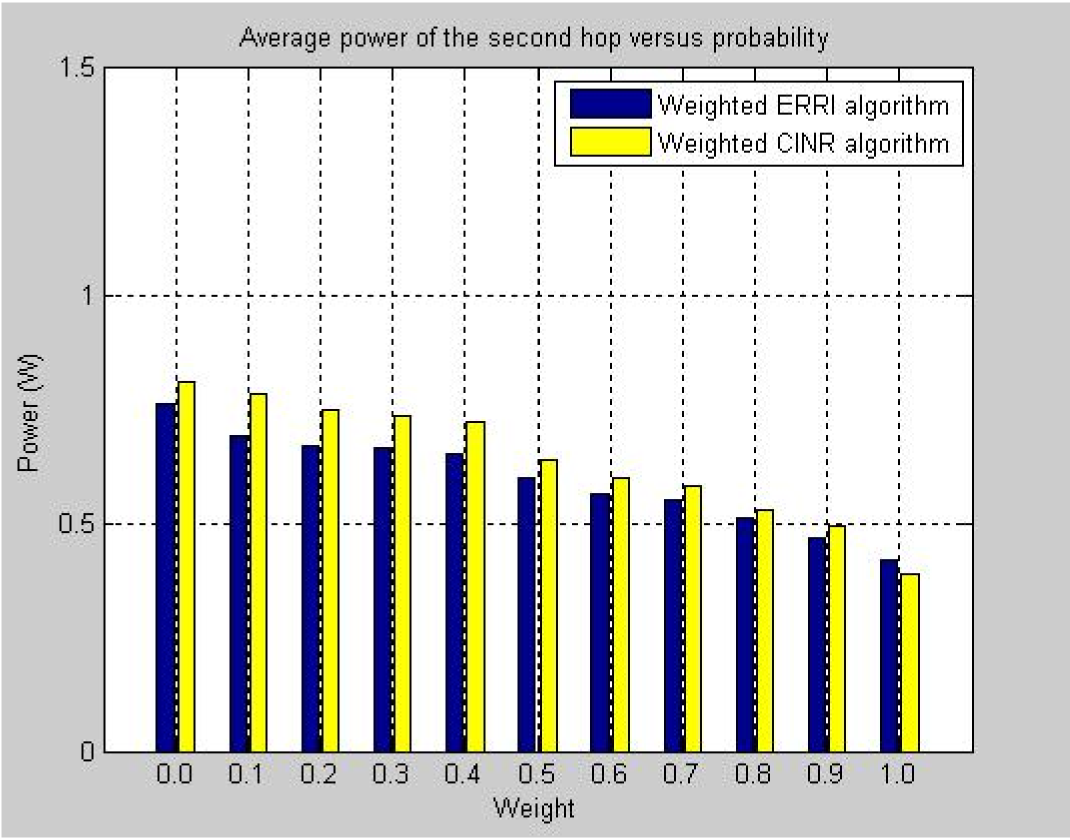


Figure5.5 The transmit power of the last mile for single user using two algorithm of transmission route selection

In real MR network, there is not only one single user absolutely. Hence, I run the simulation to observe the throughput and transmit power of the last mile when MS increases. MSs move around in the environment and select one of relay paths to uplink data in the two-hop system. Apparently differing from the result of single user, two throughput using different algorithms decline when the weight about ranges from

0.7 to 0.9. The reason is that the algorithms do not consider the bottleneck of the transmission data load. When the weight ranges from 0.7 to 0.9, MS may consider the last mile not to consider the first hop according these two algorithms, so the throughput would be limited due to the first hop using the worst burst profile. Therefore, the weight of the last mile could not be set too high as soon as possible due to the decline of the throughput. But the two algorithms have worse throughput than that of the 802.16 system w/o relay when the mobile move around the environment. For example, MSs could use the burst profiles, 64QAM+CC3/4 of the first hop and 16QAM+CC3/4 of the last mile to transmit data compared to the no-relay path using QPSK+CC1/2 originally, MSs could use QPSK+CC1/2 of the last mile and lower the transmit power of MSs. But, it will get worse throughput. Therefore, it could observe in Figure5.6 and Figure 5.7 that the system could get worse throughput and less transmit power if MSs always use relay to transmit data than that of the system if MSs sometimes use relay or sometimes don't use relay to transmit data in transparent relay system.

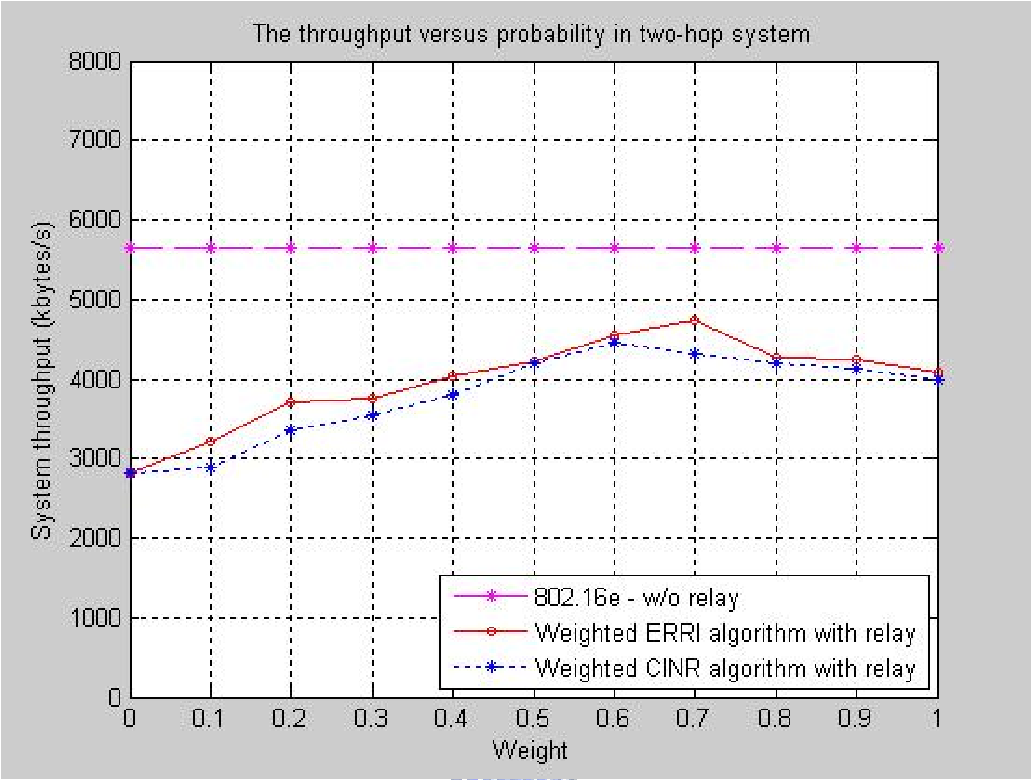


Figure5.6 The simulation throughput using two algorithms of transmission route selection with relay and 802.16e w/o relay

As for the transmit power of MS of the last mile, the results are shown in Figure5.7. Using the two algorithms, we could use less and less power for MS to transmit data absolutely while the weight of the last mile declines continuously. And the transmit power of MS using weighted ERRI algorithm is less than the transmit power of MS using weighted CINR algorithm when the weight of the last mile is less than 1. The reason is that MSs choose the relay path having the worse burst profile of the last mile due to the variation of CINR that the changeable CINR having range is not as the fix ERRI value in the same burst profile. The cost function of weighted CINR algorithm is changeable compared to it of weighted ERRI algorithm. Hence, the transmit power using weighted ERRI algorithm begins to be less than the transmit power using weighted CINR algorithm when the weight of the last mile is less than 1. But, when the weight of the last mile equals 0.9, the transmit powers using two algorithms individually are almost close and it represents the selected relay paths are almost the same. Finally, the transmit power using weighted CINR algorithm is less because it means the max CINR considering only one hop condition. The two algorithm using relay get less transmit throughput than that of 802.16e system not using relay due to the 802.16j system sacrifices better throughput to achieve less transmit power of MSs.

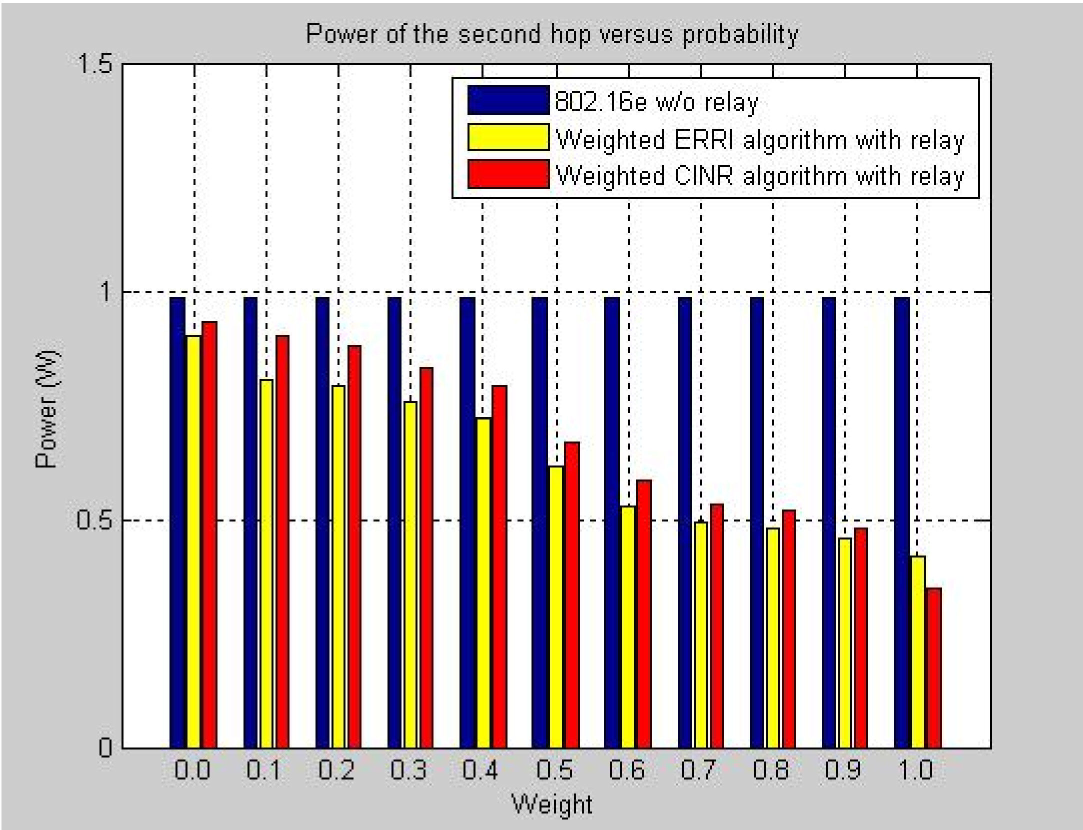


Figure5.7 The transmit power of the last mile for multiple user using two algorithm of transmission route selection and 802.16e w/o relay

Chapter 6 Conclusion and Future Work

In this thesis propose two selection algorithms of transmission route in MR network. Using the weighted ERRI algorithm and weighted CINR algorithm concept, we can observe the throughput change of different weight of the last mile in two-hop system. With the aid of two Formulas, the optimal relay is selected taking care of the path throughput seriously according to the weight of the last mile in one diverse path.

The simulation results show the comparison of two proposed algorithm, weighted ERRI algorithm, and weighted CINR algorithm. In order to increase the system throughput and lower the transmit power of MS, we adjust the weight of the last mile. In terms of throughput in two hop network, as a single user, the throughput of two algorithms is almost the same because the frame that is not full has been uplink. But when the users increase more, the throughput of weighted ERRI algorithm is larger than the throughput of weighted CINR algorithm since the CINR may differ from each other by many dB (decibel) and it has a range to use the same burst profile. If the difference of dB between some leap to other leaps are more, some leap has bigger the ability of domination. So, when the weight of the last mile increases to 0.8 and 0.9, MS using weighted CINR algorithm may also choose the worst path to transmit data. And, it meets the bottleneck of the transmission data load, so the throughput declines. On the other hand, the each value of equation of weighted ERRI algorithm in each weight of the last mile is fix because the ERRI is fix in specific burst profile. So, using this equation doesn't meet the range problem. So, in multiple users system, the throughput will increase when the weight of the last mile increases, but when the weight of the last mile increases to 0.8 and 0.9, it also meets the same problem, the bottleneck of the transmission data load to have near throughput of weighted CINR algorithm. As a whole, weighted ERRI algorithm achieves better throughput than weighted CINR algorithm except the weight of the last mile equaling to 0.5. In terms of the transmit power of MS, transmit power of MS using weighted CINR algorithm are less than it using weighted ERRI algorithm while the weight is larger than 0.5 and transmit power of MS using weighted CINR algorithm are smaller than it using weighted ERRI algorithm while the weight is much than 0.5. Because we want to lower the transmit power of the last mile and focus on the last mile to increase the weight of it, we choose the weighted ERRI algorithm to get less transmit power of MS.

Therefore, if we want to focus the importance of the last mile and get more throughput and less transmit power of MS, we choose weighted ERRI algorithm that is the realistic amount of transmission not weight CINR algorithm that is the variation of RF. Weighted CINR algorithm is more changeable due to the RF variation and MS uses this algorithm to select the worst relay path resulting in less throughput. It prefers to use weighted ERRI algorithm for MSs.

But, using weighted ERRI algorithm or weighted CINR algorithm, there is one problem that the throughput will decline although MS uses less transmit power of the last mile when the weight of the last mile increases highly. The bottleneck of the transmission data load still exists. So, there is a tradeoff between throughput and power. Maybe we can add a function of load balancing combined into weighted ERRI algorithm to solve the problem of the load bottleneck and MS can reduce transmit power at the same time. The mechanism can enhance the completeness of weighted ERRI algorithm and performance of transmission route selection in such scenarios are evaluated as well in the future.

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