Performance analysis and test of the DVB-RCT system

Master of Science Thesis

In Communication System Test

by

Peng Li and Qi Cheng

Department of Electronics, Computer and Software Systems (ECS),

School of ICT,

Royal Institute of Technology (KTH)

Stockholm, 03/2006

Supervisor/Examiner: Svante Signell

Abstract

Nowadays, the next generation communication technology based on OFDM (A) has been promoted to supply the WMAN services for big cities and areas. Mobile broadband has become a very hot topic around the world. Sweden also needs the WMAN service to provide Internet access and other services for its north large area with small population density.

In Europe, DVB-T (Digital Video Broadcasting- Terrestrial) network has covered almost all countries and supplied high speed unidirectional downlink Mpeg-2 stream transmissions. In order to realize WMAN service in Sweden, an uplink interactive communication channel should be supplied, which is utilized together with DVB-T to establish a WMAN network based on IP application. ETSI EN 301 958 DVB-RCT and IEEE 802.16 WiMAX are two candidate standards to be considered.

In this thesis, a comprehensive comparison that targets the standards and the applications between DVB-RCT and WiMAX has been done. The feasibility of adopting DVB-RCT, especially in mobile situations has been analyzed. In addition, in order to evaluate the performances of Runcom DVB-T/RCT solutions for supplying IP applications, a full test proposal including lab test and field test was accomplished. Based on automatic measurement of IP traffic performance, the lab test bed was developed at KIT, Gävle. With different PHY and MAC configurations, the parameters that can reveal the QoS of DVB-RCT service such as throughput, packet loss rate, etc. have been captured and analyzed. In the end, a beta field trial using air interface was conducted within Gävle Technology Park office building.

Acknowledgments

Abbreviations

ATSC: Advance Television Systems Committee
ADSL: Asymmetrical Digital Subscriber Loop
BS: Base Station
BS3: Burst Structure 3
BWA: Broadband Wireless Access
COFDM: Coded Orthogonal Frequency Division Multiplexing
CPE: Customer Premises Equipment
D-ITG: Distribute Internet Traffic Generator
DSL: Digital Subscriber Line
DTTB: Digital Terrestrial Television Broadcasting
DVB-RCT: Digital Video Broadcasting-Return Channel Terrestrial
DVB-T: Digital Video Broadcasting-Terrestrial
FEC: Forward Error Correct
FFT: Fast Fourier Transform
FTP: File Transfer Protocol
GSM: Global System for Mobile communication
HDTV: High-Definition television
HTTP: Hypertext Transfer Protocol
IP: Internet Protocol
ISDB-T: Integrated Services Digital Braodcasting-Terrestrial
ISDN: Integrated Services Digital Network
IDT: Inter Departure Time

LAN: Local Area Network
LOS: Line Of Sight
MAC: Medium Access Control
MAS: Medium Access Scheme
MPE-FEC: MultiProtocol Encapsulated FEC
MPEG2: Moving Picture Experts Group
NIU: Network Interface Unit
NLOS: No-Line of Sight
OFDM: Orthogonal Frequency Division Multiplexing
OFDMA: Orthogonal Frequency Division Multiplexing Access
PHY: PHYsical layer
PS: Packet Size
PSTN: Public Switched Telephone Network
QAM: Quadrature Amplitude Modulation
QoS: Quality of Service
QPSK: Quaternary Phase shift Keying
RCTT: Return Channel Terrestrial Terminal
RCTT: Return Channel Terrestrial Terminal
RS: Reed-Solomon

RTT: Return-Trip-Time
SDTV: Standard Definition television
SFN: Single Frequency Network
SOHO: Small Office/Home Office
STU: Set Top Unit
TCP: Transfer Control Protocol
UDP: User Datagram Protocol
UHF: Ultra High Frequency
VHF: Very High Frequency
VOD: Video-on-Demand
VoIP: Voice over Internet Protocol
WAN: Wide Area Network
WCDMA: Wideband Code Division Multiple Access
WiMAX: Worldwide Interoperability for Microwave Access
XDSL: A/H/RADSL

Contents

List of Figures

Lists of Tables

1 Introduction

1.1 Background

Wireless is one of the quite hot topics in telecom industries nowadays. Because the 'last mile' problem, the biggest challenge in the delivery of broadband services directly to end users' terminals can be solved by the broadband wireless access methods. Compared with the wired access technologies, broadband wireless access counterparts have their own advantages. They are very convenient for customers; they are less restricted by the distance (the distance of wireless connection can be up to several tens of miles). They need almost no cable layout in buildings. IEEE802.11b/g is a very good example. This technology has become very popular in the last several years, and it is now used nearly everywhere such as bus station, airport, train station, public building and meeting place. But because it is especially used in point to point configuration as wireless LAN and its coverage area can be only several hundred meters, so for large distance wireless connections such as wireless WAN, there should be some other technologies to match this demand.

DVB-T (Digital Video Broadcasting - Terrestrial), serving as the downlink and DVB-RCT (Digital Video Broadcasting - Return Channel Terrestrial), serving as the uplink, are ideal technologies candidate for large distance wireless access. All around the world, especially in Europe, VHF and UHF bands are highly saturated. DVB-T (EN 300 744) is a frequency efficient standard to broadcast digital TV. Its network is deployed not only within Europe but also in other countries all over the world, such as Singapore, Australia and Brazil [11]. As a digital TV broadcasting standard, DVB-T offers many new features not supported by the traditional analog TV. Among them, interactive services are very fascinating. These kinds of services can be realized by means of both DVB-T and DVB-RCT. Although DVB-T is originally designed to broadcast digital TV, the hierarchical modulation mode allows it to provide two virtual channels (High/Low Priority streams) within a single radio frequency channel. So this technology can provide two independent services in the same frequency channel. Typically, the High Priority stream carries the basic digital TV signals with relatively low data rate and high error protection, whereas Low Priority streams can be used to provide other services such as broadband services or increase the quality of the High Priority stream. From technique point of view, the interactive services can be carried by the Low Priority stream. [2]

Not only from technique point of view but also from market point of view, if commercial terrestrial digital TV's business only focuses on pure digital broadcasting TV programs, there will be huge economic failure and resource waste. As the result, service providers and broadcasters are looking for new added value services such as (wireless broad band access) to increase both the usage efficiency and revenues.

To provide interactive services a return channel from the end user to the service provider is needed. Traditionally, the return channel is provided by using gateways to the existing telecom networks (e.g. PSTN, ISDN, GSM, ADSL), but some kind of interactive services have a strong and real-time relationship with the TV program. So, timing requirements of these kinds of interactive services make these networks not feasible. Furthermore, to create a return channel, some problems such as infrastructure cost, local population density, existing network conditions should be considered. DVB-RCT is the standardized dedicated return channels for the DVB-T, which is specially designed to cope with the requirements of the incoming interactive services added to the DVB-T network. So, DVB-RCT may be an ideal return channel for broadband wireless access.

As mentioned above, when intending to provide broadband access to nearly 100% of population in a wide region, wired connection methods are not good candidates because they are very expensive. For example, the population distribution of many European countries such as Sweden, Finland and German makes it impossible a 100% coverage network without wireless connections in the 'last mile'. DVB-T Television networks usually cover 100% of the population. Besides, by using fixed as well as portable and mobile terminals, DVB-T can reach everywhere. Therefore, new public digital TV networks with a perfect return channel can implement new applications such as Internet browsing, VoIP, E-mail, E-learning. To achieve widespread, high speed access by all citizens to the information society services is one of the goals of many developed and developing countries. Currently, there is an ideal terrestrial return channel formed by DVB-RCT. DVB-RCT can provide interactive abilities to DVB-T by using the existing infrastructure already used to broadcast digital TV services. With DVB-RCT, DVB-T becomes a bidirectional terrestrial wireless communication system.

DVB-RCT standard makes use of a Multiple Access Orthogonal Frequency Division Multiplex (OFDMA) arrangement, to constitute a high bandwidth Wireless Interactive Terrestrial Digital TV system. It was officially approved by the DVB forum in April 2001. It is expected to let DVB-RCT act as a companion to the DVB-T broadcasting

standard. DVB-RCT offers a wireless interaction channel for these real-time Interactive Digital Terrestrial Television Services. Because this standard uses the latest technique in digital communications, it has many fantastic advantages:

- DVB-RCT is spectrum efficient, low cost, and powerful. It provides a flexible Wireless Multiple Access based on well-known Orthogonal Frequency Division (OFDM) technique that is well suited for transmission in the terrestrial channel.
- DVB-RCT can serve large cells, up to 65kms radius, providing a typical bit-rate capacity of several kilobits per second (the maximum bit-rate can be up to several megabits per second with small cells), for each TV viewer, even at the edge of the coverage area. Typically, these large cells closely match the downstream coverage area of the Digital Television broadcast signal.
- DVB-RCT can handle very large peaks in traffic, as it has been specifically designed to process up to 20,000 short interactions per second in Tele-polling Mode, in each sector of each cell.
- DVB-RCT can be employed with smaller cells, to constitute denser networks of up to 3.5km radius cells, providing to the user a bit-rate capacity of up to several Megabits per second per user.
- DVB-RCT does not require access to spectrum on a primary basis; the system has been designed to use any gaps or under-utilized spectrum anywhere in Bands III, IV and V without interfering with the primary analogue and digital broadcasting services.
- DVB-RCT is able to serve portable devices; bringing interactivity everywhere the Terrestrial Digital broadcast signal is receivable,
- DVB-RCT can be used around the world, which uses the different DVB-T system: 6, 7 or 8 MHz channels,
- DVB-RCT does not require more than 0,5W rms transmission power from the User Terminal or Set Top Box to the base station. [11]

Compared with traditional return channels such as XDSL, GSM, GPRS, DVB-RCT has many good features:

- DVB-RCT can offer independent implement solutions.
- DVB-RCT has low charge for RC.
- DVB-RCT has very low deployment cost.
- DVB-RCT can offer scalable solutions.
- DVB-RCT offer portable or even mobile terminals.
- DVB-RCT has broadband capabilities. [11]

1.2   DVB-T/RCT System Scheme

The interactive digital broadcasting system (DVB-T/RCT) is a bi-directional broadband wireless network, so this system is suitable for various broadband applications. Because it is originally designed for digital TV, so both standards are working in the VHF/UHF Bands (around several hundred megahertz), which can be received by normal TV antennas. The output power of the RCT base station is relatively low; the CPE's is even lower. The total system has very low power consumption and it is feasible to be used in moving situations.
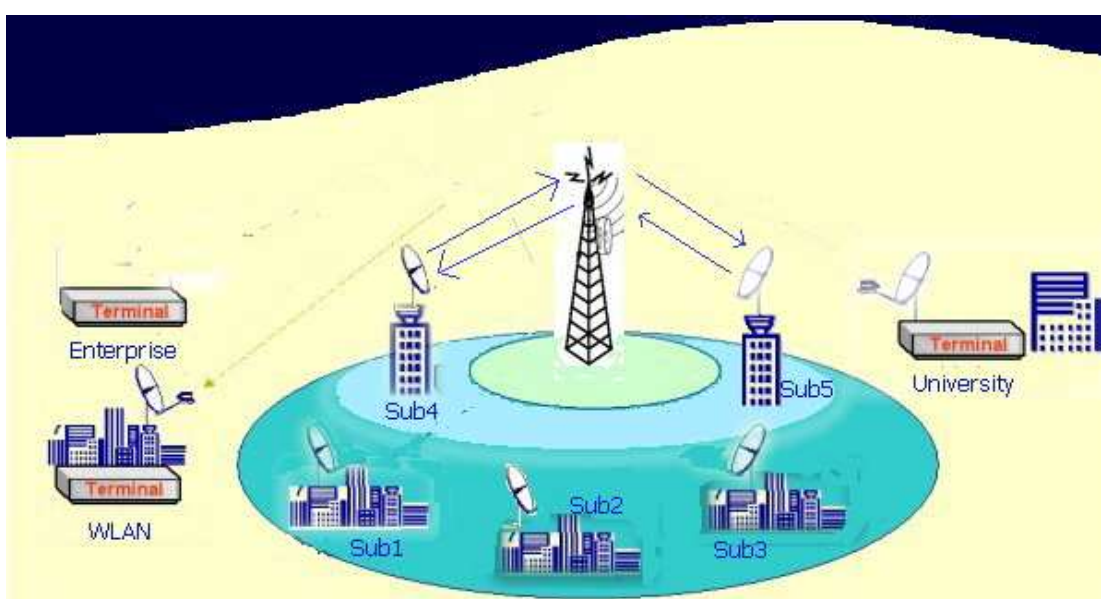
Figure 1-1 *DVB-T/RCT system schemes*

Figure 1-2 describes a system model for terrestrial interactive networks which provide interactive services by using both DVB-T and DVB-RCT standards. There are two channels between the service providers and the end users. One is a unidirectional broadband channel for broadcasting digital TV programs from the service provider to the user (broadcast channel). The other is a bi-directional channel for interaction purpose (interaction channel). The interactive system consists of a forward interaction channel (downstream) conveyed to the user via a DVB-T compliant terrestrial broadcast network, and a return interaction channel based on a wireless VHF/UHF transmission (upstream) of the same type. The downstream transmission from the base station provides synchronization, ranging, and allocation information to all terminals (RCTTs). This kind of information is very important because they allow RCTTs to synchronously access the network and then to transmit upstream

synchronized information to the Base Station.

The DVB-RCT system obeys the following rules: [**12**]

- Modulation scheme is OFDM for both downstream (fully DVB-T compliant) and upstream; therefore, several parallel carriers are available in the upstream to be allocated to different users, in different time slots, for transmitting data and commands back to the base station.
- Each authorized RCTT transmits one or several low bit rate modulated carriers towards the base station,
- The carriers are frequency-locked and power ranged and the timing of the modulation is synchronized by the base station.
- On the Base Station side, the upstream signal is demodulated, using a FFT process, just like the one performed in a DVB-T receiver.
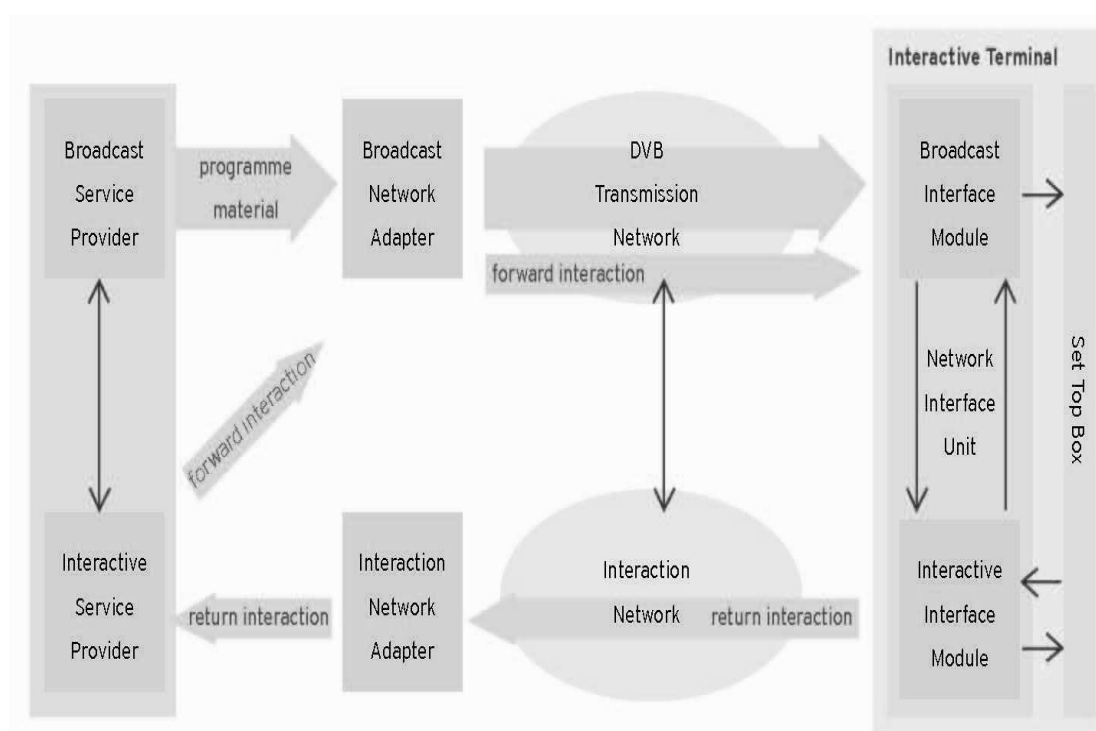
Figure 1-2 *Conceptual block diagram for terrestrial interactive networks*

To allow access by multiple users, the return terrestrial channel is partitioned both in the frequency domain and the time domain. A set of time-frequency slots are created by this kind of channel partitioning. This partitioning becomes a powerful way to share the RF source between RCTTs. Each available time-frequency slots can be allocated to a certain user under the control of the Base Station. Multiple slots

allocation is possible (both on the same carrier and onto different parallel carriers) to cope with bandwidth peak demands. To avoid any interference between users, the system provides two options: one is to use a Nyquist filter or to arrange the sub-carriers as orthogonal and the other is to separate symbols by inserting Guard Intervals. These two methods are exclusive and correspond to two scenarios of exploitations: large or small size transmission cells. The DVB-RCT standard provides several partitioning characterized by their carrier spacing (~1 kHz, ~2 kHz, ~4 kHz), then the symbol duration (~1 ms, ~ 0.5 ms, ~0.25 ms). These three basic modes refer to the downstream DVB-T reference clock. Accordingly, the DVB-RCT system can be used in every country around the world whatever the channel raster they operate (i.e.: 6, 7 or 8 MHz channels). Furthermore, the DVB-RCT channel can be equipped with either 1024 or 2048 carriers. Due to the three carrier spacings offered, the bandwidth of the DVB-RCT channel can be 1 MHz or 2 MHz or 4 MHz or 8 MHz (or more precisely, 1/8, 1/4, 1/2 or 1/1 of the RF channel raster bandwidth). In short, in addition to its intrinsic spectrum efficiency, the DVB-RCT uses any unused or under used megahertz of spectrum, to provide a DVB-T return path.

In the interaction system, service providers send the data to be broadcasted to the DVB-T transmission sites. TV signals and the interactive data are encapsulated into MPEG-2 (Motion Pictures Experts Group) packets and send via DVB-T network to end user terminals. The terminal provides interface for both the broadcast and the interaction channels and sends information to different devices. The user sends the interactive response back to base station via DVB-RCT network, and finally reaches to the service provider.

1.3   State of the art

Based on the excellent features of DVB-RCT, many applications can be implemented by using DVB-RCT as the network uplink. In order to make the DVB-RCT technique match the specific situations, different design parameters must be determined. The architecture of the total system depends on many factors such as: the situation of the existing network (whether there is already a DVB-T network), local geographical character, Quality of Service requirements, desired coverage area, expected bit rate, user density (hotspot). Nowadays, many people are focusing on many projects and trials for this standard to test the effects of different parameters on the total system. On the other hand, the efforts are not only focus on the system, but also on the device and chipset. And these efforts can be divided into the following aspects:

Digital TV broadcast. Broadcaster expects to use the total broadcasting network as efficient as possible. As the uplink of the interactive digital TV network, DVB-RCT can be integrated in the total broadcasting network. In this kind of applications, DVB-RCT needs to have the same coverage area as DVB-T, but with very low bit rate, since the applications implemented in the interactive broadcast system are very simple and easy to be accomplished. These interactive services can have long delays (e.g. E-health, E-announcement, E-education, E-quiz, E-mail, Tele-voting, Tele-advertisement etc.) and low bit rate. And the responses of the end use are occasionally. So the DVB-RCT system can be very simple and can have very large coverage area. The only thing must be considered is the system ability to cope with a large number of simultaneous connections.

One of the exciting trends is that DVB-RCT is used not only for indoor fixed usage, but also for outdoor, portable trials are in process. With the design and the test of portable CPEs, the goal of enjoying interactive digital TV programs in everywhere can be realized very soon.

Tele-communication. Tele-communication service provider expected to use the most optimistic technology to realize all their services. DVB-RCT offers them a very good opportunity. The demands of these services (TV Internet Browsing, Video on Demand, Voice-Over-IP, Video Conference, network game, Audio-talk) are almost the same, which is very high data bit rate in populated areas. Since the architectures of the DVB-RCT are very similar to cellular networks in these kinds of applications, the DVB-T/RCT base station need less output power than used in digital TV broadcast. Hence it will have smaller coverage area and the total users in the cell can be less compared with the broadcast users. In this kind of applications, system capacity and channel interferences are the main factors to be considered.

Using DVB-RCT in moving situations to realize wireless communications is fascinating in the last couple of years. Many trials are in process. In this application, the size and the power consumption of the CPE are very important. Furthermore, the Doppler shift will affect the performance greatly. And some special antenna should be used to compensate the lost.

Silicon solutions. Designing and manufacturing low-cost integrated interactive terminals for digital terrestrial TV and other telecommunication applications based on DVB-RCT technology is another direction for DVB-RCT technique development.

Some companies even developed embedded solutions for DVB-RCT Set-top-box (STB). So the DVB-RCT can be implemented in many portable devices, such as laptops, palmtops and many internet appliances. These solutions can integrate the digital part, base band part and media access controller onto a single board, eliminating a large number of I/O pins thus reducing board complexity, size and manufacturing cost. There already have many system-on-board base station and system-on-chip terminal products or prototypes.

1.4   *Problem Definition*

DVB-RCT is a very promising candidate to provide broadband wireless connections (BWC). However, the real possibility cannot be gotten from current standard and documentations. Further research and analyze are needed to verify the actual performance of the DVB-RCT system as the uplink in different scenarios. On the other hand, as the broadband wireless connection standard, DVB-RCT faces several existing counterparts, such as DVB-H, DVB-RCS, WiMAX, GSM, and WCDMA. Systematic analysis on these standards can help understand the real value of DVB-RCT in wireless communication. Besides, the market prospect must be considered as a very important aspect.

Only theoretical analysis is not enough. Based on the dedicated design, both lab and field test of DVB-RCT wireless communication system will give more information. Base on the real system, the actual value of the DVB-RCT will be estimated, and the effect of several factors such as (the type of antenna, the output power of the transmitter, noise and modulation mode) on coverage area and transmission capacity. Moreover, the actual feasibility of the DVB-RCT used in broadband wireless connection can be verified by implementing real telecom services, such as VoIP, FTP, VOD services. So carry on these services has great significance.

Last but not the least, as mentioned in the previous paragraph, Wi-Fi (IEEE802.11b/g) is a very hot topic and exists nearly everywhere. Normally, the Wi-Fi and the DVB-RCT system will be put together to form the total wireless access. So the effect of the hotspot on the up-level wireless communication systems, especially on DVB-T/RCT systems, needs to be analyzed.

1.5   Scope and Contributions

This master thesis is intended to verify the feasibility of the DVB-RCT to act as the uplink of the wireless interactive data transmission system. In order to fulfill this goal, MAC and PHY layer of the DVB-RCT standard is analyzed and some important parameters are compared with those of WiMax and DVB-H. Furthermore, the market prospect and the possible applications of these candidate standards are discussed. Based on all above theoretical research, a real wireless system is integrated and the self-designed lab and field tested are implemented. Finally, explanations are given for the results which are obtained in the tests.

The content of this master thesis is as follows:

Description of possible applications of candidate BWA standards: Some proceeding projects trialed on DVB-RCT will be introduced. Furthermore, some kind of promising applications that can be implemented by DVB-RCT will be analyzed. The analysis includes the implementation feasibility, cost, performance, and the markets. Besides discussing the applications of DVB-RCT, some applications using WiMax and DVB-H will be introduced. And the possibility of replace these methods with DVB-RCT will be presented.

Comparison of DVB-RCT, WiMax and DVB-H standards: Since all of these three standards use the OFDM modulations, there will be much similarity both in their MAC, PHY layer, and transmission specifications. However, there are different standards for different purpose, so there must be some apparent distinguishes among them. Both the similarity and the difference (modulation specification, data bit rate, coverage area, transmission mechanism) will be discussed in the following chapter. And the same situation appears in the data transmission systems (transmitter and receiver output power, linking budget, working frequency, network architecture, mobility and integration).

Analysis of published test: In order to compare several broadband wireless access standards not only on theoretical level but also on practical level, it is necessary to collect and analyze some test methods and results for WiMax and other standards. One IP traffic test for ATSC (Canada) interactive data transmission system and one traffic models and streaming media applications test for WiMax (USA) wireless system are described and analyzed. Some other published test methods will be simply

mentioned.

Integration of DVB-RCT wireless communication system and its test: Using Runcom's DVB-RCT base station and CPE, a simple wireless communication system is created. First, by using IP traffic quality measurement software D-ITG in Linux operating system, the performance of this system can be verified. Two types of traffic pattern (UDP and TCP) are implemented and several parameters (throughput, bit rate, round trip delay, jitter and packets loss) are recorded and analyzed. Second, the same system is tested in the real environment. Besides the previous lab test contend, some kind of typical broadband services are tested in this system, such as ftp download and upload, internet browse and Voice on IP. Both line-of-sight and none-line-of-sight situations are tested. Finally, a WLAN will be added to the DVB-RCT terminal and the same services are tested on DVB-RCT systems. The effect of hotspot on DVB-RCT system will be got.

Test result analysis: Based on the test record, the performance of the DVB-RCT system will be obtained. Compared with the published test results of other standards, the value and significance of applying DVB-RCT to broadband wireless access can be got.

This master thesis is organized as follows. Chapter 2 contains a brief description of the application scenarios of several wireless communication standards. (DVB-RCT, WiMax, DVB-H). Chapter 3 includes the comparison of DVB-RCT and WiMax standard. The comparison is emphasized on important parameters, MAC layer and PHY layer. Chapter 4 is a brief introduction of some published tests. These tests include DVB-RCT, WiMax and ATSC interactive data transmission systems. Chapter 5 is the description of self-designed lab and field tests of the DVB-RCT system (based on Runcom hardware) with actual applications. Chapter 6 is the analysis of the test result and the comparison of the result with some similar result got from the WiMax test.

2 Application scenarios

DVB interactive wireless communication systems are intended to broadcast digital TV, but because of its fascinating performance, this system can have the same function as other wireless data transmission system. This chapter describes some up-to-date applications for wireless data transmission system and some possible scenarios for implementation of DVB system are introduced.

2.1 Broadcast scenario

2.1.1 System description

DVB-T and DVB-RCT are bidirectional wireless communication systems which can support many applications. The original purpose of these interactive systems is the digital TV broadcasting. Both standards regulate the two systems work in VHF/UHF bands, that is between 470~860 MHz, so the transmission and reception of the digital TV signal can use traditional TV reception antennas. Figure 2-1 show the structure of the interactive digital TV broadcasting system.
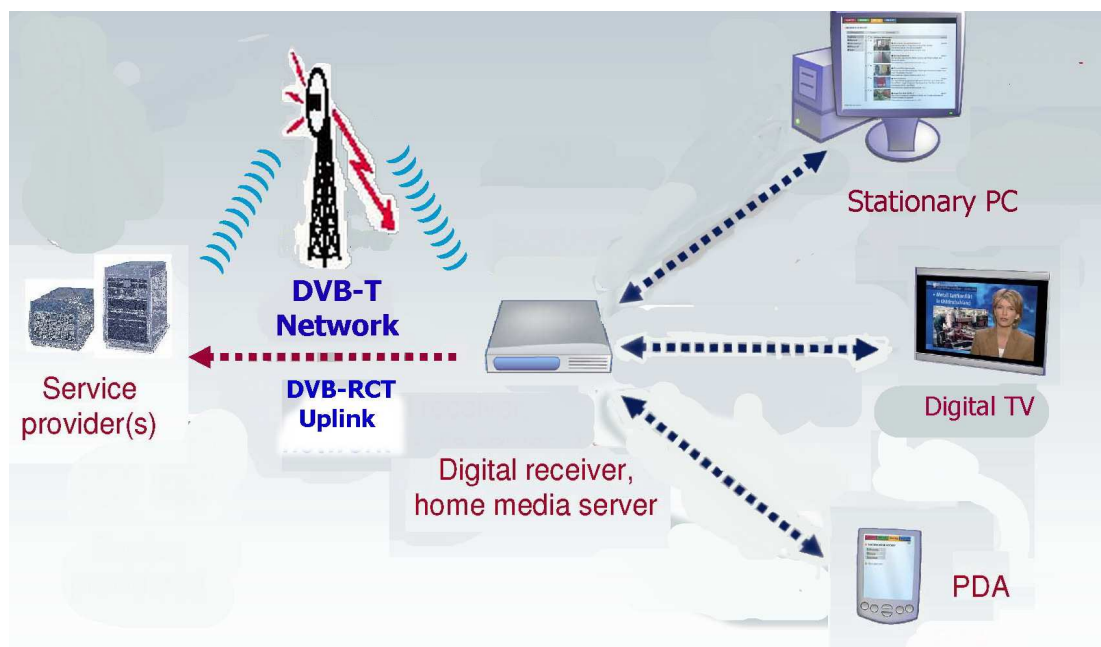
Figure 2-1 *Structure of the interactive DVB broadcasting system*

DVB-RCT uses OFDMA technique to partition the RF channels both in time and

frequency domain, provide a matrix of time-frequency slots. Each time slot is divided the specific frequency band into set of carriers which is called sub-channels. So a certain number of users can send requests or information to the base station simultaneously. All this mechanism is controlled by the Media Access Controller at the base station and the necessary control information such as the amount of slots used both in time and frequency domain will passes through the downlink to end users.

Figure 2-1 describes the structure of the interactive DVB broadcasting system. The digital TV program will pass through the DVB-T network to the end use terminals. A part of the downstream and the DVB-RCT network form the interactive channels. Necessary control information go by the downstream to the digital receiver and the user's feedback the any kind of request will send back to the base station. For the digital receiver (STB), it can serve as a media server. After various modifications, it can offer digital programs not only to digital TV but also to stationary PC, hand-held devices such as PDA etc.

2.1.2   Up-to-date broadcasting applications

DVB-T system is now deployed in many European countries, so there are various applications for interactive digital TV. Some of them are combined with other services from different systems.
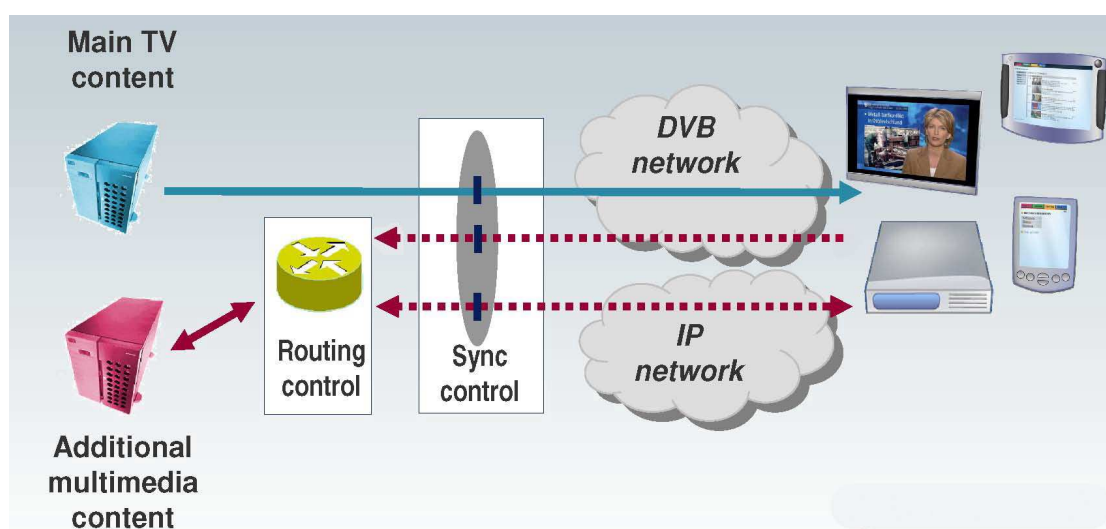
Figure 2-2 *DVB network supplement with IP network*

The interactive digital TV system now can offer traditional interactive services such as VOD, E-advertisement, E-education, E-game service. In the last couple of years,

some promising services are coming into view. One of these new services is video streaming with supplementary AV content over broadband IP network.

Live or recorded streaming over broadband IP is a very popular service these days. But because of the throughput limitation of IP network, a small number of viewers can enjoy the program simultaneously. To solve the problem of server overload because of the peak traffic, using DVB-T network to transmit video stream and using DVB-RCT and IP network to offer supplementary information is a fascinating solution. This application not only reduces the IP network peak traffic but also increases the efficiency of DVB bandwidth use. However, the synchronization control of different networks is a crucial problem, harmonize three different network will increase the system complexity. Future working should be done to make this application more promising.

2.2 Broadband Wireless Access Scenario

2.2.1   System description

DVB-T/RCT system is a digital interactive broadcasting system. That mean they are an asymmetric wireless communication system. For this reason, DVB-T/RCT can be implemented as a broadband wireless access method and used in many scenarios.

Figure 2-3 shows the system structure of the DVB-T/RCT broadband wireless connections. A DVB wireless service provides communication paths between a subscriber site and a core network (the network to which DVB-T/RCT is providing access). Examples of a core network are the public telephone network and the Internet. DVB standards are concerned with the air interface between a subscriber's transceiver station and a base transceiver station. From subscriber side, a subscriber first sends communication request to base stations, after get the permit to use certain resources the subscriber sends wireless traffic at a speed ranging from several hundred kilobits to several ten megabits per second from a fixed antenna on the roof of a building or on the top of a moving vehicle. The base stations receives transmissions from multiple locations and sends these traffic over wired or wireless link to a switching center. The switch center sends traffic to ISP or the public switched telephone network. From service center side, the specific application will transmit from base station to end user CPE by the DVB protocol. Base station not only transmits and receives information but also sends synchronization and acknowledgment to subscribers. When the

information arrives at the subscriber, CPE will use wired or wireless methods to connect to wireless router and then the LAN or WLAN will send the applications to all users.[13]
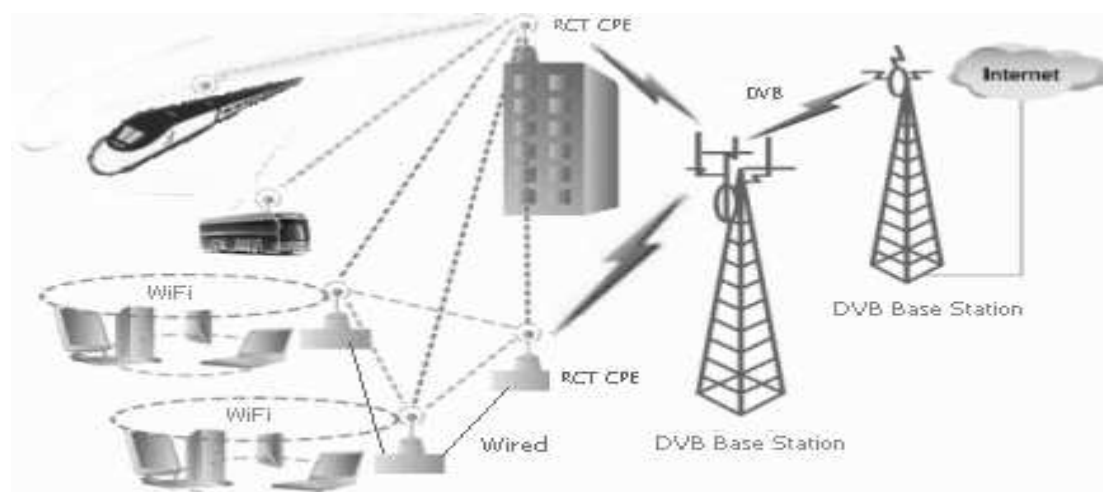
Figure 2-3 *DVB Broadband wireless communication system*

2.2.2   Up-to-date wireless communication scenarios

Wireless communication is very popular these days, not only the WLAN technique has already matured, but also WMAN technique is under way. For the Residential Community, WMAN can offer Business/Residential wireless Access and Data&Voice Backhaul. For the Public Hot Spot, WMAN and WLAN can offer high-capacity point to point or point to multipoint connections. For enterprise, WMAN can offer last mile access. All these applications can make a revolution in the format of telecommunication. People can enjoy very ease, fast and flexible service with very low cost.

Besides all applications mentioned above, one application – 'internet on board' is the main up-to-date applications for public transportations nowadays. And many wireless communication methods are implemented in this application. And the result is very fascinating. However, DVB-RCT has not been used in this kind of applications, the principle of these technologies is the same, and the implement methods can be used by DVB system.

Figure 2-4 shows the function of the wireless communication methods in the 'internet on board'. To offer stable and fast internet service on board, the most appropriate

access method should be carefully considered. Since the reception target is always in moving, the effect of location shift as well as the changing geographic situation in time must be considered.

There are three scenarios that have already been implemented. First one is just use satellite as the communications linkage. Both the downlink and the uplink pass through the satellite. The main advantage of this method is the moving effect can be neglect because the satellite is high enough to conquer the small location shift. Moreover, satellite communications can offer pretty fast and stable wireless communications. But this method has apparent disadvantages: price. The cost of this kind of satellite communications is very high. The channel is expected to be occupied all the time no matter whether the specific channel is been used. So, spread 'internet on board' using this method in public transportations is not feasible. Second one is using the hybrid network of both satellite and GSM or 3G network. Some companies just use the GSM or 3G network as the false system of the total communication system, the main task is done by satellite, GSM and 3G network take effect only when satellite can not satisfy the specific conditions. Some other companies have developed
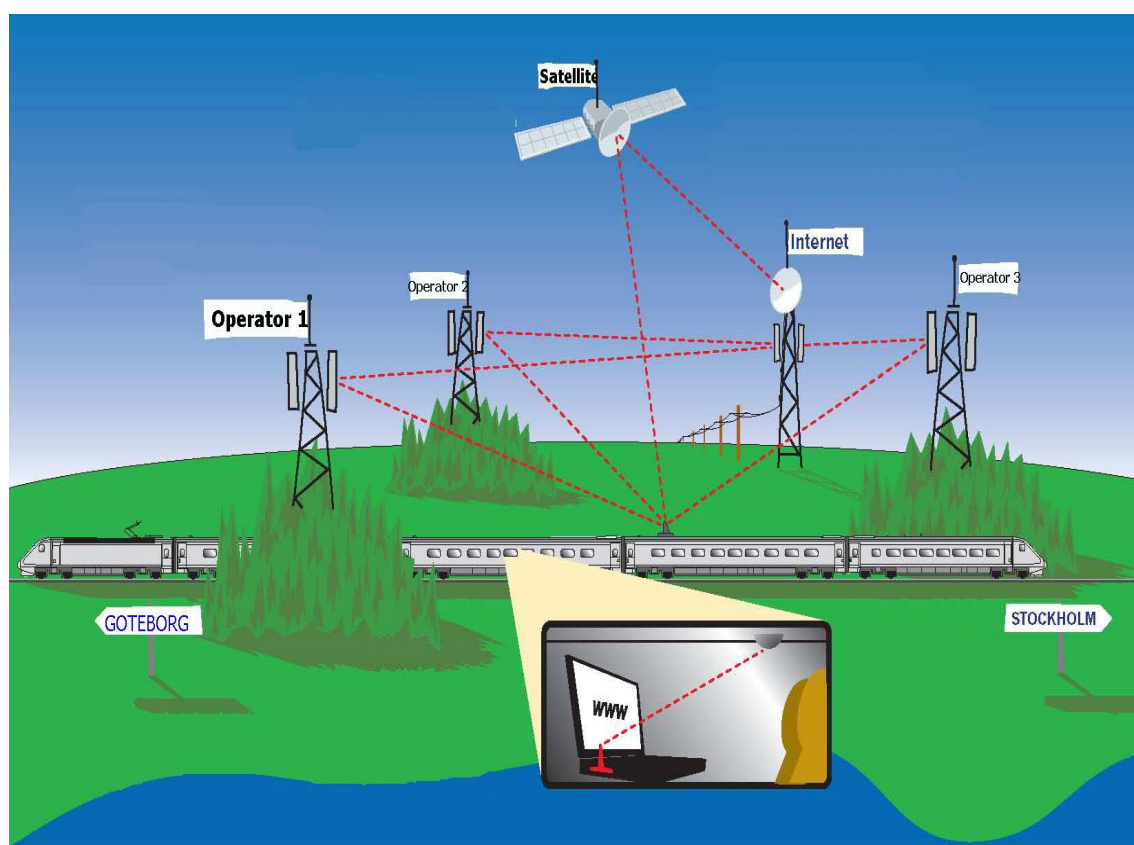
Figure 2-4 *Function of 'Internet on Board'*

some kind of wireless communication system which uses GSM and 3G network as the downlink and satellite as the uplink. This kind of network uses the existing mobile

network and just updates some part to match the internet on train. This method can reduce the total cost of the system and nearly have no problem of moving effect because of the sufficient of the mobile network. But this kind of implementation has its own problem. That is the bandwidth of the GSM network sometimes does not match de demand of the customer. The internet realized by these hybrid networks is not actually the broadband internet on board.

The third one is also a hybrid networks comprised of satellite and WiMAX. The WiMAX acts as the downlink and the satellite acts as the uplink. We all know that WiMAX can have very high transmission speed up to several ten megabits, so this scenario can realize the real broadband internet on board. But there is no WiMAX network in Europe or many other countries. To fulfill this goal, the entire network infrastructures have to be built. Furthermore, it is the mobile wireless communications, to compensate the moving loss, more base stations and costly smart antennas have to be used, so the total cost of the network will be very high.

2.2.3   Possibility of using DVB-T/RCT

Because of the drawbacks of all the above technology mentioned in section 2.2.2, the 'Internet on Board' has not prevalent up to present. As the wireless communication standards, DVB-T/RCT systems have strong possibility to be used in this field and the market prospect is very promising. Drawing this conclusion is based on the following reasons:

First, The customers on board always use the service which needs high speed in downlink but pretty low speed in uplink, such as surf the internet, download files, sending email, voice-on- IP and even video-on-demand. And DVB-T/RCT is asymmetric wireless communication system. The DVB-T downlink can offer enough bandwidth for transmitting data even for the video stream. And DVB is an always on system. This application can increase its efficiency. This feature matches the situations of the "Internet on Board" service perfectly. So, it can realize the real 'Broadband on Board'.

Second, in most European countries, the DVB-T network has already existed. So, to create the wireless communications system for 'Internet on Board' only needs to upgrade the DVB-T network with DVB-RCT module block. The total cost of the downlink and uplink infrastructures is very low. Even considering the compensation of the moving loss for the high speed train, there is several more base stations to be added into the total network, the cost will be much lower than other techniques, such as WiMAX and satellite.

Third, DVB-RCT is a very efficient, simple wireless standard. It can be integrated to portable or mobile devices. Because it works in pretty low frequency compared with

WiMAX, GSM and satellite, it can prevent the moving effect more easily than those techniques. Moreover, DVB-RCT needs very low power to create and maintain connections, so this technique is very suitable to amount on board not only on train, but also on bus and ship etc.

But there still exists some problems to hinder the development of the DVB-RCT. First is the cost of the base station and CPE. No large companies have claimed to support DVB-RCT and this standard are now just in trial. So the production mount of the base station and CPE can not increase quickly. This will make the price keep in very high lever. So decreasing the price of DVB facilities to a reasonable level can not be realized until some big counterparts begin to love this technique. Second, there is no specific regulation in the standard to describe the wireless communication, such as hand over mechanism, Doppler shift compensation, antenna usage. More efforts should be done to consummate DVB-RCT standard, especially the part of solving the problems in moving situations.

3 Comparison of DVB-RCT and WiMAX

Among the new generation of broadband wireless access standards, DVB-RCT and WiMAX are two promising candidates for the uplink of the wireless communication system. Both of these two standards use the OFDM modulation technique, so they have many similarities in several aspects, such as in standards specification and in the architecture of the real system. But on the other hand, they should also have many differences. Comparing these two techniques in details is very useful for the evaluation of the feasibility of the DVB-RCT as the uplink of the broadband wireless access, especially in the moving situations. In this chapter, besides the theoretical comparison of these two standards, the performance of them as the uplink for the broadband on board will be discussed.

3.1 OFDMA theory and WiMAX overview

3.1.1   OFDMA theory

The concept of using parallel data transmission by means of frequency division multiplexing (FDM) was accomplished in mid 1960s. And the origin of this concept can be tracked around 1950s in USA[14]. The idea of this concept is to use parallel data streams and FDM with overlapping sub-channels to avoid the use of high speed equalization (cancel the frequency dependent attenuation of inter-symbol-interference) and to prevent impulsive noise, and multi path distortion as well as to completely use the available resource of frequency. The initial applications were in the military communications. In the telecommunications field, OFDM is often combined with the discrete multi-tone (DMT), multi-channel modulation and multi-carrier modulation (MCM). In OFDM, each carrier is orthogonal to all other carriers. However, this condition is not always maintained in MCM. OFDM is an optimal version of multi-carrier transmission schemes.

In a conventional serial data system, the symbols are transmitted sequentially, that means each data symbol is allowed to use the entire available bandwidth. In a parallel data transmission system several symbols are transmitted at the same time, which offers possibilities for alleviating many of the problems encountered with serial systems. In OFDM, the data is divided among large number of closely spaced carriers. This is called "frequency division multiplex". Actually, this is not a multiple access

technique, since there is no common medium to be shared. The entire bandwidth is filled from a single source of data. Data is transferred in a parallel way not in a serial pattern. Only a small amount of the data is carried on each carrier, and by this lowering of the bit rate per carrier (not the total bit rate), the influence of inter symbol interference is significantly reduced. In principle, many modulation schemes could be used to modulate the data at a low bit rate onto each carrier. It is an important part of the OFDM system design that the bandwidth occupied is greater than the correlation bandwidth of the fading channel. Then, although some of the carriers are degraded by multi-path fading, the majority of the carriers should still be adequately received. OFDM can effectively randomize burst errors caused by Rayleigh fading, which comes from interleaving due to parallelization. Because of this, many symbols are only slightly distorted instead of completely damaged. Because of dividing an entire channel bandwidth into many narrow sub-bands, the frequency response over each individual sub-band is relatively flat. Since each sub-channel covers only a small fraction of the original bandwidth, equalization is potentially simpler than in a serial data system. A simple equalization algorithm can minimize mean-square distortion on each sub-channel, and the implementation of differential encoding may make it possible to avoid equalization altogether. This allows the precise reconstruction of majority of them, even without forward error correction (FEC). Furthermore, the effect of delay spread can be reduced by using guard interval.

OFDM can be simply defined as a form of multi-carrier modulation where its carrier spacing is carefully selected so that each sub-carrier is orthogonal to the other sub-carriers. As is well known, orthogonal signals can be separated at the receiver by correlation techniques; hence, inter symbol interference among channels can be eliminated. Orthogonal effect can be achieved by carefully selecting carrier spacing, such as letting the carrier spacing be equal to the reciprocal of the useful symbol period.

The exciting transmission characteristics of OFDM for wireless communication promoted the development of OFDM-based multiple access systems. In the OFDMA mechanism, the OFDM symbol is divided into different sub-channels and can be accessed in specific instants of time. So the time and frequency are divided into a set of mutually orthogonal rectangles. The total system can be seen as the combination of TDMA and FDMA. The following picture (Figure 3-1) shows the basic relation of frequency and time parameters:
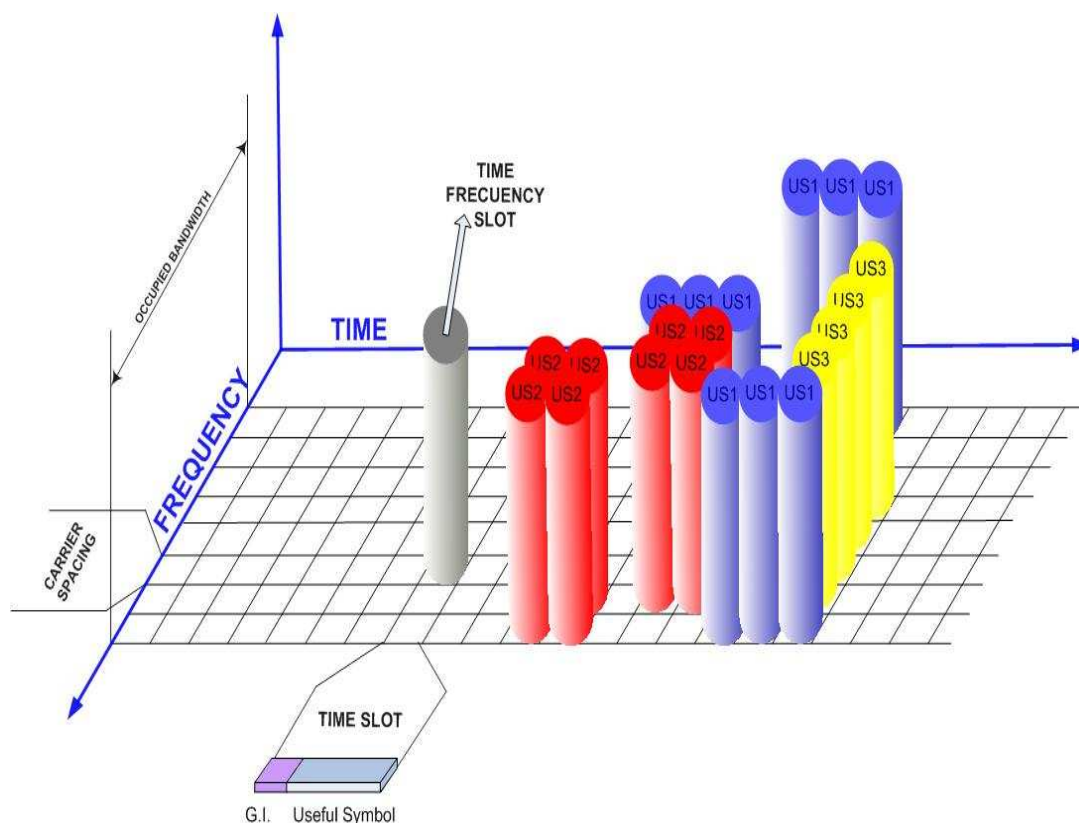
Figure 3-1 *Relation of time and frequency in OFDMA*

The graph shows that two important parameters will determine the capacity of OFDM to transmit data. One is the number of sub-carriers per OFDM symbol, the other is the time duration for one burst structure. In principle, it is not necessary that the sub-carriers are adjacent to form the sub-channel. So, OFDM modulation provides a very flexible organization structure and offers the maximum time and frequency diversity.

3.1.2   WiMAX technique overview

WiMAX is a new standard being developed by the IEEE that focuses on solving the problems of point to multipoint broadband outdoor wireless networks. The core functions of a fixed that means stationary. WiMAX system is to provide network access to buildings. In a home or small business, WiMAX will compete with cable or DSL networks. In a mid-size commercial building, WiMAX can support high-data-rate connections that might otherwise be available only with a fiber-optic line. Figure 3-2 shows the basic function of the WiMAX as the broadband wireless access method.

IEEE Standard 802.16-2001 defines the Wireless MAN air interface, a single-carrier

(SC) modulation scheme for 10-66 GHz operation. At these frequencies, only line-of-sight communication can be realized, but in the following standards such as IEEE 802.16e, the none-line-of-sight function has been added. In WiMAX standards, tremendous spectral allocations such as 1.3 GHz of spectrum are available. The standard takes full advantage of the allocations, specifying bit rates of up to 120 Mbps on each reusable 25 MHz channel because of the OFDM modulation. [13]
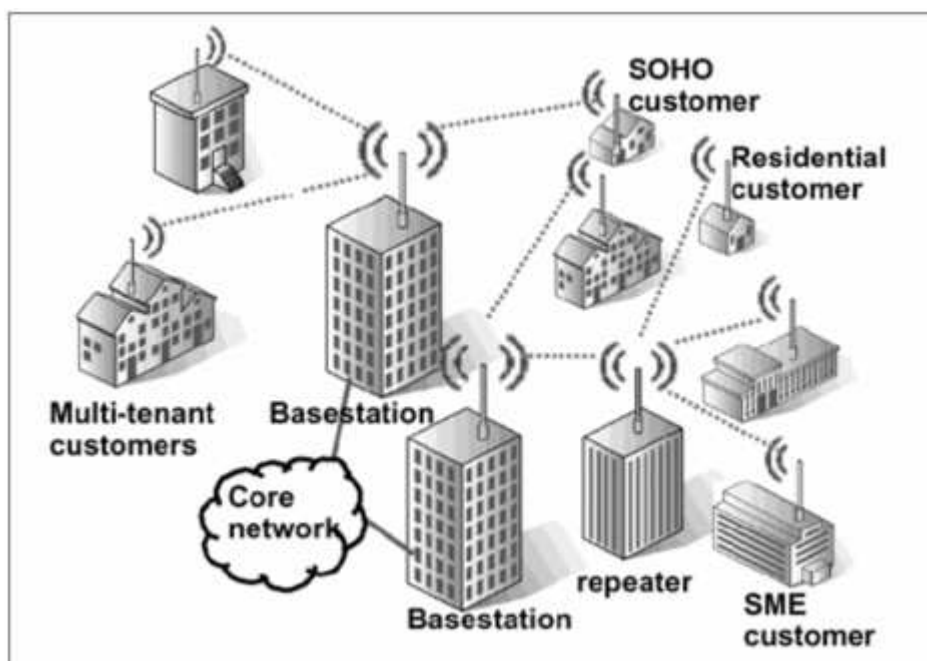
Figure 3-2 *Basic function of WiMAX as BWA method*

As mentioned before, the primary markets of WiMAX include industrial, commercial, and multi-tenant residential buildings. The opportunities for the success of such operations are now being demonstrated all over the world and the availability of standard equipment is sure to be verified.

From the previous description of DVB-RCT and WiMAX, the difference of the first generation and the next generation broadband wireless network are clear. First generation networks were designed by applying cable modem technology to create a wireless communication solution. The corresponding networks have substantial performance limitations and restrictions on their deployment, generally due to the following two technical issues: [13]

● **Poor response to link impairments:**

First generation systems do not respond well to rain fades, obstructions, or non-line-of-sight (NLOS) conditions. They require very tall base station antennas and line-of-sight (LOS) access to all of the customer-premise equipment (CPE).

● **Poor response to co-channel interference:**

Wireless systems, particularly in unlicensed bands, have to cope well with co-channel interference, but the first generation systems can not satisfy this requirement.

● **Other limitations:**

In addition, first generation networks also suffer from other limitations, such as the power consumption of the system, the cost of base station and CPE equipment and high installation expenses.

Because the market for broadband access is as strong as it ever has been, it is now a challenge for the next generation of wireless networks to overcome the limitations of the first generation of equipment and compete effectively with terrestrial, DSL, cable, and satellite technologies. Next generation BWA networks are being designed to address the limitations of first generation networks, using a combination of several technologies, all of which require high performance, flexible signal processing subsystems. For the new generation of wireless systems such as DVB-T/RCT and WiMAX, they have the following features:

● **Modulation Techniques:**

The most advanced developments utilize adaptive modulation schemes to improve the quality-of service (QoS). Lower order modulation schemes, such as QPSK, can be used when the linking loss are very high, and higher order schemes such as 64QAM can be used when linking loss are very low. This helps a BWA base station to dynamically adapt to changing conditions for each subscriber to ensure a specified QoS.

● **Adaptive coding Techniques:**

Forward Error Correction (FEC) coding introduces overhead and as a result reduces the payload data in a wireless system. In ideal conditions, it is optimal to use lower order FEC coding to increase the payload data throughput, but when impairments are high, it is desirable to switch to higher order FEC coding to ensure a specified QoS. Many next generation BWA systems are employing adaptive coding schemes to optimize their throughput and maintain a high QoS.

● **Interference Mitigation:**

Interferences in BWA systems include obstructions, rain fades, and co-channel interference from other transmission sources. Many new systems are utilizing smart antenna techniques, including adaptive beam forming, to increase the signal-to-noise ratio, cancel interfering signals, and increase the coverage area of BWA base stations.

3.2 Comparison of DVB-RCT and WiMAX

3.2.1 MAC layer comparison

Although DVB-RCT and WiMAX are different broadband wireless access standards, they have many similarities both in the standards specification and system implementation because of using the same modulation technique. From standards point of view, MAC layer specification is a very important part because it provides services to the higher layer protocols that enable transparent and independent control of the transmission and reception of data from physical layer. There are many commons in DVB-RCT and WiMAX MAC layers:
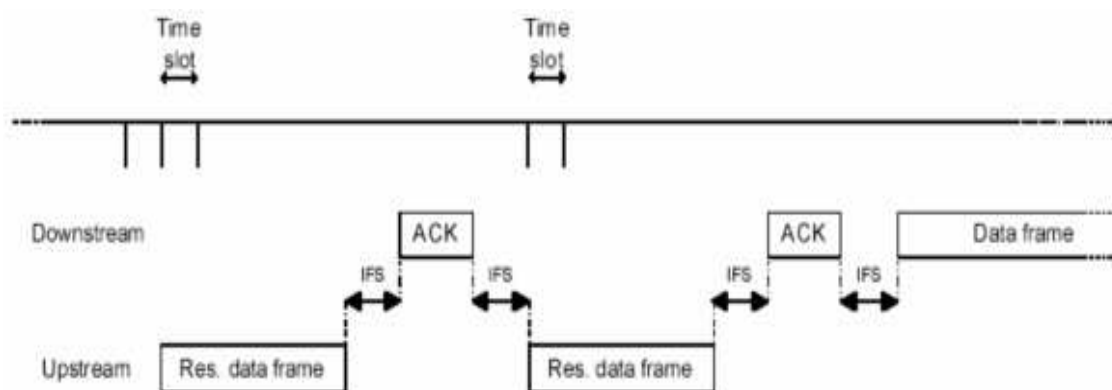
Figure 3-3 *Reservation-based access mode*

● Bandwidths in both downstream and upstream directions are controlled by base station: The upstream physical layer access method is based on the use of a combination of Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA). That means the upstream is divided into a number of "time slots". Each time slot is then divided in the frequency domain into sets of carriers defined as sub-channels. The MAC layer controls the assignment of resources (sub-channels and time slots) by resource request and grant message.

The MAC is carried out through messaging in a nominated downstream channel. For DVB-RCT, MAC layer uses the default configuration message, transmission control message and re-provision message to realize the resources assignment. For WiMAX, MAC layer uses uplink channel descriptor message and uplink map (UL-MAP) message to realize the resources assignment.

● Upstream multiple access methods of these two standards allow both contention and reservation-based data transmission.

● Both standards support variable-length packets and collision avoidance to enhance MAC efficiency: As mentioned above, the MAC specification allows the packet size larger and smaller than the ATM cells, and both contention and reservation-based access modes have collision avoidance mechanism to handle multi-subscribers access the same resource simultaneously.

● MAC can support IP, ATM and other kinds of traffic: Higher layer services are provided by the Interactive Network Adapter (INA) to the Set Top Unit (STU). The INA is thus responsible for indicating the transmission mode and rate to the MAC layer for each type of service and MAC translates these specifications to the uniform standards format (for DVB-RCT, changes to ETSI EN 301 958 specification; for WiMAX, changes to 802.16 specification).

But there still exists some difference in the MAC specifications: In the WiMAX MAC specifications, certain kinds of services such as asynchronous service, synchronous service and MSDU ordering have regulations in details. But in DVB-RCT standard, there is no such kind of specifications in MAC layer. Furthermore, some kinds of scheduling, such as unsolicited granted service (UGS), mesh, WMAN are regulated in WiMAX standards but not in DVB-RCT standards. That is because DVB-RCT is originally designed to realize some kind of simple interactive applications such as polling, e-school and e-commerce. This purpose for the DVB-RCT may restrict its possibility to be used in the broadband wireless connections.

3.2.2   Comparison of Capability

The capability discussed here is mainly referred to throughput. Although both of these two standards use OFDM technique, there still exists some difference in the throughput because of the standard specifications and system architectures.

For the DVB-RCT, only burst structure 3 is discussed here because this is the most

commonly used transmission mode and it owns the highest capacity. The function of calculating the capacity is:

$$C_{taltal} = N_c \frac{1}{N_b N_s T_{symbol}} S_A S_b \tag{3-1}$$

where

C_{total} is the bit data rate of the DVB-RCT system in bits/s.

N_c is the number of sub-channels in the total bandwidth.

N_b is the number of burst structure per ATM cell.

N_s is the number of OFDM symbol per burst structure.

T_{symbol} is the time duration per OFDM symbol in μs .

S_A is the size of one ATM cell in bytes.

S_B is the size of byte in bits.

Table 3-1 *Data rate (DVB-RCT) in different modulation schemes*

ID	Modulation	Coding rate	Information bits/symbol	Information bits/OFDM symbol	Peak data rate (Mb/s MHz)
1	QPSK	1/2	1	24	0.70
2	QPSK	3/4	1.5	36	1.05
3	16QAM	1/2	2	48	1.40.
4	16QAM	3/4	3	72	2.10
5	64QAM	2/3	4	96	2.80
6	64QAM	3/4	4.5	108	3.25

Using equation 3-1, the ideal bit data rate for burst structure 3 in different modulations can be calculated. For example, if modulation scheme is OPSK; coding rate is 1/2; the number of sub-channels is 54 in 8MHz bandwidth; the number of burst structure 3 per ATM cell is 3; the number of OFDM symbol per burst structure 3 is 6

and the OFDM symbol duration in 8MHz, 2k carriers, 2k carrier spacing is 250us, the bit data rate is 5.68 Mb/s. Table 3-1 shows the different bit data rate in 6 modulation schemes.

Using the same method, the bit data rate of WiMAX can be calculated. One important parameter is used to compare the bit data rate of these two standards -- the peak data rate per MHz is used.

Table 3-2 *Data rate (WiMAX) in different modulation schemes [15]*

ID	Modulation	Coding rate	Information bits/symbol	Information bits/OFDM symbol	Peak data rate (Mb/s MHz)
1	QPSK	1/2	1	184	0.79
2	QPSK	3/4	1.5	280	1.20
3	16QAM	1/2	2	376	1.61.
4	16QAM	3/4	3	568	2.44
5	64QAM	2/3	4	760	3.26
6	64QAM	3/4	4.5	856	3.67

From the tables above, the feasibility to use WiMAX or DVB-RCT as the uplink of the broadband wireless access can be guaranteed. Both of them have very high data rate if using high order modulation and the data rate in the most robust modulation can match the demand. So, they can be used in many different situations with different QoS requirement. But there are several factors to lead to some difference about the throughput of these two standards. First, WiMAX usually uses 10~20 MHz bandwidth, but DVB-RCT can only own 8MHz, so the total throughput of WiMAX is higher than the DVB-RCT system. Second, WiMAX is a symmetric system, which means its uplink and downlink own the same modulation scheme; but for DVB-RCT, its modulation scheme is different from the downlink DVB-T. For example, the WiMAX can support 256 FFT in its uplink but DVB-RCT can not support this modulation scheme. So for the specification usage, DVB-RCT has to use some other

method to compensate the drawback of lacking necessary modulation scheme.

To get more accurate conclusions, some parameters must be considered such as guard interval, useful symbol duration etc. After some modifications, equation 3-1 can be changed to:

$$C_{capacity} = N_c \frac{1}{N_b N_s T_{symbol} (1 + GI)} S_A S_b R_u \qquad (3-2)$$

where

GI: is the guard interval,

R_u: is useful bandwidth ratio

But from the analysis above, if DVB and WiMAX use the same bandwidth, the performance of the two systems has little difference. So it is meaningful to compare these two standards even they have different designing purpose and different system structure (for DVB, it is an asymmetric system but for WiMAX, it is a symmetric system).

3.2.3   Comparison of link budget

An important part to implement a wireless communication system is link budget. Here, some factors which affect the uplink qualities will be analyzed to insure the network will meet expectations and operate optimally. Commonly, link budget is consisted of output power of devices, antenna gain, transmission loss and receiving threshold. Since the antenna is independent of standards, the analysis is mainly focused on output power of devices, transmission loss and receiving threshold.

3.2.3.1 Output power

The output power not only determines the communication quality and range of the wireless system, but also affects the possibility to implement portable and hand-held applications. It is necessary to check the output power of these two candidate facilities.

From the downlink point of view, the output power of WiMAX is from 20dBm to 35dBm and the average value is 28dBm; the output power of DVB-T is from 16dBm to 28dBm and the average value is 24 dBm. From the uplink point of view, the output power of WiMAX is from 17dBm to 24dBm and the average value is 21dBm; the output power of DVB-RCT is from 15dBm to 20dBm and the average value is 18dBm. So, the output power of DVB is less than WiMAX facilities both in the downlink and uplink. DVB system can reduce 10~15% of power consumption which is needed for

the WiMAX facilities. That means, in some sense, DVB-RCT is more adaptive to portable and hand-held devices. More over, large output power may lead to large interference when several transmitters worked together.

3.2.3.2 Transmission loss

For wireless communications, free space path loss is an important factor to affect the total transmission loss. For VHF/UHF signal propagates in free space (radio channel), the path loss model can be expressed by the following equation:

$$L_0 = \left(\frac{4\pi d}{\lambda} \right)^2 \tag{3-3}$$

where

$\lambda = cT_c = c / f_c$ (f_c is the signal frequency),

d is the distance between the transmitter and receiver,

So,

$$L_0 = \left(\frac{4\pi d f_c}{c} \right)^2 \tag{3-4}$$

Since, $c = 3 \times 10^8 m$, f_c is in GHz unit:

$$L_0 = \left(\frac{4\pi d f_c \times 10^9}{3 \times 10^8} \right)^2 \tag{3-5}$$

By taking $\log_{10}$ (log) of both sides of above equation to obtain the dB version

$$L_0 = 10 \log \left(\frac{4\pi d f_c \times 10^9}{3 \times 10^8} \right)^2$$

$$= 20 \log \left(\frac{4\pi \times 10}{3} \right) + 20 \log f_c + 20 \log d$$

$$= 32.4 + 20\log f_c + 20\log d \qquad\qquad (3\text{-}6)$$

If the system loss is considered, the loss equation will be:

$$L_t = \log(\frac{P_r}{P_t}) = \log\left(\frac{4\pi df_c}{c}\right)^2 - \log G_t - \log G_r + \log L_s \qquad (3\text{-}7)$$

Where:

G_t is the antenna gain of transmitter and G_r is the antenna gain of receiver,

L_s is the system loss factor.

Assuming that implementing the two standards use the same facilities which have same antenna gain and system loss factor, if the two systems work for the same area, the path loss is only related to the working frequency. For WiMAX, the RF part typically working at several GHz or even several ten GHz; but for DVB-RCT, the RF part typically working at several hundred MHz. There is a very huge difference of path loss between these two standards. Table 3-3 shows the difference in different working frequencies (assume DVB-RCT only working at 768MHz):

Table 3-3 *Path loss difference at several working frequencies*

Working Frequency WiMAX (GHz)	3.5	11	30	66
Difference of pass loss(dB)	14.2	23.1	31.8	37.8

From the table above, the advantages of DVB-RCT are very clear. It owns very little free space path loss comparing with WiMAX and can be act as an ideal solution for the wireless communication.

3.3 Doppler Effect

If the broadband on board service will be implemented by WiMAX and DVB-RCT standards, Doppler Effect must be considered because of the high speed of the moving target.

The Doppler Effect is the apparent change in the frequency of a wave when there is relative location change between the source of the wave and the moving target. So the

moving train is a typical instance to generate Doppler Effect.

If the target moves towards the stationary observer at a speed V_t and the target signal

frequency is f_t, the Doppler Effect can be expressed by the following equations:

$$f_{doppler} = f_o - f_t$$

$$= \sqrt{\frac{1 + v_t / c}{1 - v_t / c}} f_t - f_t$$

$$= (1 + v_t/c - \frac{1}{2}(v_b/c)^2 + \cdots) f_t - f_t$$

$$\approx \frac{V_t}{c} f_t \qquad (3\text{-}8)$$

where:

f_o is the frequency in the observer side,

c is the transmission speed of the signal and the motion is along the line of sight.

When the motion is in the arbitrary direction, the frequency in the observer side can be expressed by:

$$f_o = f_s \frac{1}{\sqrt{1 - v_s^2 / c^2}} \left(1 + \frac{v \cos \theta}{c}\right) \qquad (3.9)$$

where:

θ is the angle between target and observer. So, the Doppler Effect can be expressed by:

$$f_{Doppler} = f_o - f_s \approx v_s \cos \theta / c \qquad (3.10)$$

From the equation above, the fact can be got that the Doppler Effect is only related to the target speed and the frequency of source signal. As mentioned in previous chapter, WiMAX normally works on higher frequency than DVB-RCT. The higher the working frequency, the more Doppler Effect will be generated on the target. In order to realize the broadband on board, it needs more methods to conquer the Doppler Effect which may increase the total cost of the system.

3.4 Conclusion

From the analysis in this chapter, the conclusion is very clear. DVB-RCT and WiMAX are two promising candidates for broadband wireless access. Although DVB-RCT does not belong to the symmetric wireless communication system and does not have the same modulation scheme as WiMAX, it still owns very large coverage area and its data rate is comparable with WiMAX. Moreover, because DVB-RCT works on only several hundred mega hertz, the free space path loss and the Doppler Effect is much smaller than WiMAX. These advantages make DVB-RCT an idea method to realize wireless applications not only in the area with low population density but also in the area with DVB-T infrastructure exist.

If the production volume of the DVB-RCT base stations and CPEs can be increased, the cost of the infrastructure of creating the wireless communication system by DVB standards can be decreased greatly. Then the implementing the DVB-RCT to the practical areas can be realized.

4 Published Field Test

Since DVB-RCT standard has comparative advantages over other candidate standards in supplying the interactive services for DVB-T network, this promising technology has been greatly concerned in Europe and other countries since 2000. Some field tests were launched around the world, but only one of which was published. In this Chapter, the published WITNESS project is detailed discussed.

WITNESS (2000-2002) main mission was to validate the operation of a Terrestrial Return Channel service from field tests, by:
• deploying up-graded interactive wireless terminals in two test sites: Ireland (Dublin) and France (Rennes).
• developing spectrum planning and frequency usage recommendations for terrestrial TV services. [5]
WITNESS project for coverage prediction is divided into two parts:

1. DVB-RCT coverage with fix roof-top antennas
The objective of this measurement campaign was to verify that, even with a limited power of 1W (30 dBm), the upstream DVB-RCT transmission cell replicates the downstream DVB-T distribution one. Besides, to verify that the DVB-RCT receiver is able to demodulate a weak DVB-RCT signal, when located in a TV transmission site radiating kilowatts of TV signals. During the test process, some amazing news shows that DVB-RCT is so great, even beyond our expectation. The result demonstrates clearly that DVB-RCT services can be provided everywhere the DVB-T signal is available. What's more, even at the extreme border of the DVB-T service area (again up to 80 kms from the DVB-T downstream source), a successful DVB-RCT return transmission has been established using a transmitting power of 15 to 20 dBm, far below the maximum power level defined at 30 dBm.

Figure 4-1 *Field Test Van*

Figure 4-2 *Measurement Points Selection*

2. DVB-RCT coverage with indoor antenna

Two different base station set-ups have been built in Rennes urban area:
• The first one was using a base station located very close to the targeted urban area (Rennes);
• The second one was using a base station located 30 km away, with use of a co-channel 'return channel booster', close to the targeted urban area. [5]

Again the results of this DVB-RCT "indoor" measurement campaign have been extremely positive:
• Using the urban base station, 100% of the tested points have worked successfully, without requesting more than 20 dBm DVB-RCT power level. Globally, the attenuation from outdoor to indoor transmission is about 9 to 12 dB and it does not compromise the DVB-RCT suitability;
• The solution with a co-channel booster has also given excellent results. Giving a 95 dB amplification to the weak signal provided by the "indoor" DVB-RCT terminal, it has been retransmitted successfully to the distant base station. [5]

The result from the WITNESS project is extremely good, demonstrating that DVB-RCT is meeting the expected requirements in terms of coverage, both for fix roof-top and indoor antennas.

The conclusions that can be drawn from these WITNESS field trials are that:
• The practical suitability of DVB-RCT technology for outdoor and indoor wireless return channel transmissions has been demonstrated;
• The power levels required were lower than the maximum specified levels, leaving headroom for future real network deployment. [5]
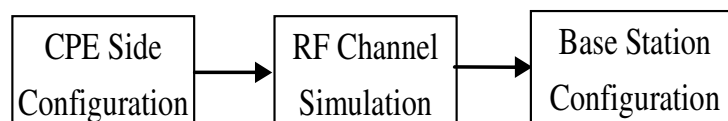
5 System Test and Analysis

5.1 Motivation

Runcom@Israel has a suit of resolutions for DVB-T/RCT system utilizing RN2821 CPE and RNBS28 Base Station. The Lab and Field measurement are aimed to investigate the performance of Runcom DVB-T/RCT communication network, especially from the IP traffic performance point of view, which is regarded as a very valuable and meaningful work in the following contexts:

1. Understanding the behavior of IP traffic over DVB-RCT uplink channel.
2. Assessing the quality of network services and attribution of network usage to end-users.
3. Investigate the uplink IP traffic performance under different MAC and PHY configurations, thus obtain the best packet configuration for each kind of services.
4. Since DVB-RCT is an alternative to WiMAX with respect to supplying the uplink service over the interactive communication channel, the test result will definitely indicate what kind of optimal configurations of these parameters would make RCT outperform WiMAX.
5. Results/Data obtained from these tests will offer valuable information about the behavior of IP traffic over DVB-T/RCT hotspot/network for the broadcasters who intend to investigate DVB-T/RCT services.
6. The test results will give a better explanation of each kind of traffic scenario and will supply more detailed information for hotspot system when implementing the CPE for IP applications.
7. The field trail will verify the hotspot performance when implementing the system for air-interface.

5.2 LAB Test

5.2.1 Overview

A test bed for evaluating both DVB-T downlink and DVB-RCT uplink is required. This test bed has to simulate a real world link and as many of the parameters that a real world system has to face as possible. Also, the test bed should be able to generate and monitor the IP traffic on the link. [[8] The General Architecture of the test bed should be like in Figure 5-1

```
┌──────────────┐     ┌──────────────┐     ┌──────────────┐
│  CPE Side    │     │  RF Channel  │     │ Base Station │
│Configuration │────▶│  Simulation  │────▶│Configuration │
└──────────────┘     └──────────────┘     └──────────────┘
```
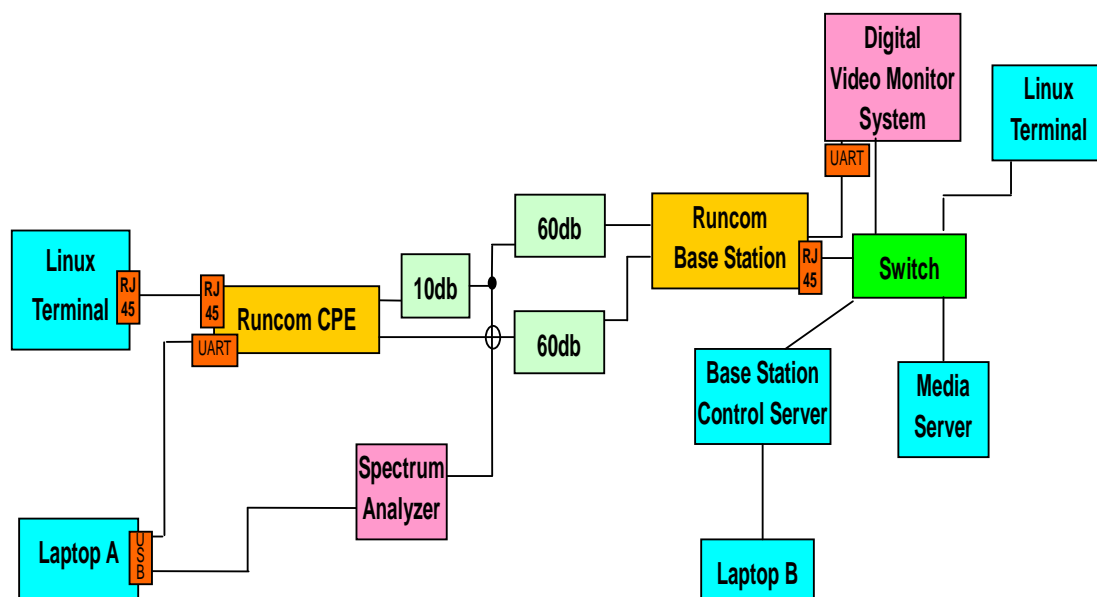
Figure 5-1 *General Architecture of the Test Bed*

In order to simulate the real RF Channel, we set up different channel simulation schemes for different test situations. The simplest architecture is to add attenuators on the link, which could be adjusted to simulate the real RF channel under different transmission mode. The best configuration is aimed to be very close to the real communication channels that addictive white noise generator, adjacent interference sources and multi-path generator should be imported to simulate the RF channel together.

In this lab measurement, because of equipment limitation, we only adopt the simplest architecture, i.e. several constant attenuators together as the RF channel path loss factor. The more detailed test bed description is introduced in the following section.

5.2.2 Test Bed Architecture

The Architecture of the KIT test bed is shown in   Figure 5-2 *Architecture of the KIT Test Bed*. In this section, a comprehensive introduction about the KIT DVB-T/RCT test bed is presented.

Figure 5-2 *Architecture of the KIT Test Bed*

5.2.2.1 Hardware Selection and connection

All of the terminals, CPE, BS and other equipments will communicate with each other based on TCP/IP protocol. The IP addresses for the relevant equipment in the test bed are listed in Table 5-1.

Table 5-1 *IP Address List*

Equipment	IP Address
Linux T (CPE)	192.168.0.103
Linux T (BS)	192.168.0.104
Runcom CPE	192.168.0.241
Runcom BS	192.168.0.88
Base Station Control Server	192.168.0.20
Laptop B	192.168.0.23

Other equipments are set to automatically capture the IP address. The detailed introduction is as follows:

1. Runcom RN 2821 CPE.

DVB-RCT CPE contains the Runcom RN-2821MOD chipset. It could achieve the following main characteristics: [**6**]

- Provide full fast IP applications (Internet, Video over IP, Voice Over IP)
- Provide a broadband return channel for interactive applications.
- Bandwidth: 6/7/8 MHz
- Provide an OFDMA uplink and a COFDM downlink.
- The cost is around 2000$.
- Provide 25Mbps uplink and 31.6 Mbps downlink data rates at 8MHz channel.
- The maximum RF input is: +10dBm
- The maximum RF output is: +24dBm
- The CPE provides two separated connectors. One is the RS232 9 pins DB connector which will connect with Laptop A at the CPE side and a standard RJ-45 Ethernet interface for Ethernet application which will directly connect with CPE side Linux terminal.

2. Runcom RN-BS28 Base Station

The characteristics for the base station are as follows: [7]

- High spectral efficiency. Downstream: 4 bps/Hz; Upstream: 3.5 bps/ Hz.
- Use 2K/1K FFT size with BS3 mode for broadband upstream.
- Adaptive modulation schemes used in both upstream and downstream: QPSK, 16QAM, 64QAM.
- Uses either advanced Turbo Coding or concatenated RS and convolution coding for upstream FEC.
- Bandwidth: Up to 20MHz.
- Cost: 60,000-70,000$.
- The maximum RF input is: +15dBm.
- The maximum RF output is: +24dBm
- The Base Station connects with the switch via a RJ-45 interface and directly connects with DVB monitor system via DB-9 MOD Ctrl port

3. Agilent PSA Series E4404B Spectrum Analyzer

Agilent PSA Series E4404B Spectrum Analyzer is adopted to capture the uplink signals from the CPE. From this equipment, both time-domain and frequency-domain OFDM signals could be clearly displayed, which will also supply the information about the sub-channels and time slots allocated for the CPE.

4. Laptop A

Laptop at the CPE side is from KIT, which functions as controller for both CPE and Spectrum Analyzer.

As the CPE controller, the laptop could remote login to the CPE via Vterm software. Some parameters and uplink information could be displayed via this laptop, which could also be recorded as the log file for future usage.

As the monitor for spectrum analyzer, the laptop could display the frequency domain spectrum utilizing the software form Agilent and capture the important information from the spectrum analyzer.

5. The ROHDE&SCHWARZ DVB-ATSC Monitor

The ROHDE&SCHWARZ DVB-ATSC Monitor is another measurement system at the base station side. DVB-T channel performance could be measured by this equipment. This equipment can also record the MAC information for analysis from the BS.

6. Base station control server

The configuration software for Runcom base station is running on the Base station control server. A laptop is used to remote login the server and to configure the base station's MAC and PHY parameters. It is a very important server that all of the modification for the BS was implemented on this server.

7. Media server

Media server is used to supply the VOD service from the application point of view. It also connects with the switch.

8. Linux terminals

Linux terminal at both CPE and BS side are used to transmit/receive the IP packets with the traffic generation software.

The configuration of the terminals is as follows:

Linux@CPE:

Processor: Pentium III 450 MHz

Memory: 256M

Operating System: Suse 9.3 with kernel 2.6.11.4

Linux@BS:

Processor: HP Server with Intel Xeon 2.8GHz CPU,

Memory: 1GB DDR II SDRAM

Operating System: Fedora 4 Linux with kernel 2.6.11.

Others: two 10/100/1000 Fast Ethernet adaptors.

5.2.2.2 Software Selection and implementation

The Lab Measurement is mainly designed to investigate the IP traffic performance. It has to be based on a software tool that could generate all kinds of IP traffic patterns, thus some very important parameters which can indicate the QoS of DVB-RCT system such as the maximum throughput, Jitter, Packet Loss Rate etc. could be obtained.

In this lab test we choose D-ITG (Distributed Internet Traffic Generator) tool developed by Universita' degli Studi di Napoli "Federico II" (Italy). It is a platform capable to produce traffic at packet level accurately replicating appropriate stochastic processes for both IDT (*Inter Departure Time*) and PS (*Packet Size*) random variables (*exponential, uniform, cauchy, normal, pareto ...*). D-ITG supports both IPv4 and IPv6 traffic generation and it is capable to generate traffic at network, transport, and application layer. D-ITG is free and may download from Internet. [**12**] In the test, we use latest version 2.4 on Linux operating system.

When testing, quite a lot of packets scenarios with different parameters configurations will be conducted. In order the save more time and man power, the process should be executed automatically and controlled by some script programs. This is so called Test Automation.

In this test, we made Perl script [3] to automatically execute the D-ITG instructions and analyze the test result log files by extracting the parameter values from them.

Figure 5-3 shows the software architectures for the lab test process:
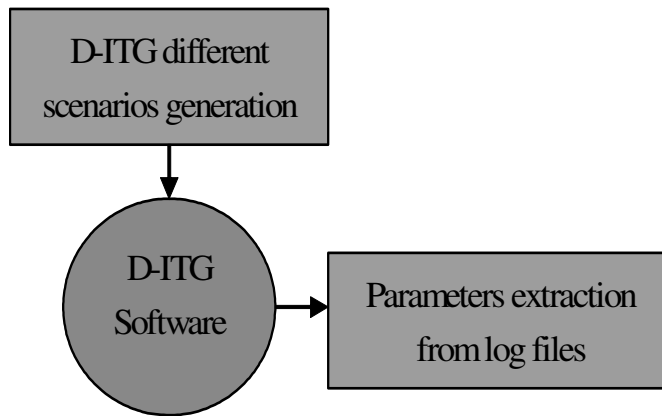
Figure 5-3 *Software Architectures*

The Script source code can be available in the Appendix.

Figure 5-4 demonstrates the log file layout of a typical traffic configuration. Detailed information about throughput, packet loss rate, jitter, delay, etc. can be extracted from that file.

```
------------------------------------------------------------
Flow number: 1
From 192.168.0.103:1025
To    192.168.0.104:9634
------------------------------------------------------------
Total time             =     60.447287 s
```

40

Figure 5-4 *Layout of a Typical Traffic Configuration*

5.2.3 Test Procedure

5.2.3.1 Parameters scale

First, Runcom parameters scale is introduced as follows:

● Inter Carrier Space:

From the standard, we can choose anyone from 1k, 2k and 4k. But Runcom's implementation will restrict the value to 4k. In our lab test, all test scenarios are based on Inter Carrier Space 4k.

● Guard Interval:

Guard Interval represents the length of time during which the symbol is repeated. From the standard, guard interval can be any value of 1/4, 1/8, 1/16 and 1/32. In Runcom's implementation, the uplink guard interval could be modified with the downlink guard interval value together. By default, this parameter is set to 1/4. We could change it to 1/8, 1/16 and 1/32 by modifying the value on the base station control server.

● Connections:

By default, the number of connection is set to one. The maximum number of connection from the standard is four, but Runcom only authorize the users to add another one more connection, i.e. the maximum connection number is two for the test.

● Modulation scheme:

According to DVB-RCT standard, the modulation scheme for DVB-RCT uplink channel could be any of QPSK, 16QAM and 64QAM. By default the BS will use QPSK if the user doesn't change the configurations at the BS control server.

● Code Rate:

The code rate can be either 1/2 or 3/4. By default, this parameter is set to 1/2.

Then the software parameters for D-ITG can be demonstrated as follows:

● Packet size:

In the lab test, typical packet sizes are chosen ranging from 64 byte to 1536 byte as follows: 64,128,256,384,512,640,768,896,1024,1152,1200,1536 in byte. This packet configuration is the most ordinary one for Internet application.

● IDT (Inter-Departure Time):

IDT is the time duration for each transmitted packet in seconds. The IDT value is decided according to the bandwidth for DVB-RCT which is restrict to 8MHz. Smaller IDT, i.e. so many packets are sent within one second, will crash the Runcom DVB-T/RCT MAC layer and finally terminate the test. Under careful consideration and pre-trial, four typical values as 1/30, 1/300, 1/670, 1/900 are approved. In the result analysis figures, we denote IDT= 1/N second as IDT-N.

● Protocol: TCP, UDP.

● The receiving power for the BS is -95dBm

5.2.3.2 Test Step

Four test steps shown in Table 5-2 were designed for the lab test process, under which a repetitive test structure T was used.

Table 5-2 *Test Configuration*

Items	No. of Connections	Guard Intervals	Test
Step 1	1	1/4	T
Step 2	2	1/4	T
Step 3	2	1/16	T
Step 4	2	1/32	T

For the last test T can be explained as follows:

The test structure T is defined as: under different IDT (1/30, 1/300, 1/670, 1/900), with different packet size (64,128,256,384,512,640,768,896,1024,1152,1200,1536), the form of TCP and UDP traffic patterns under QPSK, 16QAM, 64QAM modulation schemes. Simply speaking, a T consists of 48 groups (4 IDT ×12 Packet size) TCP and 48 groups of UDP traffic for each modulation scheme.

5.2.4 Test Result Analysis

The results and analysis of the performance assessment for TCP and UDP traffic over DVB-T/RCT communication network are presented in this section. We start with the analysis of TCP and UDP throughput; follow by measuring the TCP round-trip-time (RTT), then by characterizing the UDP packet loss behavior, and finally the examination of UDP delay variance (Jitter).

5.2.4.1 Throughput Analysis:

In [4], we get the ideal data throughput of DVB-RCT as

Table 5-3.

Table 5-3 *DVB-RCT Ideal Throughput*

| Transmission | Sub-Channel Throughput (kbps) | | | | US Throughput (Mbps) | | | |
| | Guard Interval | | | | Guard Interval | | | |
Mode	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
QPSK ½	76.2	84.6	89.6	92.4	4.11	4.57	4.84	4.99
QPSK ¾	114.3	127.0	134.5	138.5	6.17	6.86	7.26	7.48
16-QAM ½	152.4	169.3	179.3	184.7	8.23	9.14	9.68	9.97
16-QAM ¾	228.6	254.0	268.9	277.1	12.34	13.71	14.52	14.96
64-QAM ½	228.6	254.0	268.9	277.1	12.34	13.71	14.52	14.96
64-QAM ¾	342.9	380.9	403.4	415.6	18.51	20.57	21.78	22.44

This value is calculated by assuming CPE using all sub-channels and time slots when transmitting data in 8MHz bandwidth. A more straightforward way to compare the ideal throughput value is in

Figure 5-5.
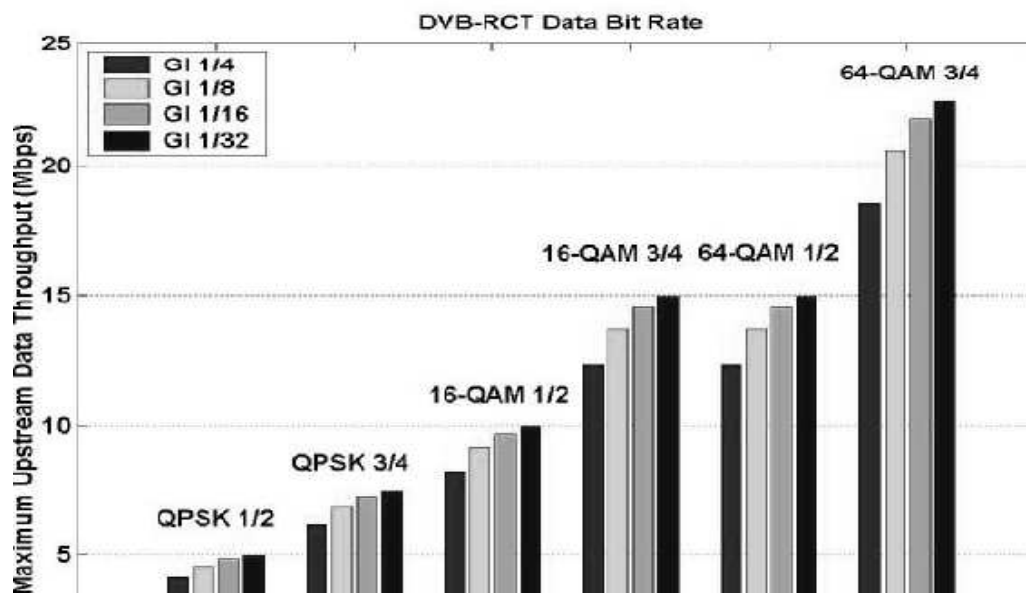
Figure 5-5 *Ideal Throughput Comparison*

In this section, the UDP and TCP throughput value for Runcom system under different configuration scenarios are analyzed. The values, due to implementation affection, should be less than the ideal calculation. The reason for each test result is analyzed. The throughput at sender side is calculated as follows:

$$\text{Throughput} = \text{packet size} \times \text{sending rate} \qquad (5\text{-}1)$$

Because of the packet loss, retransmission, channel, bandwidth limitation and eventually transmitter buffer overflow, the throughput at receiver side will not be the same as formulated at the sending side. [**9**]

● **Receiving throughput with TCP traffic**

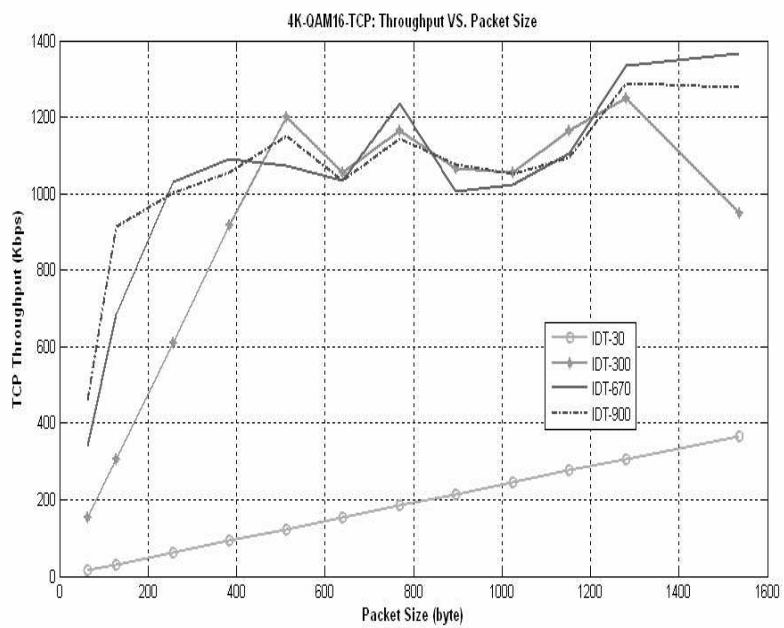**QPSK and 16QAM TCP Throughput value for test step-1 are shown in**
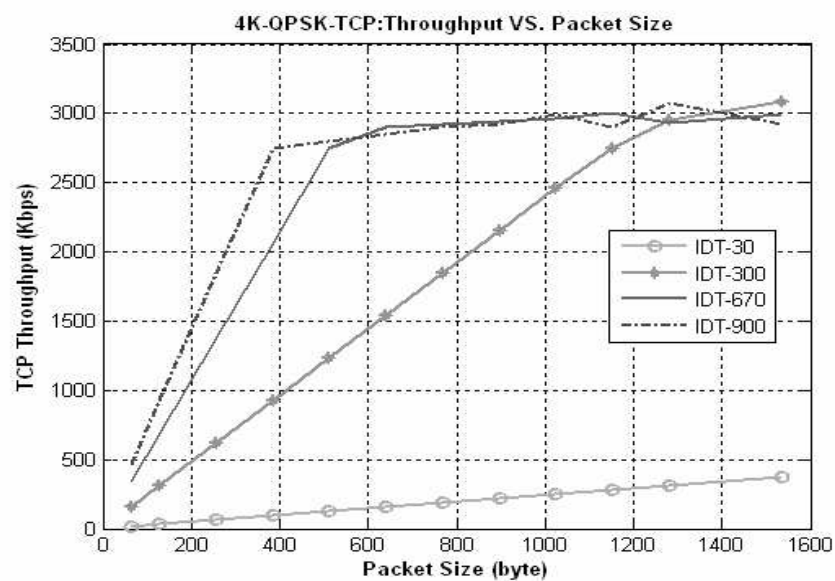
Figure 5-6.

Figure 5-6 *Step-1 TCP Throughput*

It is noticed that a linear relationship exist between throughput and package size for small packages for both of the modulation schemes. When the package size becomes larger, the TCP throughput for QPSK will be stably saturated at around 3Mbps, while, for 16QAM the saturation value is much lower, which fluctuates to the maximum value around 1.35Mbps. For IDT-30, both of the two modulation schemes can not be saturated because of such low sending rate (IDT) will never enable CPE sufficiently use all the resources. For 64QAM, the trial failed. The Runcom system can not afford TCP transmission utilizing 64QAM when the receiving power level is not high enough. It can be explained as follows:

The robust character of modulation schemes decreases from QPSK to 64QAM. That's because the detector needs to detect only two levels and two phase angles to determine the symbols for QPSK; but for 16QAM and 64QAM, the detector will do more work. Based on the standard, the more robust the modulation, the less power it needs. Typically, in order to achieve the same bit error rate (BER), different signal to noise ratio (SRN) should be guaranteed. The relationship could be obtained in Figure 5-7. It is obvious that based on the same level of BER, e.g. 10^{-3}, the required SNR value will increase as the modulation changes from BPSK, QPSK to 16QAM. It means the base station needs to offer more output power to maintain the same performance when the modulation scheme changed from BPSK to QPSK and finally to 64QAM.
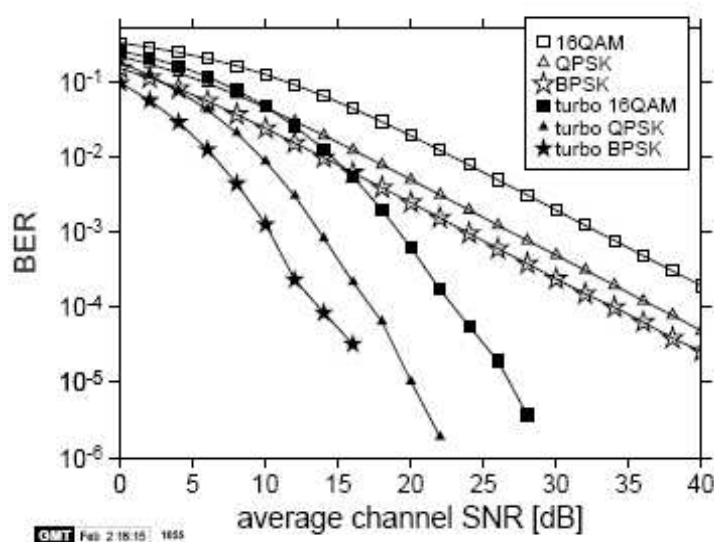
Figure 5-7 *BER vs. SNR with different modulation*

On one hand, because the BS is a beta version product that is very vulnerable and difficult to control, especially for the software part, through which the power could be changed, manually changing the output power or decreasing the attenuators in the

channel would be a great risk to perform. Even though the BS could adaptively adjust the power itself to adapt to the modulation, the power was still not large enough for 64QAM transmission. One the other hand, TCP protocol has worse performance than UDP with respect to throughput value measurement. It is the characteristic that facing to connection and handshake procedure will lower down the performance for TCP. That's why TCP 64QAM throughput value could not been obtained and 16QAM throughput doesn't demonstrate a good result. In the future, a variable attenuator could be adopted using for the LAB test. A better performance could be obtained by adjusting the channel attenuator to some proper values.

If investigating the reason for this 16QAM throughput dropping, it could be explained as follows. In

Figure 5-8 , the standard payloads for a BS3 for different modulation scheme are listed.

	QPSK		16-QAM		64-QAM	
Coding Rate	½	¾	½	¾	½	¾
Data Payload	18 bytes	27 bytes	36 bytes	54 bytes	54 bytes	81 bytes

Figure 5-8 *BS3 Payloads under Different Modulation Schemes*

It is clear to see that the BS3 payload increases from QPSK to 64QAM. While in the MAC layer protocol, after the base station grant a certain number of sub-channels and time slots to the CPE, the data frame is organized as follows in Figure 5-9.
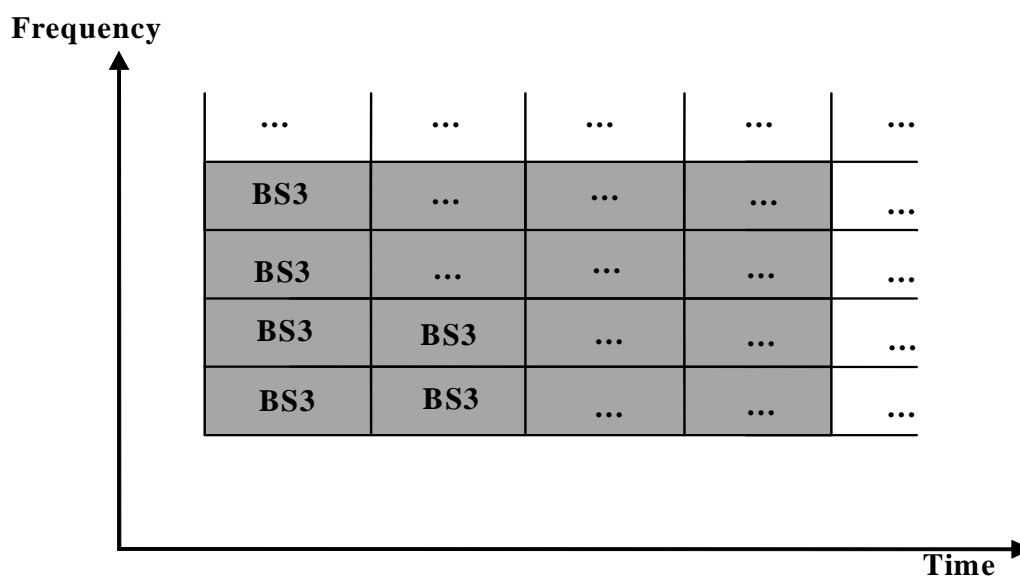
Figure 5-9 *Resources Allocation*

For a certain frame, the number of BS3 is constant. But with different modulation scheme, the payload of the transmission frame is different, which will increases from QPSK to 64QAM. As known, the TCP uses a receiving buffer at the receiver side sockets and the capacity of the buffer (window) is a constant value. For QPSK mode, the frame payload is smaller than the buffer size at the receiver side. Every time the frame is transmitted, the acknowledge conformation is sent back to enable a continuous transmission. When the package size reaches a certain value, the payload size will match the buffer size, and the throughput reaches the maximum value.

But for 16QAM, the payload of a data frame becomes larger, which is twice of the QPSK size. When a certain packet size is adopted, the payload might saturate the buffer at the receiver, thus cause the sender computer receiving no acknowledgment confirmation from the destination. Then, the sender has to wait for a time-out to retransmit the frame, thus lead to an insufficient usage for the time slots. That's the reason why 16QAM maximum throughput is lower than QPSK.

For 64QAM, from the spectrum analyzer we found that the sending OFDM signals appear occasionally, i.e., most of the time, the channel has no transmission. After a while, the connection was crashed. Moreover, the lower power at the BS side also accounts for the bad performance for 16QAM and 64QAM

We can conclude that under the same power level it is evident to see that QPSK is more suitable for TCP traffic transmission. This could be evident in the filed test section for FTP transmission.
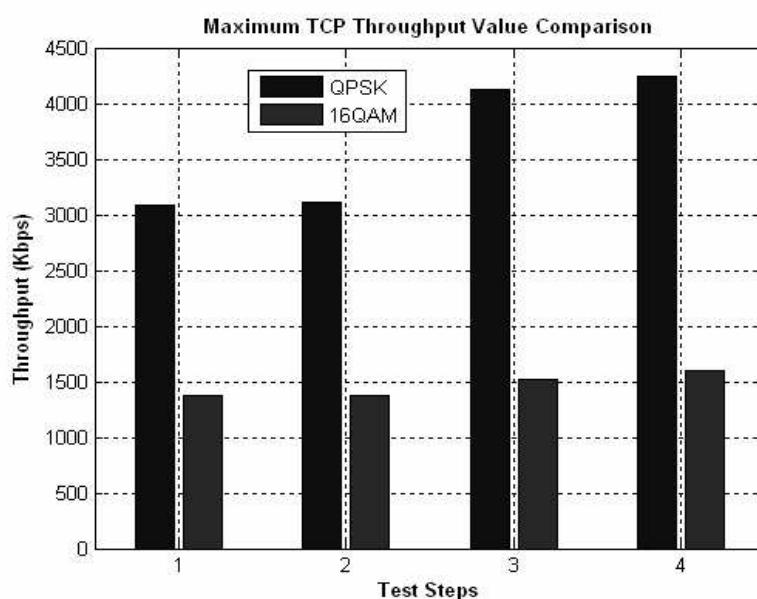

Figure 5-10 *Maximum TCP throughput*

Figure 5-10 presents the maximum TCP throughput value for all test steps. We can see that the value for step-1 and step-2 are almost at the same level. When decreasing the guard intervals, the QPSK throughput increases very fast as shown in step-3 and step-4. The reason for this incensement will be analyzed in the following UDP throughput section. 16QAM also yields this trend, but the improvement doesn't increase much.
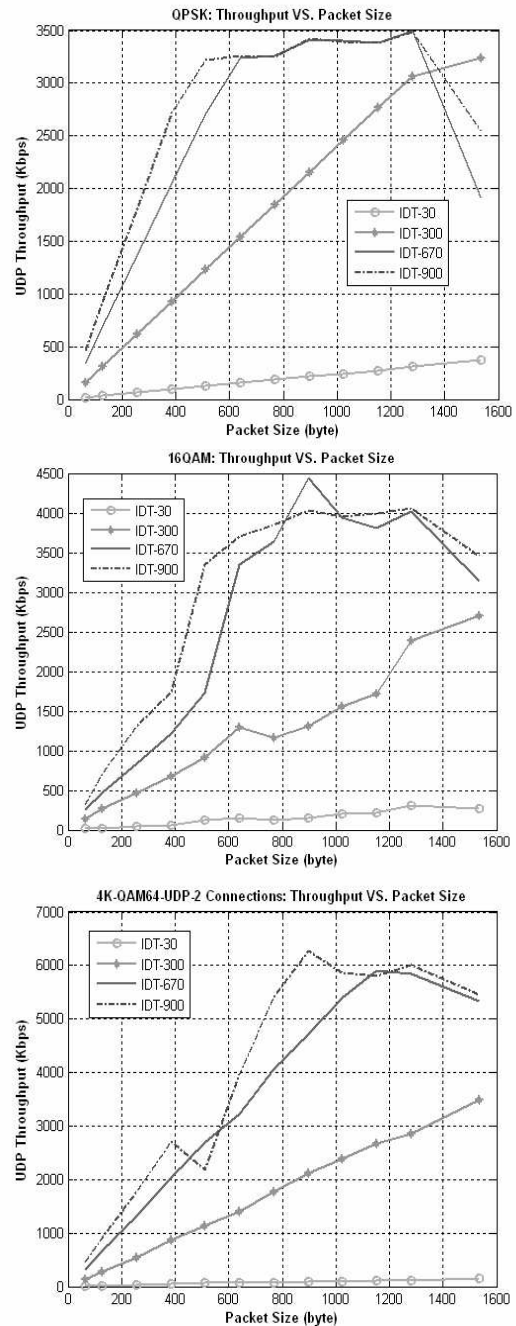
- **Receiving throughput with UDP traffic**

The UDP throughput with different modulation schemes for step-1 and step-2 are shown in

and Figure 5-12.
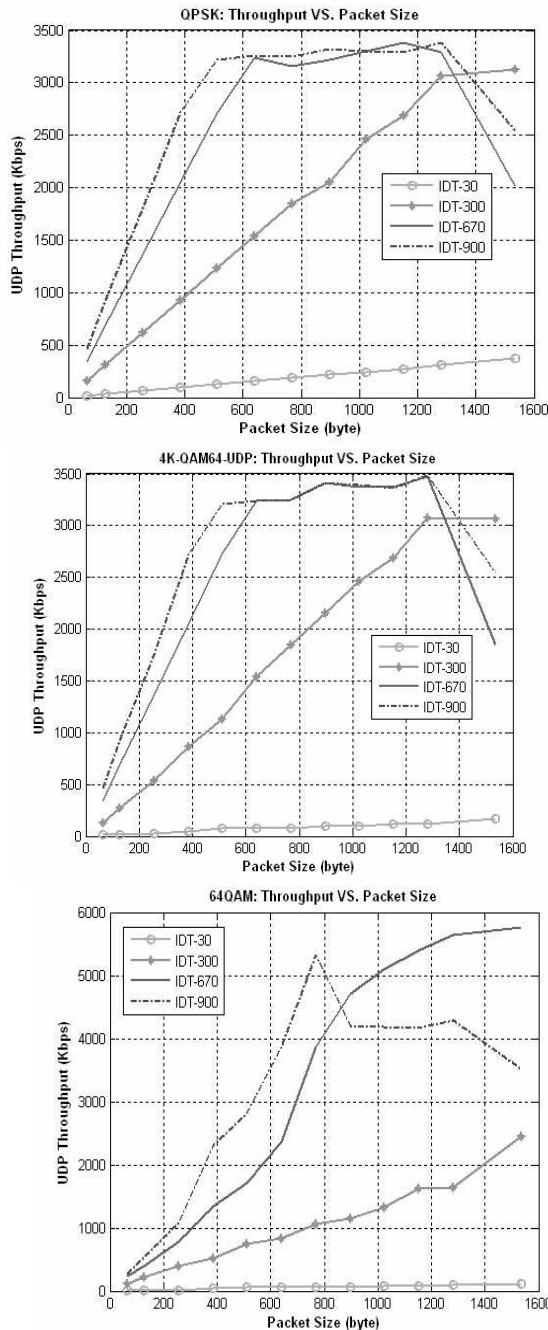
Figure 5-11 *Step-1 UDP Throughput*   **Figure 5-12** *Step-2 UDP Throughput*

Based on the results from step-1 and step-2 QPSK modulation scheme, it is evident to conclude that the throughput doesn't increase even another connection is created. But with 16QAM, adding another connection will increase the throughput value a little bit. The reasons can be explained as follows:

1. In **Error! Reference source not found.**, the basic structure for the uplink transmission in time domain is demonstrated.
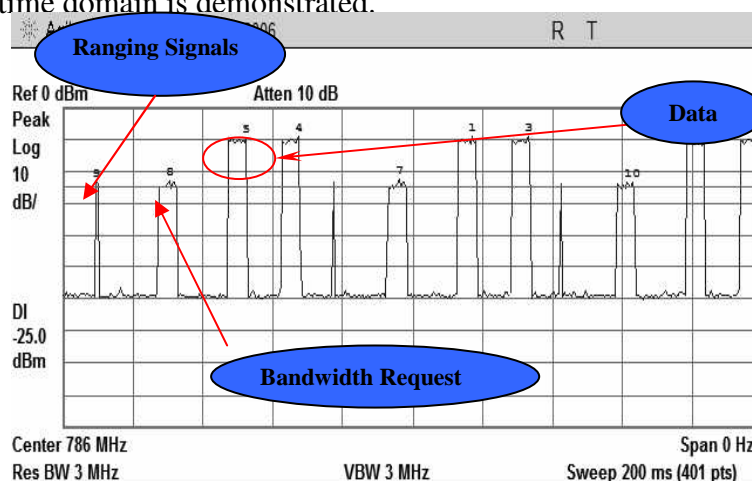
**Figure 5-13** *Basic Time Domain Pattern*

First, a short ranging signal is sent by CPE to request resources. After the BS resource grant message, another bandwidth request signal is sent again because of the insufficient granted resources from BS. In this case, CPE has to wait for another resources grant message from BS until the bandwidth and sub-channels are enough for transmission. Then CPE could send data using a certain kind of modulation scheme. When the maximum throughput was achieved using QPSK, the time domain signals pattern was captured as follows in Figure 5-14
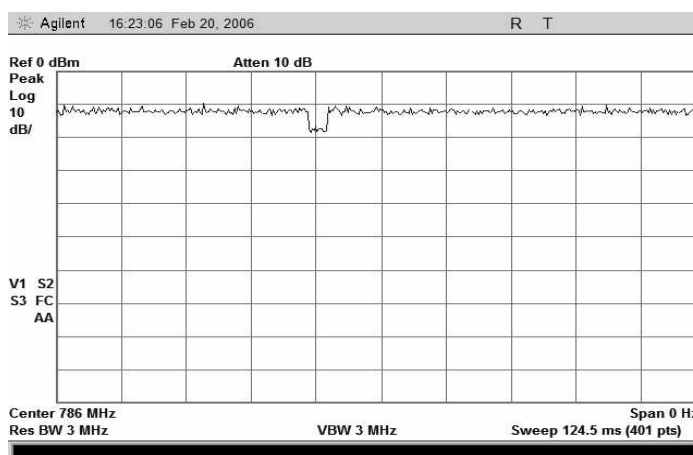
Figure 5-14   *the Maximum Throughput for QPSK Step-1*

It is clear to see that CPE has used time slots for one connection. For sub-channels, with the help of the software Mac-Reader from Chammika Mannakkara, it is proved that the CPE also used all 59 sub-channels. That's why even adding another connection, the throughput still remains the same.

2. For 16QAM, adding one more connection will increase the throughput to around 1000Kbps. The time domain pattern for 16QAM maximum throughput was captured in Figure 5-15
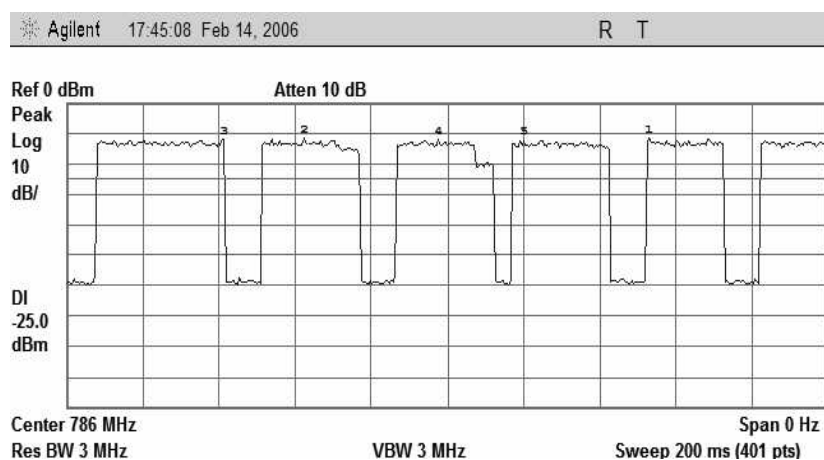
Figure 5-15 *the Maximum Throughput for 16QAM Step-1*

It is clearly to see that for 16QAM, the CPE doesn't use all time slots when achieving the maximum throughput. So adding another connection will create the transmission at the data slots where the other connection doesn't use, thus increase the throughput. For different modulation schemes, as it has been analyzed in the TCP section, the payload of BS3 is larger when using 16QAM and 64 QAM compared with QPSK. So, in every time unit, the payload for the transmission is larger, thus increase the throughput for UDP.

The maximum throughputs for different test steps are shown in Figure 5-16
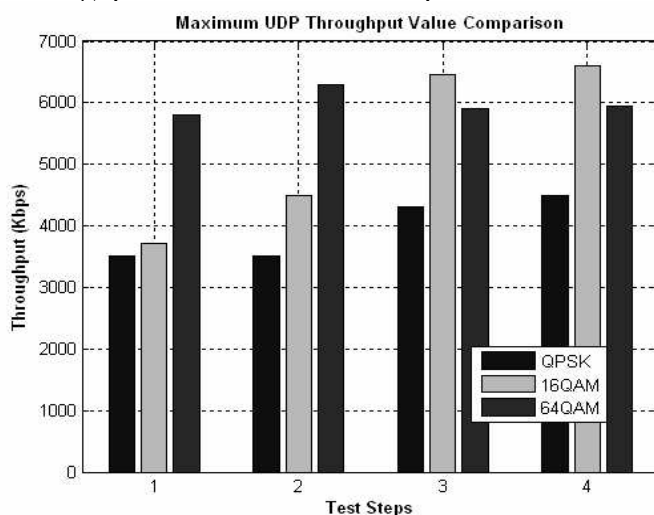
Figure 5-16 *Maximum UDP throughput*

Basically, it can be concluded that the shorter the Guard Intervals the larger the throughput for UDP traffic. The reason can be explained as follows:

On one hand, one OFDM symbol's duration in time domain is calculated using the following equation:

$$1 \text{ OFDM Symbol} = (1+GI) \times (1/CS) \qquad\qquad \text{Eq 5-2}$$

Where, GI= Guard Interval   CS=Carrier Space (4k)

If the GI value is decreased from 1/4 to 1/32, the time duration for one OFDM symbol will be decreased.

On the other hand, as shown in Figure 5-13, the repetitive structure is consist of one ranging symbol which has 5 sub-channels, one bandwidth request symbol which is used to request time-slots and sub-channels for data and data symbols. When one OFDM symbol is shorter in time, the base station's bandwidth grant message will come earlier because of Runcom's implementation. Then, the time slots will be arranged more efficiently. That means the throughput for unit time slot can be increased.

5.2.4.2 TCP Round-Trip-Time Delay Analysis

The TCP Round-Trip-Time is calculated at the sender using the following equation:

$$RTT= TimeR - TimeS \qquad \text{Eq 5-3}$$

Where TimeR represents the time when the acknowledge signal from the receiver is received, whereas TimeS represents the sending time stamp from the sender. [[9]

Figure5-17 depicts the variation of the TCP RTT in relation with the packet size. This is the typical case for Guard Interval 1/32, 16QAM situation. From this figure we see that for IDT-30, the RTT delay vibrates below 700 milliseconds whereas the patterns for IDT-300,670,900 are almost the same. When the package size is small, bigger RTT delay takes place which is more than 600 milliseconds, whereas, as the package size is larger the RTT delay tends to be stable around 400 milliseconds.
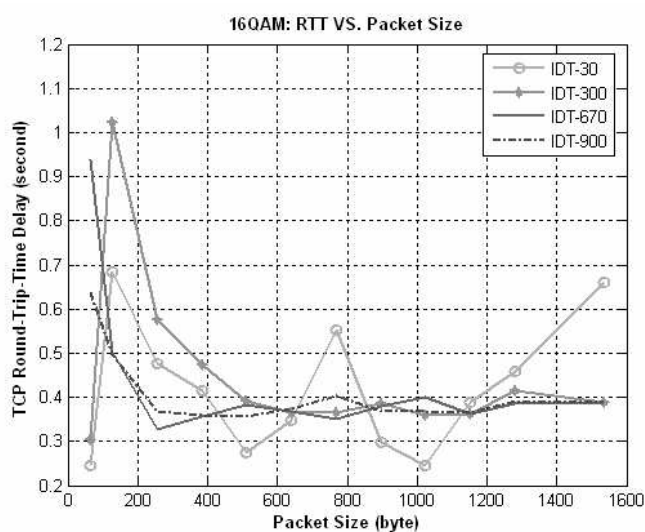

Figure5-17 TCP RTT Delay

As known, TCP uses the buffers to collect packets. For smaller packet, both the sender and receiver side buffers are filled with more packages which results more demanding processing to both sender and receiver, such as hand-shaking, overhead processing etc. That's the reason why smaller packets tend to be larger RTT delays. Furthermore, in the context of channel error protection, small packets tend to be more susceptible to errors, thus more packet retransmissions are required. This can explain the increase in RTT delays when small packets are transmitted at higher sending rates.

5.2.4.3 UDP package loss rate analysis
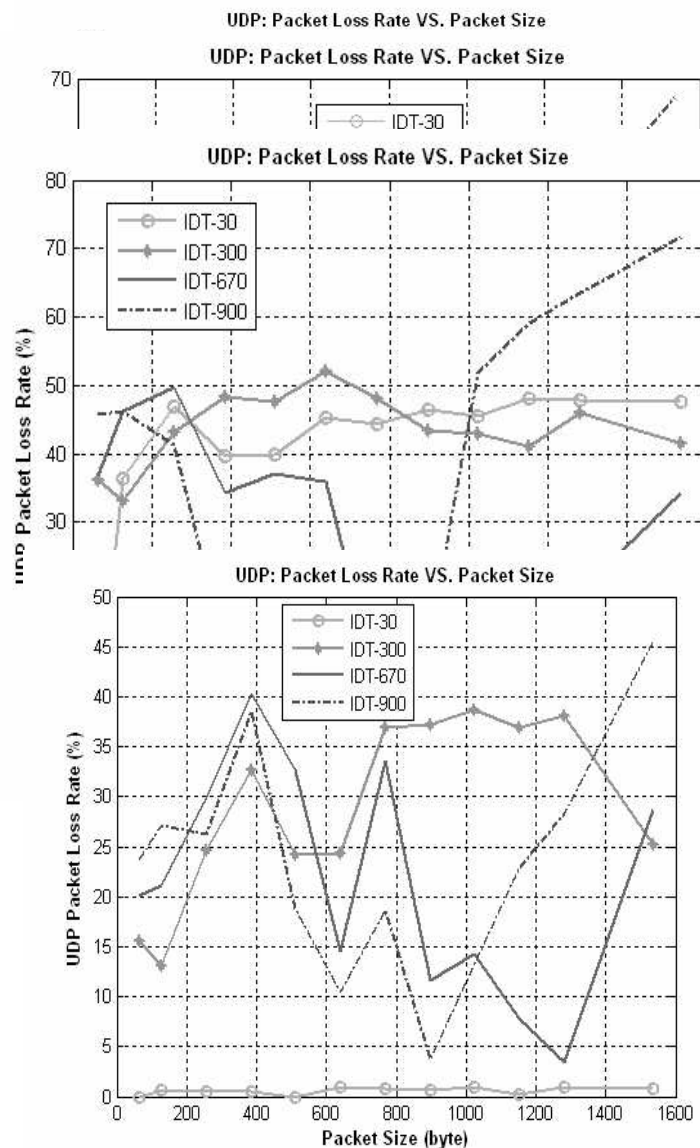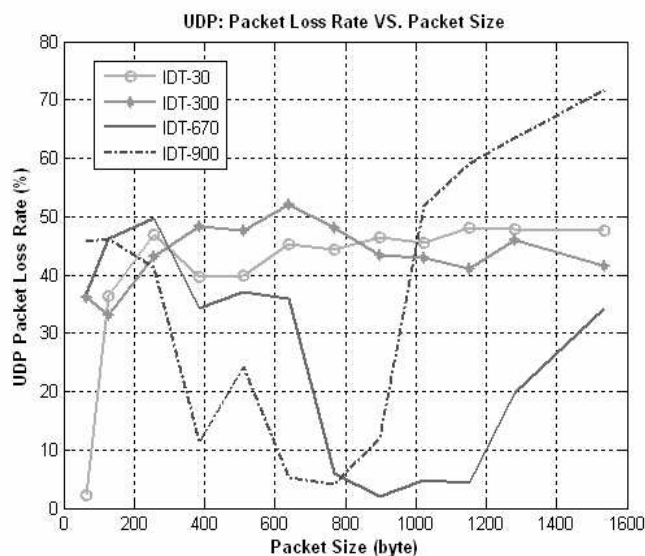
Figure 5-18 *UDP Packet Loss Rate Analysis*

The Packet Loss Rate is defined as:

Packet loss rate = (input_count – output_count) /input_count   Eq 5-4

The above Figure 5-18 is from step-3 i.e. 2 Connections guard interval 1/16. It is evident to see that the packet loss rate for IDT-30 is increasing a lot as the modulation scheme changing from QPSK to 64QAM. That is because QPSK is a more robust modulation scheme than 16 QAM and 64 QAM, thus leads to a very low packets loss rate. So is for IDT-300, 670, 900, especially when packet size is small. When the package becomes larger, it is clearly to see that for QPSK IDT-670,900, the packets drop fast.

For 16QAM and 64QAM IDT-670, 900 the packet loss rate vibrate quite a lot that for certain packet size such as 650byte and 900 byte, it drops down very fast to a low value, while for certain packet size such as 1400 byte, the value rise up to a very large peak. So it is known that this modulation is especially suitable for a certain kind of Internet service which typically uses this kind of packet configuration. The special packet selective characteristic for a certain modulation scheme indicates the configuration of the packet size for a better transmission.

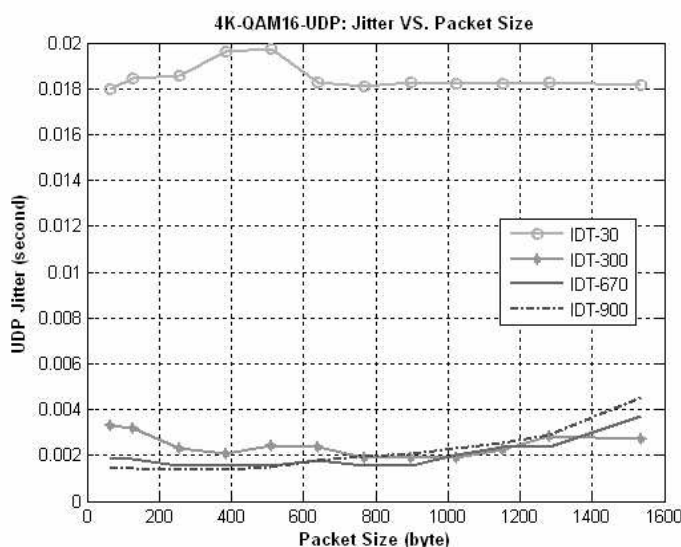## 5.2.4.4 UDP Jitter Analysis

This section is to investigate the packet delay variation, i.e. jitter. By definition, jitter is expressed as:

Jitter (N) = packet delay (N) – packet delay (N-1)   Eq 5-5

Where N, N-1 represent the index of receiving packets.

In Figure 5-19, the jitter value with respect to the packet size at a certain Carrier to Noise Ratio is shown. This is the jitter value from Step-1 QAM16 modulation scheme.


Figure 5-19 *UDP Jitter Analysis*

The Jitter value represents the stability of the system. It is believed that the smaller the jitter, the better the system performance. From the above figure, a conclusion can be drawn: larger packet tends to be worse in jitter performance. But from the figure, IDT-30 leads to a very large jitter value which is far above other IDT configurations. The reason for such a larger jitter is explained as follows:

The first packet delay for a certain transmission frame will be very large compared to the following packet transmission. That's because it needs to create port for transmission which will be time consuming. For larger IDT, such as IDT-30, the total number of packets sent out is smaller than other IDT cases. If calculating the average jitter value, the first larger delay will affect the total average jitter value a lot when IDT is larger. That's why the jitter of IDT-30 is much larger than other IDT configurations.

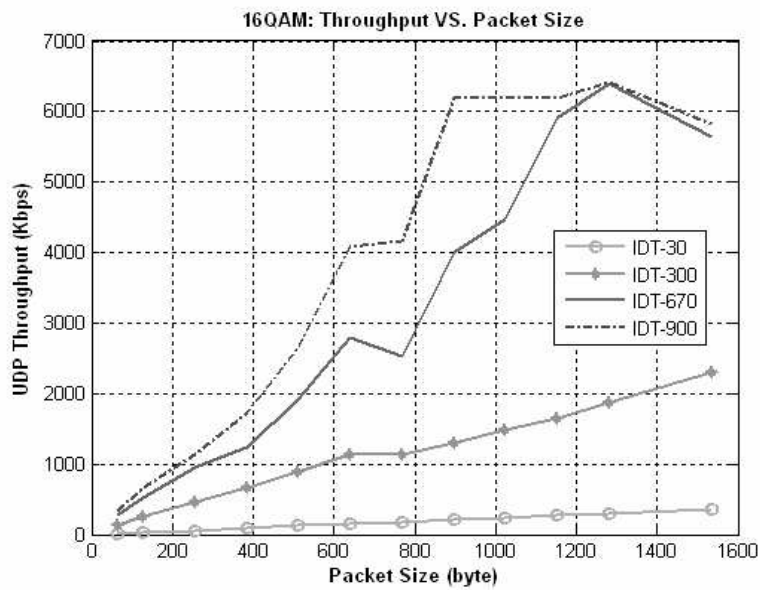## 5.2.4.5 DVB-RCT and WiMAX Analysis

In this section, the WiMAX and DVB-RCT IP traffic assessment results are discussed. The WiMAX throughput analysis result is in Figure 5-20. **[[8]**
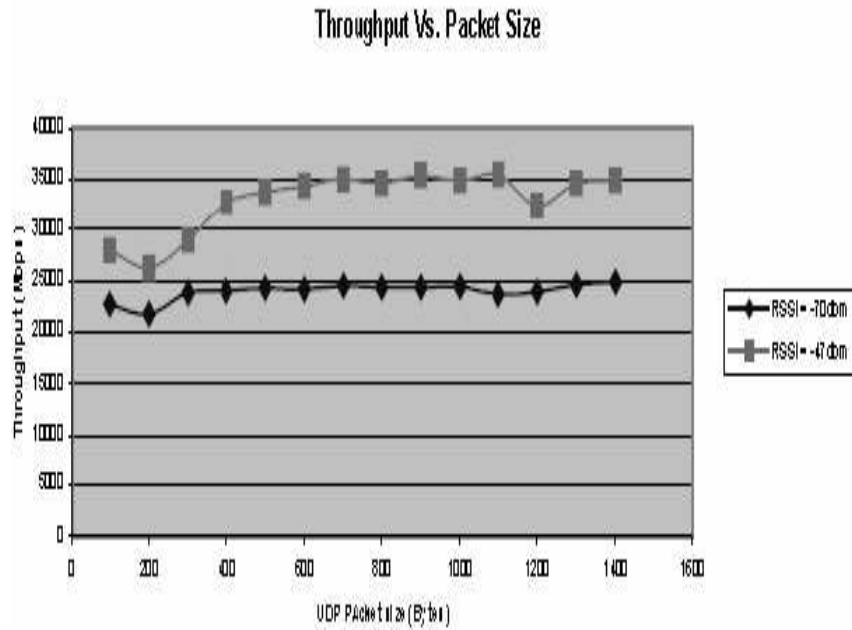
Figure 5-20 *WiMAX UDP Throughput*

The typical DVB-RCT UDP throughput is in Figure 5-21.

Figure 5-21 *DVB-RCT UDP Throughput*

The test configurations and results for both of them are listed in

Table 5-4.

Table 5-4 *WiMAX and DVB-RCT Comparison*

Item	WiMAX		DVB-RCT
Bandwidth	20 MHz		8 MHz
Receiving Power Level	-70dBm	-47dBm	-95dBm
Maximum Throughput	25Mbps	35Mbps	6.5Mbps
Throughput/Hz	1.25bps	1.75bps	0.8125bps

Based on the table above, the throughput/Hz value for DVB-RCT seems smaller than the WiMAX counterpart. But as seen in the above table, the receiving power which has a positive affection to the throughput value is much larger for WiMAX, whereas for DVB-RCT, the receiving power level is almost 20dBm smaller than WiMAX. Because of the restriction of LAB test condition, the same receiving power level measurement for the two standards wasn't conducted. But it is believed that by increasing the receiving power level for DVB-RCT, the maximum throughput value might be comparable with WiMAX or even surpasses WiMAX to some extent.
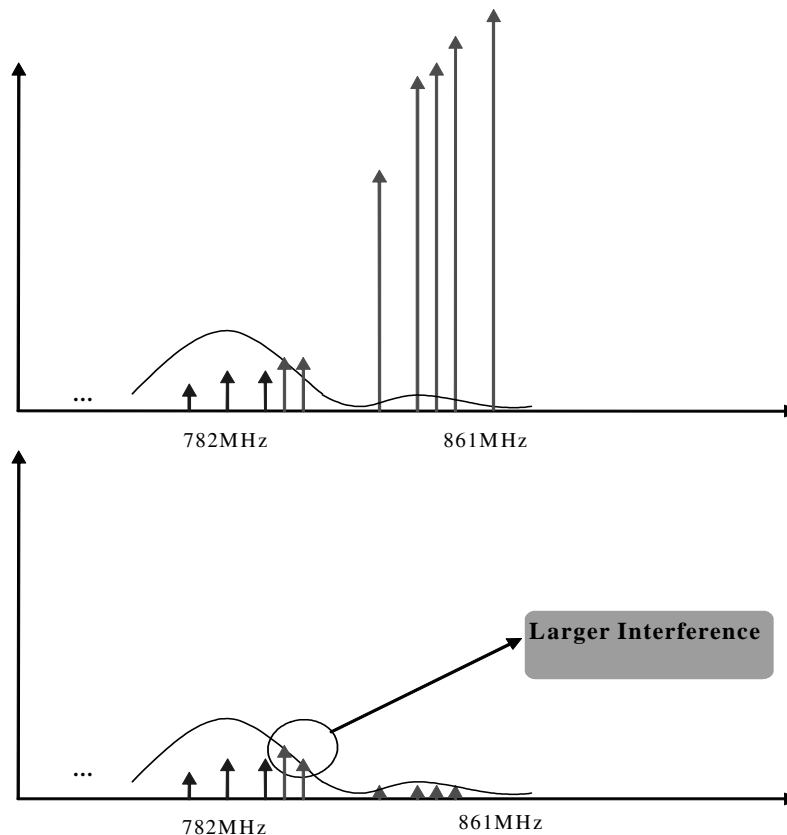
5.3 Field Test

The field test is conducted to verify the hotspot performance when implementing the system for air-interface. The first trial for the field test was not successful. The reason is as follows:

The first trial used roof-mounted antenna which is shared by both uplink and downlink streams. After the antenna, a filter was used for uplink channel to avoid other signals especially DVB-T signals interfering with RCT channel. But the filter is not designed well, the frequency selective characteristic is pretty bad, thus the downstream DVB-T signals will leak in to the DVB-RCT upstream channel. The poor filter characteristic is shown in Figure 5-22. We can see that the interference from DVB-T downlink channel even overwhelms the weak DVB-RCT received signals, which the base station can not decode.

For the test configuration, the downlink (DVB-T) center frequency is 861MHz, the uplink (DVB-RCT) center frequency is 786 MHz, both uplink and downlink's bandwidths are 8 MHz. The received RCT signals are very weak, whereas the

transmitting downlink signals are very strong in power.

Figure 5-22 *Filter Characteristic*

5.3.1 Test Configuration

In order to conduct the field test, another solution has been worked out to continue our beta measurement using the air-interface. The downlink DVB-T frequency has been changed to another frequency band which is far enough from the DVB-RCT channel. This frequency band must not be occupied by any other applications. So it won't cause interference with other licensed services. What's more, the roof mounted antenna and power amplifier won't be used. Instead, Runcom base station's own power output and separated antennas for transmitting and receiving has been adopted. The basic configuration for the field test is in Figure 5-23.
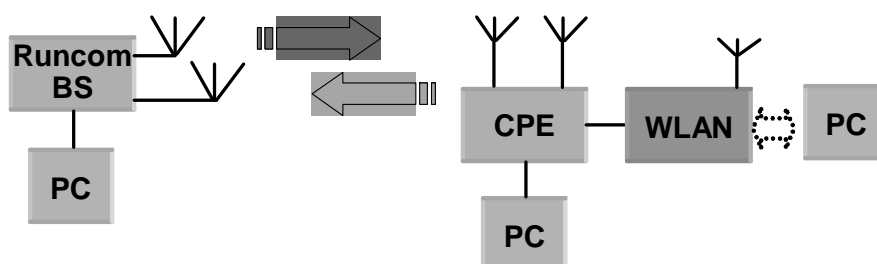
Figure 5-23 *Field Test Configuration*

The hotspot part is added at the CPE side with a Wireless router connected with the CPE using RJ-45 interface. The router is set a fixed IP address. The terminal PC will visit the BS side PC through the WLAN utilizing DVB-T/RCT network air-interface. Other Parameters are listed in Table 5-5.

Table 5-5 *Field Test Configuration Table*

| Frequency Alignment	Downlink DVB-T: 686 MHz	
	Uplink DVB-RCT: 786 MHz	
Bandwidth	8 MHz	
Antenna	BS	Tx: Log Periodic Antenna Vertical Polarization
		105-1300MHz Gain 8db
		Longest Element 1460 mm
		Shortest Element 90 mm Power 500 Wat
		Rx: Outdoor TV Antenna Horizontal Polarization
		Gain 11-15 db Front/Back 28 db
		Element 43 Channels 21-69
	CPE	Tx: GSM Antenna Horizontal Polarization
		Gain: 10 db
		Rx: Outdoor TV Antenna Vertical Polarization
		Gain 11-15 db Front/Back 28 db
		Element 43 Channels 21-69

For the BS and CPE side Rx Antennas, the outdoor TV Antennas were adopted which had bad performances in the NLOS indoor receiving situation. Since the field test was restricted within only 3-4 days with little resources, i.e. we had no car or van to supply power outside the building, all filed tests had to be conducted in the building. So in order to avoid reflections caused by utilizing outdoor antenna in the NLOS indoor environment, in the future test, antennas should be selected carefully according to the environment.

5.3.2 Test Procedure

For Field test, besides IP traffic measurement for test step-1 which will be

concentrated on the throughput value, another application service test was added. This application test is based on Client and Server architecture in Figure 5-24.
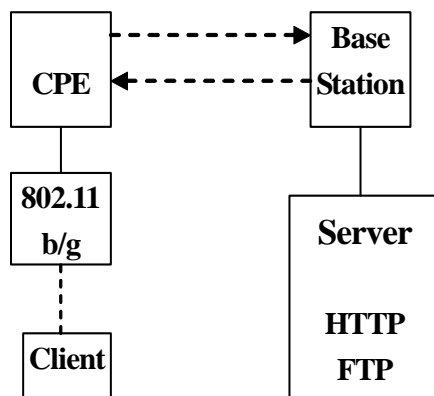

Figure 5-24 *Application Test Configuration*

The HTTP service is supplied by installing Apache web server on the Server at base station side. The FTP service is supplied by ServU FTP server.

The field test was conducted at three different places which are within Gävle Technology Park office building as three typical test cases.

The First Case 1: Line-of-Sight
Distance: 5 m

Field Test Case 2: None-Line-of-Sight
 Distance: 15m
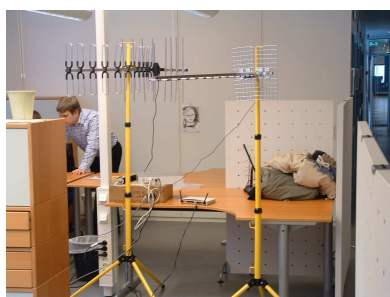
Figure 5-25 *Field Test Case-1*

Figure 5-26 *Field Test Case-2*

Field Test Case 3:   None-Line-of-Sight
Distance: 30 m
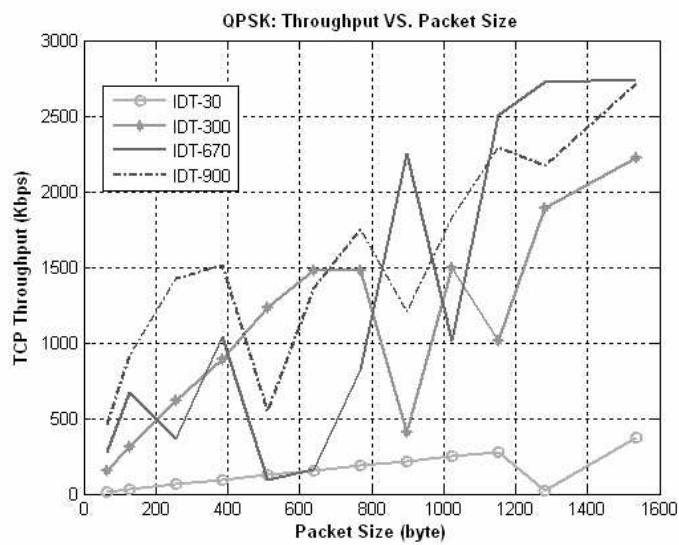
On the top floor of the building

5.3.3 Test Result Analysis

● **Case 1**

Table 5-6 *Test Configuration for Field Case-1*

Modulation	QPSK
Guard Interval	1/4
Code Rate	1/2
Protocol	TCP
Down Stream Power	-96.73dBm

Figure 5-27 *QPSK TCP Throughput for Field Case-1*

Compared with

Figure 5-6, lab test result, the throughput value fluctuates a lot and is smaller than the lab test result but not that much. It is because the test is conducted within a very short distance and line-of-sight situation. Furthermore, the maximum throughput is also affected by the add-on WLAN hotspot function which can be investigated in the following cases.

In Table 5-7, we can see the application performances for this configuration:

Table 5-7 Application Test Field Case-1

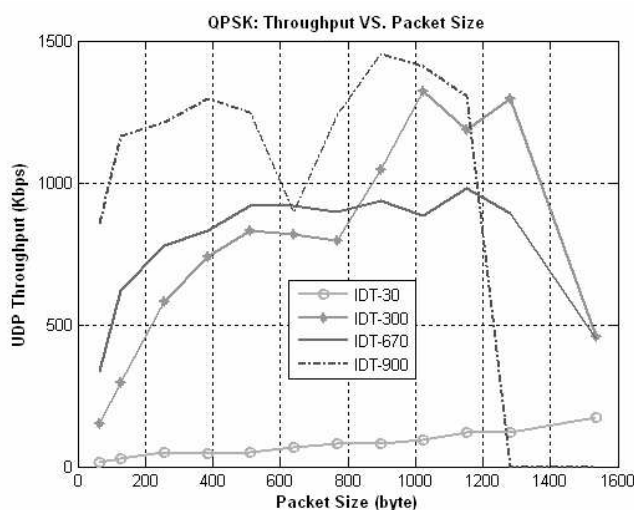| HTTP	Positive	
FTP	Upload	249.87 KBps
	Download	325.87 KBps

● **Case 2**

In field test case 2, UDP traffic measurement is mainly conducted, because TCP traffic can not be successfully tested for the power restriction reason.

1. QPSK:

Uplink transmission power: PWR REF+Attenuation= -17 + (-30) = -47dBm
Downlink receiving power: -82 dBm

Figure 5-28 *Field Case-2 QPSK Throughput*

For QPSK, the receiving power is almost the same as we do in the Lab test. But, because of the Hotspot additional cost, the throughput value is almost half of the Lab test.

Table 5-8 *Application Test Field Case-2 QPSK*

HTTP	Positive	
FTP	Upload	220.87 KBps
	Download	325 KBps

2. 16QAM

Uplink transmission power: PWR REF+Attenuation = -13 + (-30) = -43dBm
Downlink receiving power: -79 dBm

In Figure 5-29, the maximum throughput value is even higher than the LAB test counterpart. This is because in the lab test, the receiving power is around -95dBm, whereas the receiving power for this case is measured to be -79dBm. As known, the larger the receiving power, the larger the throughput value. So in this case, the maximum throughput is even higher.
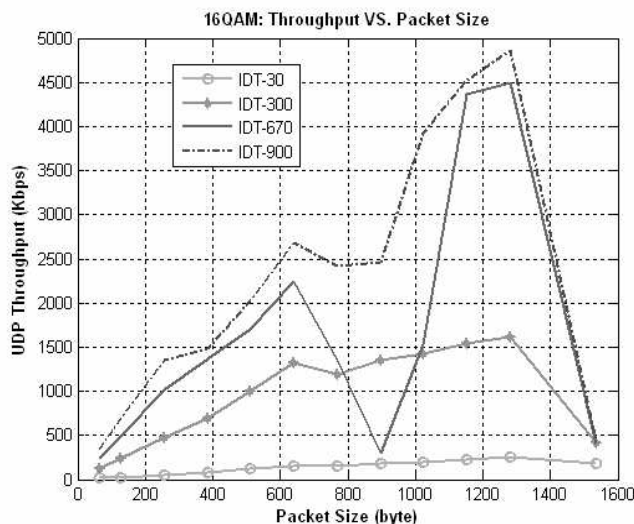
Figure 5-29 *Field Case-2 16QAM Throughput*

Table 5-9 *Application Test Field Case-2 16QAM*

HTTP	Positive	
FTP	Upload	12 KBps
	Download	110 KBps

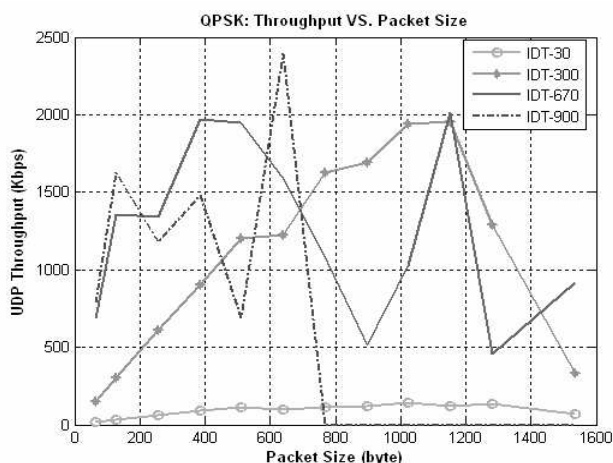**3. 64QAM**

For 64QAM, the test could not be conducted, because 64QAM is so vulnerable that the connection can be easily damaged. For the application trial for 64QAM, nothing can be transmitted using the DVB-RCT uplink. The downlink (DVB-T) download speed is even reduced to 10KBps.

● **Case 3**

QPSK: Downlink receiving power: -68 dBm

Uplink transmission power: 3 dBm

Figure 5-30 *Field Case-3 QPSK Throughput*

The maximum throughput value for QPSK is around 2400 Kbps, which is 1Mbps smaller than the Lab test maximum value. The application test result was listed in Table 5-10.

Table 5-10 *Application Test Field Case-3 QPSK*

HTTP	Positive	
FTP	Upload	13.36 KBps
	Download	200.5 KBps

For 16QAM and 64QAM, all of the test can not be conducted.

● **Conclusion**

Even though this very simple beta trial was conducted within only 3 days and accompanied with quite a lot of difficulties, still communication utilizing the air-interface was tested. Several conclusions could be draw as follows:

1. The hotspot implementation using Runcom RN2821 CPE is feasible. It could supply high quality of service if using proper antenna and proper base station parameter configuration.

2. Some typical Internet services such as HTTP, FTP can be realized based on DVB-T/RCT services

3. Different modulation schemes are suitable for different services. From this test result, it is clear to see that for FTP service, QPSK modulation is the best. That's because FTP is based on TCP protocol, it has worse performance as the modulation changes from QPSK to 64QAM.

4. The test result does not match the theoretical analysis. The reasonable explanations are:

First, as previously mentioned, almost all field tests are indoor ones. Instead of outdoor antenna implemented, proper indoor antennas should be used to avoid huge

reflection caused by indoor barriers.

Second, the base station always works in the adaptive mode. It is impossible for us to increase its output power to specific value as we wish. Even by using some software to change the parameters in its MAC layer, the output power can be increased only several dB.

Third, in the real communication system, high performance filter and LNA should be used to increase the SNR of the signal transmitted from the base station. But in our test, it is impossible for us to use them. So the performance of the DVB-RCT can not match our demand.

6 Conclusion and Future work

6.1 Conclusion

In this thesis work, a comparison between DVB-RCT and WiMAX has been achieved. The superiorities of adopting DVB-RCT as WMAN access have been analyzed. In order to evaluate DVB-RCT uplink performance based on Runcom implementation, a full test proposal containing both lab and field test has been designed. After the test work conducted at KIT Gävle, the result proves that DVB-RCT can supply high quality QoS as WiMAX. The IP traffic performances for both standards are comparable. Regarding the cost of importing both resolutions for supplying WMAN access for Sweden, DVB-RCT is preferred for its lower cost by reusing existed DVB-T infrastructures and more suitable for mobile applications.

6.2 Future work

Although the field test with air-interface was conducted, because of the poor filter characteristic, the roof mounted antenna and power amplifier were not used. In the future work, a better designed filter should be configured at the BS. With the help of power amplifier and roof mounted antenna, a longer distance and more typical test scenarios could be achieved.

Appendix: Perl Script File

1. autosendtcp /* TCP Traffic Sender*/

#!/usr/bin/perl

Performance analysis and test
of the DVB-RCT system

```perl
open(SFILE,"TCP_cn")||die("Can not open script file!\n");
print("Please Input your log file name for current test case:\n");
$name=<STDIN>;
open(FFILE,">>$name")||die("Can not open scripe file!\n");
$line=<SFILE>;


while($line ne ""){

system("./ITGSend $line");

sleep(2);
system("./ITGDec /tmp/ITGSend.log >> $name");



$line=<SFILE>;

}
print("All kinds of packets have been sent successfully!\n");
close(SFILE);
close(FFILE);
```

2. autosendudp   /*UDP Traffic Sender*/

```perl
#!/usr/bin/perl

open(SFILE,"UDP_Script")||die("Can not open script file!\n");
$line=<SFILE>;

while($line ne ""){
system("./ITGSend $line");
sleep(5);
$line=<SFILE>;

}
print("All kinds of packets have been sent successfully!\n");
```

3. Finddelay /*TCP RTT Delay Finder*/
```perl
#!/usr/bin/perl
```

Performance analysis and test
of the DVB-RCT system

```perl
print("Please Input the file name:\n");
$name=<STDIN>;
open(SFILE,"$name")||die("Can not open log file!\n");
open(DFILE,">Delaylog_$name")||die("Can not open report file!\n");
$lineread=<SFILE>;
$flag=1;

  while($lineread ne ""){

     if($lineread=~/^Average/)
       {

          chop($lineread);
          @valuet=split(/ +/,$lineread);

          if($valuet[1] eq "delay"){
              if(($flag % 2) != 0){

            print DFILE ("$valuet[3],");
             }
               $flag++;
               if(($flag % 24)== 0){

            print DFILE ("\n");
}
}
}
$lineread=<SFILE>;
}
```

4. FindRecv   /* Parameter Extraction for Throughput, Packet Loss Rate and Jitter */
```perl
#!/usr/bin/perl

print("Please Input The Parameter You Will Find With The First Character Capitalized...\n");
$Find=<STDIN>;
chop($Find);
```

Performance analysis and test
of the DVB-RCT system

```perl
print("Please Input The Target File...\n");
$name=<STDIN>;
chop($name);


open(SFILE,"$name")||die("Can not open log file!\n");
if($Find eq "Throughput"){
open(DFILE,">Throughput_$name")||die("Can not open report file!\n");
}
elsif($Find eq "Packets"){
open(DFILE,">Ploss_$name")||die("Can not open report file!\n");
}
else{
open(DFILE,">Jitter_$name")||die("Can not open report file!\n");
}
$lineread=<SFILE>;
$Flag=1;

  while($lineread ne ""){

      if($Find eq "Throughput"){

          if($lineread=~/^$Find/){

                  chop($lineread);
                  @valuet=split(/ +/,$lineread);
                  $pri=$valuet[3];
                  print DFILE ("$pri,");

                      if(($Flag % 12)==0){

                          print DFILE ("\n");
                      }
                  $Flag++;
              }
          }

      elsif ($Find eq "Packets"){

          if($lineread=~/^$Find/){

                  chop($lineread);
                  @valuet=split(/ +/,$lineread);
                  $pri=$valuet[4];
                  print DFILE ("$pri,");
```

```perl
                    if(($Flag % 12)==0){

                        print DFILE ("\n");
                    }
                $Flag++;
            }
        }
    elsif($Find eq "Jitter"){
                if($lineread=~/^$Average/){

                    chop($lineread);
                    @valuet=split(/ +/,$lineread);
                        if($valuet[1] eq "jitter"){

                            $pri=$valuet[3];
                            print DFILE ("$pri,");

                            if(($Flag % 12)==0){

                                print DFILE ("\n");
                            }
                        $Flag++;
                        }

                }

    }
    else{

        print(" You Have Typed Wrong Character, Please Restart This Program...\n");

        last;
    }


$lineread=<SFILE>;
}
close(SFILE);
close(DFILE);
```

5. Log Processing   /* Friendly Printed Log Function*/

```perl
#!/usr/bin/perl
print("Please Input The Log Name:\n");
```

Performance analysis and test
of the DVB-RCT system

```
$log_name=<STDIN>;
print("Please Input the Script Name for this test:\n");
$scriptname=<STDIN>;


open(SFILE,"$log_name")||die("Can not open log file!\n");
open(NFILE,">>P$log_name")||die("Can not create New log file!\n");
open(CFILE,"$scriptname")||die("Can not open script file!\n");


$linescript=<CFILE>;


while($linescript ne ""){

    if($scriptname eq "UDP_Script"){

        chop($linescript);
        @wordsu=split(/ +/,$linescript);
        $idttime =      $wordsu[5];
        $packagesize= $wordsu[7];


    }
     else{

         chop($linescript);
         @wordst=split(/ +/,$linescript);
         $idttime =      $wordst[9];
         $packagesize= $wordst[11];

             }

print NFILE (" Sending Rate = $idttime pak/sec    Package Size = $packagesize byte\n");
for($count=1;$count<=37;$count++){
     $linelog=<SFILE>;
     print NFILE ("$linelog");

}
   print NFILE ("\n");

 $linescript=<CFILE>;



}
close(SFILE);
close(NFILE);
close(CFILE);
```

Bibliography

[3].David Till, "Teach yourself Perl 5 in 21 Days", Sams, June 1996.

[4].Francisco Fraile Gil, David Gómez Barquero, "On the Capability of DVB-RCT to provide Interactive Services", March 2004.

[5].Gerard Faria, "DVB-RCT: The Missing Link for Digital Terrestrial TV", Harris, Broadcast Communications, 2004

[6].Runcom, "RN-2821 CPE User's Guide", www.runcom.com

[7].Runcom, "RN-BS28PM Base Station Module", www.runcom.com

[8].Terry Moltzan, "Design and Analysis of a Wireless Telemetry System Utilizing IEEE 802.16", Spring 2005.

[9].Wei Li, Hong Liu, and Gilles Gagnon, "Performance Assessment of IP Traffic over

[10].ATSC Interactive Datacasting Systems", IEEE Transactions on Consumer Electronics, Vol. 51, No. 1, FEBRUARY 2005

[11].www.dvb.org

[12].www.grid.unina.it/software/ITG/

[1314] Gerard Faria, "DVB-RCT, The missing link for digital terrestrial TV", 2002

[1516] Fabio Scalise, "DVB-RCT, A standard for interactive DVB-T", 2002

[13] Khalid Anwar Usmani, "Metropolitan area network", 2004

[14] Dusan Matie, "OFDM as a possible modulation technique for multimedia applications in the range of mm waves", 1998,10

[15] Arunabha Ghosh and David R. Wolter, "Broadband Wireless Access withWiMax/8O2.16: Current Performance Benchmarks and Future Potential", 2005.1