UNIVERSITY OF ÇUKUROVA INSTITUTE OF NATURAL AND APPLIED SCIENCE

MSC THESIS

Seyhun Barbaros YABACI

ANALYSIS AND COMPARISON OF EXISTING HIGH DATA-RATE MOBIL TECHNOLOGIES (HSPA - WIMAX AND WI-FI)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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We certified that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on 22/01/2010.

Signature....................................	Signature....................	Signature…………….……..
Assoc. Prof.Dr. Turgut İKİZ	Asst. Prof. Dr. Sami ARICA	Asst.Prof. Dr. M. Fatih AKAY
Supervisor	Member	Member

This MSc Thesis is performed in Department of Institute of Basic And Applied Sciences of Cukurova University.

Registration Number:

Prof. Dr. İlhami YEĞİNGİL

Director

Institute of Basic And Applied Sciences

ABSTRACT

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Supervisor: Assoc. Prof. Dr. Turgut İKİZ
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Jury: Assoc. Prof. Dr. Turgut İKİZ
Asst. Prof. Dr. Sami ARICA
Asst. Prof. Dr. M. Fatih AKAY

The wireless communication basically can be defined as transfer of information without use of any kind of cable media. Electromagnetic waves used for wireless transmission over the air interface The model of data communication with electromagnetic waves requires three basic steps. The information modulated onto electromagnetic waves via different modulation techniques(GMSK, 4PSK, 16QAM, 64QAM) then distributed the users via different multiple access techniques (TDMA, FDMA, CDMA, OFDMA). Transmitted data recovered at receiver side by applying these steps in reverse order (de-multiple access, demultilpexing and demodulation).

Today, there are multiple technologies emerged from different standarts for data transmission over wireless access. Furthermore, many new standarts being defined for future work to supply the demand for higher data rates. In this thesis, three prominent technologies that currently operational, is chosen for analysis and comparison in regarding to their physical layer properties and air interface effectiveness. All of these technologies is designed and evolved for their primary usage area (voice and video communicaton for cellular systems, long range data for WiMAX and short range data for WiFi). The primary advancement areas is achieving better spectrum efficiency and higher data rates per sector. This demand causes convergence of air interface properties and increases similarities of radio access methods in near future.

The objective of this thesis, making an analysis of different existing high data-rate wireless broadband technologies in physical layer aspects. It is necessary to avoid a strict comparison for these technologies since the technological aspects offers their convergence point is very similar in physical layer properties.

Keywords: Wireless Data Communication, UMTS, WiMAX, LAN, GSM

ÖZ

YÜKSEK LİSANS TEZİ

MEVCUT YÜKSEK VERİ HIZLI KABLOSUZ MOBİL TEKNOLOJİLERİN ANALİZ VE İNCELENMESİ (HSPA - WIMAX AND WI-FI)

Seyhun Barbaros YABACI

ÇUKUROVA ÜNIVERSITESI
FEN BILIMLERI ENSTITÜSÜ
ELEKTRIK ELEKTRONIK MÜHENDISLIĞI ANABILIM DALI

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Yrd. Doç. Dr. Sami ARICA
Yrd. Doç. Dr. M. Fatih AKAY

Kablosuz iletişim teknikleri herhangi bir taşıyıcı dalgaklavuzu ortamı kullanılmadan elektromanyetik dalgalar kullanılarak yapılan iletişim şekillerini kapsamaktadır. Elektromanyetik dalgalar kullanılarak yapılan veri iletimi 3 temel aşamada özetlenebilir. Kullanıcı verileri öncelikle modulasyon teknikleri (GMSK, BPSK, 4PSK, 16QAM, 64 QAM) ile elektromanyetik dalgalar üzerine module edilir. Daha sonra çoklu erişim teknikleri (TDMA, FDMA, CDMA, OFDMA) kullanılarak kullanıcı kanallarına, verilen bantgenişliği içinde dağıtılır. Alıcı tarafında bu adımlar ters sıra ile uygulanarak (çoklu erişimin çözülmesi ve demodulasyon) iletilen veri elde edilmektedir.

Günümüzde, kablosuz erişim ortamından veri transferi sağlanması amacı ile kullanılan ve değişik standartlarla tanımlanan birçok kablosuz erişim teknolojisi bulunmaktadır. Bu tezin kapsamında, alanlarında baskın olarak kullanılan üç farklı kablosuz erişim teknolojisi fiziksel katman özellikleri ve hava arayüzü kullanım etkinlikleri açısından analiz ve kıyaslama için yer almaktadır. Bu teknolojiler öncelikler kendi alanlarında uygun şekilde hizmet vermek üzere tasarlanmış (Hücresel şebekeler için ses ve veri iletimi, WiMAX için uzun menzilli ve çok kullanıcılı veri iletimi, Wi-Fi sistemleri için kısa mesafe ve az kullanıcılı veri iletimi) ve evrimleşmişlerdir. Bu tezin kapsamı içinde günümüzde kullanılan üç farklı kablosuz erişim teknolojisinin fiziksel katman bazında analizi ve kıyaslaması yapılacaktır. Bununla birlikte sonuç ve kıyaslama kısmında, teknolojilerin kullanım alanlarına dayanan farklılıklardan dolayı sıkı parametrelere dayanan ve basite indirgenmiş bir kıyaslama yapılmamış ve daha çok teknolojilerin yakınsama noktaları üzerinde durulmuştur.

Anahtar Kelimeler: Kablosuz Veri İletimi, UMTS, WiMAX, LAN, GSM

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LIST OF ABBREVIATONS

ASN	Access Service Network
AUC	Authentication Center
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BPSK	Binary Phase Shift Keying
BSC	Base Station Controller(GSM)
BSS	Base Station Subsystem(GSM)
BTS	Base Transceiver Station(GSM)
CDMA	Code Divison Multiple Access
CN	Core Network
CPCH	Common Pilot Channel(GSM)
CQI	Cell Quality Index
CSN	Connectivity Service Network
DCCH	Dedicated Control Channel
DL	Downlink
DPCCH	Dedicated Physical Control Channel
DPDCH	Dedicated Physical Data Channel
DSCH	Downlink Shared Channel
DSL	Digital Subscriber Line
DSP	Digital Signal Processing
DSSS	Direct Sequence ,Spread Spectrum
EDGE	Enhanced Data rates for GSM Evolution
EGPRS	Enhanced GPRS
ESS	Extended Service Set
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FFT	Fast Fourier Transform
FHSS	Frequency Hopping Spread Spectrum
FUSC	Full Usage of Subcarriers

GGSN	Gateway GPRS Support Node
GMSC	Gateway Mobile Switching Center
GMSK	Gaussian Minimum Shift keying
GPRS	Global Packet Radio Service
GSM	Global System for Mobile Communication
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HS-DSCH	High Speed Downlink Shared Channel
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Access
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier transform
IP	Internet Protocol
ISI	Intersymbol Interference
LAN	Local Area Network
MAC	Medium Access Control
MAN	Metropolitan Area Network
MDHO	Macro Diversity Handover
MIMO	Multıple In Multıple Out
MS	Mobile Station
MSC	Mobile Switching Center
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OVSF	Orthogonal Variable Spreading Factor
PCH	Paging Channel
PLMN	Public Land Mobile Network
PSTN	Public Switched Telephony Network
PUSC	Partial Usage of Subcarriers
QAM	Qudrature Amplitude Modulation
QoS	Quality of Service
RACH	Random Access Channel

RAN	Radio Access Network
RNC	Radio Network Controller
SGSN	Serving GPRS Support Node
SIM	Subscriber Identity Module
SNR	Signal to noise Ratio
TCH	Traffic Channel
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TS	Time Slot
UCD	Uplink Channel Descriptor
UL	Uplink Channel Descriptor
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Locating Register
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access,
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolita Area Network

1. INTRODUCTION

DSL lines has long used for broadband access for digital data transmission. As a fairly new technology, wireless data access access has advantages over fixed wired technology such as cost efficiency, expandibility easiness, portability and mobility. The main application area for these wireless systems are not only the internet access for computers and digital devices, but beyond this, connecting, automation and management of various devices and equipment. In wireless content the “coverage area” can defined as whole country, a city or just single building.

A general model for data transfer over wireless acces technologies is given in Figure 1.1. To transmit a data over any medium via electromagnetic waves, the data first have to be digitalized and modulated over given frequency. Various modulation schemas can be used depending to signal clearance (in other terms carrier over interference ratio). Higher order modulation allows more bit to transfer but more susceptible to interference and requires more error correction ratios. After the modulation of the signal data has to be transferred to users via multiple access mechanisms such as FDMA, TDMA, WCDMA and OFDMA. More complex multiple access methods requires more processing power of DSP chips and increases cost. Simple versions of TDMA and FDMA actually does not need for DSP chips.

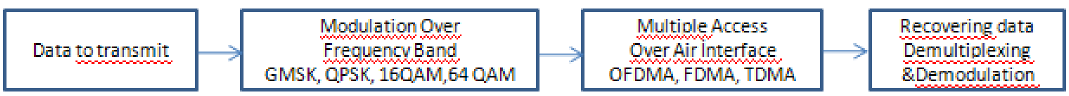

Figure 1.1 General Data Communication Model of Wireless Systems

For broadband wireless access today there is existing primary technologies are given as 802.16 Wireless MAN (Wimax is a commercial name), 802.11 WLAN (Wi-Fi is a brand name for 802.11g) and 3G cellular technology UMTS-HSPA. These technologies emerged from different backgrounds and primarily designed for different purposes. But their application area increasingly becoming closer by the time; providing high speed and portabile high rate wireless data access for users.

UMTS (Universal Mobile Telecommunications System) is a third generation mobile technology. UMTS evolved from existing 2g and 2,5g GSM technologies and differs from their predecessors by using WCDMA channel coding instead of TMDA and FDMA technologies. HSPA is defined as data transmission protocol of UMTS system.

Wi-Fi (Wireless fidelity) is designed primarily as wireless local network access for internet. It is based on IEEE 802.11 standarts. Wi-Fi uses OFDM channel coding technology for air interface. Existing Wi-Fi systems are currently providing internet access for users inbuilding areas such as airports, hotels, shooping centers and public buildings.

WiMAX (Worldwide Interoperability for Microwave Access) is a broadband wireless technology and basically designed as a last mile solution for users as an alternative to wired DSL systems. Like Wi-Fi, WiMAX uses OFDM and its based on IEEE standart 802.16. Another main application of WiMAX is providing backbone high speed data access for fixed Wi-Fi hot spots and other point to multipoint wireless systems.

In this thesis, firstly detailed analysis of each technologies will be made. Their technological background will be investigated and depending this background, strong and weak points of each one will be discussed. At conclusion, dual comparisons between technologies will be made by using analyze data of previous chapters. Comparison table of three technologies, containing weakness and strengths of each one, also will be provided at conclusion section.

2. PRELIMINARY WORK

Today, there are multiple technologies emerged from different standarts for data transmission over wireless access. Furthermore many new standarts being defined for future work to supply the demand for higher data rates. The background network structure of these technologies is fairly ineffective for comparison, since it is not related with air interface performance of a wireless system.

The first and foremost (in coverage area aspect) of these technologies is cellular system that currently evolved to 3G HSPA data access technology. Cellular systems are evolved from generation to generation. Currently, second (GSM) and third (3G) generation of cellular systems are operating at 900 and 2100 Mhz frequency bands. GSM uses TDMA and FDMA for multiplexing and 3G uses WCDMA for multiplexing. Current cellular systems are more suitable for circuit switched operation thus less effective for data transmission. But wider usage area (voice and video) and commercial applications make data network applications more realistic for these networks. For lower density data operations currently cellular systems seems more suitable.

The second of these technologies is IEEE 802.16 Wireless MAN, commercialized as WiMAX brand name. Defined by IEEE 802.16 standarts WiMAX has much more technological advancement in comparison to cellular technology. WiMAX uses OFDMA for multiple access technology, and higher order modulation techniques. But in mobility terms WiMAX is falls behind from the cellular technology but has more mobility in latest versions prior to previous ones. But data rates especially higher than cellular systems and overall network structure is more suitable for data services.

IEEE 802.11 is wireless LAN technology and known as commercial brand name Wi-Fi. 802.11 standarts is developed for last mile alternative of cable operating DSL and designed only fixed data access over relatively short distances. Current versions of 802.11 networks can deliver very high data rates in comparison to other technologies in small areas per user and per sector basis.

All of these technologies is designed and evolved for their primary usage area (voice and video communicaton for cellular systems, long range data for WiMAX and short range data for WiFi). Their evolution will be continious for higher demands of the users. The primary advancement areas is achieving better spectrum efficiency and higher data rates per sector by using more advanced modulation techniques. This demand causes convergence of air interface properties and increases similarities of radio access methods in near future.

3. MATERIAL and METHOD

3.1. Cellular Systems and Data Access Technology

3.1.1. Cellular System Concept and Evolution of Cellular Networks

In concept, cellular mobile networks defined as generation by generation. A "Generation" represents the evolutional leap between radio access technologies.

First generation mobile systems were the analog systems. These systems were providing basic speech communications and other speech based services. First generation systems evolved to currently use second generation. Improvements of these generations are TDMA/CDMA usage and digital processing. European based GSM system is current dominant second generation cellular system of the world. Second generation GSM systems offers several crucial advantages for mobile networks prior to previous ones. By using digital technology speech data effectively compressed and multiplexed via various codecs, thus offering much better system capacity and bandwidth usage than 1G system. By using digital signals, required signal strength for communication decreased dramatically allowing much smaller cells and tighter usage of cell structures. This also means low power usage of overall system, much smaller&cheaper user and system equipment (mobile station and base stations in GSM terms).

By using digitally transmitted and processed data it is possible to change the accessed cell while transmitting data. This process is called "handover", one of the key features of GSM system. By these feature, mobile subscribers migrating from cell to cell without their communications interrupted.

GSM system also has data transmission technologies: GPRS and EGPRS (EDGE). Data services is an originally addition to second generation system, enabling packet switching on the existing speech based radio network system. GPRS provides max 80 kbps and edge 236 kbps data transmission rates.

The next step after second generation (GSM), is third generation UMTS system. Whilst 2G systems based upon speech services, 3G system predominantly oriented towards data traffic and multimedia communications. By W-CDMA coding technology, spectrum efficiency and capacity usage better than GSM, enabling UMTS system has higher data rates for communication. UMTS packet access technology is HSPA (High speed packet access), summing of two protocols HSDPA (High Speed Downlink Packet Access) and HSUPA(High Speed Uplink Packet Access). The maximum theoretical data rates data rates can be given as 14.4 mbit/s for HSDPA and 5.7 Mbit/s for HSUPA.

The most important characteristic of cellular mobile network technologies is backward compatibility. This means that both 2G and 3G networks simultaneously exist and cooperate with each other.

3.1.2. Cellular Systems General Network Architecture

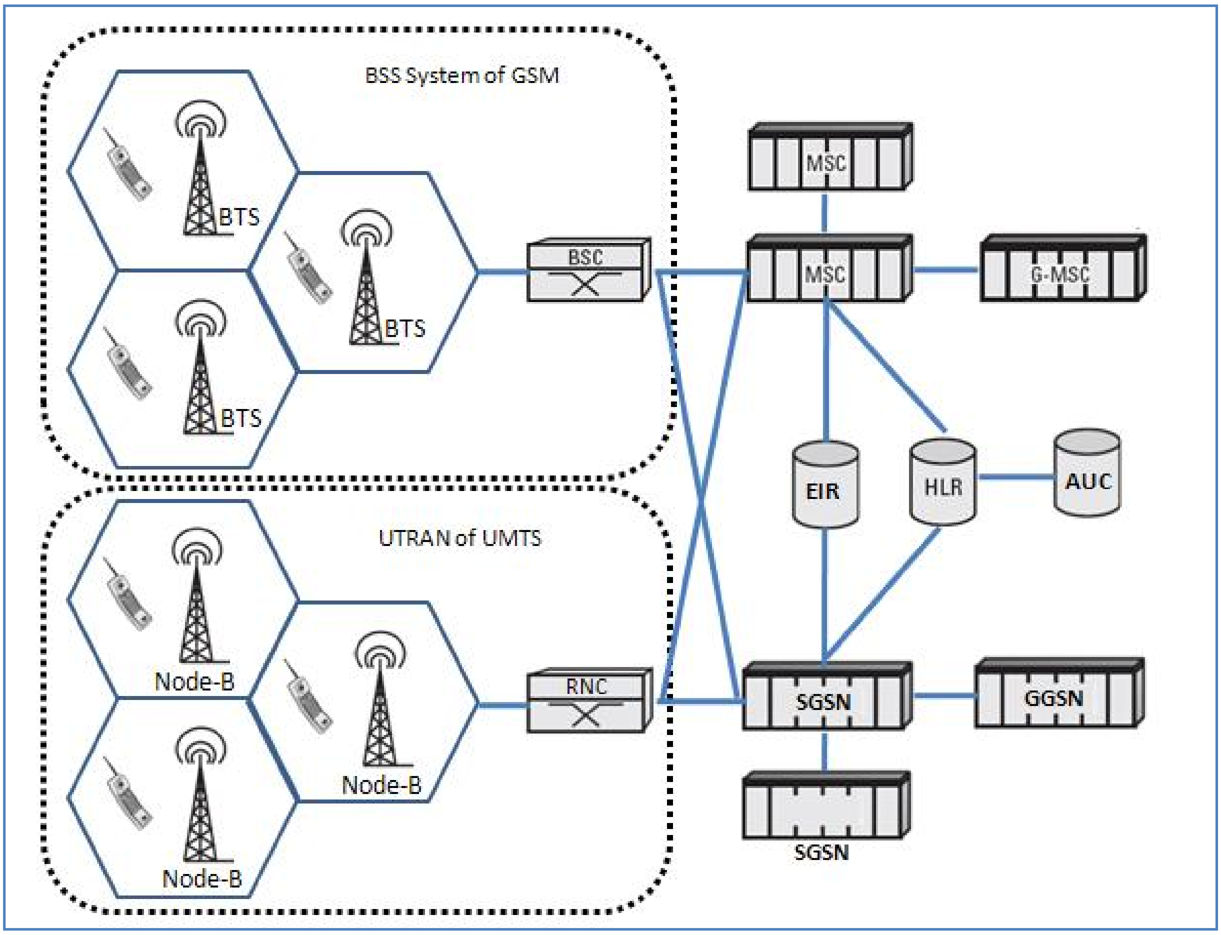

Figure 3.1 The Block Diagram of Cellular System's Network Architecture

The network structure of cellular systems is based on earlier non-cellular radio network systems. The logical structure of cellular network fundamentally divided to three parts; User Equipment, Radio Access Network and Core Network, as shown in Figure 3.1.

User Equipment: The parts of the user equipments are Mobile Terminal and SIM&USIM. Mobile Equipment (ME) provides radio network access functions to the radio access network via air interface. SIM&USIM (Subscriber Identity Module) is a smartcard that holds information for authentication process.

Radio Access Network of GSM (Base Station System)

The components of GSM Base Station System (BSS) are Base station Controller (BSC) and Base Transceiver Station (BTS).

The Base Station Controller (BSC) manages BSS operations as an intelligence point. The main functions of BSC are;

- Handling of the mobile station connection and handover
- Radio network management
- Transcoding and rate adaptation
- Traffic concentration
- Transmission management of the BTSs
- Remote control of the BTSs

The Base Transceiver Station (BTS) is consisted of one or more GSM cells, and performs radio related functions. It also includes transmission equipments and and transforms air interface data to BSC for further processing.

UMTS Radio Access Network (UTRAN)

Radio Access Network (RAN) consists of Node-B and RNC units. Node-B communicates with ME via air interface and performs radio related functions. These functions are:

- Channel coding
- Interleaving
- Rate adaptation
- Spreading and Scrambling operations

Some intelligent functions also performed on Node-B such as radio resource management and HSDPA MAC functionality. Radio Network Controller (RNC) controls all of radio resources in its domain (via connected node-B's). Main functions of RNC;

- Radio related control signaling.
- Layer 2 interface operations from/to Node-B's.
- Mapping of radio access bearers to air interface transport channels.

- Handover decisions and power control functions

Core Network Components

Mobile Services Switching Centre (MSC) is the center of circuit switching operations of CN. Its functions are;

- Switching function for circuit-switched connections
- Supports user mobility(Handover and Location Area Update)
- Stores the current location area of users
- User authentication processes.

Gateway Mobile Services Switching Centre (GMSC) is a variant of MSC that provides interfacing with various external networks such as ISDN and PSTN networks.

Home Location Register (HLR) holds user data such as authentication information and user keys. Also stores information about UE, which part of mobile radio network that it operates.

Visitor Location Register (VLR) is similar to HLR, but it just holds user data of its location area. If a user changes its location area related VLR data is updated.

Serving GPRS Support Node (SGSN) is the center of packet switched operations , its tasks are similar to MSC, but for packet switching operation. In addition to packet routing SGSN performs authentication functions and stores local copy of user data(similar to VLR)

Gateway GPRS Support Node (GGSN) serves as a gateway point to other packet switching networks similar to GMSC on the packet side.

Authentication Center (AUC): In mobile systems user data ciphered and all subscriptions to mobile network is authenticated for general security and call confidentiality. The AUC provides parameters for these operations.

Equipment Identity Register (EIR): In addition to authentication process, another security function for mobile equipment used in mobile systems via EIR. EIR controls the mobile equipment for its validity. This process prevents the usage of stolen or non-approved Mobile equipment.

3.1.3. GSM Radio Network Access Technology

Frequency bands of different GSM based Networks are given in Table 2.1. GSM supports full duplex service that allows simultaneous transmission and reception. Therefore frequency band has uplink (MS to BTS) and downlink (BTS to MS) components separated by duplex distances.

Table 3.1. GSM 900 and 1800 systems frequency allocations

	Uplink	Downlink	# of RF channel	Channel Seperation	Duplex space
GSM 900	890-915	935-960	124	200 Khz	45 Mhz
GSM 1800	1710-1785	1805-1880	374	200 Khz	95 Mhz
GSM 850	824-849	869-894	124	200 Khz	45 Mhz
GSM 1900	1850-1910	1930-1990	299	200 Khz	80 Mhz

GSM system uses two radio access methods for air interface; TDMA (Time division multiple access) and FDMA (Frequency division multiple access). These two system combined to achieve better spectrum efficiency. For FDMA system frequency band divided to number of channels by seperation distance 200 Khz as given in Table 2.1. TDMA system uses frame structure as given in Table 2.2.

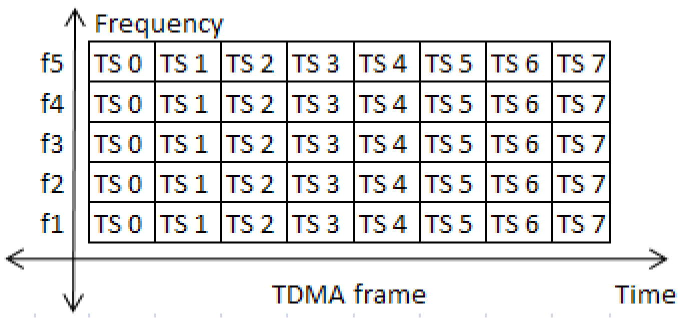

Figure 3.2. TDMA and FDMA based frame structure of GSM

By using FDMA and TDMA at the same time two dimensional channel structure achieved. A TDMA frame consists of 8 TS (Time Slot). Each time slot corresponds to a “physical channel”. “Logical channels” of GSM mapped on these physical channels.

There are two types of logical channels in GSM; Traffic channels and Control Channels. Traffic Channels carries coded speech or data of users. Control Channels carries numerous signaling data for communication.

The control channels in GSM defined in three common title, Broadcast channels, Common control channels and dedicated control channels.

Broadcast Channels (BCH): Purpose of these channels are broadcasting critical cell information to the attached MS's in the cell service area, thus broadcasted in downlink (BTS to MS direction) only. Without decoding these channels, MS's cannot communicate with GSM cells.

- Frequency Correction Channel (FCCH): This is a repeated burst that consisted of totally zeroes. MS uses these bursts for frequency correction.
- Synchronization Channel (SCH): MS uses these channels bursts for time synchronization. Carries information about TDMA frame number and Base Station Identity Code (BSIC) of the BTS.
- Broadcast Control Channel (BCCH): This channel carries cell specific information to the MS's. In BCCH data, all channel configuration information of BTS exits, for example frame numbers for available for RACH in uplink or which frame number a paging request will be sent on paging channel.

Common Control Channels (CCCH): These control channels are used for initial channel assignment processes for system or mobile originated communication.

- Paging Channel (PCH): These channel used for paging process. MS periodically listen this channel and respond the system originated calls via RACH channel.
- Random Access Channel (RACH): This channel used is by MS to request of allocation for SDCCH channel. This request arises from either a paging response to a system originated call setup or starting an MS originated call setup and registration/updating processes.

- Access Grant Channel (AGCH): As its name implied, AGCH used to inform MS's which SDCCH channels allocated for them.

Dedicated Control Channels (DCCH):

- Stand Alone Dedicated Control Channel (SDCCH): This channel dedicated to one MS and carries signaling information between MS and BTS. For call setup initiating and registration/updating SDCCH usage needed. (Notice that, the "stand alone" term on the name implies SDCCH used when no TCH is active)
- Slow Associated Control Channel (SACCH): This is an associated control channel used with a TCH (carries control information during a call) or SDCCH. Measurement reports on uplink and Timing advance – Power control in downlink send on this channel.
- Fast Associated Control Channel (FACCH): This channel used only under necessary conditions when SACCH periods not fast enough, such as handover process. Associated with a TCH channel.

Several logical channels can share the same physical channel or Time Slot (TS). On TS0 (on one carrier per cell, the BCCH-carrier) the broadcast channels and the common control channels are multiplexed. Control channels and Traffic channels mapped together on the physical channels. An example of these mapping is given in Table 2.2. In these example mapping, BCCH and other control channels (except sdcch and related sacch) mapped on the TS 0. TS1 and TS2 reserved for SDCCH, and other time slots reserved for traffic data. This configuration denotes 1 carrier , total 8 TS and 2 SDCCH/8 plus 5 traffic TS configuration. This is a very low capacity for real world, in reality practically never used. In real cases demand for traffic capacity so high in city centers normal configuration for cell total 48-64 TS, 3-6 TS reserved for SDCCH/8 and 44-60 TS reserved for Traffic data.

Table 3.2. Example mapping of logical channels to physical channels of GSM

FN	TS 0	TS 1	TS 2	TS 3	TS 4	TS 5	TS 6	TS 7
0	FCCH	SDCCH 0	SDCCH 8	TCH	TCH	TCH	TCH	TCH
1	SCH	SDCCH 0	SDCCH 8	TCH	TCH	TCH	TCH	TCH
2	BCCH 1	SDCCH 0	SDCCH 8	TCH	TCH	TCH	TCH	TCH
3	BCCH 2	SDCCH 0	SDCCH 8	TCH	TCH	TCH	TCH	TCH
4	BCCH 3	SDCCH 1	SDCCH 9	TCH	TCH	TCH	TCH	TCH
5	BCCH 4	SDCCH 1	SDCCH 9	TCH	TCH	TCH	TCH	TCH
6	AGCH/PCH	SDCCH 1	SDCCH 9	TCH	TCH	TCH	TCH	TCH
7	AGCH/PCH	SDCCH 1	SDCCH 9	TCH	TCH	TCH	TCH	TCH
8	AGCH/PCH	SDCCH 2	SDCCH 10	TCH	TCH	TCH	TCH	TCH
9	AGCH/PCH	SDCCH 2	SDCCH 10	TCH	TCH	TCH	TCH	TCH
10	FCCH	SDCCH 2	SDCCH 10	TCH	TCH	TCH	TCH	TCH
11	SCH	SDCCH 2	SDCCH 10	TCH	TCH	TCH	TCH	TCH
12	AGCH/PCH	SDCCH 3	SDCCH 11	TCH	TCH	TCH	TCH	TCH
13	AGCH/PCH	SDCCH 3	SDCCH 11	TCH	TCH	TCH	TCH	TCH
14	AGCH/PCH	SDCCH 3	SDCCH 11	TCH	TCH	TCH	TCH	TCH
15	AGCH/PCH	SDCCH 3	SDCCH 11	TCH	TCH	TCH	TCH	TCH
16	AGCH/PCH	SDCCH 4	SDCCH 12	TCH	TCH	TCH	TCH	TCH
17	AGCH/PCH	SDCCH 4	SDCCH 12	TCH	TCH	TCH	TCH	TCH
18	AGCH/PCH	SDCCH 4	SDCCH 12	TCH	TCH	TCH	TCH	TCH
19	AGCH/PCH	SDCCH 4	SDCCH 12	TCH	TCH	TCH	TCH	TCH
20	FCCH	SDCCH 5	SDCCH 13	TCH	TCH	TCH	TCH	TCH
21	SCH	SDCCH 5	SDCCH 13	TCH	TCH	TCH	TCH	TCH
22	CBCH	SDCCH 5	SDCCH 13	TCH	TCH	TCH	TCH	TCH
23	CBCH	SDCCH 5	SDCCH 13	TCH	TCH	TCH	TCH	TCH
24	CBCH	SDCCH 6	SDCCH 14	TCH	TCH	TCH	TCH	TCH
25	CBCH	SDCCH 6	SDCCH 14	TCH	TCH	TCH	TCH	TCH
26	AGCH/PCH	SDCCH 6	SDCCH 14	TCH	TCH	TCH	TCH	TCH
27	AGCH/PCH	SDCCH 6	SDCCH 14	TCH	TCH	TCH	TCH	TCH
28	AGCH/PCH	SDCCH 7	SDCCH 15	TCH	TCH	TCH	TCH	TCH
29	AGCH/PCH	SDCCH 7	SDCCH 15	TCH	TCH	TCH	TCH	TCH
30	FCCH	SDCCH 7	SDCCH 15	TCH	TCH	TCH	TCH	TCH
31	SCH	SDCCH 7	SDCCH 15	TCH	TCH	TCH	TCH	TCH

3.1.3.1. Mobility of GSM System Idle mode and Handover

Idle mode Operations

GSM network consists of many neighbor cells that creates continious air interface. In order to communicate to the network, a mobile station must choose best serving cell in its location. When a MS powered on, it firstly measures the BCCH carriers signal strengths of its PLMN(Public Land Mobile Network) cells. If it can measure one more allowed BCCH carriers, makes a decision on basically measured signal strengths to camp on a cell. The selection process can also be adjusted by parameters that makes one or more cell more favourable than other cells. If MS receives system information from BCCH carrier of the cell that is camped on and if necessary register itself on a new location area.

Ms periodically performs measurements when its idle mode (not making a traffic channel connection with network), at least once every 30 seconds, depends on operator settings. These measurements and cell based parameters provides inputs for cell reselection algorithm. If a cell provides better conditions according to algorithm MS camps on these new cell. And again if necessary updates its location area if new cells location area different from the previous one. Idle mode operation steps are summarized in Figure 3.3.

Camping on a cell in idle mode serves for basically three purposes;

- MS can receive system information from the network via periodically listening serving cells BCCH carrier.
- To know which cell to access on provides MS to access network for starting a call, via random access channel of selected cells.
- The network knows MS camped on which cell thus location area of the MS. (Location area is used for selected cell group for paging process). So Network can access to MS when incoming call is received.

As a summary, the idle mode operation can be divided into 4 processes.

1. PLMN selection
2. Cell selection
3. Cell reselection
4. Location Updating

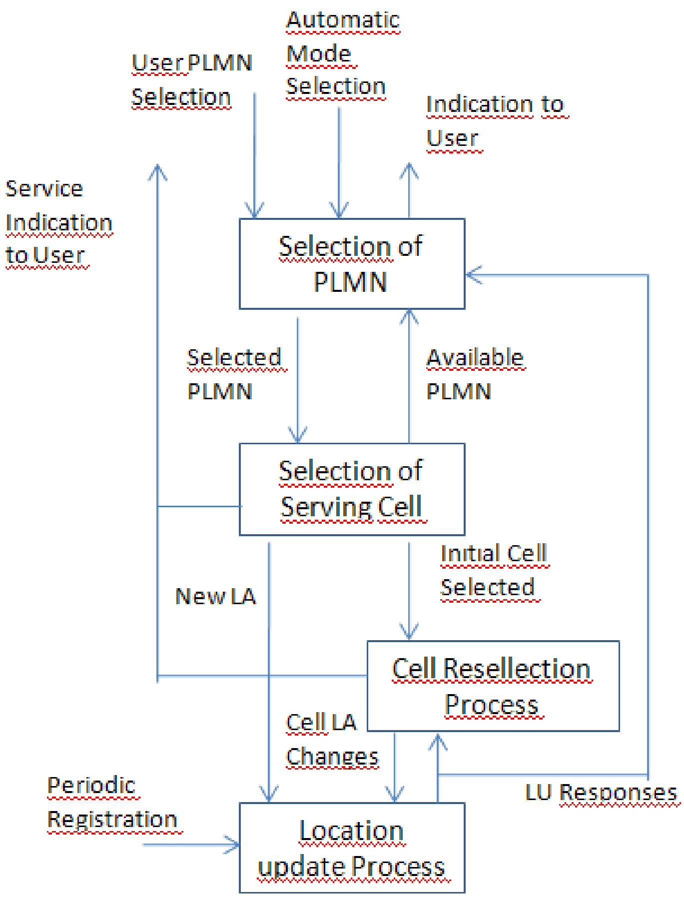

Figure 3.3. Idle Mode Processes in GSM Network

Active mode operations: Handover and Locating Algorithm

In a cellular system the ongoing calls of the moving users must be carried between the neighbour cells to ensure the communication continuity. This process called handover. The handover decision is a result of locating algorithm and given by network and specifically on BSC. The signal strength measurements of serving and neighbor cells and network parameter settings are used as inputs for locating algorithm. In the active mode, locating algorithm completes a calculation cycle for every 480 ms. The handover process can be carried just for circuit switched connections, not for packet data.

The reasons that produces handover decision;

- Decreasing field strength of the serving cell prior to neighbouring cell/cells.
- Decreasing signal quality of serving cell.
- Exceeding allowed timing advance limits for serving cell.
- Parameter settings that favoured another cell.

While in active mode(ongoing communication state) an MS periodically measures serving cells signal strength and quality. The list of BCCH carrier frequencies of neighbour cells sent to MS by BSC. Ms periodically tunes for BCCH frequencies of the defined neighbour cells and measures their signal strength. By these measurements locating algorithm concludes on a candidate cell list for possible handover decision (Figure 3.5). If other conditions that largely setted by network parameters are fulfilled, algorithm produces handover decision. If handover decision given by BSC, a handover command send to MS by BTS referring the new time slot and traffic channels frequency of target cell. Then MS tunes at the next time slot to its new time slot and frequency. The handover process is shown in Figure 3.4.

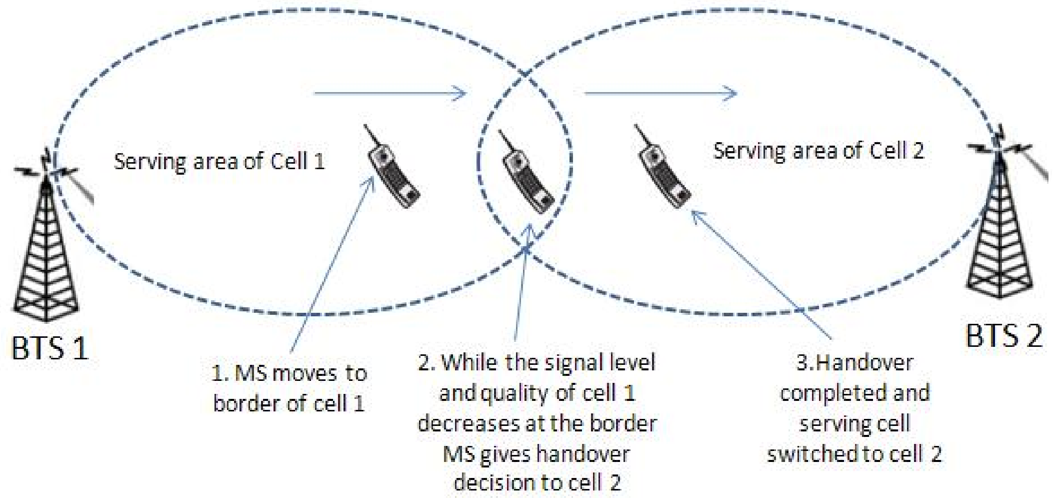

Figure 3.4. Handover process

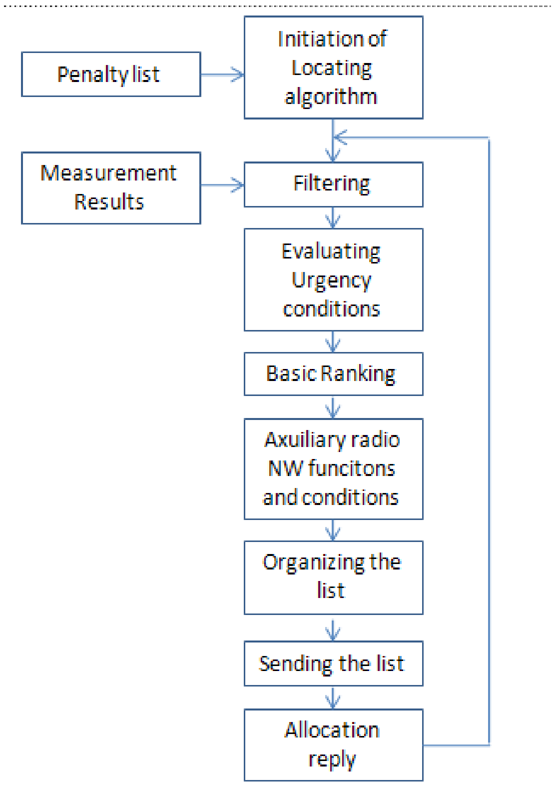

Figure 3.5. Main flow of the Handover & Locating algorithm

3.1.3.2. GSM data access technology (GPRS –EDGE)

GSM is actually designed for carrying simultaneous duplex speech data, it is based on the circuit switched system. GPRS is an extenison of GSM architecture. Packet data traffic runs on a new backbone IP network and is separate from the existing GSM core network that is used mainly for speech. To carry data packets on air interface we have to reserve some traffic channels for this purpose. This data channels called PDCH’s (packet data channels).

Normally a Traffic channel has 13 kbit/s data rate capacity. The burst structure of this channel consists of encrypted bits, training sequence bits and guard bits. Encrypted bits are carries both information and additional coding for error connection purposes. A PDCH channel has similar structure as TCH channel but various coding schemes applied for data correction purposes. The choosing of coding scheme heavily depended upon the clearence of the signal on air interface means high carrier to interferer (C/I) ratio. By changing applied coding schemes data rates for each time slot also changed.

Table 3.3. Coding Schemes for GPRS

Coding Scheme	Max Data Rate per TS	Target C/I
CS-1	8	6
CS-2	12	9
CS-3	14.4	12
CS-4	20	17

At the limit values, coding of GPRS System can carry maximum 20 kbit/s for each time slot. But these are theoratical values, heavily depended upon radio conditions. To achieve more data rate, GSM terminals(e.g. MS) can use more than one time slot at the same time. Time slot usage capacity at downlink and uplink combinations determines the GPRS class of a terminal. In Table 2.4 Mobile Classes and data transfer rates are summarized.

Table 3.4. Mobile classes and Data transfer rates

	Used PDCH		Data rate(CS-4)	
Mobile Class	Downlink	Uplink	Downlink	Uplink
Class 4	3	1	60	20
Class 8	4	1	80	20
Class 10	4	2	80	40

EGPRS (Enhanced GPRS)

To achieve higher data rates in same TS and frequency limitations, there is another technology in GSM named EDGE. The main improvement on EDGE is modulation scheme. Edge usus 8 PSK modulation, which allows transmitting 3 bits per symbol versus 1 bit of the GMSK (Figure 2.6). The distance between the different symbols is shorter using 8 PSK modulation than when using GMSK. Thus 8 PSK is more sensitive to quality degradations of radio enviroment.

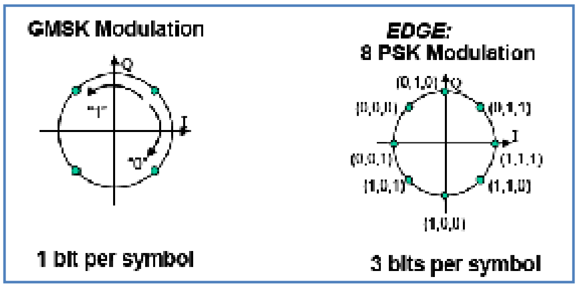

Figure 3.6. GMSK versus 8 PSK Modulation

As a result, under poor radio conditions GMSK takes advantage, but in good signal quality 8 PSK has distinct advantage over date rates. So EDGE technology uses a mixture of modulation and coding schemes as given in Table 3.5.

Table 3.5. Edge modulation schemes and data rates

Coding Scheme	Modulation Method	Max data rate	MCS family	Max Data rate(Kbps)
MCS-9	8 PSK	59.2	A	236.8
MCS-8	8 PSK	54.4	A	217.6
MCS-7	8 PSK	44.8	B	179.2
MCS-6	8 PSK	29.6	A	118.4
MCS-5	8 PSK	22.4	B	89.6
MCS-4	GMSK	17.6	C	70.4
MCS-3	GMSK	14.8	A	59.2
MCS-2	GMSK	11.2	B	44.8
MCS-1	GMSK	8.8	C	35.2

For a class 8&10 EDGE capability MS can achieve 4*59.2=236.8 Kbps max data rate for edge technology in GSM system.

3.1.4. Third Generation Cellular System: UMTS Radio Network

As its predecessor, UMTS also supports full duplex communication, But it has extra allocated TDD (Time Division Duplex) bands in frequency spectrum. In Table 3.6 frequency band allocation of UMTS in Europe is given. UMTS carriers has 5 MHz bandwidth, 12 carrier reserved for FDD and 5 reserved for TDD.

Table 3.6. Frequency bands for UMTS

Frequency Band	Mode	# of Carrier	Carrier BW
1900-1920	TDD	4	5 MHz
1920-1980	FDD-UL	12	5 MHz
2010-2025	TDD	3	5 MHz
2110-2170	FDD-DL	12	5 MHz

For radio access in UMTS, W-CDMA (Wideband Code Division Multiple Access) technology is used. Direct-Sequence Code Division Multiple Access (DS-CDMA) system, i.e. user information bits are spread over a wide bandwidth by multiplying the user data with quasi-random bits (called chips) derived from CDMA spreading codes.

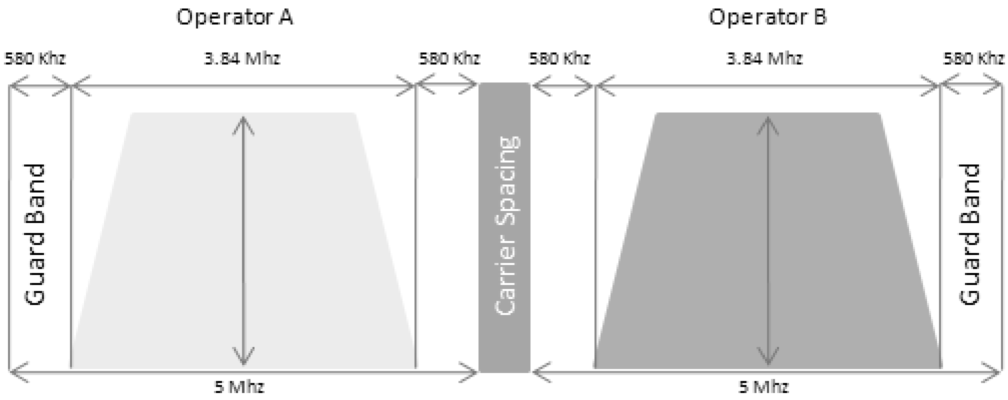

Figure 3.7. UMTS carrier bands and guard bands

3.1.4.1. Spreading and despreading

User data spreaded over the all carrier bandwidth via spreading codes. To spread the given user data BPSK (binary phase shift keying) modulated signal with data rate R) , it multiplied by 8 code bit (chip) sequence. Graphical representation of this operation is shown in Figure 3.8, a data symbol multiplied by eight chip long spreading code.UMTS has 5 Mhz band width but guard band takes approximately 1.16 MHz of this, remaining 3.84 MHz bandwidth used for data tranfer and it also determines the chip rate of the system (3.84 Megachips).

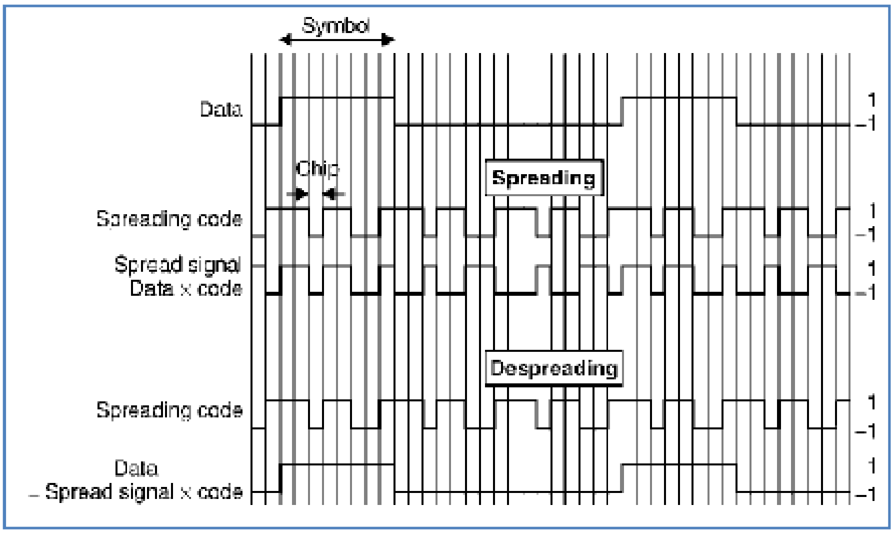

Figure 3.8. Spreading and despreading process, HOLMA H. A.,2007

In this case, the signalling rate increased by a factor of 8, thus user data widened to whole spectrum. Because of this CDMA systems are called spread spectrum systems.

The basic principle of correlation reciever for CDMA systems is shown in Figure 2.9. The correlation reciever sums despreaded data signal and by this operation amplifies it by a factor of 8. This effect is named as “processing gain” of the system. For an example if our data has 12.2 kbps bit rate(data rate of speech service) then processing gain becomes; 10*log10(3.84e6/12.2e3) = 25 dB. Despreaded siganl has to be higher power density over interference. Given; Eb defined as energy density per user bit, and No interference noise power density, Eb/No for speech service at least has to be 5 dB. So for this wideband system noise to interferer ratio = 5-25 dB= -20 dB. In other words the data signal can stil be recovered below the thermal noise level that higher than 20 dB from original signal.

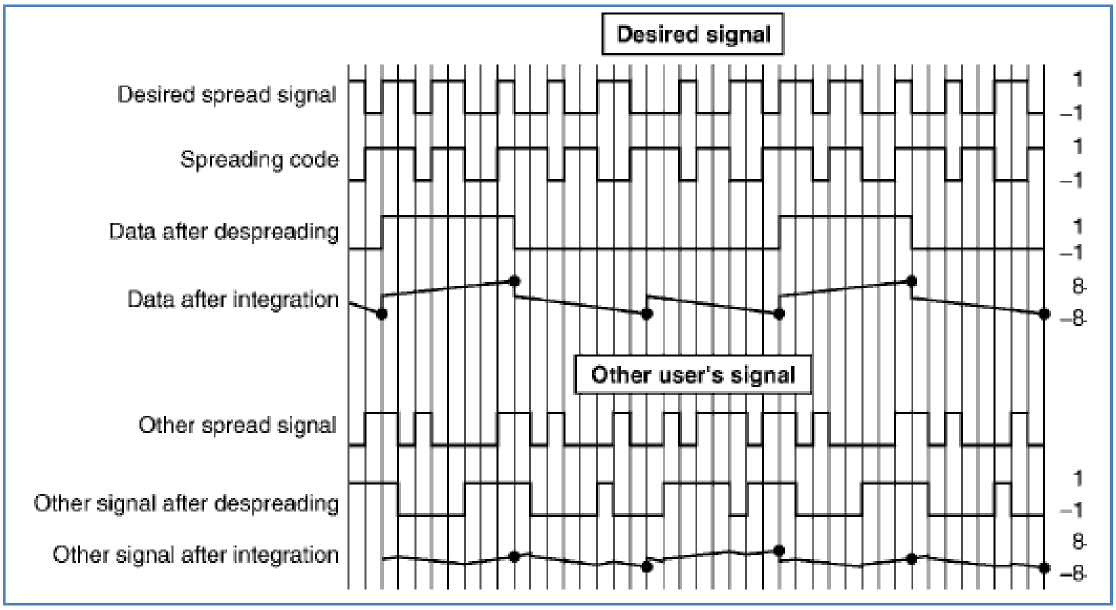

Figure 3.9. Principle of CDMA correlation receiver, HOLMA H. A.,2007

It can be clearly seen that higher bit rates for transmission means lower processing gain for a wideband system. For example 2 Mbps hspa data rate processing gain yields to 2.8 dB processing gain that means 2 dB or higher Eb/No ratio.

3.1.4.2. Mobility in UMTS : Handover Types

Like GSM system UMTS also has handover features. But there is distinct handover types used in UMTS system to balance the network and providing smooth cell to cell mobility. There is three basic type of handover in UMTS:

- Softer Handover: Mobile station communicates different sectors of the same Node-b at the same time as shown in figure 2.10.

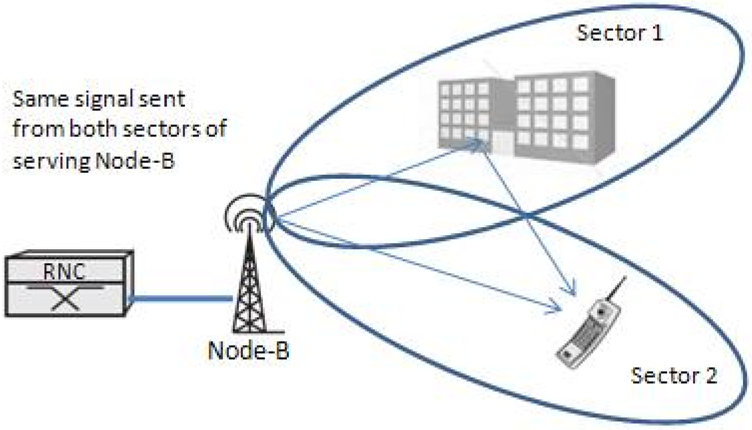

Figure 3.10. Softer Handover

- Soft handover: Mobile station communicates different node-b sectors at the same time as shown in figure 2.11.

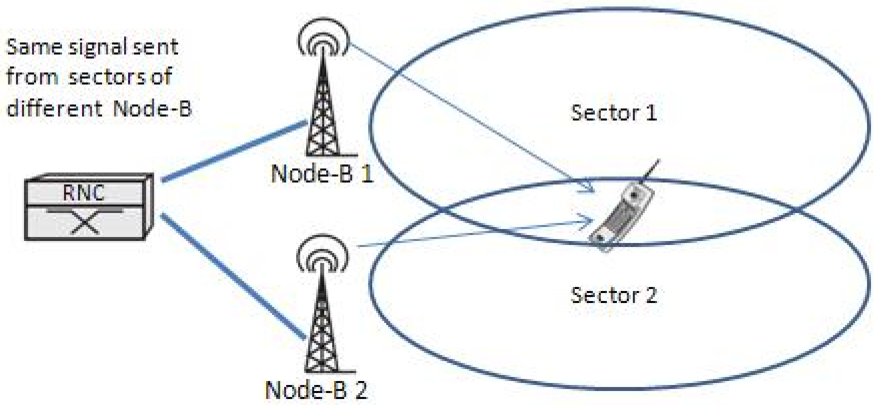

Figure 3.11. Soft Handover

Soft and softer handovers primarily necessary for power control of system. This features prevents penetration of mobile stations to adjacent cells without power control thus depleting the radio sources at the air interface. But achieving this is not with an additional cost, mobile station uses the resources of the two serving cell at the same time, thus decreasing usable capacity of both cell.

- Hard handovers: The term hard handover depicts the necessity of frequency/carrier change during communication. The two types of handovers can be made on UMTS system; interfrequency (between WCDMA carriers) and intra-frequency (between WCDMA and GSM or WCDMA-TDD).

3.1.4.3. Physical Layer of UMTS

In UMTS physical layer, the data generated by higher layers carried over air interface by transport channels. Each transport channel is mapped on their corresponding physical channel. Primariliy, there are two types of transport channel defined in 3G specifications. Dedicated control channels which specifically dedicated for single user by certain codes and common control channels which resource used by all cells or defined cell groups.

Transport Channels

Dedicated transport channel (DCH) is carries information for a single user. The information on this transport channel consists of both control/command and traffic/user data. Dedicated channel supports fast power control, fast data rate change and soft handover.

Common Transport Channels does not have (and does not need) soft handover feature. There are six types of them, listed as below.

- Broadcast Channel (BCH): Carries information for network and UMTS cell.

- Forward Access Channel (FACH): Carries control information to the terminals or terminal groups within the cell area
- Paging Channel (PCH): Carries data for paging procedure (i.e. system originated call setup)
- Random Access Channel (RACH): Carries control information from the terminals to Node-B
- Uplink common packet channel (CPCH): Similar to RACH carries user data in uplink direction.
- Downlink shared channel (DSCH): Similar to FACH carries user data for in downlink direction.

Usage of BCH, FACH, PCH and RACH mandatory for UMTS network whilst CPCH and DSCH optional.

Table 3.7. Physical channels and mapping of transport channels

Physical Channels	Transport Channels
Primary Common Control Physical Channel (PCCPCH)	BCH
Secondary Common Control Physical Channel (SCCPCH)	FACH - PCH
Physical Random Access Channel (PRACH)	RACH
Dedicated Physical Data Channel (DPDCH)	DCH
Dedicated Physical Control Channel (DPCCH)	DCH
Physical Downlink Shared Channel (PDSCH)	DSCH
Physical Common Packet Channel (PCPCH)	CPCH
Synchronisation Channel (SCH)	Phsical layer procedure only
Common Pilot Channel (CPICH)	Phsical layer procedure only
Acquisition Indication Channel (AICH)	Phsical layer procedure only
Paging Indication Channel (PICH)	Phsical layer procedure only
CPCH Status Indication Channel (CSICH)	Phsical layer procedure only
Collision Detection/Channel Assignment Indicator Channel (CD/CA-ICH)	Phsical layer procedure only

Transport channels mapped on the physical channels as given in table 2.7. Some physical channels bears the same name of their transport channel. Additionally 6 more physical cahnnel defined for only physical layer requirements, not carries relevant data for higher layers.

Scrambling and Spreading

There are two types of codes used in UMTS system scrambling codes and channelization codes. Scrambling codes is needed to separate terminals or base stations from each other.

Channelization codes are used for to separate signals that coming from the same source (user equipment or Node-B). In downlink direction each channelization code represents a transmission link to single user equipment. In uplink direction channelization codes separates physical data and control channels. The channelization codes are orthongonal codes. These codes are produced by using Orthogonal Variable Spreading Factor (OVSF) technique. The logical structure of channelization codes given in Figure 2.12

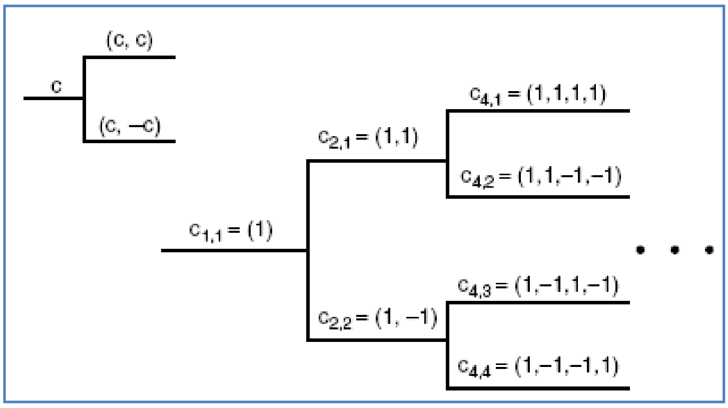

Figure 3.12. Channelization code tree

Uplink spreading and modulation

In the uplink band scrambling codes are used for separating user equipments. There are two types of scrambling codes used; long (3.84 Megachips) and short codes. (256 chips) These code groups used in just one cell area and millions of codes exists. Therefore in the uplink direction no scrambling code planning needed. In modulation scheme QPSK are used in uplink direction.

Downlink spreading and modulation

In the downlink direction spreading codes (channelization codes) used for separating different data channels as mentioned before. One code tree can be used per cell both dedicated and common channels. Dedicated channels are given to user equipments thus spreading codes in downlink direction separates user terminals.

Scrambling codes in downlink direction separates different cells and these codes uses just long codes and limited to 512 primary codes. While planning these codes grouped in 64 group per site (and each one has 8 for sectors).

3.1.4.4. UMTS data access technology

User data transmission in UMTS Release 99

Second generation systems are designed primarily for circuit switched operation and supports one type of service per user. Data can be carried on circuit switched basis. In UMTS each user has its own dedicated channel for speech, video call or data. And also user data can be carried on common data channels (FACH, CPCH for uplink DSCH, RACH for downlink).

For release 99 UMTS primary data transfer methodology is using dedicated channels. For each user equipment two dedicated channel are used; DPCCH (dedicated physical control channel) and DPDCH (dedicated physical data channel). DPCCH carries control information for user data transmission and has fixed spreading factor 256. DPDCH carries user data and its spreading factor changes frame by frame basis, varies from 4 up to 256.

In the uplink direction, BPSK modulation used and with spreading factor 4 maximum channel bit rate for one code equals 960 kbps, and after channel coding user bit rate approximately becomes 400-500 kbps. Channel bit rates for various spreading factors are given in Table 3.8. For higher data rates multiple codes can be used at the same time.

Table 3.8. User and Channel bit rates in Uplink Direction

Spreading Factor	Channel Bit Rate(Kbps)	User Bit Rate
256	15	7,5
128	30	15
64	60	30
32	120	60
16	240	120
8	480	240
4	960	480

Maximum 6 parallel codes can be used for transmission with and maximum achievable user data bit rate in the uplink direction givens as; (960*6)/2 = 2.8 Mbps.

In downlink direction spreading factors ranges 4 to 512. (512 do not provide sufficient data rate even voice call so used for only low rate data activity). Channel bit rates for various spreading factors are given in Table 3.9. Modulation differs from uplink, QPSK modulation used in downlink direction.

Table 3.9. User and Channel bit rates in Downlink Direction

Spreading Factor	Channel Bit Rate(Kbps)	User Bit Rate
512	15	7,5
256	30	15
128	60	30
64	120	60
32	240	120
16	480	240
8	960	480
4	1920	960

Maximum number of DPDCH in downlink direction is 3, based on the fact remaining branch of code tree already being used by other physical channels. Thus, in downlink direction maximum achievable user data bit rate becomes; (1920*4)/2 = 2.8 Mbps.

User data transmission in UMTS Release 5: HSDPA (High Speed Downlink Packet Access)

In release 99 for user data transmission four transport channel defined as common channels, FACH -DSCH for downlink and RACH-CPCH for uplink.

In release 5 for UMTS, there is new common data transport transfer channel defined, HS-DSCH (High speed downlink shared channel). HS-DSCH has no fast power control and soft handover properties. It supports multicode operation. To achieve more speed in operation, user data scheduling and MAC layer operations done in the Node-B.

In HS-DSCH 16QAM modulation scheme used and depending on mobile class up to 15 paralell codes can bu used for transmission. The terminal capabilities and achievable data rates in HSDPA given in Table 3.10.

Table 3.10. Achievable raw data rated for HSDPA with parallel code usage

Category	Number of Parallel codes used	Achievable data rate(Mbps)
1	5	1,20
2	5	1,20
3	5	1,80
4	5	1,80
5	5	3,60
6	5	3,60
7	10	7,20
8	10	7,20
9	15	10,20
10	15	14,40
11	5	0,90
12	5	1,8

3.2. 802.16 WMAN (WiMAX)

3.2.1. WiMAX Overview

Wimax is based on wireless metropolitan area networking (WMAN) standarts devoloped by IEEE 802.16 group. Original 802.16 standarts has many revisions and amendments. First version of WiMAX, defined as fixed WiMAX based on 802.16-2004 standarts. Later, to support nomadic and mobile applications, 802.16e-2005 standarts formed. This version referred as mobile WiMAX. Basic characteristics of these standarts are given in Table 3.11.

Table 3.11. Basic characteristics of various standarts of IEEE 802.16

	802.16(2001)	802.16 2004	802.16-2005
Frequency band	10GHz–66GHz	2GHz–11GHz	2GHz–11GHz for fixed 2GHz–6GHz for mobile
Application	Fixed LOS	Fixed NLOS	Fixed and mobile NLOS
MAC architecture	Point-to-multipoint	Point-to-multipoint	Point-to-multipoint
Transmission scheme	Single carrier only	Single carrier, 256 OFDM or 2,048 OFDM	Single carrier, 256 OFDM or scalable OFDM with 128, 512, 1,024, or 2,048 subcarriers
Modulation	QPSK, 16 QAM, 64 QAM		
Gross Data rate	32Mbps–134.4Mbps	1Mbps–75Mbps	1Mbps–75Mbps
Multiplexing	TDMA	OFDMA	
Duplexing	TDD-FDD		
Channel BW's	20-25-28 Mhz	1.7, 3.5, 7, 14, 1.25, 5, 10, 15, 8.75 Mhz	1.7, 3.5, 7, 14, 1.25, 5, 10, 15, 8.75 Mhz
Air-interface Design	WirelessMAN-SC	WirelessMAN-SCa WirelessMAN-OFDM WirelessMAN-OFDMA WirelessHUMANa	WirelessMAN-SCa WirelessMAN-OFDM WirelessMAN-OFDMA WirelessHUMANa
implementation	None	256-OFDM as fixed Wimax	Scalable OFDMA as Mobile WiMAX

To meet various requierenmnts of applications and design scenierios, WiMAX standarts has multiple pysical layer design options and other features (MAC architecture, duplexing, frequency bands, etc).

IEEE 802.16e-2005 mobile Wimax is newer standart thus interest of deploying networks shifted towards to it. All mobile WiMAX profiles uses scalable ODMA as pyhsical layer, TDD for duplexing and point to multi point MAC.

3.2.2. Prominent WiMAX features

- OFDM based Pyhsical Layer: WiMAX has OFDM(orthogonal frequency division multiplexing) based physical layer. For NLOS operation multipath fading is an essential problem, and OFDM provides goods resistance for this.
- High Data Rates: Because of being designed primarily for data transfer, physical layer data rates of WiMAX standarts are very high. For a 20 MHz wide spectrum over 70 Mbps data rates can be achieved per sector. But infact, as other wireless systems, it depends on other conditions such as modulation and error correction ratings and of course signal clearence.

- Scalable bandwidth : WiMAX FFT size can be scalable dynamically prior to available bandwidth. This allows supporting roaming across different networks and changing data rates.
- Adaptive Modulation and Coding: WiMAX has support for various coding and modulation schemes the fully utilize good signal conditions like many other communication systems. Adaptation algorithms primarily chooses most efficent modulation and coding schemes depending on measured signal to noise ratio.
- Support for TDD and FDD: Both fixed and mobile variations of Wimax can operate Frequency Division Duplex and Time Division Duplex modes. Because of distinct advantages over transmission of packet switching system TDD mode dominantly used in implementations. In TDD mode uplink/downlink ratio can be chosen. TDD also allows reciprocity (usage of channels both uplink or downlink according to selection) and can be implemented in nonpaired spectrum allocations. TDD transmitter also has less complex design.
- OFDMA(Orthogonal frequency division multiple access): To support multiple access of different users, OFDMA used inWimax. OFDMA provides frequency and multiuser diversity and subsequently improves system capacity.
- Quality of Service Support: QoS is fundamental aspect of connection oriented services (e.g. voice and video). Wimax MAC layer designed to support large numer of users with various connection types per terminals with their own QoS requirements.
- Mobility: To achieve real cellular structure mobile Wimax has protocols and mechanisms for supporting handovers between cells.
- IP based architecture: Reference network architecture for Wimax based on IP protocole. This feature primarily provides easy conjunciton with other IP based networks and supporting IP based yet rich applications.

3.2.3. Physical layer of Wimax

The physical layer of WiMAX based on OFDM. OFDM has best spectral efficiency among current radio access technics. It also provides very good multipath fading resistance for non line of sight applications which is very crucial for a radio network performance. OFDM currently used by DSL, Wi-Fi and DVB-H systems.

3.2.3.1. Basics of OFDM

OFDM originated from FDM (frequency division multliplexing) systems. Like its successor, FDM also carries a high rate signal into paralelel low bit rate signals. But due to practical reasons, implementations of such systems has very high costs. Evolution from FDM to OFDM possible with FFT DSP processors that makes modulation and demodulation process feasible.

OFDM subcarriers are orthogonal to each other in frequency domain, thus can not interfere each other at their peak points(Figure 3.1). Since carrier orthogonality eliminates the necessity of guard bands, and provides mıuch tighter carrier orientation in frequency domain, OFDM is much more efficient spectrally, versus FDM (Figure 3.2).

OFDM utilizes the multicarrier modulation schemes. In these technique, high bit rate data streams are divided into many low bit rate substreams than modulated onto seperate OFDM subcarriers. The multicarrier transmitter and reciever structure are given in Figure 3.13 and 3.14. Using low bit rate substreams for transmission provides especially ISI (intersymbol interference) resistance due to selection of symbol time large enough that makes channel induced delays insignificant. This is important specifically for high data rate sytems which has very low symbol durations.

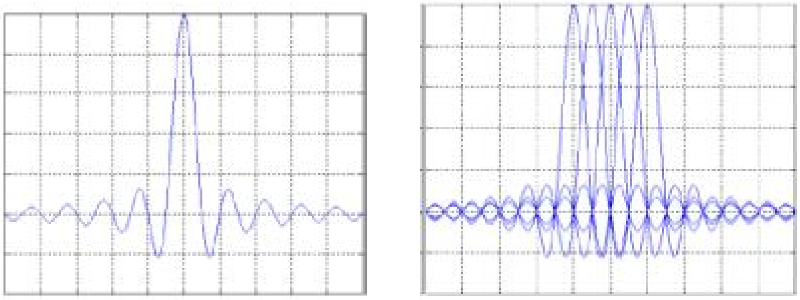

Figure 3.13. An OFDM subcarrier and OFDM signal consisting of subcarriers.

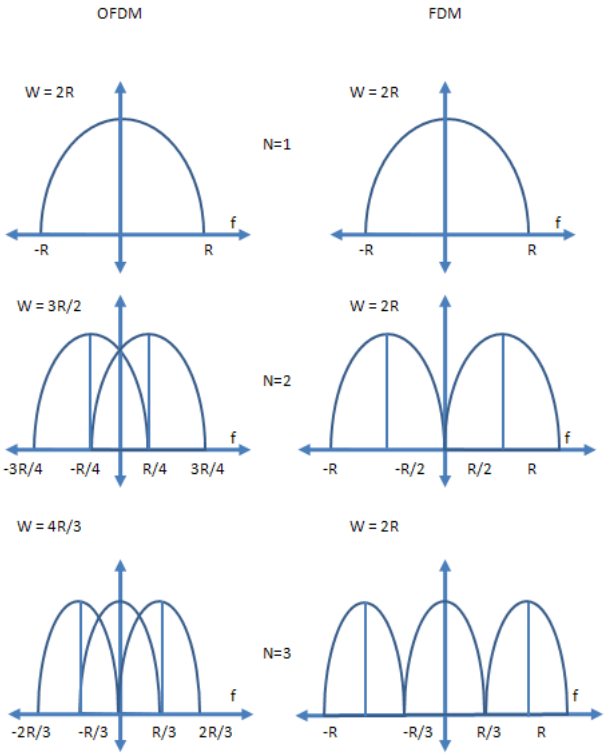

Figure 3.14. Spectral efficiency of OFDM versus FDM.

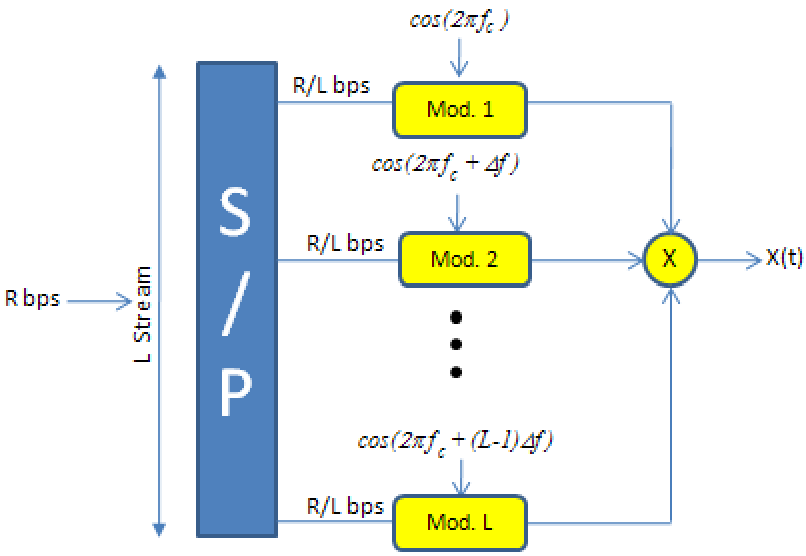

Figure 3.15. Basic multicarrier transmitter:

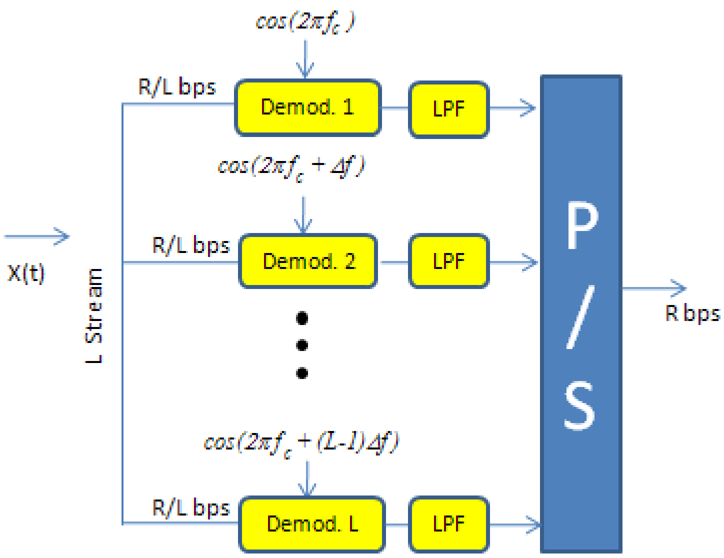

Figure 3.16. Basic multicarrier receiver

The basic idea of multicarrier modulation is quite understandable, but in implementation process creates many problems. Since in realsystems, subcarriers can not have perfectly rectangular pulse shapes, there will be large bandwidth penalty required. At the receiver side extensive (and expensive) low pass filtering required to distunguish orthagonal subcarriers. It can be seen that, also, L seperate RF unit needed for demodulation.

To eliminate the requirement for L radio unit both receiver and transmitter side, OFDM uses computational technique by using DSP processors. FFT (Fast Fourier Transform) and IFFT (Inverse fast fourier transform) are effective implementations of DFT (discrete fourier transform), and used for processing ortohogonal subcarrier stacks using just one radio unit.

In the processing phase, L paralell data symbols first grouped in time domain into blocks. These blocks are called OFDM symbols. There are guard periods between two consecutive OFDM symbols. To eliminate ISI between these symbols the guard period should be chosen larger than expected delay spread (Figure 3.17).

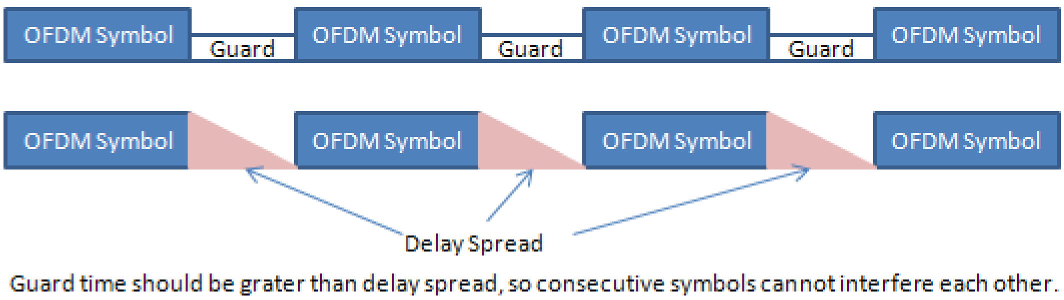

Figure 3.17. Relation between guard time and delay spread.

To recover ortohogonal subcarriers and avoid ISI within each OFDM symbol the L seperate modulated stream applied to IFFT and actually convoluted onto single carrier. But these single carrier has the orthogonal streams actually convoluted into it and can be recovered by applying FFT transform.

In the procedure below the key steps of OFDM system summarized;

1. Wideband signal B breaked into L narrowband signal. The total signal rate is the same as original signal, but ISI eliminated for each signal by using cyclic prefix that exceeding delay spread.

2. Subcarriers modulated using an IFFT operator and convoluted to single wideband radio signal.
3. As an IFFT post process requirement, a cyclic prefix must be added to OFDM signal. Composed signal sent on wireless channel.
4. At the recevier side cyclic prefix removed (or summed upon the original signal). Using FFT operation L received symbol demodulated and data symbols for L channel recovered.

In order to maintain transmission and make OFDMA system work, whole process must be synchronized in time domain.

The Figure 3.18 depicts an OFDM implementation block diagram. L independent QAM signals(the vector X) as seperate subcarrier. These symbols created from a serial bit stream converted to paralel multiple streams. After IFFT applied each of these signals headed onto paralel to serial converter than converted one wideband digital signal.

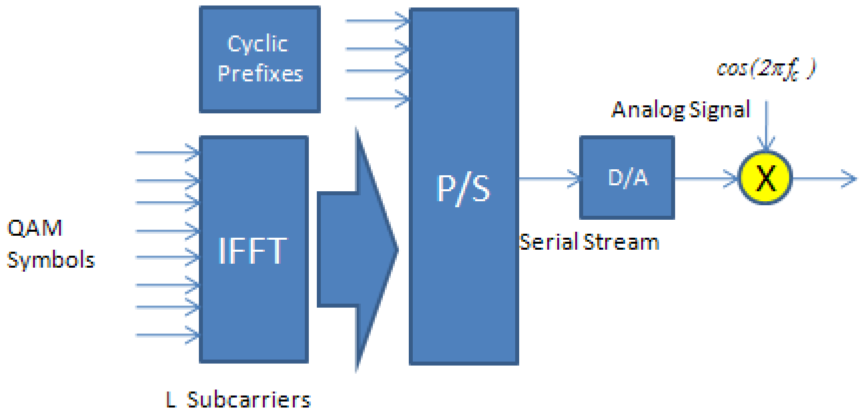

Figure 3.18. Close up of an OFDM transmitter

Spectral Efficiency of OFDM: The most prominent feature of OFDM, its selection of subcarrier frequencies thus forming very spectrally effienct transmission scheme. As its name predictates, the subcarriers chosen orthogonal to each other, which means not interfering each other in the case of overlapping. For implementing

OFDM principle, the data sequence block processed on DFT (discrete fourier transform). Thus OFDM receivers and transmitters uses IFFT and FFT for signal processing instead of complex filtering. This yields extremely easy implementation of recievers and transmitters.

ISI resistance: To completely eliminate ISI in OFDM systems, guard intervals between symbols chosen large enough that exceeds multipath delay spread. But using guara intervals results in decrease at spectral effiency of whole system. Using more carrier for transmitting and larger FFT sizes means larger the symbol period thus increases spectral efficiency.

FFT sizes: As mentioned before, large FFT sizes expands the symbol time and reduces the subcarrier spacing, thus increases available subcarriers. IT also concludes that increased spectral efficiency. But it has another effect; makes the system more sensitive to doppler spreads (shifts) in mobile conditions. So the size of FFT has to be carefully balanced to avoid this effect.

For computational requirements OFDM has distinct advantage over equalizer based systems. IFFT and FFT operations implemented in DSP processors, for higher data rates processing complexity changes just sligthy.

Another aspect of OFDM, changing frequencies of subcarriers gives the robustness of system against fading dips of transmitted spectrum. Additonally it also provides narrowband resistance of system since only small number of subcarriers normally could be effected.

3.2.3.2. OFDMA

In an OFDM system, time and frequency resources can be allocated to different users and services by subchannelization. OFDMA is a multiple access scheme that provides operation of data streams from multiple users on to the downlink subchannels and the uplink multiple access by means of uplink subchannels. The basic mechanism for OFDMA system is given in Figure 3.19.

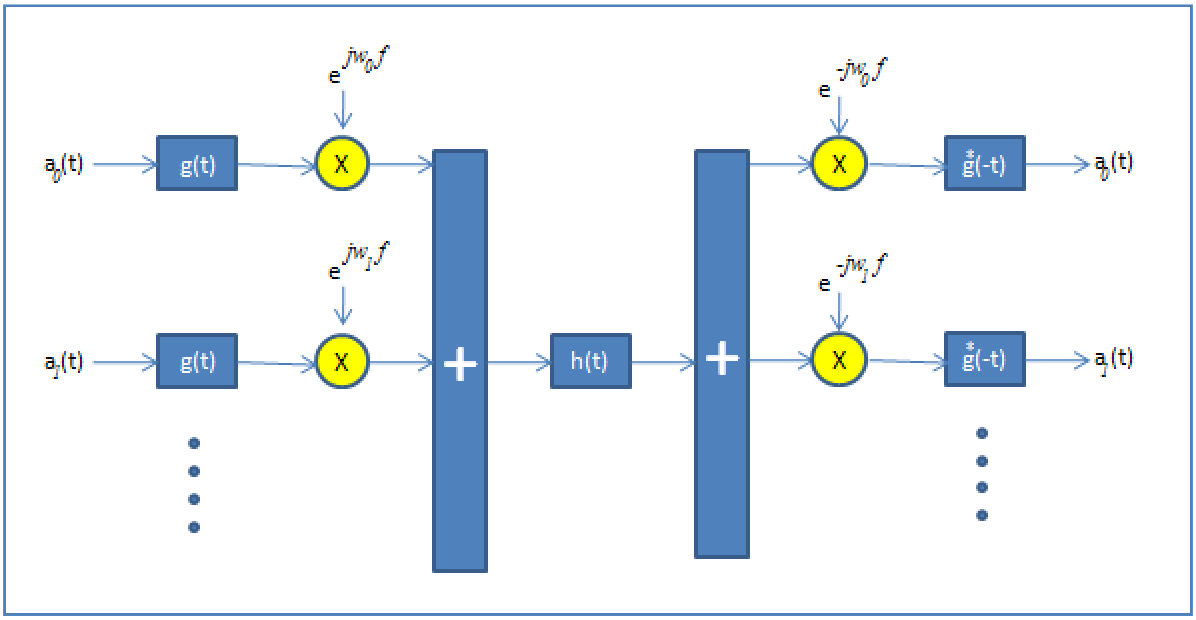

Figure 3.19. Basic architecture of an OFDMA system

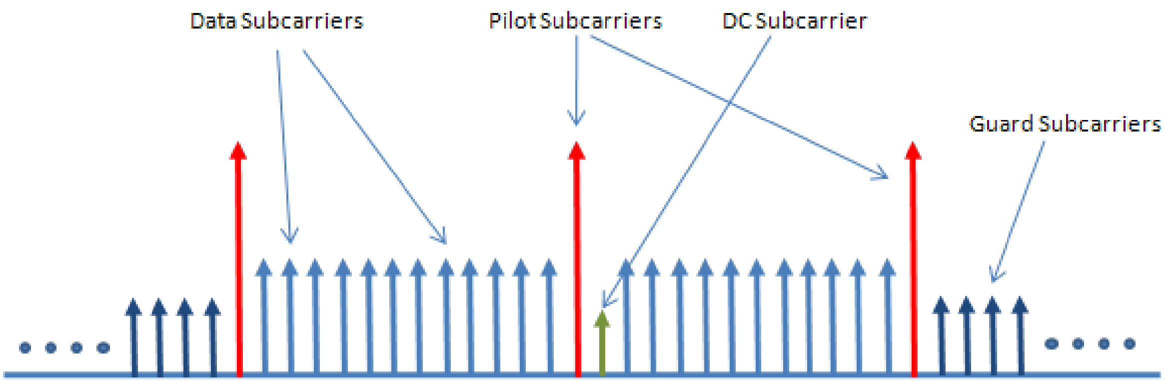

Figure 3.20. OFDMA subcarrier structure

Subcarriers in OFDM

There are three types of OFDMA symbol structure as shown in Figure 3.20. As mentioned before, OFDM system utilizes subcarriers when dividing high the rate data into low rate data streams. There are three type of subcarriers;

- Data subcarriers: Data transmission for various QoS requierments
- Pilot subcarriers: Provisdes reference data for measurements and synchronization.
- Null subcarriers for guarding purposes.

Active subcarriers are grouped into subchannels (subset of subcarriers). In Wimax OFDMA physical layer both DL and UL subchannelization supported. One slot, defined as a frequency-time resource unit, consists of 48 subcarriers. These subcarriers arranged in diversity or contiguous methods. There are two defined subccarrier arrangement method DL PUSC or DL FUSC can be used. With DL PUSC, available sub carriers are grouped into 14 contiguous subcarriers.

Subchannaliziton

A subchannel consists of a group of OFDM subcarriers. In fixed Wimax there is only UL subchannels limited to certain number (16). These 16 subchannels assigned to SS's (subscriber station) in the uplink with various numbers (1,2,4,8 or all sets to a SS). Thus subscriber stations transmits only a small percentage of available bandwidth, these provides link budget improvements. By using 1/16 subchannelization factor 12 dB link budget enhancement provided.

Mobile Wimax based on OFDMA physical layer, uses subchannelization in both uplink and downlink directions. At the downlink direction a base station uses a group or just a single subchannel. In the case of cellular radio enviroment such a reuse of fraction of available bandwidth becomes inevitable. Subchannels, also, can be assigned into differnet users and serves as a multiple access mechanisim. This Access mechanism is defined as Orthoganal Frequency Division Multiple Access (OFDMA).

The allocation of suncarriers into the subchannels can be done in two ways, either selecting randomly or contiguously from available bandwidth. Using subchannels provides frequency diversity which is very usefull for mobile applications due to eliminating narrowband interference.

Scalable OFDMA

IEEE 802.16e-2005 mode based on scalable OFDMA concept. For various spectrum allocation and usage model requirements S-OFDMA supports a wide range of bandwidths.

For all versions the subcarrier frequency spacing fixed at 10.94 kHz, but FFT size adjusted to available bandwidth.

3.2.4. Wimax OFDM parameters

Mobile and Fixed WiMAX has different set of parameters for OFDM pyhsical layer. These parameters are summarized in Table 3.12. Fixed Wimax based on 802.16-2004 has a 256 FFT based physical layer. Mobile WiMAX based on IEEE 802.16e-2005 uses a scalable OFDMA based physical layer. FFT size can change between 128 to 2048 bits for mobile WiMAX.

For fixed WiMAX FFT size is 256. 192 subcarrier reserved for data, plus 8 pilot subcarriers and 56 subcarriers used for guarding purposes. Subcarrier spacing varies with bandwidth becuse of fixed FFT size.

For mobile WiMAX, FFT size can be scalable proior to available bandwidth. Thus subcarrier spacing always kept 10,94 kHz by adjusting FFT size. This feature important for higher layers because it fixes the OFDM symbol duration that basic resource unit for overall system.

Table 3.12. Wimax OFDM parameters

	Fixed WIMAX	Mobile Wimax			
FFT size	256	128	512	1024	2048
Nnumber of used data subcarriers	192	72	360	720	1440
Number of pilot subcarriers	8	12	60	120	240
Number of null/guardband subcarriers	56	44	92	184	368
Cyclic prefix or guard time(Tg/Tb)	1/3, 1/16, 1/8, 1/4				
Oversampling rate(Fs/BW)	Depends on BW: 7/6 for 256 OFDM, 8/7 for multiples of 1,75 Mhz, 28/25 for multiples of 1,25 MHz, 1,5 MHz, 2 MHz, or 2,75 MHz.				
Channel bandwidth(MHz)	3.5	1.25	5	10	20
Subcarrier frequency spacing(kHz)	15.625	10.94			
Useful symbol time(microseconds)	64	91.4			
Guard Tine(microseconds)	8	11.4			
OFDM symbol duration(microseconds)	72	102.9			
Number of OFDM symbols in 5 ms frame	69	48			

3.2.5. Slot and Frame Structure

Another important aspect of air interface is slot and frame structure. The minimum time frequency resource unit for a WiMAX system is a slot. Each slot can be mapped over one subchannel that uses one more OFDM symbols. The slots assigned to users by scheduling basis and subsequently assigned slots gives a user its data region. Data region requirements changes by demand, QoS and channel conditions.

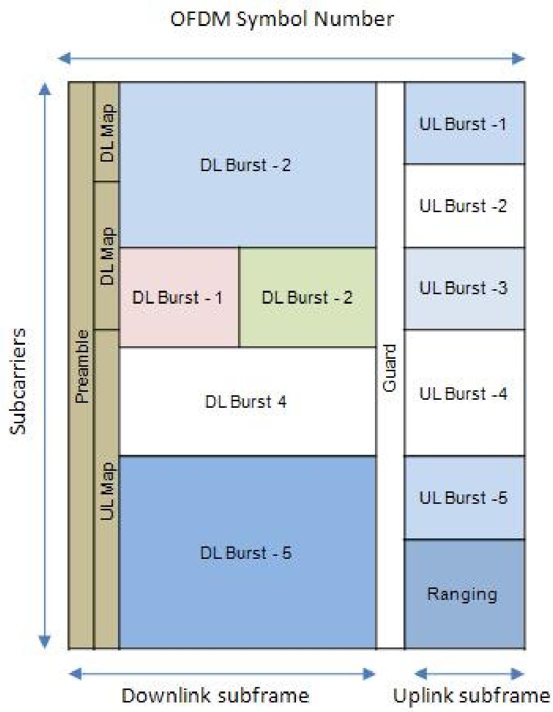

Figure 3.21. OFDMA Frame structure

OFDMA frame structure is given in figure 3.21. This frame consists of uplink and downlink part, the UL/DL ratio can be chosen by operators preferences. Frequency division duplexing also applicable in WiMAX. In this case same frame structure applied but transmitted over different OFDM carriers. But that clearly can be seen TDD has more advantages over FDD. Obviously TDD allows much more effective usage of bandwidth by changeable DL/UL ratios. So it does'nt needs paired spectrum allocations, and also its transceiver design is simpler. But TDD mode needs fully synchronized network structure obviously for avoding interference between neighbouring cells in a cellular network structure.

Downlink subframe starts with preamble which used for physical layer procedures. Other configuration information stored in subsequent DL and UL MAP layers. Different users allocated data regions of the frame and this information obtained from UL and DL MAP messages. Each data region of the frame can be sent with different modulation schemes, such as important messages like MAP information sending over BPSK modulation. The uplink subframe also consists of one more uplink bursts that came from different users. A part of uplink subframe is used for general acces and named as ranging channel. Ranging channel also used for random to make uplink bandwidth requests. The channel quality measurements carried on UL subframe from channel quality indicator channel(CQICH).

This frame structure gives WiMAX flexibilty over allocating users and packets on the single frame.

3.2.6. Adaptive Modulation and Coding

Modulation and coding schemes in WiMAX, can be changed for each burst and for each link. Selection of modulation scheme depends on the signal conditions of the channels. The mobile provides DL signal information to the base station via channel quality indicator channel. Base station can estimate channel quality from the recived signal fort he uplink direciton. The base station makes modulaiton scheme decisions in order to maximize throughput for available SNIR ratio. Adaptive modulation and coding increases the whloe system capacity and quality both fot UL and DL direction.

Available modulations for OFDM DL part are QPSK, 16QAM and 64 QAM modulations. These are mandatory for fixed and mobile WiMAX. For the uplink part 64 QAM modulation is optional. Constellation diagrams for these modulation schemas can be seen in Figure 3.11.

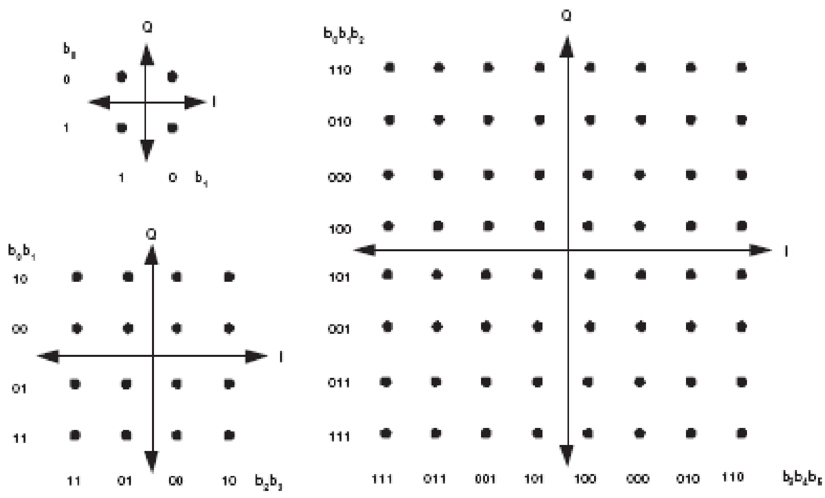

Figure 3.22. QPSK, 16 QAM and 64 QAM modulations constellation diagrams

3.2.7. Mobility Management of WiMAX

Sleep mode

This mode of operation is optional feature in WiMAX. This mode initiated when MS has active connections and registered itself into network, connecting one or more BS. MS temporarily halts its communication operations from BS's for a predefined set of times. This times defined by sleep window sizes called unavailability intervals. At these times MS cannot use DL and UL connections. There are three types of power saving classes. For type 1, sleep window increased step by step until it reaches final size. In type 2, sleep window size always kept same. And type 3, unlike previous ones, there is one single sleep window, then MS enters active state, this is usefaull for multicasting operations.

Idle Mode

Like other cellular systems, an idle mode MS does not transmit in UL direction and register itself to the network, but listens DL direction paging messages. Idle mode operation in Wimax allows MS to eliminate the handoff procedures while not involving in data operation.

Group of BS's are assigned to a paging group(Figure 3.23) and an MS in idle mode monitors its locations paging group periodically. If its location changes to new paging group area, MS sends a paging group update message to the BS. In the idle mode operation MS may be available or not for paging. When not available for paging MS can power down or make ranging negotiations with other BS's, or scan for negihbouring BS' power levels and SNR ratio's.

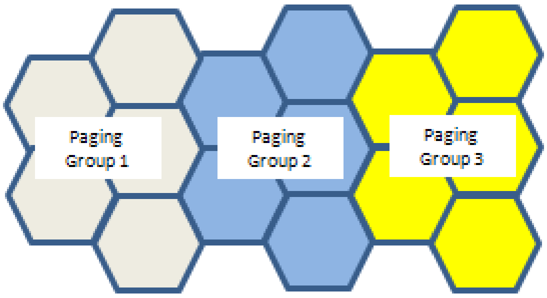

Figure 3.23. Paging Area Example

Mobility and Handoff

Mobile version of WiMAX has mobility support as its name predicates. Handoff procedure decision is made on layer 3, based on provided data from layer 1 and 2. In mobility management each MS monitors and mesaures the radio conditions of neighbouring BS's. This scanning process are made on scanning intervals allocated to each MS by BS. In these scanning periods the neighbour BS identity and frequency informations sent from serving BS to MS over the broadcast channel. The MS measures RSSI and SINR signal to noise ratio of neighbouring BS's. MS's optionally associate with other BS's and make some initial ranging.

The MS can be migrate from one BS's air interface to another BS's air interface. This procedure defined as handoff process(or handover recently defined);

1. Cell reselection: In this state MS scans and associate with one or more BS's, try to determine as a handoff target.
2. Handoff decision and initiation: MS itself or BS makes the decision for MS to migrate the other BS's service area. Handoff request made by MS and BS

sends the possible candidate list for MS. After scanning and measurements MS reports to BS which target is suitable for handover.

3. Synchronization: MS syncronized with target BS's DL frames and decodes DL-MAP, UL-MAP and DCD-UCD messages and accesses the information about ranging channel.
4. Ranging: MS perform initial ranging procedures via ranging channel and synchonizes in uplink direction.
5. Termination of context with BS: After establishing new link, MS may terninate its connection with previous BS, and handoff process completed..

Macro Diversity Handover and Fast BS switching (Soft Handover)

There are two other optional handover types defined in WiMAX standarts that improves system stability, macro diversity handover (MDHO) and Fast BS switching (FBSS). These are different procedures from standart handover process.

In MDHO (Figure 3.24 and Figure 3.25), MS communicates with two BS at the same time but different frame times, it closely resembles soft handover mechanism of CDMA systems. As an active set in an CDMA system, there is defined diversity set for an MS which consists of communicated BS list. One of the BS in this mode defined as anchor BS. The UL MAP and DL MAP of all diversity set BS's monitored by MS. The DL signals come from different BS's combined before decoding thus providing macro diversity. In the UL side MDHO used for error correction and packet selection.

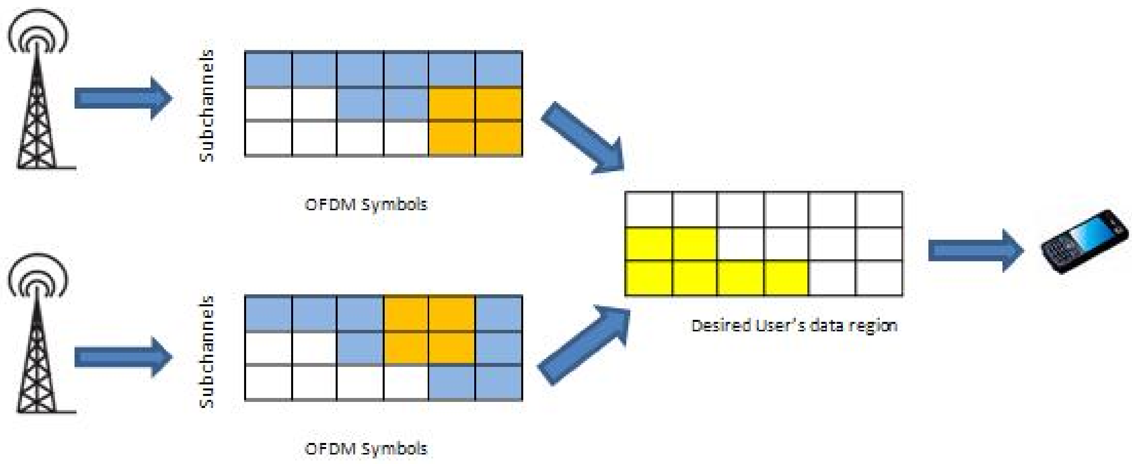

Figure 3.24. DL Macro Diversity Handover

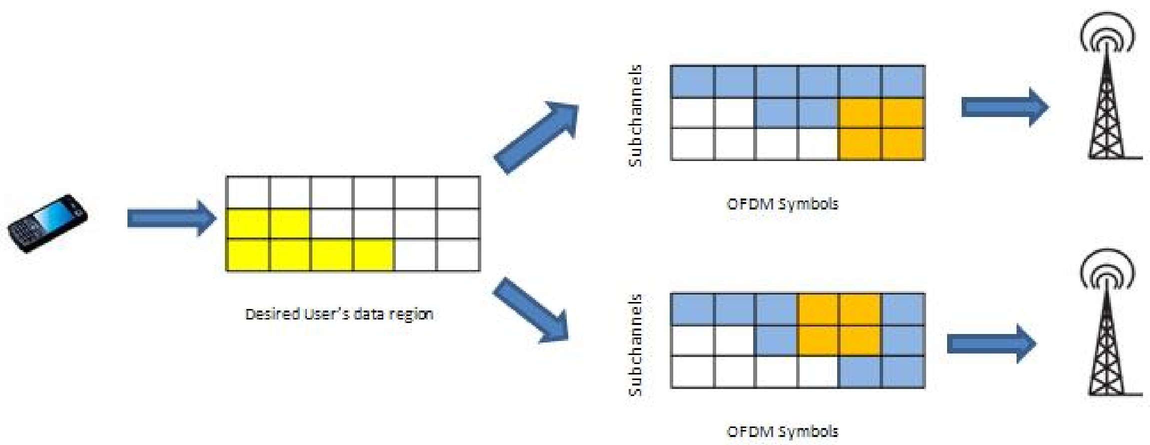

Figure 3.25. UL Macro Diversity Handover

FBSS is very similar to MDHO, but the main difference is, MS communicates only anchor BS while monitoring other diversity set BS's. Because of connection already started with other BS's (or CID, connection identifier taken in system) MS can switch its anchor BS without needing standart handoff procedures. Obviously, these type of handover performed very faster than standart handoff.

3.2.8. WiMAX Reference NW architecture

Reference network architecture of WiMAX basically defined by three section, shown in Figure 3.15.

- MS:Mobile stations, users acces the WiMAX network by Mobile stations via air interface.
- ASN: The access service network: This part consists of base stations and acces network. Acces network provides base stations connectivity to access service network gateway. Base stations (BS) controls the air interface and Radio resource management functions. ASN gateway is the connection point of IP network (CSN) to access service network.
- CSN: Connectivity service network: IP core network functions managed by CSN and this part provides IP connectivity to other external networks (e.g. internet or corporate network) CSN responsible for IP address management, management of QoS and internwtworking with other networks (PSTN, GSM, UMTS etc.)

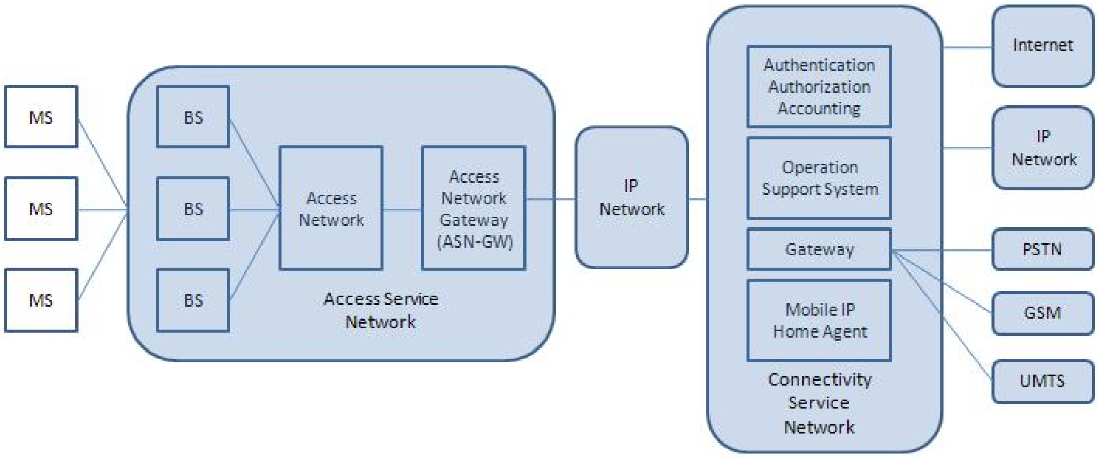

Figure 3.26. IP based, simplified NW architecture of Wimax

3.2.9. Advanced Antenna Techniques

Another important feature applicable in WiMAX is usage of multiple antenna techniques. Using antenna arrays for creating multiple air channels brings to air interface many benefits but their applicability depends on usage of advanced processing techniques.

There are basically three types of multiple antenna techniques Spatial Diversity, Spatial Multiplexing, and Beamforming. All of these antenna techniques referred as MIMO techniques(multiple input/multiple output). The main benefits of MIMO techniques summarized as;

- Increasing SNR ratio, thus reducing error rate and enhancing reliability
- Using multiple air channels, increasing data rates.
- Providing higher power output and more coverage.
- Less transmit power in the same coverage area.

Spatial Diversity as depicted in figure 3.27, mainly increases transmit power by using antenna arrays. By increasing transmit power, SNR ratio also increases, overall performance is enhanced. To eliminate the interference between the same signals that comes from different antennas, signals are space-time coded and directed to antennes.

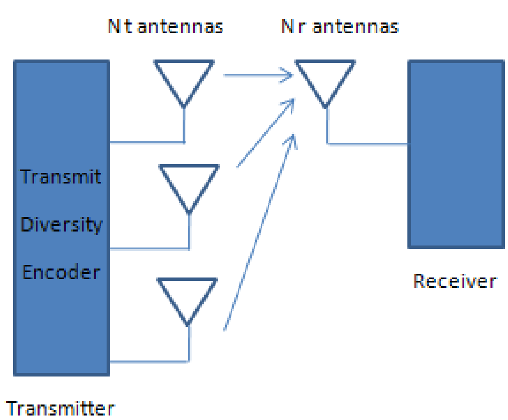

Figure 3.27. Spatial Transmit Diversity

Beamforming is similar to transmit diversity but signals directed to antennas prior to their direction, beamforming provides focusing same energy and rises the SNR.

The most sophisticated MIMO technique, is spatial multiplexing is depicted in figure 3.17, by the same manner as previous ones, space-time coded transmitted signals directed to different antennas and multiplexed between them. At the receiver side, also multiple arrays of antennas decodes these signals in multipath channels. These technique primarily enhances the data rate, much more desirable gain for the wireless system.

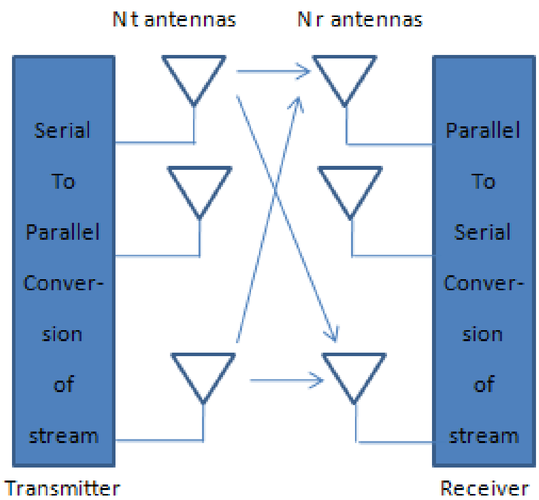

Figure 3.28. Spatial Multiplexing

3.2.10. Data rates of WiMAX at pysical Layer

Due to flexible standarts defined for WiMAX maximum and typical data rates changes heavily by operating parameters. The main parameters that have effect on the data rates are channel bandwidth, modulation and coding scheme. Table 3.3 summarizes pysical layer maximum data rates in the aspect of changing parameters. The TDD ratio is assumed 3:1 and this rates given for per sector basis and will be shared among users. In this case advanced antenna techniques does not assumed, MIMO and spatial multiplexing techniques can increase peak data rates.

Table 3.13. Physical layer data rates at different coding schemas for WiMAX.

		Fixed Wimax		Mobile Wimax			
Kanal Bantgenişliği		3.5 Mhz		5 Mhz		10 Mhz	
Fiziksel Katman modu		256 OFDM		512 OFDM		1024 OFDM	
Modulasyon	Code Rate	DL	UL	DL	UL	DL	UL
BPSK	1/2	0,95	0,33	NA	NA	NA	NA
QPSK	1/2	1,88	0,65	1,58	1,14	6,34	4,6
QPSK	3/4	2,82	0,98	4,75	3,43	9,5	7,06
16 QAM	1/2	3,76	1,31	6,34	4,57	12,67	9,41
16 QAM	3/4	5,65	1,96	9,5	6,85	19,01	14,11
64 QAM	1/2	5,65	1,96	9,5	6,85	19,01	14,11
64 QAM	2/3	7,53	2,61	12,67	9,14	25,34	18,82
64 QAM	3/4	8,47	2,94	14,26	10,28	28,51	21,17
64 QAM	5/6	9,41	3,26	15,84	11,42	31,68	23,52

As a further example, various peak data rates can be seen in Figure 3.4, for an 10 Mhz bandwidth and different UL/DL ratio TDD usage by using different MIMO values. The peak data rate here is 63 Mbit for DL.

Table 3.14. User and sector peak data rates with MIMO usage

	DL/UL oranı		1:0	3:1	2:1	3:2	1:1	0:1
User Peak Rate	SIMO (1x2)	DL	31,68	23,04	20,16	18,72	15,84	0
		UL	0	4,03	5,04	6,05	7,06	14,11
	MIMO 2x2	DL	63,36	46,08	40,32	37,44	31,68	0
		UL	0	4,03	5,04	6,05	7,06	14,11
Sector Peak Rate	SIMO 1x2	DL	31,68	23,04	20,16	18,72	15,84	0
		UL	0	4,03	5,04	6,05	7,06	14,11
	MIMO (2x2)	DL	63,36	46,08	40,32	37,44	31,68	0
		UL	0	8,06	10,08	12,10	14,12	28,22

3.3. 802.11 (Wi-Fi) Wireless Networks

3.3.1. 802.11 Overview and Standarts Structures

802.11 is a member of IEEE 802 standarts family. IEEE 802 standarts family specifies standarts for Local Area Network (LAN) technologies. MAC and physical layers are two mandatory components of all 802 networks. The duties of MAC layer consists of medium access and data transfer. Transmission and reception onto physical medium is task of the physical layer.

802.11 standarts consists of MAC layer and physical layer specifications. Original 802.11 physical layer standarts includes two different layer interface structure; a frequency-hopping spread-spectrum (FHSS) and a direct-sequence spread-spectrum (DSSS) based. Later revisions 802.11a,b,g(and etc.) phsical layer changes to basically OFDM. Standarts structure and its relation to OSI reference model shown in Table 3.15.

Table 3.15. 802.11 standarts family and relation to OSI model

802 General architecture	802.1 Management	802.2 LLC control						Data link layer
		802.3 MAC PHY	802.5 MAC PHY	802.11 MAC				MAC sublayer
				802.11 FHSS - DSSS	802.11a OFDM	802.11b OFDM	802.11g OFDM	Physical Layer

3.3.2. 802.11 Network components

An 802.11 network consists of four major components; cable connected distrubuted system, wireless access points, air interface, and user stations. To achieve large coverage area, more than one Access points must be connected. Since this access points has to communicate to each other, a distrubution system must be provided. These system may be land based, or other wireless technology can be used for distrubution (such as WiMAX, UMTS or LTE). In cable based systems Ethernet infrastructure preferably used.

The task of access point is transferring data to air interface. The modulation and framing for air interface performed at the access points. Access points also provides multiple access for users.

Air interface is consisted of RF layers that defined as a physical medium of 802.11 standart. Data frames transferred throughly on RF channels. User stations are battery powered handheld devices or portable computers which has wireless interfaces.

3.3.3. Network Types

The basic service set of a 802.11 network depicts a group of stations that communicates with each other. The service area of the wireless medium is depends on propagation area. In the figure 4.1 an independent service basic service set (BSS) is shown, three computers communicating with each other.

Infrastructure networks is seperated from independent networks by usage of access points. All communication on air interface must be transmitted via access points in these networks. Thus, the service area boundaries of network is defined by access point's signal availability. This type of organization seems disadvantaged due to increasing transmission needs in spite of direct communication between terminals. But in fact, it allows simpler air interface because of eliminating necessity of building neighbour relationships between user terminals thus much more effectively uses air interface. Access points also supports power saving features such as buffering frames for battery user terminals that is important for increasing battery life of mobile equipments. Independent and infrastructure BSS representation is shown in Figure 3.29.

Figure 3.29. Independent and infrastructure BSS network structure

User terminals must be associate with one 802.11 access point to Access to network. In the process, mobile stations always initiates first with Access points, then

Access points may provide entry to network based on association request. A mobile station in 802.11 network can can only access just one Access point at a time. But there is no limit for user equipments that an Access point can serve theoratically.

To extend the network area the BSS's are connected via backbone network. The linking the BSS as extended service set (ESS) can be create fairly large sized network. The backbone technology doesn't specified in 802.11 standart. The service area of basic sets can have overlaps, and users can not move between service areas without first dropped int he its currents network access points. An ESS consisted from five different BSS is shown in figure 3.30.

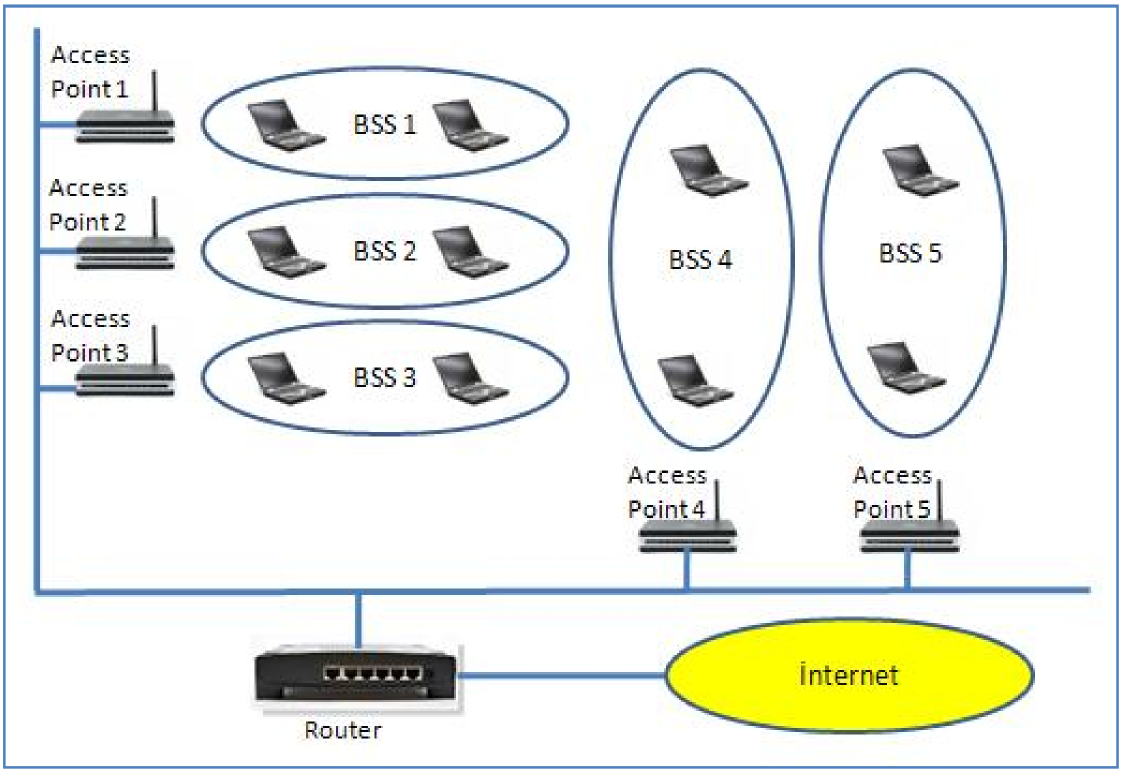

Figure 3.30. Extended service set

The user stations within the ESS can communicate with each other regarless their BSS area. The wireless medium here can be seen as a single layer 2 interface. The backbone connection also regarded as a layer 2 conneciton. Several Access points can be connected via single hub bor switch or they can use virtual Lan connections. 802.11 standarts can be support mobility within the ESS boundaries at link layer level. ESS's are highest level structures can be implemented in 802.11 standarts.

3.3.4. Physical Layer architecture of 802.11 Network

802.11 networks operates on 2.4 GHz and 5.8 GHz ISM (industrial, scientific and medical) frequency bands. Due to its reservation for free operation, devices on these bands restricted by power and frequency regulations. The equipments that operates in these bands should have interference resistant pysical layer since common other devices may create strong interference on the band.

The spread spectrum radio access techniques is basic for 802.11 physical layers. These methods distrubutes signal to available bandwidth to aviod narrowband interference. The original 802.11 physical layer has two standart radio access techniques; FHSS (frequency hopping spread spectrum) and DSSS (direct sequence spread spectrum). Both of these methods operated in 2.4 Ghz ISM bands. In FHSS method the spectrum divided 79 nonoverlapping channels across the 2.402 to 2.480 GHz range. FHSS WLAN's hops among these channels at slower rates than symbol rates which is 1 Mhz. FHSS mode is currently obsolote technology for WLAN applications. A three dimensional graphical represntation of frequency hopping system is given in Figure 3.31.

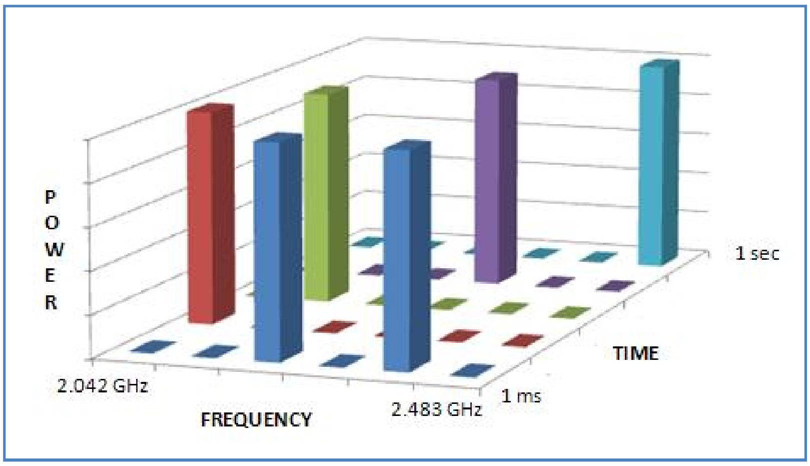

Figure 3.31. Frequency Hopping Three Dimensional Example

DSSS WLAN’s use 22 MHz channels, this channelization allows up to three operating WLAN’s in same service area. In the spread spectrum technique, each bit spreaded over specturm via wideband spreading codes. The spread spectrum systems can well operates under low SNR conditions due to processing gain of spreaded signals. Beside original standarts DSSS systems used in 802.11b-g networks and supports data transfer up to 2 Mbps. DSSS spreading example for single data bits are given in Figure 3.32

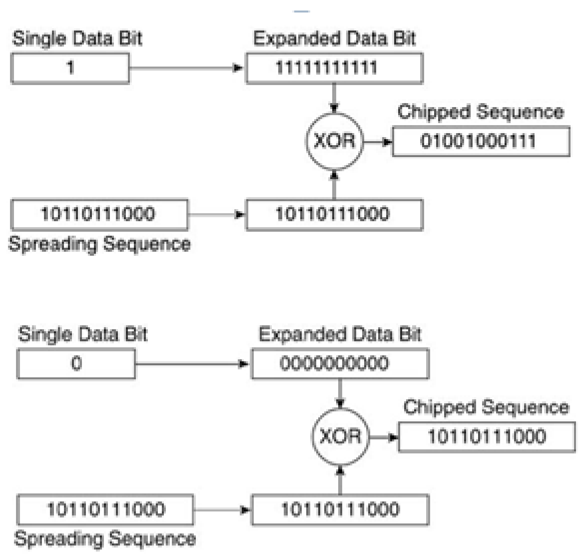

Figure 3.32. DSS spreading example, for bit 0 and 1.

OFDM used in 802.11a,g and n type WLAN physical layers. In OFDM system single transmission scheme carried on multiple streams, than mapped on multiple subcarriers. These subcarriers transferred on wireless medium than combined again one high data rate stream. In fact OFDM closely resembles FDM technique but differs from it on implementation. FDM subcarriers spaced from each other in frequency domain and avoids overlapping whilst OFDM allows overlapping since subcarriers are chosen as orthogonal to each other.

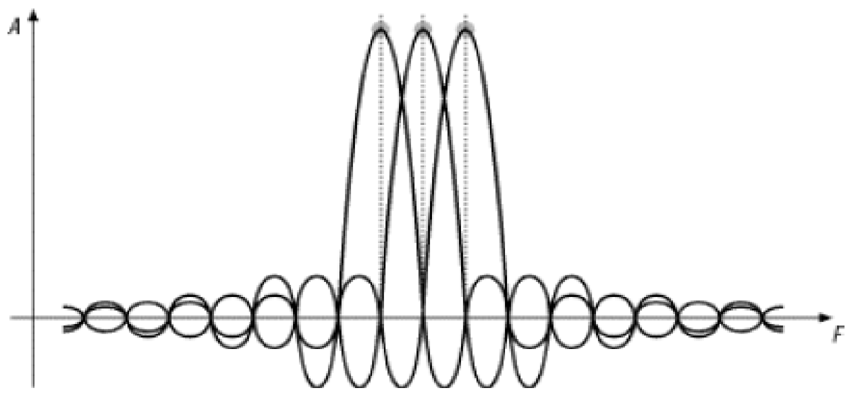

Figure 3.33. OFDM subcarriers in frequency domain, ROSHAN P., 2003

The orthagonality in frequency spectrum is depicted in Figure 3.33. It can be seen that at the peak of the each subcarrier the other subcarriers amplitude equals zero. Thus despite the overlapping, these subcarriers does not interferes each other. The implementation of OFDM principles in real systems can possible with digital signal processors. DSP chips used for implementing FFT and IFFT operations that required for orthogonal subcarrier operations.

The channel bandwidth of 802.11a networks are 20 Mhz and divided to 52 subchannels. 4 of these reserved for pilot carriers, and remaining 48 are used for data operations. 802.11g networks has different OFDM parameters, their operating frequencies are 2.4 Ghz ISM bands. 802.11g networks also has backward compatibility with 802.11b Networks. Both 802.11a and 802.11g networks supports up to 54 Mbps data rates.

3.3.5. 802.11 Networks Standarts Summary and Table

From the first release of 1997, many improvements are made on basic standarts. In Table 3.16 various standarts of 802.11 networks are compared.

Table 3.16. Maximum data rates and frequency bands of IEEE 802.11 standarts

Standart	Release Date	Bandwidth	Max. Raw Data rate	Frequency Band	Max. Range(m) Indoor/Outdoor	Air Interface Modulation	Modulation Schemas
802.11	1997	20 Mhz	2 Mbps	2.4 Ghz	20/100	FH-DSSS	GFSK, DPSK, DPQSK
802.11a	1999	20 Mhz	54 Mbps	5 Ghz	30/150	OFDM	BPSK, QPSK, 16QAM, 64QAM
802.11b	1999	20 Mhz	11 Mbps	2.4 Ghz	30/150	DSSS, HR-DSSS	DPSK, DPQSK
802.11g	2003	20 Mhz	54 Mbps	2.4 Ghz	30/150	OFDM for higher bit rates ,DSSS for lower bit rates	BPSK, QPSK, 16QAM, 64QAM
802.11n	2009	40 Mhz	72.2 Mbps (Single stream; multiple streams can be used)	2.4 / 5 Ghz	70/300	OFDM for higher bit rates ,DSSS for lower bit rates	BPSK, QPSK, 16QAM, 64QAM

Very first standart is 802.11 released at 1997. Today this standart is obsolete and known as legacy mode. It has 1 and 2 Mbit per second raw data rate. In the air interface DSSS(direct sequence spread spectrum) spreading method has used. The security on the air interface purposely kept weak. This standart operates on 2.4 GHz band and has relatively short indoor/ourdoor coverage range (20-100 m).

802.11a has been released at 1999, it supports higher data rates (up to 54 Mbit) and works on 5 GHz frequency band. Due to its high frequency band it has weak penetration for indoor applications and easily degraded performance due to obstacles (walls etc.). But it has more coverage from original version. (35-120 m) But its operation frequency is nearly free from interferences compared to 2.4 GHZ spectrum. 802.11a standart has first OFDM based air interface in WLAN applications and very effective in regard to raw data bit rate prior to original 802.11 or 802.11b. But in implentation 802.11a devices lagged behind 802.11b due to production and cost problems stems from higher band frequency operations.

802.11b standart is released at the same time with 802.11a standart and it operates at 2.4 Ghz band. It has moderate data rate capacity (11 Mb) prior to

802.11a, but less expensive and easy implementation. Coverage are slightly more than 802.11a (40-150 m.) due to lower frequency bandwidth and more effective for non line off sight operations from 802.11a due to higher penetration ratios. 802.11b is used widely today and first successfull release of WLAN devices. Like legacy mode 802.11b devices uses DSSS based air interface.

802.11g is today most widely used standart, released at June 2003. This specification is marketed as Wi-Fi. 802.11g devices are backward compatible means that can operate with 802.11b devices together. Differently from other standarts 802.11g uses different modulation schemes depending on data speeds. For higher speeds between 6 - 54 Mbit/s OFDM is used, for lower speeds DSSS is preferred like 802.11b. 802.11g has same range with 802.11b for indoor and outdoor but has higher data rates due to its OFDM based air interface heritaged from 802.11a. 802.11g devices suffers from interference that comes from other ISM band and neighbour Wi-Fi devices.

802.11n released at October 2009, it operates at 2.4 and 5 Ghz bands. It has OFDM based air interface and 20 and 40 Mhz bandwidth can be used with 64 QAM modulation schema utilized. But using 2*20 Mhz channel occupies nearly whole ISM bandwidth and decreases feasibility for already crowded band. 802.11n has MIMO (multiple in and multiple out) and spatial division multiplexing features. Both outdoor and indoor coverage enhanced(70 and 250 m. respectively). It has 72.2 Mbit/s peak data rate for 20 Mhz channel per stream(non MIMO). For 40 Mhz channel and using multiple streams, raw data rate can be multiplied up to 600 Mbit/s(current produced devices can support 300 Mbit/s). 802.11n standarts has backward compatibility for previous standarts 802.11a. Early products based on 802.11n drafts produced at early 2009, due to demand for higher data rates.

4. RESEARCH AND DISCUSSION

4.1. Comparison Of Analyzed Wireless Data Access Standarts

The achievable physical layer data rates, range of covered area and other physical layer properties (modulation types, duplexing and multiplexing) is summarized in table 4.1. The specifications given here are relative to rapidly advancing technological circumcitances, so can not be accepted certain performance criterias of defined radio technology.

Table 4.1. Comparison of wireless technologies

	Fixed Wimax	**Mobile Wimax**	**3G HSPA+**	**Wi-fi**
Standarts	IEEE 802.16	IEEE 802.16e	3GPP Rel 7	IEEE 802.11
Maximum Downlink Data Rate	9.4 Mbps, 3:1 DL/UL TDD ratio	46 Mbps, with 3:1 DL/UL TDD and 2*2 MIMO	28 Mbit with 15 paralel code and 2*2 MIMO	300 Mbit using 802.11n, 2*2 MIMO
Maximum Uplink Data Rate	6.5 Mbit 1:1 DL/UL TDD ratio	14 Mbps with 1:1 DL/UL ratio, 10 Mhz BW , 2*2	11.5 Mbps, with class 7 terminals	
Bandwidth	3.5 Mhz - 7 Mhz	3.5 Mhz - 10 Mhz	5 Mhz	1.25 Mhz
Modulation	QPSK, 16 QAM, 64QAM	QPSK, 16 QAM, 64QAM	QPSK, 16 QAM, 64QAM	BPSK, QPSK, 16 QAM, 64QAM
Multiplexing	TDM	TDM/OFDMA	TDM/CDMA	CSMA
Duplexing	TDD,FDD	TDD	FDD	TDD
Frequency Band	3.5 Ghz - 5.8 Ghz	2.5 Ghz - 3.5 Ghz	900-1800-2100 Mhz	2.4 Ghz, 5 Ghz
Coverage Area	5 km	3 km	5 km	50 m indoor, 100 m
Mobility	No	Yes	Yes	No

It is obvious that, normal typical data rates of standarts can not be clearly estimated from maximum theoretical physical layer data rates. As an example, to achieve maximum DL HSDPA+ data rate of 28 Mbps, 64QAM modulation must be used. The higher modulation schemas are clearly much more susceptible to interference thus using this type of modulation only possible under very clear signal conditions (nearly CQI 25 or higher as 3G specification). Most of non-line of sight transmissions does not seem to fulfill conditions for high modulation and coding schemas since the multipath fading effects decreases signal quality fairly. Same dependency for high signal to noise ratios are also exits for all wireless technologies so it is not seems possible to get maximum data rates under real conditions.

Another fact that since the wireless medium is a shared source for multiple users, maximum rates actually represents “per sector” capability of transmission data at high speeds. By the increasing user numbers, common source will be divided per user and thus transmitted data on the medium.

A simple comparison for technologies can be described in figure 4.1, regarding to five basic critera; Quality of Service, coverage, price per data bit, typical data rates, mobility and coverage. Cellular systems provides best QoS, coverage and mobility but has very high price per bit and lower data rates. 802.11 Wi-Fi systems has very high data rates and cost advantage for price per bit but lacks mobility, has very small coverage per station basis and very low QoS values. WiMAX seems balanced for all aspects.

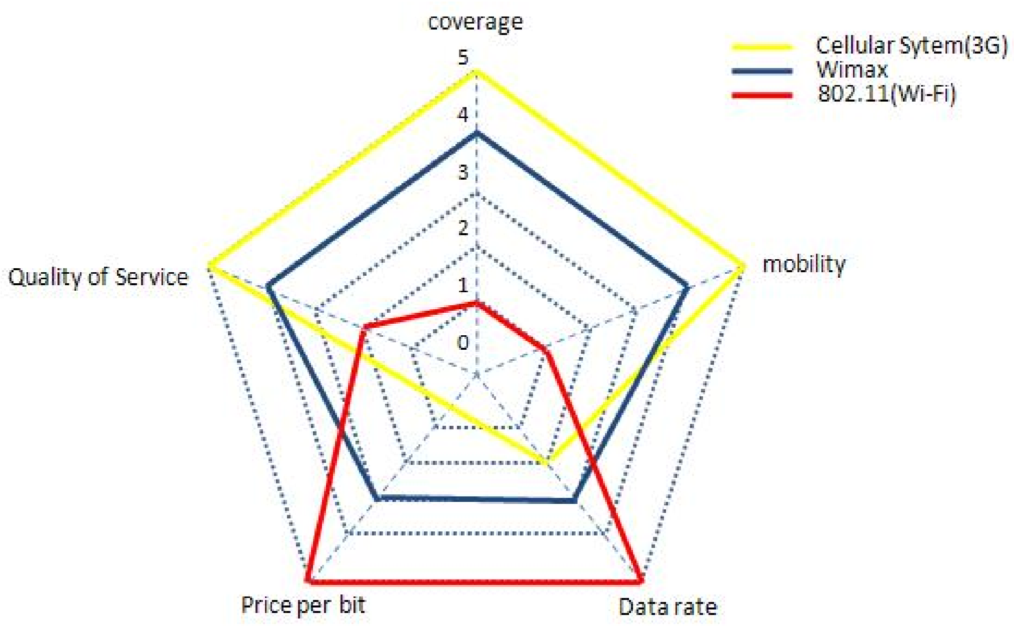

Figure 4.1. Comparison for wireless technologies, regarding to five criteria.

5. CONCLUSION

5.1. Convergence of Wireless Broadband Systems

Cellular Systems

For third generation cellular systems, dedicated channels are used for data transfer. Packet data transferred from dedicated user channels which separated from each other by WCDMA codes. To transfer packet data on a circuit switched system is certainly ineffective way to use network sources especially air interface side. Earlier UMTS systems data performance suffers from disadvantage of this structure much more. Later releases of UMTS standarts sacrifices key radio network features such as soft handover and power control at the sake of increasing data performance of system. But implementation of two different radio system on same network creates problems for radio network planning thus reducing the overall UMTS performance both circuit switch and HS data aspects. Mostly, operators utilizes two carrier strategy, circuit switched data and packet data carried on different carriers.

The next generation of the cellular systems named as LTE (Long term evolution). LTE, unlike UMTS, has OFDMA based physical layer. LTE also has many features that similar to WiMAX currently posseses, such as scalable bandwidth, support for advanced antenna techniques and IP based network architecture. As its standarts completed, very high data rate(over 100 Mbps per sector) support expected from future LTE systems.

WiMAX and Wireless MAN's

Wimax has already IP based physical layer and its physical layer is designed for data transfer over wide metropolitan area networking. OFDM based physical layer and time division duplexing allows effective usage of available spectrum. Data rates of WiMAX relatively high compared to other systems as its bandwidth allows. One major drawback of WiMAX systems is relatively QoS support for voice and streaming video communication. Furthermore mobility is a major challenge for the system since the network structure of the existing systems does not allows seamlessly changing the serving cell, without distruption of the existing session. Such an high level of mobility currently exists on second and third generation cellular systems.

Wi-Fi and LAN systems

It seems that 802.11 systems provides best results for their usage area. Used as a last mile solution for LAN systems, WLAN's today extensively used at hot spots for many in-building and outdoor solutions without requiring cellular structure. Since primarily used for short range coverage and operating on unlicensed ISM bands, and due to power regulations applied on ISM band devices, WLAN systems does not reflects any performance problems in short ranges. But its not suitable solution over large coverage areas and high number of users, due to capacity requirements.

5.2. Future of Wireless Data Access Technologies

Commercially, from the first generation toward to fourth, cellular systems had been based on voice telecommunication that generated main profits for operators. Today cellular network's coverage area spans whole area of the country. For customers, cellular systems have been gradually replaced with PSTN networks and today becomes primary personel communication channel for users. The operators have invested heavily for infrastructure and licenses of frequency bands. Today fourth generation of cellular systems are being released with new license bands. From the third generation, cellular systems network starting to evolve to provide data communication for users.

As evolving to fourth generation cellular systems becomes converging to data communication basis. Some of key features for data communication such as OFDM based air interface, IP based network structure and TDD duplexing is already included in 4G standarts. All of these features already implemented in WiMAX. In similar manner, to provide enough mobility and cellular structure for users WiMAX standarts has evolved. Mobile WiMAX systems has subchannelization which provides frequency reuse for a cellular network and handover features that allows full mobility for users. Cellular and WiMAX wireless standarts has similar deployment conditions such as licensed bands and wide cellular coverage areas. In the near future two technologies will likely converge to each other both technologically and commercially. Compatibility to previous standarts is another factor to consider for future prospects. Fourth generation LTE devices likely be compatible with previous standarts; GSM and UMTS. But same for exists as user terminals has the capability for supporting multiple standarts such as WiMAX and Wi-Fi. Since 802.11(Wi-Fi) devices are currently operated in ISM bands that needs no licensing, there is no competition on its usage area. Rather 802.11 standarts are complentary last mile solution for other long range technologies. So WLAN technologies will be evolved its path to higher data rates.

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BIOGRAPY

Seyhun Barbaros YABACI was born on 1976, city of Adana, Turkey. He graduated from the University of Çukurova in Electrical and Electronical Engineering at 1998. His graduation Thesis 16 Bit I/O Card Project/PC based automation.(completed as hardware and software) is awarded as 1'st Prize of Siemens/Simko 1998 Creative Ideas Competition. After graduation, he was completed his military service in 1998 - 2000. He was awarded by Turkish Army for services at 1999 İzmit Earthquake save and rescue works. In 2000, He started working as a Test and Optimization engineer in GSM operator Turkcell.

Between years 2002-2007, he worked at TURKCELL for different departments, including Operation and Maintanence and Cell Planning Optimization. In 2007, He was awarded by Turkcell (diet award) by work of first time tunnel coverage for Turkey by using the tunnels itself as a waveguide. (Osmaniye – Kızlac Tunnel coverage project). Since 2007 he has working as a GSM-UMTS Cell Planning Engineer for TURKCELL. Beside from Cell Planning, Mr. YABACI is specialized for planning and implementation of In Building coverage systems of Cellular Networks and giving courses in this area as trainer. He designed and implemented GSM and 3G network of Kayseri Kadir Has stadium with using multiple cells in indoor enviroment, this Project is submitted in IIR 2009 Dubai conference as case study at behalf of TURKCELL.