Synchronization Techniques for WI-MAX Systems

By

Venkatanath Varma Kuchampudi

Problem Report submitted to the
College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Electrical Engineering

Brian D.Woerner, Ph.D., Chair
Matthew C.Valenti, Ph.D.
Daryl Reynolds, Ph.D.

Lane Department of Computer Science and Electrical Engineering
Morgantown, West Virginia
2008

Abstract

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Wi-Max presents a whole new breakthrough in the field of broadband wireless communications. It is an advancement of the Wi-Fi technology and offers a broad range for wireless communications in the order of 30-50km. The Problem Report discusses the various types of broadband. It addresses the problem of Outage in Wi-Max systems. It also discusses about the various types of fading (small and large scale) that occur in a broadband wireless system. The discussion then focuses on how we can combat the various types of fading and provide synchronization in Wi-Max systems. Wi-Max systems are very useful in rural and sub-urban areas where the use of traditional Digital Subscriber Line cables would be very expensive. As it operates in an unlicensed spectrum it can be easily deployed and can offer both voice and video services. Hence it can be used for various services like Television, Radio, Internet, Cell phones etc.

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation and gratitude to my advisor, Dr. Brian D.Woerner, for giving me this opportunity to work on this topic. His knowledge and encouragement have been of great value throughout the course of my research.

I wish to express my sincere thanks to the members of my committee, Dr. Daryl Reynolds, and Dr. Matthew Valenti. Their understanding and constructive comments have been important throughout this work.

Lastly, I owe my sincere thanks to my friends and family, for their constant support and valuable encouragement throughout this endeavor.

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Chapter 1

Introduction

Broadband refers to a signaling method that includes or handles a wide-range of frequencies which may be divided into channels. These channels serve the purpose of simultaneous data transmission like a television would receive more channels if it uses the broadband. It is often called as High-Speed Internet because it has high rate of data transmission. For Internet users with broadband connections, the Internet becomes a tool that is used more frequently for a greater variety of transactions than the individuals with dial-up or narrowband connections. The broadband of frequencies allows various kinds of data like audio, video etc simultaneously without interfering with each other. The broadband can support more than a hundred channels of digital audio and still be very reliable due to negligible interference[19]. Broadband is very useful for cities where the population density is high and various kinds of data need to be transmitted simultaneously.

1.1 History and Evolution:

Prior to the broadband only the Digital Subscriber lines with a very limited range of frequencies were used. This would enable only one kind of data to be transmitted and at very low data rates. The introduction of broadband broke all the barriers of the traditional communication line. They introduced transmission of any kind of data at any time through the use of channels. Different channels occupy different frequencies through the transmission medium, and guard bands are introduced into the frequency range between channels to ensure that there is no interference between the channels. The availability of a wide band of frequencies enables the system to carry multiple data, voice and video channels during a single transmission. There are various kinds of broadband technologies that make up the Broadband picture. They are:

1. Digital Subscriber Line and T-Carrier Systems
2. Cable Modem
3. Fiber to the Home and Office
4. Power line Broadband
5. Satellite Broadband
6. Wireless Broadband

The most common technologies for broadband in many countries are DSL and cable modems. Choice among these broadband technologies is made by taking into consideration various factors like the users location, the minimum speed the user needs, the way the technologies are packaged by the service providers, and cost.

1.1.1: Digital Subscriber Line and T-Carrier systems

Digital Subscriber line (DSL) is a technology that provides data transmission over ordinary copper telephone lines in digital format rather than the traditional analog form. Telephone companies are the major sources for the many different versions of DSL like ADSL, SDSL, and HDSL etc. These telephone companies provide DSL services themselves or lease the lines to other DSL service providers. Twisted pair copper wiring is capable of handling a much greater bandwidth than that needed for voice. This is basically used by the telephone companies for the communication. DSL uses the bandwidth that is in excess to the required amount for voice tranmission to carry extra information over the telephone lines by creating new channels for upstream and downstream traffic. The DSL provides direct Digital Data Transmission which eliminates the inefficiency of “Analog-to-Digital and digital-to-Analog” conversion. This direct transmission of digital signals allows the phone company providing DSL to send much more information over the telephone line for transmitting more data. DSL can be broadly classified into two categories: `Asymmetric DSL' and `Symmetric DSL'. Downstream speeds are greater than upstream speeds for Asymmetric DSL whereas they are the same for Symmetric DSL. Symmetric DSL does not allow the users to share the line with the analog phone while Asymmetric DSL provides this facility. As the phone lines were not made initially planning for frequency availability for DSL it is generally used for very short distances like less than 3 miles. As the distance between the telephone exchange and the user increases, the data rates are correspondingly reduced. The Asymmetric DSL (ADSL) has higher data flow in one direction than the other and hence its called Asymmetric DSL. It is useful for consumer connecting to the internet where we need to achieve moderate upload speeds combined with high-speed download.

The various versions of DSL have different upstream speed limits, downstream speed limits and distance limitations. The T-Carrier system is a digitally multiplexed carrier system that is made up of multiple channels and consists of high speed lines. Each channel on a line can be provided a throughput of 64 Kbps. A multiplexer is used to combine (multiplex) different channels carrying voice and data so that they can be transmitted at the same time over a single line. The modulation technique used by the digital signals over the T-carrier systems is Pulse Code Modulation (PCM) and uses Time-Division multiplexing. As the T-carrier system uses 2 pairs of wires it provides full duplex with one pair for transmission and the other for reception at the same time.

The telephone companies also offer T-carrier systems besides DSL for high speed broadband connections. The disadvantages of DSL are overcome by T-Carrier. The T-Carrier system has a raw throughput of 1.5 Mbps and DSL provides a maximum throughput of 1.5 Mbps. T-Carrier systems is more expensive as they have higher infrastructure requirements. They become increasingly expensive once the user starts becoming more remote. The T-Carrier is hence basically used by businesses that require continuous high speed internet connections.

1.1.2 Cable Modem

The cable modem takes advantage of the unused bandwidth on a cable television network to deliver broadband internet. The basic purpose of the device is to modulate a data signal over cable wire. In a cable TV system, signals from the various channels are each given a 6-MHz slice of the cable's available bandwidth and then sent down the cable to your house. In some systems, coaxial cable is the only medium used for distributing signals. In other systems, fiber-optic cable goes from the cable company to different neighborhoods or areas. Then the fiber is terminated and the signals move onto coaxial cable for distribution to individual houses. Data services on cable systems allocate two channels, one for downstream traffic and one for upstream traffic, at 6MHz and separated by a minimum of 8 MHz to avoid inter-channel interference. DOCSIS, Data over Cable Service Interface Specialization, defines the interface requirements for cable modems which are involved in high speed data distribution over cable television system networks. The cable modem can have multiple users but they have to share a common cable and hence the speed delivered by a cable modem system depends on the number of users. The bandwidth available per user decreases with increase in the number of users and this leads to performance degradation. DOCSIS, Data over Cable Service Interface Specialization, 3.0 standard defines the value of downstream traffic rates between 27Mbps to36 Mbps and upstream traffic rates between 320 Kbps to 10 Mbps. The cable modem does not depend on the distance from the central cable office as in DSL but rather the speed depends on the number of users.

1.1.3 Fiber to the Home and Office

Fiber to the home is a broadband telecommunication technique which is based on fiber-optic cables. It can perform various functions and deliver services like internet, telephone and television simultaneously. The Fiber-optic cables are based on the principle of transmission of data in the form of light waves. They use the concept of total internal reflection and the light waves at the transmitter and receiver are made to strike at certain angles so that there are no losses in the transmission. The architectures that are commonly used are the Fiber to the Building (FTTB), Fiber to the Curb (FTTC) and Fiber to the Node (FTTN) networks. FTTB as the name indicates provides dedicated fiber to each building or block of buildings. In this method, the fiber is terminated at a remote terminal from where a cable line or a telephone line connects it to the individual user. These networks when used in conjunction with a cable provide a speed of 10-100 Mbps and a speed of 50Mbps when used with DSL over telephone lines. FTTC typically ends the fiber to about 500 to 1000 feet from the subscriber, terminating at a particular point and serving about eight to twelve subscribers. In FTTN, the fiber terminates at a distance of about 5000 feet from the subscriber and serves up to 500 subscribers. DSL technology is used by FTTC and FTTN to connect to Individual users from the remote terminal and provide a rate of about 20 Mbps.

1.1.4 Broadband over Power lines

Broadband over Power Lines provide broadband internet access through power lines. It uses the Power Line Communications technology for providing this service. This technique uses RF signals which are sent over the medium and low voltage AC power lines to allow end users to connect to the internet. The RF signal is modulated by a digital signal and this signal is sent over the power lines. The frequency used is the band of frequencies not used for transmitting electricity. The end user gets the RF signals which travels along the power line wires and then pass through the transformers and reach the end user's home or business. An interface at the end user converts it into Ethernet compatible data. The Broadband over power lines tends to generate lot of radio interference as most power line radio communications radio signals occupy the frequency band between 1.6MHz and 80 MHz. Broadband over power line communication will also interfere with the many shortwave and amateur radio broadcasts that are present in these frequencies.

1.1.5 Satellite Broadband

The Satellite broadband technique makes use of a geostationary satellite orbiting the earth to communicate data between the user and the internet service provider. The satellite used is specifically geosynchronous as this is in synchronization with the earth’s rotation speed and it also finishes rotation in the orbit in 24 hours. There can be both 1 way and 2 way satellite communication techniques. The 1-way uses the downstream traffic from the Internet Service provider to the user through the satellite whereas the upstream uses a normal dial-up connection. The 2-way satellite system uses the satellite for both the upstream and downstream data transmission and the time taken increases. The 2-way system becomes more expensive as it requires high power in the electromagnetic signal to make two trips from and to the satellite. The problem with satellite communication is it would be affected by climate changes. The satellite communication typically gives the consumer a download speed of about 500 Kbps and an upload speed of about 80 Kbps. This is considerably less as compared to the other techniques. This is hence mostly used in rural areas and in areas where the other forms of communication are not present and it is very difficult to get the other forms there. Cost can make satellite broadband uneconomical unless no alternative technology is available.

1.1.6 Wireless Broadband

Wi-Fi is a general representation for wireless local area networks (WLAN) that are in accordance with the IEEE 802.11 wireless networking standards. The interface over-the-air between a wireless client and base station or between two wireless clients is specified by the IEEE 802.11 standard. IEEE 802.11 has many versions like 802.11a, 802.11b, 802.11g and 802.11n etc. and all of them operate in the unlicensed frequency bands. 802.11a uses the `Orthogonal Frequency Division Multiplexing (OFDM)' technology, operates in the 5 GHz frequency band and provides a data rate of 54 Mbps. 802.11b uses the `Direct Sequence Spread Spectrum (DSSS)' technique, operates in the 2.4 GHz frequency band and provides a data rate of 11 Mbps. 802.11g uses the OFDM technique, operates in the 2.4 GHz frequency band and provides a data rate of 54 Mbps. OFDM transmits different parts of a message by increasing bandwidth and data capacity by splitting a broad carrier channel into multiple, closely spaced narrowband carriers, each of which use a different frequency. Also the narrowband carriers are placed such that neighboring carrier channels are orthogonal to one another to avoid overlap and thereby interference. 802.11n, which is still under research uses the `Multiple Input Multiple Output (MIMO) technique in addition to the OFDM technology and can deliver a data rate of about 200 Mbps. This can be done over a wider range using the MIMO as it uses multiple transmit and receive antennas to increase the data throughput and reliability of a wireless communication system. Wi-Fi is especially useful in offices and households as it decreases the amount of cables but the problem with Wi-Fi is its range is limited to a few hundred meters. Wi-Max, which stands for `Worldwide Interoperability for Microwave Access', is the ‘last mile’ solution for delivering broadband directly to homes and offices by the Wireless Internet Service Providers. The standard used previously is the Line of Sight operation but as it is useful even for the Non Line of Sight operation it is based on the IEEE 802.16 standard which gives the specifications for the Wireless MAN interface specification for wireless Metropolitan Area Networks. Wi-Max has a long transmission range of about 30 miles owing to its use of directional antennas. 802.16 can deliver a maximum throughput of 124 Mbps which includes space for encountering the NLOS conditions. Wi-Max uses a 256-carrier OFDM as compared to 64-carrier OFDM scheme by Wi-Fi hence achieving higher data rate. The bandwidth is between 1.5 and 20 MHz.

1.2 Drawbacks of Traditional Broadband Techniques:

The various broadband techniques that are in use have various drawbacks due to which the use of Wi-Max becomes indispensable. DSL, Cable, Fiber and Broadband over power lines are all very expensive due to the high cost involved in the use of cable and also the cost associated with the physical laying of cables in DSL, Cable and Fiber to Home broadband techniques. The Broadband over power lines is comparatively better in the aspect of transmission over existing power lines but they generate lot of radio interference as most power line radio communications radio signals occupy the frequency band between 1.6MHz and 80 MHz and since many shortwave radio broadcasts and amateur radio broadcasts also have their frequency bands in this region, BPL communications tend to interfere with these communications that are already present. Satellite communications have been in use for a long time but the effect of the distance to be traveled for the communication via satellite and the various environmental disturbances that can decrease the signal power have led to them being outweighed by the advantages of Wi-Max. Wi-Fi is useful over very short distances like a building etc. So the use of Wi-Max becomes a necessity when it comes to cost and also the ease with which the data can be transferred. Also, the frequency band occupied by the Wi-Max in the range of 10-66 GHz does not have interference from any existing communication frequency range. Now we look at Wi-Max and the various advantages it can offer to us over the other traditional broadband techniques.

1.3 Wi-Max:

Wi Max, the Worldwide Interoperability for Microwave Access, is a telecommunications technology aimed at providing wireless data over long distances in a variety of ways from point to point links to full mobile cellular type access. Wi-Max is useful in providing long range access and it is highly useful for sub-urban and rural areas. Wi-Max sets up a connection between the Base station and the User. Each connection is based on different scheduling algorithms which ensure the Quality of Service as opposed to the Wi-Fi system where packets receive different priorities based on their tags, hence Quality of Service cannot be guaranteed and it rather depends on packets and flows. Wi-Fi system can be used in a small area like a business, airport etc. Wi-Max can be useful in interconnecting the various Wi-Fi hotspots with each other and other parts of the internet.

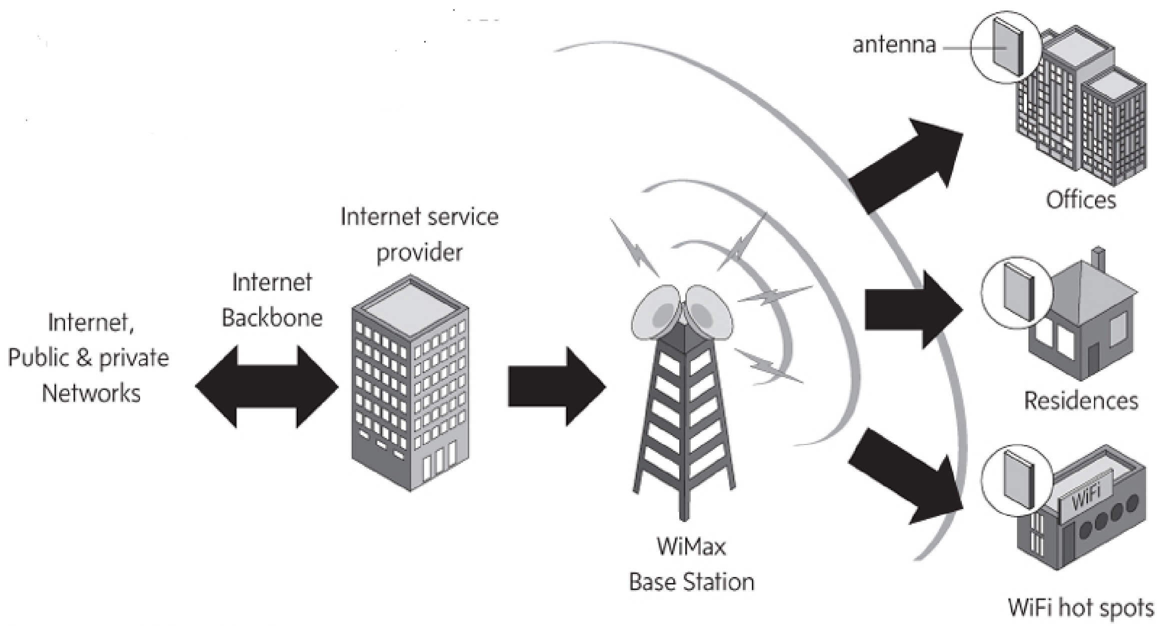


Fig: Wi-Max operation[20]

Wi-Max comes in two varieties. One uses Point-to-point communication which would be useful to transfer data from high traffic locations where carriers find it very expensive and difficult to use the wired lines. This can be used in developing countries where there is a need for moving data in the high traffic locations but in developed countries like the US the requirement would be of the second type i.e. point-to-multipoint communication. We start our discussion of Wi-Max beginning with a wireless channel. The wireless channel is to be considered as Additive White Gaussian Channel (AWGN) i.e we consider the signal is affected by thermal noise produced by the receiver which is basically the noise producer by the receiver due to the random movement of the electrons and this agitation produces the heat and thereby noise and this is called thermal noise. The term white is used to indicate that the noise has equal power over all frequency components. The power spectral density is equal to $N_0/2$. The Additive term indicates that the noise sample adds to the signal to corrupt it.

$$r(t)=s(t)+n(t)$$

where s(t) is the signal , r(t) is the received signal and n(t) is the noise signal with 0 mean and standard deviation $N_0/2$. There is also fading due to the various paths in which the wireless signal might traverse. This fading affects the signal to a large extent as compared to the thermal noise. The fading parameters like the attenuation and delay are found by using the distributions like Rayleigh fading , Rician fading, Nakagami-m fading etc.

1.4 Challenges Faced by Broadband Wireless

1.4.1 Large-Scale Fading:

This is the representation for path loss or the average signal attenuation due to signal over large areas. The main constituents of large-scale fading are path loss and shadowing.

1.4.1.1 Path-Loss:

This is best described by Free Space Path model. The main assumption in Free Space model is that the transmitting antenna is Isotropic i.e. transmitter radiates energy equally in all directions and also considered that there are no objects between the transmitter and the receiver. Another assumption is that the transmission medium is perfect and does not absorb any energy which is practically not true. In practicality, we find that as the distance between the transmitter and the receiver increases there is increased absorption (energy loss) by the transmission medium and hence the receiver signal power decreases.

1.4.1.2 Shadowing:

This indicates the variations due to terrain and objects in the environment when the signal is transmitted over long distances. Hence we add a random component to the path loss to account for this variation in power. This component is random but is assumed to be log-normally distributed hence this is also called Log-Normal Shadowing.

1.4.2 Small-Scale Fading:

This occurs mainly due to the rapid fluctuations of the received signal power over a small distance. This occurs when two or more signals are received at the receiver with different angles of arrival, phase and amplitude. They can either combine constructively or destructively to cause fading and the receiver signal power can increase or receiver signal power goes to almost negligible levels.

1.5 Fading Distributions:

The receiver signal power depends mainly on the presence of Line-Of-Sight or Non-Line-Of Sight components in the transmission path between the receiver and transmitter and also the severity of the fading channels.

1.5.1Rayleigh Fading:

This is used for channels that do not have a strong Line-Of-Sight component between the transmitter and the receiver. Gaussian model is considered because there are a large number of scattered signals and the application of Central Limit theorem ends up as a Gaussian distribution.

1.5.2 Nakagami-m Fading:

This is a modified form of Rayleigh Fading which has a factor m added to the Rayleigh fading equation and for m=1 it becomes Rayleigh fading. This parameter is based on the severity of fading channel conditions.

1.5.3 Rician Fading:

This is useful when there is a strong Line-Of-Sight signal between the transmitter and the receiver. This modifies into Rayleigh if the strong Line-Of-Sight signal fades.

1.6 DIVERSITY:

Diversity techniques are used to combat fading by using the multi-path nature of the wireless channel and finding the least correlated path between the transmitter and receiver to avoid high signal losses due to noise. The various techniques used are Time Diversity, Frequency Diversity and Spatial Diversity. Diversity combats fading by exploiting the multi-path nature of nature of the wireless channel and finding highly uncorrelated signal paths between the transmitter and the receiver. This diversity leads us to OFDM where the signals are orthogonal to each other and hence are least correlated. In a conventional serial modulation scheme in which bits are transmitted over the channel one after another, a deep fade will result in the destruction of the affected bits. This will lead to a totally misinterpreted message at the receiver. Orthogonal Frequency Division Multiplexing (OFDM) is a scheme in which a block of bits is transmitted in parallel, each at a low baud rate. The basic idea behind the scheme is to spread out the effect of a fade over many bits. Rather than have a few adjacent bits completely destroyed by a fade, we now have all the bits slightly affected. In the case of minimum change of bits/signals the original bits can be estimated by using certain algorithms.

1.6.1 Orthogonal Frequency Division Multiplexing (OFDM):

The OFDM the Sub-carrier frequencies are chosen such that the Sub-carriers are orthogonal to each other which eliminate Cross talk between the Sub-Carriers and the need for Inter-Carrier Bands. This feature helps in simplifying the design of both the Transmitter and the Receiver in the way that it does not require a separate filter for each channel as in the Conventional FDM. The OFDM technique is an effective transmission scheme to cope with many channel impairments, such as co channel interference, severe multi path fading, and impulsive parasitic noise.

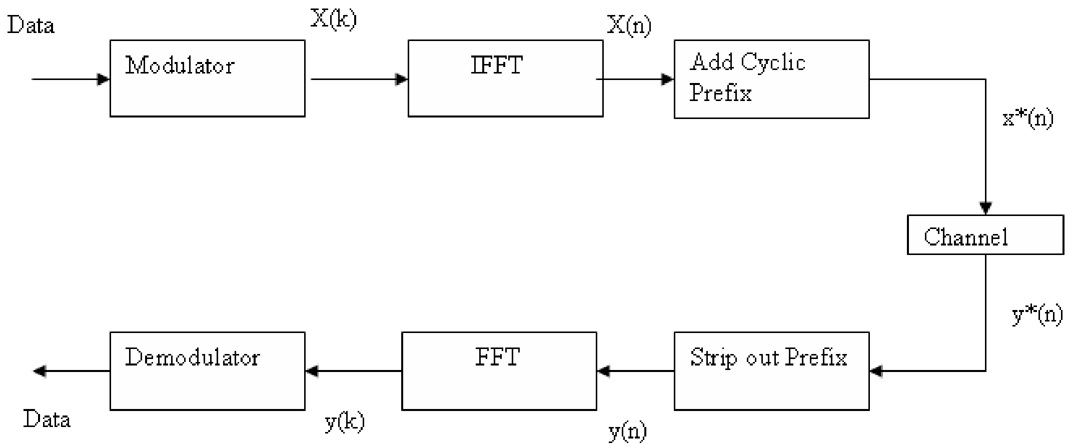


Fig: Block Diagram of an OFDM Transmitter and Receiver using Fast Fourier Transform

It uses a large number of closely spaced orthogonal sub-carriers. Each sub-carrier is modulated with any conventional modulation scheme like QAM at a low symbol rate such that it maintains data rates similar to the conventional single carrier modulation schemes which operate in the same Bandwidth. OFDM is a combination of many slowly-modulated Narrowband signals rather than one rapidly-modulated wideband signal and by having this feature there is a chance of inserting guard bands due to the low symbol rate and these guard bands are useful to handle time-spreading and mitigate Inter Symbol Interference (ISI). In OFDM, frequency synchronization is very essential between the transmitter and the receiver without which the Sub-carriers will no longer be orthogonal which will lead to Inter-Carrier interference i.e. cross talk between sub-carriers. These offsets are caused by the Mismatched transmitter and receiver oscillations, or by Doppler shift due to movement.

1.6.2 Reason for using Wi-Max

Wi-Max is very useful in providing broadband services to rural and sub-urban areas at a cheaper price as compared. As it operates in an unlicensed spectrum it can be easily deployed and can offer both voice and video services. It is the most versatile of all broadband wireless technologies[18].

It is a wireless alternative to cable and DSL for last mile broadband access. It is almost indispensable for last mile access as it is very expensive to lay cables to remote areas. It is different from a Wi-Fi in the way that it can offer services to a wider area of the order of 50km (31 miles) and can offer connectivity between users without a Direct Line-Of-Sight (LOS) component[17]. It can provide shared data rates up to 70Mbits/sec which is enough to support 60 businesses which use the T1 (1.544 Mbits/sec line rate) type connectivity and over a thousand homes at 1Mbit/sec DSL level connectivity. Can reach data transmission speeds at over 100 Mbps for high mobility services and 1Gbps for low-mobility services and the various services include TV(Video), Radio(Audio), Internet, Cell phone etc.

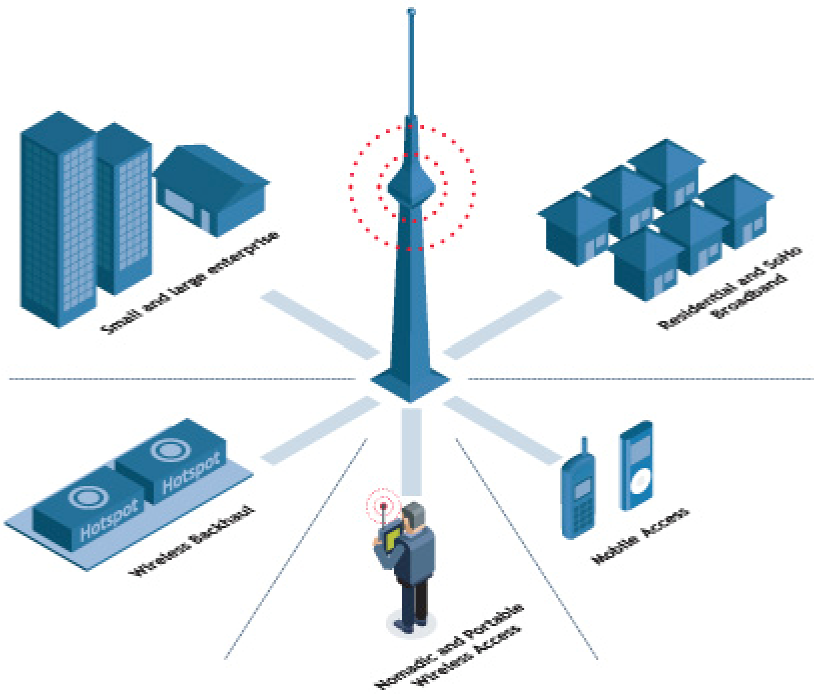
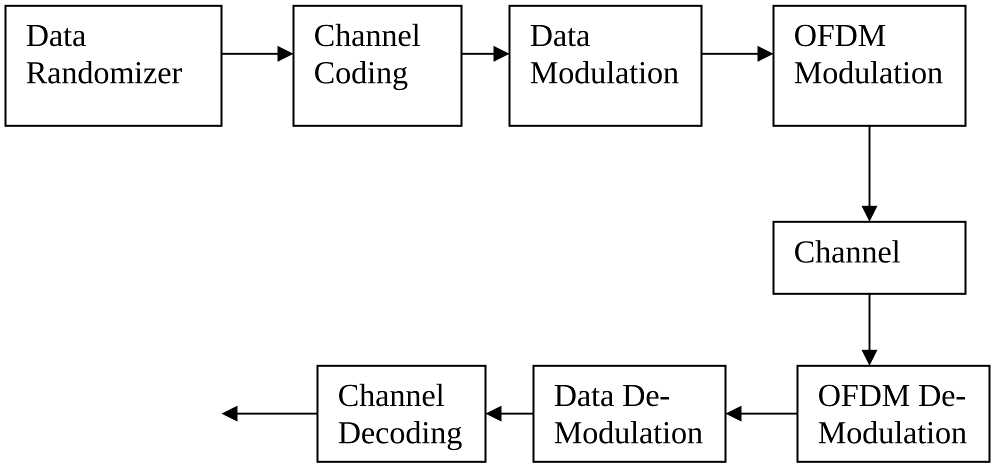


Fig: Applications of Wi-Max[21]

CHAPTER-2

Wi-Max

2.1 Structure of Wi-max



2.2 Discussion of structure of wi-max

2.2.1 Modulation:

The theoretical data rates are 70 Mb/s with a range of up to a maximum of 50 km. But in the practical sense it works well up to a range of 20 to 30km. The frequency band to be used should be less than 11GHz as specified by the IEEE 802.16-2004. Both the FDD and TDD can be used[15].

Broadband: Having instantaneous bandwidths greater than around 1MHz and data rates greater than around 1.5Mb/s. Both FDD and TDD are supported in the targeted operation of 10-66 GHz frequency band for the Physical layer[16].

2.3 Modulation and Coding Supported in Wi MAX

	Downlink	**Uplink**
Modulation	BPSK, QPSK, 16 QAM, 64 QAM; BPSK optional for OFDMA-PHY	BPSK, QPSK, 16 QAM; 64 QAM optional
Coding	Mandatory: convolutional codes at rate 1/2, 2/3, 3/4, 5/6 Optional: convolutional turbo codes at rate 1/2, 2/3, 3/4, 5/6; repetition codes at rate 1/2, 1/3, 1/6, LDPC, RS-Codes for OFDM-PHY	Mandatory: convolutional codes at rate 1/2, 2/3, 3/4, 5/6 Optional: convolutional turbo codes at rate 1/2, 2/3, 3/4, 5/6; repetition codes at rate 1/2, 1/3, 1/6, LDPC

Phase shift keying is the Digital modulation scheme that is used to convey data by changing or modulating the phase of a reference signal.

2.3.1 BPSK (Binary Phase Shift Keying)**:** This uses two phases which are separated by 180 degrees. So the symbols transmitted are 180 degrees out of phase. This is the most robust as it requires serious distortion to make the demodulator make an incorrect decision as the symbols are 180 degrees out of phase.

2.3.2 QPSK (Quadrature Phase Shift keying): This uses two bits per symbol and uses four phases which are equally spaced around a circle. Due to the four phases and its encoding of two bits per symbol hence it operates at twice the rate of BPSK. The even(or odd) bits are used to modulate the in-phase component of the carrier signal and the other bits are used to modulate the quadrature-phase component of the carrier signal.

2.3.3 QAM(Quadrature Amplitude Modulation): This modulation scheme conveys data by changing (modulating) the amplitude of two carrier waves. These are generally sinusoidal waves which are 90 degrees out of phase.

2.3.4 LDPC(Low Density Parity Check) codes: This is an error correcting code used to transmit a message over a noisy transmission channel. LDPC is one of the most effective error correcting code to date. LDPC code represents an n-bit message encoded as more then n bits and this redundancy is useful to aid in recovering from channel errors.

The rates shown are the aggregate physical-layer data rate that is shared among all users in the sector for the TDD case, assuming a 3:1 downlink-to-uplink bandwidth ratio. The calculations here assume a frame size of 5 ms, a 12.5 percent OFDM guard interval overhead, and a PUSC sub carrier permutation scheme. It is also assumed that all usable OFDM data symbols are available for user traffic except one symbol used for downlink frame overhead. We can further increase the peak rates in rich multi path channels by using spatial multiplexing using multiple antennas at the transmitter or receiver.

2.4 Relationship between IEEE 802.16 and Wi-Max:

Basically, WiMAX is a group which promotes the 802.16 standard. They are trying to standard how 802.16 is used. It is similar to the relationship of WiFi and 802.11.

2.5 USES OF WI MAX:

1) High speed of up to 70 Mb/s and long range of around 50km. This is very economical in low density populations where the cost of laying cables and using the DSL technology would be very expensive.
2) It gives more options to users like offering carriers and their customers more options to choose from depending on their business models and lifestyles.
3) Support point-to- point and point-to-multipoint broadband wireless communications.
4) Non-Line-of-sight is also offered.
5) There are more spectrums available. We can operate in Licensed Band(2.5GHz, 3.5GHz) and license exempt (5.8GHZ) radio spectrums, and other potentially lower frequency bands(700MHz -900 MHz)[22].

2.6 OUTAGE:

When there are many users connected to the Wi-Max server and there is an outage we need to have proper mechanism to overcome all the users trying to connect back as soon as the server turns back up. This is typically termed as the Outage problem. We use the concept of priority to allocate the data rates. If the channel conditions are good we can transfer at a higher data rate. So when the signals are bring transmitted from the various users the scheduler does a moving average conversion and the signals which are above the average have the higher priority and are served first and the signals which are below the average have lower priority and are served at lower data rates. If the poor channel conditions(maybe due to distance, terrain etc) user is served with higher data rates noise is generated and hence the better the channel conditions the higher the data rate served.

CHAPTER 3

Synchronization

There are various synchronization techniques available such that there is no major lag between the transmitted and received signals which leads to data corruption. This ultimately leads to wrong signal being interpreted and leads to entire message disruption. The most commonly used technique is the use of Guard Interval which is the least complex of all the synchronization techniques.

3.1 SURVEY OF SYNCHRONIZATION TECHNIQUES FOR OFDM

3.1.1 Insertion of Pilot Symbols for synchronization

The First technique we consider is the least complex of all the techniques where we insert some synchronization symbols within the OFDM signals as Pilot Symbols [2]. The receiver used these synchronization symbols to generate the frame clock. Synchronization is necessary to eliminate the buffering required between elements of the network. The military was the first to use the frame clock as a way of encrypting secret messages. The frame clock was set up in such a manner that it was virtually impossible for an unauthorized user to recover the frame clock and interpret the data. However, the insertion of pilot symbols decreases the system capacity. Guard-interval-based low complexity frame synchronization is used for the estimation of the start position of a frame for a non-data aided frame. It uses the Guard Interval and the in-phase and quadrature sign bits of the OFDM data to estimate the frame position. In the case of the channel being time-dispersive, the inter symbol interference will introduce errors in the frame synchronization scheme[23]. These OFDM synchronization problems are solved by using a joint technique which is a combination of Channel estimation and Phase error Tracking. It simultaneously eliminates the distortion caused by the time-varying multi-path fading channel, Carrier Frequency Offset and Sampling Clock Offset [24]. Channel Estimation is enhanced by using a decision directed Channel Estimator with tracking in data sub carriers and the Phase Error Tracking accuracy is enhanced by using Weighted-Average Phase Error Tracking.

3.1.2 Frame Synchronization Schemes:

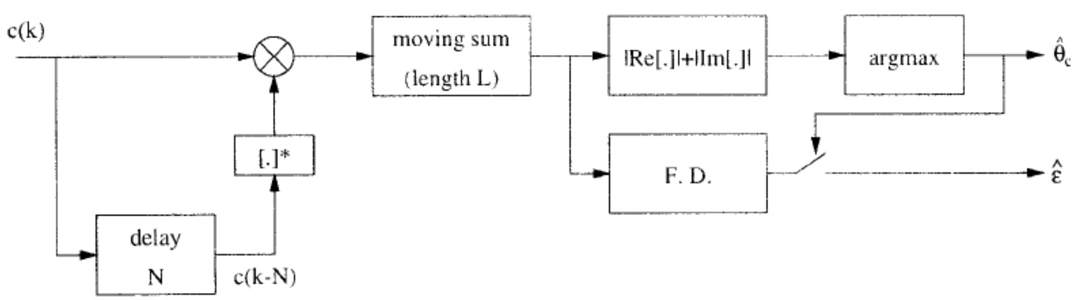
3.1.2.1 If a Base band signal that is transmitted is modulated with the same number of values and a discrete Fourier Transform is found, we find that the result shows that zeros exist in the modulated values and these act as virtual carriers. This shows that the data can be recovered in the receiver by DFT if the orthogonality is preserved in the OFDM block.

Inter Symbol Interference (ISI) occurs due to the multi-path effect in time-dispersive channels and this is caused by signals arriving at the receiver at different phases, amplitudes etc. The orthogonality in OFDM symbols is lost due to the effect of Inter-Symbol interference. Distortion of the signal is caused by previously transmitted signals and has an effect on the presently transmitted signals. This is Inter Symbol Interference. The previous signals have noise and other unwanted components which might lead to total corruption of the present signals[13]. A Guard interval is inserted in front of each OFDM block to avoid the corruption of signals. The Guard band duplicates the last few samples of the transmitted signal and adds them as a prefix to form an OFDM frame. Hence the use of guard band becomes very essential to avoid Inter Symbol Interference.

3.1.2.2 There is another technique which is a frame synchronization scheme and is based on the inherent correlation property of the OFDM signals with the Guard interval[3]. The in-phase and quadrature phase components of the signal are quantized to complex values. In order to reduce the complexity we consider only the sign bits of the in-phase and quadrature phase components. Concatenation of log likelihood functions gives the output of the moving sum and produces consecutive OFDM frames. The frame errors have an influence on the FFT output symbols when Additive-White Gaussian Noise (AWGN) channel is used. In the case of the Start position of the frame being located within the guard interval, each FFT symbol will be rotated by a different angle and from sub-carrier to sub-carrier the angle increases proportionally to frequency offset. In case the estimated start position of the frame is located within the data interval the sampled OFDM frame will contain samples that belong to the OFDM frame. Hence we find that each symbol at the output is dispersed and rotated due to the Inter-Symbol Interference from the other frame. This can be carefully corrected but the dispersion of signal caused by ISI forms a Bit Error Rate (BER) and in addition to this there is also the effect of channel impairment. Due to the presence of all these effects the Guard interval used to estimate the frame location is interfered by the previous symbol. We use various smoothing algorithms to combat this. The Moving Average (MA) scheme, Shortened Moving Average (SMA) scheme, Exponentially Weighted Moving Average (EWMA) scheme and Exponentially Weighted Average(EWA). The Moving Average, Shortened Moving Average and the Exponentially Weighted Moving Average algorithms are realized as FIR filters and the Exponentially Weighted Average algorithm is realized as an IIR filter.

3.1.3 Low-Complexity Frequency Offset Correction Scheme:

Due to the mismatch between the oscillators or the Doppler Effect in mobile radio channels, Carrier frequency error exists between the transmitter and the receiver. This has an effect on the OFDM system performance as the frequency offset introduces Inter Carrier Interference (ICI) which reduces the orthogonality between the various sub-carriers which form the OFDM signal. This reduction of orthogonality in the OFDM system deteriorates the system performance. The frequency error can be corrected by using a feedback or a tracking loop where a frequency detector is used in the setup to estimate the frequency offset.



System block diagram of the ML estimator for frequency offset and frame position.

Fig: ML estimator for Frequency Offset and Frame Position[3]

Algorithms to estimate the frequency offset are classified as:

a) Algorithms based on the special synchronization blocks analysis. These special synchronization blocks are embedded in the OFDM temporal frame (Data-aided)[4,7].:

   These require synchronization blocks for the estimation of the frequency offset and provide better results than the existing ones but the insertion of blocks reduces the rate of flow of information. Thus we must avoid having more synchronization blocks and they should be very small in number as compared to the number of data blocks. They can estimate the offset once they receive the synchronization blocks which makes the time for acquisition longer and finally the nonlinearity of the channel increases the estimation complexity.

b) Algorithms based on the received data analysis at the output of the FFT (non data-aided)[5,12]:

   They require no special blocks but have a poor performance in the Radio and Mobile environments.

c) Algorithms based on the sampled received signal analysis before the FFT block and making use of the redundancy introduced by the inserted guard interval in the OFDM signal frame (GIB)[6,10]:

   It makes use of the inherent data property of the OFDM signal and achieves accurate synchronization. The last few samples of guard interval are used by the Guard Interval-Based (GIB) frequency detector uses to estimate the frequency offset and thereby estimate the small frame synchronization error. This will induce error in the GIB frequency detector which also has a direct effect on GIB frame synchronization scheme[6].

Hence if we have to get good frame synchronization by using the low-complexity frame synchronization scheme, frame position and frequency offset must be estimated simultaneously. The guard interval is generated by duplicating the last few samples of the signal and is placed as a prefix in front of the block and this interval should be greater than the channel impulse response to eliminate ISI.

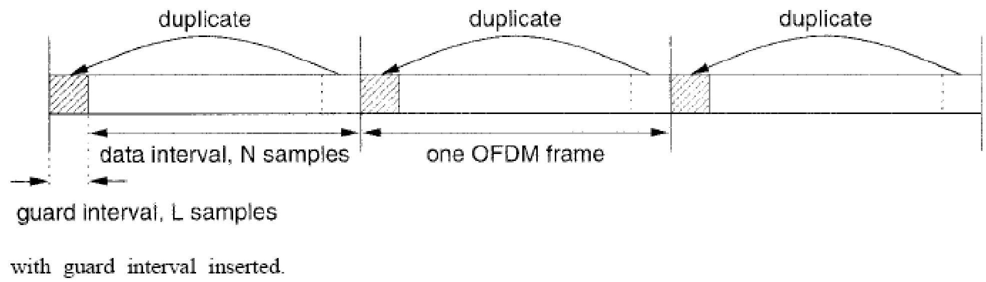


Fig: OFDM Signals with Guard Bands[23]

3.1.3.1 Cyclic Prefix:

Cyclic prefix is usually added to eliminate the Inter-Symbol Interference introduced by the multi-path channel. Cyclic Prefix is a copy of the last few symbols and added in front of the transmitted OFDM symbol. Consider that the cyclic prefix contains the last µ samples of the input x (n). From the Figure above we can see that the signal becomes $x^*(n)$ after the addition of cyclic prefix. Length of the cyclic prefix (T_g) is to be chosen such that this length does not exceed the maximum time delay and is equal to the maximum delay of the channel µ. Considering each input sequence to be of length N the output sequence would be of length N+ µ. From the figure, we see that the output $y^*(n)$ is the output signal with the cyclic prefix. But for the data recovery we need to eliminate this cyclic prefix. The overhead of µ/N and a data reduction of N/(µ+N) occurs due to the presence of cyclic prefix. There is a loss of energy because the cyclic prefix consists of redundant data. Due to this energy loss, an E_b/N_0 axis shift occurs. This is dependent on the ratio of energy used to send information. Ex: If there are 128 symbols , 8 pilot symbols and a cyclic prefix of length of 64 then the ratio of the energy used is 128/(128+8+64) = 0.64 and the E_b/N_0 axis is shifted by 10 log(0.64)= -1.93 dB.

3.1.4 Carrier Frequency Acquisition Scheme:

The frequency offset range is <=0.5 which is +-1/2 of the inter-carrier spacing in the GIB frequency offset correction scheme. It suffers from the sub-carrier interference once the offset goes greater than 0.5. This problem can be solved by using the correlation between the received data with corrected offset frequency and the training sequence with the condition that the auto correlation function of the training sequence has its maximum at zero. In the frequency acquisition problem can be turned to be a PN sequence estimation problem [11]. After the frequency offset correction ,the unknown multiple of the inter-carrier spacing can be found by shifting the training sequence and correlating it with the received data. The frequency offset detector does the operation of estimating the frequency offset error symbol-by-symbol by finding the difference and feeds the corrected frequency into the receiver and reconstructs the samples. The received samples are also corrupted by channel impairment and this is not detected by the receiver at the synchronization stage. Though the training data is known at the receiver, we do not have the information about the channel response of each channel. So an assumption is made that the channel responses of neighboring sub-channels are considered virtually same considering the fact that each sub-channel bandwidth is very small in comparison to the overall bandwidth of the OFDM system. From the model we see that for larger channel response amplitude, the sub-channel difference is smaller. The signals of adjacent channels will interfere with the signal in the current channel when there is frequency offset. When the frequency offset is determined, the sub-channels that may be interfered by adjacent channels are discarded. The frequency offset is determined by calculating the difference of the channel responses between adjacent sub-channels thereby eliminating multi-path effect.

3.1.5 Adaptive TDD Synchronization

If the movable uplink/ downlink (UL) TDD boundary is not synchronized among all frames in base stations, severe co-channel interference conditions can occur Therefore in order to reduce the interference outage and to improve the spectral efficiency of the system, a Single frequency cell (SFC) network architecture is used which uses Distributed-boundary synchronization (DBS) via Inter-Sector Signaling. This arrangement synchronizes TDD boundaries dynamically among adjacent sectors for each frame in order to avoid sector-to-sector interference but still preserving the efficiency of Adaptive TDD resource. The Channel Assignment schemes that have been existing only perform interference cancellation through the directional antenna rejection capabilities. They are insufficient in the presence of Sector-to-Sector Interference (SS_I) and Terminal-to-Terminal Interference (TT_I) [25]. Single Frequency Cell assignment technique maintains the properties of Channel Assignment schemes while avoiding Sector-to-Sector Interference and Terminal-to-Terminal Interference. In the SFC architecture, a group of neighboring sectors is assigned to use the same frequency channel. Prevention of co-channel signals in neighboring sectors interfering with each other is done by the base stations not being located at the cell centre as is generally the case in cellular architecture. In the SFC architecture, the base stations are located at the cell edges with their antennas oriented to radiate towards each other i.e. towards the centre of the single frequency cell structure. The terminal antennas are oriented to radiate aligned towards the base stations. Therefore, DL or UL interference is reduced to a large extent. This can achieve high levels of Signal to Interference Ratio which is the ratio of the Average received modulated Carrier Power to the Average received co-channel interference power.

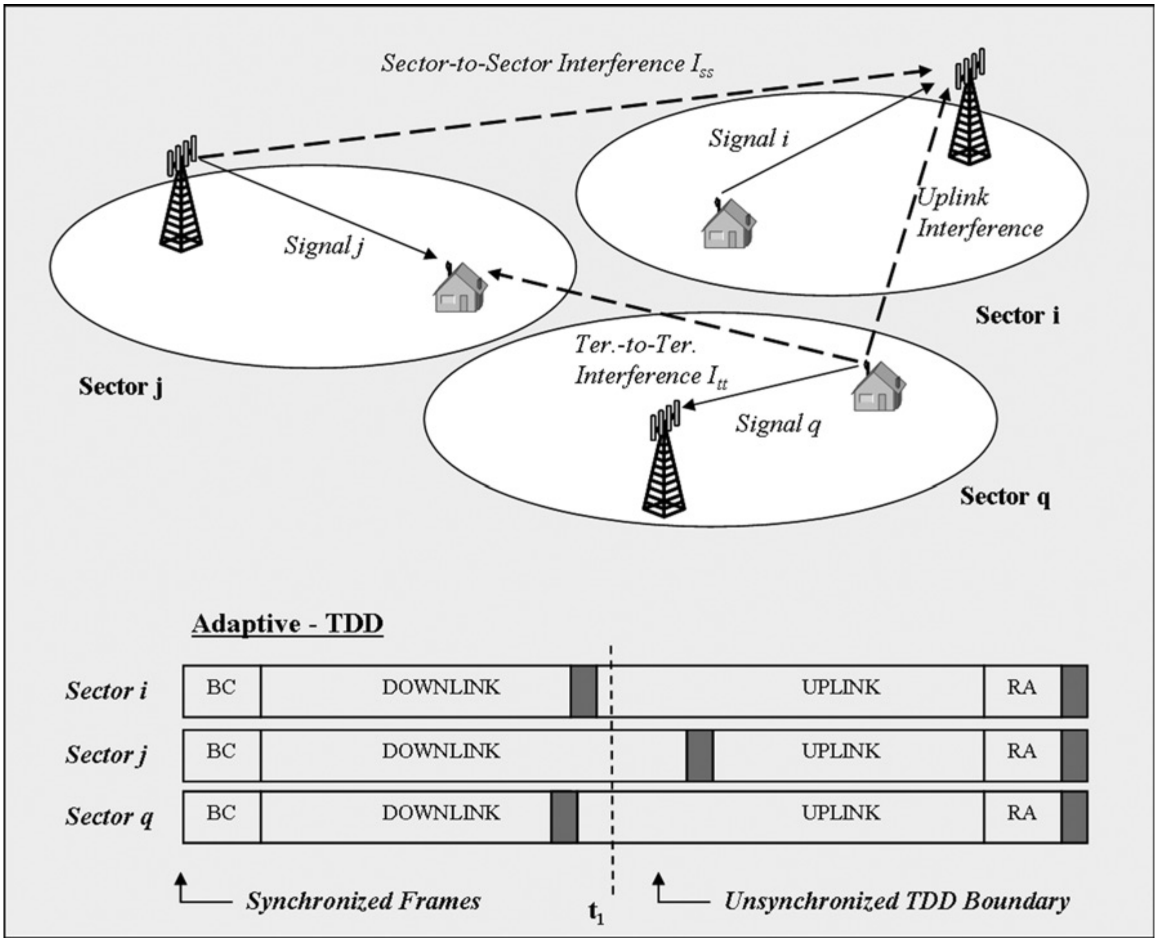


Fig: Directions of Interference in ATDD Systems[25]

3.1.6 Synchronization for MIMO OFDM Systems

There are various algorithms to achieve time and frequency synchronization for MIMO OFDM systems and the time and frequency synchronization can be performed sequentially.

Coarse time synchronization and fractional frequency offset estimation[27]:

A cyclic prefix is present in OFDM systems. In the case of multi-path, the correlation between the cyclic prefix and the data part will be corrupted due to fading effect in the multi-path environment. First we consider the case of synchronization for single path. In this method, time synchronization is performed by correlating the received samples that are at a distance of the number of sub-carriers over a particular length window where the length of the window and the length of the cyclic prefix are the same. A number of consecutive OFDM samples are considered for averaging in order to compensate for the losses in some samples. The time and frequency offset are estimated jointly from the correlation value. The time offset is estimated by taking the maximum of the argument of the correlation value. But in the case of multi-path environment the length of the correlation window which ahs been set to the length of the cyclic prefix has to be adjusted according to the channel maximum time delay spread. We estimate multi-paths by finding the magnitudes of the channel response and comparing with the proper threshold. Then these elements are arranged in ascending order and the maximum channel delay spread is calculated by finding the difference between the first and the last values. Based on the maximum time delay spread that is found the Correlation window size is adjusted accordingly. So this algorithm effectively finds whether the channel is single or multi-path and adjusts the correlation window in such a way that the Inter Symbol Interference is eliminated.

3.2 ANALYSIS, BENEFITS AND DISADVANTAGES OF VARIOUS TECHNIQUES:

1) This is one of the most basic methods for synchronization. The benefits of this technique are it is very easy to implement and low complexity. The problem with inserting the pilot symbols is it decreases the system capacity as it uses up some space for these symbols.

2) In the first method of frequency synchronization schemes, start position if found within the guard interval each FFT symbol will be rotated by a different angle from sub-carrier to sub-carrier the angle increases proportionally to frequency offset whereas if it is located within the data the sampled OFDM frame will contain samples that belong to the OFDM frame. The disadvantage is each symbol at the output is dispersed and rotated due to the ISI from the other frame. We can use various smoothing algorithms to overcome this difficulty.

3) In the low-complexity frequency correction scheme, the frequency error is corrected by introducing a feedback loop. The benefits are we can exactly feedback the difference or the frequency offset and correct it. So we can get good frame synchronization. The guard interval is generated by duplicating the last few symbols of the signal and places it in front of block and this is advantageous in that we can easily get the lost signals and have less ISI by using the guard interval greater than the channel response to eliminate ISI. The disadvantage is we have to send the last few samples twice which cause a loss of bandwidth which could be used to send more data.

4) In the carrier frequency acquisition scheme, the frequency offset is determined by calculating the difference of the channel responses between adjacent sub-channels and thereby the multi-path effect is eliminated.

5) In the adaptive Time Division duplex method of synchronization, the base stations are located at the corners rather then the traditional centre location and radiate towards each other and the use of the directional antennas compensates the small re-use distance and achieves high signal to interference ratio. It reduces interference outage and improves systems spectral efficiency. As compared to the interference cancellation by antenna arrays and beam forming, this structure achieves similar performance without cost for complex radio transceivers and multiple antenna elements. The disadvantage is this technique cannot be applied to the already existing traditional centre located base station structures and the cost of changing the location of base station would be very high.

6) The synchronization for MIMO OFDM just requires a preamble transmitted in all transmit antennas. This should be done in the same OFDM time instant. Hence the complexity of the system is low and it shows good performance even at a low SNR in multi-path environment. Also, due to the diversity gain the synchronization performances in MIMO channel are much greater than in the Single Input Single Output channel.

CONCLUSION

In this report we analyze various synchronization techniques in order to overcome and eliminate the problem of data corruption due to time and frequency offset. We also analyze the problem of outage which could be one of the major challenges faced by the Wi-max technology. It can be finally concluded that Wi-Max is indeed the ‘last mile’ solution for transmission over long distances.

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