To Develop an Algorithm to Minimize the Effect of Fading for Broadband Services.

DISSERTATION-II

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by

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December,2014

CERTIFICATE

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DECLARATION

I, **Shivtaj Kaur**, student of M-Tech Electronics and communication under Department of Electronics and communication of Lovely Professional University, Punjab, hereby declare that all the information furnished in this Dissertation-II report is based on my own intensive research and is genuine.

This thesis does not, to the best of my knowledge, contain part of my work which has been submitted for the award of my degree either of this university or any other university without proper citation.

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ABSTRACT

In this final project report, we propose an algorithm to minimize the effect of fading. To achieve higher capacity with better performance; Orthogonal Frequency Division Multiplexing (OFDM) is utilized. OFDM do the removal of the deterioration in the channel due to multipath fading. It does the conversion of the frequency selective fading channel into flat fading channel. Our aim is to design an algorithm for channel estimation in OFDM

In this paper, improvement in channel estimation of OFDM system is shown in terms of Bit Error Rate (BER), Symbol Error Rate (SER) and Mean Square Error (MSE). Improvement is shown between Least Square Error estimation (LSE), Minimum Mean Square Error estimation (MMSE) and Time Domain Minimum Mean Square Error Estimation (TDMMSE).

The TD MMSE technique shows better performance with minimum complexity than Least Square Error (LSE) estimation and Minimum Mean Square Error (MMSE) estimation.

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LIST OF ABBREVIATIONS

WMAN	Wireless metropolitans area networking
DSL	Digital Subscriber Line
LOS	Line of sight
NLOS	Non Line of Sight
QOS	Quality of support
OFDMA	Orthogonal Frequency Division multiplexing Access
BER	bit error rate
CP	Cyclic prefix
SNR	Signal to noise Ratio
FCH	Frame Control Header
DOCSIS	Data over Cable Service Interface Specification
HPRD	High Rate Packet Data
ISP	Internet Service Provider
BS	Base Station
SS	Subscriber station
ISI	Inter Symbol Interference
ICI	Inter carrier Interference
HSDPA	High-Speed Downlink Packet Access

Chapter 1

INTRODUCTION

WIMAX, the world wide interoperability for microwave access, is a technology which provides wireless transmission of data in variety of ways, ranging from point to point links to the full mobile cellular access .The technology based on the IEEE 802.16 provides broadband services for fixed and mobile subscribers. IEEE 802.16d supports fixed broadband services; an amendment to the IEEE 802.16d that could add mobility support is IEEE 802.16e forms the basis for the WiMAX solution for the nomadic and mobile applications and is referred to as mobile WiMAX.

WiMAX defines a WMAN2, a kind of a huge hot-spot that provides interoperable broadband wireless connectivity to fixed, portable, and nomadic users.

WiMAX will substitute other broadband technologies competing in the same segment and will become an excellent solution for the deployment of the well-known last mile infrastructures in places where it is very difficult to get with other technologies, such as cable or DSL, and where the costs of deployment and maintenance of such technologies would not be profitable. In this way, WiMAX will connect rural areas in developing countries as well as underserved metropolitan areas. [1]

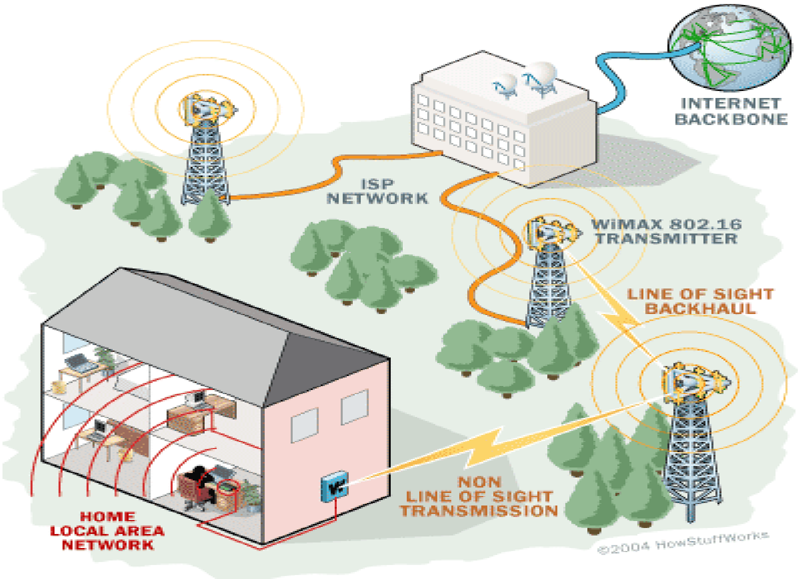


Figure 1 : How WiMAX works

The WIMAX physical layer is based on orthogonal freq division multiplexing a scheme that offers good resistance to multipath, and allows WiMAX to operate in NLOS conditions, MOBILE WIMAX uses OFDM as a multiple access technique, whereby different users can be allocated different subsets of the OFDM tones .OFDMA facilitates the exploitation of frequency diversity and multiuser diversity to significantly improve the system capacity.

OFDM a transmission scheme called multicarrier modulation ,divides a high bit rate stream into several parallel lower bit rates streams and modulating each stream on a separate carriers-often called subcarriers ,OFDM minimizes ISI by making the symbol duration larger enough so that the channel induced delays –delay spread are an insignificant delay of symbol duration ,therefore in high data rate systems in which the symbol duration is small being inversely proportional to the data rate, splitting the data stream into parallel streams increases symbol duration such that the delay spread is only a small fraction of symbol duration.

It’s a hybrid of FDMA and TDMA is an multiple access technique where the users are dynamically assigned subcarriers in different time slots, OFDMA is flexible multiple access technique and the significant advantage of OFDMA relative to OFDM is its potential to reduce the transmit power and to relax the peak to average power ratio problem. Lower data rates and burst data are handled much more efficiently in OFDMA than in single user OFDM.

1.1 The WiMAX standard

The IEEE 802.16 standard was firstly designed to address communications with direct visibility in the frequency band from 10 to 66 GHz. Due to the fact that non-line-of-sight transmissions are difficult when communicating at high frequencies, the amendment 802.16a was specified for working in a lower frequency band, between 2 and 11 GHz. The IEEE 802.16d specification is a variation of the fixed standard (IEEE 802.16a) with the main advantage of optimizing the power consumption of the mobile devices. The last revision of this specification is better known as IEEE 802.16-2004 [2].

	802.16	802.16-2004	802.16e
Spectrum	10-66 GHz	< 11 GHz	< 6 GHz
Maximum	32-134 Mbps (28 MHz channel)	up to 70 Mbps (20 MHz channel)	up to 15 Mbps data rate (5 MHz channel)
Alignment	LoS	LoS and NLoS	LoS and NLoS
Coverage	2-5 km approx	5-10 km approx (maximum of 50 km)	2-5 km approx. Range
Channel Bandwidth	20, 25 and 28 MHz	Flexible from 1.25 up to 20 MHz	Equal to 802.16-2004
Modulation	2-PAM, 4-QAM, 16-QAM, and 64-QAM	OFDM with 256,subcarriers 2PAM, 4-QAM, 16-QAM, and 64-QAM	OFDMA with 2048, subcarriers 2-PAM, 4-QAM, 16-QAM, and 64-QAM
Mobility	Fixed	Fixed and Pedestrian	Vehicular (20-100 km/h)

Table 1: IEEE 802.16, IEEE 802.16-2004, and IEEE 802.16e standards

WiMAX standard-based products are designed to work not only with IEEE 802.16-2004 but also with the IEEE 802.16e specification. While the 802.16-2004 is primarily intended for stationary transmission, the 802.16e is oriented to both stationary and mobile deployments.

1.2 Relationship with other wireless technologies

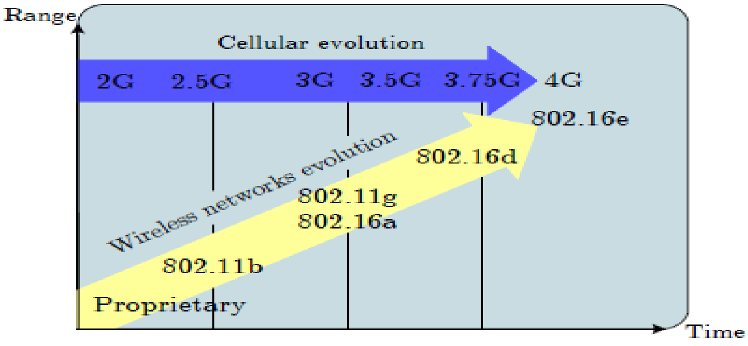


Figure 2: Convergence in wireless communications

Wireless access to data networks is expected to be an area of rapid growth for mobile communication systems. The mentioned convergence between wireless and cellular networks is illustrated in Figure 1.2.

In any case, both WLAN and cellular mobile applications are being widely expanded to offer the demanded wireless access. However, they experience several difficulties for reaching a complete mobile broadband access, bounded by factors such as bandwidth, coverage area, and infrastructure costs. On one hand, Wi-Fi provides a high data rate, but only on a short range of distances and with a slow movement of the user. On the other hand, UMTS[13] offers larger ranges and vehicular mobility, but instead, it provides lower data rates, and requires high investments for its deployment. WiMAX tries to balance this situation. As shown in Figure 1.3, it fills the gap between Wi-Fi and UMTS, thus providing vehicular mobility (included in IEEE 802.16e), and high service areas and data rates.

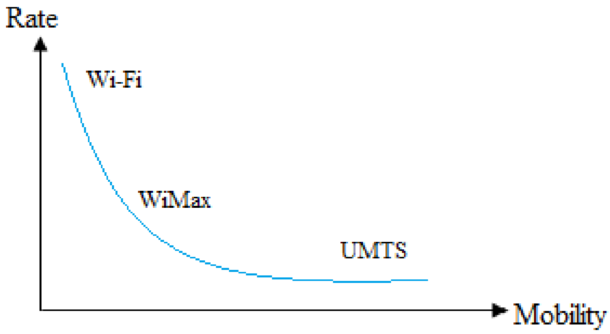
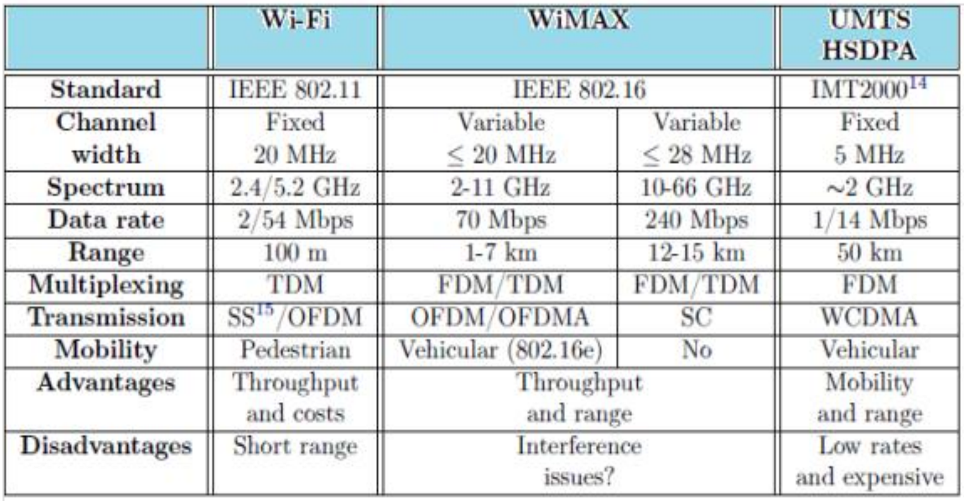


Figure 3: WiMAX filling the gap between Wi-Fi and UMTS



	Wi-Fi	**WiMAX**		**UMTS HSDPA**
Standard	IEEE 802.11	IEEE 802.16		IMT2000[14]
Channel width	Fixed 20 MHz	Variable $\leq$ 20 MHz	Variable $\leq$ 28 MHz	Fixed 5 MHz
Spectrum	2.4/5.2 GHz	2-11 GHz	10-66 GHz	~2 GHz
Data rate	2/54 Mbps	70 Mbps	240 Mbps	1/14 Mbps
Range	100 m	1-7 km	12-15 km	50 km
Multiplexing	TDM	FDM/TDM	FDM/TDM	FDM
Transmission	SS[15]/OFDM	OFDM/OFDMA	SC	WCDMA
Mobility	Pedestrian	Vehicular (802.16e)	No	Vehicular
Advantages	Throughput and costs	Throughput and range		Mobility and range
Disadvantages	Short range	Interference issues?		Low rates and expensive

Table 2: Comparative table between Wi-Fi, WiMAX and UMTS

1.3 System Model

IEEE 802.16 supports two modes of operation: PTP and PMP.

1.3.1 Point-to-point (PTP)

The PTP link refers to a dedicated link that connects only two nodes: BS and subscriber terminal. It utilizes resources in an inefficient way and substantially causes high operation costs. It is usually only used to serve high-value customers who need extremely high bandwidth, such as business high-rises, video postproduction houses, or scientific research organizations. In these cases, a single connection contains all the available bandwidth to generate high throughput.

1.3.2 Point-to-multipoint (PMP)

The PMP topology, where a group of subscriber terminals are connected to a BS separately (shown in Figure), is a better choice for users who do not need to use the entire bandwidth. Under PMP topology, sectoral antennas with highly directional parabolic dishes (each dish refers to a sector) are used for frequency reuse. The available bandwidth now is shared between a group of users, and the cost for each subscriber is reduced.

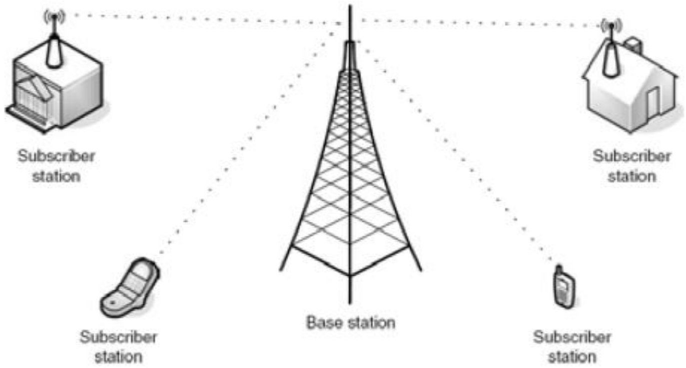


Figure 4: Point-to-multipoint (PMP)

1.3.3 Mesh Topology

In addition to PTP and PMP, 802.16a introduces the mesh topology, which is a more flexible, effective, reliable, and portable network architecture based on the multihop concept. Mesh networks are wireless data networks that give the SSs more intelligence than traditional wireless transmitters and receivers. In a PMP network, all the connections must go through the BS, while with mesh topology, every SS can act as an access point and is able to route packets to its neighbors by itself to enlarge the geographical coverage of a network. The architecture of a mesh system is shown in Figure. The routing across the network can be either proactive (using predetermined routing tables) or reactive (generating routes on demand).

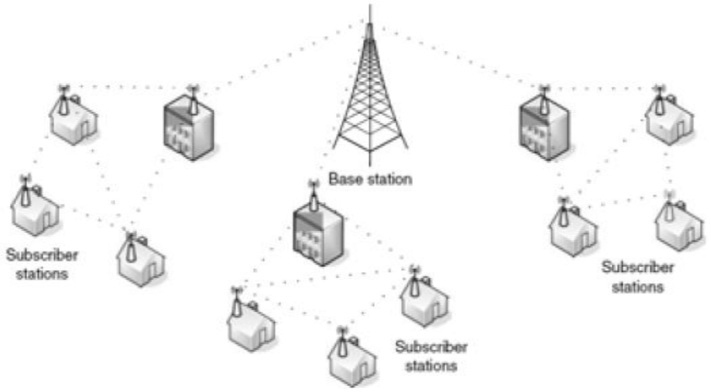


Figure 5: Mesh Topology

1.4 WiMAX as a Metro-Access

WiMAX is a worldwide certification addressing interoperability across IEEE 802.16 standards-based products. The IEEE 802.16 standard with specific revisions addresses two usage models:

Fixed (IEEE 802.16d)

Portable (IEEE 802.16e)

1.4.1 Fixed (IEEE 802.16d)

Fixed WiMAX is the 802.16d standards or as it is sometimes called 802.16-2004. Its product profile utilizes the OFDM 256-FFT (Fast Fourier Transform) system profile, which is just different enough from Mobile WiMAX (802.16e) that the two are incompatible.If the Forum had elected to use an OFDMA version in Fixed WiMAX, it would have been far easier to provide an upgrade path. This particular disconnect likely points to the emerging understanding of the marketplace power of WiMAX

The Fixed WiMAX 802.16-2004 standard supports both time division duplex (TDD) and frequency division duplex (FDD) services---the latter of which is far more popular with mobile wireless providers than the newer TDD approach.

1.4.2 Portable (IEEE 802.16e)

The true Mobile WiMAX standard of 802.16e is divergent from Fixed WiMAX. Based on the same OFDM base technology adopted in 802.16-2004, the 802.16e version is designed to deliver service across many more sub-channels than the OFDM 256-FFT. It is important to note that both standards support single carrier, OFDM 256-FFT and at least OFDMA 1K-FFT. The 802.16e standard adds OFDMA 2K-FFT, 512-FFT and 128-FFT capability. Sub-channelization facilitates access at varying distance by providing operators the capability to dynamically reduce the number of channels while increasing the gain of signal to each channel in order to reach customers farther away. At longer ranges, modulations like QPSK (which offer robust links but lower bandwidth) can give way at shorter ranges to 64 QAM (which are more sensitive links, but offer much higher bandwidth) for example. Each subscriber is linked to a number of sub channels that obviate multi-path interference.

1.5 Key features of WiMAX

- Interoperability**:** A key differentiation for WiMAX is the interoperability of certified equipment, resulting in large economy of scale and assurance for service providers that equipment from different vendors is interoperable. 530 leading companies in the communications and computing industries, members of the WiMAX Forum, are currently driving a common platform for the global deployment of IP-based broadband
- Wider coverage**:** The technology behind WiMAX has been optimized to provide excellent coverage; wider areas, better predictability of coverage and lower cost as it

means fewer base stations and backhaul, simple RF planning, shorter towers and faster CPE install times.

- Lower cost : A standards based platform for WiMAX drives down costs and delivers volume economics to WiMAX equipment
- Industry Standard: for all usage models (fixed to mobile). WiMAX was designed to become the most cost-effective solution for carriers for any usage model from fixed to mobile. Newer versions of the WiMAX standard support higher speeds of mobility and always maintains backward compatibility with previous Mobile WiMAX releases.
- Higher capacity: advantage of WiMAX is the use of Orthogonal Frequency-Division Multiplexing over CDMA which is used in older technologies like Edge, GPRS, and HSPA. OFDM delivers higher spectral efficiency and therefore higher data rate and overall system capacity.
- High data rates: The inclusion of MIMO (Multiple Input Multiple Output) antenna techniques along with flexible sub-channelization schemes, Advanced Coding and Modulation all enable the Mobile WiMAX technology to support peak DL (Downlink) data rates up to 63 Mbps per sector and peak UL (Uplink) data rates up to 28 Mbps per sector in a 10 MHz channel.
- Quality of Services (QoS): QoS defines Service Flows which can map to different code points that enable end-to-end IP based QoS. Additionally, sub channelization schemes provide a flexible mechanism for optimal scheduling of space, frequency and time resources over the air interface on a frame-by-frame basis.
- Scalability: Mobile WiMAX technology is designed to be able to scale to work in different channelization's from 1.25 to 20 MHz to comply with varied worldwide requirements as efforts proceed to achieve spectrum harmonization in the longer term. This also allows diverse economics to realize the multifaceted benefits of the mobile WiMAX technology for their specific geographic needs such as providing affordable internet access in rural settings versus enhancing the capacity of mobile broadband access in metro and suburban areas.
- Security: Support for a diverse set of user credentials exists including, SIM/USIM cards, Smart Cards, Digital Certificates, and Username/Password schemes.

- Mobility: WiMAX supports optimized handover schemes with latencies less than 50 milliseconds to ensure real-time applications such as VoIP perform without service degradation. Flexible key management schemes assure that security is maintained.

1.6 Advantages of WiMAX

Component Suppliers

- Assured wide market acceptance of developed and components
- Lower production costs due to economies of scale
- Reduced risk due to interoperability Equipment manufacturers
- Stable supply of low cost components and chips
- Freedom to focus on development of network elements consistent with core competencies, while knowing that equipment will interoperate with third party products
- Engineering development efficiencies
- Lower production costs due to economies of scale

Operators and Service Providers

- Lower investment risk due to freedom of choice among multiple vendors and solutions
- Ability to tailor network to specific applications by mixing and matching equipment from different vendors
- Improved operator business case with lower OPEX End Users
- Lower subscriber fees
- Wider choice of terminals enabling cost performance analysis
- Portability of terminals when moving locations/networks from WiMAX operator “A” to operator “B”
- Lower service rates over time due to cost efficiencies in the delivery chain.

1.7 OFDM Technology

Orthogonal frequency division multiplexing (OFDM) technology provides operators with an efficient means to overcome the challenges of NLOS propagation. OFDM is based on the traditional frequency division multiplexing (FDM), which enables simultaneous transmission of multiple signals by separating them into different frequency bands (subcarriers) and sending them in parallel. In FDM, guard bands are needed to reduce the interference between different frequencies, which causes bandwidth wastage .Therefore, it is not a spectrum-efficient and cost-effective solution. However, OFDM is a more spectrum-efficient method that removes all the guard bands but keeps the modulated signals orthogonal to mitigate the interference level.

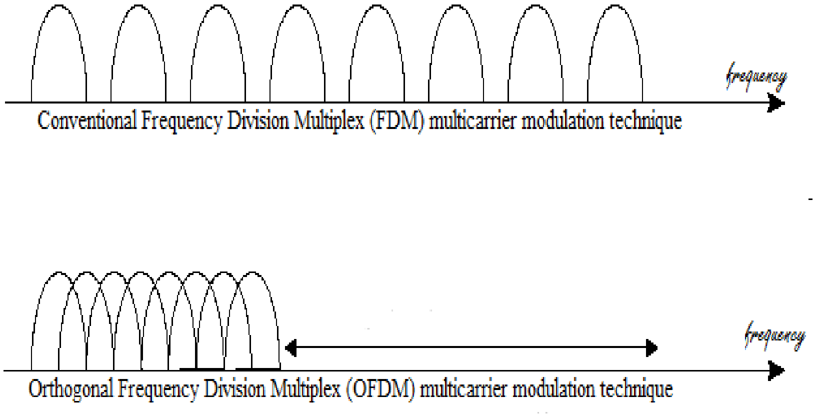


Figure 6: Comparisons between FDM and OFDMA

As shown in figure the required bandwidth in OFDM is significantly decreased by spacing multiple modulated carriers closer until they are actually overlapping. OFDM uses fast Fourier transforms (FFT) and inverse FFT to convert serial data to multiple channels. The FFT size is 256, which means a total number of 256 sub channels (Carriers) are defined for OFDM. In OFDM, the original signal is divided into 256 subcarriers and transmitted in parallel. Therefore, OFDM is referred to as a multicarrier modulation scheme. Compared to single-carrier schemes, OFDM is more robust against multipath propagation delay owing to the use of narrower subcarriers with low bit rates resulting in long symbol periods. A guard time is introduced at each OFDM symbol to further mitigate the effect of multipath delay spread.

The WiMAX OFDM waveform offers the advantage of being able to operate with the larger delay spread of the NLOS environment. By virtue of the OFDM symbol time and use of a cyclic prefix, the OFDM waveform eliminates the inter-symbol interference (ISI) problems and the complexities of adaptive equalization. Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate intersymbol interference (ISI) [1] and to achieve a diversity gain, i.e. a signal-to-noise ratio improvement. This mechanism also facilitates the design of single frequency networks (SFNs), where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single- carrier system. The total signal bandwidth, in a classical parallel data system, can be divided into N non overlapping frequency sub channels. Each sub channel is modulated with a separate symbol and then the N sub channels are frequency multiplexed. The general practice of avoiding spectral overlap of sub channels was applied to eliminate inter-carrier interference (ICI).This resulted to insufficient utilization of the existing spectrum. An idea was proposed in the mid-1960s to deal with this wastefulness through the development of frequency division multiplexing (FDM) with overlapping sub channels. The sub channels were arranged so that the sidebands of the individual carriers overlap without causing ICI.

1.8 OFDM Parameters in WiMAX

As mentioned previously, the fixed and mobile versions of WiMAX have slightly different implementations of the OFDM physical layer.

1.8.1 Fixed WiMAX OFDM-PHY

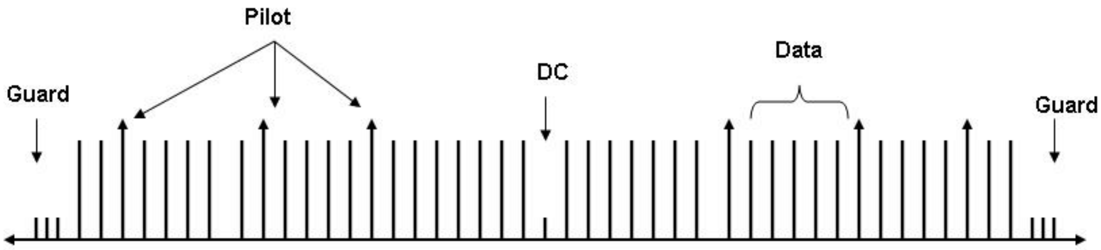
For this version the FFT size is fixed at 256, which 192 subcarriers used for carrying data, 8 used as pilot subcarriers for channel estimation and synchronization purposes, and the rest used as guard band subcarriers.6 Since the FFT size is fixed, the subcarrier spacing varies with channel bandwidth. When larger bandwidths are used, the subcarrier spacing increases, and the symbol time decreases. Decreasing symbol time implies that a larger fraction needs to be allocated as guard time to overcome delay spread. WiMAX allows a wide range of guard times that allow system designers to make appropriate trade-offs between spectral efficiency and delay spread robustness

1.8.2 Mobile WiMAX OFDMA OFDMA-PHY

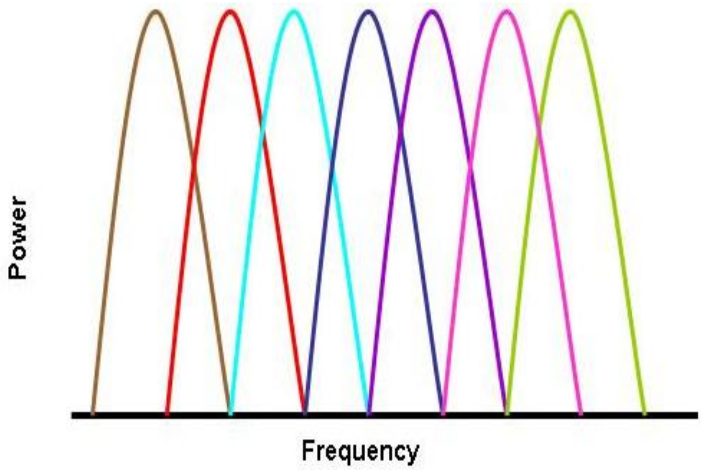
In mobile WiMAX, the FFT size is scalable from 128 to 2,048. Here, when the available bandwidth increases, the FFT size is also increased such that the subcarrier spacing is always 10.94 kHz. This keeps the OFDM symbol duration, which is the basic resource unit, fixed and therefore makes scaling have minimal impact on higher layers. A scalable design also keeps the costs low. The subcarrier spacing of 10.94 kHz was chosen as a good balance between satisfying the delay spread and Doppler spread requirements for operating in mixed fixed and mobile environments. This subcarrier spacing can support delay spread values up to 20µs and vehicular mobility up to 125 kmph when operating in 3.5GHz.

1.8.3 Sub Channelization OFDMA

Sub Channelization in the uplink is an option within WiMAX. Without sub channelization, regulatory restrictions and the need for cost effective CPEs, typically cause the link budget to be asymmetrical, this causes the system range to be up link limited. Sub channeling enables he link budget to be balanced such that the system gains are similar for both the up and down links. Sub channeling concentrates the transmit power into fewer OFDM carriers; this is what increases the system gain that can either be used to extend the reach of the system, overcome the building penetration losses, and or reduce the power consumption of the CPE. The use of sub channeling is further expanded in orthogonal frequency division multiple access (OFDMA) to enable a more flexible use of resources that can support nomadic or mobile operation.



OFDM sub-carriers



Orthogonal frequency division

Fig. 7: OFDM frequency description. [3]

Chapter 2

REVIEW OF LITERATURE

Mukesh Patidar, Rupesh dubey, Nitin kumar Jain, Sarita kulpariya in their paper “Performance Analysis of WiMAX 802.16e Physical Layer Model” discussed the model building of the WiMAX physical layer using simulink in Matlab R2009a version. In the paper, transmitter and receiver model are simulated according to the parameters established by the standards, to evaluate the performance. Also convolution coding has been used to improve the system performance. The performance analysis has been done by studying the bit loss and packet losses occurred during transmission over the channel. [4]

Muhammad Kalimuddin Khan, R.A.Carrasco and I.J. Wassell, in their paper,” Channel Estimation Algorithm for OFDM based Fixed Wireless Access (FWA) Networks” investigated the use of pilot symbols assisted channel estimation over broadband fixed wireless access system where pilot tones are transmitted over equally spaced sub-carriers of OFDM. The Least Square Error (LSE) algorithm is investigated to estimate broadband Fixed Wireless Access (FWA) channels. The effect of varying the location sub carriers for pilot symbols is also investigated along with the power variation of the pilot tones transmitted with respect to the information symbols. The performance comparison shows good estimation of the time varying channel. The simulation results are plotted using BPSK /QPSK modulation schemes. [5]

Habib Senol, Erdal Panayırcı, H. Vincent,’s paper” Joint Channel Estimation and Equalization for OFDM based Broadband Communications in Rapidly Varying Mobile Channels”, is concerned with the challenging and timely problem of channel estimation for orthogonal frequency division multiplexing (OFDM) systems in the presence of frequency selective and very rapidly time varying channels. In OFDM systems operating over rapidly time-varying channels, the orthogonality between subcarriers is destroyed leading to inter-carrier interference (ICI) and resulting in an irreducible error floor. The band-limited, discrete cosine serial expansion of low-dimensionality is employed to represent the time-varying channel. In this work, the problem of iterative channel estimation has been investigated and a new iterative channel estimation algorithm has been proposed for OFDM systems operating over frequency selective and very rapidly time-varying channels. The channel estimation algorithm is based on the EM-MAP technique which incorporates also the channel equalization and the data detection. [6]

Shaiyek Md. Buland Taslim, Shaikh Md. Rubayiat Tousif, Mohammad Tareq,in the paper “A Novel Algorithm with a New Form of Adaptive Modulation for Mobile WiMAX Performance Improvement” ,presents a new form of Adaptive Modulation (AM), which has the ability to improve the data rate of Mobile WiMAX OFDMA system especially at low SNR values, this new form of AM will combine together with the simplest Peak to Average Power ratio (PAPR) reduction technique, which is the clipping to produce a novel algorithm called Modulation adaptation and Clipping algorithm (MC) has the ability to improve the performance of Mobile WiMAX system through reducing the PAPR, improving the SER performance, and increasing the data rate. The proposed Adaptive modulation (AM) has the ability of using the high order modulation scheme such as 256-QAM and 64-QAM to map the data onto the carriers at low SNR values such as 2, 5, and 8 dB. The clipping technique was combined together with the new form of AM to produce a novel algorithm has the ability to reduce the PAPR, enhance the data rate, and improve the performance of the SER at low SNR values compared to the SER performance of the Mobile WiMAX system when applying the normal OFDMA with high order modulation schemes such as 16QAM, 64QAM, 128QAM, and 256QAM. [7]

Xiaoyan Zhao, Lizhen CuiIn’s paper “A New Frame synchronization Algorithm for OFDM WiMAX System in Simulink”, firstly, The WiMAX PHY system model is constructed according to IEEE802.16d standard, then a new frame synchronization algorithm in accord with IEEE802.16d downlink frame structure is proposed. The new algorithm is achieved by twice synchronization which is coarse and fine synchronization respectively. The simulation result shows that the new algorithm can generates the impulse-shaped timing metric and the timing metric still maintain the sharper and distinct peak under the low SNR or over multipath fading channel. [8]

Zeyad T. Sharef Ammar E. Alaradi Bara’a T. Sharef in their paper “Performance Evaluation for WiMAX 802.16e OFDMA Physical Layer” studied a detailed link level simulation and optimized to investigate the physical layer performance of WiMAX, IEEE 802.16e over AWGN and multipath Rayleigh fading channels, in which ITU-Reference channel models have been used. Two 802.16e based OFDMA transceivers have been designed by using MATLAB Simulink, the first one doesn’t support channel estimation whereas the second does. Moreover, the effect of fading channel, Doppler shift and cyclic prefix on the system design performance has been analyzed and investigated. The outcomes of simulation results clarified how the use of channel estimation improves the system performance, whereas obviously, the investigated system suffers from severe performance degradation and high probability of error whenever channel estimation is not applied. [9]

Fakher Eldin M. Suliman, Nuha M. Elhassan, Tertiel A. Ibrahim, in the paper “Frequency Offset Estimation and Cell Search Algorithms for OFDMA Based Mobile”, employed the fine and coarse frequency offset estimation algorithms by using the packet preamble structure adopted by the IEEE 802.16 standardization workgroup have been presented and simulated. Joint detection of the coarse frequency offset and the cell search under fading and A WGN was obtained. The simulation results of these algorithms accurately estimated the frequency offset in the received frame. For future work, the whole transceiver system of the WiMAX can be simulated and implemented applying the same parameters. Also, the performance of these algorithms can be tested under different types of noise and channels. [10]

Shuang Wang, Xizhong Lou, Ting Peng, Renzhi Ma, Qingjian Wei presented a research Paper in 2011 “A Novel Design of Reference Signal Scheme for LTE”. In this paper they represented a novel design of reference signal scheme for LTE .This design is useful to estimate the channel response .The research paper simulation results shows that when we use block pattern of reference signal to estimate the channel response once, the signal to noise ratio performance of the new reference signal scheme can improve 0.6 dB than that of without channel estimation. Since OFDM systems are very sensitive to frequency offset, supposes the transmitter and the receiver are both fixed. In another word, the Doppler frequency shift is 0. For adapting the channel environment with Doppler shift, we need to estimate the frequency offset of the received signal and correct it, which will be made in follow-up research. [11]

CHAPTER 3

RATIONABLE AND SCOPE OT THE STUDY

3.1 Features of a Practical OFDM System

Following are the main features of the OFDM:

1. Some processing is done on the source data, such as coding for correcting errors interleaving and mapping of bits onto symbols. An example of mapping used is QAM.
2. The symbols are modulated onto orthogonal sub-carriers. This is done by using IFFT.
3. Orthogonally is maintained during channel transmission. This is achieved by adding a cyclic prefix to the OFDM frame to be sent. The cyclic prefix consists of the L last samples of the frame, which are copied and placed in the beginning of the frame. It must be longer than the channel impulse response.
4. Synchronization: the introduced cyclic prefix can be used to detect the start of each frame. This is done by using the fact that the L first and last samples are the same and therefore correlated. This works under the assumption that one OFDM frame can be considered to be stationary.
5. Demodulation of the received signal by using FFT.
6. Channel equalization: the channel can be estimated either by using a training sequence or sending known so-called pilot symbols at predefined sub-carriers.
7. Decoding and de-interleaving.

3.2 The OFDM Principle

In this chapter we look at the principles of an orthogonal division multiplexing (OFDM) system. Since our objective is to investigate channel estimation methods for OFDM systems, it is essential to acquire a solid understanding of OFDM systems before proceeding with the channel estimation investigation.

3.2.1 Multi-carrier Modulation

Multi-carrier modulation was first proposed in 60's and forms the basis of the OFDM modulation technique. In multi-carrier modulation, the available bandwidth W is divided into number of N_c sub-bands or sub-carriers, each with a width of $\Delta f = \frac{W}{N_c}$. This subdivision is illustrated in Figure 9.

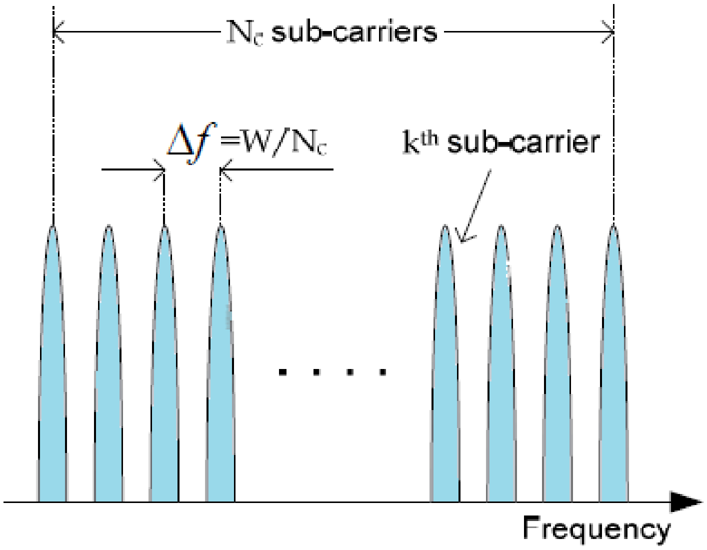


Figure 8: Subdivision of bandwidth into Nc sub-carriers

Instead of transmitting the data symbols serially, the multi-carrier transmitter partitions the data into blocks of N_c data symbols that are transmitted in parallel by modulating the N_c carriers. The symbol duration for a modulated carrier is $T_s = \frac{1}{W}$ .The multi-carrier signal can be written as a set of modulated carriers as [12 Z]

$$s(t) = \sum_0^{N_c-1} x_k \Psi_k(t) \qquad 3.1$$

Where x_k is the data symbol modulating the k^{th} sub-carrier

$\Psi_k(t)$**,** is the modulation waveform at the k^{th} sub-carrier and

s(t) is the multi-carrier modulated signal

The process of generating a multi-carrier modulated signal is illustrated in the Figure 8.

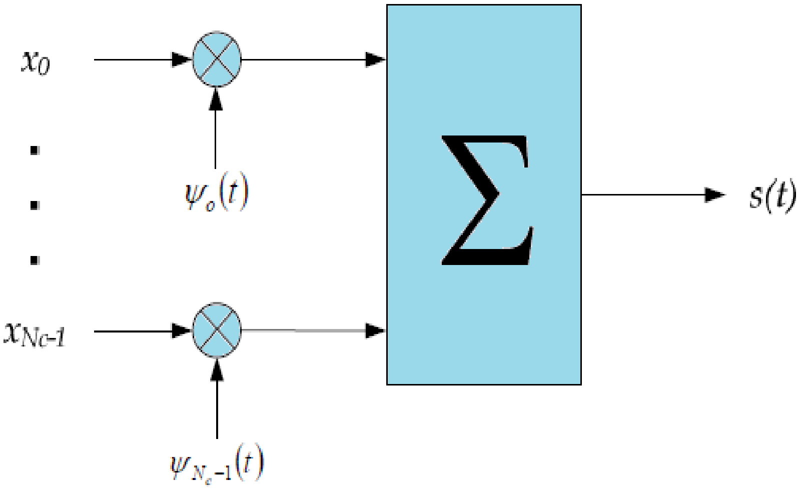


Figure 9: Multi-carrier modulation

A number of steps can be taken when designing a multi-carrier system to mitigate the effects of fading.

- In time domain, the data symbol duration can be made much longer than the maximum excess delay of the channel. This can be done either by choosing $T_s \gg \tau_{max}$.
- In frequency domain, the bandwidth of the sub-carriers can be made small compared to the coherence bandwidth of the channel$B_{coh} \gg W/N_c$. The sub-bands then experience flat fading, which reduces the equalization to a single complex multiplication per carrier.

3.3 Cyclic prefix

Intersymbol-interference (ISI) is induced in a signal when it passes through a frequency-selective channel. In OFDM systems, it causes the loss of orthogonality of the sub-carriers, resulting in intercarrier interference (ICI). The concept of cyclic prefix (CP) was introduced to combat this problem [14z].

Cyclic prefix is a copy of the last part of the OFDM symbol that is pre-appended to the transmitted symbol, as shown in Figure 3-5, and removed before demodulation.

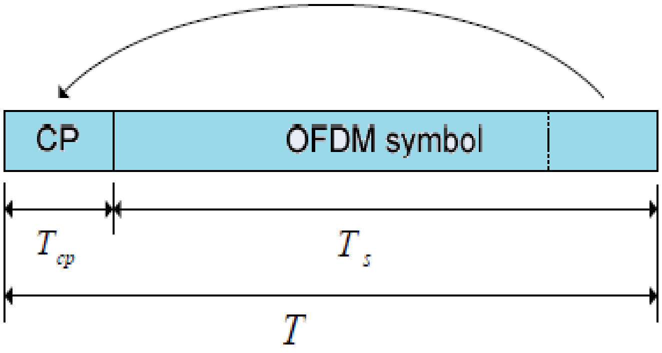


Figure 10: Cyclic Prefix

The length of cyclic prefix should be at least as long as the significant part of the channel impulse response experienced by the transmitted signal. This way the benefit of the cyclic prefix is two-fold:-

• ISI is avoided since cyclic prefix acts as guard space between successive symbols.

• Linear convolution with the channel impulse response is converted into a cyclic convolution.

Since cyclic convolution in time domain corresponds to a scalar multiplication in the frequency domain, the sub-carriers remain orthogonal and there is no ICI.

The advantages of CP are not without a cost. The transmitted energy required to transmit the signal increases with the length of cyclic prefix. This SNR loss (SNR_{loss}) due to the insertion of CP is given as [12]

$$SNR_{loss} = -10log_{10}(1 - \frac{T_{cp}}{T}) \tag{3.2}$$

Where T_{cp} is the length of the cyclic prefix, T_s is the symbol time, and

T =T_{cp} -T_s is the length of the transmitted symbol.

3.4 Channel Fading

Fading is the rapid fluctuations of received signal strength over short time intervals and/or travel distances caused by interference from multiple copies of Transmitted signal arriving at receiver at slightly different times

Three most important effects:

1. Rapid changes in signal strengths over small travel distances or short time periods.
2. Changes in the frequency of signals.
3. Multiple signals arriving at different times. When added together at the antenna, signals are spread out in time. This can cause a smearing of the signal and interference between bits that are received.

Fading signals occur due to reflections from ground & surrounding buildings (clutter) as well as scattered signals from trees, people, towers, etc.

A fading channel is a communication channel comprising fading. In wireless systems, fading may be either due to multipath propagation, referred to as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading.

The presence of reflectors in the environment surrounding a transmitter and receiver create multiple paths that a transmitted signal can traverse. As a result, the receiver sees the superposition of multiple copies of the transmitted signal, each traversing a different path. Each signal copy will experience differences in attenuation, delay and phase shift while travelling from the source to the receiver. This can result in either constructive or destructive interference, amplifying or attenuating the signal power seen at the receiver. Strong destructive interference is frequently referred to as a deep fade and may result in temporary failure of communication due to a severe drop in the channel signal-to-noise ratio.

3.5 Rayleigh fading

Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices. Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communications channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian variables. Rayleigh fading is a reasonable model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver.

3.6 Inter Symbol Interference

In a multipath environment, a transmitted symbol takes different times to reach the receiver through different propagation paths. From the receiver’s point of view, the channel introduces time dispersion in which the duration of the received symbol is stretched. Extending the symbol duration causes the current received symbol to over-lap previous received symbols and results in inter symbol interference (ISI). In OFDM, ISI usually refers to interference of an OFDM symbol by previous OFDM symbols. For a given system bandwidth the symbol rate for an OFDM signal is much lower than a single carrier transmission scheme. For example for a single carrier BPSK modulation, the symbol rate corresponds to the bit rate of the transmission. However for OFDM the system bandwidth is broken up into N subcarriers, resulting in a symbol rate that is N times lower than the single carrier transmission. This low symbol rate makes OFDM naturally resistant to effects of Inter-Symbol Interference (ISI) caused by multipath propagation. Multipath propagation is caused by the radio transmission signal reflecting off objects in the propagation environment, such as walls, buildings, mountains, etc. These multiple signals arrive at the receiver at different times due to the transmission distances being different. This spreads the symbol boundaries causing energy leakage between them.

3.7 ISI with Varying Guard

When the signal is transmitted through antenna in NLOS condition then the signal will undergo the effect in signal shift in terms of phase and frequency which is now making the interference with the other signals. So we insert the pilot and nulls to normalize the effect, even though signal will face the ISI, so we will guard interval to reduce the ISI.

3.8 Effect of AWGN on OFDM

Noise exists in all communications systems operating over an analog physical channel, such as radio. The main sources are thermal background noise, and electrical noise in the receiver amplifiers, and inter-cellular interference. In addition to this noise can also be generated internally to the communications system as a result of Inter-Symbol Interference (ISI), Inter-Carrier Interference (ICI), and Inter- Modulation Distortion (IMD). These sources of noise decrease the Signal to Noise Ratio (SNR), ultimately limiting the spectral efficiency of the system. Noise, in all its forms, is the main detrimental effect in most radio communication systems. It is therefore important to study the effects of noise on the communications error rate and some of the tradeoffs that exist between the level of noise and system spectral efficiency. Most types of noise present in radio communication systems can be modeled accurately using Additive White Gaussian Noise (AWGN). This noise has a uniform spectral density (making it white), and a Gaussian distribution in amplitude (this is also referred to as a normal distribution). Thermal and electrical noise from amplification, primarily have white Gaussian noise properties, allowing them to be modeled accurately with AWGN. Also most other noise sources have AWGN properties due to the transmission being OFDM. OFDM signals have a spectral density and a Gaussian amplitude distribution provided that the number of carriers is large (greater than about 20 subcarriers), because of this the inter-cellular interference from other OFDM systems have AWGN properties. For the same reason ICI, ISI, and IMD also have AWGN properties for OFDM signals.

3.9 Equalizer

The primary function of the equalizer is to compensate the effect of distortion introduced by the fading channel over the transmitted OFDM symbols .MMSE EQUALIZER has been implemented over the MATLAB and the effect of SNR over symbol error rate has been calculated for the BPSK signals and could be extended over any modulated schemes.

3.10 Fading Channel Characteristics

A Rayleigh fading simulator has been developed to determine the performance in wide range of channel conditions, both frequency selective fading and flat fading conditions are simulated depending on gain and time delay settings.

3.11 Modulation

Modulation is the process of varying one or more properties of a high-frequency periodic waveform, called the carrier signal, with a modulating signal which typically contains information to be transmitted. The three key parameters of a periodic waveform are its amplitude, its phase and its frequency. Any of these properties can be modified in accordance with a low frequency signal to obtain the modulated signal.

Typically a high-frequency sinusoid waveform is used as carrier signal, but a square wave pulse train may also be used. In digital modulation, an analog carrier signal is modulated by a discrete signal. Digital modulation methods can be considered as digital-to-analog conversion, and the corresponding demodulation or detection as analog-to-digital conversion. The changes in the carrier signal are chosen from a finite number of M alternative symbols. The most fundamental digital modulation techniques are based on keying:

1. PSK (phase-shift keying), a finite number of phases are used.
2. FSK (frequency-shift keying), a finite number of frequencies are used.
3. ASK (amplitude-shift keying), a finite number of amplitudes are used.
4. QAM (quadrature amplitude modulation), a finite number of at least two phases, and at least two amplitudes are used.

3.11.1 Phase-Shift Keying and Binary Phase-Shift Keying

Phase-shift keying (PSK) is a digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave). BPSK (also sometimes called PRK, Phase Reversal Keying, or 2PSK) is the simplest form of phase shift keying (PSK).

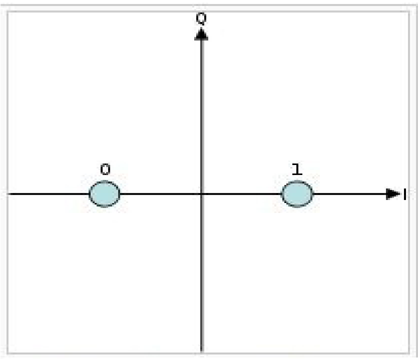


Figure 11: Constellation Diagram for BPSK

It uses two phases which are separated by 180 and so can also be termed 2-PSK.

$$s_n(t) = \surd\sqrt{2Eb / Tb} = Tb \cos (2(\pi)\, fct + \pi\, (1 - n)) \qquad (3.3)$$

Where n = 0; 1

It does not particularly matter exactly where the constellation points are positioned, and in this figure they are shown on the real axis, at 0 and 180. This modulation is the most robust of all the PSKs since it takes the highest level of noise or distortion to make the demodulator reach an incorrect decision. It is, however, only able to modulate at 1 bit/symbol (as seen in the figure) and so is unsuitable for high data-rate applications when bandwidth is limited. Bit Error Rate is given by following:

$$P_b = Q\, (\sqrt{2Eb/N0} \quad) \qquad (3.4)$$

3.11.2 Quadrature Phase-Shift Keying

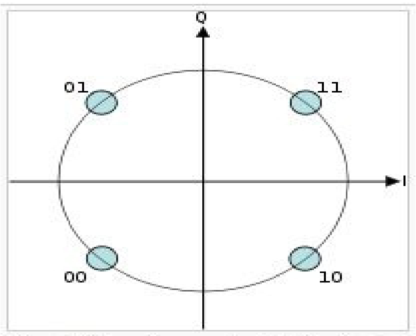


Figure 12: Constellation Diagram for QPSK

Sometimes this is known as quaternary PSK, quadric phase PSK, 4-PSK, or 4-QAM. (Although the root concepts of QPSK and 4-QAM are different, the resulting modulated radio waves are exactly the same.) QPSK uses four points on the constellation diagram, equispaced around a circle. With four phases, QPSK can encode two bits per symbol, shown in the diagram with gray coding to minimize the bit error rate (BER) sometimes misperceived as twice the BER of BPSK.

s_n(t) =$\sqrt{2\mathrm{Es}/\mathrm{Ts}}$ cos (2(π) fct + (2n -1)(π)/'4) (3.5)

Where n = 1; 2; 3; 4

P_b = Q ($\sqrt{2\mathrm{Eb}/\mathrm{N0}}$) (3.6)

P_S = 1 -$(1 - \mathrm{Pb})^2$ (3.7)

3.11.3 Offset QPSK

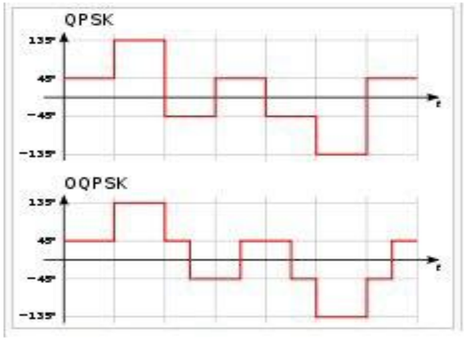


Figure 13: Difference between QPSK and OQPSK

Offset quadrature phase-shift keying (OQPSK) is a variant of phase-shift keying modulation using 4 different values of the phase to transmit. It is sometimes called staggered quadrature phase-shift keying (SQPSK).Taking four values of the phase (two bits) at a time to construct a QPSK symbol can allow the phase of the signal to jump by as much as 180 at a time. When the signal is low-pass filtered(as is typical in a transmitter), these phase-shifts result in large amplitude fluctuations, an undesirable quality in communication systems. By offsetting the timing of the odd and even bits by one bit-period, or half a symbol-period, the in-phase and quadrature components will never change at the same time.

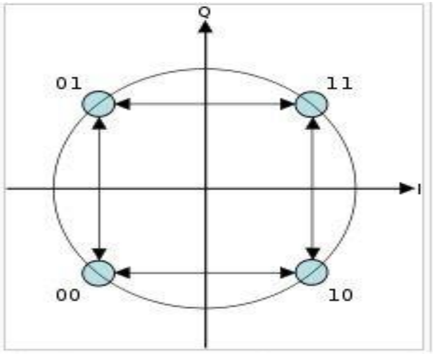


Figure 14: Constellation Diagram for OQPSK

In the constellation diagram shown on the right, it can be seen that this will limit the phase-shift to no more than 90 at a time. This yields much lower amplitude fluctuations than non-offset QPSK and is sometimes preferred in practice. The picture shows the difference in the behavior of the phase between ordinary QPSK and OQPSK. It can be seen that in the first plot the phase can change by 180 at once, while in OQPSK the changes are never greater than 90.The modulated signal is shown below for a short segment of a random binary data-stream. Note the half symbol-period offset between the two component waves. The sudden phase-shifts occur about twice as often as for QPSK (since the signals no longer change together), but they are less severe. In other words, the magnitude of jumps is smaller in OQPSK when compared to QPSK.

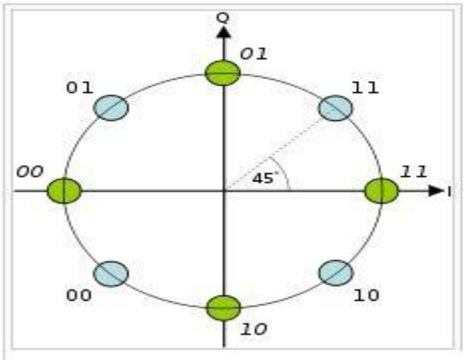


Figure 15: Constellation Diagram for π /4 QPSK

3.11.4 π /4 QPSK

This variant of QPSK uses two identical constellations which are rotated by 45 ($\pi/4$) radians, hence the name) with respect to one another. Usually, either the even or odd symbols are used to select points from one of the constellations or the other symbols select points from the other constellation. This also reduces the phase-shifts from a maximum of 180, but only to a maximum of 135 and so the amplitude fluctuations of 4QPSK are between OQPSK and non-offset QPSK [2]. One property this modulation scheme possesses is that if the modulated signal is represented in the complex domain, it does not have any paths through the origin. In other words, the signal does not pass through the origin. This lowers the dynamical range of fluctuations in the signal which is desirable when engineering communications signals. On the other hand π / 4QPSK lends itself to easy demodulation and has been adopted for use in, for example, TDMA cellular telephone systems.

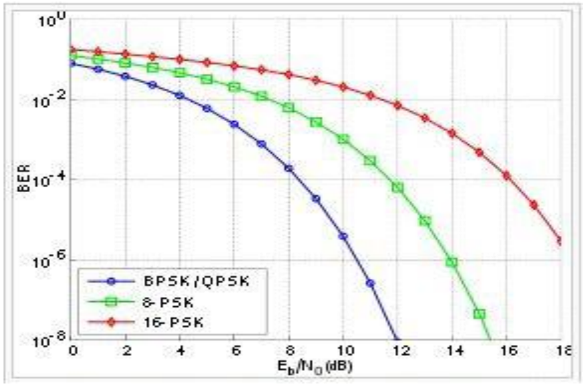


Figure 16: BER Comparisons

3.11.5 Quadrature Amplitude Modulation

QAM is both an analog and a digital modulation scheme. It conveys two analog message signals, or two digital bit streams, by changing (modulating) the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme. The two carrier waves, usually sinusoids, are out of phase with each other by 90 and are thus called quadrature carriers or quadrature components hence the name of the scheme. [3] The modulated waves are summed, and the resulting waveform is a combination of both phase-shift keying (PSK) and amplitude-shift keying (ASK), or (in the analog case) of phase modulation (PM) and amplitude modulation.

In the digital QAM case, a finite number of at least two phases and at least two amplitudes are used. PSK modulators are often designed using the QAM principle, but are not considered as QAM since the amplitude of the modulated carrier signal is constant. QAM is used extensively as a modulation scheme for digital telecommunication systems. Spectral efficiencies of 6 bits/s/Hz can be achieved with QAM. [6]

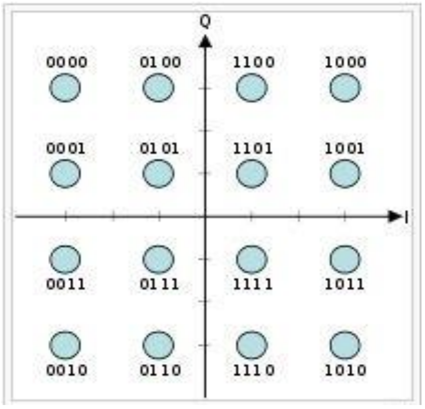


Figure 17: Constellation Diagram for QAM

3.12 Channel Equalization and Channel Estimation

An important advantage of the OFDM transmission technique as compared to single carrier systems is seen in frequency-selective channels. The signal processing in the receiver is rather simple in this case. The orthogonality of the OFDM sub-carriers is maintained after transmission over the radio channel and the effect of ICI is reduced to a multiplication of each subcarrier by a complex transfer factor. Therefore, equalizing the signal is very simple, whereas equalization may not be feasible in the case of conventional single carrier transmission covering the same bandwidth. In 1980, Hirosaki introduced an equalization algorithm to further suppress ISI and ICI [13], which results from a channel impulse response or timing and frequency errors such as channel distortion, synchronization error, or phase error. His implementation was designed for a sub channel-based equalizer for an orthogonally multiplexed QAM system. Phase error implementation was designed for a sub channel-based equalizer for an orthogonally multiplexed QAM system [15].

OFDM systems transmit data in blocks. Two straightforward ways of identifying the channel in an OFDM system is to either insert a training sequence between consecutive blocks or to insert pilot tones inside each block. The unknown finite-impulse response of the channel can then be identified in the time domain by the training sequence or in the frequency domain by the pilot tones. Pilot symbol-assisted modulation schemes obtain the channel frequency response based on the estimate of the known frequency domain pilot symbols that are interleaved among the transmitted data symbols. The pilot subcarriers assist the sampling of the channel frequency response [16]. The corresponding sampling frequency needs to be higher than the Nyquist frequency required for the alias-free representation of the channel frequency response at the Doppler frequency encountered. This addition to the data can be seen in the .Application of QAM modulation and pilot tones where applied to high-speed OFDM system. A pilot based method is used to reduce interference from multipath and co-channels. His analysis and simulation focused on the deployment of OFDM for mobile communication. Subcarrier-selective allocating scheme was introduced in which allocated more data through transmission of dependable subcarriers near the center of the transmission frequency band. He concluded that these subcarriers suffered less channel distortion.

CHAPTER 4

PROPOSED RESEARCH METHODOLOGY

4.1 Background for channel estimation

Fig.1 shows a generic simulation layout for a TDMA based mobile system, which exploits channel estimation and signal detection operations in equalization. The digital source is usually protected by channel coding and interleaved against fading phenomenon, after which the binary signal is modulated and transmitted over multipath fading channel. Additive noise is added and the sum signal is received. Due to the multipath channel there is some intersymbol interference (ISI) in the received signal.

Therefore a signal detector (like MLSE or MAP) needs to know channel impulse response (CIR) characteristics to ensure successful equalization (removal of ISI). Note that equalization without separate channel estimation (e.g., with linear, decision-feedback, blind equalizers [17] is also possible, but not discussed in this report. After detection the signal is deinterleaved and channel decoded to extract the original message.

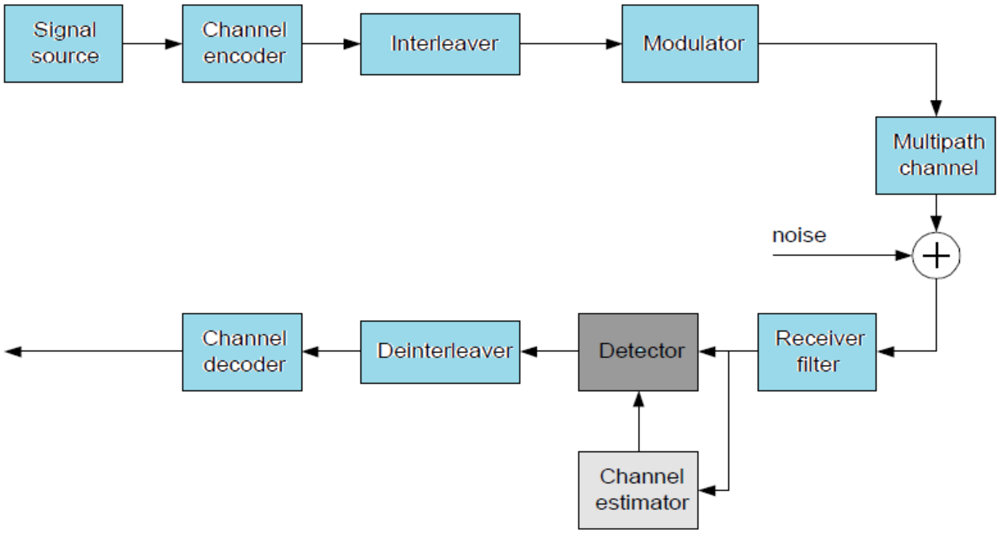


Figure 18: Block diagram for a system utilizing channel estimator and detection.

In this report we are mainly interested in the channel estimation part. There are a few different approaches of channel estimation, like Least-squares (LS) or Linear Minimum Mean Squared Error (LMMSE) methods [18].

4.4.1 Constraints Used in Channel Estimation/Data Detection

All the works mentioned above, use a subset of the following constraints on the channel estimate or data, regardless of the estimation technique used. Following is a survey of these constraints and the work that employs them.

Data Constraints: Finite alphabet constraint: Data is usually drawn from a finite alphabet set. The authors in [24] and [29]make use of this constraint.

Code: Data usually exhibits some form of redundancy like a code that helps reduce the row probability [26]

Transmit precoding: The data might also contain some form of precoding (to facilitate equalization at the receiver) such as a cyclic prefix, silent guard bands [46] and known symbol precoding [37].

Pilots: Pilots represent the most primitive form of redundancy and are usually inserted to perform channel estimation or simply to initialize the estimation process [38].

Channel Constraints:

Finite delay spread: The channel is usually of finite impulse response with a maximum delay spread that is assumed available to the receiver.

Sparsity: the Sparsity of a multipath fading channel is defined as the ratio of the time duration spanned by the multipath to their number [22]. The number of paths and their delays are usually stationary. However, their amplitudes and relative phases usually very much more rapidly with time. This essentially reduces the number of parameters to be estimated to that of the number of multipath in the channel.

Frequency correlation: In addition to information about which of the channel taps are inactive, we usually have additional statistical information about the active ones. Thus, it is usually assumed that the taps are Gaussian (zero mean or not depending on whether the channel exhibits Rayleigh or Rician fading) with a certain covariance matrix. This matrix is a measure of the frequency correlation among the taps [30]. Time correlation: As channels vary with time, they exhibit some form of time correlation. Time-variant behavior could also be more structured, e.g., following a state-space model [34].

Uncertainty information: Channel also suffers from non ideal effects such as nonlinearities and rapid time-variations that are difficult to model. The aggregate effect of this non ideal behavior could be represented as uncertainty information that can be used to build robust receivers [26].

Regardless of the approach used for channel estimation or the constraints employed, estimation can be carried out in any of the two domains (time and frequency). Below, we classify the approaches that are used in either of these two domains. We also discuss the advantages and disadvantages of estimation in these domains. All these methods for channel estimation are either in the frequency domain or in the time domain. Below is a survey of various works in the two domains.

4.2 Pilot assignment in OFDM Systems

In PSA channel estimation, the pilot symbols can be placed in block-type or comb-type structures. As shown in Figure 3.2 (b), for block-type arrangement, the entire OFDM symbol is dedicated to carrier pilot samples on ail the subcarriers for channel estimation and sent periodically in the time-domain. The estimate obtained with the training symbol will be used to detect data symbols within the OFDM packet. This arrangement is most suitable for static or slow varying channel. The estimation of channel response is usually obtained by Least Square (LS) or Minimum Mean Square Error (MMSE) estimation of the training pilots [12]. Because the training block contains ail frequencies, channel interpolation in the FD is not required. However, it is relatively insensitive to frequency selectivity. In a time varying channel, the comb-type structure as depicted in Figure 3.2 (a) is more suitable.

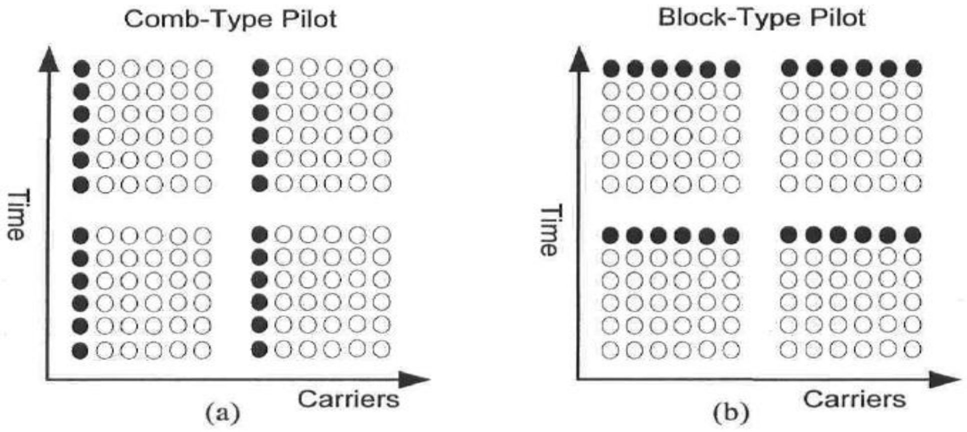


Figure 19: Two Basic Types of Pilot Arrangement for OFDM Channel Estimations

In the comb-type arrangement, pilot symbols are spread on selected subcarriers and repeated over multiple symbols. Channel estimation is performed at each symbol and interpolation is required to infer the channel frequency values of the non-pilot subcarriers. The comb-type pilot arrangement is sensitive to frequency selectivity compared with block-type. So the pilot spacing must be much smaller than the coherence bandwidth of the channel. However, assuming that the payload of pilot signals is the same as that of block-type, comp-type pilot assignment has a higher re-transmission rate [23]. The channel estimation based on pilot arrangement in OFDM systems has been investigated in [21]. The choice of pilot arrangement depends on the channel environment.

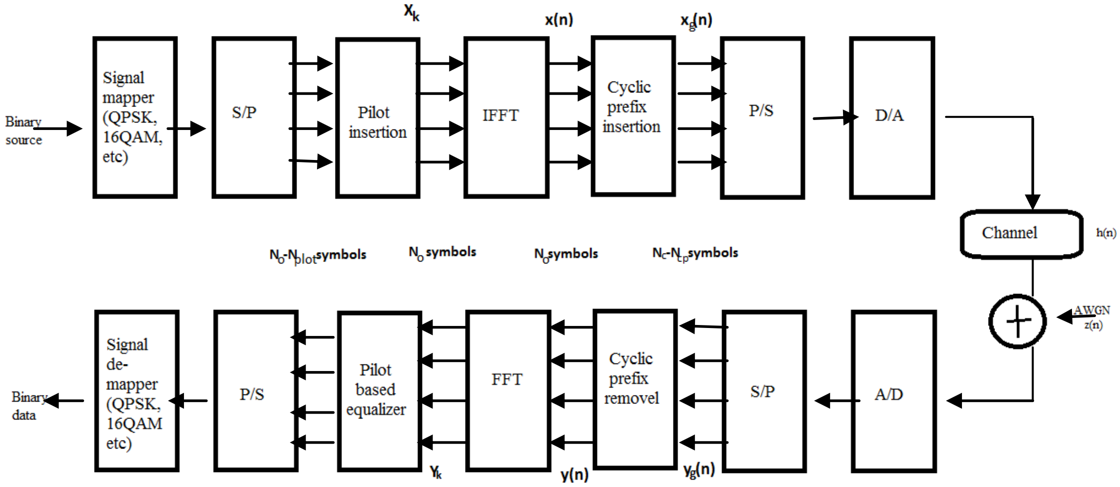


Figure 20: Pilot-based OFDM system model

Figure 4-1 presents an OFDM system that utilizes pilot-based channel estimation method for equalization at the receiver end. At the transmitter, binary data is mapped to a specific modulation (QPSK, 16QAM, 64QAM) and the modulated data undergoes serial-to parallel (S/P) conversion, forming a vector of ($N_o - N_{pilot}$) symbols. [21] N_o is the number of occupied sub-carriers and N_{pilot} is the number of pilot sub-carriers. Known N_{pilot} pilot symbols are then inserted into the modulated data, forming frequency-domain transmitted data X_k of lengthN_o.N_c-Point Inverse Fourier transform (IFFT) is performed on zero-padded X_k to generate time-domain vector x (n). Cyclic prefix of N_{cp} is then preappended to x (n) forming x_g(n) vector of $N_c + N_{cp}$ symbols.After parallel to serial conversion (P/S), D/A conversion and low-pass filtering, x_g(n) is transmitted over a linear time-invariant AWGN channel h (n) with noise z (n).

4.3 Block-Type Pilot Channel Estimation

In block-type pilot-based channel estimation, as shown in Figure 19, OFDM channel estimation symbols are transmitted periodically, and all subcarriers are used as pilots. The task here is to estimate the channel conditions (specified by$\overline{H}$ or $\overline{g}$) given the pilot signals (specified by matrix $\underline{X}$or vector $\overline{X}$) and received signals (specified by $\overline{Y}$), with or without using certain knowledge of the channel statistics. The receiver uses the estimated channel conditions to decode the received data inside the block until the next pilot symbol arrives. The estimation can be based on least square (LS), minimum mean-square error (MMSE), and modified MMSE.

4.3.1 LS Estimator

The LS estimator minimizes the parameter $(\overline{Y}-\underline{X}\overline{H})^H(\overline{Y}$-$\underline{X}\overline{H})$, where $(\cdot)^H$ means the conjugate transpose operation. It is shown that the LS estimator of $\overline{H}$ is given by [2].

$$\widehat{H}_{LS} = \underline{X}^{-1}\overline{Y} = [(X_k/Y_k)]^T \qquad \text{(k=0,.....,N-1)} \tag{4.1}$$

Without using any knowledge of the statistics of the channels, the LS estimators are calculated with very low complexity, but they suffer from a high mean-square error.

4.3.2 MMSE Estimator

The MMSE estimator employs the second-order statistics of the channel conditions to minimize the mean-square error.

Denote by$\underline{R}_{gg}$,$\underline{R}_{HH}$, $\underline{R}_{YY}$and the auto covariance matrix of $\overline{g}$, $\overline{H}$, and $\overline{Y}$, respectively, and by$\underline{R}_{gy}$ the cross covariance matrix between $\overline{g}$ and $\overline{Y}$. Also denote by $\sigma_N^2$the noise variance, $\{\left|\overline{N}^2\right|\}$. Assume the channel vector $\overline{g}$ and the noise $\overline{N}$ are uncorrelated, it is derived that

$$\underline{R}_{HH} = E\left\{\overline{H}\,\overline{H}^H\right\} = E\left\{\left(\underline{F}\overline{g}\right)\left(\underline{F}\overline{g}\right)^H\right\} = F\underline{R}_{gg}\underline{F}^H \tag{4.2}$$

$$\underline{R}_{gy} = \mathrm{E}\left\{\overline{g}\left(\underline{\mathrm{X}}\,\underline{F}\overline{g}+\overline{N}\right)^{\mathrm{H}}\right\} = \underline{R}_{gg}\underline{F}^H\underline{X}^H \tag{4.3}$$

$$\underline{R}_{YY} = E\left\{\overline{Y}\,\overline{Y}^H\right\} = \underline{X}\,\underline{F}\,\underline{R}_{gg}\underline{F}^H\underline{X}^H + \sigma_N^2 I_N \tag{4.4}$$

Assume $\underline{R}_{gg}$(thus $\underline{R}_{HH}$) and σ_N^2 are known at the receiver in advance, the MMSE estimator of $\overline{g}$ is given by $\hat{g}_{MMSE} = \underline{R}_{gy}\underline{R}_{YY}{}^{-1}\overline{Y}^{H\overline{H}}$ (4.5)

Note that if $\overline{g}$ is not Gaussian, $\hat{g}_{MMSE}$is not necessarily a minimum mean-square error estimator, but it is still the best linear estimator in the mean-square error sense. At last, it is calculated that

$$\begin{aligned}\widehat{H}_{MMSE} &= \underline{F}\hat{g}_{MMSE} = \underline{F}[\left(\underline{F}^H\ \underline{X}^H\right)^{-1}\underline{R}_{gg}{}^{-1}\sigma_N^2 + XF\ ]^{-1}\overline{Y} \\ &= \underline{F}\ \underline{R}_{gg}[\left(\underline{F}^H\ \underline{X}^H\underline{X}\ \underline{F}\ \right)^{-1}\sigma_N^2 + \underline{R}_{gg}]\underline{F}^{-1}\widehat{H}_{LS} \qquad (4.6) \\ &= \underline{R}_{HH}[\underline{R}_{HH} + \sigma_N^2\underline{X}\ \underline{X}^H]^{-1}\widehat{H}_{LS}\end{aligned}$$

The MMSE estimator yields much better performance than LS estimators, especially under the low SNR scenarios. A major drawback of the MMSE estimator is its high computational complexity, especially if matrix inversions are needed each time the data in $\underline{X}$ changes.

4.3.3 Channel estimation review TDMMSE

Based on the principle of PSA OFDM transmission scheme, we can assign pilots both in the TD and in the FD. An optimum MMSE channel estimator based on pilots is proposed in [39], which makes full use of the TD and FD correlation of the FR of time-varying dispersive fading channels. Therefore the MMSE estimator can only be found when the channel's statistics are known. A more realistic case is where the channel's statistics mismatch is also considered. We are proposing TD MMSE channel estimation technique. The TD MMSE channel estimation has been proven to give better results in chapter 4.

4.4 Algorithm

1. Consider some random input.
2. Assume information per bit, SNR, and FFT Length.
3. Performing modulation by applying various modulation techniques (QPSK, 16QAM, etc)

4. The data is given to some AWGN channel.

5. Demodulation is done

6. Estimating the channel by using separate time domain LS, MMSE method.

7. Got better BER performance compared to normal LS and MMSE method.

4.9 Flowchart

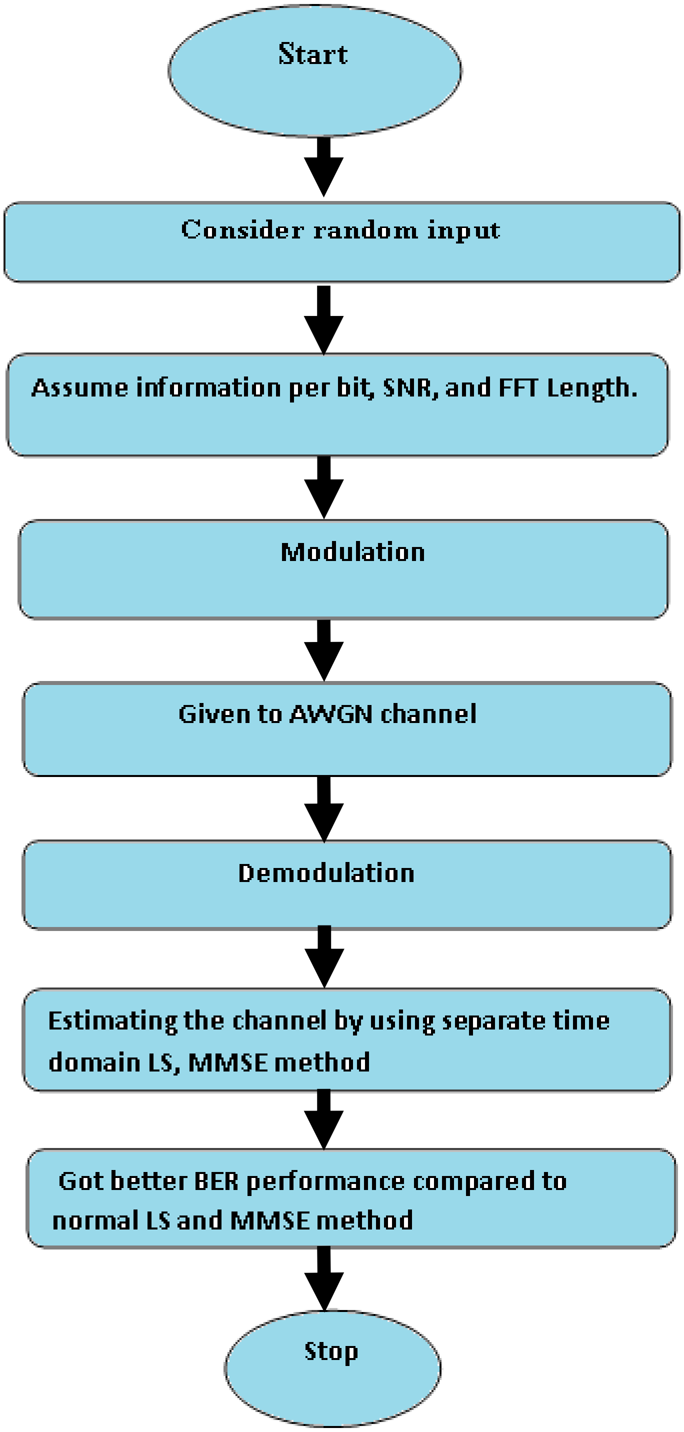


Table 3: Methodology flow chart

CHAPTER 5

RESULTS AND DISCUSSION

In this section, we will see the channel estimation done by using various techniques and then calculating for the bit error rate for all the three techniques. After that we will do the same with the modified technique and see the results for bit error rate calculations. The difference is shown on the following plots done with the help of Matlab.

5.1) Simulation results for comb type pilot arrangement

For comb type pilot arrangement, an OFDM system with N=500 subcarriers is considered. The spacing between pilots is taken as 5. So the number of pilots are 100 and number of information symbols are 400. In the simulation, 16QAM modulation is considered.

Figure 21 demonstrates the mean square error of channel estimation at different E_S/N_0 in dB. As E_S/N_0increases mean square error decreases for all LSE, MMSE and TD MMSE. Figure 22 shows SNR versus Bit Error Rate (BER). As SNR increases Bit Error Rate decreases for both cases. For a given SNR, TD MMSE estimator shows better performance than LSE and MMSE estimator. The complexity of TD MMSE estimators will be larger than LSE and MMSE estimators but give better performance in comparison to LSE and MMSE.

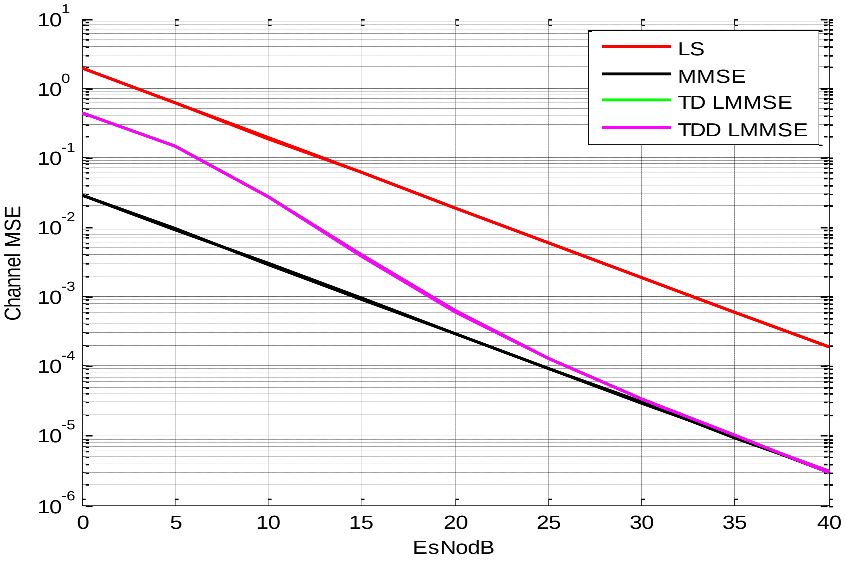


Figure 21: Channel MSE for LSE, MMSE TD MMSE estimators at different $E_S/N_0\ db$

Figure 22 demonstrate Bit Error Rate (BER) performance (SNR versus BER) for different modulations in MMSE, LSE and TD MMSE estimators respectively. It shows that as SNR increases the Bit error rate decreases, as theoretically expected.

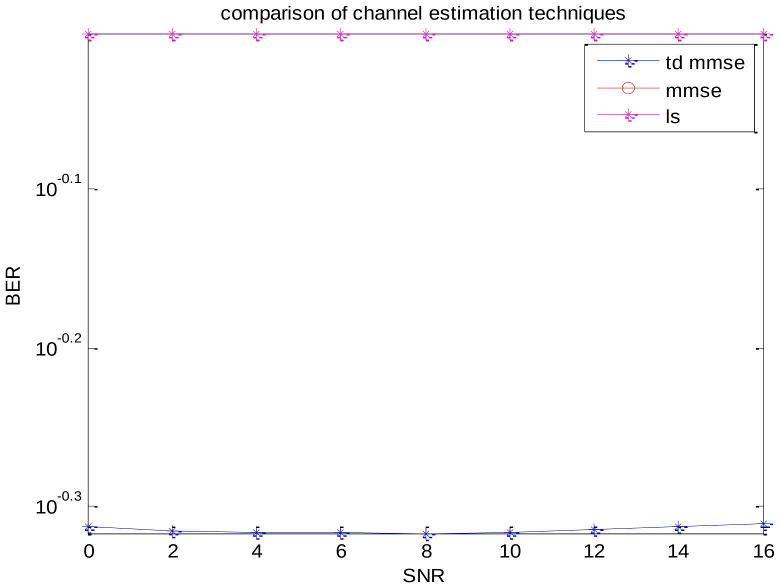


Figure 22: Comparision of Channel Estimation techniques

From Figures 21 and 22, the TD MMSE estimators have less Bit Error Rate than LSE estimators in low SNRs. But at higher SNRs, both will have nearly equal performance. At lower SNRs noise is the prominent factor. In this case, TD MMSE estimator works better. But at higher SNRs, it is better to go for LSE estimator because of its simplicity where noise is less effective.

5.2) Simulation results for interpolation techniques

Figures 10 and 11 shows the results for various interpolation techniques used in the simulation. Figure 10 shows the simulated QAM signal and the effect of noise and Rayleigh Fading channel. The FFT, spline, linear and cubic interpolation interpolation techniques are applied using the LSE estimation. It is found that spline interpolation having better performance than linear and other interpolation techniques (Figure 30).

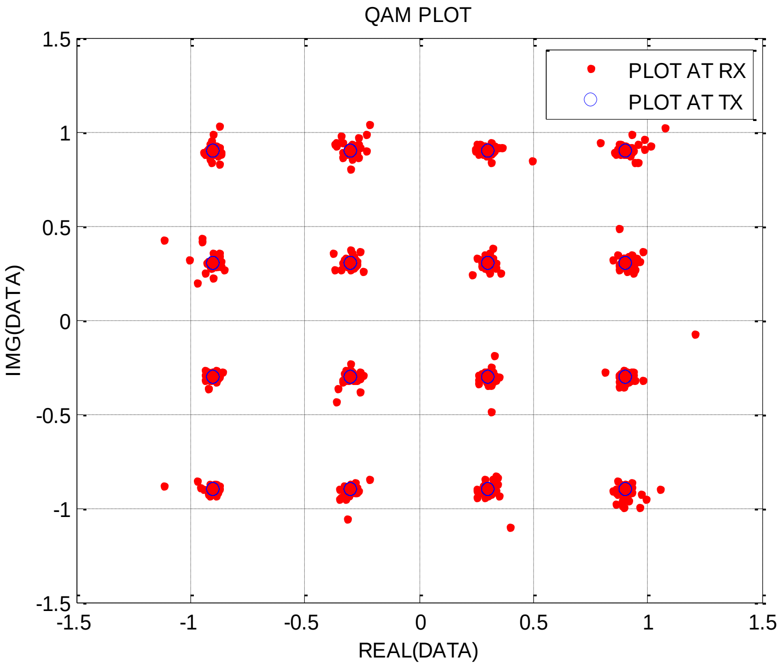


Figure 23: Simulated QAM signal

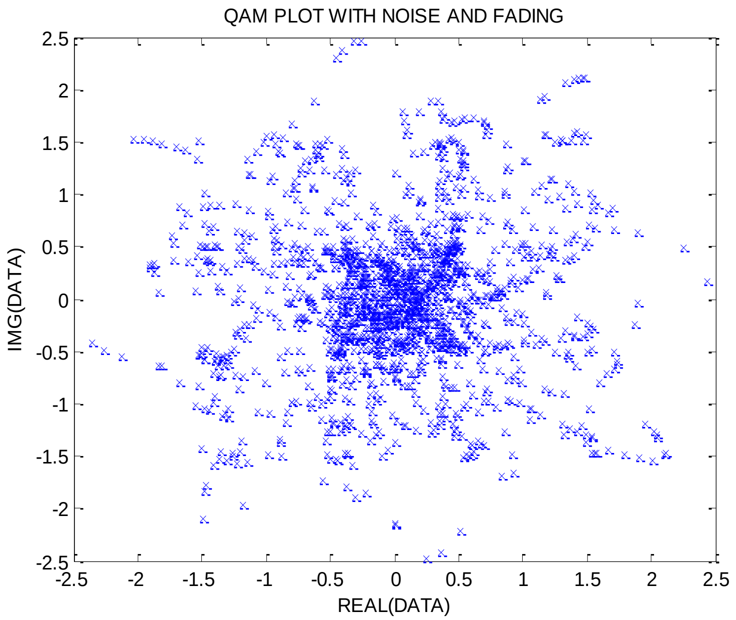


Figure24: QAM plot with noise and fading

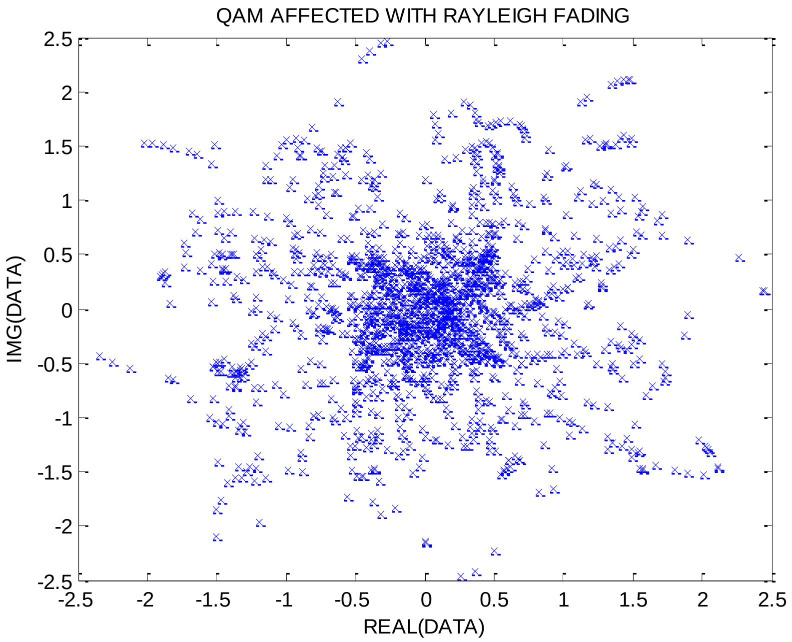


Figure 25: QAM affected with Rayleigh Fading

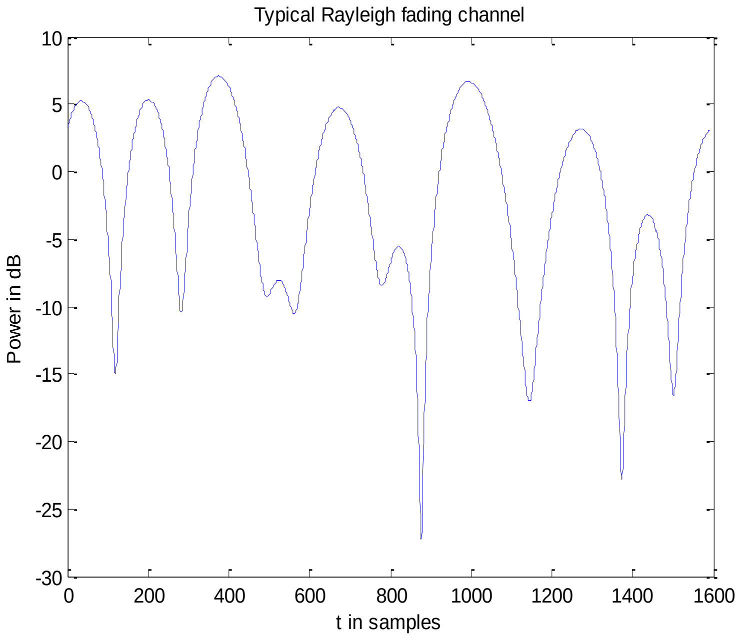


Figure 26: A typical example of Rayleigh Fading channel.

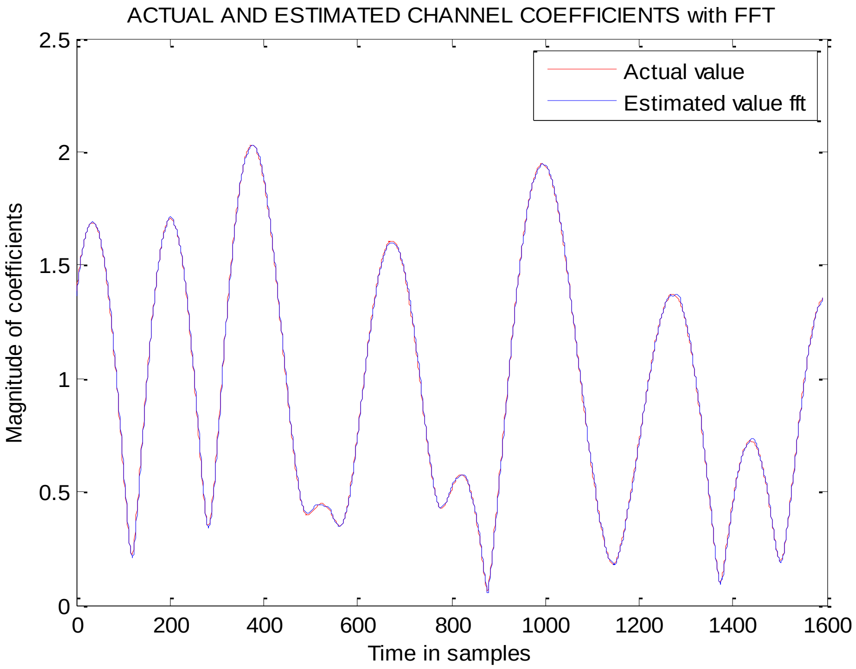


Figure 27: Results for FFT interpolation

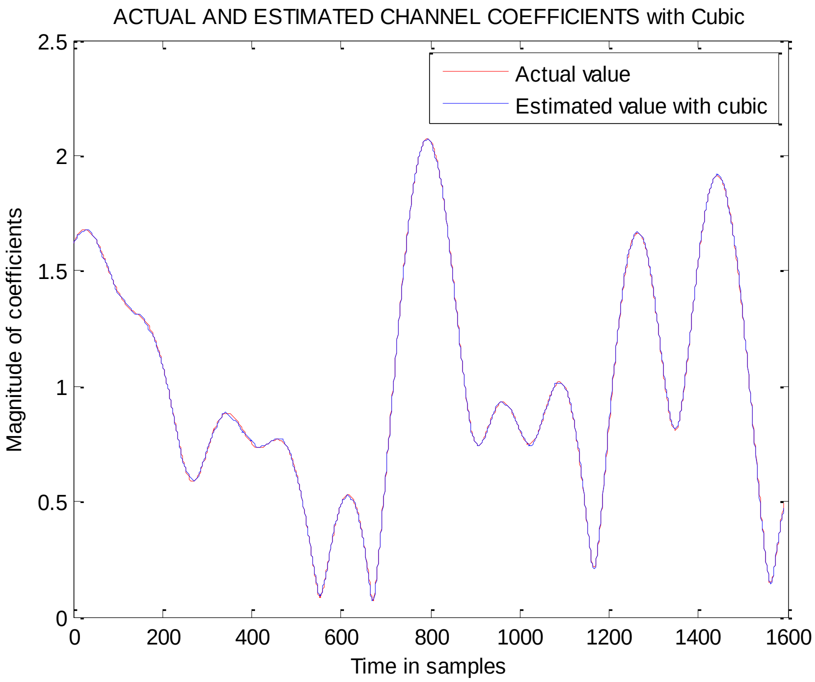


Figure 28: Results for Cubic Interpolation

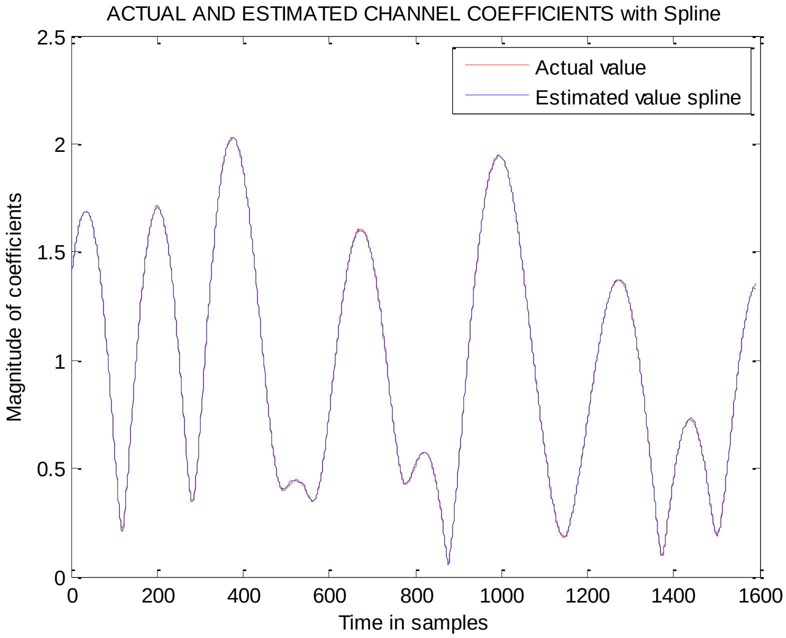


Figure 29: Results for Spline Interpolation

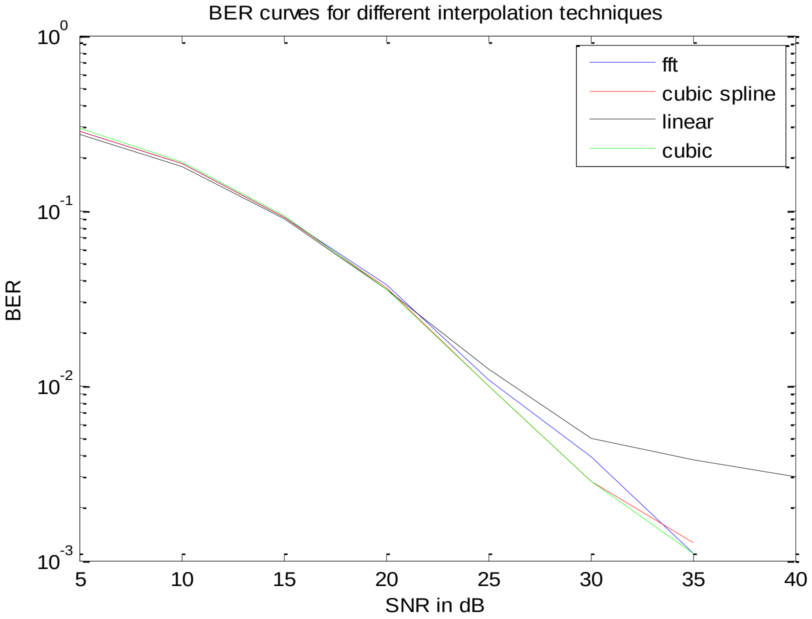


Figure 30: BER curves for different FFT, spine, linear and cubic interpolation techniques.

CHAPTER 6

CONCLUSION

The performance of three types of estimators (LSE, MMSE and TD MMSE estimators) has been theoretically and experimentally evaluated for both block type and comb type pilot arrangements. The estimators in this study can be used to efficiently estimate the channel in an OFDM system, given certain knowledge about channel statistics. The complexity of TD MMSE is large compare to the LSE and MMSE estimator. For high SNRs, the LSE estimator is both simple and adequate. The TD MMSE estimator has good performance but high complexity. The LSE estimator has low complexity, but its performance is not as good as that TD MMSE estimator basically at low SNRs. Pilot carriers are used to estimate the channel impulse response.

The estimated channel can be used to get back the data sent by transmitter certainly with some error. In the simulation, 500 numbers of carriers in one OFDM block is used, in which one fifth are used for pilot carriers and rest are of data carriers. BER for different SNR conditions for QAM signaling is calculated. The performance of LSE with MMSE estimator is also investigated. MMSE estimation is better that LSE estimator in low SNRs; whereas at high SNRs, performance of LSE estimator approaches to MMSE estimator. Various interpolation techniques for channel estimation are also used. It is found that higher order interpolation technique (spline) is giving better performance than lower order interpolation technique (linear).

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