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Channel Estimation Based On TDS-OFDM under Severely Fading MIMO Channel

S. Pushkala[1], C. Vanitha[2], C. Rajeshwari[3]
[1,2,3]Department of ECE, T.S.M Jain College of Technology, Villupuram, India

***Abstract*— In most cases of wireless communications, many types of fading occur due to reflection, refraction, diffraction of objects. Fading will be severe in the moving channels due to delay spread and Doppler shift. Due to these effects ISI and ICI occurs which reduces the Qos in the transmission channels. To reduce this interferences OFDM (Orthogonal Frequency Division Multiplexing) is introduced in the channel. The proposed system used here is TDS OFDM (Time Division Synchronous OFDM) which is a type of OFDM in which a PN Sequence is introduced as a GI length of the data code. This TDS method reduces the complexity of the channel transmission in the MIMO channels. . To analyze the performance of TDS in the OFDM, the padded pseudo-noise sequences in consecutive OFDM blocks are used and its robustness over time varying channel.**

Index Terms— Fading, OFDM, Pseudo-noise, TDS OFDM.

I. Introduction

1.1 Digital Multi-Carrier Modulation system

Recently, a worldwide convergence has occurred for the use of Orthogonal Division Frequency Multiplexing as an emerging technology for high data rates. In particular, the wireless local network systems such as WiMax, WiBro, WiFi etc., and the emerging fourth-generation (or the so-called 3.9G) mobile systems are all OFDM based systems. OFDM is a digital multi-carrier modulation scheme, which uses a large number of closely-spaced orthogonal sub-carriers that is particularly suitable for frequency-selective channels and high data rates. This technique transforms a frequency selective wide-band channel into a group of non-selective narrow-band channels, which makes its robust against large delay spreads by preserving orthogonality in the frequency domain. Moreover, the introduction of a so-called cyclic prefix at the transmitter reduces the complexity at receiver to FFT processing and one tap scalar equalizer at the receiver. The simplified equalization at receiver, however, requires knowledge of the channel over which the signal is transmitted. To facilitate the estimation of the channel in an OFDM system (such as WiMax, WiBro, WiFi, and 3.9/4G), known signals or pilots could be inserted in the transmitted OFDM symbol. Different methods can then be applied to estimate the channel using these known pilots. The focus of this report is to investigate performance of different channel estimators for an OFDM-based 3.9G system. There are several modulation methods which basically related to FDMA concept used in wireless communication.Commonly employed modulation methods are as follows: In telecommunications, frequency division multiplexing (FDM) is a technique by which the total bandwidth available in a communication medium is divided into a series of non-overlapping frequency sub-bands, each of which is used to carry a separate signal. This allows a single transmission medium such as a cable or optical fiber to be shared by many signals. An example of a system using FDM is cable television, in which many television channels are carried simultaneously on a single cable. Where frequency-division multiplexing is used as to allow multiple users to share a physical communications channel, it is called frequency-division multiple access (FDMA).FDMA is the traditional way of separating radio signals from different transmitters.

FDMA (Frequency Division Multiple Access) is a channel access method used in multiple-access protocols as a channelization protocol. FDMA gives users an individual allocation of one or several frequency bands, or channels. It is particularly commonplace in satellite communication. FDMA, like other Multiple Access systems, coordinates access between multiple users. Orthogonal Frequency Division Multiplexing (OFDM), essentially identical to coded OFDM (COFDM) and Discrete Multi-Tone Modulation (DMT), is a Frequency-Division Multiplexing (FDM) scheme used as a digital multi-carrier modulation method. A large number of closely-spaced orthogonal sub-carriers are used to carry data. The data is divided into several parallel data streams or channels, one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme (such as Quadrature Amplitude Modulation Or Phase-Shift Keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth OFDM has been in theory for decades but just entered real world applications in recent years thanks to the availability of modern chips that can handle complex digital signal processing.

Wire line and wireless, fixed and mobile communications or networking technologies have chosen OFDM to achieve higher data rate (what is called broadband). Examples of such technologies are: ADSL, Home Plug AV, WiMedia UWB, Wi-Fi (802.11a/g),WiMAX.

OFDM has developed into a popular scheme for wide band digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, wireless networking and broadband internet access. The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multi path) without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wide band signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to handle time-spreading and eliminate inter symbol interference (ISI). Since the early days of electronics, as advances in technology were taking place, the boundaries of both local and global communication began eroding, resulting in a world that is smaller and hence more easily accessible for the sharing of knowledge and information. The pioneering work by Bell and Marconi formed the cornerstone of the information age exists today and paved the way for the future of telecommunications.

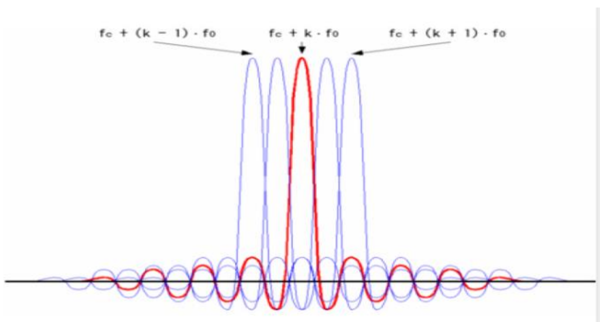

Fig. 1. OFDM - number of closely-spaced orthogonal sub-carriers

Traditionally, local communications was done over wires, as this presented a cost-effective way of ensuring a reliable transfer of information. For long-distance communications, transmission of information over radio waves was needed. Although this was convenient from a hardware standpoint, radio-waves transmission raised doubts over the corruption of the information and was often dependent on high-power transmitters to overcome weather conditions, large buildings, and interference from other source.

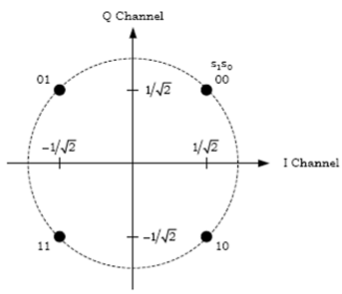

Fig. 2. QPSK Constellation Mapping

Sometimes known as quaternary or quadriphase PSK, 4-PSK, or 4-QAM, 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 Grey coding to minimize the BER — twice the rate of BPSK. Analysis shows that this may be used either to double the data rate compared to a BPSK system while maintaining the bandwidth of the signal or to maintain the data-rate of BPSK but halve the bandwidth needed. Although QPSK can be viewed as a quaternary modulation, it is easier to see it as two independently modulated quadrature carriers. With this interpretation, the even (or odd) bits are used to modulate the in-phase component of the carrier, while the odd (or even) bits are used to modulate the quadrature-phase component of the carrier. BPSK is used on both carriers and they can be independently demodulated.

1.2 Cause of Fading

In a typical wireless communications system, the transmitted signal typically undergoes refractions, shadowing and various reflections due to the presence of various objects (buildings, trees, etc.) in the channel. As a consequence the waves emitted by the receiver arrive at the receiver antenna over multiple paths, a phenomenon known as multipath propagation. The complete set of propagation paths between transmitter and receiver forms the multipath channel. Each path can be characterized by three parameters: delay, attenuation and phase shift. The path delay depends on the path length and on the speed at which a wave is propagating in the different media along the path, while the attenuation and phase shift is caused by fading. In NLOS case, there is no direct line of sight between the transmitter and receiver, so all incoming waves have been reflected at least once. The multipath propagation scenario in NLOS case the envelope of the received signal can be best described by a Rayleigh distribution, and the fading is known as Rayleigh fading.

The discrete time-variant channel impulse response h(t) of the complex multipath channel can be Written

$$h(\boldsymbol{\tau},\boldsymbol{t}) = \sum_{n} \boldsymbol{a_n}(\boldsymbol{t}) \boldsymbol{e}^{-j2\pi f_c \tau_n(t)} \; \boldsymbol{\delta}(\boldsymbol{\tau}-\boldsymbol{\tau_n}(\boldsymbol{t})) \qquad (1)$$

Where a_n (t) is the attenuation factor for the signal received on the n -th path time instant t . The relationship between coherence bandwidth 0 f and bandwidth of the transmitted signal W determines the type of fading degradation. The channel is said to experience frequency-selective fading when f_0<W, whereas frequency non-selective or flat fading occurs when the f_0 > W.

1.3. Effect of Impulse Noise in OFDM

Impulse noise is a significant problem in some orthogonal frequency division multiplexing (OFDM) applications. It has been observed in practice that the degradation caused by impulse noise depends only on the total energy of the noise during each OFDM symbol, not on the structure of the noise.

This 'noise bucket' effect is explained by showing that even for a small number of impulses per symbol the noise distribution at the input of the receiver decision device is close to Gaussian. This is because of the spreading effect of the discrete Fourier transform. One of the advantages of orthogonal frequency division multiplexing (OFDM) compared to single carrier systems is its robustness against impulse noise. However impulse noise is still a serious problem in OFDM based systems including digital video broadcasting (DVB) and several techniques to mitigate the effects of impulse noise have been proposed. There are many different sources of impulse noise such as car ignitions.

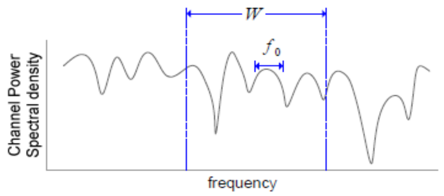

Fig.3. Typical frequency-selective fading channel

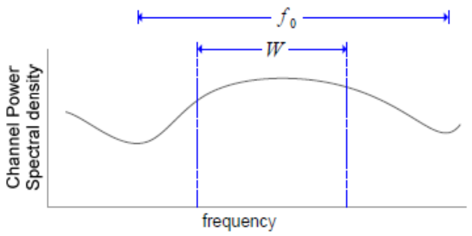

Fig. 4. Typical flat fading channel

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1.4 Impulse Noise and its Effects in OFDM

Impulse noise can potentially affect a number of receiver functions. For example, it can cause the input amplifier to overload or disrupt the automatic gain control. These effects are not considered here, here only the effect of impulse noise on the baseband digital section of the receiver is considered.

The received time domain baseband OFDM signal is mathematically expressed as

$$r(k)= x(k) + n(k) * \ i\ (k) \tag{2}$$

where x(k) is the wanted OFDM signal, n(k) is additive white Gaussian noise (AWGN) with zero mean and variance and i(k) is the impulse noise. The statistical properties of i(k) depend on both the form of impulse noise at the receiver input and on the filtering properties of the receiver front end. A number of impulse noise models based on theoretical analysis or experimental data have been presented in previous literature. However very recent research by the BBC, which measured a variety of impulse noise sources of practical importance in OFDM applications, concluded that impulse noise can be modeled as gated Gaussian noise.

The 'noise bucket'concept applies in quantifying the performance of OFDM impaired by impulse noise. The decision noise becomes approximately Gaussian even with a small number of impulse occurrences. The theoretical and simulation results for system SER agree closely.

1.5 CS-OFDM

The compressed sensing (CS) theorem shows that one can sample the signal of interest with much fewer samples than that with Nyquist rate and recover it with high probability as long as some criteria is satisfied. The main two criteria are that signal is sparse and the vector in sensing basis is incoherence with the vectors in the presentation basis.

To realize this theory, one needs to know these two important principles of CS: sparsity and incoherence. In the previous section, it was shown that the received data symbol transmitted on k^{th} sub-carrier is given by the corresponding transmitted symbol multiplied with the channel frequency response, sampled at the k th sub-carrier frequency plus noise. For linear channel time-invariant (LTI) channel with AWGN, this corresponds to a parallel set of AWGN channels with equal SNR. As a consequence, the raw bit-error-rate (BER) performance will be identical to that of a single carrier modulation over AWGN, except for the SNR loss due to cyclic prefix. Disadvantages of the existing systems are i) Channel estimation is carried out only with data obtained from guard interval. ii) Longer delay channels will cause IBI (Inter Block Interference) leads poor channel estimation. iii) ICI suppression rate depends on channels delay spread.

II. Proposed System

2.1 TDS OFDM

OFDM has been widely recognized as a prominent physical layer technique for future wireless communications. There are basically three types of OFDM: cyclic prefix OFDM (CP-OFDM), zero padding OFDM(ZP-OFDM), and time domain synchronous OFDM (TDS-OFDM). The most widely used CP-OFDM utilizes a CP as the guard interval in between successive OFDM data blocks to alleviate inter-block interference (IBI). The CP is replaced by a zero padding in ZP-OFDM. Unlike CP-OFDM or ZP-OFDM, TDSOFDM adopts a known pseudorandom noise (PN) sequence as the guard interval as well as the training sequence (TS) for time-domain synchronization and channel estimation. Hence, higher spectrum efficiency can be achieved due to the avoidance of frequency-domain pilots for channel estimation as adopted by CP-OFDM and ZP-OFDM. TDS-OFDM is the key technology of the international digital television broadcasting standard called digital television/terrestrial multimedia broadcasting (DTMB), which has been proposed by China, and has been successfully deployed in China, Cuba, Cambodia, etc.

However, the mutual interferences between the PN sequence and the OFDM data block in TDS-OFDM make time-domain channel estimation and frequency-domain data demodulation mutually conditional, so an iterative interference cancellation algorithm has to be implemented, which unfortunately cannot remove the interferences completely. Due to this, it is difficult for TDS-OFDM to support interference-sensitive high-order constellations like 256QAM in multipath channels with large delay spread. Currently, the highest modulation order that can be supported by TDS-OFDM is 64 QAM while CP-OFDM in the recently announced next-generation digital television broadcasting standard called DVB-T2 can support 256QAM to achieve higher spectrum efficiency.

One attractive solution is the dual PN padding OFDM (DPNOFDM) scheme, whereby two repeated PN sequences are inserted in every TDS-OFDM symbol to avoid the interference from the OFDM data block into the second PN sequence. However, the extra PN sequence decreases the spectrum efficiency, especially when the original guard interval length is long such as in wireless broadcasting systems.

2.2 Channel Equalizer

Channel equalization is essential to mitigate signal distortions and plays an important role in improving receiver performance.

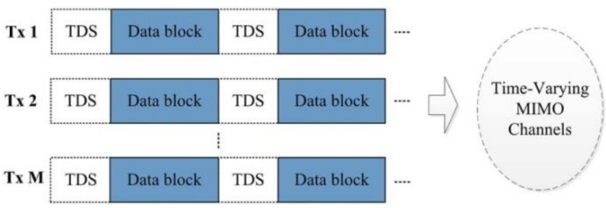

Fig. 5. Frame structure of MIMO TDS-OFDM.

Fortunately, one of major advantages in OFDM systems over single-carrier systems is that channel equalization is simplified due to inherent robustness to multi-path fading channels. In MB-OFDM systems, it is sufficient to use a single-tap (zero forcing) frequency domain equalizer in order to undo multipath channel effects.

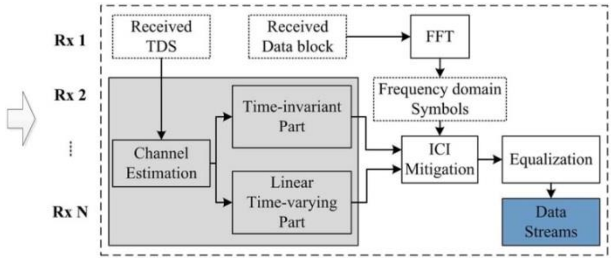

Fig. 6. Receiver side of MIMO TDS-OFDM with ICI mitigation.

A preamble in MB-OFDM contains six channel estimation sequence (CES) symbols which can be used for channel equalization directly in frequency domain without interpolation processes from time domain.

2.3 OFDM with Cyclic Prefix

Two difficulties arise when the signal is transmitted over a dispersive channel. One difficulty is that channel dispersion destroys the orthogonality between subcarriers and causes Inter Carrier Interference (ICI). In addition, a system may transmit multiple OFDM symbols in a series so that a dispersive channel causes intersymbol interference (ISI) between successive OFDM symbols. The insertion of a silent guard period between successive OFDM symbols would avoid ISI in a dispersive environment but it does not avoid the loss of the subcarrier orthogonality. solved this problem with the introduction of a cyclic prefix. This cyclic prefix both preserves the orthogonality of the subcarriers and prevents ISI between successive OFDM symbols. Therefore, equalization at the receiver is very simple.

This often motivates the use of OFDM in wireless systems. Between consecutive OFDM signals a guard period is inserted that contains a cyclic extension of the OFDM symbol. The OFDM signal is extended over a period Δ so that

$$s(t) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} x_k e^{j2\pi f_k t}, \qquad -\Delta < t < NT \tag{3}$$

The signal then passes through a channel, modeled by a finite-length impulse response limited to the interval $[0, \Delta_h]$. If the length of the cyclic prefix Δ is chosen such that $\Delta > \Delta_h$ the received OFDM symbol evaluated on the interval [0, NT], ignoring any noise effects, becomes

$$r(t) = s(t) * h(t) \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} H_k x_k e^{j2\pi f_k t}, 0 < t < NT \tag{4}$$

Where

$$H_k = \int_0^{\Delta_k} h(\tau) e^{j2\pi f_k \tau} d\tau \tag{5}$$

is the Fourier transform of *h(t)* evaluated at the frequency f_k. Note that within this interval the received signal is similar to the original signal except that $H_k x_k$ modulates the *k*-th subcarrier instead of $\boldsymbol{x_k}$ In this way the cyclic prefix preserves the orthogonality of the subcarriers.The OFDM signal can be demodulated as described in the previous section, taking an FFT of the sampled data over the interval [0, NT], ignoring the received signal before and after $0 < t \leq NT$. The received data (disregarding additive noise) then has the form,

$$y_k = H_k x_k, \qquad k = 0, \ldots, N-1 \tag{6}$$

The received data in Equation 3 and 4 can be recovered with '**N** parallel one-tap equalizers. This simple channel equalization motivates the use of a cyclic prefix and often the use of OFDM itself. Because the signal is ignored within the cyclic prefix this prefix also acts as the above mentioned silent guard period preventing ISI between successive OFDM symbols. The use of a cyclic prefix in the transmitted signal has the disadvantage of requiring more transmit energy. The loss of transmit energy (or loss of signal-to-noise ratio (SNR)) due to the cyclic prefix is

$$E_{loss} = \frac{NT}{NT+\Delta} \tag{7}$$

This is also a measure of the bit rate reduction required by a cyclic prefix. That is, if each subcarrier can transmit "*b*" bits, the overall bit rate in an OFDM system is ***Nb/(NT + Δ)*** bits per second as compared to the bit rate of ***b/T*** in a system without a cyclic prefix.

If latency requirements allow, these losses can be made small by choosing a symbol period **NT** much longer than the length of the cyclic prefix Δ.

OFDM systems often experience not only channel dispersion as addressed above, but also additive white Gaussian noise, Doppler spreading and synchronization errors. Many of these impairments can be modeled as AWGN if they are relatively small. Synchronization errors such as carrier frequency offsets, carrier phase noise, sample clock offsets and symbol timing offsets. The inclusion of Gaussian noise in the signal model yields a received OFDM signal $r(t) = s(t) * h(t) + n_t(t)$ and Equation extended with a noise term becomes

$$y_k = H_k x_k + n_{k,}, \quad k = 0, \ldots, N-1. \tag{8}$$

Where n_k is the FFT of the sampled noise terms $n_t(nT)$, n = 0,.....,N-1 . If the received noise $n_t(t)$ is white, the noise n_k after the FFT will also be white. In a fading channel the channel variations affect the performance of the OFDM system. For a fixed sampling period, the OFDM symbol length increases with the number of subcarriers and so do its sensitivity to channel variations. To illustrate the effects, consider an OFDM system in a flat-fading channel, a channel with a time-varying one-tap impulse response ***a(t).*** The transmitted OFDM signal is multiplied with this time-varying scalar which yields the received r(t) = ***a(t)s(t).*** The multiplication appears as a convolution in the frequency domain causing spreading of the subcarriers and, consequently, ICI. The sampled signal after the DFT is of the form

$$y_l = \sum_{k=0}^{N-1} x_k A(k-l), \tag{9}$$

Where A(k-l) is the DFT of the now time-varying channel tap a(nT), n=0,…,N-1

In some cases the above spreading may be desirable as it is a way to introduce diversity. A frequency domain channel equalizer can exploit such diversity. Other systems requiring orthogonality between subcarriers may suffer from the spreading. For a fixed sampling time the ICI due to the Doppler spreading increases with the number of carriers., using a central limit theorem argument, characterize the effect of the ICI as an additive Gaussian noise with a variance that increases with the number of subcarriers and with the maximum Doppler frequency. This noise is correlated in time, but white across subcarriers. The ICI leads to an error floor which may be unacceptable. Antenna diversity or coding are suggested to reduce this error floor.

2.4 Design of OFDM Signals

The number of subcarriers N, the bandwidth of each subcarrier 1/NT, the bandwidth of the system B ≈ 1/T, and the length of the cyclic prefix Δ are all important parameters in the design of an OFDM system.

First, the length of the cyclic prefix should be chosen to be a small fraction of the OFDM symbol length to minimize the loss of SNR (or data rate). Because the size of the cyclic prefix is directly related to the delay spread **τ** of the channel a rule of thumb is that the length of the OFDM symbol NT >> **τ** or, equivalently, the number of subcarriers N >> **τ** B . However, if the OFDM symbol length NT is too long the ICI caused by Doppler spreading in the fading channel can become performance limiting. If the intercarrier spacing 1/NT is chosen much larger than the maximum Doppler frequency f_d, the system is relatively insensitive to the Doppler spread and the associated ICI. Therefore, the number of subcarriers should satisfy $f_d \ll 1/NT$ or equivalently $N \ll B/f_d$. The above two constraints result in the following restriction on the number of subcarriers

$$\tau B \ll N \ll \frac{B}{f_d} \tag{10}$$

Equation also states a requirement on the delay- and Doppler-spread of the physical channel for proper design of an OFDM system. The far left hand side and the far right hand side also lead to $f_d\boldsymbol{\tau} \ll 1$, which means that the more the channel is under spread, i.e., the more correlated the channel is in either time or frequency, the easier it is to find a exact number of subcarriers N. The UMTS has been assigned frequencies in the 2.2 GHz band. Operators expect to be assigned 5 MHz for uplink and 5 MHz for downlink transmission and therefore in the following it is assumed a sample frequency of 5 MHz A proper design of a radio interface based on OFDM depends on the characteristics of the radio environment in these bands.

For the evaluation of the UMTS, ETSI has developed a set of channel models that describe the environment for different transmission situations (indoor, pedestrian, and vehicular). The system should typically be used in all these environments and therefore based on the worst values for the Doppler frequencies and channel delay spreads. The vehicular channel models adopt a mobile speed of 120 km/h. This speed corresponds to a maximum Doppler frequency of about 250 Hz. Advantages of the proposed system is it gives better QoS with maximum channel delay spread close to or even larger than the GI(guard interval) length and Less complexity.

III. Experimental Results And Conclusion

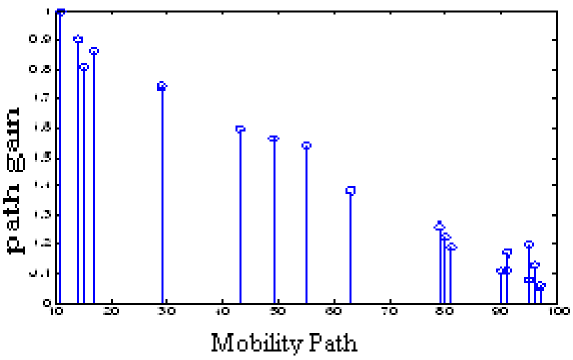

Fig. 7. Channel path gains with a longer path delay

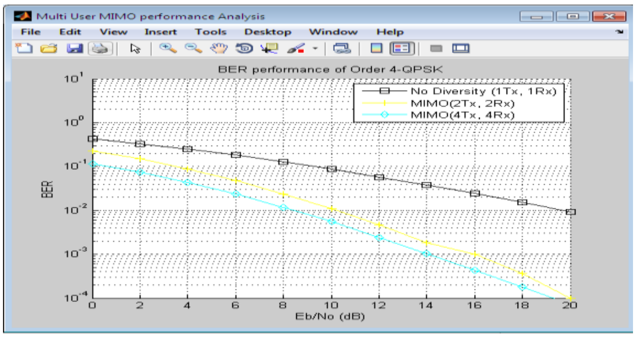

Fig.8. MIMO BER analysis over 4-QPSK

In the experiments, an introduction of OFDM systems in high mobility channels, specifically, different channel types, OFDM, ISI, and ICI over cyclic prefix are analyzed. Mathematical descriptions of the channel, OFDM, and cyclic prefix and auxiliary information retrieval for estimations were given as well as MATLAB simulations to verify and present a practical implementation. The MSE performance of this method outperforms the conventional schemes and is close to the theoretical simulations by simultaneously exploiting the time-domain PN sequence and frequency-domain pilots. Simulation results show that the proposed scheme has a good MSE performance in both static and mobile scenarios and can well support the 64 QAM, especially when the maximum channel delay spread is fairly close to or even larger than the GI length.

This scheme can be extended to determine the most appropriate number of antennas to be used & to determine the most appropriate number of relay required to re-modulate the symbols by carefully considering their potential benefits and then assigning a specific modulation scheme with specific antenna configurations. As a further benefit, MS with maximum possible mapping rate can be used for high throughput to estimate the impulse noise in OFDM system without using any statistical properties and improve signal strength by using MMSE and also to analyze performance of proposed sparse reconstruction algorithm by assuming impulse noise as sparse (narrow pulse).

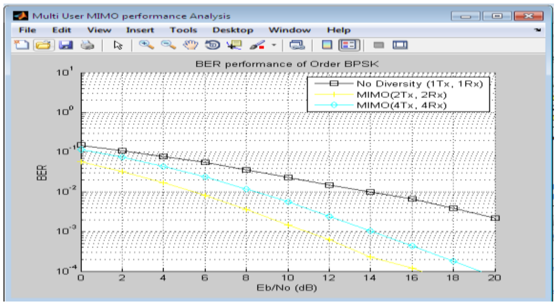

Fig. 9. MIMO BER performance over BPSK modulations

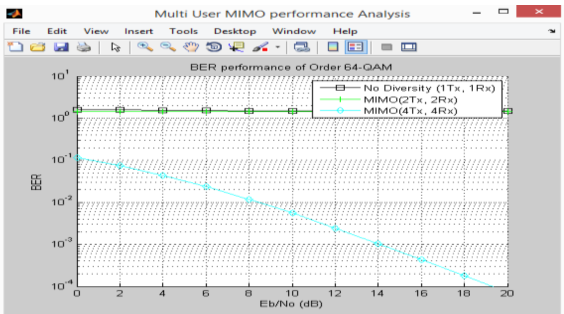

Fig. 10. MIMOBER performance over 64 –QAM modulation

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