Channel Estimation in MIMO OFDM System in 5G using Deep Learning

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***Abstract*—In this paper, using the wireless communication configuration of MIMO systems we try to estimate the channel for 5G technology. As the 5th Generation is used, its characteristic nature implores testing the channel estimation in Orthogonal Frequency Division Multiplexing (OFDM) system. Further, We investigate and visualise the step by step outputs of each block in the long chain of Modulation and demodulation for channel estimation. By employing the Least Squares Channel Estimator (LSE) and Minimum Mean-Square Error Estimator(MMSE) ,we try to provide meaningful results based on their comparisons. Wireless technology is the modern method of quick and reliable telecommunication which when recruited under 5G has advanced the field to new horizons.**

I. Introduction

This paper seeks to evaluate the effectiveness and accuracy of 5G channel estimation in a Multiple Input and Multiple Outputs (MIMO) system incorporating the Orthogonal Frequency-Division Multiplexing(OFDM) technique for minimisation of error and how to transmit and receive the OFDM signal through wireless communication in a very effective manner. In recent years, optimization of the wireless communication system has become critical with the rapid growth of mobile communication services and emerging broadband mobile Internet access services. So we need to come up with a high bandwidth and better data rate technology to overcome our need. We are using MIMO system as multiple antennas for both transmitters and receivers vastly improve communication performance, because of the increase in the number of antennas as compared to SISO(Single Input Single Output) it provides us with multiple degrees of freedom which is also referred to as spatial degree of freedom. This spatial degree of freedom could be used can either be used for diversity or multiplexing or both depending on one's need.

OFDM is one such technology which helps us achieve that because of plenty of reasons as : (i)As the symbol rate is inversely proportional to symbol duration, as a result every sub-carrier has comparatively long symbols. Robustness of long symbols against multi-path fading, as noticed in wireless channels, (ii) Due to frequency selective nature of the channel when the channel is in deep fade (i.e. the received energy on this carrier is very low), rather than the whole bit stream only the exact bit value is lost which is also a plus, (iii) As the system has more than one carrier therefore it allows more than one user benefits at the same time by assigning multiple sub-carrier . A figure that demonstrates the fundamental block of an OFDM system is shown below:

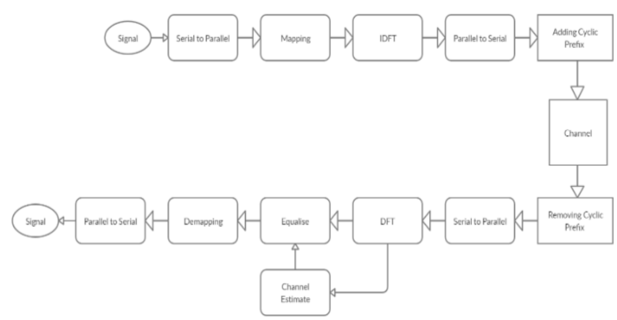

Fig. 1. Block Diagram depiction of an OFDM model

Implementation of the OFDM system is achieved using MATLAB.

The channel estimation techniques implemented at the receiver end are MMSE and LSE.

II. MIMO

Multiple-input multiple-output (MIMO) is a dynamic technique that has become the cornerstone of advanced generations of communication systems. MIMO is specially relevant in the field of practical wireless communication setups. The channel utilization peaks as well as the robustness of the channel is enhanced on MIMO system utilisation.An enlarged link capacity with improved stability to transmit data combined with improved spectral efficiency are prime characteristics of the system configuration. Owning to this it holds an advantage in controlled situations over other system configurations like Single input single output(SISO), single input multiple output (SIMO) and multiple input single outputs (MISO).

Further, Battikh, et al. [1] have showcased that intuitively MIMO outperforms MISO in terms of throughput and is able to accommodate a higher number of users which although leads to more divided cell capacity, provides a higher throughput in high load in the outer rings. They are enabled for wireless communication by incorporating a transmitting and a receiving antennae with a wireless channel in between for seamless transmission. The multi-path technology is used widely in WiFi, Wi-Max,LTE,etc. The space time diversity

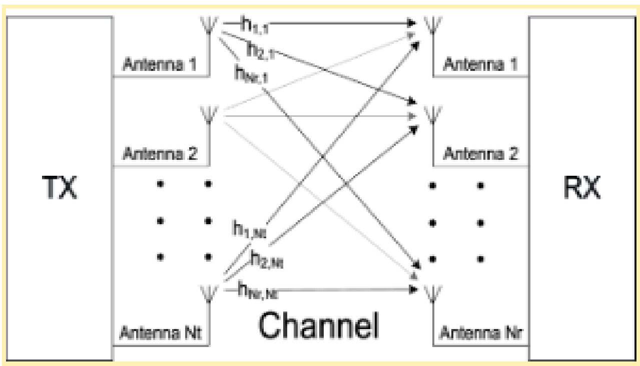

Fig. 2. MIMO system [2]

is the most widely availed in case of MIMO systems. The Alamouti space time block code [3] is the most simplified version from the whole family of orthogonal space time codes. The capacity of MIMO channels by the Shannon formulae [4] is given by -

$$C = \max_{f(x)} K(X;Y) = \max_{f(x)} \int_{S_x, S_y} f(x,y) \log\left(\frac{f(x,y)}{f(x)f(y)}\right) \tag{1}$$

Here the variable values are as follows.The support for the random variable S_x is *X* and that for *Y* is S_y. *K(X;Y)*-mutual information factor of the channel.The probability density function(pdf) of *Y* is $f(y)$ and probability density function(pdf) of *X* is $f(x)$.Shannon showed that the channel capacity is equal to the mutual information of the channel maximized over all possible input distributions.

III. OFDM : Orthogonal Frequency Division Multiplexing

Our next goal in communication and data transmission is to meet high data rates and achieve efficient use of limited spectrum. The idea is to allow the exploitation of locally available frequency bands, on a temporary basis but under a non interfering constraint.Most modern digital communication standards use Orthogonal Frequency Division Multiplexing (OFDM) as the air interface, because of its flexibility and robustness in frequency-selective channels. OFDM allows high-speed data transmission across a dispersive channel, so is used in many new and emerging high speed wired and wireless communications.

Orthogonal frequency division multiplexing (OFDM) transmission scheme is another type of a multi-channel system, which is similar to the FMT transmission scheme in the sense that it employs multiple sub-carriers [5].It does not use individual band-limited filters and oscillators for each sub-channel and furthermore, the spectra of sub-carriers are overlapped for bandwidth efficiency, unlike the FMT scheme where the wide-band is fully divided into N orthogonal narrow-band sub-channels. The multiple orthogonal sub-carrier signals, which are overlapped in spectrum, can be produced by generalizing the single-carrier Nyquist criterion in Equation into the multi-carrier criterion.

OFDM is symbol based, and can be viewed as a large number of low bit-rate carriers transmitting in parallel. Using synchronized time and frequency, these carriers transmit simultaneously, thus consequently forming a single block of spectrum and further ensures that the orthogonal nature of the structure is maintained.

The orthogonality property of OFDM signals can be better visualized by looking at its spectrum. In the frequency domain each OFDM sub-carrier has a sinc, $sin(x)/x$, frequency response as shown in the Fig.3.

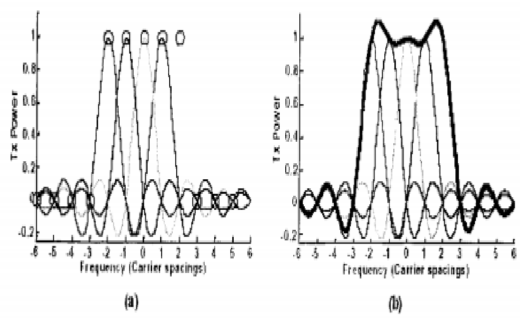

Fig. 3. Frequency Response of the sub-carrier in a 5 Tone OFDM Signal [5]
(a)Shows the spectrum of each carrier and the discrete frequency samples seen by an OFDM receiver
(b)Shows the overall combined response of the 5 sub-carriers (thick black line).

These multiple carriers can be referred as sub-carriers as they form a single OFDM transmission. Also it is worth noting that the orthogonality between sub-carriers in OFDM systems allows inserting and extracting pilots without any sort of interference. Each sub-carrier is modulated with a typical digital modulation scheme (such as 64QAM, QPSK etc.) at low symbol rate. However, when we combine sub-carriers, it enables data rates similar to a typical single-carrier modulation schemes and that too within equivalent bandwidths.

The way how OFDM signal is represented in time and frequency domain is shown in Figure 4 and also with the frequency selective nature of the OFDM signal

The relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers and in order to generate OFDM successfully. For this very reason, based on the Input data and the modulation scheme used, OFDM is generated by firstly choosing the spectrum required, where each carrier to be produced is assigned some data to

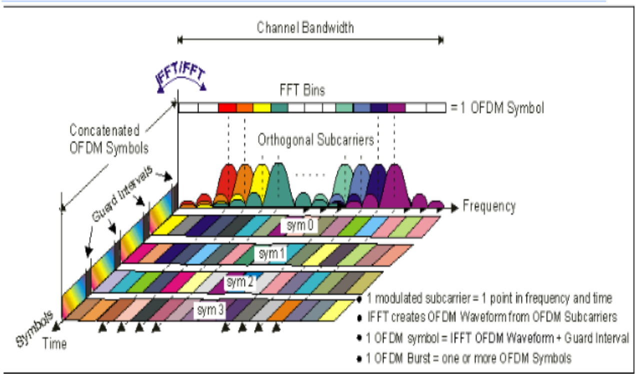

Fig. 4. Frequency-Time Representative of an OFDM signal [6]

transmit. The input serial data stream is formatted into the word size required for transmission and then shifted into a parallel format. The data is then transmitted in parallel by assigning each data word to one carrier during transmission..

On each carrier, the data to be transmitted is mapped into a phase shift keying (PSK) format. Based on the modulation method, the data on each symbol is then mapped to a phase angle. The symbol rate for an OFDM signal is significantly lower than a single carrier transmission scheme for a given system bandwidth.

The system bandwidth for OFDM is broken up into N sub-carriers, 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 multi-path propagation. As multi-path propagation is caused by the radio transmission signal reflecting off objects in the propagation environment, such as walls, buildings, mountains, etc. so 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. On an OFDM signal, Inter-Symbol Interference effects can be further improved by the addition of a guard period to the start of each symbol which is basically a cyclic copy that extends the length of the symbol waveform. Also the guard period provides protection against time-offset errors in the receiver.

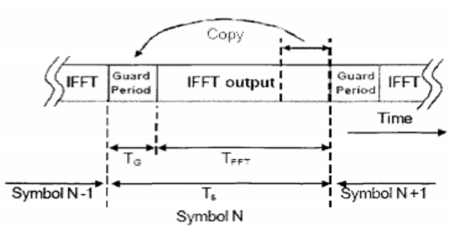

Fig. 5. Addition of a guard period of an OFDM signal [6]

The total length of the symbol is Ts=Tg + Tfft, where Ts is the total length of the symbol in samples, Tg is the length of the guard period in samples, and Tfft is the size of the IFFT used to generate the OFDM signal. The receiver basically does the reverse operation to the transmitter to retrieve the information transmitted. The guard period/interval is removed and the FFT of each symbol is then taken to find the original transmitted spectrum. We evaluate the phase angle of each transmission carrier and which is then converted back to the data word by demodulating the received phase. The data words are then assembled back to the same word size as the original data.

We can use a simple analog based implementation to show the basic principles of generating an OFDM system. In this analog based OFDM system there are N sinusoidal input signals and each sub-carrier transmits one bit of information (N bits total) as indicated by its presence or absence in the output spectrum. The frequency of each sub-carrier is selected to form an orthogonal signal set which are also available at the receiver for signal recovery. We note that the output is updated at a periodic interval T (symbol period). To maintain orthogonality, T must be the reciprocal of the sub-carrier spacing. This is a result of the symbol time corresponding to the inverse of the carrier spacing. As far as the receiver is concerned each OFDM symbol transmitted for a fixed time (Tfft). This symbol time corresponds to the inverse of the sub-carrier spacing of 1/Tfft (Hz).

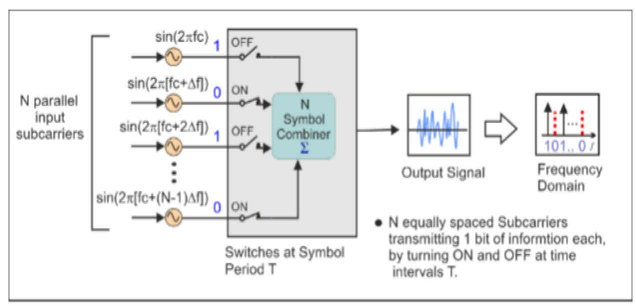

Fig. 6. Simple OFDM Generation [6]

The concepts used in the simple analog OFDM implementation can be further extended to the digital domain by using a combination of Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) digital signal processing. These transforms are important from the OFDM perspective because they can be viewed as mapping digitally modulated input data (data symbols) onto orthogonal sub-carriers. In principle, the IFFT takes frequency-domain input data (modulated sub-carriers represented by complex numbers) and converts it to the time-domain output data (analog OFDM symbol waveform).

In a digitally implemented OFDM system, the input bits are grouped and mapped to source data symbols that are a complex number representing the modulation constellation point (e.g., the BPSK or QAM symbols that would be present in a single sub-carrier system). These complex source symbols are treated by the transmitter as though they are in the frequency-domain and are the inputs to an IFFT block that transforms the data into the time-domain. The IFFT takes in N source symbols at a time (where N is the number of sub-carriers in the system).

Each of these N input symbols has a period of T seconds (symbol period). We recall that the output of the IFFT is N orthogonal sinusoids with each having a different frequency, while the lowest frequency is DC.

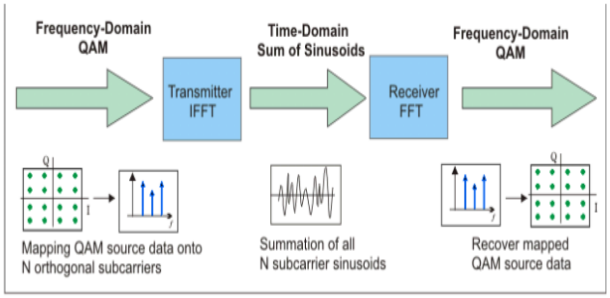

Fig. 7. Simplified OFDM Signal Block Diagram [6]

Input symbols for any sub-carrier specify both the amplitude as well as the phase of the sinusoid as it represents the constellation points which are mapped and are complex values. We get the summation of all N sinusoids as IFFT output and the IFFT block provides a convenient and easy way to modulate data onto N orthogonal sub-carriers and finally a single OFDM symbol is formed from the IFFT block of N output samples.

So, we can infer that a OFDM carrier signal is the sum of one or more OFDM symbols. Inverse FFT is computed when the IFFT block is completely loaded, thus giving a set of complex time-domain samples representing the combined OFDM sub-carrier waveform. To create a 3.2 microseconds (20Msps/64) duration OFDM waveform, the samples are clocked out at 20 Msps (mega samples per second). To complete the OFDM symbol, a 0.8 microseconds duration Guard Interval is then added to the beginning of the OFDM waveform. A guard interval is added to each symbol to minimize Inter Symbol Interference (ISI) and the channel delay spread. This produces a "single" OFDM symbol with a time duration of (3.2 + 0.8) microseconds = 4 microseconds in length. Now, for the remaining input data bits, this process is replicated to create additional OFDM symbols. Finally the single OFDM symbols are concatenated together and then appended to a 4 microseconds SIGNAL symbol and a 16 microseconds Preamble to complete the OFDM frame structure, where SIGNAL symbol provides Rate and Length information while Preamble is used for synchronization. OFDM frame is finally completed and is now ready to be transmitted as an OFDM Burst.

IV. Pilot Addition

The channel for transmission is often with faults and complications. A pilot signal is a helpful tool in checking the channel robustness. It's usually a mono-frequency single which is deployed over the communication system for multiple reasons.Pilot assists in reversal of signal distortions when signal travels through a channel,coordination and synchronisation of system and control purpose. Channel estimations can be easily done if a pilot symbol known at both the transmitter and receiver end is utilised for interpolation for estimation of channel responses.However choice of channel estimation technique is largely dependent on time variation, computation power, complexity and threshold of performance metrics.

Pilot structure classification based on the arrangement of pilot signals is as follows.

1) **Block Type** - In this OFDM symbols with pilot symbols are transmitted periodically for channel estimation. Using these pilots, a time-domain interpolation is performed to estimate the channel along the time axis.This type is most suited for frequency-selective channels. Coherence time is an important parameter as pilot symbols frequency should match the coherence time which in turn is denoted as the inverse of Doppler frequency($f_{doppler}$). Hence S_t, the period of pilot symbol in time must satisfy -

$$S_t \leq \frac{1}{f_{Doppler}} \tag{2}$$

The arrangement is shown below -

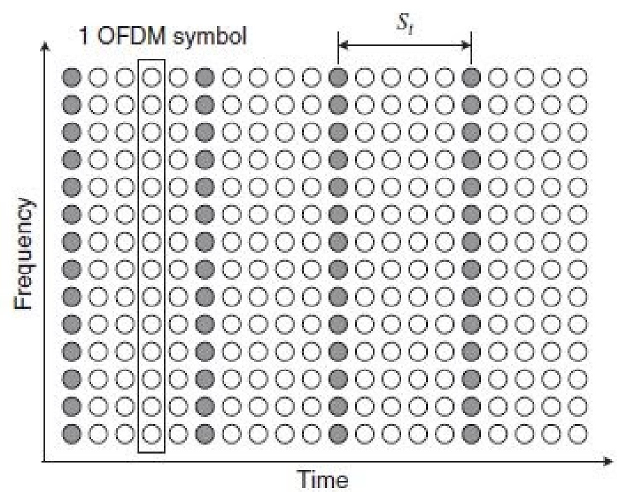

Fig. 8. Block Type - Pilot [5]

2) **Comb type** -In this every OFDM symbol has pilot tones at the periodically-located sub-carriers, which are used for a frequency-domain interpolation to estimate the channel along the frequency axis. It's most suitable for fast-fading channels, but not for frequency-selective channels.Coherence bandwidth is an important parameter as pilot symbols frequency should match the coherence bandwidth which in turn is inverse of the maximum delay spread $\sigma_{\max}$, the This is done to track the frequency-selective channel characteristics.Hence S_f, the period of pilot tone in frequency must satisfy -

$$S_f \leq \frac{1}{\sigma_{\max}} \tag{3}$$

The arrangement is shown below -

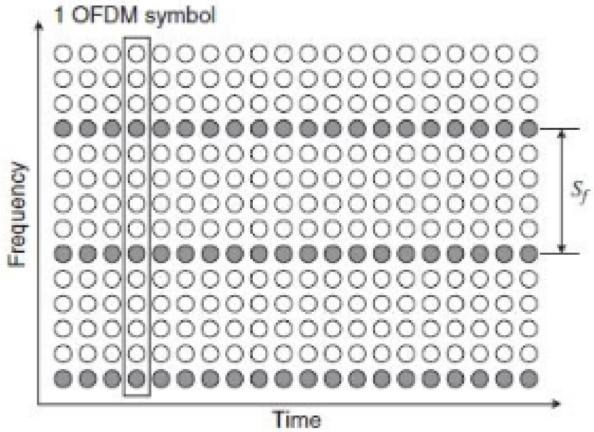

Fig. 9. Comb Type - Pilot [5]

3) **Lattice type** - In this the pilot tones are inserted along both the time and frequency axes with given periods. The pilot tones scattered in both time and frequency axes facilitate time/frequency-domain interpolations for channel estimation.The pilot symbol arrangement must satisfy -

$$S_t \leq \frac{1}{f_{Doppler}} \quad and \quad S_f \leq \frac{1}{\sigma_{\max}} \tag{4}$$

where $f_{Doppler}$ and $\sigma_{\max}$ denote the Doppler spreading and maximum delay spread, respectively. The arrangement is shown below -

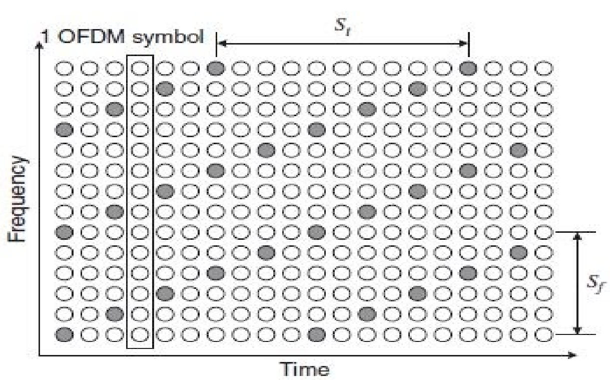

Fig. 10. Lattice Type - Pilot [5]

In this paper, We have opted for frequency domain based pilot symbols as it's a fast-fading channel in accordance with the cyclic prefix. Pilot symbols are added at a regular frequency to the signal for helping in establishing the reliability of the wireless communication channel.Reference used for this [5].

V. Cyclic Prefix in OFDM System

In order for OFDM systems to work efficiently and reliably one of the key element for OFDM data transmission is cyclic prefix. The main purpose of cyclic prefix is that it acts as a buffer region or in other words a guard interval that the protects the OFDM signals from inter-symbol interference(ISI) and inter-channel interference(ICI). One of the way to implement cyclic prefix is to use a cyclic prefix with almost same length as the length of the channel eventually eliminating ISI and ICI, but also using a cyclic prefix of a very short length can make the ISI and ICI to be spectrally concentrated which almost nullifies their impact on the performance of the system [7].

The cyclic prefix however two main functions in an OFDM data transmission : one was mentioned earlier that it basically provides with a guard interval to eliminate inter-symbol interference and second is that it repeats the signal so the convolution of frequency selective channel can be modeled as circular convolution which helps in converting to a frequency domain via Discrete Fourier Transform (DFT) or Inverse Fast Fourier Transform (IFFT). Let us consider a model for

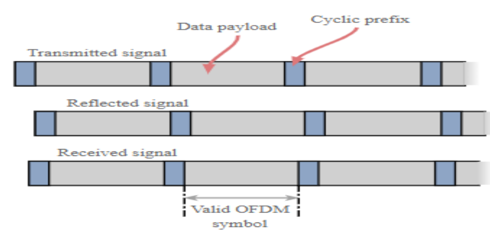

Fig. 11. OFDM Cyclic Prefix [8]

frequency selective channel without some noise as :

$$y(n) = h(0)x(n)+h(1)x(n-1)+h(2)x(n-2)+\ldots+h(L-1)x(n-L+1) \tag{5}$$

As, we can see that this channel not only depends on $x(n)$ at time instant n but also **n-1** and **n-2**, so it has inter-symbol interference in time domain which represents a frequency selective channel. Here, $h(0), h(1), \ldots, h(L-1)$ are the coefficients.

Now lets us transmit two consecutive symbols in OFDM and process them using IFFT :
First symbols are X_0 X_1 $X_2 \ldots$,$X_(n-1)$ and these symbols are loaded in the sub-carriers and are processed using the IFFT operation to get $x(0)$ $x(1)$ $x(2)$ $\ldots$ $x(n-1)$ and,
Second symbols are X_1^1 X_2^1 X_3^1 $\ldots X_{n-1}^1$ and these symbols are loaded in the sub-carriers and are processed using the IFFT operation to get get $x^1(0)$ $x^1(1)$ $x^1(2) \ldots x_{n-1}^1$.
So we successfully transmitted two consecutively OFDM symbol namely x and x^1.
Hence the output of the $x^1(0)$ signal would be :

$$y(0) = h(0)+h(1)x(n-1)+h(2)x(n-2)+\cdots+h(L-1)x(n-L+1) \tag{6}$$

And from the above equation makes it evident that we have inter-block interference(IBI) because frequency selective nature of the channel and now we can use a cyclic prefix to avoid these IBI between blocks of a channel.

Therefore instead of transmitting only the IFFT of the signals we will add a prefix which is :

$$x(n-\bar{L})\ldots\ldots x(n-2)x(n-1) \tag{7}$$

which results in transmitted signal into transforming like :

$$x(n-\bar{L})\ldots\ldots x(n-2)x(n-1)x(0)x(1)x(2)\ldots x(n-1) \tag{8}$$

Basically last $\bar{L}$ samples (or $\bar{L}$ samples from the tail) are taken and prefixed into the transmitted signal which results in transmission of (n+ $\bar{L}$) samples and thus we are cycling samples from the tail of OFDM block to the beginning of the OFDM block to add a prefix hence this is called **CYCLIC PREFIX**.

Because of equation 6, equation 8 turns out to be :

$$y(0)=h(0)x(0)+h(1)x(n-1)+h(2)x(n-2)+\cdots+h(L-1)x(n-L+1) \tag{9}$$

Thus the interference is now restricted to the samples from the same block and this is how we avoided the inter block interference using cyclic prefix.

Addition of cyclic prefix has resulted in circular convolution at the output of the OFDM signal.

The in general equation in frequency domain could be :

$$Y(k)=H(k)\cdot X(k) \tag{10}$$

Here,$Y(k)$ is the symbol on the k^{th} sub-carrier , $H(k)$ is the channel co-efficient of k^{th} and $X(k)$ is the symbol on the k^{th} sub-carrier . And we can notice that each sub-carrier is experiencing **FLAT FADING**. Therefore one of the main motivation we set for OFDM was to eliminate the frequency selective nature of the wireless channel and now we are witnessing with the help of cyclic prefix we are able to convert this wireless communication channel into a frequency flat fading channel across each sub-carrier.

This also proves the advantage of OFDM over single carrier transmission as we are transmitting n symbols in parallel (as compared to single signal in single carrier transmission) over n sub-carriers and the time of each OFDM symbol is n/B here B is net band of transmission and we are expanding the time of each symbol in OFDM (as in single carrier transmission the time was $1/B$) thereby removing the frequency selective nature of the OFDM.

VI. Channel Estimation Techniques : LSE and MMSE

The number of channel estimates that have to be estimated in multiple-input multiple-output (MIMO) system is in general much larger, than in a single antenna communication scheme. This leads to lower signal to noise ratios (SNR) of the channel estimates if a constant pilot power independent from the number of transmit antennas is assumed.The use of long-term spatial channel characteristics can improve channel estimation for MIMO wireless systems. Separating the signal and the noise subspace followed by a dimension reduction can significantly reduce additive noise on channel estimates. This leads to improved channel estimation, especially for MIMO systems with high numbers of antennas, and to lower pilot power requirements. [9] As channel estimation can be either in time domain or frequency domain, the estimators that are used must be relevant to the domain. In this paper most of the mathematics deal with frequency domain,Hence the most widely sought after estimators, LSE(Least Square Estimation) and MMSE(Minimum Mean Square Error) [10] algorithms are used.

Least Square Estimation(LSE) is a relatively simple and easy to implement algorithm.The complexity is also very low.Its calculated by minimising the euclidean square distance between the transmitted and received power signal. It's usually accompanied by a high Mean Square Error.The LSE channel for sub-carrier on which pilot symbols are located is given by -

$$h_p^{LS}=X_p^H y_p \tag{11}$$

here,h_p^{LS} is LS estimation channel frequency response and, X_p^H is transmitted symbols and, y_p is the received signals

Minimum Mean-Square Error Estimator(MMSE) is a relatively complex and difficult to implement algorithm as it involves convolution and inverse matrix mathematics. Usually the normalisation of transmitted data is done to reduce the MMSE. The MMSE channel estimation applies the channel statistics to minimise the MSE estimate of the channel responses is given by -

$$H_p^{MMSE}=R_{HH_P}\left(R_{H_PH_P}+\sigma_\mu^2\left(XX^H\right)^{-1}\right)h_p^{LS} \tag{12}$$

here, R_{HH_P} is the cross-correlation matrix between all sub-carriers and sub-carriers with reference signal, $R_{H_PH_P}$ Auto-correlation matrix of sub-carriers of reference signal.

Due to the inversion matrix lemma, the complexity of MMSE estimator is high. Every time inversion is needed data changes. By transmitting the average data the complexity of the estimator can be reduced, therefore we replace the term,

$$\left(\mathrm{XX^H}\right)^{-1}=\mathrm{E}\left[\left(\mathrm{XX^H}\right)^{-1}\right] \tag{13}$$

Therefore, the simplified MMSE estimator becomes,

$$H_p^{MMSE}=\mathrm{R_{HHp}}\left(\mathrm{R_{HpHp}}+(\beta/\mathrm{SNR})\mathrm{I_p}\right)^{-1}h_p^{LS} \tag{14}$$

VII. Monte Carlo Simulations

Monte Carlo simulations is a tool for simulating the results while taking in account the risk factor of the operation. Its highly useful in quantitative and qualitative scrutiny of data.Its more of a reformative tool that allows the user to gain insight into a wide range of possible outcomes that they may encounter while running simulations.Monte Carlo is specially useful in showing edge cases for a scenario, with best and worst possible outcomes, along with the cases in between available for scrutiny. A major mathematical concept it uses from the field of probability is pdf (or density function).Hence it accounts for the weighted probability of what the outcome may be.In this way, Monte Carlo simulation provides a much more comprehensive view of what may happen. Wen-Long

Jin,et al[11], showed that Monte Carlo simulations gave similar results to analytical models built for evaluating results of Inter Vehicle Wireless communication. This improved as the number of iterations were increased. Further Monte Carlo simulations can be of various types as illustrated in the chart.

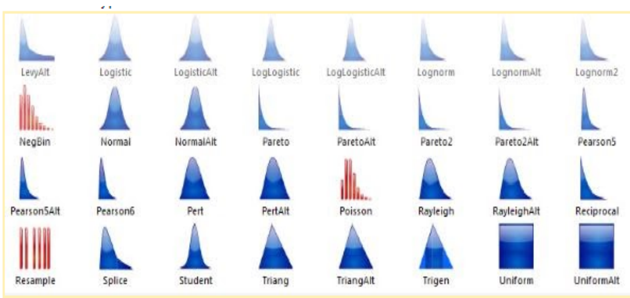

Fig. 12. Various types of Monte Carlo Simulations[12]

VIII. Hard Decision Decoding

In this paper, We have employed the use of Hard-decision decoding over other techniques such as soft decoding,etc. This technique basically intakes a stream of bits from the receiver end and samples the pulses received. It compares the samples with a fixed threshold value and irrespective of the difference between the sample and the threshold,assign it as 0 or 1.

Following the example and methodology of Ohno,et al.[13],We implemented only one Inverse Fourier Transform(IFFT) at the transmitter and one Fourier Transform (FFT) at Receiver end. This was found to be most computationally efficient and least taxing on the hardware. Further it's the most bandwidth efficiency loss minimising setup.

IX. Results

Following are the step by step results gathered from the execution and implementation of the code.

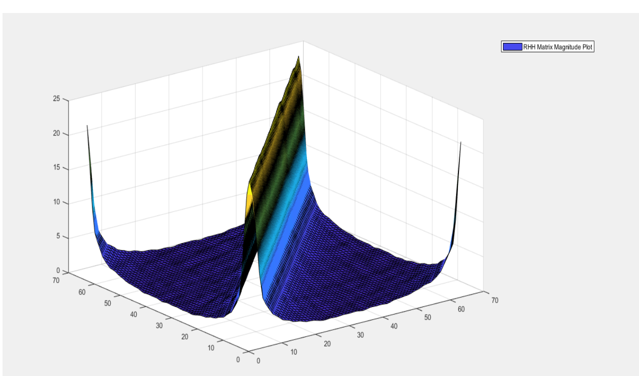

Fig. 13. Auto Covariance of the Channel Frequency response

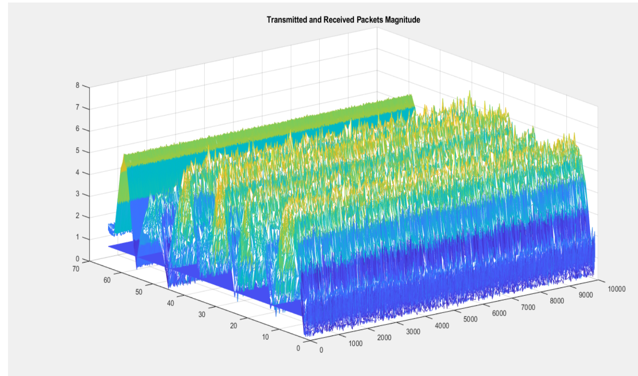

Fig. 14. Transmitted and Received packets Magnitude

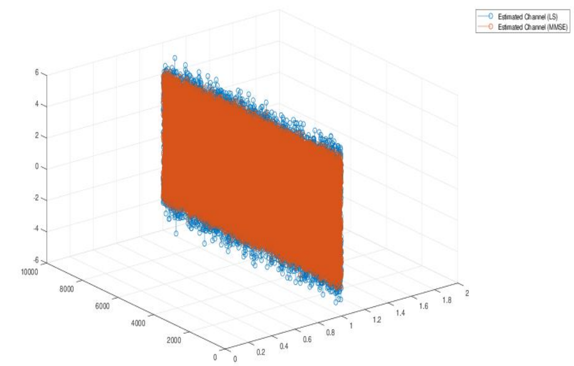

Fig. 15. 3D plot of Channel Estimation in LS and MMSE

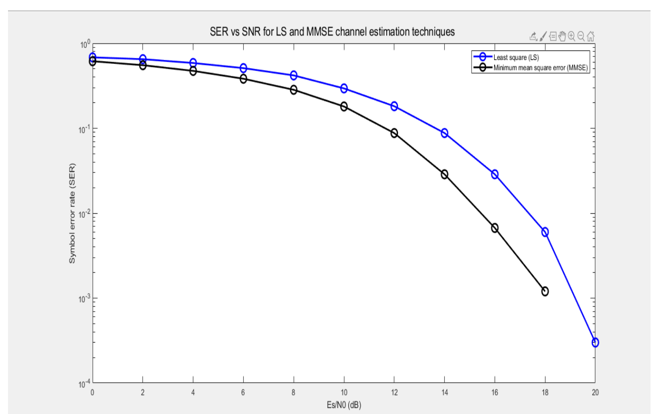

Fig. 16. Channel Estimation plot of LS and MMSE

X. Conclusion

In this section we discuss the aforementioned results. We need efficient channel estimation techniques that can combat the dynamically changing channel.The RHH 3D plot gives the shape of a (type of value RHH is). It's a typical mathematical curve with a peak in center along the axis. The transmitted and received packet are also plotted in 3D for all n=10000 so as to emphasise on the difference in their values on a macro level. Then we developed a plot for the Estimation by LSE and MMSE.This provides a rough picture and insight into the results we can expect. Finally a plot for BER vs SNR has been generated of the LSE and MMSE for various SNR's. It's evident from the last plot that even though LSE is easier to implement than MMSE and easy to fit, the results provided by MMSE are more accurate. It can further be seen that for lower values of SNR, LSE and MMSE values map each other. When the SNR is augmented, LSE performs poorly in comparison to MMSE. It would be interesting to find the inversion point of this trend.

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CONTRIBUTION

Respected Sir,

With all due respect sir, we would want to bring a major point to your notice. Our BTP was a fruition of our team effort and hard work. No individual section of our project (from codes to simulink to documentation) was the work of a single member. We organized numerous meets to coordinate and work on everything together. Every idea was the result of us brainstorming as a team. As a result we think it's impossible to find clear cut boundaries of everyone's work. So we make this plea that you grade us equally. For every error, the whole team is responsible and every gain is our coordinated and collective effort.

As each and everyone had helped the other in each task from codes to simulink and finally drafting the paper and the presentation. We request you to grade us as a whole.

Submitted for your purview.

Hoping for your favourable consideration.

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