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Channel Estimation using Frequency Index Modulation for MIMO-OFDM on Doubly Selective Faded Noisy Channel

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) plays an important role in wireless communication due to its high transmission rate. Information is conveyed across spatial and temporal dimensions in space time shift keying (STSK) technique which is basically used to handle multiplexing diversity and gains. On the other hand, index modulation integrated OFDM not only communicates information through conventional signal constellations as in classical OFDM, but also through indexes of the sub-carriers. OFDM integrated with index modulation communicates signal or information through conventional signal constellations as in classical OFDM, but also through indexes of the sub-carriers. In index modulation, the sub-carriers are transmitted over particular index and can be implemented effectively. The active indices are chosen and further information bits are transmitted. This paper examines frequency index modulation to increase throughput and bit error performance by carrying extra bits of information in each subcarrier block and to reduce detector complexity. In this paper deep neural network-based channel estimation performance analysis is performed for doubly selective faded noisy channel with frequency index modulation for OFDM. The DNN takes the advantages of the LMMSE channel estimation to further improve the performance. The DNN is first trained with simulated data and then it tracks the dynamic channel state. Bit error rate (BER) are evaluated for carrying out performance information in each subcarrier block and to reduce detector complexity.

Keywords: *OFDM, Frequency Index Modulation, Channel Estimation, Bit Error Rate*

1. INTRODUCTION

One of the most prominent multi-functional MIMO (Multiple Input Multiple Output) technique is the Space-Time Shift Keying (STSK). The tasks of transmission diversity and multiplexing are very successfully achieved through these techniques [1]. The spatial shifting key (SSK) and spatial modulation (SM) just receive diversity gains while Space-Time Shift Keying (STSK) transmits as well as receives diversity gains. This implies that the information is distributed in temporal and spatial dimensions through STSK. Traditional PSK/QAM symbols are employed to map the information and one of the dispersion matrices gets activated for the transmission of additional information [2]-[5]. One of the major challenges pertaining to broadband fade channels is multipath fade distortion and this distortion is often dealt with by multi-vector modulation. This is done through the attainment of a few parallel channels from dispersive broadband channels through a narrow channel with flat attenuation [6][7]. The most commonly used MC modulation technique is the orthogonal frequency division multiplexing (OFDM). The reason being, a low complexity implementation is offered by it and it is the most robust amongst the broadband channels. OFDM is assisted with STSK to overcome the degradation of SC-STSK pertaining to broadband channels. The indexes involved in the transmitting antennas of a MIMO system are used along with constellations of conventional Mary signals in SM. The traditional MIMO schemes depend on spatial multiplexing for data rate enhancement and spatial diversity for improvement of error performance. In an SM scheme, multiple transmission antennas related to one MIMO system are employed in another ending [8][9]. Within SM, information is carried by two units: the constellation symbols M-ary and the transmission antennas. In order to examine the channel performance other than MIMO, the OFDM was integrated with index modulation. Within index modulation, the transmission of sub-carriers is carried over specific index and its implementation cold be done effectively. The IM concept derived from SM is considered as the basis to propose a new multi-vector transmission scheme such as OFDM-IM. The incoming bit stream gets divided into M-bit constellation bits and index selection through the OFDM-IM diagram [10]. The present analysis involves the investigation of frequency index modulation within OFDM-IM and it also carries out the performance analysis. The channel estimation techniques pertaining to the related work is carried out in section2. The procedure for frequency index OFDM-IM technique is described in the section 3. The analysis of the results and discussion is carried out in section 4.

2. LITERATURE REVIEW

Araújo et al. [1] Author has presented new CSI estimation techniques for huge MIMO-OFDM systems that take advantage of the channel's sparsity and multidimensionality. By supposing that, the BS and UE get a finite range of RF chains, the presented tensor-based estimators allow UEs to calculate the MIMO channel. The MIMO channel is frequency-selective, and the framework has restricted pilot assets for channel collection, which allows for lower training costs. T-MMSE is an excellent choice for a larger number of routes, but T-OMP-JS and T-OMP-SS are better in terrible dispersion conditions with a lesser variety of pathways because of their excellent complexity-performance tradeoffs.

Qiao et al. [2] Researchers have summarized practically all of the work available on channel estimation and equalization in UWA MIMO-OFDM systems in this study. All of these studies focused on distinct aspects of channel estimation or equalization, and a variety of techniques were suggested and evaluated to address specific challenges. The minimization in time and space complication of the receiver, as in MIMO transmission, is a similar topic addressed by most of these recommended techniques.

Zhu et al. [3] Researchers investigated resilient safe beam forming architectures for a power dividing MIMO SWIPT IoT systems in this research, using a non-Linear EH framework with co-operative jam and norm-bounded channel uncertainty. The specified problem formulation has been reduced to a two-layer form that is manageable. An SPCA-based iterative approach has been developed to lower the evaluation cost of the 1-D search approach. The presented robust architecture performs better in traditional systems, according to simulation results.

Zhang et al. [4] In this research, authors have focused on modelling and investigation of the narrowband DPA-MIMO based transceiver system, and for this type a dispersed array-of-sub-arrays structure functioning on mmWave bands, researchers proposed effective channel estimation and hybrid pre-coding techniques. Because of the partially shared scatterers across the scattered sub-arrays at mmWave frequencies at the TX/RX, the DPA-MIMO channel has a significant potential of manifesting a hidden structural sparsity in the beam-domain channel vector. Researchers have devised an organized SMV issue for estimating the AoDs, AoAs, and related gains of relevant pathways. The open-loop training beam designs were constructed by decreasing the total coherence of the corresponding measurement matrix in order to provide strong recovery outcomes and minimize the training response overhead.

Kuai et al. [5] In this research, they use the organized Turbo-CS architecture to leverage the sparsity architecture of the huge MIMO-OFDM channel to enhance prediction performance in both the angle-frequency and angle-delay domains. They demonstrate though for a small N, the suggested STCS-based algorithms may be well forecasted by condition development. Lastly, actual spatial channel designs are investigated using STCS-FS and STCS-DS.

Schulz et al. [6] The revolutionary idea of low-cost optical wireless links for the backhaul and fronthaul of tiny radio cells in 4G and 5G mobile networks is presented in this research. LEDs serve as transmitters, while photodiodes serve as receivers, all of which are combined with rate-adaptive digital signal processing. Throughout the complete evaluation period, the visible range was never less than 180 m, with 1 km seen in more than 99 percent of the time. When mist and sunshine were present occasionally, rate-adaptive broadcasting greatly increases accessibility.

Shakeri et al. [7] The sparse channel estimation issue for (large) MIMO-OFDM systems was investigated in this paper. Dependent on the quantity of learning pilot tones, researchers presented the separate block diagonal framework for training data and derived conceptual assurances for channel restoration. In addition, they looked at the repeated block diagonal paradigm for training samples, which yields Tucker decomposition for the analyses. In comparison to standard recovery strategies, this approach enables for the restoration of channel coefficients utilising sparse tensor recovery methods, which utilise fewer computing parameters and storage.

Ren et al. [8] In this study, an STBC-OFDM system is suggested and used in UWA communications as a mix of OFDM and MIMO technologies. Due to the sparsity of the UWA channel, the multi-path sparse communication system is investigated. Simulated approximation of the UWA channel uses CS concept. The estimate of the MIMOOFDM UWA channel is enhanced using an enhanced OMP technique for uncertain signal sparsity.

3. METHODOLOGY

As with advancement of communication system since last few years, there is advancement in speed of data transmission over channel. As it is known that first-generation and second-generation data communication was limited to only text and voice message. Further in third generation, mobile and web application services was advanced over text data. And finally, in fourth generation communication system was advanced with video data or live video conferencing with high data quality in 3D graphics. Similarly, fifth generation is also advanced and currently researchers are developing techniques in 5G scenario. As with advancement of lifestyle of an individual's requires accessing of communication services at anywhere at any time with high data transmission speed [1].

With increasing demand of high data speed at high quality had increased the congestion rate or increased the data traffic rate in wireless environment. So as to fulfil the increasing demand of data speed and its quality many research work are focused in order to reduce the hurdles in 4G or 5G communication channel. Broadband communication is termed as idea that shows the capability of the wireless channel [2]. Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technique that is used for high data transmission rate with improved quality in noisy wireless channel. could be a technique used for high-speed data transmission over indoor and outside wireless communication systems which divide the signal bandwidth into many subcarriers before the transmission of data bits from transmitter.

In such multicarrier modulation technique, the available channel bandwidth is divided into many narrow subcarriers with specified frequency range that means a small fraction of bandwidth is allotted to each sub carriers. The overall throughput of the OFDM will be the combination of throughput of each subcarrier. Therefore, the information rate of each sub-carrier is also a fraction of overall system. This feature of OFDM system supports to design a system that would be capable for supporting high data transmission rates with maintenance of the memory of the channel. Orthogonal Frequency Division Multiplexing (OFDM) is a type of application in wireless channel that reduces the multipath fading caused due to obstacles in the path of transmitting data that makes the system complex [3]. The idea of IM can be referred for the systems of communication other than the systems of MIMO. Example- IM techniques can be implemented impressively as sub-carriers of the system of OFDM.

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OFDM-IM is a latest scheme of multi-vector transmission proposed on the basis of concept of IM from SM. The diagram of OFDM-IM distributes the coming bit stream into the M-bit constellation bits and index selection only a subgroup of available subcarriers is picked as active while rest inactive subcarriers are set as zero and are not used, pursuant to index selection bits. On the other hand, The modulation of active subcarriers are done on the basis of M-ary constellation bits. Moreover the transmission of information is not only done by data symbols like classic OFDM but also done by the active subcarriers indices, used for the transmitting the corresponding symbols of data for scheme of OFDM. If you are finding system of an OFDM with NF subcarriers then you directly prefer the active subcarriers indices, like techniques of IM used in the transmission of antennas of MA-SM system. For each frame shown in the fig 1 a total of

$$m = pG = (\log_2 \binom{N}{K} + K\log_2 M)G \qquad (1)$$

transmitted bits where $p = p_1 + p_2$ and $p_2 = K \log_2 M$. j_g and s_g indicates the selected indices vector and symbols of M-ary with K×1 dimensions, respectively.

Primary, the creator of OFDM-IM subblock create the N×1 subblocks of OFDM-IM x_g where g = 1, . . . , G, then the creator of OFDM-IM block gets $N_F \times 1$ main OFDM-IM frame x by combining these G subblocks of OFDM-IM.

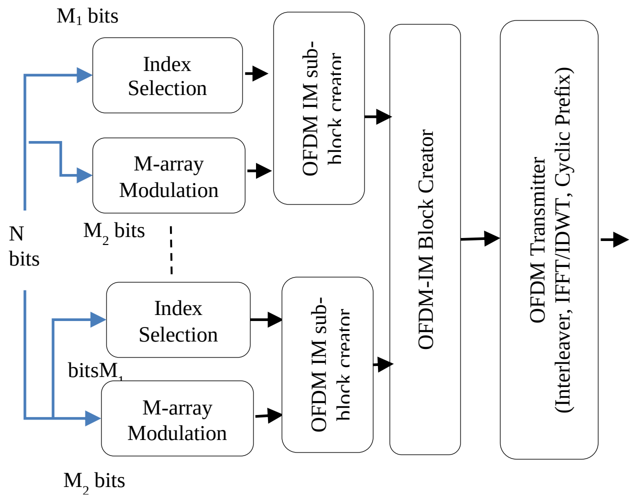

Figure 1. OFDM-IM Transmitter

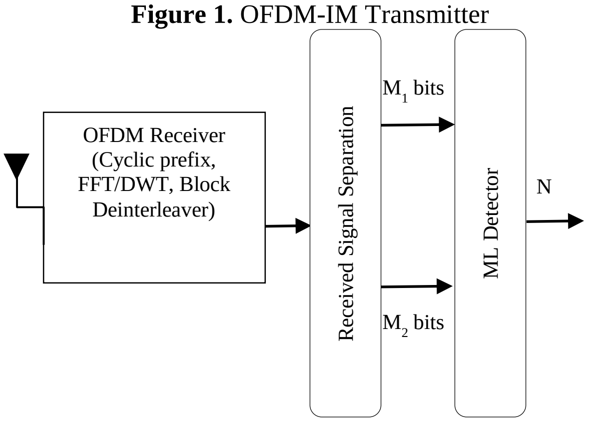

Figure 2. OFDM-IM Receiver

Further, interleaving of G×N block can be processed for ensuring that subcarriers of subblock are dominanced by uncorrelated fading wireless channels. At the end, the procedures of classical OFDM like cyclic prefix (CP), inverse fast insertion, digital-to-analog conversion (DAC) and Fourier transform (IFFT), are applied. The noise in the wireless channel is further estimated using channel estimation techniques.

It is an essential technique mainly used in wireless system. Due to continuous mobility of the transmitter or receiver with respect to change in time in wireless communicating channel, the transmitter or receiver is affected from surroundings i.e. buildings, poles, hills, vehicles, flats, congestion, etc. This results in reception of distorted transmitted signal that causes difficulties in recovery of original data bits. For high precise transmission there is requirement of channel estimation at the mobile receiver end for high quality of service (QoS) [7]. In this paper, frequency index modulation in OFDM-IM is investigated and analyzed the performance which are discussed in further sections.

3.1 System Models and Techniques

The number of information bits which are processed within each group is represented by b and N represents the number of parallel groups in which the information bits have been divided into. b_N represents number of information bits. Out of the X_n available indices, X active indices will be assigned by the index modulation selector. Then, K code words are generated through the sub-inputs N_2 of m bits that remain. For the improvement of BER and getting diversity gain enhanced, the active indices are employed to map and inter-leave L code words. The series to parallel conversion takes place for the generated data and a single frame is formed from it. The OFDM modulation is then done and the data gets transmitted. For the system proposed in the present research, OFDM modulation along with Nc subcarriers is considered. The subcarriers have equal division of N groups. Within the frequency domain of each group Mg= Nc/N subcarriers exist. Within each group of subcarrier, the number of indices in active state is K and the available number of subcarriers is Na within the virtual domain. Very large values may be assumed by Nc and if it is directly related to the Nc, multiple combinations pertaining to the active indices exist. The selection of active indices is thus a hectic task. In order to select index, the subcarriers are divided into N smaller groups. At the transmitter's input, the division of information bits is done into G groups. The upcoming sections discuss the details pertaining to the transmitter and receiver models.

3.2 Transmitter Model

The bG data bits are divided into N groups that have length of b bits. The IM selector and the convolution STTC encoder are then utilized to process these b bits within each group of the transmitter. As far as the operational strategy method is considered, the square codes are different in comparison to the convolution codes. At this stage, we do have complete information about the memory component quantity, the quantity of bits input to the encoder and the output from it. Gone are the days when the encoder was just a black box. The reason being, there was no information about the components utilized for the creation and extraction of bits from the information. In order to understand the manner in which memory components are connected to the encoder to perform encoding, the so called 'generator polynomials' are effectively utilized.

3.3 Channel Fading and Noise: Doubly Selective Fading

The propagation model of free-space provides us a simple explanations for the propagation loss in the theoretical manner, while transacting with satellite and other systems of communications where receiver and transmitter have the line of sight between each other. However, several obstructions can interlope in the signal transmission with the ground communications. The signals to be diffracted and reflected by many surfaces (like densely wooded areas ,buildings, rough terrain and mountains) for arriving to its destination. These obstacles affect the division of signals and reason behind delay or their arrival at narrowly distinct times. This terminology is called as multipath propagation and causes as a real world communications terminology called as fading.

The time selective and frequency selective channel model is stated in equation (2)

$$h(t,\tau) = \sum_{l}\sum_{\mu} a_{l,\mu}\exp[j(\varphi_{l,\mu} + 2\pi f_{max}\cos(\beta_{l,\mu}t))]\delta(\tau - \tau_l) \quad (2)$$

Where, l = Index for multipath $\{0 \le l \le L\}$, $a_{l,\mu}$= Path dependent amplitude, $\varphi_{l,\mu}$ = Arrival angle, $\beta_{l,\mu}$= Phase, τ_l = Time delay

In the communicating channel, noise is analyzed by some ideal noise values that exists in real scenario and termed as Additive White Gaussian Noise (AWGN). Such noisy channels generates noise that is independent to frequency and causes distortion to the transmitted signals.

Inspite, AWGN is calculated on the basis of its spectral power density which is calculated as in equation 3:

$$S_W(f) = \frac{N_O}{2} \quad (3)$$

In the equation N_0 is a constant value and the factor 1/2 is assumed which indicates that the ½ of power spectral is associated with positive frequencies and the other half with negative frequencies. In AWGN, the amplitude of noise is distributed over the channel using Gaussian function. As AWGN is simple to implement and easy to understand its mathematical model.

3.4 Receiver Model

By proper utilization of the channel model at the ncth subcarrier that exists between the nth receiver antenna and the mth transmitter antenna, and the subsequent CP removal, the following mathematical equation is achieved.

$$Y[n] = H[n]*S[n] + noise[n] \quad (4)$$

Y[n] = Received at nth sub-carrier, H[n] = Channel Matrix, S[n] = Compressed b_g transmitted prior to the detection can thus be obtained, Noise[n]= channel noise

The block splitter then absorbs the received signal Y[n] and the detection of received signals within N groups is done specifically. The Y[n] signal is received within the nth group. An enhanced data rate within the time delay spread environments that have effective equalization is supported by orthogonal frequency division multiplexing or OFDM. The channel state information (CSI) is required for equalization. The OFDM systems receive the pilots within the predetermined subcarriers as training signals. The guard interval is employed to drop the inter symbol interference within the channel estimation.

The following relation represents the received signal:

$$Y(k)=X(k)H(k)+W(k) \quad (5)$$

Where, Y(k)= received signal vector, X(k)=matrix that composes the transmitted signaling points within the diagonal, H(k)=channel attenuation vector

3.5 Deep Neural Network based Channel Estimation

This work is intended towards noise estimation in AWGN channel. So, channel estimation is a technique that is used to estimate the impact of noise to transmitted data bits. As in actual scenario there is existence of noise in the channel which causes distortion to the transmitted bits and received bits will not be the what that send actually. So, it is quite necessary to estimate the noise level in channel. With the help of this technique receiver can recover the original transmitted signal with minimum error rate. It always helps receiver to equalize the received bits further as the transmitting channel is partially or fully known to them which helps to measure the characteristics of the channel.

A broadband radio channel is always provided with selected frequency and time domain which limits their range. Whereas, in mobile communication OFDM system data bits are transmitted in different sub-carriers which identified as uneven for the transmitting channel because these sub-carriers are transmitted in different frequency as well as time domain.

So, there is need of dynamic channel estimation technique which may adapt according to transmitting scenario. Non-blind or pilot-based channel estimation is quite adaptive to such dynamic environment. As there are two types of pilot-based channel estimation technique. One is block based and other is comb type. The figure 4 shows the block type pilot arrangement for channel estimation. As from figure it is noticed that the pilot symbols or bits are arrangement at specified location in time domain vertically. Such arrangement is best suited in short range radio signals. As these symbols are inserted in time domain so it is insensitive to the frequency selection.

Another type of pilot arrangement is comb type which is illustrated in fig 5. In comb type the pilot bits or symbols are arranged distributed uniformly among each OFDM block. In such scenario it is assumed that the transmitted signal contains identical pilot arrangement. In such type of arrangement their is requirement of high data transmission range which is resistive to the fading environment. As OFDM system transmit data in sub-carriers, so each sub-carriers contains pilot symbols and channel interpolates the non-pilot containing sub-carrier with pilot carrying sub-carriers. The comb type arrangement is arranged in frequency domain and is sensitive to the frequency selection.

As a reference signal, pilot symbol is used to estimate channel noise which is wireless medium. Whenever short CP is employed then first and fifth symbol slot is selected in OFDM signal. Similarly, long CP is selected first and fourth symbol slot are selected in OFDM signal bits.

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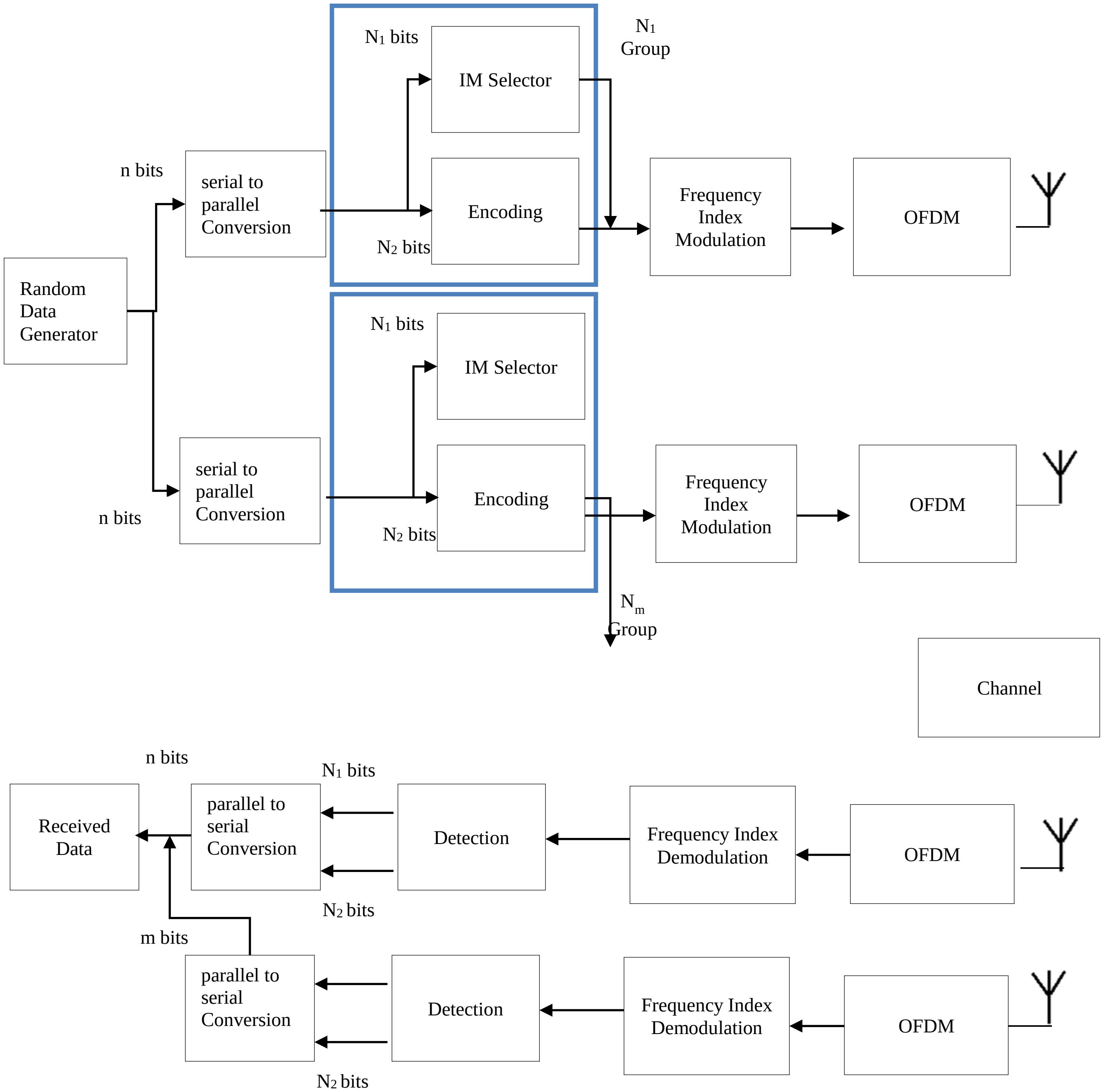

Figure 3. The transceiver architecture

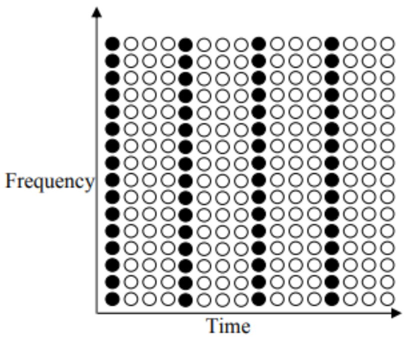

Figure 4. Pilot Bit Insertion as Block Type

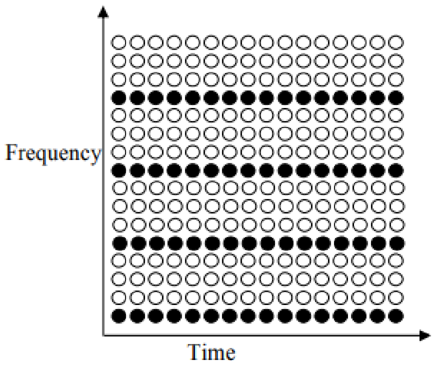

Figure 5. Pilot Bit Insertion as Comb Type

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3.6 Linear Minimum Mean Square Error (LMMSE) Channel Estimation

One of the optimal channel estimation technique is Linear minimum mean square error (LMMSE) with respect to mean square error rate but with high complexity. This technique is used to track time and frequency domain. The information of noise and channel statistics is required which was priori unknown at the receiver for LMMSE estimation. The LMMSE estimation is performed along the frequency domain and the minimum cost function is estimated as in equation 6:

$$J(LMMSE) = E\{||H_n - DY_n||^2 \qquad (6)$$

Where, D = Matrix whose coefficients have to be optimized

H_n^{LMMSE} = The estimated channel frequency response vector

$$H_n^{LMMSE} = D_{opt} Y_n \qquad (7)$$

Where D_{opt} = The channel covariance matrix along the frequency axis and calculated as in equation (8):

$$D_{opt} = R_H X_n^H (X_n R_H X_n^H + \sigma^2 I)^{-1} \qquad (8)$$

Where, I= M*M identity matrix

R_H = M*M channel covariance matrix along the frequency axis

And $(.)^H$ is the Hermitian transpose

σ^2=noise variance

$$H_n^{LMMSE} = R_H X_n^H (X_n R_H X_n^H + \sigma^2 I)^{-1} H_n^{LS} \qquad (9)$$

H_n^{LS} = Channel frequency response vector with LS estimated samples

3.7 Deep Neural Network based Channel Estimation

As shown in fig 6, the given algorithm for estimation of channel based on the DNN has two levels, such as training level and testing level.

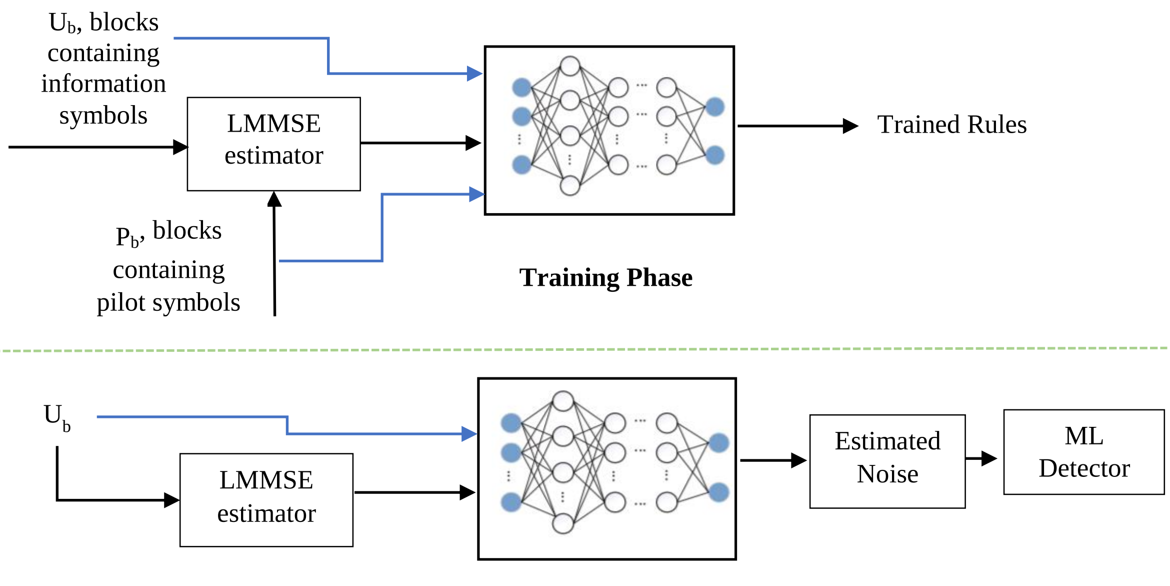

Figure 6. DNN based channel estimation

The estimator of channel based on DNN taken the completely coupled feedforward deep neural network with N−2 hidden layers and N layers. Hidden layers includes 'n' neurons, Each neuron shows a nonlinear change of weighted total of values of output of the preceding layer. The statement for the function of activation is as follows:

$$f(x) = \begin{Bmatrix} 0 \; for \; x < 0 \\ x \; for \; x \geq 0 \end{Bmatrix} \qquad (10)$$

Primarily, the DNN is tutored with simulated data. The channels can be tracked dynamically with the help of DNN with tutored regulations in the testing stage and then symbols that are transmitted are recognized. Training Phase: Suppose that the sub-block including all pilot symbols be 'Ub' in mth block. The pilots and symbols of information are both called and appended as DNN's input data in the training phase. This DNN takes estimations of LMMSE as an input and tutor the model. Testing Phase: The accepted symbol of channel information is fed to DNN, having the similar structure as in training phase. The parameters that are trained are loaded and input is transferred for estimation channel prediction. Then recognizer of ML is used in getting information bits estimation.

4. RESULTS AND DISCUSSION

4.1 Simulation Setup

In this section, the simulation setup of DNN based channel estimation is presented. In our implementations, we have utilized the MATLAB platform for training and testing scenarios. The training is performed with different data samples. The DNN models are trained on different data samples. For training, the model simulation was performed with 10000 data samples in which 7000 data samples are used for training and 3000 data samples are used for testing. The learning rate was set to be 0.0003. In simulation of proposed methodology, Bit Error Rate performance is analyzed under

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AWGN channel with frequency index modulation technique. The methodology is simulated and compared with each other with variable signal to noise ratio (Eb/No) which are shown below. The BER performances of these schemes are evaluated by Monte Carlo simulations.

4.2 Performance Parameters

While simulating the deep learning model, the performance parameters used here are Bit Error Rate (BER). The bit error rate represents the error while channel estimation and equalization of received data. This is evaluated by finding the difference between transmitted and received equalized value. BER is calculated as in eqn (11).

$$BER = \frac{(x_t - x_r)}{N} \tag{11}$$

Where,
x_t=transmitted data samples.
X_r= received data samples.
N= Number of samples.

During training, another parameter used in this paper is mean square error (MSE). MSE is calculated as by evaluating differences between targeted and reconstructed values. MSE is calculated as in eqn (12).

$$loss_{mse} = \frac{\sum_{i=1}^{N}((x_t - x_r)^2}{N} \tag{12}$$

Where, x_t=target value, X_r=reconstructed value, N= Number of samples.

4.3 Results

Figure 7 represents the BER performance of frequency index modulation for MIMO OFDM. The figure represents that after 6db noise in the channel there is constant BER. The figure illustrates that there is high BER at low SNR value and it decreases with increasing SNR. Similarly, in figure 8, MSE was evaluated with varying SNR. A comparative graph is presented here in which MSE while testing is evaluated using proposed DNN algorithm and LMMSE [19].

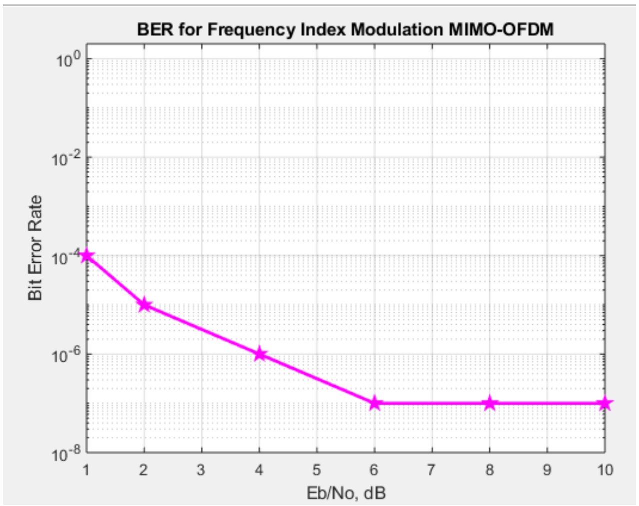

Figure 7. BER Performance Evaluation

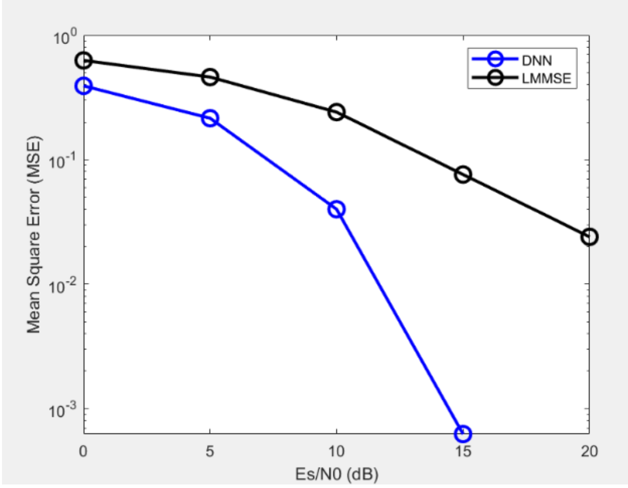

Figure 8. Comparative MSE Analysis for DNN and LMMSE based Channel Estimation

5. CONCLUSION

Modulation index is an emerging term in which indices are used to store information and paired with transmission resource such as subcarriers. It has been discovered that OFDM-IM (OFDM with IM) is more profitable frequency-domain technique of IM in comparing with the classical OFDM in the contrast. In this paper, we have proposed a modulation algorithm are used with space time frequency indices that reduces the complexity when transmitted over frequency selective transmission channels. This paper also includes the algorithm of channel estimation based on the DNN for channels of doubly selective. The algorithm of DNN profits from the generalization capability of deep learning and excellent learning, and needs no especial knowledge about the statistics of channel. The outcomes represent the enhancement of estimator of DNN over LMMSE. The limitation of this work is that with low SNR value there is a decrease in estimation performance which needed to be optimized. These limitations can be improved in the future.

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