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ANALYSIS OF PAPR, BER AND CHANNEL ESTIMATION IN MULTI CARRIER MODULATION SYSTEMS USING NEURAL NETWORKS

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ABSTRACT

The interference cancellation (IC) technique is a good choice for channel estimation (CE) in orthogonal frequency division multiplexing (OFDM) and Filter Bank Multicarrier (FBMC) systems due to the fact that it has a high level of accuracy in CE. FBMC is a crucial mechanism employed in 5G networks to optimize the available bandwidth while satisfying the demands for high spectral efficiency (SE). It is a feasible substitute for the OFDM modulation technique. The primary objective of this article is to examine the process of CE and IC, peak to average power ratio (PAPR) and bit error rate (BER) analysis in FBMC. Neural networks (NNs) are employed to approximate the optimal channel and retrieve the accurate transmitted signal with a minimal BER. We employ scattered pilots in both the time and frequency domains to estimate the channel for doubly-selective channels (DSC). Additionally, we utilize low-complexity IC techniques. The proposal for CE and IC includes the implementation of NN. The output sequences generated by the CE and IC algorithms serve as inputs for the NN. The results demonstrate that the proposed strategy closely approximates the ideal channel and exhibits a better BER performance compared to previous methods. This approach almost enhances the accuracy of CEs and significantly reduces the computational complexity (CC) in 5G networks.

Keywords : *BER, channel estimation(CE), Deep learning(DL), FBMC, interference cancellation(IC), MMSE, OFDM, PAPR, Recurrent neural network(RNN), LS, LSTM.*

1. INTRODUCTION

Future wireless systems must possess the capability to accommodate a diverse array of prospective applications, encompassing transmissions with little delay, machine-to-machine (M2M) interactions, and large data rates. Traditional OFDM is incapable of flexibly allocating the available time-frequency resources due to its inadequate spectrum behaviour. FBMC is a highly effective alternative to OFDM for a wide variety of applications, because to its significantly enhanced spectrum characteristics. CE and IC are crucial processes for achieving accurate signal

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recovery with a low BER under conditions of low Signal to Noise Ratio (SNR). FBMC is a widely used transmission method that operates inside the structural framework of the upcoming 5G technology. This process plays a important role, especially in the context of 5G, where there is a strong need to obtain a significant 1000-fold increase in data transmission speeds. The modulation scheme of FBMC [1] is based on the multicarrier (MC) approach, which is a versatile method that enables the achievement of FBMC's communication goals. MCM involves using a waveform that consists of numerous carriers placed closely together in a specific block to transmit data. The carrier blocks assemble in a structure called a filter bank, which is a crucial architectural component of the FBMC system. Current research in mobile communication systems is focusing on exploring highly flexible 5G networks, which is a departure from the previous paradigms of 3G and 4G networks [2]. In the context of the demanding requirements of 5G technology, MCM is seen as a powerful tool that can effectively meet the diverse needs of this advanced environment. It is important to note the similarity between OFDM and the previous 4G modulation technique in this situation. OFDM, which precedes MC, incorporates a cyclic prefix (CP) as a guard interval, significantly reducing both inter symbol interference (ISI) and delay in wireless networks. Although the OFDM approach has virtues, it also has drawbacks that reduce its effectiveness in addressing the difficulties of 5G. One of the main issues with this is that it limits the efficiency of bandwidth usage. This problem is made worse by its vulnerability to increased side-lobes, which leads to a significant increase in spectral expansion [3].

2. RELATED WORKS

The investigation on CE in FBMC system is enhanced by the introduction of a new scattered pilot technique, which is supported by evidence in [4]. This strategy relies on the identified use of a small number of additional pilot symbols, carefully employed to reduce the impact of imaginary interference on every individual pilot [6]. Expanding on this significant advancement, a sophisticated combination of transmitting numerous signals simultaneously and cancelling interference at the receiving end, as described in [5], creates a revolutionary strategy. This complex coordination results in an effective approach, characterized by the careful elimination of internal disturbances without accidentally leaving out any data symbols. This methodological enhancement inevitably brings about increased SE, surpassing the standards set by previous approaches. In order to clarify the fundamental principles, [5] presents a predictive approach specifically designed for channels that are both time-varying and frequency-selective. This approach utilizes the time and frequency correlations to enhance the effectiveness of the scatter pilot constellation [6]. The authors propose a technique that utilizes power multiplexing in the transmitter and a successive interference cancellation (SIC) method in the receiver to eliminate intrinsic interference. This technique does not compromise any data symbols and achieves a higher SE compared to previous techniques mentioned in [7]. The method they provide predicts DSCs by utilizing the time and frequency correlation of the scatter pilot. A technology called iterative interference cancellation (IIC) is employed to mitigate interference at the pilot and data positions. This strategy is suitable to any linear modulation method, including OFDM and FBMC [8]. The authors in [9] devise a distinctive preamble structure to improve the performance of CE. Within this symmetrical configuration, the interference weights are considered and the symmetry pattern is utilized to effectively eliminate the interference. MCM systems have been extensively employed for the purpose of transmitting data at high rates. CP-OFDM is often regarded as the most extensively studied and widely adopted MC technology among the many wireless communications standards [9-10]. The study focuses on IIC in order to eliminate inherent interference terms in FBMC-QAM systems. This study proposes the use of an IIC receiver to divide the received signal into subcarrier components that are numbered as even and odd. The receiver then iteratively reduces the interference impact by demodulating the even subcarrier symbols [11]. The authors propose a strategy for combined channel estimation and pilot design for multiuser multiple input multiple output (MU-MIMO) channels, utilizing the deep learning (DL) method. In order to reduce the mean square error (MSE) of CE, they employ two-layer neural networks (TNNs) for pilot design and deep neural networks (DNNs) for CE training. To effectively remove interference among several users, the SIC approach is utilized throughout the channel estimate procedure [12].

3. MCM SCHEMES USING NN

OFDM employs a principle that enables the simultaneous transmission of multiple messages over a solitary radio channel. Every modulation

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station in FDM employs a distinct group of frequencies. Each frequency signal possesses sufficient separation to prevent overlap with other signals or frequencies within the spectrum. Each frequency transmission undergoes separate bandpass filtering to extract the complementary signal, omitting the signal relevant for the receiver at the base station. The original signal is inverted in order to receive the acknowledged signal [17]. MCM, also known as OFDM, transmits a limited number of bits across many channels by employing two carrier signals of identical frequency. The filters are commonly arranged in an alternating pattern, either even or odd, and possess a high degree of spectral selectivity in order to minimize interference with adjacent subcarriers. Additionally, the filters are uniformly distributed at regular intervals [18].

In MC systems, the time position is denoted by p, the subcarrier position is denoted by q, and the transmitted symbols $s_{q,p}$ are modulated by the base pulses $P_{q,p}(t)$. This modulation results in the transmitted signal $T_x(t)$ being in the time domain.

$$T_x(t) = \sum_{p=0}^{K-1} \sum_{q=0}^{L-1} P_{q,p}(t)\; s_{q,p}$$

where $P_{q,p}(t) = P_t(t - pT)\; e^{j\left(2\Pi q(t-pT)+\phi_{q,p}\right)}$

The basis pulse $P_{q,p}(t)$ is a time and frequency shifted variant of the prototype filter(PF) $P_t(t)$. The received base pulse $R_{q,p}(t)$ is stated in the following form, utilizing several PFs by the receiver can be represented as,

$$R_{q,p}(t) = P_r(t - pT)\; e^{j\left(2\Pi q(t-pT)+\phi_{q,p}\right)}$$

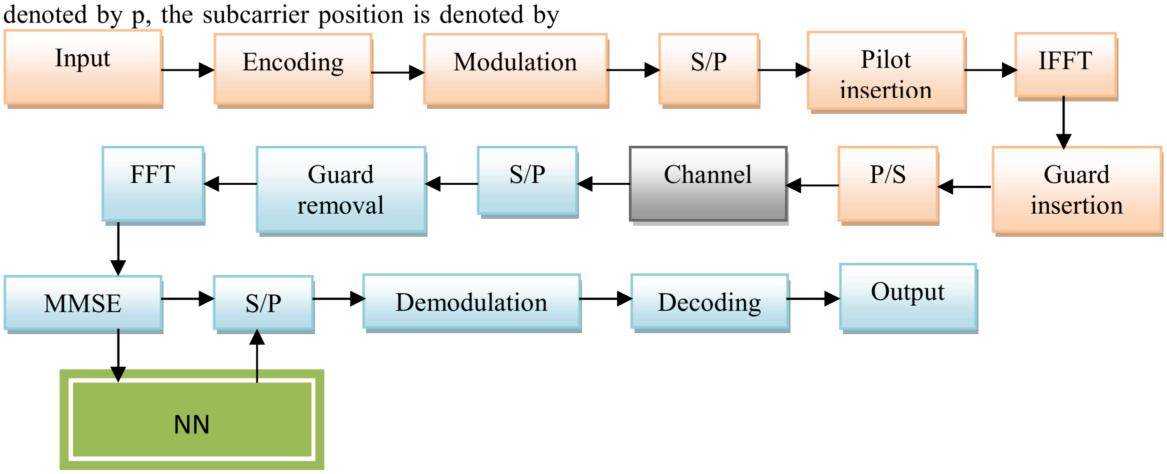

Figure 1. OFDM using NN

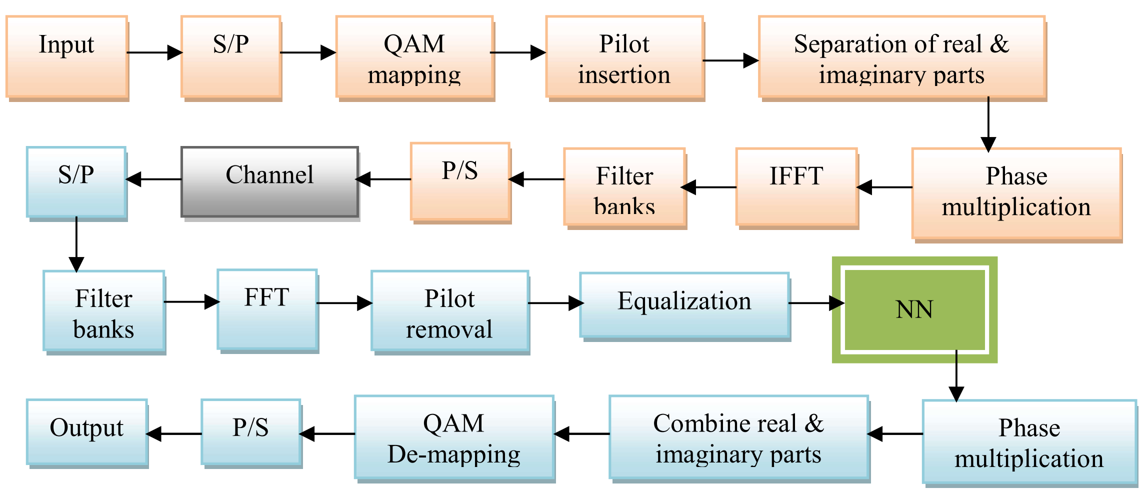

Figure 2. FBMC using NN

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Doubly Selective Channel Estimation (DSCE): Many papers aim to calculate the channel impulse response(IR) in the context of a DSC. The number of active subcarriers in real systems is lesser than the length of the FFT. When subcarriers are zero, it is not feasible to precisely estimate the channel transfer function(CTF), which hinders an exact measurement of the IR [16]. In order to find a pseudo IR for the CTF, one must apply an IFFT to the active subcarriers, assuming a rectangular filter. While the actual IR may have a finite duration, the delay taps of the pseudo IR are not restricted in time. Estimation strategies at the edge rely on the expectation that the delay taps have a constrained duration, which is caused by the truncation of the CTF. The intricacy of computing is an additional aspect. Although it is possible to accurately estimate the IR, it is still essential to evaluate the matrix multiplication, which introduces a substantial CC. By making direct predictions of the transmission matrix, it is possible to circumvent all of these constraints. Interpolation is commonly used to approach the one-tap channel in practical systems, resulting in some degree of occurrence. The diagonal elements of the channel coefficients are represented by a single tap. This is made possible by a robust correlation between frequency and time. As mentioned before, it is computationally more efficient to directly evaluate the underlying correlation without utilizing the diversion of the CTF.

Interference Cancellation (IC) : We explore a simplified IC approach for channel equalization, while also addressing the challenge of estimating DSCs. Interference has a negative impact on the least square(LS) channel estimates at the pilot sites. Therefore, it is essential to incorporate IC into the channel estimating process. Cancelling this interference can enhance the precision of the CE.

CE and IC based on NN : In this, we will examine a widely-used technique for estimating channel conditions. This technique is considered a leader in incorporating DL frameworks to reduce mistakes in CE. This methodology aims to overcome the limitations of LS and Linear-MMSE (LMMSE) estimations by using a CE based on RNN. This approach enhances the effectiveness of MMSE in estimating channel properties, drawing on a careful combination of theoretical and practical foundations. The proposed architecture of the RNN is highly sophisticated, resembling an intricately organized architectural masterpiece. As shown in Figure 3, this NN architecture comprising of three essential layers: the input layer(IL), the hidden layer(HL), and the output layer(OL). Although there is a possibility of multiple HLs within an RNN, our conceptual schema effectively explores this design area. The architecture effectively achieves a compromise between complexity and functionality, incorporating a carefully calibrated assembly of neurons in its HLs to seamlessly adapt to the specific requirements of both OFDM and FBMC systems.

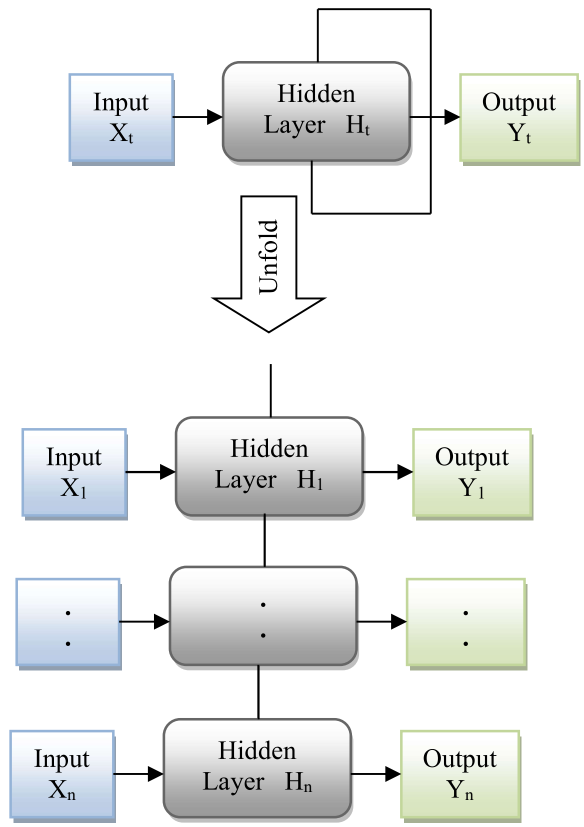

Figure 3. Structure of RNN

We begin apart on an exploration that effectively combines theoretical sophistication and empirical validation, carefully negotiating the domains of modulation, computing, and CE. The objective of this study is to examine the phenomenon of CE mistakes by combining theoretical concepts with practical applications. It seeks to understand and improve the accuracy of estimating communication channel properties by integrating DL and NN designs. As shown in Figure 3, the RNN's architectural design demonstrates a painstaking effort to improve channel estimates and reduce errors in OFDM and FBMC systems.

Long short term memory (LSTM) based channel estimation : This article presents a set of CE techniques based on the utilization of NNs. To address the difficulties associated with CE, a practical approach arises by using NN paradigms, specifically the powerful framework of RNNs. The RNN framework incorporates a temporal understanding, where the input at the current time step smoothly transitions into the output of the previous time step. The complex interplay of components in the RNN allows it to effectively retain and recall previous input data, enabling a seamless integration of time-based relationships [16]. The computational core of the elementary RNN cell plays a crucial role in coordinating a wide range of findings that create a unified operational environment, thus guiding the CE process to achieve its intended goals effectively.

The basic Simple RNN cell, although conceptually elegant, has inherent restrictions that require careful analysis. A significant constraint is its inability to utilize future data points for decision-making, despite the temporal relationship among the channel's past, present, and future states at a certain time step 'p'. In order to improve the network's performance and overcome the temporal imbalance, it is crucial to install the network in a contextual manner. Furthermore, the concise structure of the RNN fails to adequately capture the long-term dependencies that are inherent in intricate data patterns. As a solution, the incorporation of LSTM networks is seen as a wise remedy. To address these mandatory needs, this study proposes the strategic implementation of LSTM networks as an effective method for CE in the context of 4G/5G communications [19].

The figure 3 illustrating our suggested framework for CE and IC, enhanced with the Adam optimizer. The complex process illustrated in Figure 4 begins with an extensive training phase, during which input signals are skillfully manipulated to reveal the channel response using MMSE estimates. The resulting channel responses are used as input parameters for the LSTM model, which is carefully adjusted during an iterative training process. The true effectiveness of this model becomes apparent during the testing phase, where the estimated channel responses of signals, obtained from real-world settings, are used as inputs for the trained LSTM model [16]. The combination of these inputs, carefully guided by the inherent dynamics of the LSTM structure, results in the calculation of the current channel response. This estimation highlights the effectiveness of the LSTM paradigm in predicting channel response and cancelling interference. It is a result of the interaction between input parameters and the minimizing of the loss function.

To summarize, the architecture shown in figure 3 and figure 4 not only represents the complex relationship between theoretical foundations and empirical verification, but also symbolizes the significant change towards LSTM-driven sophistication in the field of CE. As researchers and scholars, our goal is to understand and explain the intricate nature of communication networks by combining theoretical innovation and computational expertise, leading to new discoveries and insights.

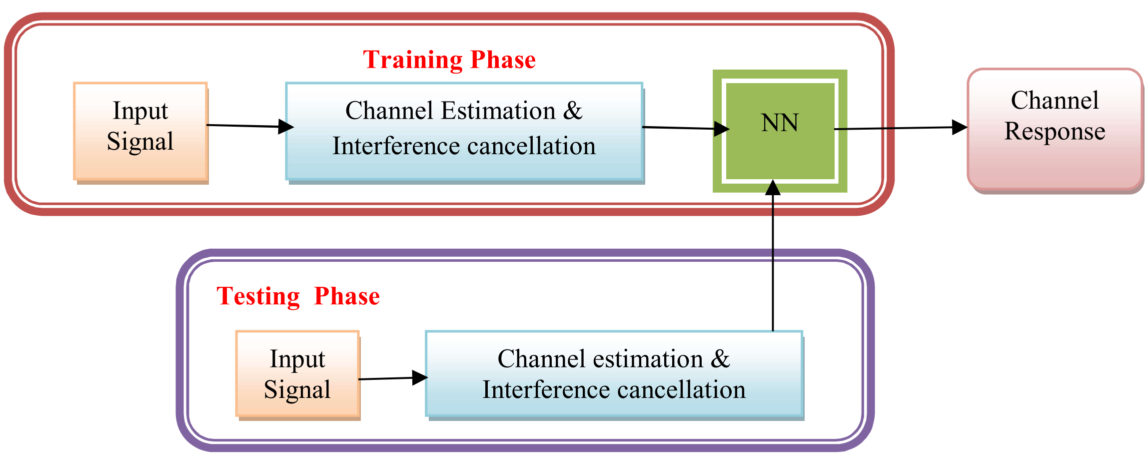

Figure 4. NN for CE&IC

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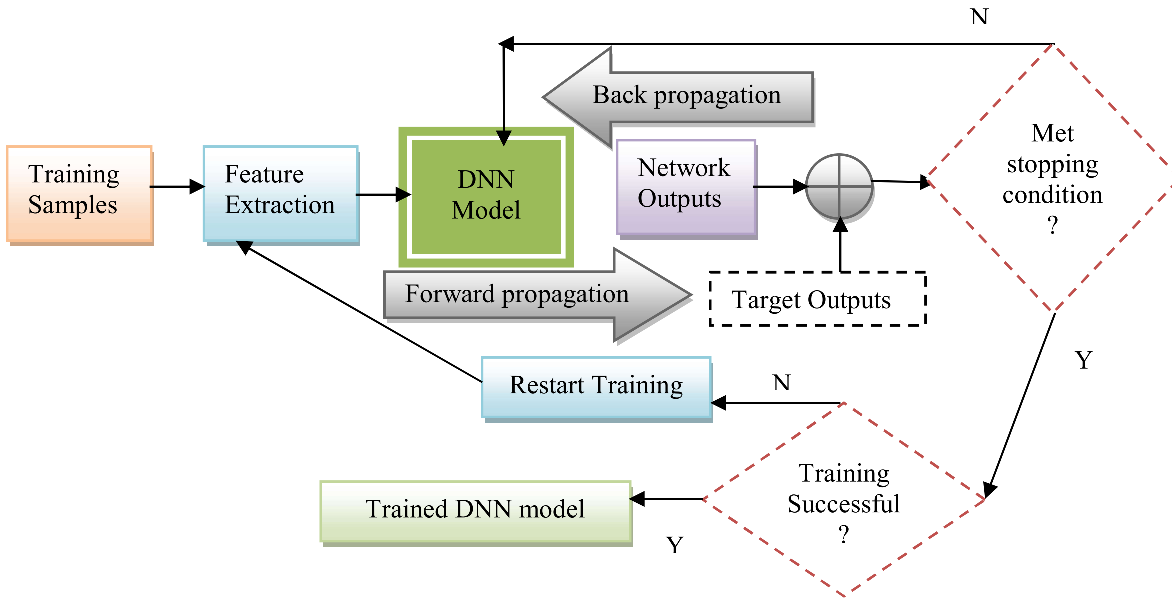

Figure 5. DNN Training process

DNN based CE Algorithm:

1. Randomly assign initial values to the weights and biases of the HLs and the OL. Set the training parameters of DNN models with appropriate values, such as the more number of epochs, the desired performance level, the minimal performance gradient, the learning rate, and the maximum allowed validation failures.

2. Provide the training samples, which consist of the received pilot symbols during training and the corresponding appropriate channel IRs.

3. Determine the OL's network outputs.

4. Determine the cost function value

5. Find the partial derivatives of the biases and weights.

6. Perform an iterative process of gradient descent by adjusting the weights and biases using the learning rate.

7. if (an excellent training outcome is produced)

8. Provide the whole trained DNN model, including the most effective weights and biases

9. else

10. Initiate the training procedure again.

11. end if.

12. Provide the current received pilot symbols, which are divided into their real and imaginary components, as inputs to the trained DNN model.

13. Collect the real and imaginary components of the predicted channel IRs to get the set of outputs for CE in systems.

14. Retrieve the transmitted signal by using the estimated channel IRs and the received signal in the presence of noise.

4. SIMULATION RESULTS

Our analysis focuses on the FBMC system, which plays a crucial role in 5G networks. The number of subcarriers is 32, and we employ 64QAM modulation. We employ a RNN architecture. The structure of this network consists of five levels. The layers consist of a sequence IL, an LSTM layer with 1520 hidden units, a fully connected layer (FCL), a Softmax layer (SL), and a classification output layer(OL). The network's input consists of the sequence of MMSE CE and IC. This sequence represents intricate and sophisticated data. The reason for dividing it into a real component and an imaginary half is that the network does not accept sequences in complex form. We produce 100 sequences for training at each SNR and 100 sequences for testing at each SNR. The purpose of these training sequences is to estimate the interference caused by the channel and to cancel it. The objective of this network is to achieve optimal CE. Our methodology focuses on coordinating CE and IC. The convergence of these dynamic processes results in the generation of output sequences, which then serve as inputs to the LSTM framework. This fosters an insightful interaction between these important components. Empirical

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validation is achieved by analyzing a range of simulation data, which demonstrate the effectiveness of our proposed strategy. It shows improved performance in terms of BER, PAPR, efficiency and accuracy compared to previous methodologies. The most important finding is that FBMC outperform OFDM systems in terms of performance.

Based on the findings depicted in the Figure 6, the BER values for all of these approaches exhibit a gradual fall as the SNR increases. The BER performance has shown minimal improvement when the SNR is increased from 0 to 18dB. The LS algorithm has the poorest performance compared to the other methods under consideration. RNNs exhibit superior performance compared to LS, DNN, and LSTM. The reason for this comes in the fact that increasing the number of neurons within the same number of layers can significantly enhance the learning accuracy of the NN for CE. At a BER CCDF of 10^{-2}, the SNR values are approximately 16dB, 15.7dB, 14 dB, 13.1 dB, 11.8 dB, 10 dB, 9.7 dB, and 8.2dB for the techniques OFDM-LS, OFDM-LSTM, FBMC-LS, OFDM-DNN, FBMC-LSTM, OFDM-RNN, FBMC-DNN and FBMC-RNN, respectively.

The figure 7 illustrates the PAPR lowering capabilities of different techniques. The RNN techniques achieved a PAPR reduction of more than 1.5 dB for FBMC and 3.5 dB for OFDM with a probability of 10^{-2}. At a CCDF of 10^{-2}, the PAPR of OFDM-LS, OFDM-LSTM, FBMC-LS, OFDM-DNN, FBMC-LSTM, OFDM-RNN, FBMC-DNN and FBMC-RNN method is approximately 9.8dB, 8dB, 7.2dB, 6.8 dB, 6.5 dB, 6.3 dB, 5.7 dB, and 5.4dB, respectively.

The figure 8 illustrates the classification performance of the proposed NN-based OFDM and FBMC, in comparison to existing techniques. The figure clearly demonstrates that the suggested strategy is better than the performance of the existing statistical methods. The RNN achieves an accuracy of more than 90% at a SNR of 20 dB.

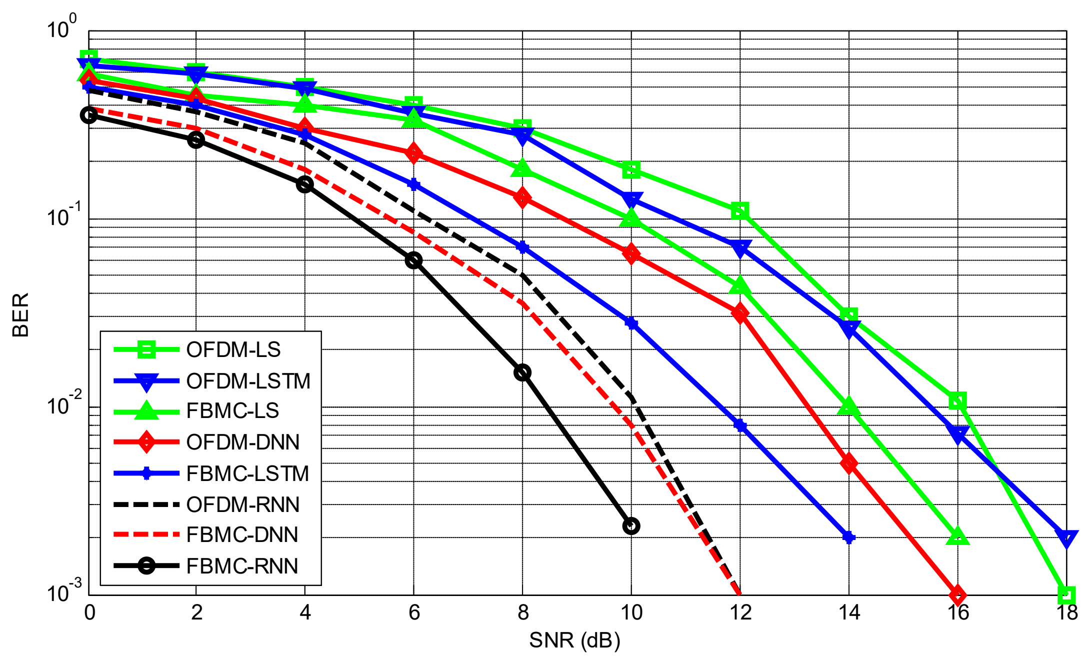

Figure 6. BER performance

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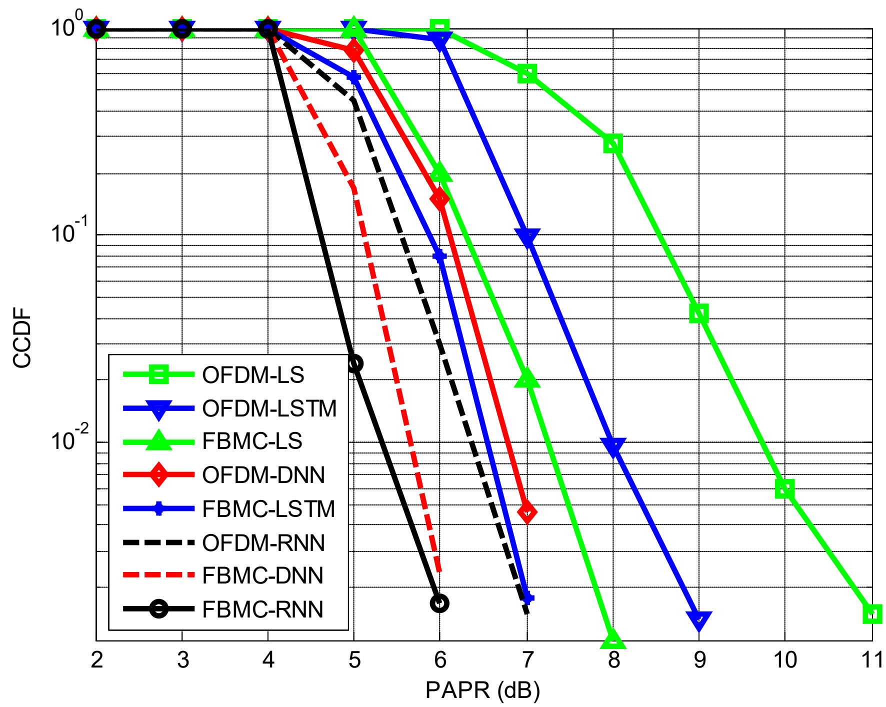

Figure 7. PAPR analysis

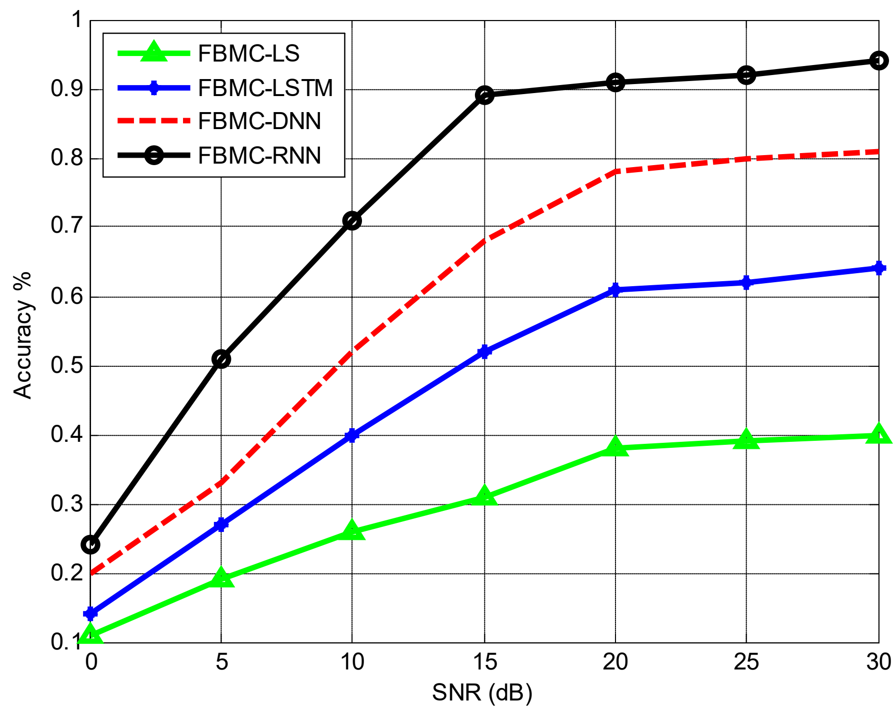

Figure 8. Accuracy vs SNR

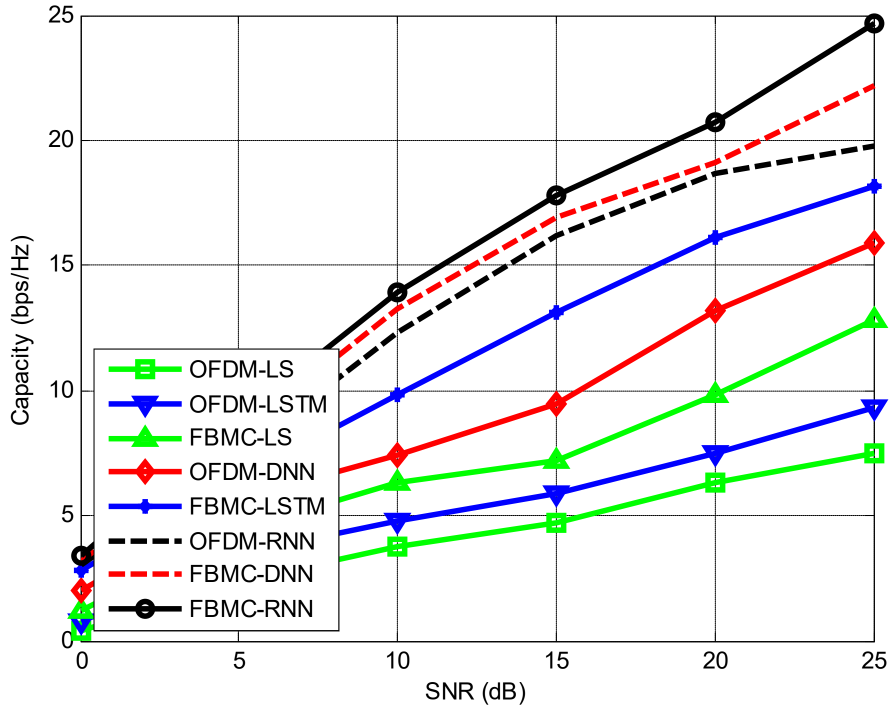

Figure 9. Capacity vs SNR

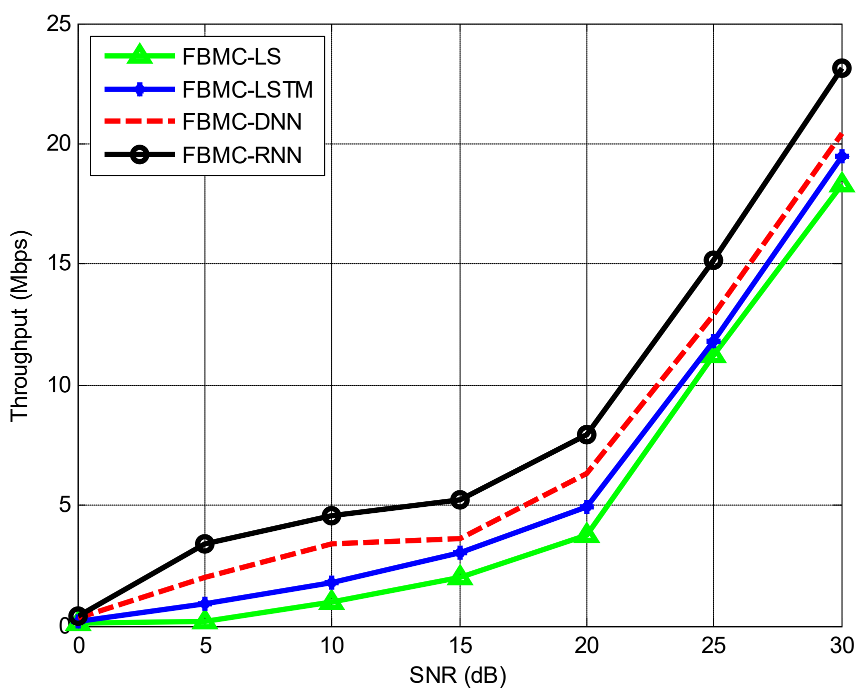

Figure 10. Throughput vs SNR

The figure 9 illustrates the relationship between capacity and SNR. When the SNR increases, the capacity also increases. The current OFDM-LS algorithm has less capacity (about 6.3

bps/Hz at 20 decibels) compared to other algorithms. The FBMC-RNN approach demonstrates a greater capacity (about 20.7 bps/Hz at 20dB) compared to the other methods. Hence, suggested approach achieved a superior channel capacity.

The figure 10 illustrates the throughput achieved by varying the average SNR. The LS method results in less throughput, around 3.8Mbps at 25dB, compared to the other techniques. The RNN shows a significant level of data processing speed, with a throughput of around 7.9 Mbps at a SNR of 10 dB.

The simulation results highlights the effectiveness of NNs in both FBMC and OFDM, demonstrating their superiority at high SNRs. This discussion ends by highlighting the emerging possibilities of RNN, which can have a significant impact on various communication systems, including MIMO and NOMA. Using these statistics, we explore a complex web of simulated outcomes, uncovering the diverse influence of RNN across a range of transmission environments. An inherent limitation of RNNs is the substantial time required for the training process, as well as the enormous amount of data necessary for effective training. The primary benefit of this technology is its exceptional precision in the testing process, achieving a 95% accuracy rate, with minimal loss. The accuracy of the RNN serves as an calculation metric and demonstrates a high level of accuracy for OFDM and FBMC systems. The BER of the restored signal is influenced by the issue of accurately estimating the Channel State Information (CSI). An issue of utmost concern is the elevated PAPR of the transmitted OFDM signal, as these substantial peaks significantly impair performance. The initial OFDM signal, characterized by a significant PAPR, is enhanced by incorporating pilot tones through various estimation techniques. The time variability of wireless signals during transmission does not have an impact on the accuracy of CE and IC, despite causing a signal frequency offset.

5. CONCLUSIONS

The article provides a detailed explanation of NN models particularly designed for CE in FBMC and OFDM systems. NN models are trained using the pilot symbols and the accurate channel IRs during the training phase. During the testing phase, the trained networks provide estimated channel impulse responses as outputs. A comparison is made between the performance of OFDM and FBMC using LS, MMSE, DNN, and RNN algorithms in terms of BER, PAPR, Throughput, Capacity, and spectral efficiency. This paper introduces a RNN for the CEIC. We employ the time and frequency correlation of scattered pilots to estimate the channel for DSCs. Additionally, we utilize low-complexity IC techniques. In the context of CEIC, the LSTM model is suggested as a variant of RNN. The output sequences of the CE and IC algorithms are utilized as inputs for the RNN. The simulation findings indicate that the proposed strategy closely approximates the ideal channel and exhibits a higher BER and PAPR reduction compared to previous methods. The applications of the findings in this article encompass the enhancement of BER in low SNRs for 5G/6G wireless communication, as well as in wireless sensor networks.

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