OFDM Index Modulation Technique

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Abstract: This paper discusses two innovative schemes for orthogonal frequency division multiplexing (OFDM): indexed modulated OFDM (OFDM-IM) and dual-mode dual-indexed OFDM-IM (DMDI-OFDM-IM). The aim is to improve spectral efficiency and error performance under frequency-selective and fast time-varying fading channels. The OFDM-IM scheme de- livers information through the indexing of activated subcarriers beyond the multiple signal constellations in conventional OFDM. This paper briefs outline a low-complexity transceiver archi- tecture for OFDM-IM based on maximum likelihood detection and log-likelihood ratio computation. A brief analysis of the error performance of conventional OFDM and DM-OFDM-IM is presented. The DMDI-OFDM-IM scheme provides additional information transmission through dual indexing by relocating symbols and selecting relocation vectors in active subcarriers, as well as utilizing inactive subcarriers, resulting in improved frequency performance. Thus, higher spectral efficiency can be achieved. And there is evidence of significant improvement in the error performance of both schemes compared to conventional OFDM under different channel conditions, confirming their potential application in efficient wireless communication systems. Index Terms—DM OFDM-IM, Error Performance, Fad- ing Channels, Index Modulation, Low-Complexity Transceiver DesignOFDM-IM, Orthogonal Frequency Division Multiplexing (OFDM), Spectral Efficiency

Keywords: DM OFDM-IM; Error Performance; Fading Channels; Index Modulation; Low-Complexity Transceiver Design OFDM-IM; Orthogonal Frequency Division Multiplexing (OFDM); Spectral Efficiency

1. INTRODUCTION

In the information age, information transmission is essential for mass, industrial, and even military needs. Orthogonal Fre- quency Division Multiplexing (OFDM) is a fundamental tech- nology for broadband digital communication, and it has led to the development of more key technologies to meet the growing demand for high-rate communication systems operating over frequency-selective fading channels. OFDM is a technique that can effectively mitigate inter-symbol interference caused by the frequency selectivity of wireless channels. It improves the stability and reliability of signals in complex environments. OFDM has been widely used in wireless communication standards, from 4G LTE to Wi-Fi [1], greatly facilitating the development of mobile communications and high-speed data transmission. OFDM provides a strong foundation for the development of new technologies, such as OFDM-IM, which promotes innovation in wireless communication.

OFDM is a key technology to support the 4G era. It is now widely used in standard broadband wireless communications. Additionally, it is also commonly used in digital TV broadcast- ing and wireless local area networks, which have significantly impacted people's lifestyles. At the same time, there has been a growing interest in achieving faster information transmission rates and implementing the Internet of Things and machinecommunication. OFDM-IM is highly regarded for its superior spectrum and energy efficiency [2].

This paper presents this modulation technique, OFDM-IM scheme, which optimizes elevated bit error rates in high mobil- ity environments. OFDM with Indexed Modulation (OFDM- IM) is an advanced communications technology that enhances traditional OFDM systems by incorporating the concept of indexed modulation. The spectrum is divided into several sub- carriers and further grouped. In each group, some subcarriers are activated (”on”) while others are inactive (”off”) [3]. The activated subcarriers transmit conventional modulated signals, such as QAM [4] or PSK [5], while the inactive subcarriers implicitly transmit information because their activated state inherently transmits data. By modulating and indexing the subcarriers [6], this dual data transmission mode of OFDM-IM greatly improves spectral efficiency. OFDM-IM can effectively resist channel fading and improve the reliability of data trans- mission while maintaining relatively low system complexity. Therefore, it is highly suitable for next-generation communi- cation technologies, such as 5G and environments that require a trade-off between power consumption and spectral efficiency [7].

The paper [8] mentions: that a key feature of next-generation broadband wireless communication systems is to support mobility. For example, problems such as slow information transmission can occur in trains or cars travelling at high speeds. This is due to the fact that during transmission of OFDM blocks, the wireless channel undergoes rapid changes due to frequency selective fading, which results in loss of sub-channel orthogonality, channel interference and fading variations. Therefore, we need a modulation method that is more flexible, adaptable and efficient.

This is how Dual Mode OFDM-IM was born. This mod- ulation scheme is an evolutionary product of OFDM-IM,

i.e. it continues the OFDM-IM characteristic of transmitting information in dual mode. This means that not only is the information carried by the conventional amplitude and phase modulation but also the selection of specific subcarriers carries the information. Dual mode OFDM-IM still has the character- istics of high spectral efficiency and strong anti-interference ability, etc. It combines two different modes of exponential modulation into a single OFDM symbol [9], thereby increasing the number of ways the system can transmit data. This means that the system can choose between two sets of subcarriers, each with different modulation characteristics. This approach provides greater flexibility and adaptability. This is because

it allows the system to choose the optimal subcarrier and modulation method based on the channel conditions and communication requirements [10]. The reason we use expo- nential modulation is that by using exponential variations in amplitude or phase, more bits can be carried in each OFDM symbol, thus improving spectral efficiency. At the same time, exponential modulation improves the signal's PAPR (Peak-to- Average Power Ratio), and lower PAPR helps to reduce the nonlinear effects of the power amplifier, thus improving signal quality. In addition, in Dual Mode OFDM-IM, the subcarriers are allocated flexibly. These subcarriers allow the system to be dynamically allocated to different users or data streams according to demand. As a result, Dual Mode OFDM-IM can adapt to more channel conditions. For example, the quality of a wireless channel varies with time and location, and if part of the channel is degraded, the system can choose to move the data to a better-quality subcarrier. Exponential modulation in DM OFDM-IM improves spectral efficiency and the dynamic subcarrier allocation increases the transmission rate, reduces the BER, and so on. Therefore, this modulation scheme can make more efficient and flexible use of spectrum resources, adapt to variable channel conditions, and meet the needs of different scenarios (e.g. mobile communications, vehicle networking, and wireless coverage in urban and rural areas). The remainder of this paper can be summarised as follows. Section II. This part introduces the basics of OFDM-IM and DM OFDM-IM. Section III examines the theoretical error performance of OFDM-IM and DM OFDM-IM. In Section IV, recent developments and a literature review are presented. Finally, Section V presents future directions and conclusions.

2. E PRINCIPLES OF OFDM-IM AND DM OFDM-IM Assume that m information bits enter the OFDM-IM trans-

mitter for each OFDM block transmission. Next, these m

bits are divided into g groups, each containing p bits, then

$m = pg$. Each group of bits containing p bits is shaded into an OFDM sub-block of length n, so $n = N/g$ [10], and N is the number of OFDM subcarriers. Unlike classical

OFDM, the mapping operation in OFDM-IM is implemented by both modulation symbols and subcarrier indexes. However, for each sub-block, only k out of n available indexes can transmit additional information bits through a subset of OFDM subcarrier indexes, and they are based on the input sequence of p1 bits selected from a predefined set of active indexes.

Afterward, the remaining bits of the sequence, P2 = klog2M

bits, are mapped onto an M-constellation map to modulate

the data symbols of the active subcarriers. Therefore, we have $p = p1 + p2$ The reason for this is that we do not activate all the subcarriers, so extra bits are sent in the OFDM index

block to compensate for the loss to send the message in full. The block diagram of the OFDM-IM transmitter is given in Fig. 1[10].

The OFDM block creator creates all the sub-blocks and forms N 1 main OFDM blocks. Unlike classical OFDM, there are some sub-blocks that are zero terms in Eq. (1)[10].

$$XF = [x(1)x(2) \cdots x(N)]T \qquad (1)$$

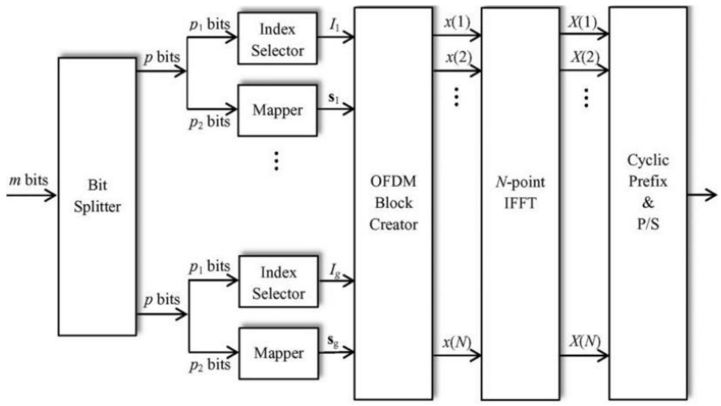

Fig.1 Block diagram of the OFDM-IM transmitter(copied from [10])

Their positions also carry information. The next step is the same as for transmission OFDM, the OFDM blocks are processed by the IFFT algorithm, this step not only shifts the signal from the frequency domain back to the time domain but also further reduces the inter-symbol interference induced by multipath propagation by adding a cyclic prefix (CP) before each OFDM symbol in an OFDM system [11]. The use of IFFT allows the sub-orthogonality of the carriers to be maintained.

Finally, the tail of an OFDM symbol may overlap with the head of the next signal due to multipath propagation. A cyclic prefix copies part of an OFDM symbol and adds it to the leading end of that symbol, while a cyclic prefix provides a buffer for multipath-induced interference, which reduces intersymbol interference and maintains orthogonality of the subcarriers in an OFDM system. And the channel equalization of OFDM is simplified by the existence of cyclic prefixes. The role of P/S is to convert data that is parallel in the frequency domain into a serial data stream for transmission over a physical channel (e.g. radio waves). In this system, it allows the system to transmit data in parallel over multiple subcarriers, greatly improving spectrum utilization.

Dual Mode OFDM-IM adds a ”dual mode” operation to OFDM-IM. In this mode, the system not only transmits information based on the activation status of the subcarriers but also transmits additional information based on the activation mode of the subcarriers [12] (e.g. single activation or group activation). With this new modulation, each subcarrier can innovatively operate in two modes. For example, one mode can activate one subcarrier in each group, while the other mode can activate multiple subcarriers. It adds an extra dimension of information through the activation modes of the subcarriers. This successfully overcomes the major drawback of the limited spectral efficiency of classical OFDM-IM [12].

In this approach, the symbol mapping of the source sub- carriers is performed in two steps. In the first step, the active subcarriers are selected using the carrier index. In the second step, relocation is performed using the relocation symbol vector. The index of the relocation symbol vector carrie additional information.

The schematic implementation of the DMDI-OFDM-IM system in a conventional OFDM system is shown in Fig. 2(a). Similar to conventional OFDM-IM, the available subcarriers are divided into g groups of n subcarriers each, and each group is coded similarly. In each group of n subcarriers, k subcarriers are called valid subcarriers and the other subcarriers are called invalid subcarriers. The indices of the active subcarriers are induced by the matrix Iu, while the system-generated Su and S′ are transmitted by the active and inactive subcarriers respectively[13].

In the basic OFDM-IM Tranmitter input Pu4 bits are used to generate symbols transmitted by the inactive subcarriers.

The inactive subcarrier symbols are in the low energy range to distinguish between active and inactive subcarriers at the receiving end. The input PU4 bits are used to generate symbols transmitted by the inactive subcarriers. The inactive subcarrier symbols are in the low energy range in order to differentiate between active and inactive subcarriers at the receiving end. After that, the OFDM block collects and arranges each subcar- rier of the IFFT block, and finally, the time domain signal is generated according to the conventional procedure for

OFDM signals Its channel impulse response is (generally assuming a frequency-selective Rayleigh fading channel)

3. THE THEORETICAL ERROR PERFORMANCE

In section III, we compared the BER and SNR of conven- tional OFDM-IM and dual-mode OFDM, BER is a measure of the proportion of erroneous bits during data transmission. a lower BER means a more reliable system. And SNR is the ratio of signal strength to background noise strength. A high SNR means that the signal strength is higher than the noise level and has better transmission quality. Then we use a graphical approach to demonstrate the superiority of OFDM-IM and DM OFDM-IM.

The BER performance of the two different modulation schemes for different values of Eb/N0. As the SNR increases, the BER decreases for both systems. This is because the higher the signal-to-noise ratio, the lower the probability of errors.

The BER of the OFDM-IM system is lower than the BER of the classical OFDM system for every value of SNR, indicating that the OFDM-IM system offers better performance for the same SNR in this comparison.

The BER of all systems decreases as the SNR increases. This is due to the increased strength of the signal with respect to the background noise, which reduces the probability of BER. In the region of lower SNR values, there is a large difference in the BER of the three systems; as the SNR value increases, the difference in their performance decreases. In the region of high SNR, the BER curves of the three systems converge. This may imply that at high signal quality, there is little difference in the performance of these systems. The "Dual-Mode" system shows better performance than single- mode OFDM or OFDM-IM at most SNR values, which suggests that this system may have advantages in processing signals and resisting noise.

The figure Fig.5 shows that for Ma = 2, the DMDI-OFDM- IM system is the most efficient, followed by DM-OFDM-

IM, then OFDM-IM, and the conventional OFDM system is the least efficient. When the modulation order is increased to Ma = 4, the efficiency of each system increases, but the order

of efficiency ranking remains the same: the DMDI-OFDM-

IM system remains the highest and the conventional OFDM system remains the lowest.

4. FUTURE DIRECTIONS AND CONCLUSIONS

We can see that OFDM-IM and Dual Mode OFDM-IM, as two new OFDM-based techniques, outperform conventional OFDM in most cases, but still have their own drawbacks. Future research directions are likely to focus on further improving spectral efficiency, reducing complexity, and im- proving robustness under different channel conditions, and may include the integration of advanced algorithms with other emerging technologies such as MIMO, deep learning, and so on. The challenges revolve around the challenge of balancing improved spectrum and energy efficiency with the computational complexity of the system, which can increase hardware requirements and power consumption. Simultaneous integration with existing and future network infrastructure re- mains a key challenge. This report discusses OFDM schemes: OFDM-IM and DM-OFDM-IM. The aim is to improve spec- tral efficiency and error performance in frequency-selective and fast-time-varying fading channels. The OFDM-IM scheme provides information by indexing activated subcarriers in- stead of multi-signal constellations in conventional OFDM. The DM-OFDM-IM scheme provides additional information transmission through dual indexing by repositioning symbols and selecting the repositioning vectors in activated subcarriers, as well as using inactive subcarriers to provide additional information transmission, thus improving frequency perfor- mance. Simulation results show that both schemes provide a significant improvement in error performance compared to conventional OFDM under different channel conditions, confirming their potential application in efficient wireless communication systems.

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