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Research article

EFFICIENT SCHEME TO SUPPRESS THE DISTURBANCE OF IMPULSIVE NOISE AMONG IOT DEVICES

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Abstract

Internet of Things (IoT) is a network of enormous things that are connected together for data communication. Therefore, IoT objects require an efficient technique for data communication. When transmitter power efficiency and performance improvement are of paramount importance, linear precoded orthogonal frequency division (LP- OFDM) is considered as a desirable candidate for uplink wireless transmission among IoT devices. However, negative ramifications of impulsive noise (IN) raise among millions of IoT devices based LP-OFDM systems need to be mitigated. In this work, a matrix interleaver (MI) is employed with LP-OFDM system to suppress the deleterious effect of IN on the performance of such a system when it is used as the transmission technique among the IoT devices. Consequently, the proposed scheme achieves a considerable bit-error-rate (BER) performance improvement when compared with the conventional approaches over multipath communication among IoT devices even in the presence of impulsive noise. Such BER improvement is achieved as a result of integrating the role of the linear precoders (i.e fast Fourier transform (FFT)) and MI to spread the effect of IN over large OFDM symbols.

Keywords: Internet of Things (IoT), Wireless Networks, Matrix interleaver (MI), Linear precoder.

摘要 物联网（IoT）是一个连接在一起进行数据通信的巨大网络。因此，物联网对象需要有效的数据通信技术。当发射机功率效率和性能改进是至关重要的时，线性预编码正交频分（LP-OFDM）被认为是 IoT 设备之间的上行链路无线传输的理想候选。然而，需要减轻数百万基于 LP-OFDM 系统的 IoT 设备中的脉冲噪声（IN）的负面影响。在这项工作中，矩阵交织器（MI）与 LP-OFDM 系统一起使用，以在其用作 IoT 设备之间的传输技术时抑制 IN 对这种系统的性能的有害影响。因此，与传统方法相比，即使在存在脉冲噪声的情况下，与 IoT 设备之间的多径通信相比，所提出的方案也实现了相当大的误码率（BER）性能改善。由于集成线性预编码器（即快速傅立叶变换（FFT））和 MI 的作用以在大 OFDM 符号上扩展 IN 的影响，实现了这种 BER 改善。

关键词: 物联网（IoT），无线网络，矩阵交织器（MI），线性预编码器

I. INTRODUCTION

Internet of Things (IoT) is an advanced automation system that can be used to deliver complete systems for a product or service. This can be achieved by exploiting network infrastructure, sensors, data mining, and artificial intelligence (AI) technology. Owing to its flexibility and ability to be suitable in any environment, IoT will widely use in industries to enhance data collection, automation, and operations. In despite, efficient transmission techniques should be utilized among the physical layers of IoT networks [1]. Hence, due to its low peak power, computationally efficient frequency domain equalizers and robust performance against frequency selective fading channels, linear precoded orthogonal frequency division multiplexing (LP-OFDM) is a transmission technique that can be employed efficiently for such purpose. LP-OFDM has been adopted in many high data rate communication standards and applications due to its spectral efficiency and robustness against frequency-selective fading channels [2]. However, the performance of such a system degrades owing to the disturbance of impulsive noise especially if the impulsive noise energy exceeds a certain threshold. Basically, impulsive (man-made) noise arises from power lines, heavy current switches and other sources. The disturbance of such a noise has a negative ramification on the bit error rate (BER) performance of LP-OFDM systems. Therefore, recent studies employed considerable efforts to analyze and mitigate the impact of this phenomenon on the performance of such systems. The negative ramification of the impulsive noise on the robustness of multicarrier comparing with single carrier systems against multiplicative fading channel is introduced in [3]-[5]. Moreover, [6] introduced a performance analysis for the OFDM system over fading channels with the presence of impulsive noise. Furthermore, Zhodkov in [7] investigated the effect of various man-made noise scenarios on the performance of OFDM system with blanking non-linearity method. Whereas, the performance of OFDM system is assessed and compared with clipping, blanking and combined clipping- blanking techniques over various impulsive noise models is presented in [8]. A novel block iterative Bayesian algorithm (Block-IBA) is introduced in [9] to suppress the deleterious effect impulsive noise on OFDM's performance. In such an approach, impulsive noise estimated and cancelled by using the guard band null and data subcarriers. Moreover, in [10] multiple thresholds are employed to propose and analyze nonlinear estimators for impulsive noise burst. In such a work, a new heuristic criterion is used to set the thresholds, however, slightly suboptimal estimation. In order to suppress them, man-made noise locations are determined by using pilot tones as syndromes in [11].

In addition, the noisy (background Gaussian plus impulsive noise) channel is reduced by using matrix interleaver (MI) with the conventional OFDM system in frequency-domain [4]. Moreover, MI is used post to the inverse discrete Fourier transform (IDFT) to spread the effect of impulsive noise over large symbols then to eliminate them and reduce channel error rate [12]-[13]. Although, significant BER performances are achieved over AWGN channel and multipath fading channel, even in the presence of impulsive noise, however with relatively burden of complexity at the receiver side. Furthermore, channel estimation in such a system is complicated and required high complexity.

In this work, LP-MI-OFDM system is proposed to overcome the deleterious effect of the man-made noise on the communication among the physical layers of IoT networks. A comprehensive investigation of the proposed LP-MI-OFDM system over multipath transmission and under the man-made impulsive noise is presented. Simulation results confirm that the proposed LP-MI-OFDM system outperforms the OFDM-MI system over both AWGN and multipath fading channel models, in the presence of impulsive noise.

The rest of this paper is organized as follows. Basics of IoT are briefly presented in Section II. Section III illustrates the LP-OFDM system over multipath fading channel and under impulsive noise. The structure of the proposed LP-MI-OFDM system is produced in Section IV. Section V demonstrates the simulation results along with their discussion. Lastly, Section VI concludes the paper.

II. BASICS OF IOT

IoT is an attractive candidate that will be utilized widely in our daily life within the forthcoming years. Basically, IoT is a technology in which variety of things are connected in a manner where each individual things has the ability to interact and exchange data with others. The main advantages of using IoT are effective resources management, technology optimization, customer engagement improvement, waste reduction, and collecting data efficiently. However, the main challenges that may impact using IoT technology are network latency, power consumption, security and privacy, complexity of design, complexity of deployment, complexity of maintenance, and flexibility. Therefore, such constraints receive great attentions in the recent studies.

In this work, most of IoT constraints can be resolved by using LP-OFDM as the transmission technique over the network of their things. High data rate, spectral efficiency and robustness against multiplicative fading channel assist to reduce the latency of IoT devices network. Furthermore, utilization of linear precoder at the transmitter side of LP-OFDM will reduce peak-to-average power ratio significantly. As a result, the deleterious effect of nonlinearity of high power amplifier on the transmitted signal will eliminate. Moreover, channel effect on such a system can be equalized in frequency-domain. This means, the receiver computational complexity and cost of design will reduce.

III. LP-OFDM SYSTEM UNDER FADING CHANNEL AND IMPULSIVE NOISE

Due to its attractive features, such as transmitter power efficiency and resilient to the dispersion of multipath fading channel, LP-OFDM is considered as the desirable approach to use in the uplink wireless communication. Thus, as shown in Fig. 1, FFT precoder is utilized at the transmitter side to get length N vector of frequency-domain samples$\mathbf{X}^{(i)} = [X_0^{(i)},\ X_1^{(i)}, \dots, X_{N-1}^{(i)}]$, which are originally selected uniformly from quadrature amplitude modulation (QAM) or phase shift keying (PSK) constellations. Then X are processed by IFFT to get the time-domain samples $\mathbf{x}^{(i)}$ as

$$\mathbf{x}^{(i)} = \mathbf{F}^H \mathrm{X}^{(i)} \quad (1)$$

where $\mathbf{x}^{(i)} = [x_0^{(i)}, x_1^{(i)}, \dots, x_{N-1}^{(i)}]$, $\mathbf{F}$ is the N × N the fast Fourier transform (FFT) matrix $(.)^H$ is the Hermitian operator. In a multipath propagation, in order to eliminate the inter-symbol interference (ISI) phenomenon, N_g samples of guard interval are appended to $\mathbf{x}$ as a cyclic prefix (CP). For practical, N_g must be greater or equal to the maximum path delay of the multipath channel.

It should be mentioned that the received signal is processed at the receiver side with the assumption of perfect time and frequency synchronization. Thus, after the CP removing, the i-th block of the received faded time domain with the presence of impulsive noise can be expressed as

$$\mathbf{r}^{(i)} = \mathbf{D}^{(i)}\mathbf{x}^{(i)} + \mathbf{w}^{(i)}, \quad (2)$$

where $\mathbf{r}_n^{(i)} = [r_0^{(i)},\ r_1^{(i)}, \dots,\ r_{N-1}^{(i)}]^T$, $\mathbf{W}^{(i)} = \mathbf{z}^{(i)} + \boldsymbol{\zeta}^{(i)}$, $\mathbf{z}_n^{(i)} = [z_0^{(i)}, z_1^{(i)}, \dots, z_{N-1}^{(i)}]$ denotes the additive white Gaussian noise (AWGN) with zero mean and variance σ^2, ζ is the impulsive noise vector, and $\mathbf{D}$ is the circulant channel matrix defined by $[\mathbf{D}]_{m,n} = h[(m-n)_{mod\ N}]$ [14]-[16], where h_l is the channel impulse response (CIR) at path l. Impulsive noise elements ζ_n can be written as [9],

$$\zeta_n = B_n G_n, \forall n \in \{0 \dots N_t - 1\} \quad (3)$$

where $N_t = N + N_g$ is the total length of the transmitted data sequence, Bernoulli process is denoted as B_n with a sequence of zeros and ones based on probability $л = P(B_n = 1)$ and $\hat{л} = P(B_n = 0) = 1 - д$, and $G_n = [G_0, G_1, \dots, G_{N_t-1}]$ is the complex Gaussian noise sequence with zero mean and variance $у_G^2$, such as $у_G^2 \gg у_z^2$ and the ratio of the man-made noise variance $у_G^2$ over the background Gaussian noise variance $у_z^2$ is м, i.e $м = \frac{у_G^2}{у_z^2}$.

The frequency-domain samples of $\mathbf{r}$ can be computed as,

$$\mathbf{R}^{(i)} = \mathbf{F}\,\mathbf{r}^{(i)} \quad (4)$$

Then at this stage, the faded samples should be equalized by using minimum mean square error (MMSE) equalizer, which has elements $Q_n = (H_n^*)(|H_n|^2 + \frac{1}{г})^{-1}$, where $\mathbf{H} = \mathbf{FDF}^H = \mathrm{diag}([H_0, H_1, \dots, H_{N-1}])$ is the frequency response of the CIR that is assumed to be known, $г = \frac{у_x^2}{у_z^2}$ is the ration of symbol variance to noise variance. In the sequel, the equalized data vector $X^{(i)} = [X_0^{(i)}, X_1^{(i)}, \dots, X_{N-1}^{(i)}]^T$ can be written as

$$\hat{\mathbf{X}}^{(i)} = \mathbf{R}^{(i)}\mathbf{Q}^{(i)} \quad (5)$$

Eventually, the equalized samples will be decoded by the IFFT.

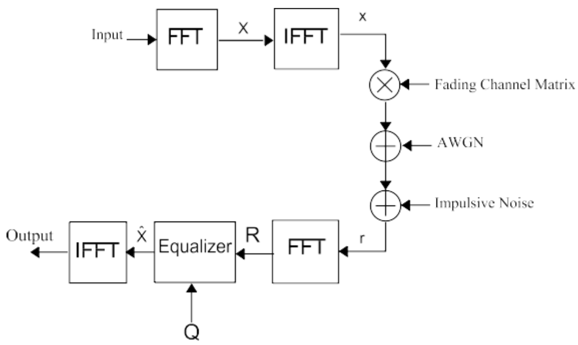

Figure 1. LP-OFDM system block diagram

IV. PROPOSED LP-MI-OFDM SYSTEM

As illustrated in the literature, to suppress the disturbance of the impulsive noise channel, matrix-interleaver (MI) can be used with OFDM system either in frequency-domain [4] or in time-domain [12], as shown in Fig. 2. In this work, MI and LP spreading ability will be integrated together in the proposed LP-MI-OFDM system to achieve two stages of impulsive noise suppression. As shown in Fig. 3, identical operations are performed with the proposed LP-MI-OFDM and the conventional MI-OFDM systems, except that the FFT/IFFT will be used before/after the interleaver at the transmitter and receiver sides, respectively, where Π and Π^{-1} represent matrix interleaver and de-interleaver operations, respectively.

Hence, the FFT of N-points incoming modulated data vector $\mathbf{d} = [d_0, d_1, \dots, d_{N-1}]^T$, is computed as

$$\mathbf{X} = \mathbf{F}\,\mathbf{d} \quad (6)$$

MI is used to provide more diversity for each sample. Then, the interleaved sequences $\hat{\mathbf{X}}$ are fed to inverse fast Fourier transforms (IFFT) to get the i-th time-domain sample as,

$$\mathbf{x}^{(\mathbf{i})} = \mathbf{F}^H \hat{\mathbf{X}}^{(i)}. \quad (7)$$

Basically, LP-BI-OFDM system can be utilized with various applications that impact with the disturbance of the impulsive noise. Hence, depending on the applied application, the number and duration (number of samples hit) of impulsive noise burst are changed.

With the assumption of perfect time and frequency synchronization, the effects of the fading channel and impulsive noise on the transmitted signal $\mathbf{x}$ are considered at the receiver side in the similar way defined formerly in (2). Then, the received sequences of signals are processed firstly by FFT. Fading channel effect on the received signal is reduced by using minimum mean square error (MMSE) equalizer on the frequency-domain samples in the similar way defined formerly in (5). Eventually, after de-interleaving, the IFFT is applied on the equalized sequence to recover the data symbols.

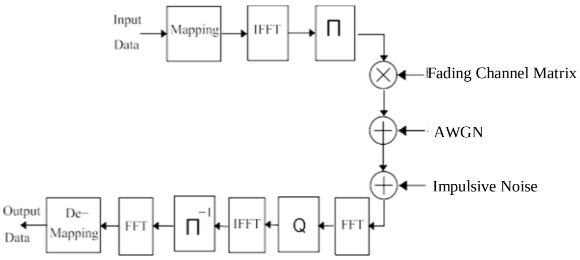

Figure 2. OFDM-MI system block diagram [12].

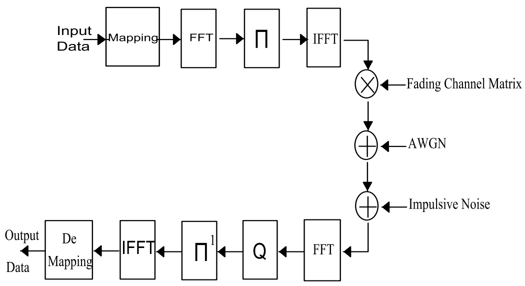

Figure 3. LP-MI-OFDM system block diagram.

V. Simulation Results and Discussion

It should be mentioned that the forthcoming results are demonstrated with the assumptions of perfect knowledge of channel response, and perfect frequency/time synchronizations. The negative ramifications of impulsive noise on the considered systems are investigated over two models of channel; Additive white Gaussian noise (AWGN) and Quasi-static (fix within entire period of symbol transmission) frequency selective fading channel.

The benefit of using LP-OFDM system with the IoT applications that work under the low power impulsive noise can be measured efficiently as illustrated in in Figs. 4-7. As clearly shown in these figures the spreading ability of the precoder plays a noticeable role to suppress the effect of impulsive noise on the performance of LP-OFDM when used as the transmission technique among the IoT devices.

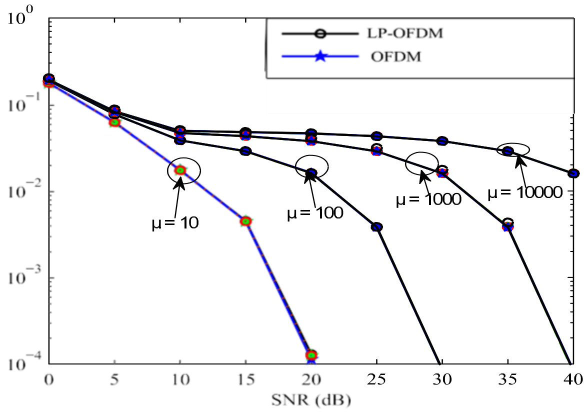

Figure 4. BER performance of LP-OFDM and conventional OFDM systems with QPSK and λ = 1 over the AWGN and impulsive noise channel models.

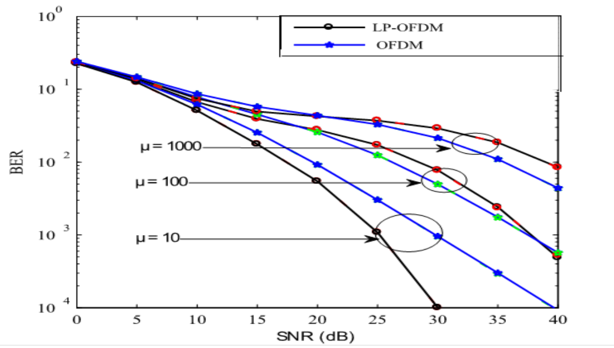

Figure 5. BER performance of LP-OFDM and conventional OFDM systems with QPSK and λ = 1 over the frequency selective fading and impulsive noise channel models.

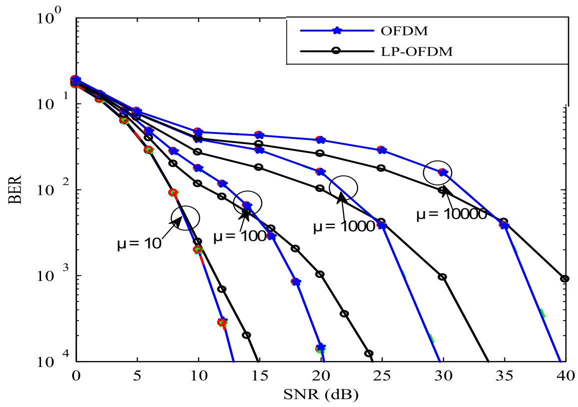

Figure 6. BER performance of LP-OFDM and conventional OFDM systems with QPSK and λ = 0.1 over the AWGN and impulsive noise channel models.

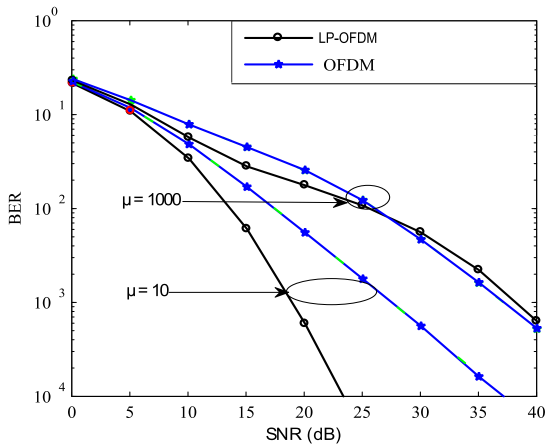

Figure 7. BER performance of LP-OFDM and conventional OFDM systems with QPSK and λ = 0.1 over the frequency selective fading and impulsive noise channel models.

As presented in [14]-[16], precoders can be utilized to increase the spectral efficiency and robustness of systems against multiplicative fading channel. In a sequel, MI is employed with LP-OFDM system to suppress the deleterious effect of somewhat sever impulsive noise burst. As clearly shown in Figs. 8-11, the proposed LP-MI-OFDM system suppresses the effect of impulsive noise and achieves considerable improvement in the BER performance as a consequence of two stages of spreading over a large number of subcarriers in each symbol by using FFT and IFFT as precoders, further to spreading that noise over the entire OFDM block owing to utilize the matrix interleaver. Finally, it is worthwhile to mention that MMSE equalizer is utilized in this work.

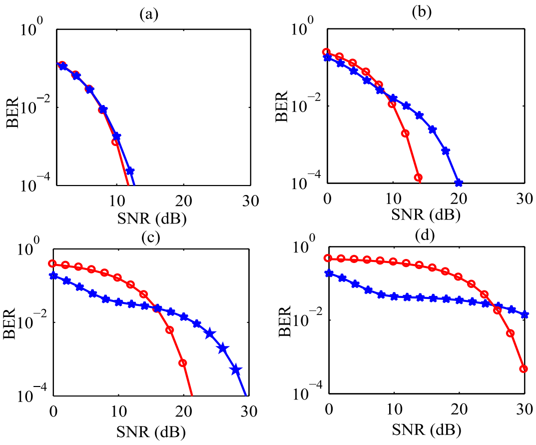

Figure 8. BER performance of LP-MI-OFDM (marker o) and conventional MI-OFDM (marker *) systems with QPSK over the AWGN and impulsive noise channel models λ = 0.1 (a. μ=10, b. μ=100, c. μ=1000, d. μ=10000).

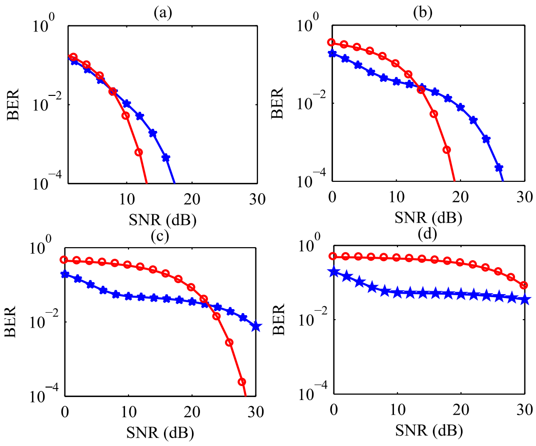

Figure 9. BER performance of LP-MI-OFDM (marker o) and conventional MI-OFDM (marker *) systems with QPSK over the AWGN and impulsive noise channel models λ = 0.5 (a. μ=10, b. μ=100, c. μ=1000, d. μ=10000).

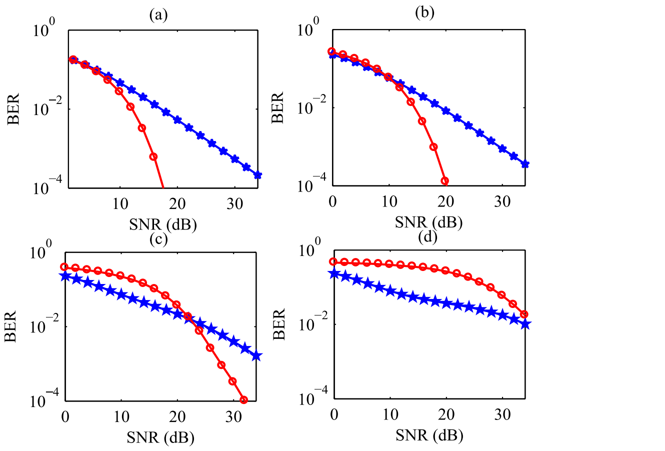

Figure 10. BER performance of LP-MI-OFDM (marker o) and conventional MI-OFDM (marker *) systems with QPSK over the frequency selective fading and impulsive noise channel models λ = 0.1 (a. μ=10, b. μ=100, c. μ=1000, d. μ=10000).

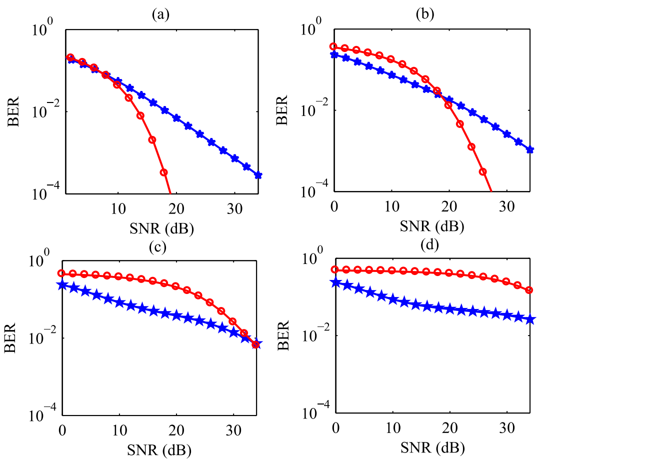

Figure 11. BER performance of LP-MI-OFDM (marker o) and conventional MI-OFDM (marker *) systems with QPSK over the frequency selective fading and impulsive noise channel models λ = 0.5 (a. μ=10, b. μ=100, c. μ=1000, d. μ=10000).

VI. Conclusion

In this work, LP-MI-OFDM scheme is proposed to suppress the deleterious effect of impulsive noise on the transmitted signal among IoT devices. Matrix interleaver (MI) is integrated with linear precoder based OFDM system to spread the effect of impulsive noise over large OFDM symbols. Consequently, the proposed scheme achieves a considerable spectral efficiency, robustness against multiplicative fading channel and bit-error-rate (BER) performance improvement when compared with the conventional approaches based IoT devices even in the presence of impulsive noise. The disturbance of severe impulsive noise on the performance of LP-OFDM system should be take into consideration in the future works.

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