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PERFORMANCE ANALYSIS OF DOWNLINK MULTIUSER CP-FREE MIMO OFDM SYSTEM WITH INTERFERENCE CANCELLATION AND ENHANCEMENT OF PHYSICAL-LAYER SECURITY

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ABSTRACT: *In scenario of considering improvement of physical layer security and spectral efficiency with effective elimination of Multiuser Interference and out-of-band (OOB) spectrum power reduction in fifth generation (5G)/future generation mobile networks, we have proposed a downlink Multiuser CP-Free MIMO OFDM system in this paper. The simulated system under consideration incorporates LQ-based generalized side-information cancellation (GSIC) interference reduction pre-coding strategy, 2D chaotic map aided encryption, Tukey windowing for OOB reduction, Regularized ZF signal detection, LDPC channel coding, Resource allocation for achievable system spectral efficiency and low order digital modulation techniques. On consideration of audio signal transmission in AWGN and MIMO Rayleigh flat fading channels, it is observable from MATLAB based simulation study that the proposed system is very much robust and effective in retrieving individual user's audio signal with substantial reduction of multiuser interference and OOB and also achieves superior Bit error rate (BER)-performance.*

KEYWORD: CP-Free MIMO OFDM, LQ-based GSIC precoding, 2D chaotic map based encryption, LDPC, OOB reduction, SNR.

INTRODUCTION

Existing 4th generation mobile communication system based on CP (Cyclic Prefix)-OFDM (Orthogonal Frequency Division Multiplexing) system maps data symbols to a plurality of orthogonal subcarriers and transmits the data symbols with reduction of Inter-Symbol Interference (ISI) occurring in various channel environments. The transfer from 4G LTE/LTE-Advanced to the next-generation mobile communication system (5G) is taking place very exciting worldwide. The standardization of the first phase 5G system in Release 15 (5G New Radio (NR)) would hopefully be made with commercial deployment of 5G NR networks in the year of 2020. In order to provide the very fast eMBB (enhanced mobile broadband) service of the next generation 5G mobile communication, it is important to increase the spectrum efficiency for accommodating the more channel capacity [1, 2].

In CP-OFDM, spectrum efficiency of the system deteriorates with utilization of CP. In perspective of fulfilment of ever-increasing demand for authenticated, confidential and secret data transmission over existing and future generation wireless networks, a considerable amount of research is being going on physical layer security which offers an information-theoretic level of secrecy with implementation of various improved cryptographic algorithms under exploitation of important characteristics of wireless channel such as fading, interference and noise. With proper designed of powerful error-correction codes called low-density parity-check (LDPC) codes, a high level of data security can be provided at the physical layer [3]. Orthogonal frequency division multiplexing (OFDM) is capable of dealing with delay spread of wireless channels and it has been widely applied in various communication systems with sufficient

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cyclic prefix (CP). To completely mitigate inter-OFDM-block interference (IBI), enough cyclic prefix (CP) must be inserted between adjacent OFDM blocks, which reduces spectral efficiency of OFDM systems, especially when the delay spread is large or the OFDM block duration is short as in many Internet of things (IoT) applications. Without sufficient CP, demodulated OFDM signals will suffer from inter-carrier interference (ICI) in addition to IBI. In CP free OFDM systems, channel estimation and signal detection are very much challenging [4].

The present study is based on the consideration of a typically assumed CP free OFDM system in which channel delay spread is considered to be low in comparison with OFDM block time and null subcarriers are placed along the channel edges for reduction of inter channel interference with concatenating active subcarriers at the central part of the channel. Such system would consider simulation parameters on the basis of 5G frame structural information at [5].

SIGNAL PROCESSING TECHNIQUES

In our present study, LDPC Channel Coding for FEC correction [6, 7] and various other useful signal processing techniques are used. A brief description is given below.

2D Chaotic Map Aided Encryption

The encryption sequences are generated by a two-dimensional (2D) coupled Logistic mapping as:

$$x_{i+1} = \mu_1 x_i (1 - x_i) + \gamma_1 y^2{}_i \text{ , i=0, 1, 2.3……………….4095} \tag{1}$$

$$y_{i+1} = \mu_2 y_i (1 - y_i) + \gamma_2 (x^2{}_i + x_i y_i) \text{, i=0, 1, 2.3……………….4095} \tag{2}$$

Where, $2.75 < \mu_1 < 3.4$, $2.75 < \mu_2 < 3.45$ and $0.15 < \gamma_1 < 0.21$, $0.13 < \gamma_2 < 0.15$

Various useful parameter values for estimating encryption sequences a and b are given in Table 1.

Table 1. Parameters used for estimating encryption sequences

User #	initial values(x_0, y_0)	μ_1	μ_2	γ_1	γ_2
User 1	0.123456789, 0.34126789	2.75	2.85	0.15	0.13
User 2	0.561234789, 0.78341269	3.00	3.15	0.18	0.14
User 3	0.245614789,0.34783469	3.10	3.20	0.17	0.15

The generated sequences x and y are chaotic in interval (0, 1). It can be seen that with only a slight change ($\sim 1\times10^{-15}$) of the initial values x_0, the chaotic state falls into two absolutely different chaotic orbits. To improve the statistical properties of the generated sequences, the following preprocessing is performed.

$$\begin{aligned} x_i &= 10^6 x_i - \text{floor}(0^6 x_i) \\ y_i &= 10^6 y_i - \text{floor}(0^6 y_i) \end{aligned} \tag{3}$$

Using Equation (3), the generated sequence *x* and *y* are used to generate the encryption sequences [8, 9]

$$\begin{aligned} a(i) &= \text{sign}(x(i) - 0.5) \\ b(i) &= \text{sign}(y(i) - 0.5) \end{aligned} \tag{4}$$

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LQ-based Generalized Side-information Cancellation (GSIC) Precoding

LQ-based GSIC precoder exhibits superior performance in cancelling MU interference. In our presently considered downlink transmission scenario, three users each of which is equipped with two receiving antennas are receiving signals from BS with six transmitting antennas. The channel assigned for three users are designated by H_1, H_2 and H_3. The channel matrix H can be undergone LQ decomposition as follows:

$$H = [H_1^T \ \ H_2^T \ \ H_3^T \ ]^T = LQ \qquad (5)$$

Where, L is a lower triangular matrix and **Q** is a unitary matrix. The channel matrix H can be rewritten as:

$$H = \begin{bmatrix} H_1 \\ H_2 \\ H_3 \end{bmatrix} = \begin{bmatrix} L_{11} & 0 & 0 \\ L_{21} & L_{22} & 0 \\ L_{31} & L_{32} & L_{33} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \end{bmatrix} = \begin{bmatrix} L_{11}Q_1 \\ L_{21}Q_1 + L_{21}Q_2 \\ L_{31}Q_1 + L_{32}Q_2 + L_{33}Q_3 \end{bmatrix} \qquad (6)$$

The unitary matrix **Q** has three orthogonal unitary matrices as

$$Q = \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \end{bmatrix} \qquad (7)$$

Where, L_{11}, L_{22} and L_{33} are triangular matrices; L_{21}, L_{31} and L_{32} are full-rank matrices; $\mathbf{Q}_1$, $\mathbf{Q}_2$, and $\mathbf{Q}_3$ are orthogonal unitary matrices. The received data matrix can be represented by

$$y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} L_{11}Q_1 \\ L_{21_1}Q_1 + L_{22}Q_2 \\ L_{31}Q_1 + L_{32}Q_2 + L_{32}Q3 \end{bmatrix} [P_1 \, P_2 \ \ P_3 \ ] \begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix} \qquad (8)$$

Where,

$$y_1 = L_{11}Q_1P_1s_1 + L_{11}Q_1P_2s_2 + L_{11}Q_1P_3s_3 + w_1 \qquad (9a)$$

$$y_2 = L_{21}Q_1P_1s_1 + L_{22}Q_2P_1s_1 + L_{21}Q_1P_2s_2 + L_{22}Q_2P_2s_2 + L_{21}Q_1P_3s_3 + L_{22}Q_2P_3s_3 + w_2 \qquad (9b)$$

$$y_3 = L_{21}Q_1P_1s_1 + L_{32}Q_2P_1s_1 + L_{33}Q_3P_1s_1 + L_{31}Q_1P_2s_2 + L_{32}Q_2P_2s_2 + L_{33}Q_3P_2s_2 + L_{31}Q_1P_3s_3 + L_{32}Q_2P_3s_3 + L_{33}Q_3P_3s_3 + w_3 \qquad (9c)$$

And w_1, w_2 and w_3 are AWGN noises. The optimal cancellation matrix Z_1 can be obtained from the following equation:

$$Z_1 = (L_{22}^H L_{22} + \frac{(N_1+N_2+N_3)\sigma_w^2}{P_{Total}} I)^{-1}(L_{22}^H L_{21}) \qquad (10)$$

Where, $T_r(Q_K^H Q_K) = N_K$, k=1,2,3, P_{Total} is the total transmitted power and σ^2_w is the noise variance estimated from a typically assumed noise floor power(-92dBm/6.31×10^{-13} watt).

Using estimated value of optimal cancellation matrix Z_1, $\tilde{L}_{31}$is estimated from the relation:

$$\tilde{L}_{31} = L_{31} - L_{32}Z_1 \qquad (11)$$

The optimal cancellation matrices $\mathbf{Z_2}$ and $\mathbf{Z_3}$ are calculated from the relation:

$$Z_2 = (L_{33}^H L_{33} + \frac{N_2\sigma_w^2}{P_{Total}} I)^{-1}(L_{33}^H \tilde{L}_{31}) \qquad (12)$$

$$Z_3 = (L_{33}^H L_{33} + \frac{N_3\sigma_w^2}{P_{Total}} I)^{-1}(L_{33}^H L_{32}) \qquad (13)$$

The scaling factor **β** for constraining the total transmit power can be written as:

$$\beta = \sqrt{P_{total}}\{N_1 + N_2 + N_3 + tr(Z_1Z_1^H) + tr(Z_2Z_2^H) + tr(Z_3Z_3^H)\}^{-\frac{1}{2}} \qquad (14)$$

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The three-user precoding matrices with the transmit power constraint can be expressed as [10]:

$$P_1 = \beta(Q_1^H - Q_2^H Z_1 - Q_3^H Z_2) \quad (15a)$$
$$P_2 = \beta(Q_2^H - Q_3^H Z_3) \quad (15b)$$
$$P_3 = \beta(Q_3^H) \quad (15c)$$

Tukey window technique for OOB Reduction

Tukey window also known as the Tapered Cosine window, is a one-parameter family of window functions used as transmit and receive windowing technique in digital communication system. It is created through the windowing of a rectangular pulse by the Tukey window. It can be regarded as a cosine lobe of width rNo/2 that is convolved with a rectangular window of width (1 − r/2) No, where, r is the ratio of taper to constant sections and its value is between 0 and 1, No is the number of samples contained in Tukey window. It r<=0 then it becomes rectangular and if r>=1, then it becomes Hann window. The default value for r is 0.5. This technique can be defined as below [11]:

$$w[k] = \begin{cases} \frac{1}{2}[1+\cos(\frac{2\pi}{r})\frac{(k-1)}{(N_o-1)} - \pi] & k < \frac{r}{2}(N_o - 1) + 1 \\ 1 & \frac{r}{2}(N_o-1)+1 \le k \le N_o - \frac{r}{2}(N_o-1) \\ \frac{1}{2}[1+\cos(\frac{2\pi}{r} - \frac{2\pi}{r}\frac{(k-1)}{(N_o-1)} - \pi)] & N_o - \frac{r}{2}(N_o-1) < k \end{cases} \quad (16)$$

$$\text{where}, k = 1,2,3 \ldots\ldots\ldots\ldots\ldots\ldots N_o$$

Regularized ZF Signal Detection

In case of considering user specific MIMO channel $\overset{t}{H}$ and received signal $\overset{t}{y}$, the Zero Forcing weight matrix can be written as:

$$W_{ZF} = (\overset{t}{H}{}^H \overset{t}{H})^{-1} \overset{t}{H}{}^H \quad (17)$$

And the detected desired signal from the transmitting antenna is given by [12]

$$\tilde{X}_{ZF} = W_{ZF}\overleftrightarrow{y} \quad (18)$$

Generally, it is observable that the MIMO fading channel $\overset{t}{H}$ used in inversion based computation shows singularity (ill conditioning). Due to ill-conditioning, Equation (18) does not provide properly estimated desired signal. A regularization parameter **σ** is introduced in Equation (18) to get desired signal as:

$$\overset{\approx}{X}_{ZF} = (\overset{t}{H}{}^H \overset{t}{H} + \sigma I)^{-1} \overset{t}{H}{}^H \overset{t}{y} \quad (19)$$

Where, I is the 6×6 identity matrix. The condition number of the regularized matrix $(\overset{t}{H}{}^H \overset{t}{H} + \sigma I)$ is much lower than the matrix $(\overset{t}{H}{}^H \overset{t}{H})$ [13].

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SYSTEM DESCRIPTION

The primary concept of the transmission mechanism of our proposed Downlink Multiuser CP-Free MIMO OFDM system with interference cancellation and enhancement of physical-layer security is illustrated in Figure 1 in brief it is considered that each user is sending analog audio samples of 8250 and these samples are converted into 8-digit binary format. The extracted binary signal is channel encoded, interleaved and subsequently processed for generating digitally modulated symbols. After performing symbol mapping, the modulated symbols are encrypted using 2D chaotic map aided encryption technique and arranged into blocks prior to performing 4096 IFFT and windowing operation. The blocked signal vector is reshaped and precoded with implementation of LQ-Based GSIC algorithm. The precoded signals for all the users are summed up after completing D/A conversion respectively and sent up from each of the six transmitting antennas. In receiving section for each user, all the transmitted signals are detected with linear signal detection schemes, A/D converted and restructured for processing to eliminate the effect of precoding. The processed signal is decrypted, demapped, digitally demodulated, deinterleaved, and channel decodedand eventually audio signal is retrieved.

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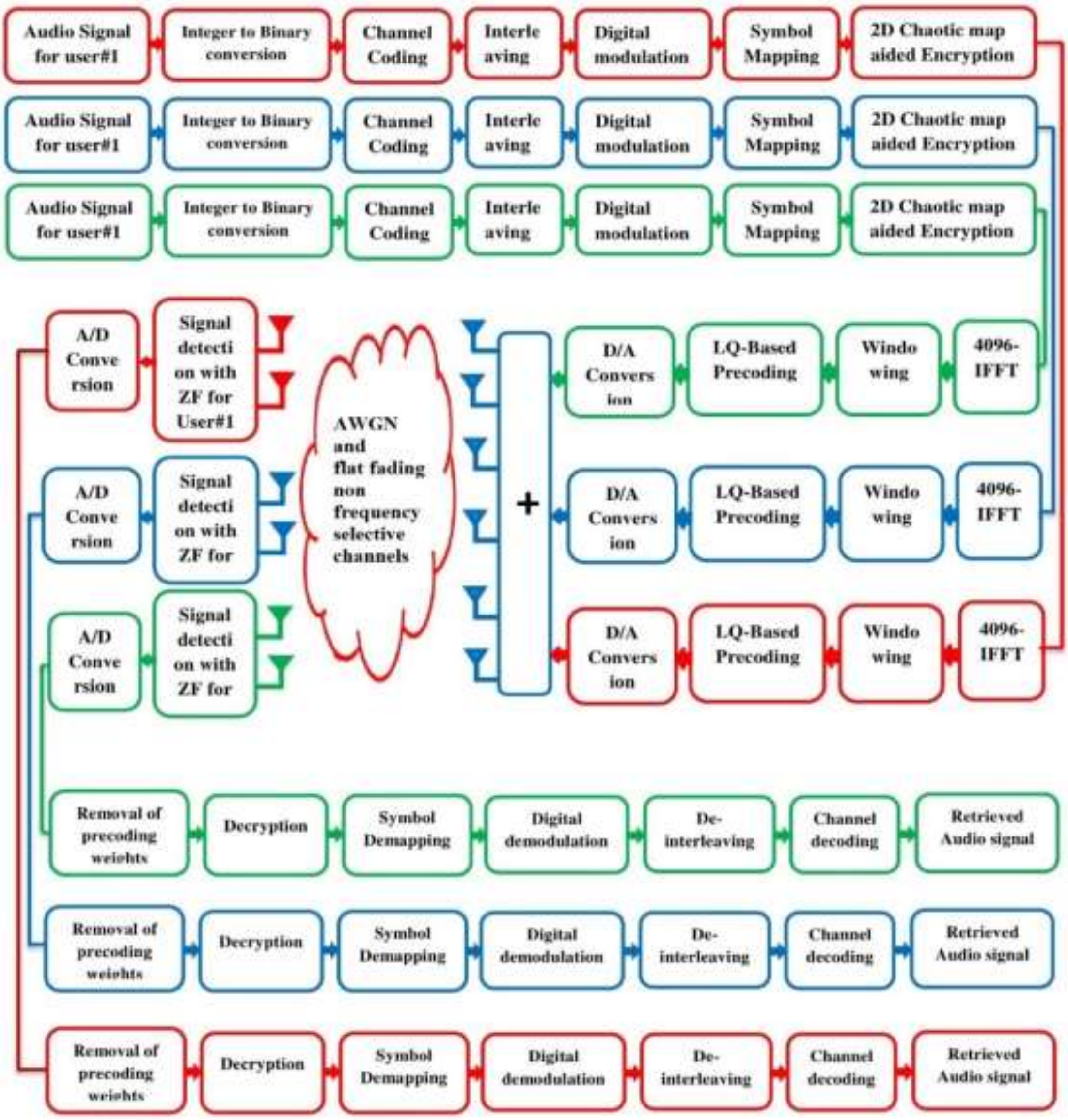

Figure 1. **Blok Diagram of LQ-based GSIC Pre-coded multi-user Downlink CP-Free MIMO OFDM system.**

RESULTS AND DISCUSSION

Under scenario of non-implementing windowing technique and from graphical illustration presented in Figure 2, it is seen that maximum OOB power reduction in case of user 1, user 2 and user 3 are found to have values of 35.22dB, 35.33dB and 38.83 dB relative to in band power. The OOB power reduction performance of the simulated system improves with implementation of windowing technique. The newly estimated maximum OOB power reduction values in case of user 1, user 2 and user 3 are 122.13dB, 121.21dB and 121.73 dB respectively.

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Table 2. Simulation parameters

Data type	Audio
No of audio samples for each of three users	8250
Pulse shaping filter	Raised cosine with roll off 0.25 and filter order 22
Precoding scheme	LQ-based Generalized Side-information Cancellation (GSIC) Precoding
PHY security enhancing technique	2D chaotic map aided encryption
FFT size	4096
Effective subcarriers in a single OFDM	3300
Null carrier distribution	398 at left, one at middle and 397 at right of frequency band
Subcarrier spacing [KHz]	60
Sampling frequency (MHz)	245.76
Carrier and System Bandwidth [MHz]	200 and 250
No of OFDM symbol for each user	20
Input data symbols	4-QAM,QPSK and DQPSK
Windowing	Tukey (Tapered cosine)
Window length (samples), WL at both ends of Tukey windowing function	398
Channel coding	LDPC
Signal detection	Regularized Zero forcing with regularizing factor 1.0×10^{-14}
Channel	AWGN and flat fading non frequency selective channels
Signal to noise ratio (SNR)	0 to 10 dB

Table 3. Estimated total power of user's Signal and Interference.

User #	User's own signal power(watt)	Interference signal power(watt)
User 1	4.7364×10^{-05}	1.5878×10^{-36}
User 2	8.3569×10^{-06}	8.0618×10^{-28}
User 3	1.7734×10^{-05}	3.5846×10^{-29}
Total Transmitted power(watt)	6.0304×10^{-05}	

Under scenario of non-implementing windowing technique and from graphical illustration presented in Figure 2, it is seen that maximum OOB power reduction in case of user 1, user 2 and user 3 are found to have values of 35.22 dB, 35.33 dB and 38.83 dB relative to in band power. The OOB power reduction performance of the simulated system improves with implementation of windowing technique. The newly estimated maximum OOB power reduction values in case of user 1, user 2 and user 3 are 122.13dB, 121.21dB and 121.73 dB respectively.

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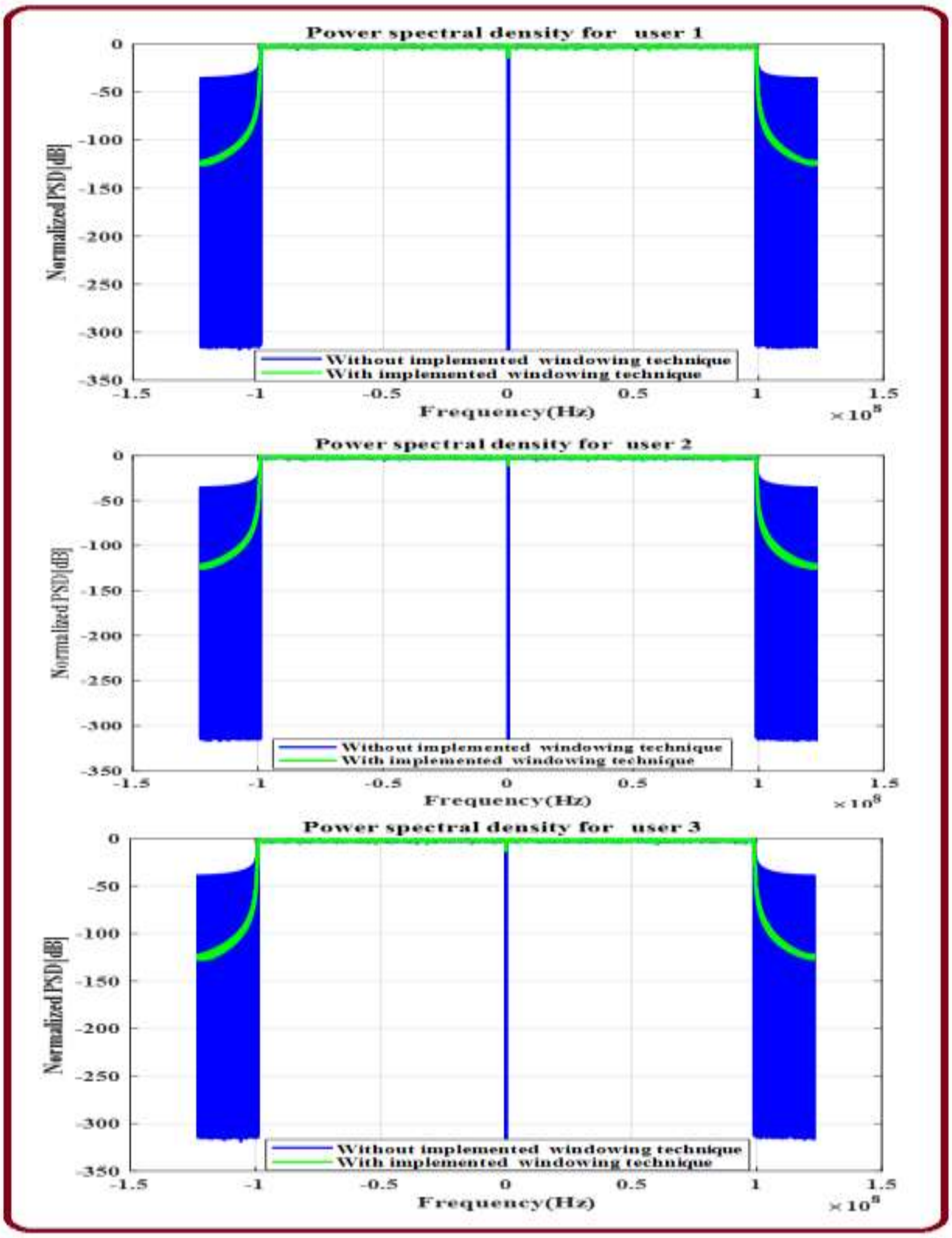

Figure 2. **Estimated power spectral density of three different users under scenario of with and without implementing windowing technique.**

It is quite obvious from graphical illustrations presented in Figure 3 through Figure 5 that the simulated system under consideration shows reasonably better performance in case of utilizing low order QAM digital modulation. In case of user #1, it is seen from Figure 3 that the estimated BERs are found to have values of 0.2 and 0.18 for QPSK and DQPSK modulations for a typically assumed SNR value of 5 dB. A significant reduction of BER value to 0.02 in case of QAM modulation occurs which ratifies achievement of system performance improvement of 10 dB and 9.54 dB are achieved in QAM as compared to QPSK and DPSK digital modulation techniques.

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For a typical assumed SNR value of 5 dB, it is observable from Figure 4 for user #2 that the estimated BER values are 0.19, 0.185 and 0.025 for QPSK, DQPSK and QAM modulation techniques respectively which signifies system performance improvement of 8.80 dB and 8.69 dB in QAM as compared to QPSK and DQPSK modulation techniques. With identical consideration of SNR value for user #3. It is noticeable from Figure 5 that the estimated BER values are 0.18, 0.075 and 0.005 for QPSK, DQPSK and QAM modulation which is indicative of system performance improvement of 15.56 dB and 11.76 dB in QAM as compared to QPSK and DQPSK.

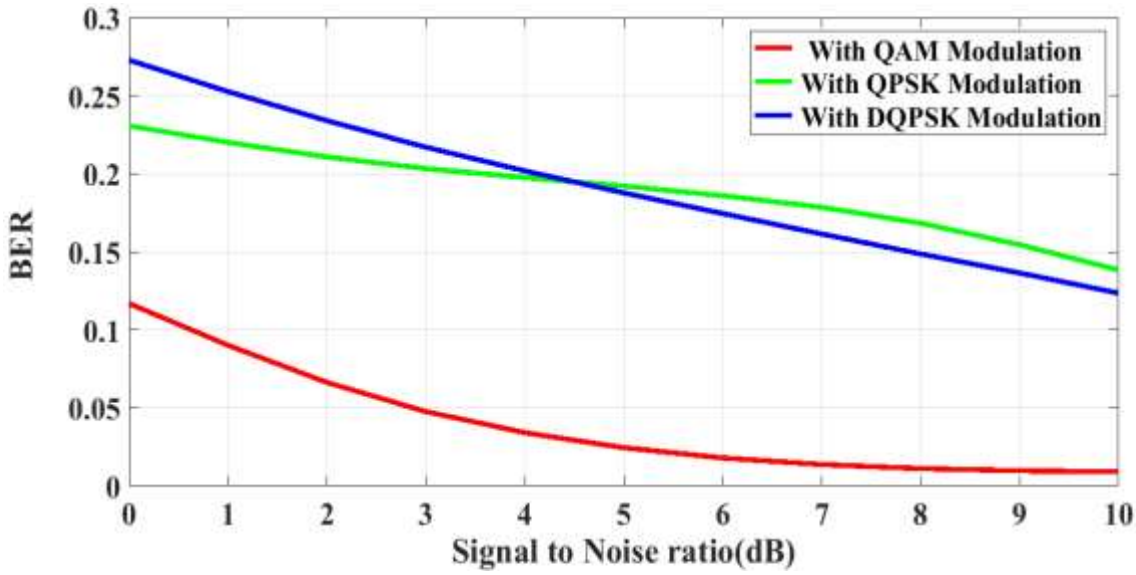

Figure 3. **BER performance of Audiosignal transmission in LQ-based GSIC Pre-coded multi-user Downlink CP-Free MIMO OFDM system for user#1 under implementation of different low order digital modulations, LDPC channel coding and Regularized ZF signal detection techniques.**

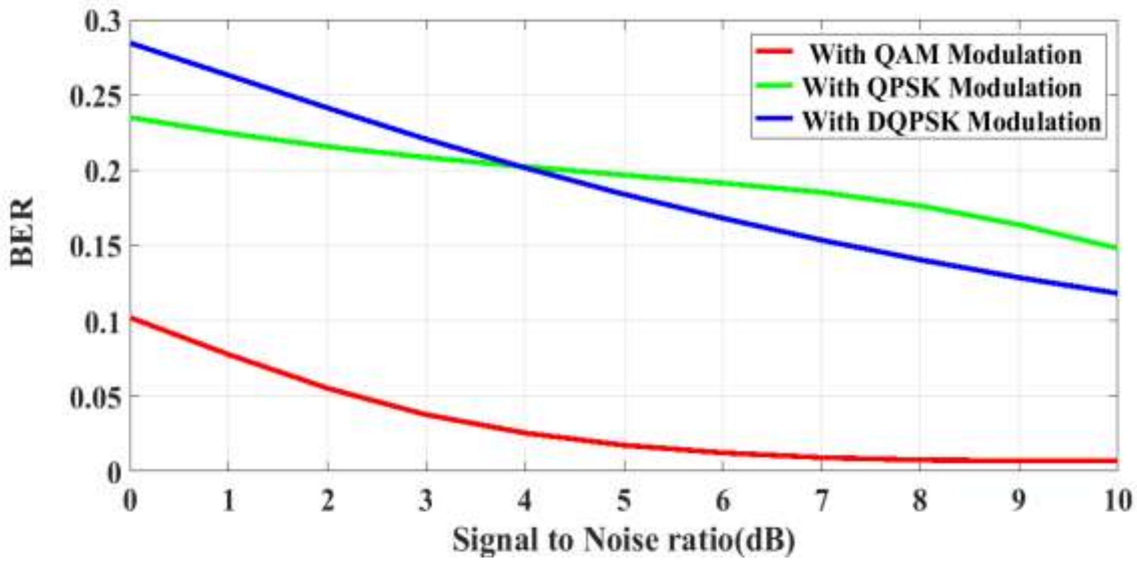

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Figure 4. **BER performance of Audio signal transmission in LQ-based GSIC Pre-coded multi-user Downlink CP-Free MIMO OFDM system for user#2 under implementation of different low order digital modulations, LDPC channel coding and Regularized ZF signal detection techniques**

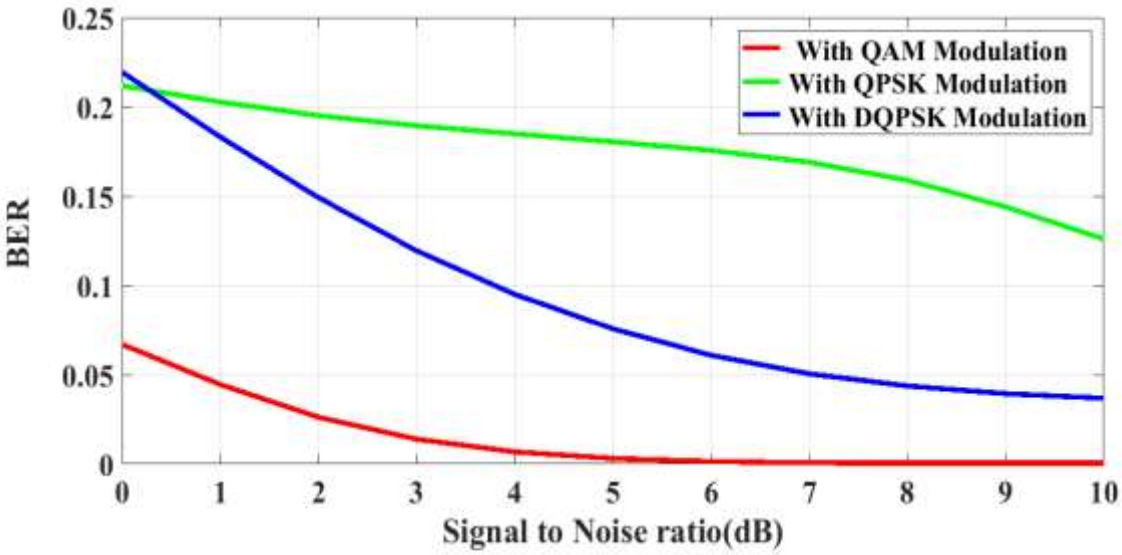

Figure 5. **BER performance of Audio signal transmission in LQ-based GSIC Pre-coded multi-user Downlink CP-Free MIMO OFDM system for user#3 under implementation of different low order digital modulations, LDPC channel coding and Regularized ZF signal detection techniques.**

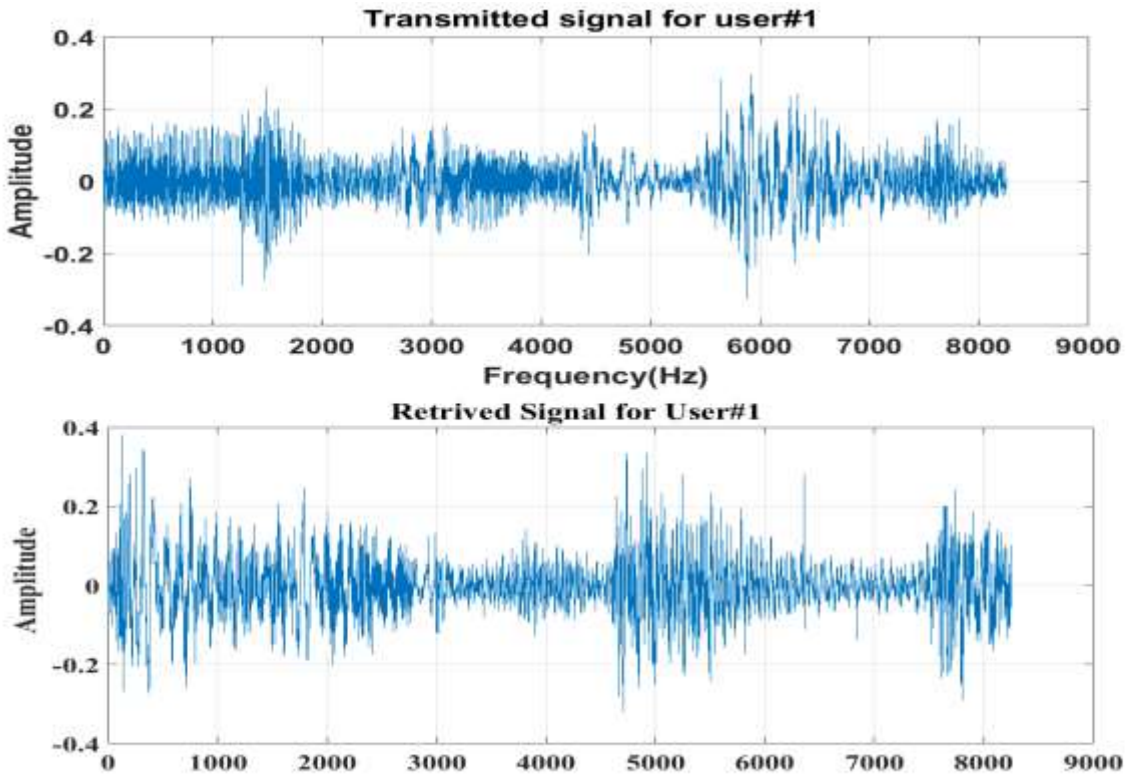

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Figure 6. **Transmitted and Retrieved Audio signals at SNR value of 10 dB in LQ-based GSIC Pre-coded multi-user Downlink CP-Free MIMO OFDM system for user#1 under implementation of 4-QAM digital modulation, LDPC channel coding and Regularized ZF signal detection techniques.**

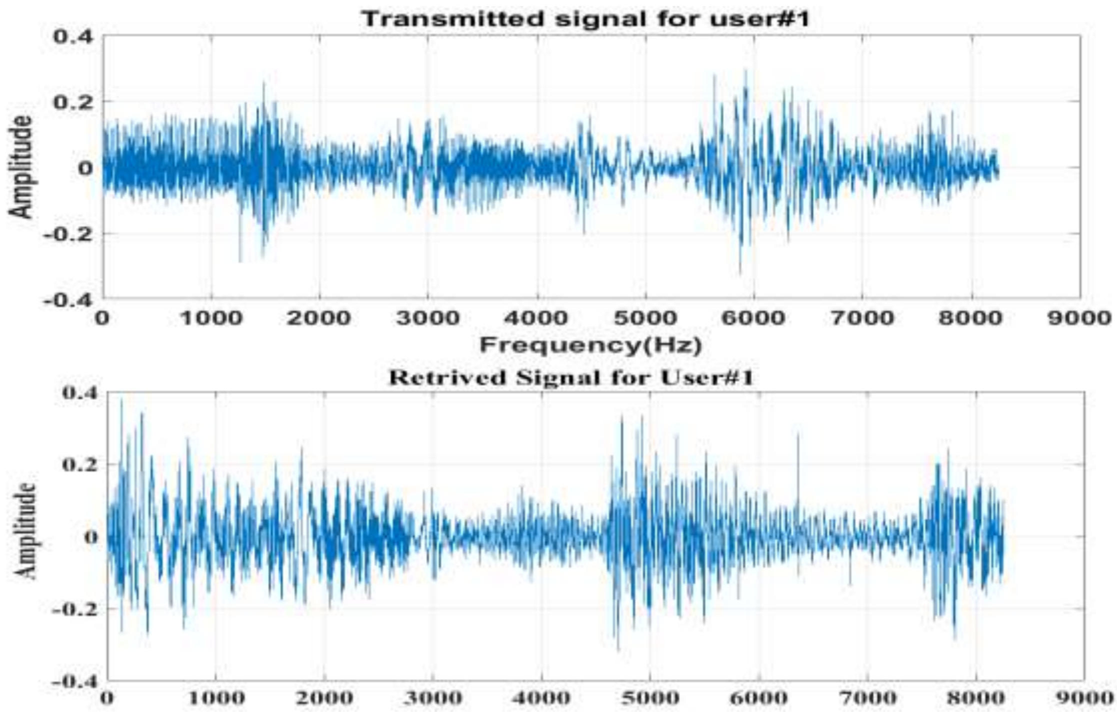

Figure 7. **Transmitted and Retrieved Audio signals at SNR value of 10 dB in LQ-based GSIC Pre-coded multi-user Downlink CP-Free MIMO OFDM system for user#2 under implementation of 4-QAM digital modulation, LDPC channel coding and Regularized ZF signal detection techniques.**

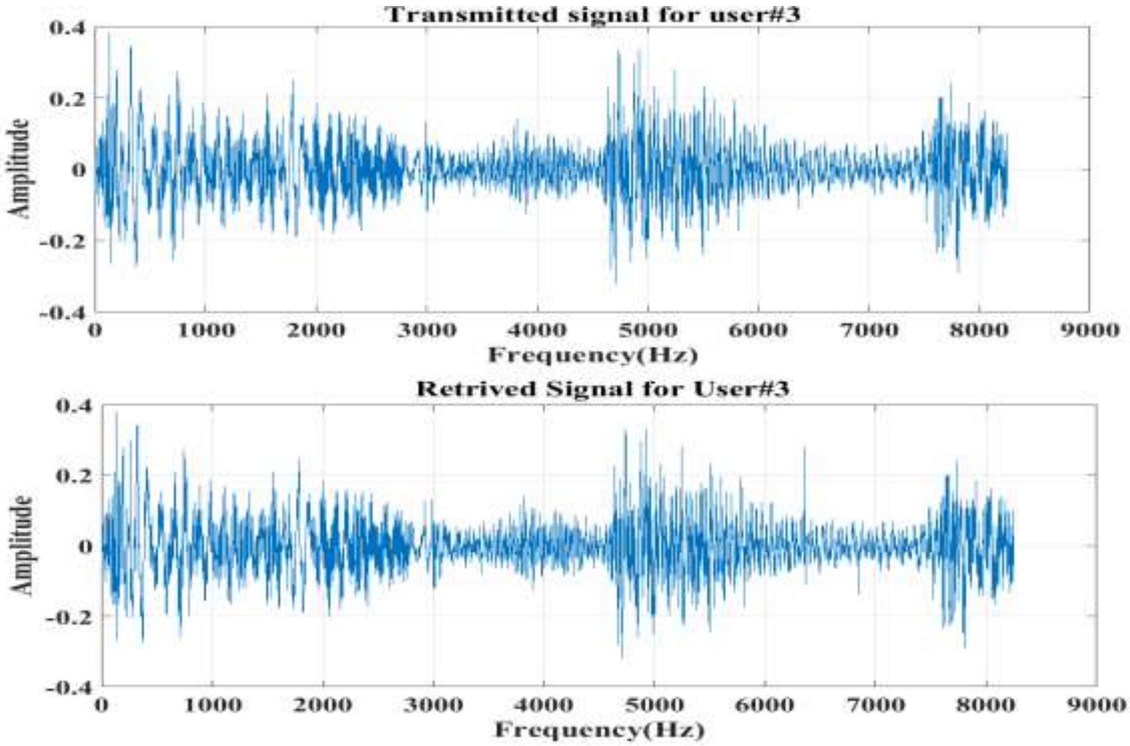

Figure 8. **Transmitted and Retrieved Audio signals at SNR value of 10 dB in LQ-based GSIC Pre-coded multi-user Downlink CP-Free MIMO OFDM system for user#3 under implementation of 4-QAM digital modulation, LDPC channel coding and Regularized ZF signal detection techniques.**

It is quite noticeable from graphical illustrations presented in spectral curves from Figure 9 through Figure 11 that the frequency spectral components in the frequency bands ranging from 0 Hz to approximately 1500 Hz for transmitted audio signals have great similarity with those of retrieved audio signals. In higher frequency band near 4000Hz, spectral amplitude variations between transmitted and retrieved audio signals are insignificant.

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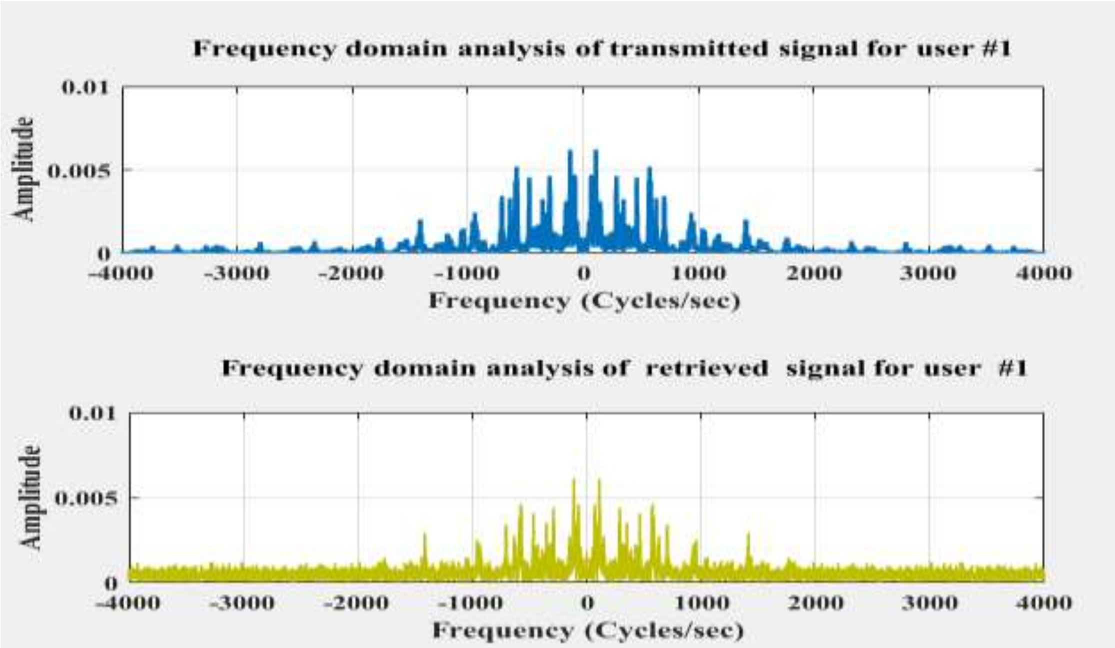

Figure 9. **Estimated Amplitude Spectrum of Transmitted and Retrieved Audio signals at SNR value of 10 dB in LQ-based GSIC Pre-coded multi-user Downlink CP-Free MIMO OFDM system for user#1 under implementation of 4-QAM digital modulation, LDPC channel coding and RegularizedZF signal detection techniques.**

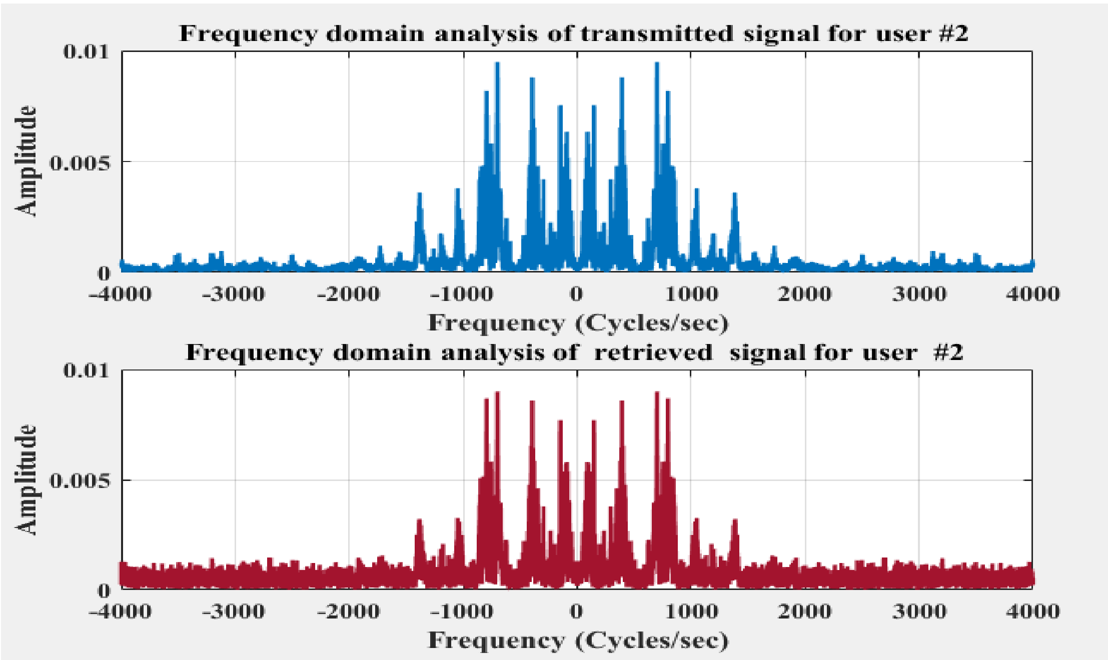

Figure 10. **Estimated Amplitude Spectrum of Transmitted and Retrieved Audio signals at SNR value of 10 dB in LQ-based GSIC Pre-coded multi-user Downlink CP-Free MIMO OFDM system for user#2 under implementation of 4-QAM digital modulation, LDPC channel coding and RegularizedZF signal detection techniques.**

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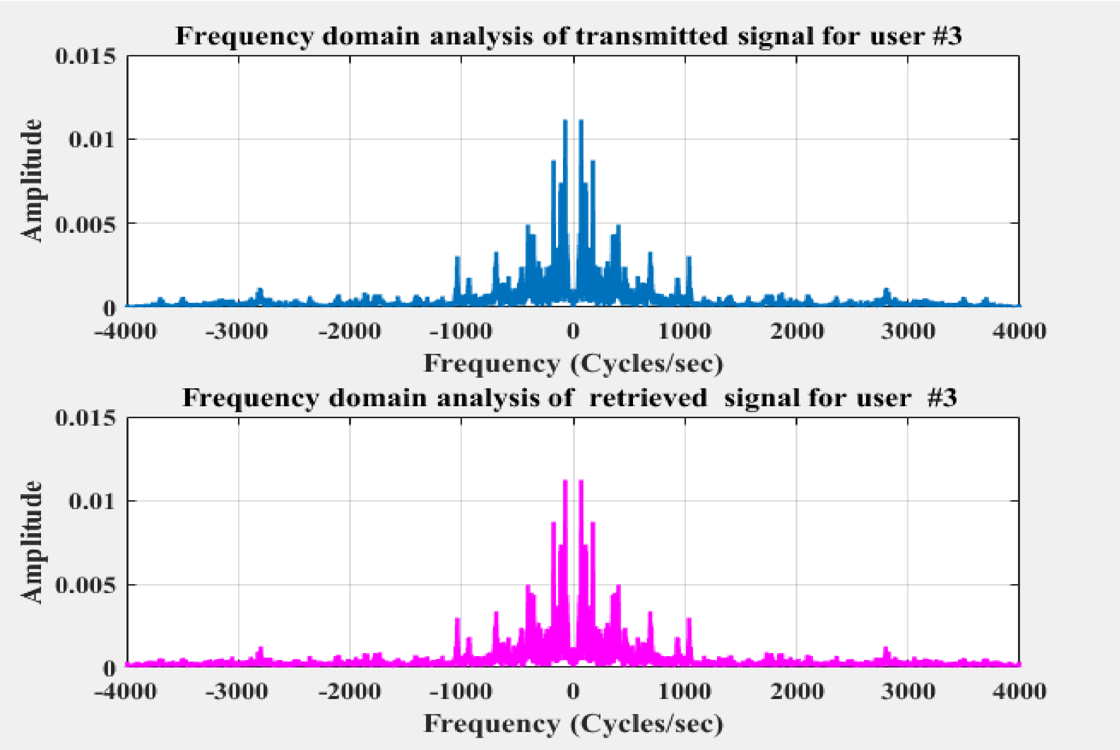

Figure 11. **Estimated Amplitude Spectrum of Transmitted and Retrieved Audio signals at SNR value of 10 dB in LQ-based GSIC Pre-coded multi-user Downlink CP-Free MIMO OFDM system for user#3 under implementation of 4-QAM digital modulation, LDPC channel coding and Regularized ZF signal detection techniques.**

CONCLUSIONS

In this paper, we made an investigative study on the performance evaluation of downlink multiuser CP-Free MIMO OFDM system. The 6×2 user specific multi-antenna configured simulated system under investigation incorporates LDPC channel coding, low order digital modulations (QAM, QPSK, DQPSK), 2D chaotic map aided encryption, Tukey windowing, Regularized ZF signal detection and LQ-based generalized side-information cancellation (GSIC) interference reduction pre-coding techniques. From critical analysis of the simulated results, it can be concluded that such LQ-based GSIC pre-coded multiuser downlink CP-Free MIMO OFDM wireless communication with QAM digital modulation is very much effective in perspective of OOB and multiuser interference reduction and satisfactory system performance.

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