

Secured Voice Frequency Signal Transmission in 5G Compatible Multiuser Downlink MIMO NOMA Wireless Communication System

Md. Humaun Kabir^{1,*}, Jinia Rahman², Shaikh Enayet Ullah²

¹Department of Computer Science and Engineering, Pundra University of Science and Technology, Bogura, Bangladesh

²Department of Applied Physics and Electronic Engineering, University of Rajshahi, Rajshahi, Bangladesh

Abstract In this paper, we investigate the performance of 2×2 multi antenna configured NOMA wireless communication system. The simulated system under investigation incorporates various types of channel coding schemes (LDPC, (3, 2) SPC and Repeat and Accumulate) and two types of low order modulation techniques (QPSK and QAM). We propose an improved ML decoding based QR channel factorization aided SIC (QR-SIC) technique and it is implemented on encrypted audio signal transmission in a hostile fading channel. Numerical simulation results show that the presently considered simulated system is very much robust and effective in retrieving audio signal under utilization of Repeat and Accumulate channel coding and QAM digital modulation techniques.

Keywords 5G, NOMA, MIMO, QR-SIC, ML decoding, LDPC, (3, 2) SPC and RA

1. Introduction

In view of consideration of increasing demand by mobile radio customers for multimedia services, higher data rates and bandwidth availability as well as anticipated traffic related to the Internet of Things (IoT), the fifth Generation (5G) /Beyond 5G (B5G) wireless communication systems will emerge to meet up unprecedented demands beyond the capability of previous generations of wireless communication networks. The 5G networks will promote the continued evolution of the way human interacting information and provide users with ultimate experience through more immersive services such as 3D connectivity (aircraft and drone), Ultra High Definition (UHD), 3D video, Online gaming applications, Augmented and virtual reality, Video/photo sharing in stadium/open air gathering, Mobile cloud/desktop cloud, Tactile Internet, Collaborative robots etc. [1-2]. OFDMA is commonly used as the multiple access technique in the present wireless communication systems which can provide concurrent interference free transmission to multiple users with orthogonal subcarriers. The main drawback of OFDMA is that it does not generally achieve the highest possible data rate for a given error probability [3-6].

Non-orthogonal multiple access (NOMA) technology has been considered as a state-of-the-art technology which can achieve higher spectrum efficiency and support more massive connectivity as compared to the traditional orthogonal multiple access techniques. Many mainstream companies have proposed NOMA for the fifth generation (5G) wireless communication standard. For downlink NOMA, non-orthogonality is achieved by introducing the power domain, either in time/frequency/code domains, for user multiplexing. User de-multiplexing is obtained through the allocation of a large power difference between the users on the transmitter side and the application of SIC on the receiver side [7]. Four categories of NOMA such as scrambling-based NOMA, spreading-based NOMA, coding-based NOMA, and interleaving-based NOMA have been suggested and their performance acceptability has also been studied at [8]. Energy harvesting technology implemented wireless powered communication networks (WPCNs) have been envisioned as a promising solution for the future Internet-of-Things (IoT). The NOMA has been recently considered for the uplink of WPCNs based IoT networks with a massive number of devices. In scenario of total energy consumption and maximization of spectral efficiency, a comprehensive study was conducted on both NOMA-based WPCN (N-WPCN) and TDMA-based WPCN (T-WPCN) at [9]. Now a days, a paramount importance is being given on integrating NOMA to unmanned aerial vehicle (UAV)-aided wireless communication networks for achieving high spectral efficiency (SE). In [10], the authors introduced NOMA transmission under consideration of user

* Corresponding author:

humaun4938@gmail.com (Md. Humaun Kabir)

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distances as the available feedback, to UAVs serving as aerial base stations (BSs). Through their extensive simulation works, a comprehensive framework was developed for deriving achievable outage probabilities and sum rates rigorously with implementation of distance feedback based NOMA strategy. NOMA technique can be applied to improve the achievable sum rate of multiple-input multiple-output (MIMO)-based multi-user visible light communication (VLC) systems. At [11], the authors proposed a normalized gain difference power allocation (NGDPA) method first through exploiting users' channel conditions for consideration of efficient and low-complexity power allocation in indoor MIMO-NOMA-based VLC systems. With employment of NOMA with the proposed NGDPA method, achievable sum rate of the 2×2 MIMO-VLC system was improved significantly. In [12], the authors made investigative study on the performance of advanced NOMA using experimental trials in outdoor using 2×2 open loop MIMO and 4×2 closed-loop MIMO. The results of their work confirmed that NOMA was capable of providing a maximum of 2.3 times more gains as compared to SU-MIMO for the case of 3-UE when combined with 4×2 closed-loop MIMO. At [13], the authors investigated on the joint power allocation and modulation optimization in two-user NOMA channels using finite-alphabet inputs with perfect CSI. Their simulation results showed that their proposed approach based on the error-rate criterion outperformed as compared to some existing NOMA schemes based on perfect SIC assumption. In [14], the authors utilized cyclostationarity based equalization scheme in power domain NOMA system for signal detection. Results of their simulation works confirmed the suitability of implemented technique in under low signal-to-noise ratio (SNR) environment. In this present study, we have presented simulation results for MIMO NOMA system under scenario of utilizing mainly encryption, different modulation, several channel coding, and successive user interference reductions techniques.

2. Signal Processing Techniques

In our present study various signal processing schemes have been used. A brief overview of these schemes is given below:

2.1. ML Decoding Based QR-SIC Algorithm

We assume that the base station is equipped with M transmitting antennas and each individual user is equipped with N receiving antennas ($M \leq N$). With perfect channel state information (H), the received signal at k^{th} user can be represented as:

$$Y_k = H_k X + W_k = H_k \sum P_k S_{k,v} + W_k \quad (1)$$

Where, H_k is the complex channel coefficient between k^{th} user and base station, P_k is the allocated power for the k^{th} user, $S_{k,v}$ is the transmitted symbol for k^{th} user from

v^{th} transmitting antenna and the term W_k denotes the receiver Gaussian noise including inter-cell interference at the receiver of k^{th} user. For the case of two users ($k = 1, 2$), assume that UE_1 is a cell-center user (near user) and UE_2 is a cell-edge user (far user), the received signals at user #1 and user #2 are given by:

$$Y_1 = H_1 X + W_1 \quad (2)$$

$$Y_2 = H_2 X + W_2 \quad (3)$$

Where, the transmitted signal X is formed from summing up of simultaneous transmission of two spatially multiplexed consecutive complex symbols of each user (X_1 and X_2) in one time slot and can be written as:

$$\begin{aligned} X &= X_1 + X_2 \\ &= \sqrt{P_1} S_1 + \sqrt{P_2} S_2 \\ &= \sqrt{P_1} \begin{pmatrix} S_{1,1} \\ S_{1,2} \end{pmatrix} + \sqrt{P_2} \begin{pmatrix} S_{2,1} \\ S_{2,2} \end{pmatrix} \end{aligned} \quad (4)$$

Where, S_1 and S_2 are transmitted signals for UE_1 and UE_2 prior to power allocation, signal components $S_{1,1}$ of UE_1 and $S_{2,1}$ of UE_2 are transmitted from first transmitting antenna and $S_{1,2}$ of UE_1 and $S_{2,2}$ of UE_2 are transmitted from second transmitting antenna. The P_1 (20% of total power) and P_2 (80% of total power) are allocated power to user #1 and user #2 respectively. On QR matrix decomposition of channel coefficient of k^{th} user, we can write,

$$H_k = Q_k R_k \quad (5)$$

Where, Q_k is $N \times M$ unitary matrix, $Q_k^H Q_k = I$, R_k is $M \times M$ upper triangular matrix. After multiplying both sides of equation (1) with complex conjugate transformed of Q_k , we get:

$$Q_k^H Y_k = R_k X + Q_k^H W_k \quad (6)$$

With utilization of Maximum Likelihood (ML) signal detection technique, we can write,

$$\begin{aligned} \hat{X}_k &= \arg \min (\|Y_k - R_k X\|^2) \\ &= \arg \min (\sum_{i=1}^M |Y_i - \sum_{j=i}^M R_{i,j} X_j|^2) \end{aligned} \quad (7)$$

Where, $\| \cdot \|^2$ is indicative of square of Frobenius norm of matrix, $R_{i,j}$ is the $(i,j)^{th}$ component of R and $| \cdot |$ implies the absolute value [15-16].

2.2. LDPC Channel Coding

Low-density parity-check (LDPC) code invented by Gallager is a linear block code with its parity-check matrix \mathbf{H} containing only a few 1's in comparison to 0's. Bilateral Tanner graph is used to make graphical representation of LDPC codes. In bilateral Tanner graph, nodes are grouped into one set of n bit nodes (or variable nodes) and the other set of m check nodes (or parity nodes). Check node i is connected to bit node j in case of any elemental value of the parity matrix unity. The decoding operates alternatively on the bit nodes and the check nodes to find the most likely codeword \mathbf{c} that satisfies the condition $\mathbf{cH}^T = \mathbf{0}$. In iterative Log Domain Sum-Product LDPC decoding in AWGN noisy channel environment of variance σ^2 and received signal

vector \mathbf{r} , the log-likelihood ratios (LLRs) instead of probability can be defined as:

$$\left. \begin{aligned} L(c_i) &\triangleq \ln[P(c_i = 0|r_i) / P(c_i = 1|r_i)] \\ L(P_{ij}) &\triangleq \ln[P_{ij}^0 / P_{ij}^1] \\ L(Q_{ij}) &\triangleq \ln[Q_{ij}^0 / Q_{ij}^1] \\ L(P_j) &\triangleq \ln[P_j^0 / P_j^1] \end{aligned} \right| \quad (8)$$

Where, $\ln(\cdot)$ represents the natural logarithm operation. The bit node j is initially set with an edge to check node i :

$$L(P_{ij}) = L(c_i) = 2r_i / \sigma^2 \quad (9)$$

In message passing from check nodes to bit nodes for each check node i with an edge to bit node j ; $L(Q_{ij})$ is updated as:

$$L(Q_{ij}) = \prod_{j'} \alpha_{ij'} \phi[\sum_{j'} \beta_{ij'}] \quad (j' = 1, 2, \dots, n; j' \neq j) \quad (10)$$

where, $\alpha_{ij} \triangleq \text{sign}[L(P_{ij})]$ and $\beta_{ij} \triangleq [L(P_{ij})]$.

The ϕ function is defined as:

$$\phi(x) = -\ln[\tanh(x/2)] = \ln[(e^x + 1)/(e^x - 1)] \quad (11)$$

From bit nodes to check nodes for each bit node j with an edge to check node i ; $L(P_j)$ is updated as:

$$L(P_j) = L(c_j) + \sum_{i'} L(Q_{ij}) \quad (i' = 1, 2, \dots, m; i' \neq i) \quad (12)$$

Decoding and soft outputs: for $j = 1, 2, 3, n$; $L(P_j)$ is updated as:

$$L(P_j) = L(c_j) + \sum_i L(P_{ij}) \quad (i = 1, 2, \dots, m) \quad (13)$$

$$c_i = \begin{cases} 1 & \text{if } L(P_j) < 0 \\ 0 & \text{else} \end{cases} \quad (14)$$

If $\mathbf{cH}^T = 0$ or the number of iterations reaches the maximum limit [17], the LDPC channel coding and decoding in MATLAB have been executed with the aid of programs available in website at [18].

2.3. Repeat and Accumulate (RA) Channel Coding

The RA is a powerful modern error-correcting channel coding scheme. In such channel coding scheme, all the extracted binary bits from the audio has been arranged into a single block and the binary bits of such block is repeated 2 times and rearranged into a single block containing binary data which is double of the number of input binary data.

2.4. (3, 2) Single Parity Check Channel Coding

In (3, 2) Single Parity Check (SPC) channel coding scheme, the binary bits are grouped into very small sized message block \mathbf{u} consisting of two consecutive bits. The

code is generated with addition of a single parity bit to the message $\mathbf{u} = [u_0, u_1]$ so that the elements of the resulting code word $\mathbf{x} = [x_0, x_1, x_2]$ are given by $x_0 = u_0$, $x_1 = u_1$ and $x_2 = u_0 \oplus u_1$ where, the symbol \oplus used here is indicative of the sum over GF (2) [19].

2.5. Data Scrambling

The transmitted voice frequency signals are encrypted in this simulation work for secured communication. The binary converted data from audio signal of each of the two users are grouped individually with each group containing 1 byte (8 bits) binary data. Each grouped binary data as plain text are encrypted with identical secret key of bit length 8 through performing XOR operation to produce encrypted/scrambled binary data [20].

3. System Model

The conceptual block diagram of the downlink multiuser MIMO NOMA wireless communication system is shown in Figure 1. In such system, both BS and users are equipped with 2 antennas. For convenience, we assume that user #1 is sufficiently close to the BS, while user #2 is not close to the BS (e.g., a cell-edge user). The BS usually allocates a high transmission power to comparatively far user and a low transmission power to near user. In this simulation work, 20% of the total power is used for user #1 and remaining 80% is for user #2. Thus, user #1 decodes the signal for user#2 first and then decodes his/her signal after subtracting the decoded signal of user #2. At terminal of user #2, the signal of user #2 can be decoded without significant interference from the signal of user #1. A segment of digitally recorded audio signal is considered as input data for each user. The sampled analog values of audio signal are converted into corresponding integer values under consideration of 256 quantization levels. The extracted binary bits in 0/1 format are encrypted and channel encoded using LDPC, (3, 2) SPC and Repeat & Accumulate coding schemes and then are digitally modulated using QPSK and QAM. The digitally modulated complex symbols are fed into spatial multiplexing encoder section for production of two independent data series for two users to be transmitted simultaneously from each of the two antennas after proper power allocation. In receiving section, all the transmitted signals are detected with QR channel factorization aided SIC scheme with implementation of ML decoding and the detected signals are subsequently sent up to spatial multiplexing decoder. The multiplexed symbols are digitally demodulated, deinterleaved, channel decoded and decrypted to recover the transmitted audio signals.

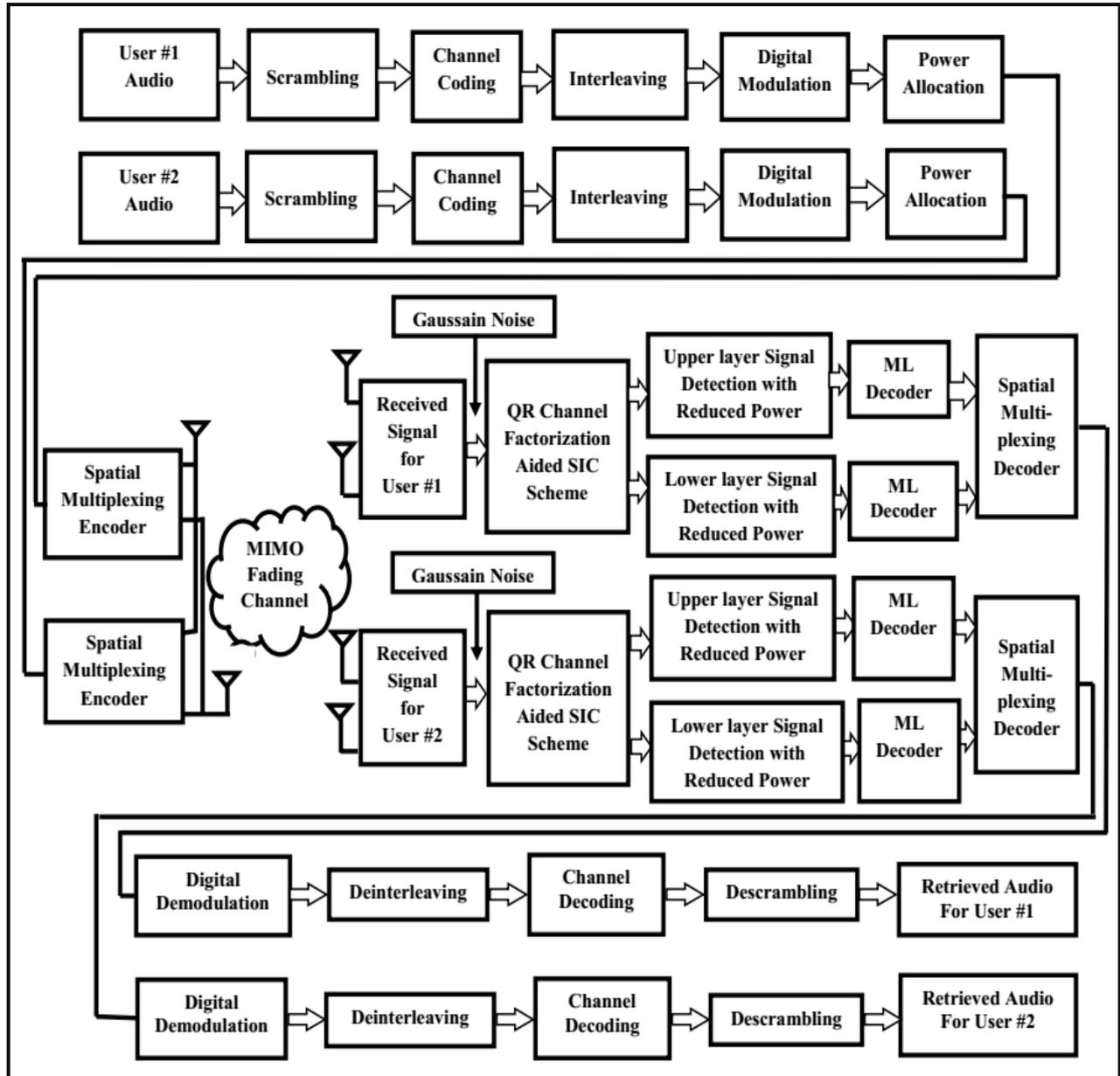


Figure 1. Block diagram of 5G compatible multiuser downlink MIMO NOMA wireless communication system

Table 1. Simulation Parameters

Parameters	Types
Data Type	Audio Signal
No. of samples	8000
Sampling Frequency (Hz)	8000
No. of bits per sample	8
No. of user	2
Antenna configuration	2x2 MIMO Channel
Channel Coding	LDPC, (3, 2) SPC and RA
Digital Modulation	QPSK and QAM
Signal Detection Scheme	ML decoding based QR-SIC Algorithm
SNR	0 to 16 dB
Channel	AWGN and Rayleigh

4. Results and Discussion

In this section, we present a series of simulation results using MATLAB to illustrate the significant impact of various types of channel coding and modulation techniques on MIMO NOMA Wireless Communication system performance in terms of bit error rate (BER). It is assumed that the channel state information (CSI) of MIMO fading channel is available at the receiver. The proposed model is simulated to evaluate the quality of the system performance with considering the following parameters presented in the Table 1.

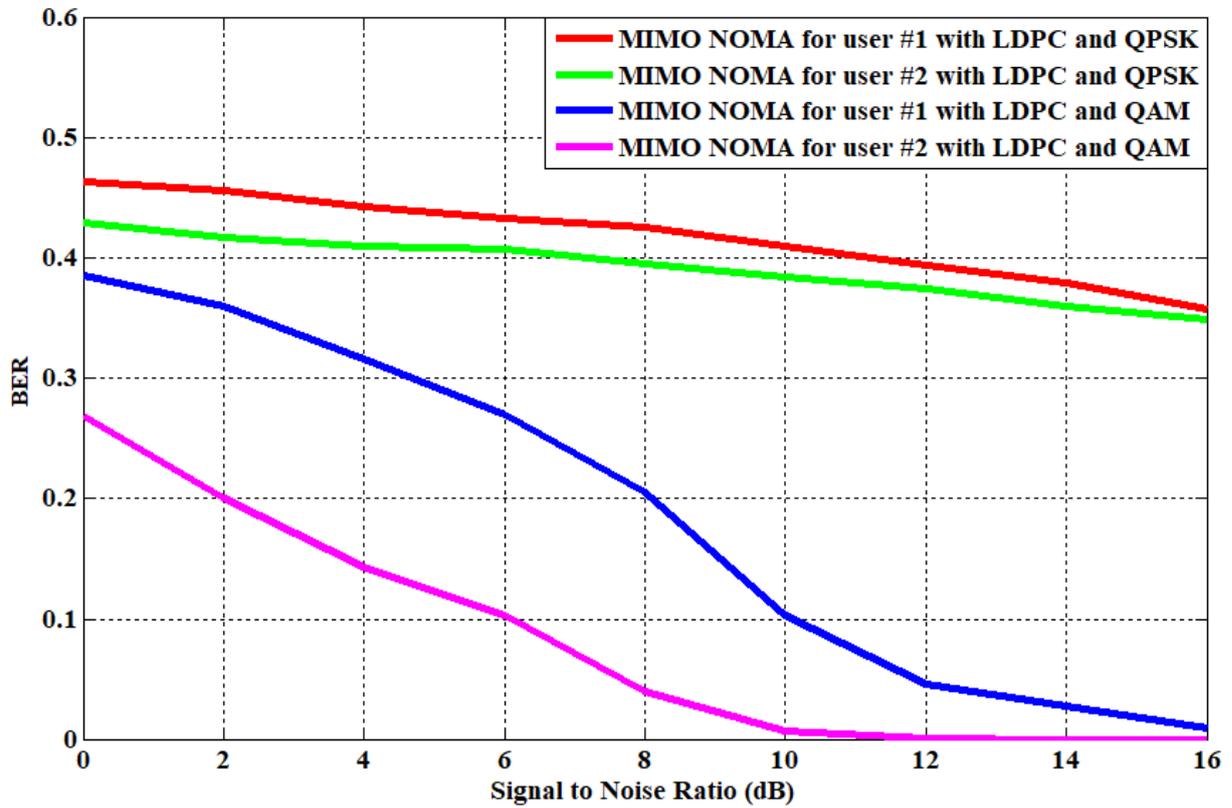


Figure 2. BER performance of LDPC channel encoded MIMO NOMA Wireless communication system with QPSK and QAM digital modulation scheme for audio data transmission

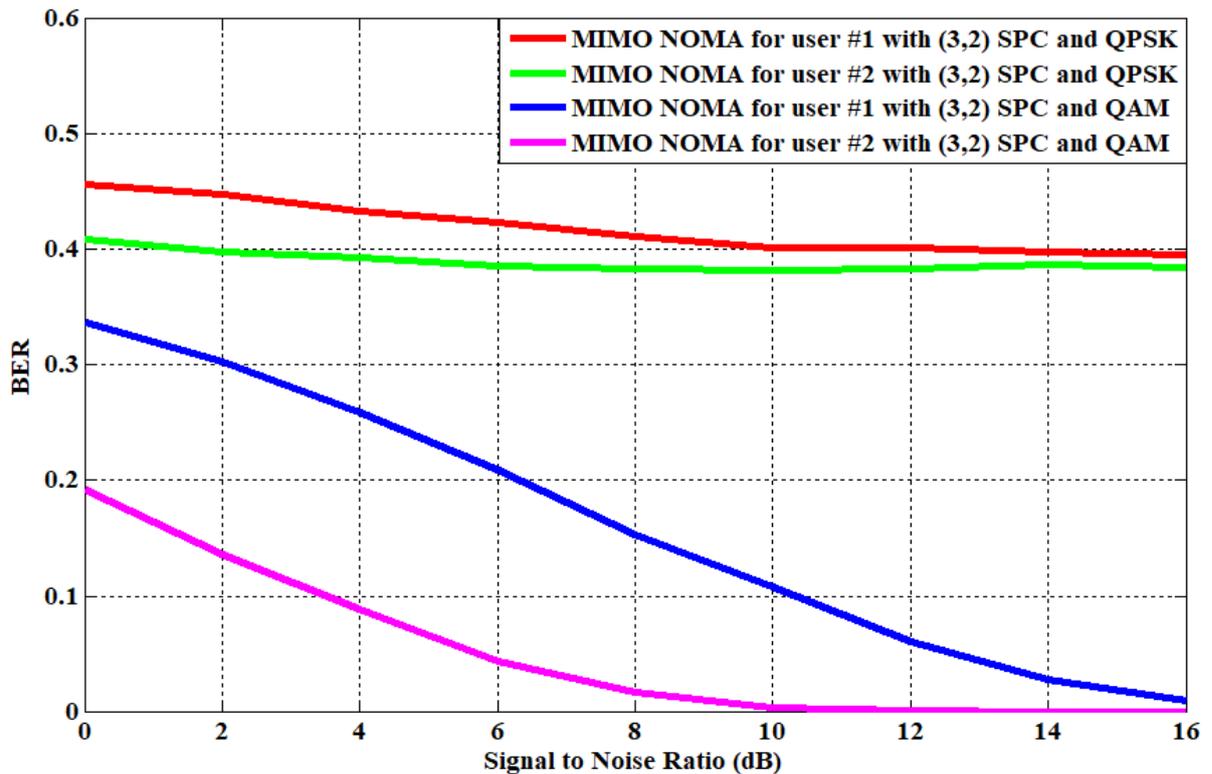


Figure 3. BER performance of (3, 2) SPC channel encoded MIMO NOMA Wireless communication system with QPSK and QAM digital modulation scheme for audio data transmission

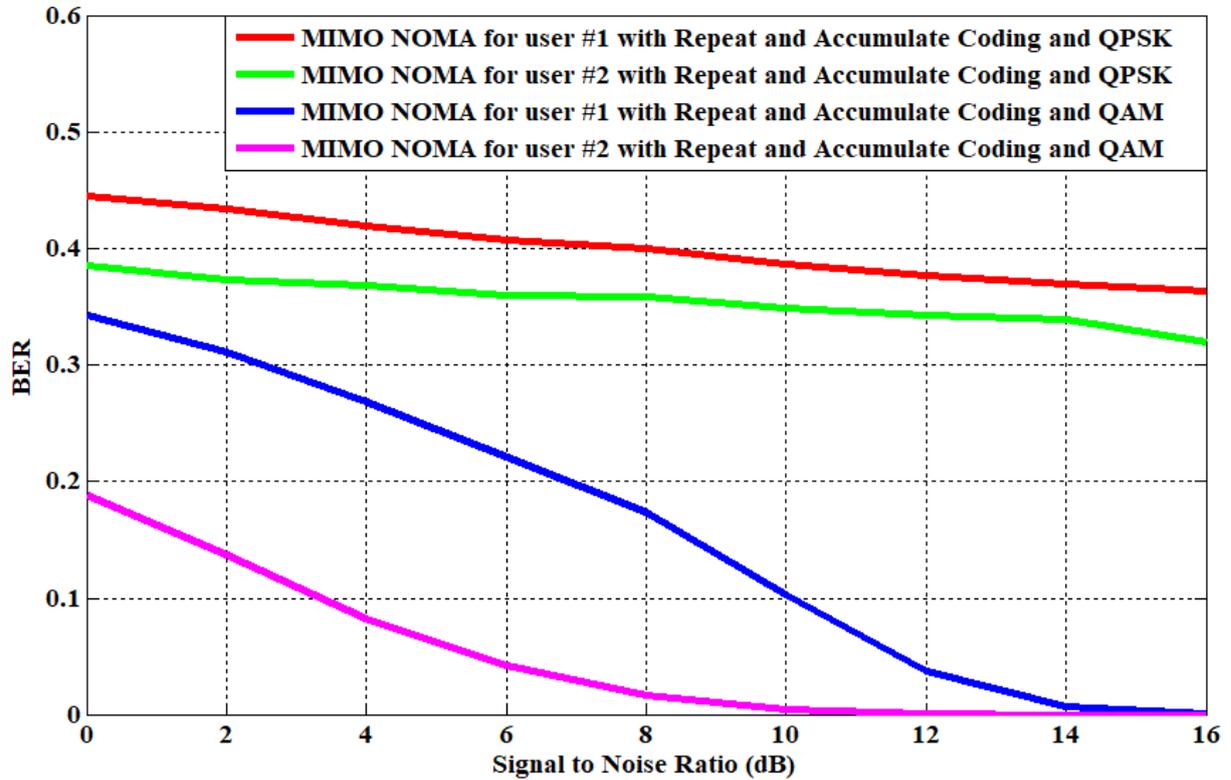


Figure 4. BER performance of Repeat and Accumulate channel encoded MIMO NOMA Wireless communication system with QPSK and QAM digital modulation scheme for audio data transmission

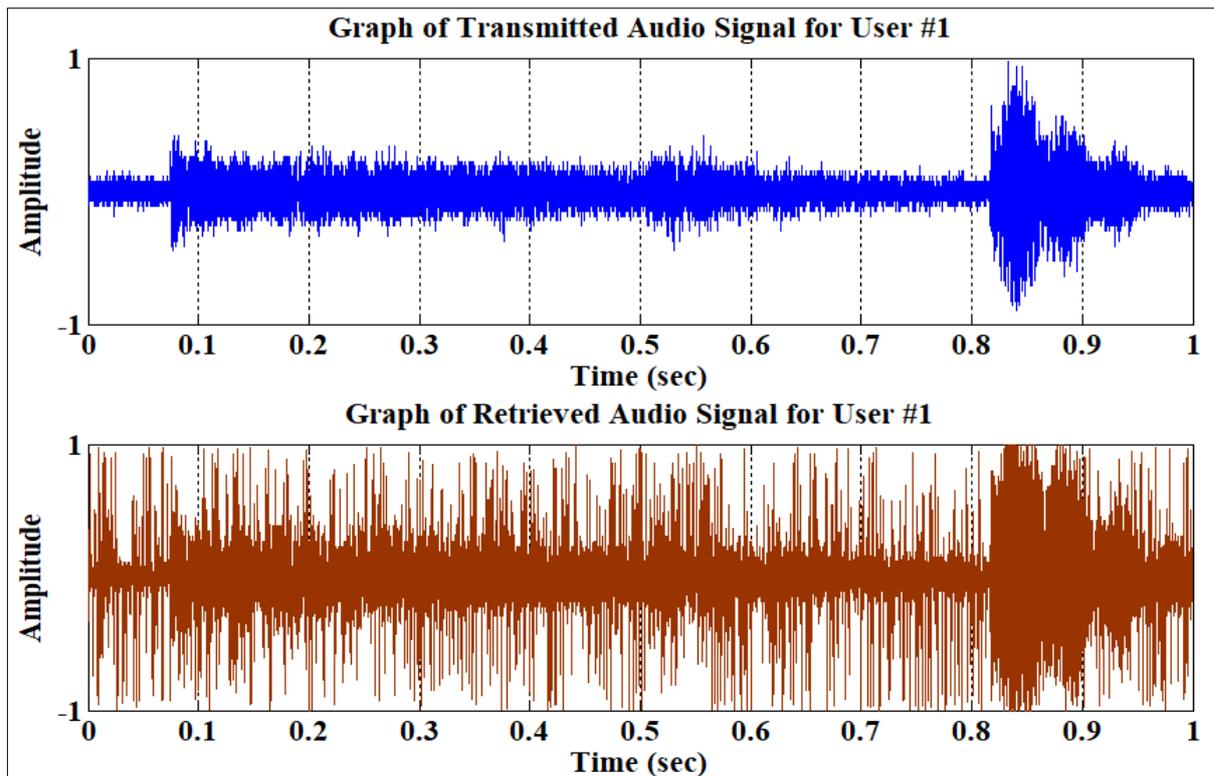


Figure 5. Transmitted and retrieved audio signals for user #1 of MIMO NOMA wireless communication system under implementation of Repeat and Accumulate channel coding with 4-QAM digital modulation at 10 dB SNR

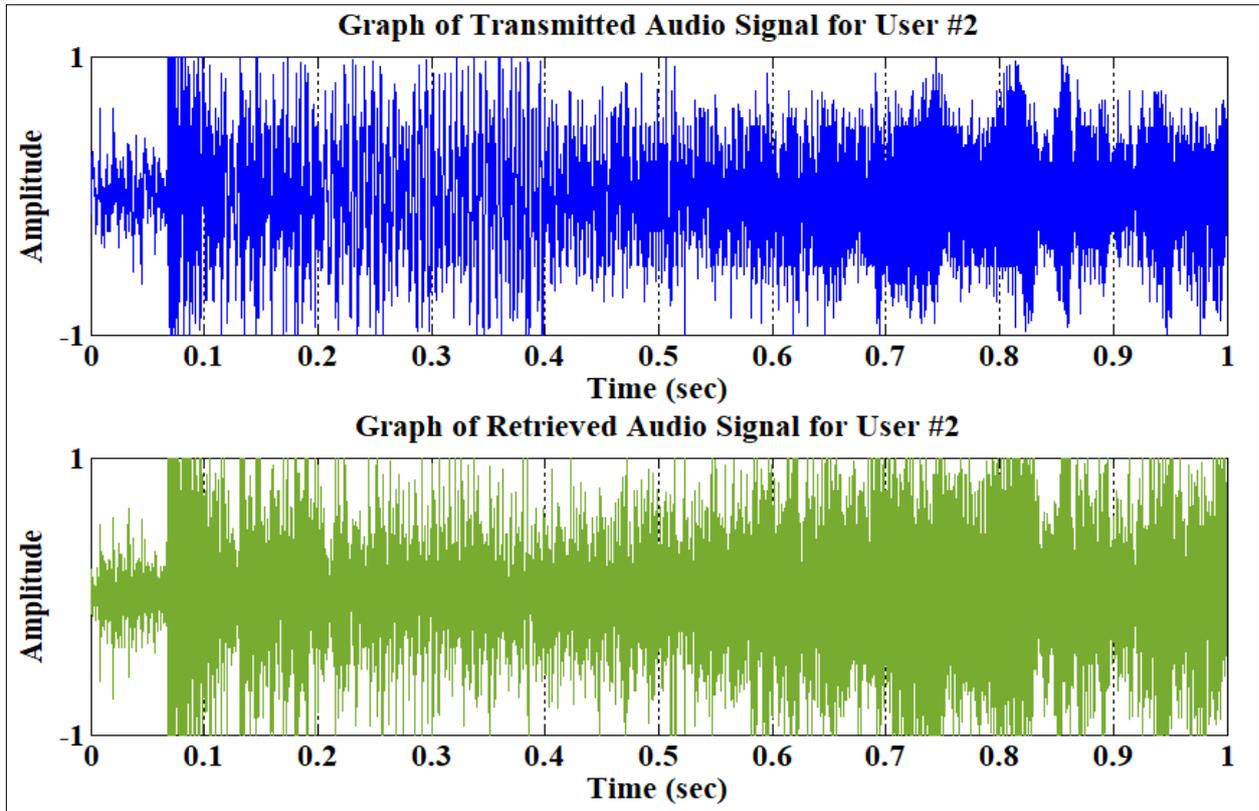


Figure 6. Transmitted and retrieved audio signals for user #2 of MIMO NOMA wireless communication system under implementation of Repeat and Accumulate channel coding with 4-QAM digital modulation at 10 dB SNR

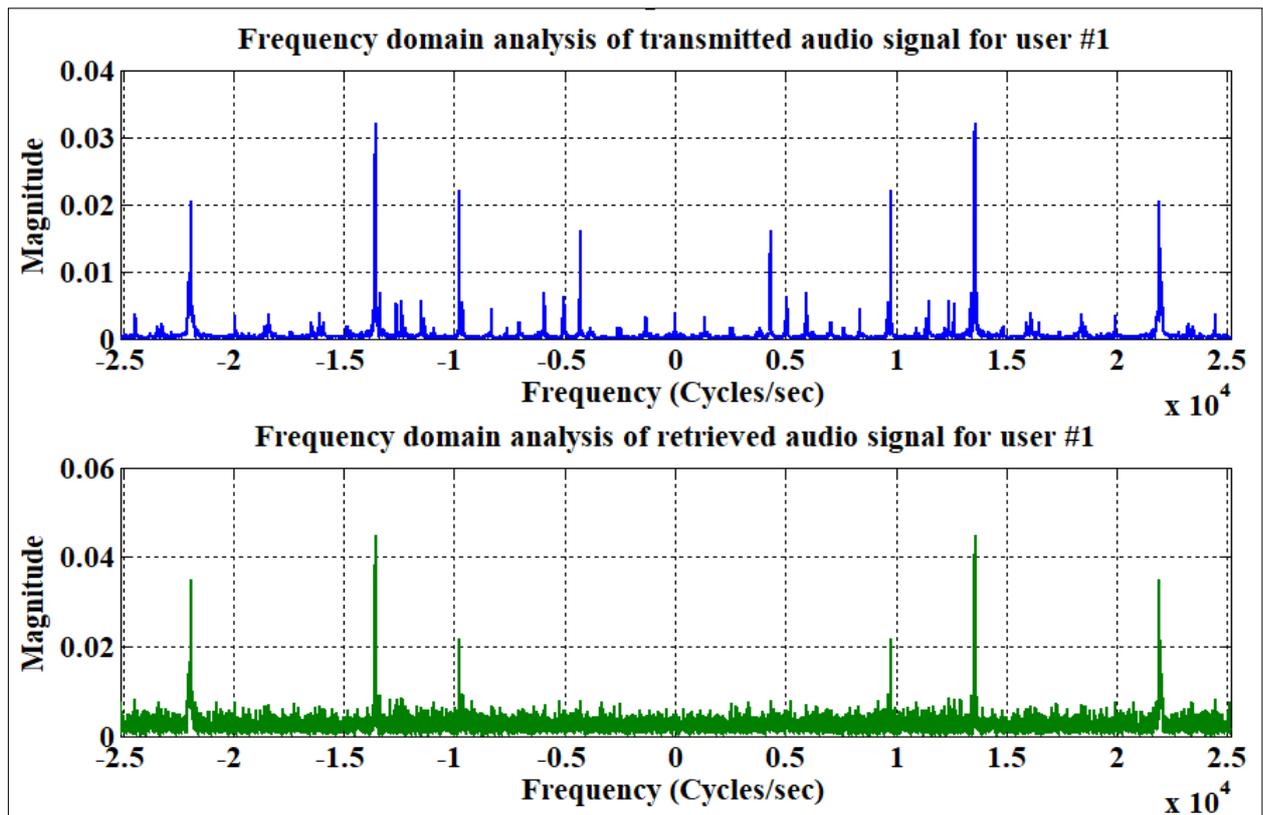


Figure 7. Frequency spectrum of transmitted and retrieved audio signals for user #1 of MIMO NOMA wireless communication system under implementation of Repeat and Accumulate channel coding with 4-QAM digital modulation at 10 dB SNR

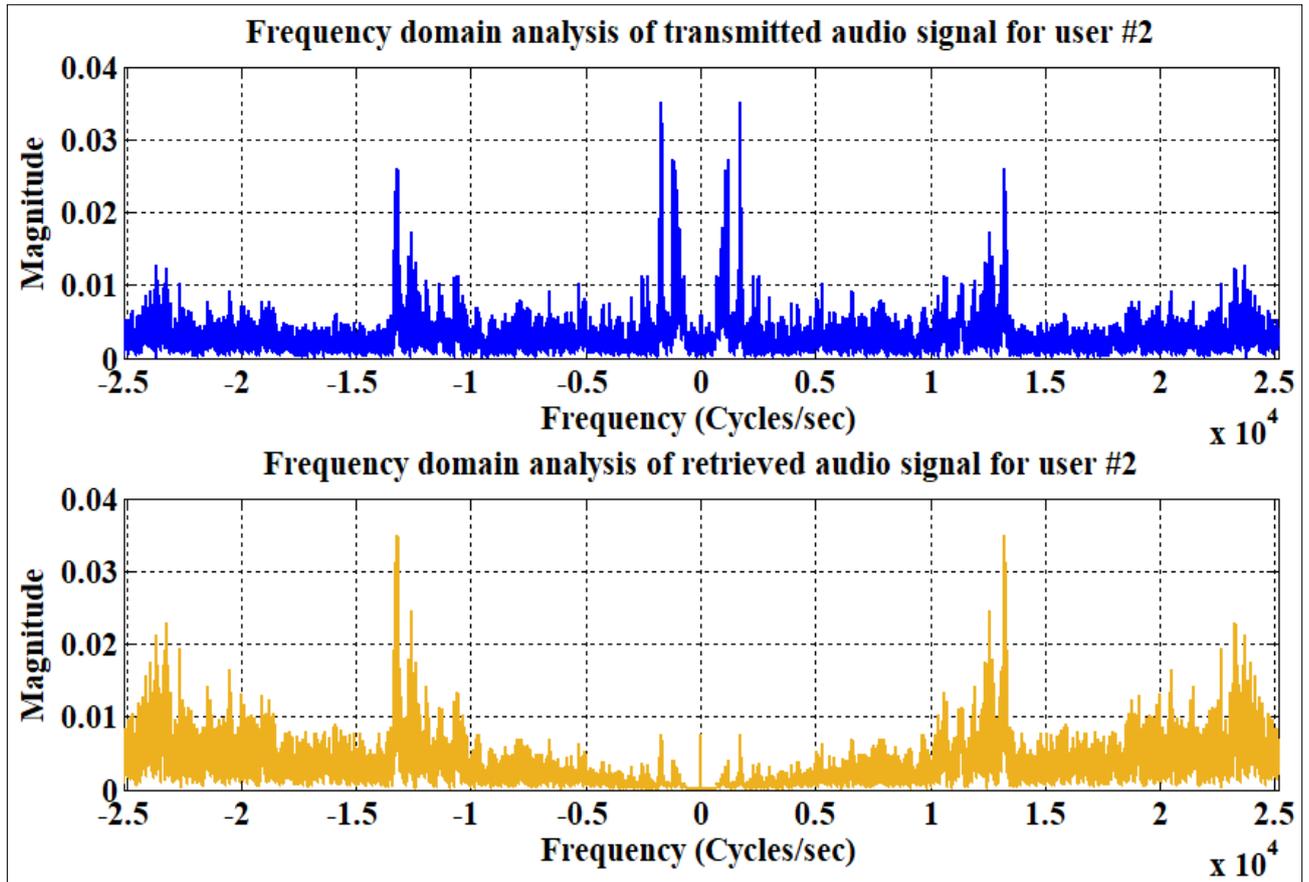


Figure 8. Frequency spectrum of transmitted and retrieved audio signals for user #2 of MIMO NOMA wireless communication system under implementation of Repeat and Accumulate channel coding with 4-QAM digital modulation at 10 dB SNR

The performance of the simulated MIMO NOMA wireless communication system in terms of estimated bit error rate (BER) in case of user #1 and user #2 under implementation of LDPC channel coding scheme with QPSK and QAM digital modulation schemes for audio signal transmission are graphically depicted in Figure 2. It is quite noticeable from Figure 2 that the estimated BER values decrease slowly for both users under utilization of QAM digital modulation technique which portrays a better BER performance in QAMs compared to QPSK at different signal to noise ratio (SNR) values ranging from 0 dB to 16 dB. Under consideration of a typically assumed SNR value of 4 dB for user #1, the estimated BER values are 0.4438 and 0.3168 which is indicative of system performance improvement of 1.46 dB in QAM as compared to QPSK. On identical scenario for user #2, the estimated BER values are found to have values of 0.4103 and 0.1438 which implies a system performance improvement of 4.55 dB. The overall system performance is not compatible for user #1 as low power (20%) is assigned as compared to user #2 (80%). At such 20% BER, a SNR gain of 6 dB is achieved with QAM for user #2 as compared to user #1.

It is keenly observable from the graphical illustration presented in Figure 3 that the simulation system shows comparatively better performance with QAM and (3, 2) SPC channel coding technique. It is quite noticeable from Figure

3 that in case of QPSK, the estimated BER performance values in case of both users are not satisfactory. For user #1 under consideration of a typically assumed SNR value of 6 dB, the estimated BER values are 0.4243 and 0.2095 with utilization of QPSK and QAM which implies a system performance improvement of 3.06 dB. In case of user #2 for identical scenario, the estimated BER values are 0.3859 and 0.0439 which is indicative of system performance improvement of 9.44 dB. The overall system performance is suitable for user #2 as more power (80%) is assigned to it as compared to user #1 (20%). At 10% BER, a SNR gain 6.8 dB is achieved with QAM for user #2 as compared to user #1.

The BER performances presented in Figure 4 are very much appreciable for utilization of QAM digital modulation and Repeat & Accumulate channel coding technique. It is quite obvious from Figure 4 that the estimated BER values decrease slowly for both users in the case of QPSK with different signal to noise ratio (SNR) values ranging from 0 dB to 16 dB. For user #1 under consideration of a typically assumed SNR value of 8 dB, the estimated BER values are 0.4001 and 0.1733 with utilization of QPSK and QAM digital modulation scheme which implies a system performance improvement of 3.63 dB. In case of user #2 for identical SNR value, the estimated BER values are 0.3594 and 0.0160 which is indicative of system performance improvement of 13.51 dB. At 10% BER, a SNR gain 6.4 is

achieved with QAM digital modulation for user #2 as compared to user #1. In Figure 5, the transmitted and retrieved audio signals for user #1 under implementation of Repeat and Accumulate channel coding with 4-QAM digital modulation at 10 dB SNR value have been presented. Similarly, in Figure 6, the transmitted and retrieved audio signals for user #2 under implementation of Repeat and Accumulate channel coding with 4-QAM digital modulation at 10 dB SNR value have been presented. The presented graphical illustrations are clearly representative of assigning power. The spectral graphs for user # 1 and user #2 are presented in Figure 7 and Figure 8 respectively. Due to assigning more power for user #2, the quality of its retrieval audio signal is reasonably acceptable.

5. Conclusions

In this paper, a comprehensive study has been undertaken on the performance evaluation of MIMO NOMA wireless communication system for transmission of secured audio signal. Numerical results ratifies the significance of exploiting digital modulation, ML decoding based QR channel factorization aided SIC (QR-SIC) and different channel coding schemes. In the context of system performance, it can be concluded that the implementation of QAM digital modulation technique in Repeat and Accumulate channel coding scheme provides satisfactory result for such a 5G compatible downlink multiuser MIMO NOMA Wireless Communication System.

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