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Research Article

Scrambled Audio Frequency Signal Transmission in a 3-slot STBC Scheme Based SC-FDMA Wireless Communication System

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Abstract: Space time block coding (STBC), an effective and efficient transmit diversity scheme implemented Multi-input multi-output (MIMO) wireless communication systems have well been accepted as robust and efficient to combat detrimental effects of wireless fading channels. In comparison with STBC, a 3- slot STBC scheme (Orthogonal STBC) shows superior performance with achievement of rate-one full-diversity and reduced decoding complexity. In this paper, an effort has been made to study the performance of Orthogonal STBC based Single Carrier Frequency Division Multiple Access (SC-FDMA) based wireless communication system on scrambled audio signal transmission. The SC-FDMA system incorporates two channel coding (CRC and ½-rated Convolutional), two linear channel equalization Successive Interference Cancellation (SIC) based Minimum Mean Square Error (MMSE-SIC) and Zero- Forcing (ZF-SIC) under QPSK, DQPSK and QAM digital modulations schemes. It is noticeable from simulation results that the system outperforms in retrieving transmitted audio signal under CRC, ZF-SIC and QAM schemes.

Keywords: SC-FDMA**,** 3-slot STBC, Channel coding, Linear channel equalization technique, Bit Error rate (BER), AWGN and Rayleigh fading channels.

INTRODUCTION

Mobile communications has become an everyday commodity. Explosive demands for mobile data are driving changes in how mobile operators will need to respond to the challenging requirements of higher capacity and improved quality of user experience. Mobile communication technologies are often divided into generations, with 1G being the analog mobile radio systems of the 1980s, 2G the first digital mobile systems and 3G, the first mobile system handling broadband data. The Long-Term Evolution (LTE) is often called "4G", but many also claim that LTE release 10, also referred to as LTE-Advanced, is the true 4G evolution step, with the first release of LTE (release 8) then being labeled as "3.9G". Currently, fourth generation wireless access systems using Long Term Evolution (LTE) are being deployed by many operators worldwide in order to offer faster access with lower latency and more efficiency than 3G/3.5G [1-2]. Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier Frequency Division Multiple Access (SC-FDMA) are modified versions of the OFDM and SC/FDE schemes. The OFDMA and SC-FDMA are used in LTE cellular systems for downlink and uplink transmission and also making the mobile terminal power-efficient [3] .

The present study has been made for performance analysis of a CRC/Convolutional encoded SC- FDMA wireless communication system with implementation of MMSE-SIC and ZF- SIC channel equalization schemes. In 2013, Sadique and Ullah made performance evaluation study for a STBC transmission scheme based Turbo encoded SC-FDMA wireless communication system on encrypted data transmission. In such simulation work, three linear signal detection techniques (Equalizers) such as Minimum Mean Square Error (MMSE), Zero Forcing (ZF) and Q-less QR Decomposition were used [4].

MATHEMATICAL MODEL

3-slot Orthogonal Space-time Block Coding

The 3-slot orthogonal space-time block coding is an orthogonal STBC (Q-STBC) coding scheme and such scheme has been found to have superior performance with achievement of rate-one full-diversity and reduced decoding complexity. In 3-slot STBC scheme, three consecutive frequency domain data symbols X1, X2 and X3 and their modified form are entered into a 2 x 3 data matrix, X of Equation(1)

$$X=\begin{bmatrix} x_1 & x_2 & x_3 \\ \dfrac{x_1^*+2e^{j\frac{2\pi}{5}}x_2^*+2e^{-j\frac{2\pi}{5}}x_3^*}{3} & \dfrac{-2e^{j\frac{2\pi}{5}}x_1^*+e^{-j\frac{\pi}{5}}x_2^*+2x_3^*}{3} & \dfrac{-2e^{-j\frac{2\pi}{5}}x_1^*+2x_2^*+e^{j\frac{\pi}{5}}x_3^*}{3} \end{bmatrix} \quad (1)$$

Generally, the symbols X_1, X_2 and X_3 and their linear combinations (second rows of data matrix X) are processed separately in three blocks of 64 symbols each as 64-point FFT operation is done on digitally modulated symbols prior to 3-slot orthogonal space-time block encoding scheme. The data symbols and their Q-STBC encoded symbols are mapped onto 64 consecutive subcarriers and converted into time domain signal by 1024-point IFFT to transmit from the first and second antenna respectively [5]. With channel equalization technique, the transmitted frequency domain signals from each of the two antennas are detected. The detected signals are processed furthermore to recover data symbols.

Channel Equalization

With channel equalization technique, the transmit signal **s** is detected from the received signal **y** under the knowledge of estimated channel state information (CSI) of 2 x 2 channel matrix H and the statistical properties of zero-mean complex Gaussian random noise **n** . The received signal y can be written as:

$$y=Hs+n \quad (2)$$

In ZF-SIC channel equalization scheme, **H** undergoes QR factorization as

$$\mathbf{H=QR=Q}\begin{bmatrix} r_{1,1} & r_{1,2} \\ 0 & r_{2,2} \end{bmatrix} \quad (3)$$

where, Q and R are the unitary and upper triangular matrix respectively. Equation (2) can be rewritten on multiplying by $\mathbf{Q^H}$ as

$$\begin{aligned}\mathbf{x} &= \mathbf{Q^H y} \\ &= \mathbf{Rs} + \mathbf{Q^H n}\end{aligned} \quad (4)$$

where, $\mathbf{Q^H n}$ is a zero-mean complex Gaussian random vector. Since $\mathbf{Q^H n}$ and **n** have the same statistical properties,$\mathbf{Q^H n}$ can be used to denote **n**. We get Equation **(4)** as

$$\mathbf{x} = \mathbf{Rs} + \mathbf{n}$$

$$\Downarrow$$

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} r_{1,1} & r_{1,2} \\ 0 & r_{2,2} \end{bmatrix}\begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (5)$$

the detected desired signal $\hat{s}$ from the transmitting antennas can written on neglecting noise term from Equation **(5)** as

$$\hat{s}_1 = \frac{\{x_1 - r_{1,2}(x_2/r_{2,2})\}}{r_{1,1}} \quad \text{and} \quad \hat{s}_2 = \frac{x_2}{r_{2,2}} \quad (6)$$

In MMSE-SIC channel equalization scheme, the received signal, channel matrix and noise are extended as

$$H_{ex} = \left[H^T \; \sqrt{\frac{N_0}{E_s}}I\right]^T, y_{ex} = \left[y^T \; \mathbf{0}^T\right] \text{and} \;\; n_{ex} = \left[n^T - \sqrt{\frac{N_0}{E_s}}s^T\right]^T \quad (7)$$

where, $\frac{N_0}{E_s}$ =1/(signal to noise ratio, SNR). On QR factorization of extended channel matrix, H_{ex} , we get

$$H_{ex} = Q_{ex} R_{ex} \tag{8}$$

Where, Q_{ex} and R_{ex} represent a unitary matrix and an upper triangular matrix respectively.
In Equation (4), we assume that y, H, n, Q and R are replaced by y_{ex},H_{ex},n_{ex},Q_{ex} and R_{ex} respectively and correspondingly the resulting system takes the following form

$$\begin{aligned} x_{ex} &= Q^H{}_{ex}\, y_{ex} \\ &= R_{ex} s + Q^H{}_{ex}\, n_{ex} \end{aligned} \tag{9}$$

Neglecting $Q^H{}_{ex}\, n_{ex}$ term, the detected desired signal $\hat{s}$ from the transmitting antennas can written from Equation (9) as **[6],**

$$\hat{s}_{\mathbf{1}} = \frac{\{x_{ex\mathbf{1}} - r_{ex\mathbf{1},\mathbf{2}}(x_{ex\mathbf{2}}/r_{ex\mathbf{2},\mathbf{2}})\}}{r_{ex\mathbf{1},\mathbf{1}}} \quad \text{and} \quad \hat{s}_{\mathbf{2}} = \frac{x_{ex\mathbf{2}}}{r_{ex\mathbf{2},\mathbf{2}}} \tag{10}$$

SYSTEM MODEL

A simulated 3 slot STBC scheme implemented SC- FDMA wireless communication system as depicted in Figure 1 utilizes ZF-SIC and MMSE-SIC linear channel equalization schemes. In such a simulated communication system, an audio signal with double channel data is extracted from a video file using Video converter. Using MATLAB, a single channel audio signal is eliminated and processed for A/D Conversion using PCM encoding. The A/D converted binary data are scrambled, channel coded, interleaved and digitally modulated using three types of digital modulations (DQPSK, QPSK and QAM**)** [7-8]. The digitally modulated data symbols are fed into 64-point FFT block and subsequently sent to Q-STBC encoding section. The quasi orthogonal STBC encoded complex data symbols are processed for subcarrier mapping, 1024-point IFFT block and Cyclic Prefixing operations and eventually transmitted from each of the two transmitting antenna. At the receiver end, reverse operation is done viz. after detecting the transmitted signals using channel equalization schemes. The signals are then processed with removal of cyclic prefixing. The signals are then fed into 1024-point FFT, subcarrier demapping and Q-STBC decoding sections. The decoded data are digitally demodulated, de-interleaved, channel decoded and descrambled and subsequently used for D/A conversion using PCM decoding scheme for retrieving transmitted audio signal.

RESULTS AND DISCUSSION

In our analysis, we have assumed that the MIMO channel state information (CSI) is available at the transmitter side and the fading process is constant during each transmitted signal. Figure 2 through Figure 5 depict the bit-error rate performance of the FEC encoded SC-FDMA system for different channel coding, channel equalization and digital modulation schemes. The simulation parameters used in our study are presented in Table 1.

In Figure 2, it is noticeable that the convolutiuonally encoded SC-FDMA system with DQPSK and MMSE-SIC shows almost flat BER performance at low SNR value area. In such a case, performance improvement can be observed with increase in SNR values. From this Figure, we can see that the system outperforms with QAM digital modulation. At 1% bit error rate , the convolutiuonally encoded SC-FDMA system with QAM is superior by 1.2 dB and 3.8 dB respectively as compared with QPSK and DQPSK. In Figure 3, it is seen that the BER performance becomes poorer in case of convolutiuonally encoded SC-FDMA system with DQPSK and ZF-SIC. The BER performances in three different digital modulations are quite distinct. At a typically assumed SNR value of 5dB, the estimated BER values are 0.0329 and 0.3451 for QAM and DQPSK which implies system performance improvement by 10.21 dB.

In Figure 4, it is found that the CRC encoded SC-FDMA system with MMSE-SIC provides almost identical performance over a significant SNR value area for DQPSK and QPSK digital modulations. At 1% bit error rate, the CRC encoded SC-FDMA system with QAM is superior by 4 dB as compared to QPSK/ DQPSK. The system outperforms in QAM digital modulation. In Figure 5, the estimated BERs are 0.0388 and 0.1464 in case of QAM and DQPSK at SNR value of 5dB for the CRC encoded SC-FDMA system with ZF-SIC which is indicative of system performance improvement by 5.77 dB. At 1% bit error rate , the CRC encoded SC-FDMA system with QAM is superior by 1.2 dB and 4.1 dB respectively as compared with QPSK and DQPSK under implemented ZF-SIC channel equalization scheme. In Figure 6, the transmitted and retrieved audio signals are presented graphically. The estimated bit error rate are 0.1551, 0.1024, 0.0572, 0.0237 and 0.0008 in case of 0 2 4 6 and 10 dB SNR values. In Figure 7, the transmitted audio signals have been compared with retrieved audio signal at 10 dB SNR value in spectral form. The graphical illustration presented in this Figure confirms satisfactory retrieval of transmitted audio signal in such a system.

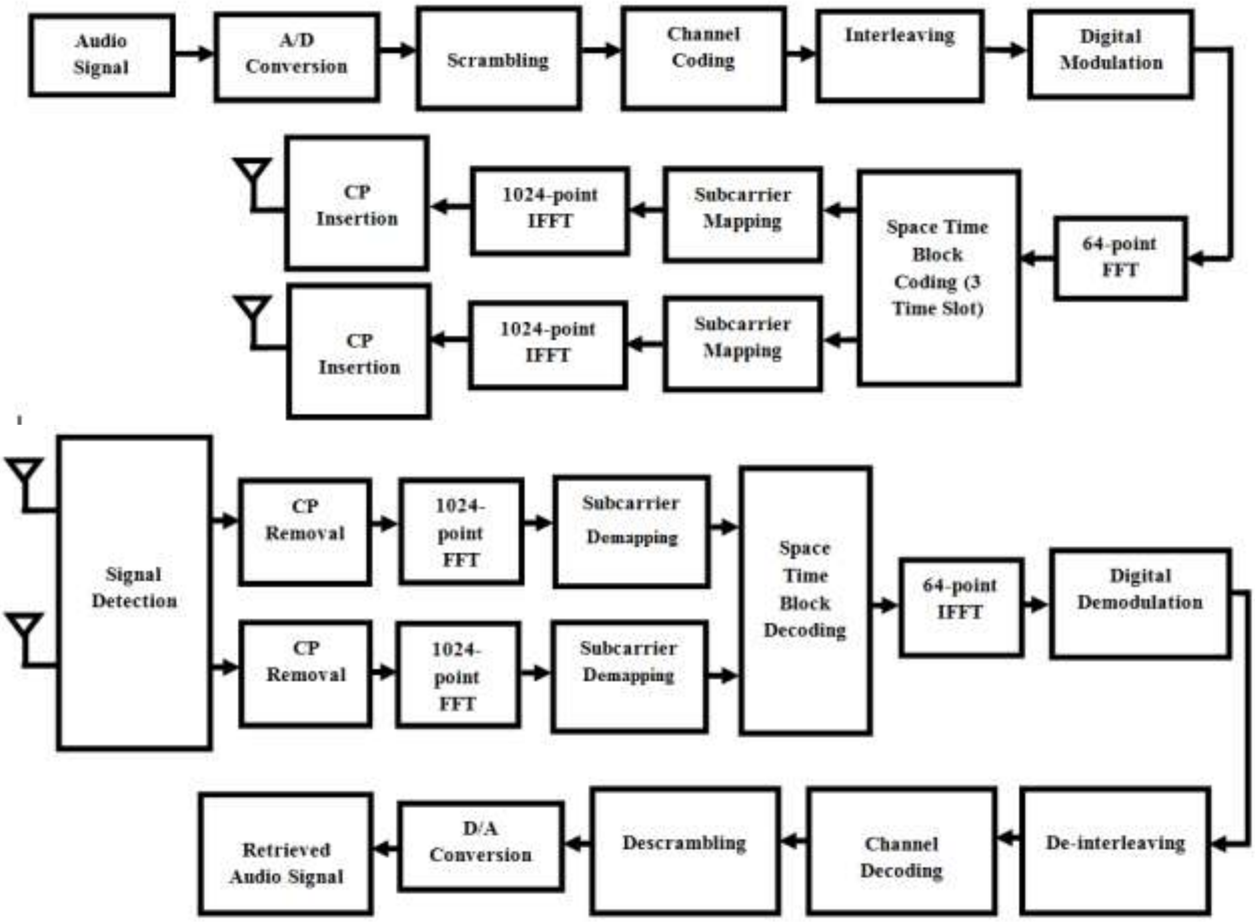

Fig-1: Block diagram of a scrambled audio frequency transmission scheme based SC-FDMA wireless communication system.

Table-1: Summary of the simulated model parameters

No. of Analog Sample of Segmented Audio Signal	3996
No. of bits used for segmented audio signal	63936
Sampling frequency of audio signal	48 KHz
Antenna Configuration	2-by-2
Channel Coding /Decoding	CRC and ½-rated Convolutional
Modulation	DQPSK, QPSK and QAM
No. of OFDM sub-carriers	1024
Signal Detection Scheme	MMSE-SIC and ZF-SIC
CP length	103 symbols
Channel	AWGN and Rayleigh
Signal to noise ratio, SNR	0 to10 dB

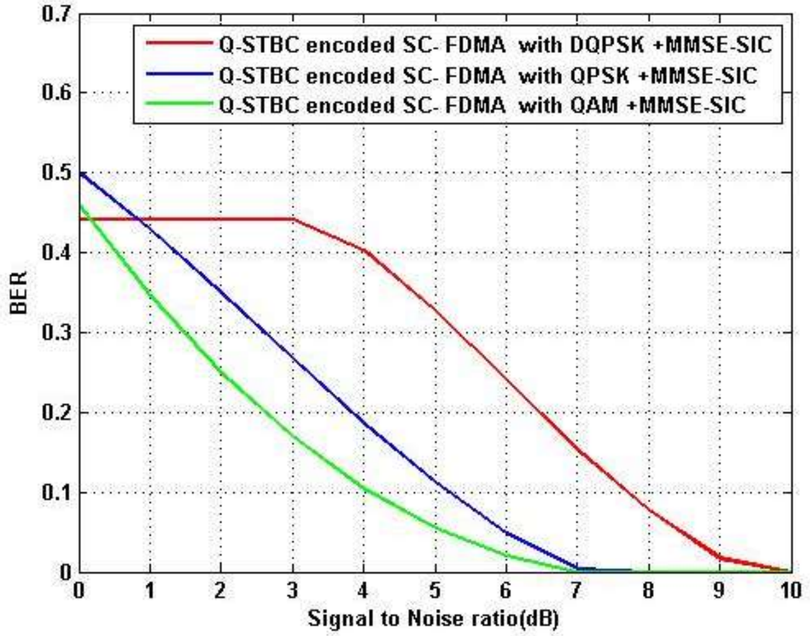

Fig-2: Performance comparison of a Convolutiuonally encoded SC-FDMA based system with MMSE-SIC based signal detection scheme and various digital modulation schemes

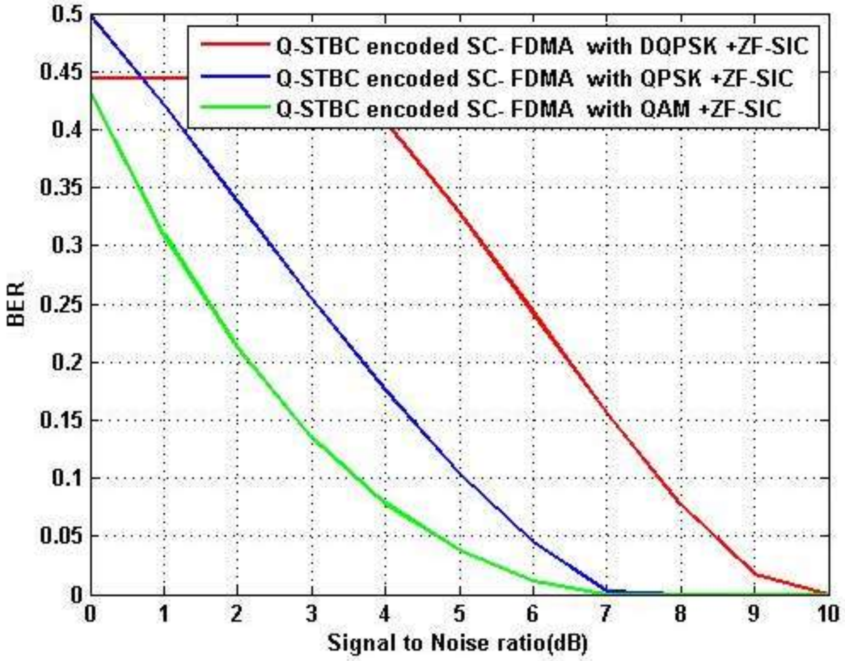

Fig-3: Performance comparison of a convolutiuonally encoded SC-FDMA based system with ZF-SIC based signal detection scheme and various digital modulation schemes

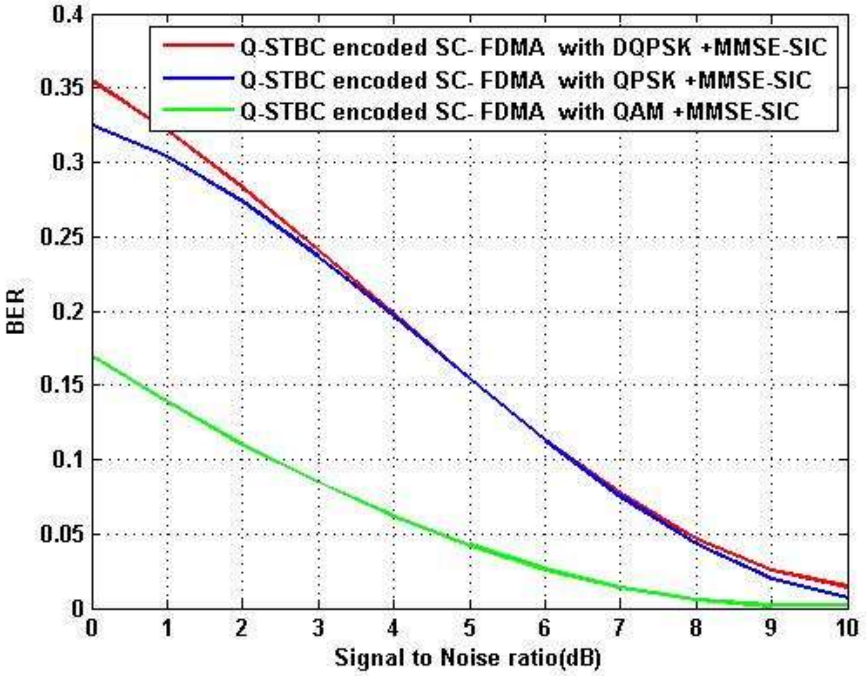

Fig- 4: Performance comparison of a CRC encoded SC-FDMA based system with MMSE-SIC based signal detection scheme and various digital modulation schemes

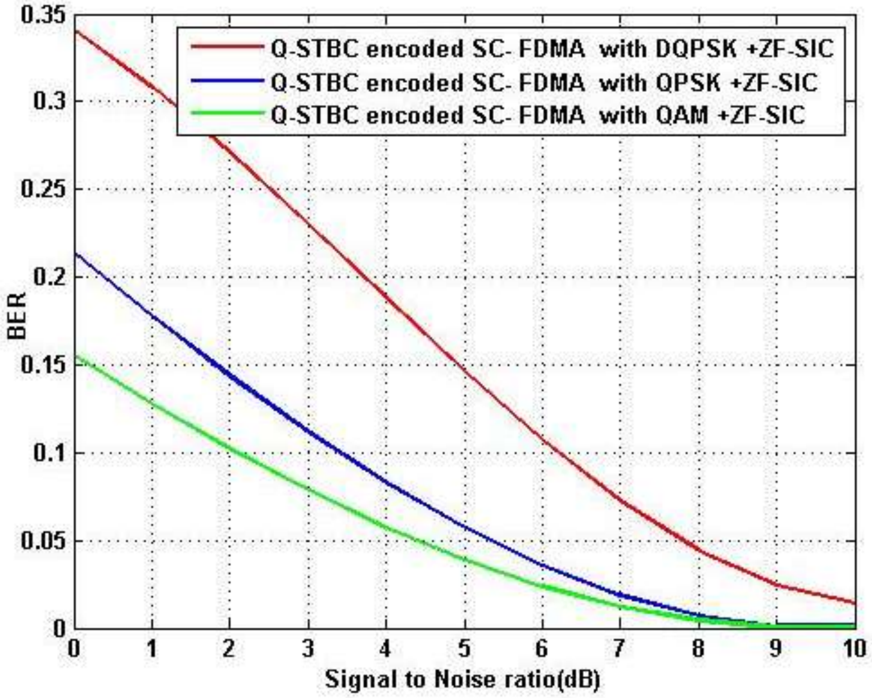

Fig-5: Performance comparison of a CRC encoded SC-FDMA based system with ZF-SIC based signal detection scheme and various digital modulation schemes

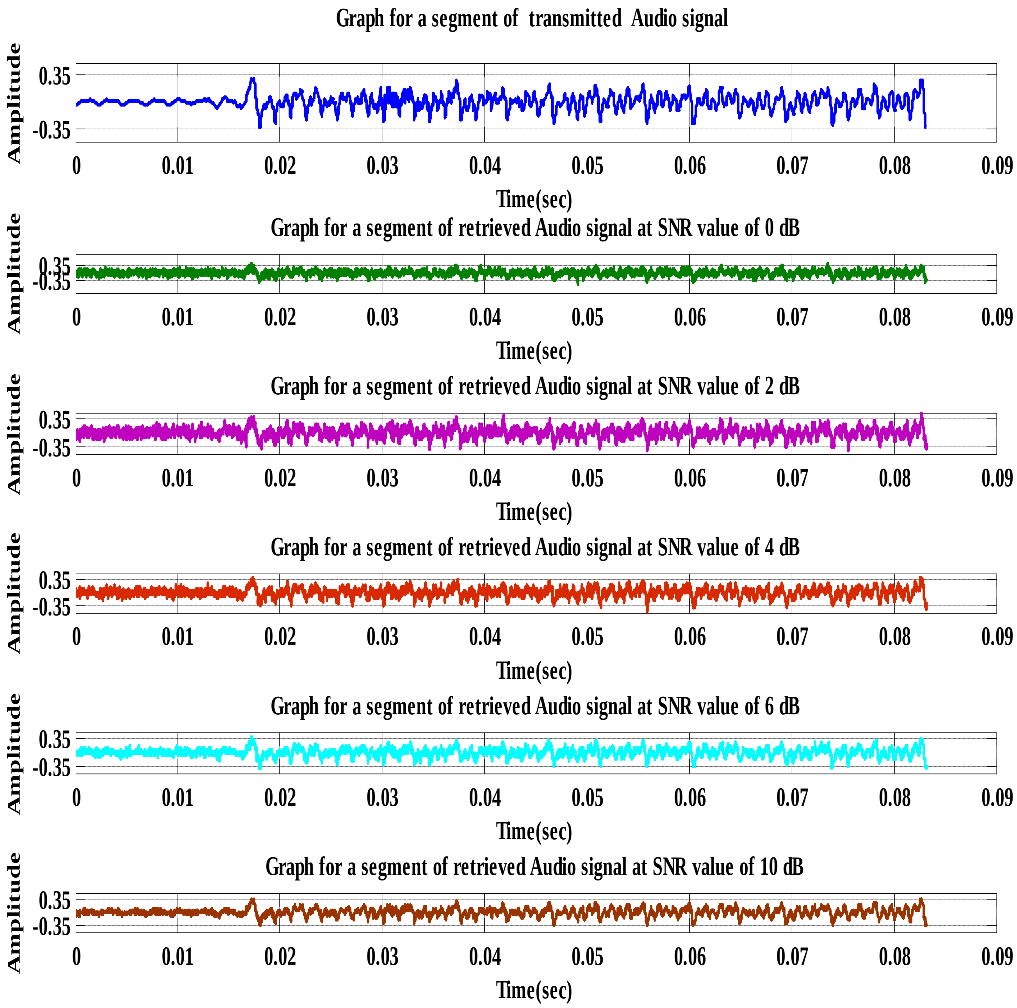

Fig-6: Transmitted and Retrieved voice frequency signals with implementation of ZF-SIC signal detection and QAM digital modulation schemes in a CRC encoded SC-FDMA wireless communication system

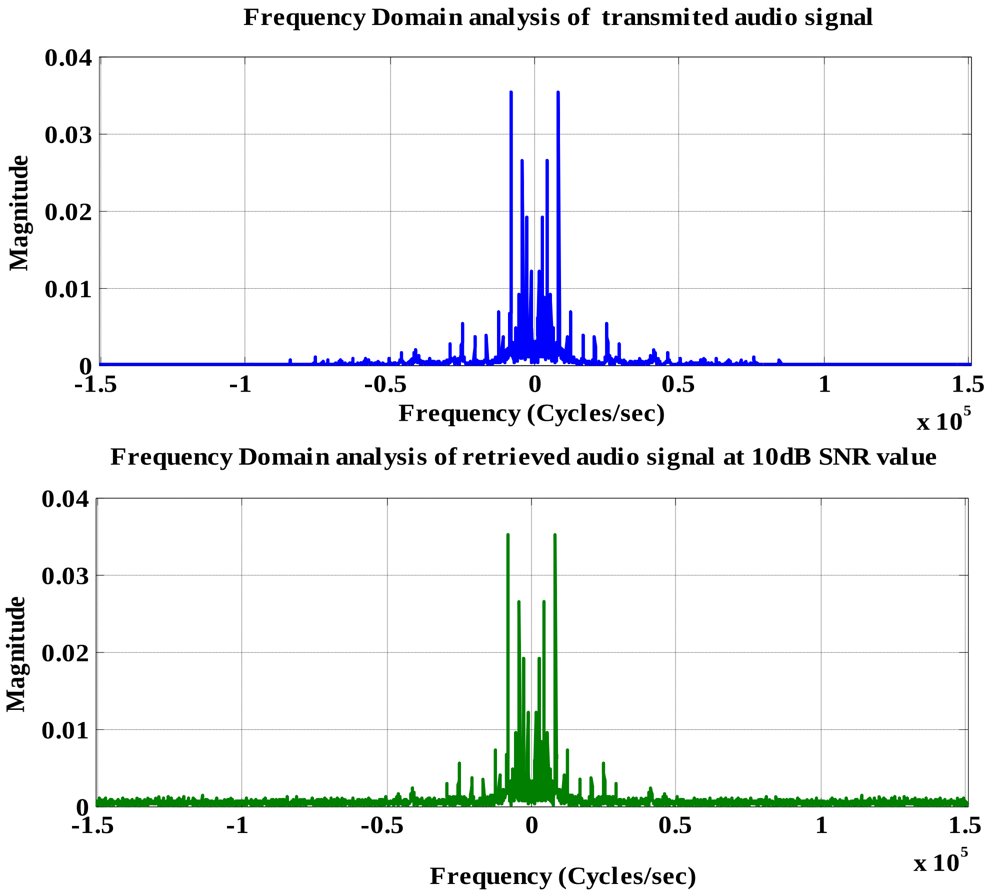

Fig-7: Comparison of amplitude spectrum of Transmitted and Retrieved audio frequency signals with implementation of ZF-SIC signal detection and QAM digital modulation schemes in a CRC encoded SC-FDMA wireless communication system

CONCLUSION

Within this paper, the BER performance of a 3-slot STBC based 2 x 2 spatially multiplexed SC-FDMA wireless communication system combined with transmit diversity and receive diversity in Rayleigh fading channel has been analyzed. We have shown the impact of various channel coding and channel equalization techniques in BER performance evaluative study of the SC- FDMA system on retrieval of transmitted audio signal. A range of satisfactory BERs at different low SNR values under Q-STBC, QAM, CRC and ZF-SIC schemes highlights the improved link reliability and performance enhancement of the FEC encoded MIMO SC- FDMA Wireless Communication System.

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