Encrypted Data Transmission in STBC Transmission Scheme Based Turbo Encoded SC- FDMA Wireless Communication System

Joarder Jafor Sadique and Shaikh Enayet Ullah

Department of Applied Physics and Electronic Engineering
Rajshahi University, Rajshahi-6205, Bangladesh
joarderjafor@yahoo.com, enayet67@yahoo.com

Abstract

In this paper, a comprehensive study has been made to evaluate the performance of a Single Carrier Frequency Division Multiple Access (SC-FDMA) based wireless communication system. The 2-by-2 spatially multiplexed Turbo encoded SC-FDMA system under investigation incorporates Quasi-orthogonal space-time block coding (Q-STBC) scheme and three linear signal detection techniques (Equalizers) such as Minimum Mean Square Error (MMSE), Zero Forcing (ZF) and Q-less QR Decomposition under BPSK, DPSK, QPSK, DQPSK and QAM digital modulations. In the present simulated system, data transmission has been secured with implemented ECB cryptographic algorithm. It is noticeable from simulation results that a significant improvement of system performance is achieved with the Q-less QR Decomposition based signal detection scheme under QAM digital modulation technique. The results also clarify that the system performance deteriorates with increase in order of digital modulation and noise power as compared to signal power.

Keywords: *SC-FDMA**,** Q-STBC, Turbo Equalization, Linear signal detection technique, Bit Error rate (BER), AWGN and Raleigh fading channels*

1. Introduction

Long-Term Evolution (LTE), a new cellular standard and also referred to as Evolved UMTS Terrestrial Radio Access (E-UTRA) has been finalized as Release 8 under 3rd Generation Partnership Project (3GPP).

LTE was commercially deployed in December 2010 with adaptation of orthogonal frequency division multiple access (OFDMA) and single-carrier frequency division multiple access (SC-FDMA) as a multiple access scheme in the downlink and uplink transmission respectively. LTE has a flexible spectrum bandwidth ranging from 1.4 to 20 MHz It is fully Internet Protocol based radio access technology that also incorporates the capability to support traffic with various levels of Quality of Services [1].

SC-FDMA is a variant of OFDM multiple access (OFDMA) in which the encoded data symbols of each user are first modulated in the time domain and then DFT-spread across the data subcarriers. In OFDMA, the data symbols corresponding to each user are generated in the frequency domain and then mapped to a distinct set of subcarriers for transmission over the radio channel. In OFDMA, each symbol occupies one subcarrier. However, SC-FDMA maps information from each data symbol onto each subcarrier allocated to a given user to offer an advantageous gain in frequency diversity. The SC–FDMA enjoys a reduced peak–to–average power ratio (PAPR) enabling a low–complexity implementation of the mobile terminal. The SC–FDMA is employed along with multiple– input multiple–output (MIMO) techniques in LTE in order to further improve coverage and capacity. In SC–FDMA, the signal recovery at the base station can be made conveniently using relatively simple frequency–domain linear equalization techniques [2, 3]. In 2008, Gilberto et.al., showed performance improvement of SC-FDMA in UTRA LTE Uplink using Turbo equalization, an advanced iterative equalization and decoding technique under Single Input Multiple Output (SIMO) antenna configuration [4]. In 2011, Zhongding et.al, emphasized on the applicability of 3 slot transmission scheme based on quasi-orthogonal space-time block codes for 4G compatible LTE-Advanced system [5].

In Global perspective of Advanced wireless communications, it has been known that on 30th October 2012, a UK based Mobile operator Everything Everywhere (EE) first launched 4G LTE mobile phone network in United Kingdom over its 11 cities with its service available on the Apple iPhone 5 mobile phone. The company's 4G LTE broadband speeds are claimed to be five times faster than 3G data speeds. In November 11,2012, USA based Mobile operator Alaska Communications announced that its customers with 4G enabled devices (4G LTE smart phones: HTC One X, Samsung Galaxy S III and Samsung Galaxy Note) will get broadband speeds ten times faster than its current 3G data speeds [6, 7]. However, in this paper, an effort has been made on observing the impact of implementing Q-STBC diversity scheme on performance enhancement of the simulated Turbo encoded SC-FDMA wireless communalization system which would provide some basic idea in physical layer of the existing 4G networking system.

2. Mathematical Model

In our presently considered spatially multiplexed Turbo encoded SC-FDMA wireless communication system, quasi-orthogonal space time block coding scheme has been implemented with various signal detection schemes. A brief description is given below.

2.1. Quasi-orthogonal Space-time Block Coding (Q-STBC) Scheme

Space time block coding (STBC), an effective and efficient transmit diversity scheme is used to combat detrimental effects of wireless fading channels and employed in most current commercial wireless systems. As compared to Alamouti STBC and orthogonal STBC coding scheme, the quasi-orthogonal STBC scheme has been found to have superior performance with achievement of rate-one full-diversity and reduced decoding complexity. Under implementation of Q-STBC scheme, three consecutive frequency domain data symbols X_1, X_2 and X_3 are quasi-orthogonally space time block encoded and are represented in a typically assumed 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 M symbols each as M-point FFT operation is done on digitally modulated symbols prior to Q-STBC encoding scheme. The data symbols and their Q-STBC encoded symbols are mapped onto M consecutive subcarriers and converted into time domain signal by N-point IFFT to transmit from the first and second antenna respectively [5]. With signal detection and 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.

2.2. Signal Detection Schemes

Linear signal detection scheme treats all transmitted signals as interferences except for the desired stream from the target transmitting antenna. The spatially –multiplexed transmitted user data (digitally modulated signal) in OFDM block and the corresponding received signals are represented by $\mathbf{x=[x_1,\ x_2]^T}$ and $\mathbf{y=[y_1,y_2]^T}$ respectively, where $\mathbf{x_i}$ and $\mathbf{y_i}$ denote the transmit signal from ith transmitting antenna and the received signal at the jth receiving antenna respectively. Let $\mathbf{n_j}$ denote the white Gaussian noise with a variance of $\boldsymbol{\sigma_n^2}$ at the jth receiving antenna and $\mathbf{h_i}$ denote the ith column vector of the channel matrix $\mathbf{H}$. The received signal $\mathbf{y}$ for the 2 x 2 MIMO MCCDMA systems can be represented as

$$\mathrm{y} = \mathrm{Hx} + \mathbf{n} = \mathrm{h}_1\mathbf{x}_1 + \mathrm{h}_2\mathbf{x}_2 \tag{2}$$

where, $\mathbf{n} = [n_1, n_{2R}]^{\mathrm{T}}$

As the interference signals from other transmitting antennas are minimized or nullified in the course of detecting the desired signal from the target transmitting antenna, the detected desired signal from the transmitting antenna with inverting channel effect by a weight matrix W is given by

$$\tilde{\mathbf{x}} = [\tilde{\mathbf{x}}_1, \tilde{\mathbf{x}}_2]^{\mathbf{T}} = \mathbf{Wy} \tag{3}$$

2.2.1. Minimum Mean Square Error (MMSE) Scheme: In Minimum mean square error (MMSE) scheme, the MMSE weight matrix is given by

$$\mathbf{W_{MMSE}} = (\mathbf{H^H H} + \sigma_{\mathbf{n}}{}^2\mathbf{I})^{-1}\mathbf{H^H} \tag{4}$$

and the detected desired signal from the transmitting antenna is given by

$$\tilde{\mathbf{x}}_{\mathbf{MMSE}} = \mathbf{W_{MMSE}y} \tag{5}$$

2.2.2. Zero-Forcing (ZF) Scheme: In Zero-Forcing (ZF) scheme, the ZF weight matrix is given by

$$\mathbf{W_{ZF}} = (\mathbf{H^H H})^{-1}\mathbf{H^H} \tag{6}$$

and the detected desired signal from the transmitting antenna is given by [8].

$$\tilde{\mathbf{x}}_{\mathbf{ZF}} = \mathbf{W}_{\mathbf{ZF}}\mathbf{y} \tag{7}$$

2.2.3. Q-Less QR Decomposition Scheme: With Q-less QR Decomposition scheme, the detected desired signal $\tilde{\mathbf{x}}$ from the transmitting antenna can be found based on the least squares approximate solution to $\tilde{\mathbf{H}} * \tilde{\mathbf{x}} = \tilde{\mathbf{y}}$ where, $\tilde{\mathbf{H}}$ and $\tilde{\mathbf{y}}$ are the channel matrix and received signal respectively. From $\tilde{\mathbf{H}}$ channel matrix, an upper triangular matrix $\tilde{\mathbf{R}}$ of the same dimension as $\tilde{\mathbf{H}}$ is estimated and using the following steps, the detected desired signal $\tilde{\mathbf{x}}$ is computed **[9].**

$$\begin{aligned}
&\tilde{\mathbf{x}} = \tilde{\mathbf{R}} \setminus (\tilde{\mathbf{R}}^{\mathbf{H}} \setminus (\tilde{\mathbf{H}}^{\mathbf{H}} * \tilde{\mathbf{y}}))\\
&\tilde{\mathbf{r}} = \tilde{\mathbf{y}} - \tilde{\mathbf{H}} * \tilde{\mathbf{x}}\\
&\tilde{\mathbf{e}} = \tilde{\mathbf{R}} \setminus (\tilde{\mathbf{R}}^{\mathbf{H}} \setminus (\tilde{\mathbf{H}}^{\mathbf{H}} * \tilde{\mathbf{r}}))\\
&\tilde{\mathbf{x}} = \tilde{\mathbf{x}} + \tilde{\mathbf{e}}
\end{aligned} \tag{8}$$

3. System Model

The block diagram of the simulated SC-FDMA based system model is shown in Figure 1. The input binary bit stream is at first encrypted using ECB cryptographic algorithm [10] and channel encoded using turbo coding scheme [11]. The turbo encoded bits are interleaved for the minimization of burst error. The interleaved and channel encoded bits are digitally modulated using BPSK, DPSK, QPSK, DQPSK and QAM [12]. The Digitally modulated symbols are then applied to M-point FFT block of size 680. To avoid potential inter-carrier interference introduced by multipath fading channels, STBC coding is applied after the M-point FFT block. The 3-time-slot duration is corresponding to the interval transmitting 3 blocks of modulation symbols with each block size M (680). The STBC coding block, together with the subsequent subcarrier mapping blocks, will map the 3 M symbols to a two-dimensional (in frequency and time domains) transmission matrix for each of the two antennas. Each OFDM block of size 1024 is then fed into IFFT section. To mitigate the effects of inter-symbol interference (ISI) caused by channel time spread, each block is typically preceded by a Cyclic Prefix (CP). The spatially multiplexed complex signals are then transmitted from each of the two transmitting antenna. At the receiver side, the transmitted signals are detected using channel equalization schemes. The detected signal is then processed with removal of CP. Now, the signal is sent up to the FFT section where demodulation occurs resulting in production of an output which is parallel to serially converted and processed for digital demodulation, de-interleaving, channel decoding and decryption. Eventually, the transmitted bit stream is retrieved.

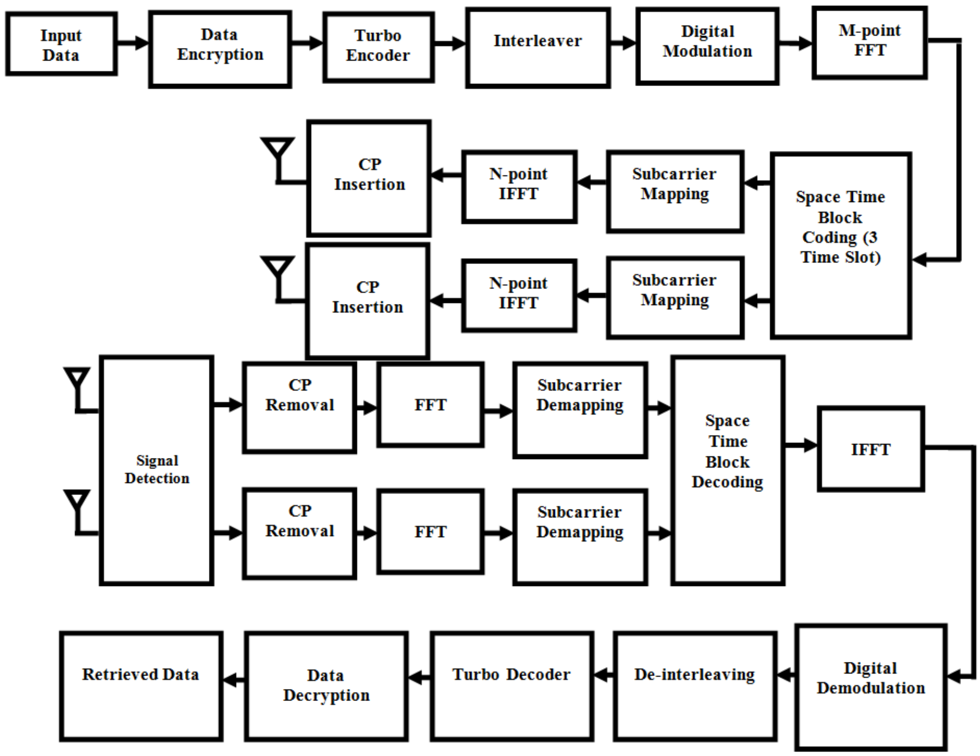

Figure 1. Block Diagram of an SC-FDMA based Wireless Communication System

4. Results and Discussion

The achievable BER performance of the secured 2×2 Single Carrier Frequency Division Multiple Access (SC-FDMA) based wireless communication system with the parameters presented in Table 1 has been evaluated by computer simulations. It is assumed that the channel state information (CSI) is available at the transmitter side and the fading process is approximately constant during each transmitted signal.

Table 1. Summary of the Simulated Model Parameters

No. of bits used	2040
Antenna configuration	2-by-2
Channel Coding /Decoding	Turbo Coding / Max-Log-MAP decoding
Modulation	BPSK, DPSK, QPSK, DQPSK and QAM
No. of OFDM sub-carriers	1024
Spreading Code	Walsh-Hadamard
Signal Detection Scheme	Mean square error (MMSE), Zero-forcing (ZF) and Q-less QR decomposition
CP length	103
Channel	AWGN and Rayleigh fading
Cryptographic algorithm	Electronic Code Book(ECB)
Signal to noise ratio, SNR	0 to10 dB

The simulation results are represented in terms of signal to noise ratio (SNR) and bit error rate (BER).

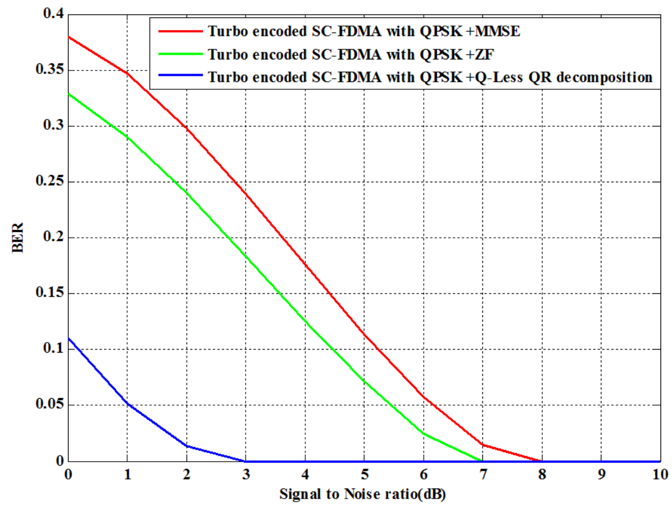

Figure 2. BER Performance of a Turbo Encoded SC-FDMA based System Incorporating MMSE, ZF and Q-Less QR Decomposition based Signal Detection Schemes under QPSK digital Modulation

In Figure 2, it is noticeable that the QPSK digitally modulated SC-FDMA system adopting Q-Less QR decomposition and MMSE signal detection schemes provides quite remarkable and worst performance respectively. For a typically assumed SNR value of 2 dB, the estimated BER values are 0.0139 and 0.2981 and the system performance is improved by 13.31 dB. Figure 2 also illustrates that the system with Q-Less QR decomposition based signal detection scheme provides better performance as compared to ZF signal detection scheme under QPSK modulation.

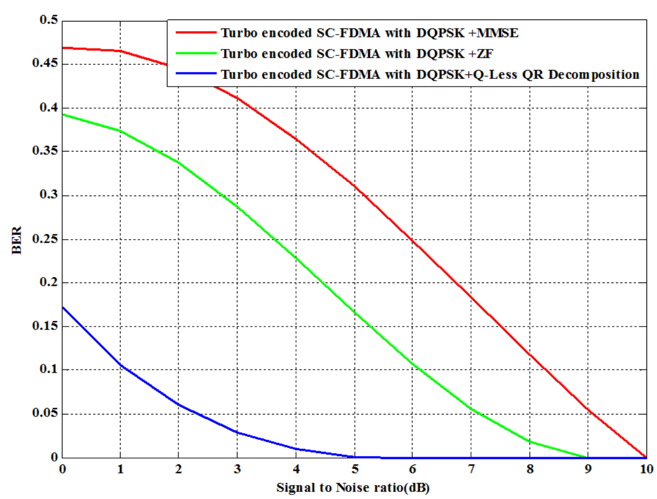

Figure 3. BER Performance of a Turbo Encoded SC-FDMA based System Incorporating MMSE, ZF and Q-Less QR Decomposition based Signal detection Schemes under DQPSK Digital Modulation

In Figure 3, it is remarkable that the DQPSK digitally modulated SC-FDMA system shows a significant performance gap with Q-Less QR decomposition and MMSE signal detection schemes. Under such situation, the system shows robust and worst performance in case of Q-Less QR decomposition and MMSE signal detection schemes. The estimated BER values are 0.0079 and 0.3654 at a particular SNR value of 4 dB and the system performance is improved by 16.65 dB. Figure 3 also justifies that the system with Q-Less QR decomposition based signal detection scheme provides better performance as compared to ZF signal detection scheme under DQPSK modulation.

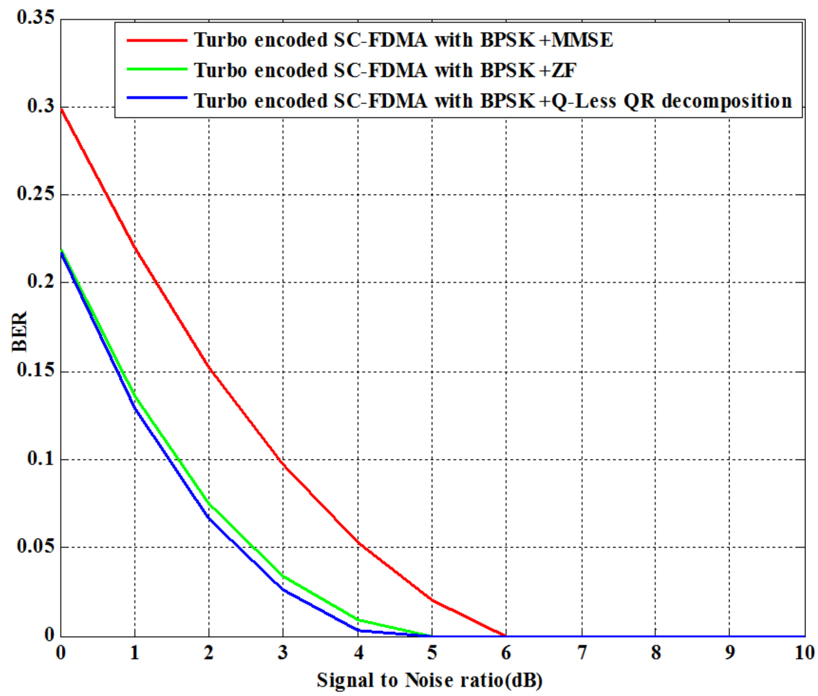

Figure 4. BER Performance of a Turbo Encoded SC-FDMA based System Incorporating MMSE, ZF and Q-Less QR Decomposition based Signal Detection Schemes under BPSK Digital Modulation

In Figure 4, it is observable that the performance of BPSK digitally modulated SC-FDMA system is not well discriminable under Q-Less QR decomposition and ZF signal detection schemes at low SNR value area. The system shows satisfactory and worst performance in case of Q-Less QR decomposition and MMSE signal detection schemes under such situation with assumption of SNR value of 3 dB, the estimated BER values are 0.0033 and 0.0929 which is indicative of system performance improvement by 14.49 dB

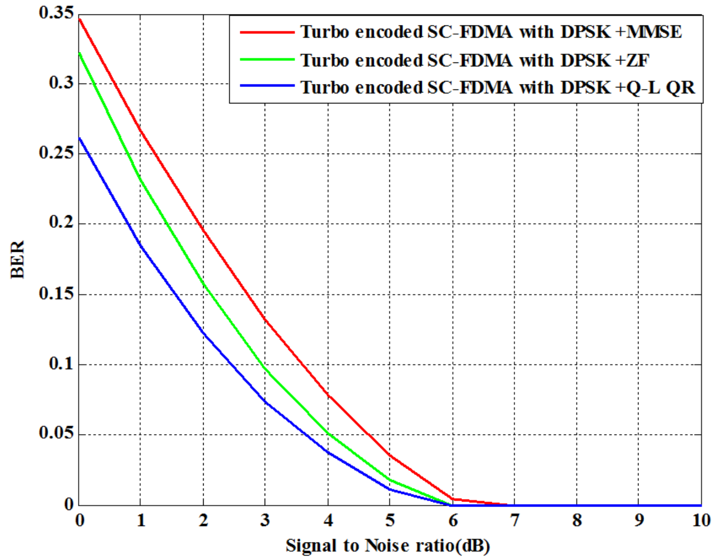

Figure 5. BER Performance of a Turbo Encoded SC-FDMA based System Incorporating MMSE, ZF and Q-Less QR Decomposition based Signal Detection Schemes under DPSK Digital Modulation

In Figure 5, it is seen that the DPSK digitally modulated SC-FDMA system with adaptation of Q-Less QR decomposition and MMSE signal detection schemes gives most acceptable and worst performance respectively. The estimated BER values for a typically assumed SNR value of 5 dB are 0.0116 and 0.0355 and the system performance is improved by 4.85 dB. Figure 5 also signifies that the system with Q-Less QR decomposition based signal detection scheme provides better performance as compared to ZF signal detection scheme under DPSK modulation.

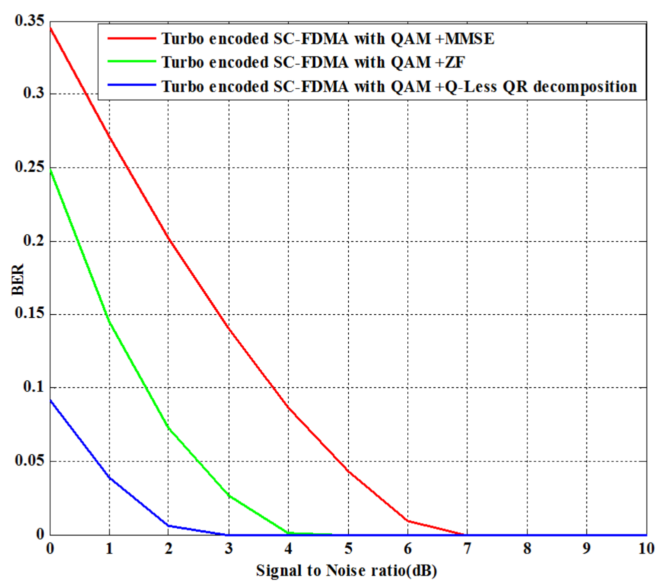

Figure 6. BER Performance of a Turbo Encoded SC-FDMA based System Incorporating MMSE, ZF and Q-Less QR Decomposition based Signal Detection Schemes under QAM Digital Modulation

In Figure 6, it is observable that the performance of QAM digitally modulated SC-FDMA system under three channel equalization schemes is well discriminable. The SC-FDMA system with implementation of Q-Less QR decomposition and MMSE signal detection schemes shows most significant and worst performance respectively. In such case, the estimated BER values are 0.0065 and 0.2026 at SNR value of 2 dB which implies that the system performance is improved by 14.93 dB. Figure 6 is also implies that the system with Q-Less QR decomposition based signal detection scheme provides better performance as compared to ZF signal detection scheme under QAM modulation.

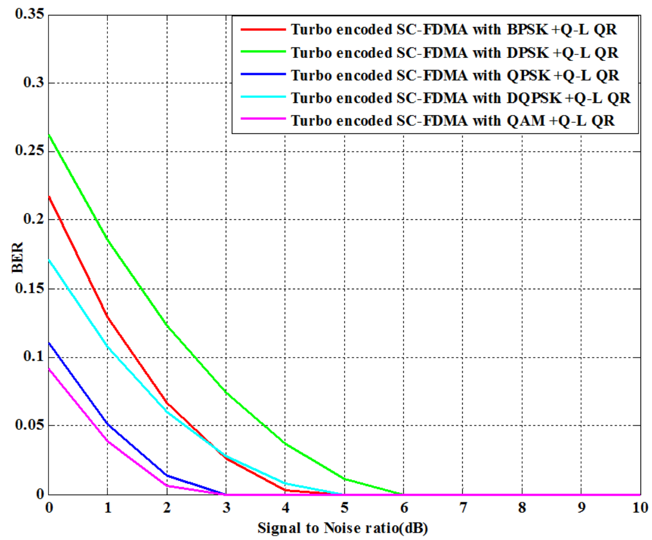

Figure 7. BER Performance of a Turbo Encoded SC-FDMA based System Incorporating Q-Less QR Decomposition based Signal Detection Scheme under Various Digital Modulation Techniques

In Figure 7, it is found that the Q-Less QR decomposition scheme based SC-FDMA system provides quite satisfactory and worst performance in QAM and DPSK digital modulations. The estimated BER values are 0.0065 and 0.1228 at a typically assumed SNR value of 2 dB which is indicative of system performance improvement by 12.76 dB. Figure 7 also confirms that the system performance in QAM digitally modulated system is acceptable as compared to other digital modulation techniques.

5. Conclusion

In this paper, simulation results for an STBC transmission scheme based Turbo encoded SC- FDMA Wireless Communication System on synthetically generated bit stream is presented. In the context of system performance, it can be concluded that the implementation of QAM digital modulation technique with Q-less QR Decomposition based signal detection technique provides satisfactory result for Turbo encoded SC- FDMA Wireless Communication System.

References

[1] S. Yasukawa, T. Kawamura, Y. Kishiyama, H. Taoka and T. Nakamura, “Experimental Evaluation on SU-MIMO Transmission with Closed-loop Precoding in LTE-Advanced Uplink”, IEEE 73rd Conference on Vehicular Technology, **(2011)**, pp. 1-5, DOI: 10.1109/VETECS.2011.5956671.

[2] M. P. Wylie-Green, E. Perrins and T. Svensson, "Introduction to CPM-SC-FDMA: A Novel Multiple-Access Power-Efficient Transmission Scheme", IEEE Transactions on Communications, vol. 59, no. 7, **(2011)**, pp. 1904-1915, DOI: 10.1109/TCOMM.2011.062911.100010.
[3] U. L. Dang, M. A. Ruder, W. H. Gerstacker and R. Schober, "MMSE Beamforming for SC–FDMA Transmission over MIMO ISI Channels with Linear Equalization", IEEE Conference on Global Telecommunications, **(2010)**, pp. 1-6, DOI: 10.1109/GLOCOM.2010.5684350.
[4] G. Berardinelli, B. E. Priyanto, T. B. Sørensen and P. Mogensen, "Improving SC-FDMA Performance by Turbo Equalization in UTRA LTE Uplink", IEEE Conference on Vehicular Technology, **(2008)**, pp. 2557 – 2561, DOI: 10.1109/VETECS.2008.562.
[5] Z. Lei, C. Yuen and F. P. S. Chin, "Quasi-Orthogonal Space-Time Block Codes for Two Transmit Antennas and Three Time Slots", IEEE Trans. on Wireless Communications, vol. 10, no. 6, **(2011)**, pp. 1983-1991.
[6] http://www.engadget.com/2012/09/11/everything-everywhere-announce-the-uks-first-major-4g-network/.
[7] http://juneauempire.com/local/2012-11-11/alaska-communications-now-has-4g-lte#.UKmplbIgd4M.
[8] Y. S. Cho, J. Kim, W. Y. Yang and C. G. Kang, "MIMO-OFDM Wireless Communications with Matlab", John Wiley and Sons (Asia) Pte. Limited, Singapore, **(2010)**.
[9] S. T. Karris, "Numerical Analysis Using MATLAB and Spreadsheets", Second Edition, Orchard Publications, California, USA, **(2004)**.
[10] W. Stallings, "Cryptography and Network Security Principles and Practices", Fourth Edition, Prentice Hall Publisher, **(2005)**.
[11] C. Heegard and S. Wicker, "Turbo Coding", Kluwer Academic Press, Boston, USA, **(1999)**.
[12] T. S. Rappaport, "Wireless communications: Principles and Practices", Second Edition, Prentice Hall Inc., New Jersey, USA, **(2004)**.

Authors

Joarder Jafor Sadique received his B.Sc. (Hons.) and M.Sc. degree both in Applied Physics and Electronic Engineering department from University of Rajshahi, Bangladesh in 2010 and 2011 respectively. During his post graduate study, he has completed a research work on MIMO SC-FDMA Wireless Communication System. His research interest includes Channel Equalization, Radio Interface technologies (OFDMA and SC-FDMA) and Antenna Diversity.

Shaikh Enayet Ullah is a Professor of the Department of Applied Physics and Electronic Engineering, Faculty of Engineering, University of Rajshahi, Rajshahi, Bangladesh. He received his B.Sc (Hons) and M.Sc degree both in Applied Physics and Electronics from University of Rajshahi in 1983 and 1985 respectively. He received his Ph.D degree in Physics from Jahangirnagar University, Bangladesh in 2000.He has earned US equivalent Bachelors and Master's degree in Physics and Electronics and Ph.D degree in Physics from a regionally accredited institution of USA from New York based World Education Services on the basis of his previously received degrees and academic activities (Teaching and Research), in 2003. He worked as a Professor and Chairman (on deputation) in the Department of Information and Communication Engineering, University of Rajshahi from 2009 to 2012. He has published more than 60 articles in multidisciplinary fields. His main research interests include Cooperative communications, MIMO-OFDM, WiMAX, Cognitive radio and LTE radio interface technologies.