Regular paper

Comparison of traffic performance of QPSK and 16-QAM modulation techniques for OFDM system

Imdadul Islam and Siddique Hossain

Abstract— Orthogonal frequency division multiplexing (OFDM) provides better spectral efficiency than frequency division multiplexing (FDM), while maintaining orthogonal relation between carriers; hence traffic is better carried by OFDM than FDM within the same spectrum. This paper reveals a comparison of spectral efficiency, performance of communication system in context of bit error rate (BER) for the same information rate and peak to average power ratio (PAPR) of quadrature amplitude shift keying (QPSK) and 16-quadrature amplitude modulation (16-QAM) technique.

Keywords— OFDM, QPSK, 16-QAM, IFFT, frequency spectrum, PAPR, BER.

1. Introduction

Today major challenge in telecommunication is to convey as much information as possible through limited spectral width. Orthogonal frequency division multiplexing (OFDM) introduces the concept of allocating more traffic channels within limited bandwidth of physical channel. Here the available bandwidth is split into several narrow band channels for simultaneous transmission. In frequency division multiplexing (FDM) a guard band is provided between individual channels, which separates the spectrum of different channels, and enables a practical band pass filter to detect individual channel. But the situation is completely different in OFDM where spectrums of adjacent channels are overlapped which resembles adjacent channel interference, but interference is avoided by maintaining orthogonal relation between sub-carriers. First of all high speed serial data is converted to low speed parallel data, as shown in Fig. 1 based on [1, 2]. Therefore transmitted signal is a vector addition of orthogonal modulated carriers, makes large peak to average power ratio, therefore dynamic range of devices should be large enough, as summarized in [3–5].

Output of each parallel line is modulated; here two different types of modulation quadrature amplitude shift keying (QPSK) and 16-quadrature amplitude modulation (16-QAM) are selected for this paper, whose constellations are shown in Fig. 2. QPSK waves have constant peaked sinusoidal wave but phase angle is different for four different combinations of 2 bits. In 16-QAM both amplitude and phase of the wave varies according to 16 different combination of 4 bits. In this paper 7 parallel lines are used, hence 7 different carrier frequencies are used for simulation. Parallel waves are again converted to an instantaneous serial waves prior to transmission. This phenomenon resembles inverse first Fourier transform (IFFT) mentioned in [3, 6–8]. At receiving end signals are detected by coherent or envelope detection but this paper considers only coherent detection. In Section 2 complete analysis of transmitted signal in both time and frequency domain is done explicitly along with carrier waves (both before and after modulation) using constellation vectors of QPSK and 16-QAM. All the equations needed to detect signal at receiving end along with evaluation of peak to average power ratio (PAPR) [9, 10] are also summarized in this section. Section 3 deals with simulation of OFDM in additive white Gaussian noise (AWGN) environment to evaluate the performance of both modulation techniques in context of bit error rate (BER) and PAPR. Finally a comparison of both modulation techniques is given in a nutshell in Section 4 based on complete analysis previous sections.

2. Methodology

Typical FFT-based OFDM communication system is shown in Fig. 1. Modulator part of the figure will use only QPSK and 16-QAM technique whose constellation is shown in Fig. 2. In OFDM each sub-carrier is modulated independently with complex modulation symbol vector and added for simultaneous transmission; it is expressed like [6, 8]:

$$v(t) = \tilde{v}(t)\mathrm{e}^{\mathrm{j}2\pi f_c t}\,. \tag{1}$$

Complex envelope $\tilde{v}(t)$ of above equation is summarized succinctly in [1–3, 6] given by

$$\tilde{v}(t) = A_c \sum_{n=0}^{N-1} \omega_n \phi_n(t)\,; \quad 0 > t > T\,, \tag{2a}$$

where A_c is the peak carrier amplitude and ω_n is the N-element parallel vector.

For orthogonal relation the sub-carrier frequencies are related as

$$\phi_n = \mathrm{e}^{\mathrm{j}2\pi f_n t} \quad \text{and} \quad f_n = \frac{1}{T}\left(n - \frac{N-1}{2}\right). \tag{2b}$$

Figure 3a shows the OFDM signal, i.e., summation of sub-carriers prior to modulation and Fig. 3b depicts the same signal after QPSK modulation. Before modulation, the waves have the same starting and ending point since each

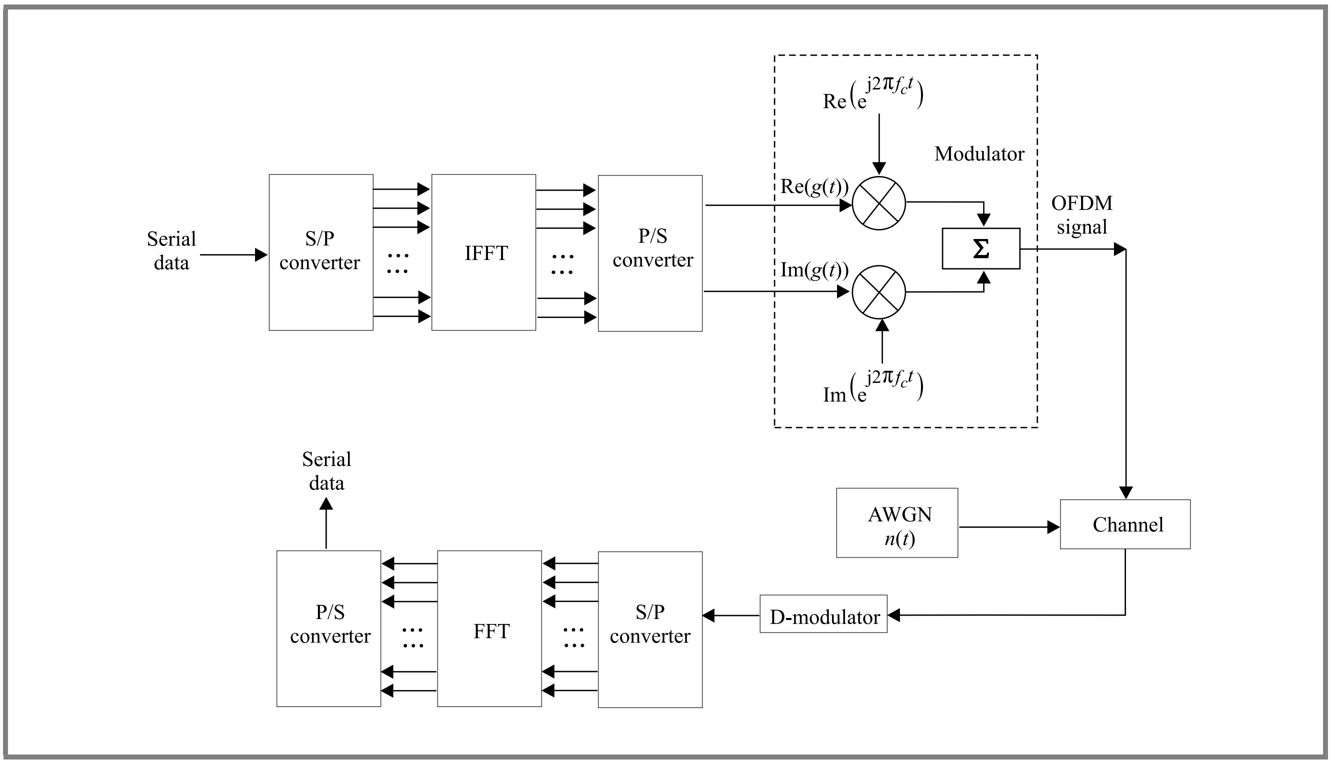


Fig. 1. OFDM communication system.

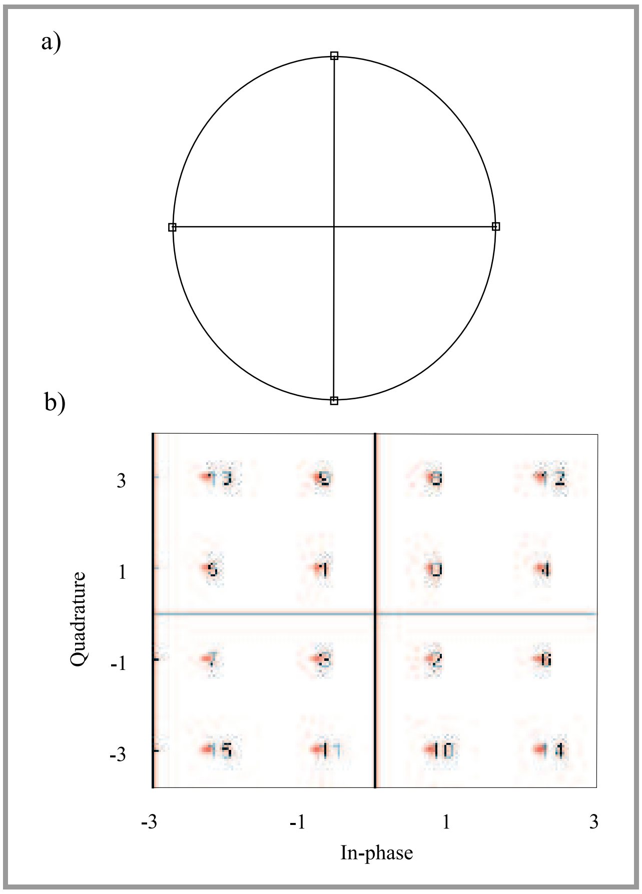


Fig. 2. Constellation vector (a) of QPSK and (b) of 16-QAM.

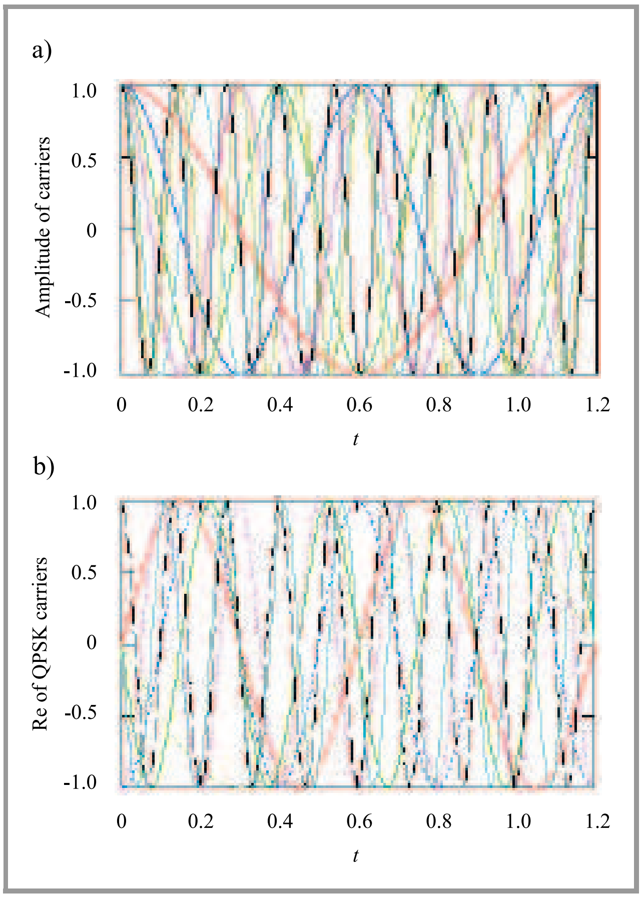


Fig. 3. Sub-carriers (a) befor and (b) after modulation.

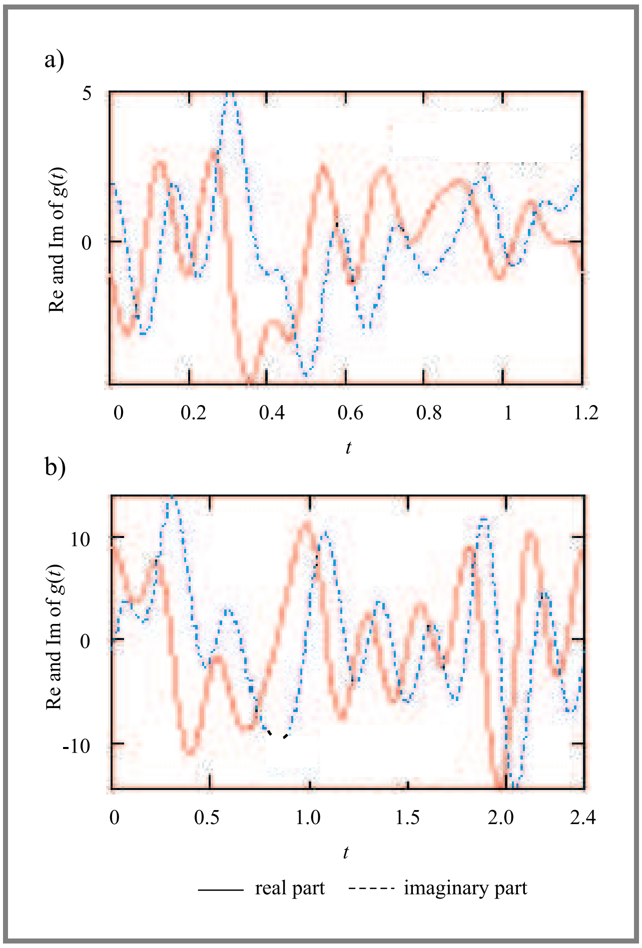


Fig. 4. Real and imaginary part of complex envelope of OFDM (a) of QPSK in time domain and (b) of 16-QAM in time domain.

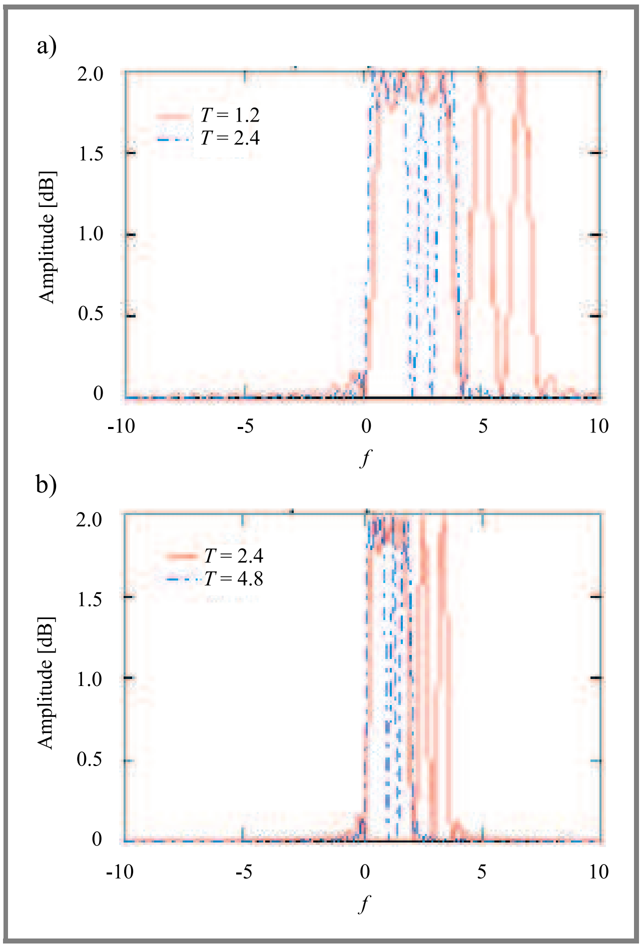


Fig. 5. Frequency spectrum of complex envelope (a) of QPSK and (b) of 16-QAM.

carrier has an integer number of cycles over a symbol period to maintain orthogonal relation but after modulation start and end points are shifted due to multiplication of constellation vectors. For Fig. 3b constellation vectors for QPSK and 16-QAM are taken as

$$W_{\mathrm{QPSK}} = \begin{bmatrix} e^{j\pi/2} \\ e^{j3\pi/2} \\ e^{j\pi} \\ e^{j\pi/2} \\ e^{j\pi} \\ e^{j\pi/2} \\ e^{j0} \end{bmatrix} \qquad W_{16\text{-QAM}} = \begin{bmatrix} 1+j \\ 3+j \\ 3-3j \\ -1+j \\ -3-3j \\ 3-i \\ 3+3i \end{bmatrix}$$

Real and imaginary part of complex envelope of 7 simultaneously transmitted signal is shown in Fig. 4 for both 16-QAM and QPSK. Signals have very wide dynamic ranges for both cases.

Frequency spectrum of complex envelope [16] is given by

$$\Psi(f) = C \sum_{n=0}^{N-1} |\operatorname{sin}c(f - f_n)T|^2 . \tag{3}$$

Spectrum of QPSK and 16-QAM signals is depicted in Fig. 5 for a symbol period of $T = 1.2$ and 2.4 units for QPSK modulation and $T = 2.4$ and 4.8 units for that of 16-QAM. Symbol period of 16-QAM is taken twice compare to that of QPSK, since each modulation symbol of 16-QAM holds 4 bits but that of QPSK holds only two bits.

If there is N different users, i.e., N sub-carriers OFDM system, nth signal block [7, 8, 11] is represented as

$$S_n(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S_{n,k}\, g_k(t - nT) . \tag{4a}$$

Entire continuous time signal:

$$S(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{\infty} \sum_{k=0}^{N-1} S_{n,k}\, g_k(t - nT) . \tag{4b}$$

Where the constellation vector $S_{n,k}$ of kth sub-carrier is recovered using cross correlation of following equation:

$$S_{n,k} = \frac{\sqrt{N}}{T_S} \left\langle S_n(t),\, \overline{g_k(t - nT)} \right\rangle , \tag{5}$$

where

$$\langle g_k,\, g_l \rangle = \int g_k(t)\, \overline{g_l(t)} dt .$$

At receiving end, the constellation vector becomes [4]:

$$R_{n,k} = \frac{\sqrt{N}}{T_S}\left\langle r_n(t),\, \overline{g_k(t-nT)}\right\rangle, \tag{6}$$

where $r_n(t) = S_n(t) + n(t)$; $n(t)$ is AWGN of environment. A maximum likelihood sequence estimator would have to choose one out of all possibly transmitted symbol sequence μ. The sequence estimator determines an estimated $< S_{n,k} >$ according to the following criterion:

$$\langle \hat{S}_{n,k} \rangle = \min \sum_k \left| R_{n,k} - H_{n,k} S_{n,k}(\mu) \right|^2, \tag{7}$$

where μ is the types of possible modulation symbols and $H_{n,k}$ is the transfer function of channel [12].
Finally peak to average power ratio is evaluated as

$$\text{PAPR} = \frac{\max\langle |s(t)|^2 \rangle}{\text{mean}\langle |s(t)|^2 \rangle}\,. \tag{8}$$

3. Simulation and results

A simulation work is done based on Eqs. (1)–(8) by the authors using MATLAB-6.5 in their own way to evaluate

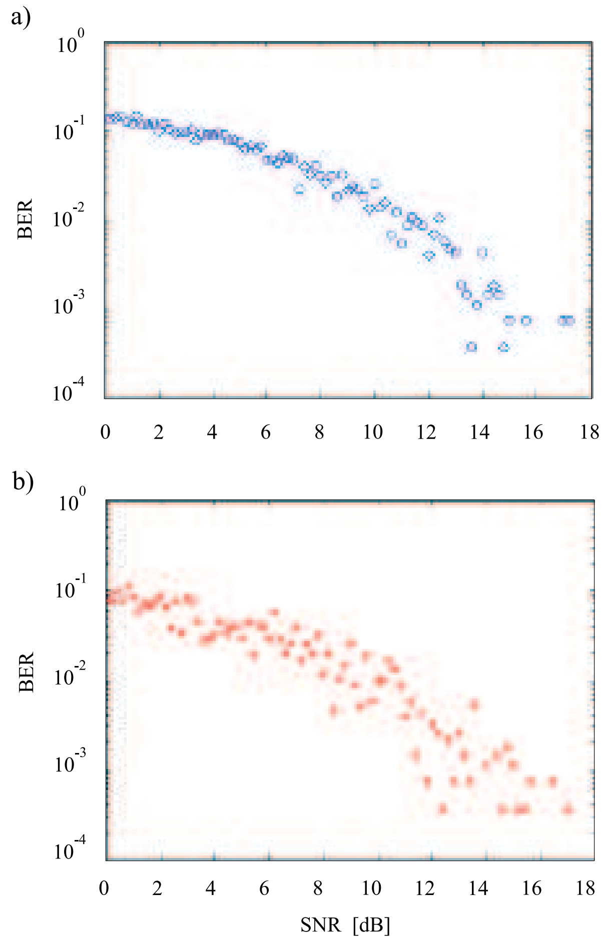


Fig. 6. Comparison of performance (a) of 16-QAM and (b) of QPSK under AWGN.

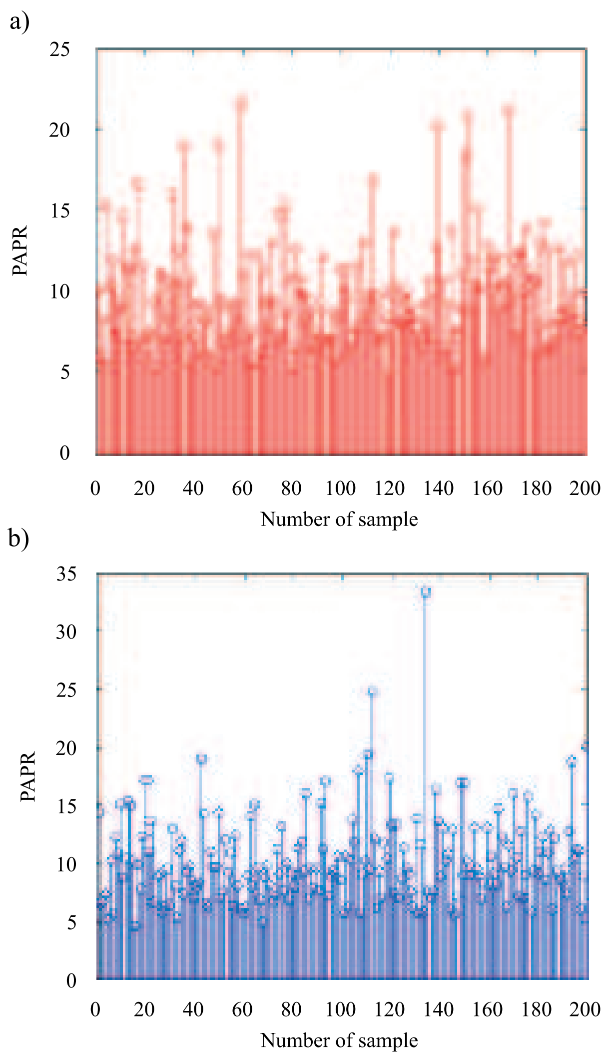


Fig. 7. Comparison of PAPR (a) of 16-QAM and (b) of QPSK.

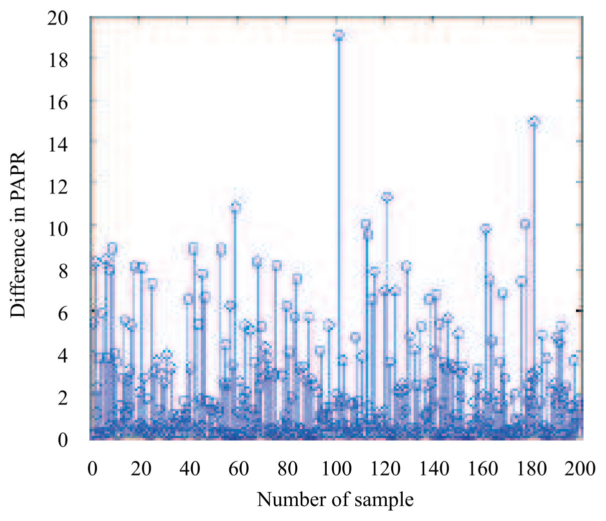


Fig. 8. Difference between PAPR of QPSK and 16-QAM for same throughput.

performance of QPSK and 16-QAM for OFDM in AWGM environment in context of spectral width, BER and PAPR shown in Figs. 5–7. Spectrum of narrower time slot becomes wider in frequency domain, visualized by solid lines of Fig. 5. Each symbol of QPSK convey 2 bits but that of 16-QAM is 4 bits/symbol therefore in time domain equivalent symbol period of 16-QAM is twice as long.

In this paper 10 000 random bits are generated to detect channel performance in AWGN environment. Rising cosine filter is used to emulate transmission medium and SNR is varied from 0 to 18 dB depicted in Fig. 6. One of the major problems in OFDM is the peak to average power ratio of un-coded signals. Here no coding technique is used to improve PAPR like [5, 13] since our aim is to compare performance of modulation technique in severe environment. Here PAPR is evaluated for 200 samples for both modulation techniques depicted in Fig. 7. Variation of PAPR lies between 5 to 15 units in Fig. 7 also verified in Fig. 8 where difference between PAPR of two modulation technique is measured shows the same difference. PAPR of QPSK and 16-QAM appear identical and it is really difficult to make command about improvement of PAPR but performance of both could be improved using coding technique summarized in [5, 13, 14].

4. Conclusion

It is obvious from Fig. 5 that spectral width of 16-QAM is narrower than that of QPSK for same information rate. Each symbol of QPSK conveys 2 bits but that of 16-QAM is 4 bits/symbol therefore in time domain equivalent symbol period of 16-QAM is twice as long. This phenomenon is verified from the simulation program. In context of BER, QPSK yields better performance than that of 16-QAM, shown in Fig. 6. Finally it could be concluded that BER performance of QPSK is better than that of 16-QAM at the expense of spectral width. Therefore 16-QAM can carry more traffic than QPSK at the expense of BER which is obvious in context of digital modulation technique hence analysis of the paper yield logical results in context of OFDM. PAPR solely depends on coding technique not on modulation technique, which is also verified from the simulation.

References

[1] B. J. Periris, R. M. A. P. Rajatheva, and V. Tralli, "Performance of self ICI cancellation based OFDM systems with carrier frequency offset estimation", in *3rd Int. Symp. Wirel. Pers. Multimed. Commun.*, Bangkok, Thailand, 2000, pp. 680–683.

[2] P. H. Moose, "A technique for orthogonal frequency division multiplexing offset correction", *IEEE Trans. Commun.*, vol. 42, no. 10, pp. 2908–2914, 1994.

[3] A. D. S. Jayalath and C. Tallambura, "Reducing the peak to average power ratio of an OFDM signal by interleaving" in *3rd Int. Symp. Wirel. Pers. Multimed. Commun.*, Bangkok, Thailand, 2000, pp. 698–703.

[4] T. May, H. Rohling, and V. Engels, "Performance analysis of Viterbi decoding for 64-DAPSK and 64-QAM modulated OFDM signals", *IEEE Trans. Commun.*, vol. 46, pp. 182–190, 1998.

[5] D. H. Guo and Ch.-Y. Hsu, "Minimization of the PARP of OFDM by linear systematic block coding", in *Asia-Pacific Conf. Commun. APCC*, Malaysia, 2003, pp. 129–133.

[6] L. W. Couch, *Digital and Analog Communication Systems*. 6th ed. Singapore: Pearson Education, 2002.

[7] D. A. Wegandt, Z. Wu, and C. R. Nassar, "High throughput, high performance OFDM via pseudo-orthogonal carrier interformely spreading codes", *IEEE Trans. Commun.*, vol. 51, no. 7, pp. 1123–1134, 2003.

[8] A. F. Molish, *Wideband Wireless Digital Communications*. Singapore: Pearson Education, 2003, Chapt. 18 and 20.

[9] H. Zhang and Y. Li, "Optimum frequency domain partial response encoding in OFDM system", *IEEE Trans. Commun.*, vol. 51, p. 1068, 2003.

[10] X. Cai, S. Zhou, and G. B. Giannakis, "Group-orthogonal multicarrier CDMA", *IEEE Trans. Commun.*, 2003 (to appear).

[11] P. Banelli and S. Cacopardi, "Theoretical anlysis and performance of ODDM signal in nonlinear AWGN channels", *IEEE Trans. Commun.*, vol. 48, no. 3, pp. 430–441, 2000.

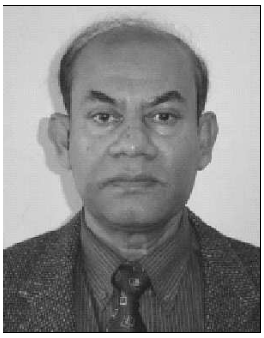
[12] M. A. Saeed, B. M. Ali, and M. H. Habaebi, "Performance evaluation of OFDM scenes over multipath fading channel", in *Asia-Pacific Conf. Commun. APCC*, Malaysia, 2003, pp. 415–419.

[13] D. H. Guo and C.-Y. Hsu, " Systematic reducing the PARP of OFDM by cyclic coding", in *Asia-Pacific Conf. Commun. APCC*, Malaysia, 2003, pp. 133–137.

[14] S. K. Yusof, N. Fisal, and T. S. Yin, "Reducing PAPR of OFDM signals using partial transmit sequences", in *Asia-Pacific Conf. Commun. APCC*, Malaysia, 2003, pp. 411–414.

Imdadul Islam has received his B.Sc. in electrical and electronic engineering from Bangladesh University of Engineering and Technology, Dhaka, in 1993 and the M.Sc. from the same institute in 1998. Now he is perusing Ph.D. at the department of EEE, BUET, Dhaka, in the field of teletraffic engineering. He worked as an Assistant Engineer in Sheba Telecom (Pvt.) Ltd. (a joint venture company between Bangladesh and Malaysia, for mobile cellular and WLL), from Sept'94 to July'96. He has very good field experiences in installation of radio base station and switching center for WLL. He is now working as an Associate Professor, at the Department of Electronics and Computer Science, Jahangirnagar University, Savar, Dhaka, Bangladesh. His research field is network traffic, OFDMA, WCDMA and array antenna systems. He has published more than 20 papers in national and international journal and conference proceedings.

e-mail: imdad22000@yahoo.com
Department of Electronic and Computer Science
Jahangirnagar University, Savar, Dhaka
Bangladesh



Siddique Hossain is the most senior Professor of Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology, Dhaka. He has more than 32 years of teaching, research and administrative experience both at home and abroad. Worked as the Head, EEE Dept., Head, CSE Dept., Dean, EEE Faculty and Director, BUET Computer Centre. He worked as a visiting faculty member of more than ten universities. He is a Senior Member of IEEE and was engaged as Chief of IEEE in Bangladesh in 1997–1998. Dr. Siddique Hossain is interested in the field of computers and communication engineering, 3G mobile communication, WCDMA for UMTS, etc. He has more than 30 publications in national, international journals and conference proceedings.

e-mail: sdq@eee.buet.ac.bd
Department of Electrical and Electronic Engineering
Bangladesh University of Engineering and Technology
Dhaka-1000, Bangladesh