Performance of M-QAM OFDM Systems in the Presence of EVM Degradation

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Abstract: ***An Orthogonal frequency division multiplexing (OFDM) has been adopted by several wireless transmission standards. The major drawback of OFDM is the large dynamic range of the transmit waveforms making OFDM vulnerable to nonlinearities of the power amplifier (PA) and causing the PA to obtain low power efficiency on the Radio frequency to dc power conversion. The commonly used performance metric to characterize a dynamic range of OFDM signal is peak-to-average power ratio (PAPR). To suppress the nonlinear effects, to reduce the PAPR value. However, this results in the increase of the error vector magnitude (EVM) and the decrease of the modulation error ratio (MER). EVM and the MER analysis is useful tool for prediction of the dynamic performance. In this paper, we compare the different performance metrics such as EVM and MER and show that they can be equivalently useful as signal to noise ratio (SNR) and bit error rate (BER).***

Keywords: Orthogonal frequency division multiplexing (OFDM), Error vector magnitude (EVM) Bit Error Rate (BER), Modulation error rate (MER).

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is an efficient modulation technique, because of its high data rate, high spectral efficiency and mitigating wireless impairments.

This technology has been proposed as the standard for broadcasting both audio and video digital signals and for wideband wireless communication systems. However their consisting of large numbers of independent QAM subcarriers, means the composite signal's peak to average power ratio (PAPR) can be significant. Nonlinear distortion is a source of major degradation of modulation fidelity in multicarrier systems, such as OFDM systems. The fundamental band of the RF nonlinear power amplifier(PA) transmitter system output for an OFDM signal input iscomposed of large numbers of inter-modulation products (IMPs) superimposed on the inband amplified OFDM subcarriers and appearing in adjacent channels as spurious out-of-band emissions. The IMP impairment of the inband signal modulation fidelity is measured by error vector magnitude (EVM).The performance of the OFDM scheme is also severely affected by the phase noise of the oscillators at the receiver. The modulation error rate (MER) is widely applied as a measure of OFDM signals' performance, which integrates impairments such as nonlinearity, IQ imbalance, phase noise, as well as Doppler frequency shift. The 3GPP standards' body has completed definition of the first release of the Long Term Evolution (LTE) system. LTE is an Orthogonal Frequency Division Multiple Access (OFDMA) system, which specifies data rates as high as 300 Mbps in 20MHz of bandwidth. LTE can be operated as a purely scheduled system (on the shared data channel) in that all traffic including delay sensitive services needs to be scheduled. Therefore, scheduler should be considered as a key element of the larger system design. The fine granularity (180 KHz Resource Block times 1millisecond Transmission Time Interval) afforded by LTE allows for packing efficiency and exploitation of time/frequency channel selectivity through opportunistic scheduling, thus enabling higher user throughputs. However, unlike what is typically the case in wired systems, more capacity does not easily translate to better user-perceived QoS for delay sensitive flows (VoIP, video-conferencing, stream video, etc.) in an opportunistic system. This is because a QoS scheduler has to carefully tradeoff *maximizationof total transmission rate* versus *balancing of various QoSmetrics (e.g., packet delays) across users*. In other words, one may need to sometimes schedule users whose delays/queues are becoming large but whose current channel is not the most favorable for a review and discussion of results on best effort and QoS scheduling.

The cell radius covered by a small cell will be short, therefore it is expected that such a small cell environment could mitigate the impact on fading. Until now in LTE and LTE-Advanced, quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (QAM) and 64-QAM have been used for the symbol modulation of orthogonal frequency division multiplexing (OFDM). However, when introducing HetNet or SCE, it appears possible that a higher order Modulation such as 256- and 1024-QAM could be implemented inside OFDM subcarriers. When 256- and 1024-QAM are implemented, error vector magnitude (EVM) must be evaluated as it will be quite difficult to produce such a precise transmitter/modulator and receiver/demodulator. However, the EVM effect on transmission performance such as bit error rate (BER) is not clarified by link-level computer simulations.

2. OFDM System Model

A. Description of OFDM system Algorithm

In OFDM system, a random bit sequence is generated, and then the bits are mapped into 64-QAM symbols. The block diagram of OFDM transmitter is shown in Fig. 1.The I and Q values of this sequence are stored as the *j I*~ and *j Q* ~

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array. The *j I~* and *j Q ~*array is next used to form the OFDM frequency domain signal, X(f). An inverse FFT function is then used to compute the time domain signal, X(t). The input time domain signal is then scaled to the required average input power level. Then the power amplified time domain signal, Xa(t) is calculated. Using the FFT function, the PA output frequency domain signal, Xa(f), is calculated. FromXa(f), the resulting OFDM symbols *j j I ,Q* are mapped.

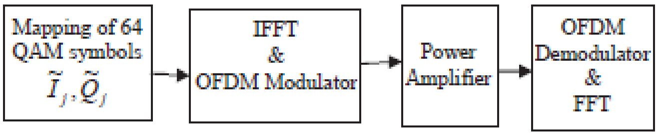

Figure 1: Block diagram of OFDM system

B. High power Amplifier Model

The IFFT output signal is then passed through a nonlinear power amplifier model. The complex envelope of the input signal into the amplifier can be expressed as

$$x_a(t) = |x(t)| e^{j\phi(t)}$$

The high power amplifier (HPA) is Rapp's solid state power amplifier model (SSPA) with amplitude and phase characteristics,

$$A[|x(t)|] = \frac{k_1 |x(t)|}{\left[1 + \left(\frac{k_1 |x(t)|}{A_o}\right)^{2p}\right]^{\frac{1}{2p}}}$$

$$\phi[|x(t)|] = \alpha_\phi \left(\frac{k_1 |x(t)|}{A_o}\right)^4$$

Where, A0 is the saturation output amplitude K1 is the small signal gain
x(t) is the complex envelope of the input signal
p is a knee factor which controls the smoothness of the transition from the linear region to the saturation region
α_Φ is typically set to zero, meaning SSPA adds no phase distortion.

3. Performance Metrics

The performance metrics such as PAPR, EVM, MER and BER which quantify the dynamic range of OFDM signals.

A. Peak to Average Power Ratio (PAPR)
PAPR for the discrete time OFDM signal x (n) is defined as the ratio of maximum signal power to average signal power

$$PAPR = 10\log\frac{\max|x(n)|^2}{Avg|x(n)|^2}$$

The PAPR reduction capability is measured by the CCDF which indicates the probability that the PAPR exceeds a certain threshold value. The CCDF of PAPR can be applied to determine the bounds for the minimum number of redundancy bits required to identify the PAPR sequences.

The complementary cumulative distribution function can be expressed as,
CCDF = Probability (PAPR > PAPR0)
Where PAPR0 is the threshold level

B. Error vector magnitude (EVM)
The below figure shows the error vector for one measured symbol. In this case with only one measured symbol, the magnitude of this small vector equals the EVM. If there were more symbols acquired than just this one, the EVM would equal the sum of the magnitudes of the error vectors for all of the measured symbols divided by the total number of measured symbols. The average power per symbol of the constellation. OFDM Signals are demodulated before EVM calculations are made.EVM is a measure of the deviation of the demodulated received symbol (*jj I ,Q*) from the original transmitted data symbol (*j j I~ ,Q~*).

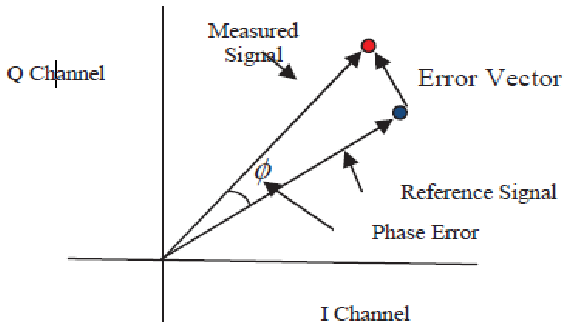

Figure 2: EVM Definition

The EVM, magnitude error and phase error can be expressed As

$$EVM_{rms} = \frac{\sqrt{\frac{1}{N}\sum_{j=1}^{N}\left[(I_j - \tilde{I}_j)^2 + (Q_j - \tilde{Q}_j)^2\right]}}{V_{\max}}$$

$$MagnitudeError = \sqrt{I_j^2 + Q_j^2} - \sqrt{\tilde{I}_j^2 + \tilde{Q}_j^2}$$

$$PhaseError = \arctan\frac{Q_j}{I_j} - \arctan\frac{\tilde{Q}_j}{\tilde{I}_j}$$

Where,
Vmax is the maximum amplitude of the ideal constellation points
N is the number of points in a measurement
jj I ,Q are the ideal and quadrature components of the j-th Measured OFDM signal *j j I~*, Q~ are the ideal and quadrature components of the j-th
Referenced OFDM signal
EVMRMS is the RMS error magnitude

C. Modulation Error Ratio (MER)

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MER is another measurement metric of OFDM system is closely related to EVM because in a single numerical value it summarizes the quality of a OFDM transmitter. The below figure shown Modulation error ratio is the ratio of average symbol power to average error power Modulation Error is used to Measure of Modulation quality.

$$MER(dB) = 10\log\left(\frac{\sum_{j=1}^{N}\left(\tilde{I}_j^{\,2}+\tilde{Q}_j^{\,2}\right)}{\sum_{j=1}^{N}\left[\left(I_j-\tilde{I}_j\right)^2+\left(Q_j-\tilde{Q}_j\right)^2\right]}\right)$$

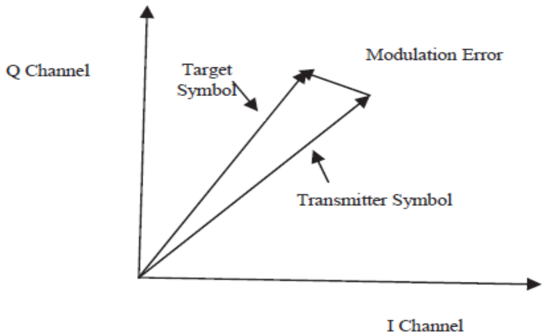

Figure 3: MER Definition

D. Bit Error Rate

BER measures how often symbols are pushed into boundaries of neighboring symbols, causing these symbols to be misinterpreted. BER does not measure the condition of the modulated signal itself, though a poor BER is an indicator of poor signal quality. Because the BER measurementdetects and counts every misinterpreted bit, it is a sensitive indicator of problems caused by transient or busty noise interference. BER is a commonly used performance metric, which describes the probability of error, Pe in terms of number of bits per bit transmitted.

$$P_e = \frac{2\left(1-\frac{1}{L}\right)}{\log_2 L} Q\left(\sqrt{\left[\frac{3\log_2 L}{L^2-1}\right]\frac{2E_b}{N_o}}\right)$$

Where,
L is the number of levels in each dimension of the *M*-array QAM modulation system
Eb is the energy per bit
N0/2 is the noise power spectral density
Q [.] is the Gaussian co-error function

4. OFDM Transmission Model

The below Figure shows a block diagram of the OFDM-based transmission model consisting of a single branch. A channel between the transmitting and receiving sides is modeled by typical additive white Gaussian noise (AWGN). On the transmitter side, baseband signals are generated by the Bernoulli binary rule and are encoded by convolutional encoding. The encoded signals are mapped to 256- or 1024-QAM by symbol modulation. OFDM modulation computes the inverse fast Fourier transform (IFFT) of the input QAM signals. Finally, cyclic prefix insertion is used as a typical OFDM transmission.

On the receiver side, first the cyclic-prefix is removed. OFDM demodulation then computes the fast Fourier transform (FFT) of the received signals to separate each subcarrier component that is then de-mapped to QAM. Each component signal is demodulated by symbol demodulation. After Viterbi decoding, the original baseband signals are detected.

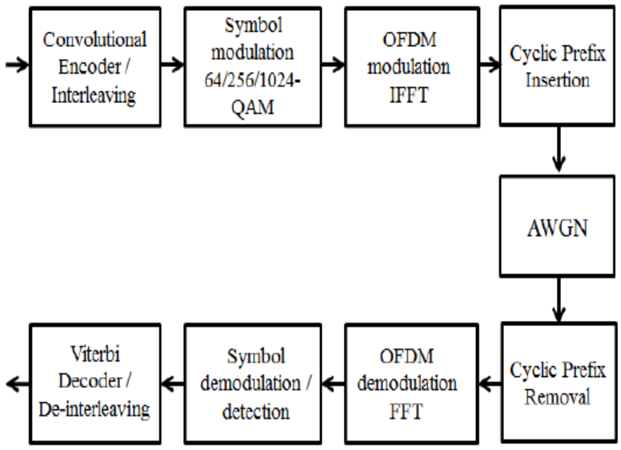

Figure 4: Block diagram of the OFDM transmission model.

5. Simulation Results

To show the PAPR, EVM, MER and BER performance of OFDM systems, we considered an OFDM system using 1024 subcarriers and different M-QAM modulations(for example M=4,16,32,64*M* is the modulation order) ,simulated by randomly generated data. PAPR is measured for OFDM system using randomly generated data bits with M array QAM modulations, the result is shown in Fig.6. In Fig. 6 it can be seen that by keeping fixed number of subcarrier (N=1024 are taken for example) and increasing the number of bits the PAPR value is not increasing rapidly as shown in Fig. 5. The PAPR of OFDM signal at each modulation changes in small fractions while keeping the subcarriers constant. The Fig. 6 shows the BER versus SNR performance of different modulation systems. It can be noticed that the BER decreasesrapidly by increasing SNR. From Fig. 6 , it is clear that the BER is lesser using 4 array QAM modulation technique rather than 16 ,32 and 64 array QAM ,by increasing the number of bits.The BER versus EVM curve shown in Fig. 7(a) .It can be noticed that the inverse relationship that exists between BER and EVM. From Fig. 7(a),it can be seen that there is a constant 1.5% difference between 4 and 16-QAM, whereas there is a 0.5% difference between 16-QAM and 32-QAM at 10-3 BER level. The BER versus MER curve shown in Fig. 7(b). In Fig. 7(b), we note that there is a constant 20 dB difference between 4 and 16-QAM, whereas there is a 50dB difference between 16-QAM and 32-QAM at 10-2 BER level. Fig. 7(c) shows EVM versus SNR performance of M –QAM OFDM system. Fig. 7(c) shows EVM versus SNR performance of M-QAM OFDM systems. It is clear that the lower the EVM, the better system performance. Fig. 7(d) shows MER versus SNR performance of M-QAM OFDM system. From Fig. 7(d),it can be seen that the higher the MER, the better system performance.

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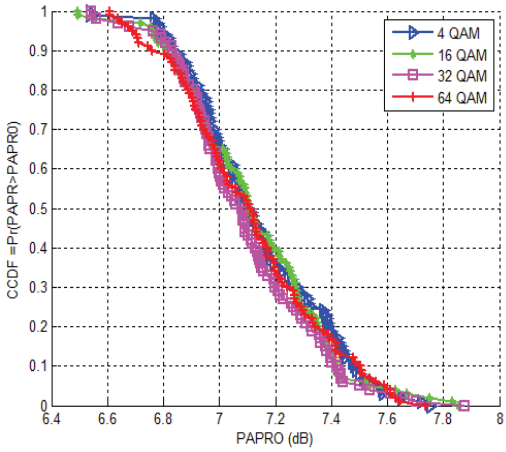

Figure 5: CCDF performance of OFDM system

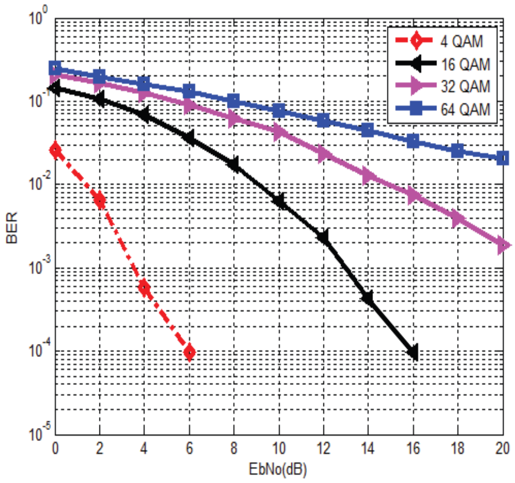

Figure 6: BER versus Eb/No performance of OFDM system

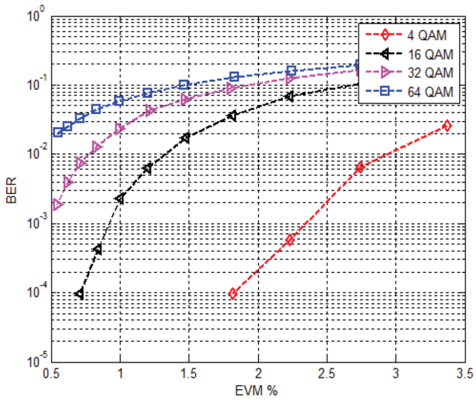

Figure 7: (a) The BER versus EVM curveperformance of M-QAM OFDM system

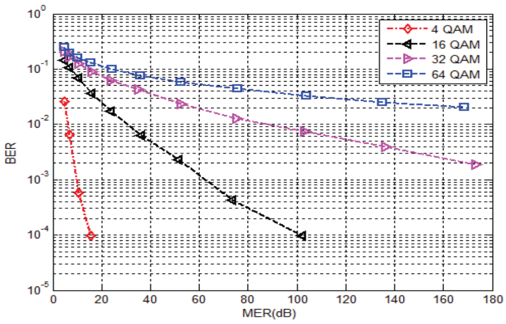

Figure 7: (b) The BER versus MER curveperformance of M-QAM OFDM system

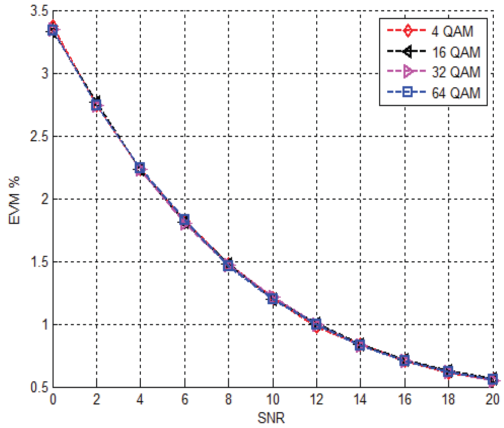

Figure 7: (c) EVM versus SNR performance of M-QAM OFDM systems.

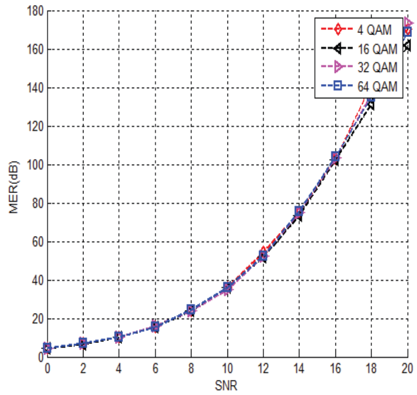

Figure 7: (d) MER versus SNR performance of M-QAM OFDM system.

6. Conclusion

In this paper, we have studied the EVM, MER and BER, performances of the M-QAM-OFDM systems subject to the nonlinear HPA in AWGN channels. An analytical description of the joint effects of this imperfection on the performance of OFDM systems has been presented. We have derived closed forms of the EVM, MER and BER expressions for AWGN channels. Analytical and simulation results show that the higher the MER and the lower EVM. EVM and MER values of OFDM systems were computed and simulated in order to relate them to BER and SNR figures. Using the measured root mean square error magnitude data in combination with the plots fromFig. 7(a) and Fig. 7(c), the dynamic performance of the OFDM receiver can be predicted.

References

[1] H. Schulze and C. L¨uders, Theory and Applications of OFDM andCDMA: Wideband Wireless Communications, Wiley, 2005.

[2] R.V. Nee & R. Prasad, OFDM wireless multimedia communications (London: Artech House, 2000).

[3] A.Frank H.P Fitzek,Basak Can, Nguyen Cong Haun, Muhammad Imadur Rahaman, and RanjeePrasad,"Cross lay eroptimization of OFDM systems for 4G wireless

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communication, ”center for Tele Infrastructure(CTIF) , Aalberg University.

[4] J. Lima Pinto, I. Darwazeh, “Phase Distortion and Error Vector Magnitude for 8-PSK Systems”, Proceedings of London Communications Symposium, LCS 2000, London, U.K., 14-15September, pp.37-40.

[5] E. Costa, S. Pupolin, “M-QAM-OFDM System Performance in the Presence of a Nonlinear Amplifier and Phase Noise” IEEE Transactions on Communications, ,pp 462-472, March 2002.

[6] J. K. Cavers, “The Effect of Data Modulation Format on Intermodulation Power in Nonlinear Amplifiers”, IEEE Transactions onCommunications, pp. 489-493, March 1994.

[7] S. H. Han, J. H. Lee, “An Overview of Peak – to – Average Power RatioReduction Techniques for Multicarrier Transmission”, *IEEETransaction on Wireless Communication*, April 2005.

[8] LajosHanzo, William Webb, and Thomas Keller.*Single- and Multi-Carrier Quadrature Amplitude Modulation*. Wiley, Chichester, 2ndedition, 2000.

[9] Michael D. McKinley, Kate A. Remley, Maciej Mylinski, J. Stevenson Kenney, Dominique Schreurs, and Bart Nauwelaers. “EVM Calculationfor Broadband Modulated Signals”. *Technical Report*,2005. Work of United States Government.

[10] R. Hassun, M. Flaherty, R. Matreci, M. Taylor, "Effective Evaluation of Link Quality using Error Vector Magnitude Techniques", Proceedings of1997 Wireless Communications Conference, Boulder, CO, USA 11-13August 1997, pp. 89-94.

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