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PRELIMINARY INVESTIGATION OF GRAY CODED M-QUADRATURE AMPLITUDE MODULATION IN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING OVER ADDITIVE WHITE GAUSSIAN NOISE CHANNEL

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Abstract. In this paper, we investigate the performance of Gray encoding M-Quadrature Amplitude Modulation (QAM) schemes in Orthogonal Frequency Division Multiplexing (OFDM) transmission over added white Gaussian noise (AWGN) channel. Gray-coded QAM with 1 to 8-bit symbol corresponding to 2 to 256-QAM respectively is generated and fed into OFDM transmission system. Performance in terms of bit error rate (BER) is presented against OFDM fast Fourier transform (FFT) size, subcarrier number, length of cyclic prefix, and tolerance to signal to noise ratio of the channel. Preliminary results show that only 16 and lower level-QAM are attractive to achieve a bit error rate (BER) of 10^{-3} with signal to noise ratio of at least 20 dB. The higher level QAM such as 256-QAM scheme will require at least a SNR of 50 db to achieve similar outcome. The study also shows that the performance of the system is not affected by the number of fft-points used, or the length of cyclic prefix inserted to the transmitted signal. However, the number of subcarriers does depend on the level of QAM used at a given SNR value.

Keywords: Orthogonal frequency division multiplexing (OFDM), quadrature amplitude modulation (QAM), gray coding, fast fourier transform (FFT)

Abstrak. Dalam makalah ini, kami menyelidik prestasi M-Modulasi Amplitud Kuadratur terkod-Gray dalam system penghantaran menggunakan skema Multiplexan Pembahagian Frekuensi Ortogonal (OFDM) melalui saluran hingar Gaussian (AWGN). QAM terkod Gray dengan 1 bit ke 8 bit per simbol bersamaan dengan 2-QAM ke 256-QAM dijana dan dimasukkan ke dalam sistem penghantaran OFDM. Prestasi sistem dalam bentuk kadar ralat bit (BER) diberi berbanding saiz jelmaan Fourier pantas (FFT), bilangan sub-pembawa, panjang prefix- kitaran, dan toleransi terhadap nisbah isyarat kepada hingar (SNR) dalam saluran. Dapatan awal menunjukkan hanya modulasi 16-QAM ke bawah boleh diterimapakai untuk mencapai BER sebanyak 10^{-3} dengan SNR sekurang-kurangnya 20 dB. Peringkat modulasi yang lebih tinggi seperti 256-QAM memerlukan SNR sebanyak 50 dB untuk mencapai hasil BER yang sama. Kajian juga menunjukkan prestasi sistem ini tidak tergugat dengan perubahan saiz FFT mahupun panjang prefix-kitaran yang dimasukkan ke dalam isyarat yang dihantar.

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Walau bagaimanapun, bilangan sub-pembawa bergantung kepada peringkat QAM yang digunakan untuk suatu nilai SNR yang diberi.

Kata kunci: Multiplexan pembahagian frekuensi ortogonal (OFDM), modulasi kuadratur (QAM), pengkodan gray, dan jelmaan fourier pantas

1.0 INTRODUCTION

Multimedia communications demanding for a higher bit rate and bandwidth require a more robust and flexible transmission technology than the one offered by the current third generation (3G) system. Even though the roll out of 3G system is stalled in many countries, like Malaysia, to actually see the effectiveness of a single carrier wideband code-division multiple access (WCDMA) system, a multicarrier technology, namely, Orthogonal Frequency Division Multiplexing (OFDM) has been introduced in satellite broadcasting system such as European Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB) [1]. This technology has also been explored in WLAN environment such as IEEE 802.11 Wireless LAN, High-performance LAN (HIPER-LAN) Type 2, and Multimedia Mobile Access Communication (MMAC) [1].

With the success of OFDM in both broadcasting and WLAN, many research efforts are now focusing on the possibility of introducing the technology in a wider macrocellular-area that would provide multimedia-rich internet access to the user [2-5].

OFDM promises to provide high data rate over hostile mobile environment with limited spectrum and inter-symbol interference caused by multipath fading. This multicarrier transmission system is able to deliver high data rate by splitting them into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers [6]. The fact that it can combat inter-symbol-interference commonly found in mobile communication system by using guard interval or cyclic prefix makes it a likely candidate for the forth coming fourth generation (4G) system [2].

Recently, an approach called link adaptation (LA) techniques has emerged as a tool to increase data rate and spectral efficiency [3] especially in OFDM transmission. In this technique, modulation, coding rate, and/or other signal transmission parameters are dynamically adapted based on channel condition to increase the system performance in terms of Bit Error Rate (BER) and throughput (bps) in various conditions such as channel mismatch, Doppler spreads, fading, etc. However, initial focus of this research is to investigate the ability of OFDM to transmit data using Gray-coded MQAM schemes as compared to other schemes like M-PSK system, eg. as in [7]. In Gray-encoding, the assignment of k-information bits (where k is the number of bit per symbol) to the $M=2^k$ possible signal amplitudes is done in such a way that adjacent signals amplitudes differ by one binary digit [8]. Research is undergoing to improve system performance by employing forward error correction such as convolutional coding and adaptive bit loading.

The organization of the paper is as follows. Section 2 gives brief overview of current OFDM system, section 3 describes the simulation model, section 4 presents the preliminary results, and section 5 concludes with proposal for future works.

2.0 OVERVIEW OF OFDM SYSTEM

The N-subcarrier OFDM system shown in Figure 1 generates N data symbols, S_n, $0 \leq n \leq N-1$, which are multiplexed to the N-subcarriers. The time domain samples, s_n transmitted during one OFDM symbol are generated by the inverse fast Fourier transform (IFFT) and transmitted over radio channel after cyclic prefix (CP) has been inserted. The channel is usually modeled by its time-variant impulse response $h(\tau,t)$ and additive white Gaussian noise (AWGN). At the receiver, the cyclic prefix is removed from the received time-domain samples, and the data samples r_n are fast Fourier transformed (FFT), in order to yield the received frequency-domain data symbols R_n [4,5].

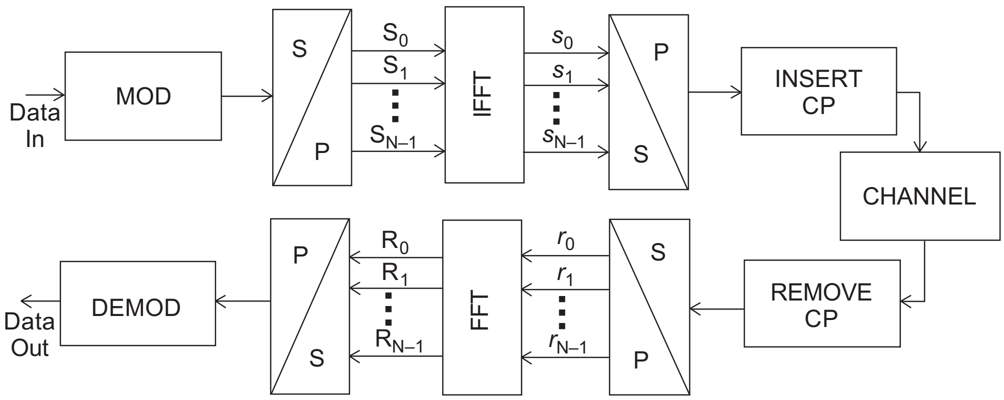

Figure 1 OFDM model

The channel response is approximately constant for the duration of one OFDM symbol because it has been subdivided into N subchannel, each with small enough bandwidth, Δf [2,4], and is referred to as the frequency domain channel transfer function H_n. The received data symbols R_n can be expressed as [4,5]:

$$R_n = S_n \, . \, H_n + n_n \tag{1}$$

where n_n is an AWGN sample.

Since the noise energy in each subcarrier is independent of channel frequency domain transfer function H_n, the local signal-to-noise-ratio (SNR) in subcarrier n, can be expressed as [4,5]:

$$\gamma_n = |H_n|^2 \, . \, \gamma \tag{2}$$

where γ is the overall SNR. If there is no signal degradation due to intersubcarrier interference (ISI) or interference from other sources appears, then the value γ_n determines the bit error probability for the transmission of data symbols over the subcarrier n [4].

2.1 Choice of OFDM Parameters

The choice of OFDM parameters is a tradeoff between various requirements. Normally, there are three main requirements that need to be determined, i.e. bandwidth, bit rate, and delay spread.

The delay spread directly dictates the cyclic prefix of an OFDM system such that the length of cyclic prefix is at least as long as the maximum delay of the channel [2]. In order to ensure that the received time-domain OFDM symbol is demodulated from the channel's steady-state rather than from its transient response, each time-domain OFDM symbol has to be extended by this cyclic prefix [5].

Once the cyclic prefix is fixed, symbol duration can be determined. To minimize the SNR loss caused by the cyclic prefix, it is preferable to have the symbol duration much larger than the cyclic prefix. [6,9,10] noted that the duration should not be arbitrarily large or it may introduce phase noise and frequency offset as well as an increase in peak-to-average power ratio. A practical design would set symbol duration at least four to five times [2,4] the cyclic prefix, implying a 1-dB SNR loss due to cyclic prefix.

The number of subcarriers can be determined from the total bandwidth divided by the subcarrier spacing, which is the inverse of the symbol duration minus the guard time [6].

As an example, suppose we are to design an OFDM system with tolerable delay spreads of 200 ns, bit rate of 20 Mbps, and bandwidth of less than 10 MHz. A delay spread of 200 ns will lead to a cyclic prefix (CP) of 800 ns. The symbol duration is at least 4–5 times the CP, if we choose 6 times the CP, then the symbol duration T_{symbol}, is 4.8 μs. The subcarrier spacing can now be calculated as $(T_{symbol} - T_{CP})^{-1} = 250$ kHz. Thus, to achieve 20 Mbps, each OFDM symbol has to carry 96 bits information $\left(96 \times \frac{1}{4.8\ \mu\text{s}} = 20\ \text{Mbps}\right)$. To do this, we may use several options, for example, use 4-QAM to get 2 bits/symbol/subcarrier. In this case we will need 48 subcarriers to get the required 96 bits per OFDM symbol. Or, we may use 8 QAM to get 3 bits/symbol/subcarrier for 32 subcarriers to achieve 96 bits per OFDM symbol. The number of subcarriers is equal to $\frac{\text{bandwidth}}{\text{carrier spacing}}$. Suppose we choose option 1, 48 subcarriers means a bandwidth of 48×250 kHz = 12 MHz, which is larger than the required value of 10 MHz. Thus, option 2 would serve the purpose in which 32-point FFT may be used. If over sampling is required, we may use higher number of FFT-points.

2.2 Motivation

This work is motivated by the fact that current research is mainly focused on broadcasting and WLAN system [2,4,5], where the former is a simplex transmission while the latter is duplex with short delay. Duplex cellular networks with bigger cell radius will undergo more interference with longer delay spreads. Lawrey [7] had done extensive work on OFDM transmission at radio channel utilizing M-Phase Shift Keying methods which are more difficult to detect due to the synchronization required for both phase and frequency. Besides, MQAM schemes are normally 5 dB superior over the same level of MPSK system [6], which set the choice of QAM as the modulation method for our OFDM transmission system. However, the early focus of this research is to see the feasibility of OFDM to adapt to the dispersive radio environment and provide a better transmission performance as compared to the current single carrier, CDMA system, using Gray encoding MQAM modulation.

3.0 SIMULATION MODEL

An OFDM transmission system is developed and simulated using MatLab 6.1 with parameters as shown in Table 1. The modulation scheme employed is MQAM with Gray encoding. In Gray edcoding QAM, the adjacent signal amplitudes is made to differ by one binary digit [10], hence ease the detection of received signal at OFDM receiver. MQAM, which in theory outperforms phase shift keying method would benefit the transmission when adaptive bit loading is later implemented.

Table 1 Simulation parameters

Parameters	Values	Remarks
IFFT points	May vary from as low as 32 to 2048	In practice however, IFFT size should not exceed 512 to avoid implementation complexity [1]
Number of subcarriers	Varies from 30 to 500	–
Modulation methods	2-QAM, 4-QAM to 256-QAM	Corresponding to sending of 1 bit, 2 to 8 bits per symbol, respectively
Signal to noise ratio (SNR)	Varies from 0 to 40 dB	Steps of 2 dB
Channel	Additive White Gaussian Noise (AWGN)	–
Number of transmitted symbols	Not limited but set to 32000 symbols	Higher value increases simulation time

4.0 RESULTS AND DISCUSSION

Figures 2 to 4 show SNR versus number of subcarriers for 16-QAM, 64-QAM, and 256-QAM, respectively. Higher modulation level such as 64 and 256-QAM require higher SNR and are not attractive even in AWGN channel. On the other hand, 16- and lower level QAM are able to achieve a BER of at least 10^{-3} at SNR of 20 dB and lower. Note that in OFDM transmission, lower level QAM maybe the only choice, given a low instantaneous SNR in the channel (see Figure 4). However, there may be time when the channel is not severely corrupted with noise when SNR is high that the high-level QAM is more attractive to employ to ensure efficient use of bandwidth.

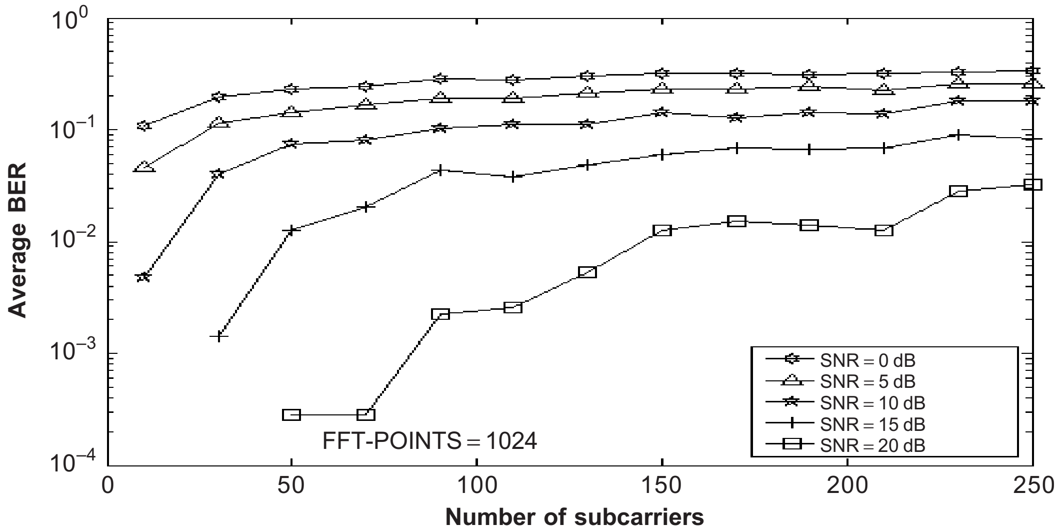

Figure 2 BER versus number of subcarriers for 16-QAM in AWGN channel at different SNR

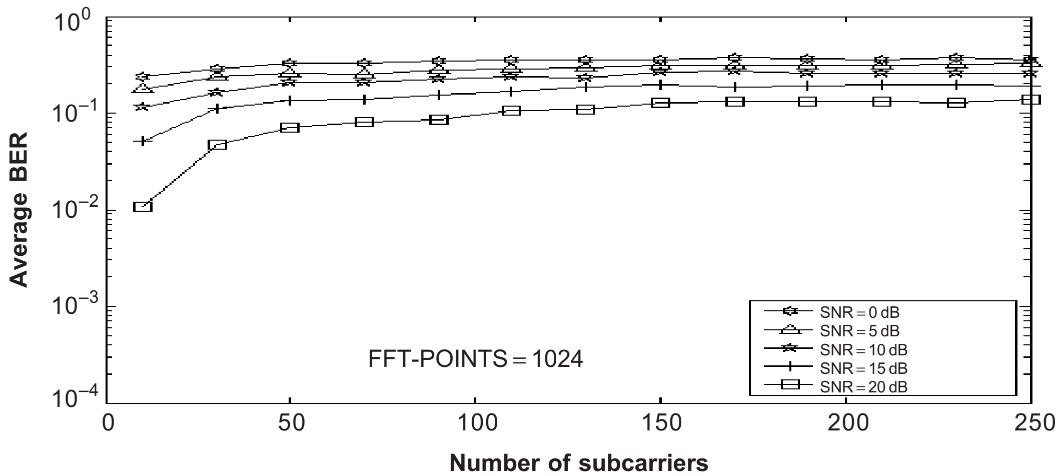

Figure 3 BER versus number of subcarriers for 64-QAM OFDM in AWGN channel at different SNR

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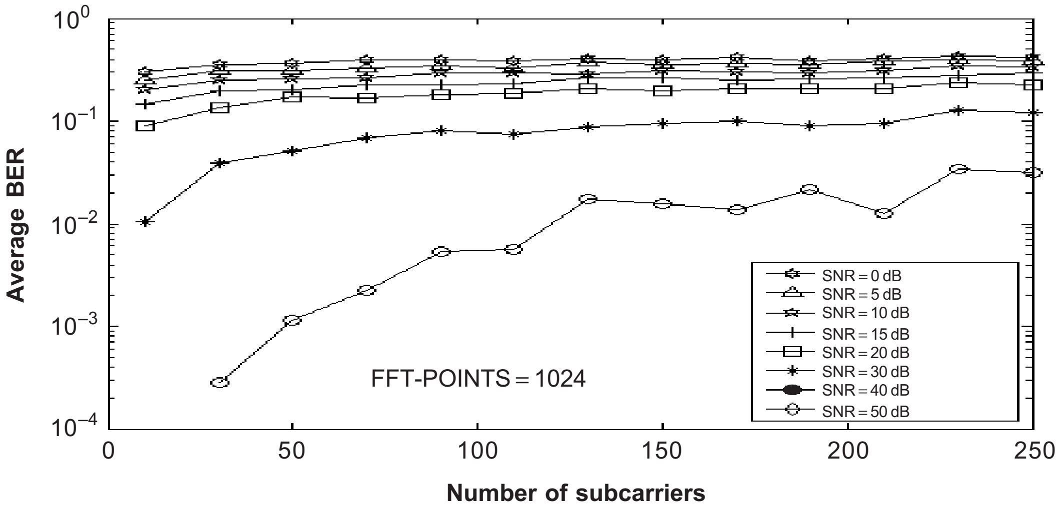

Figure 4 BER versus number of subcarriers for 256-QAM OFDM in AWGN at different SNR

This method of adaptively choosing the type of modulation to be used depending on the current condition of the channel will be further investigated.

Figures 5 and 6 show BER versus SNR for MQAM OFDM with fft-points of 256 and 2048, respectively. Results show that the number of fft-points does not affect the overall BER performance as long as it is kept at least 4 times the number of subcarriers to allow guard band, or at least twice the size of subcarriers in the absence of guard band. However, the performance of BER against the number of subcarriers varies from one level of modulation to the other, as shown in Figure 7, in which higher modulation cannot tolerate large number of subcarriers for a given SNR. To further

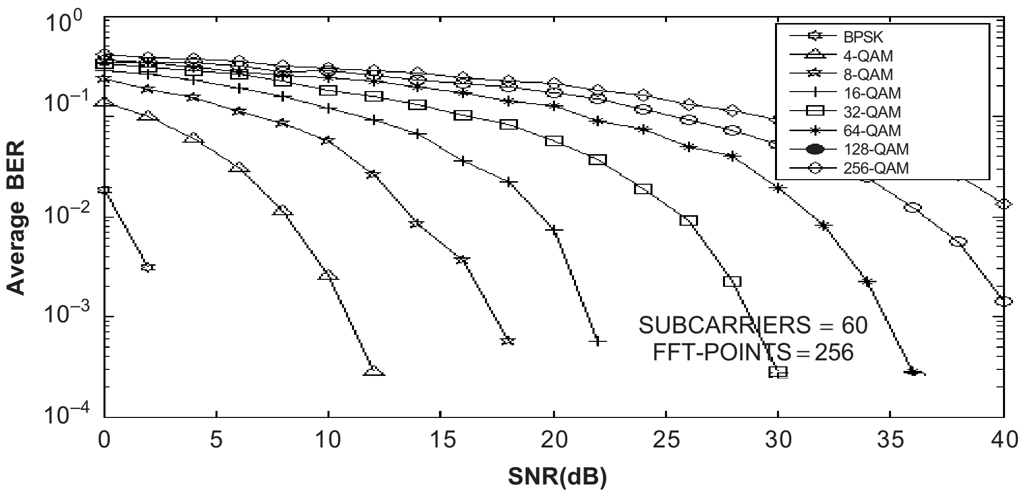

Figure 5 BER versus SNR for M-QAM OFDM in AWGN channel with FFT-points = 256

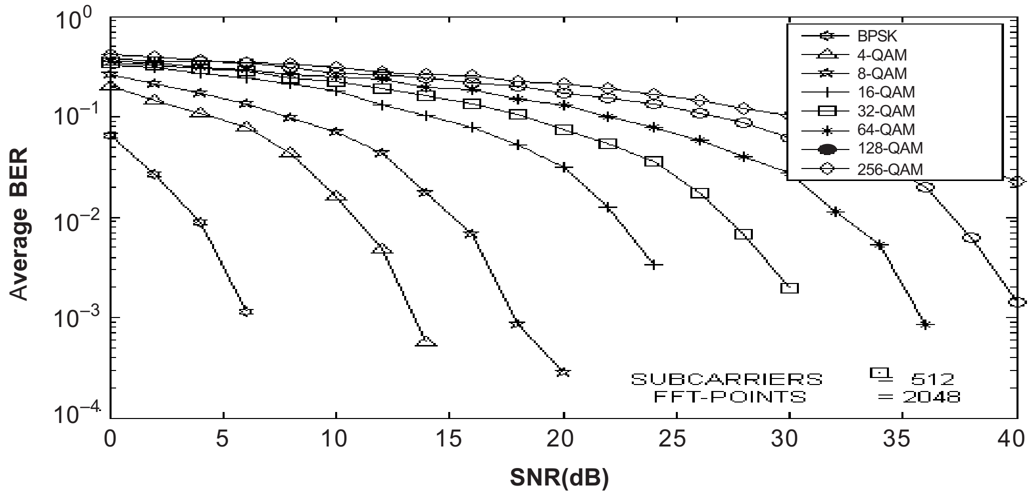

Figure 6 BER versus SNR for M-QAM OFDM in AWGN channel with FFT-points = 2048

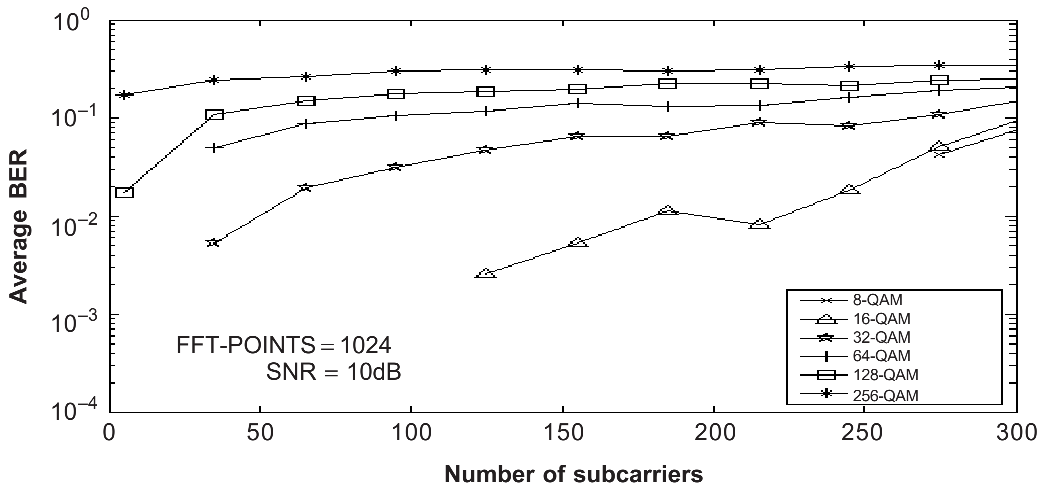

Figure 7 BER versus number of subcarriers for M-QAM OFDM over AWGN channel at SNR = 10 dB

illustrate the result, we have selected 64-QAM scheme using different number of subcarriers to show that BER deteriorates as the number of subcarriers increases for a given SNR as shown in Figure 8. The length of cyclic prefix (CP) does not affect the overall system performance, especially in AWGN channel as shown in Figure 9. However, the length of CP should be as long as the maximum delay of the channel. Current investigation is underway to see the effects of CP in an indoor fading channel with various delay spreads.

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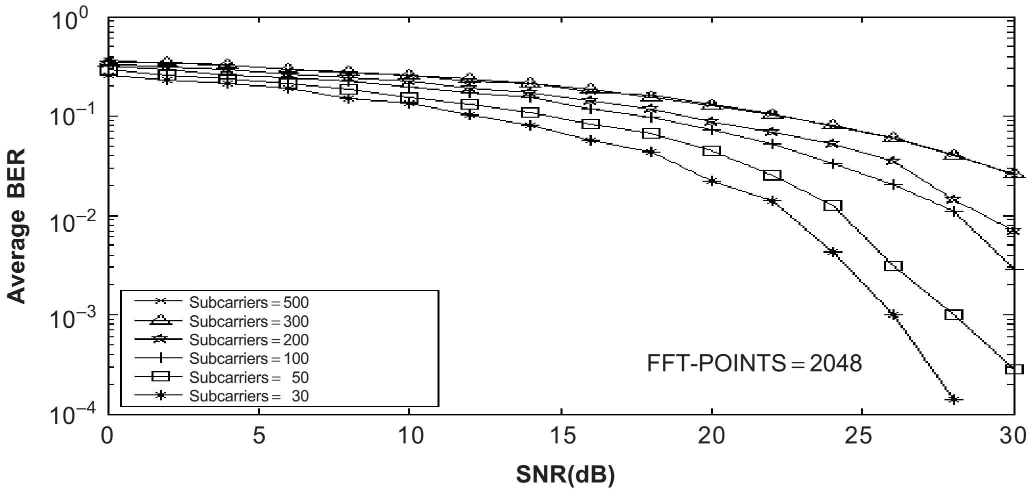

Figure 8 BER versus SNR for 64-QAM over AWGN channel using different number of subcarriers

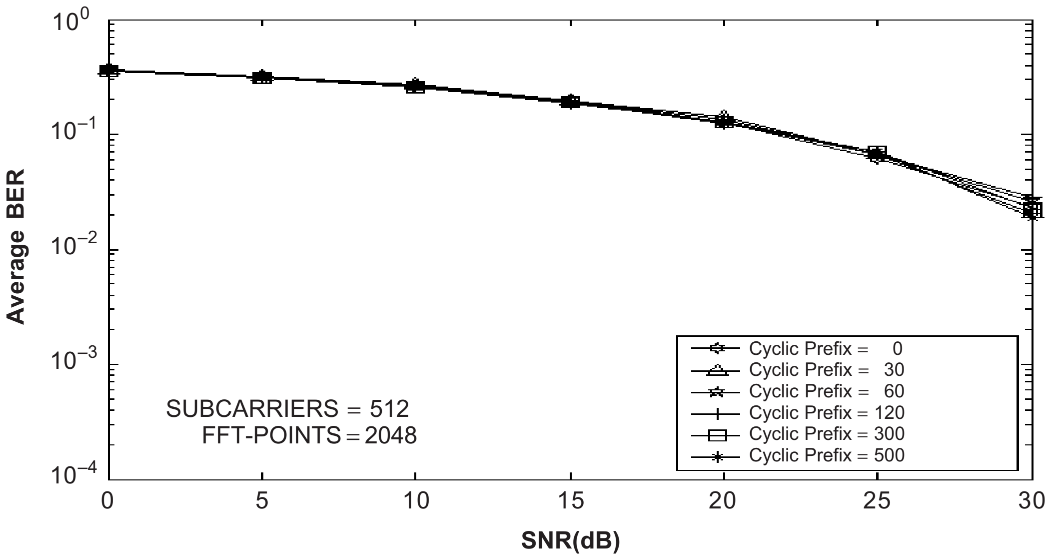

Figure 9 BER versus SNR for 64-QAM over AWGN channel utilizing different length of cyclic prefix

5.0 CONCLUSIONS

From this preliminary investigation, it can be seen that OFDM with QAM modulation can be further improved in terms of BER performance. Results show that without correction mechanism like forward error correction incorporated in the system, only 16 and lower level QAM are attractive to achieve a bit error rate (BER) of 10^{-3} with signal to noise ratio of at least 20 dB. The 256-QAM system, however, will require at

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least a SNR of 50 dB to achieve similar outcome. The study also shows that the performance of the system is not affected by the number of fft-points used, or the length of cyclic prefix inserted to the transmitted signal. However, the number of subcarriers does depend on the level of QAM used at a given SNR value. Further works is currently ongoing to determine the best forward error correction to be utilized to mitigate some of the degrading effects in the system, as well as incorporating adaptive bit loading to ensure efficient bandwidth utilization.

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