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EFFECT OF SUBCARRIERS ON ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING AT DIFFERENT MOBILE SPEEDS

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ABSTRACT

With recent increase in the demand for mobile communication services, future generations of mobile systems are expected to provide very high data rate transmissions as well as improved quality of service to users within commercial feasibility so as to avoid poor reception which the users are experiencing nowadays. OFDM which is a form of multicarrier transmission is a promising technique capable of providing quality of service at high data rates. In this paper, the OFDM system was developed for orthogonal 32, 64, and 128 subcarriers at different mobile speeds of 30km/h, 60km/h and 120km/h over frequency selective multipath channel. The developed model was simulated using MATLAB application package. OFDM-4QAM modulation format was employed to provide the parallel transmission and the received signal was compared with the transmitted signal to analyze the bit error rate performance of the OFDM system. The results obtained showed that as the number of subcarriers increased from 32, through 64 to 128, the BER increased accordingly for all the mobile speeds considered and the effect is more noticeable at high signal-to-noise ratio. The increase in bit error rate indicates performance degradation. From the results, OFDM system is prone to more CFO as the number of subcarriers is increased due to increase in the complexity of FFT.

Keywords: *Orthogonal frequency division multiplexing (OFDM), subcarriers, data rate, Fast Fourier Transform (FFT), carrier frequency offsets (CFO)*

1. INTRODUCTION

In mobile communications the need for high speed data transmission has increased with the rapid growth of digital communications in recent years. However, these systems suffer from multipath propagation effects such as signal fading, Doppler spread and delay spread [11], [7], [9], [2]. These effects combine to cause smearing together of successive symbols, called intersymbol interference (ISI) distortion, at high speed mobile data transmissions. This problem causes the received signal to be unintelligible as a result of distorted transmitted signal. Many methods have been proposed to combat the multipath effects in mobile communication at high data rate despite the harsh condition of the radio environment due to the many reflected waves and other effects. Adaptive equalization at the receiver is proposed by some literatures as a solution, but there are practical difficulties in operating this equalization in real-time at several Mbps with compact, low-cost hardware. Diversity technique is also inefficient at high bit rates.

A promising strategy that eliminates the need for complex equalizers and still meets high data rate is orthogonal frequency division multiplexing (OFDM) – a multiple carrier modulation scheme. Single-carrier techniques are vulnerable to fading and multipath propagation, especially in the case of very high data rates. OFDM transforms a frequency-selective wideband channel into a group of non-selective narrowband channels, which makes it robust against large delay spreads by preserving orthogonality in the frequency domain [3], [5], [8]. The idea of using a Discrete Fourier Transform (DFT) for the generation and reception of OFDM signals eliminates the requirement of banks of analog subcarrier oscillators [10] in the early design.

The recent developments in technology have lowered the cost of the signal processing that is needed to implement OFDM system. As a result of the introduction of cyclic redundancy at the transmitter, the systems complexity is reduced to only Fast Fourier Transform (FFT) processing and one-tap scalar equalization at the receiver [12], [4]. The total data rate to be sent in the channel is divided among the various subcarriers and each one is modulated by a low data rate stream. This is achieved by making all subcarriers orthogonal to one another, preventing intercarrier interference (ICI) between the closely spaced carriers. If there is a loss of orthogonality between the subcarriers, ICI occurs between the closely spaced subcarriers. However, OFDM is sensitive to frequency errors [6], [1].

In this paper, the effect of increasing the subcarriers was investigated with data rate of 1 Mbps transmitted over the frequency selective mobile multipath channel at different mobile speeds. The OFDM-4QAM signalling scheme which provides way of parallel transmission are compared to analyze the BER performance of the designed OFDM system. The results obtained showed that as the number of subcarriers increases, the BER also increases accordingly, which indicates poor performance.

2. MATERIALS AND METHODS

2.1 System Model

In this paper, the OFDM system model consists of the transmitter, the frequency-selective mobile multipath channel and the receiver. The transmitter consists of signal mapper, serial-to-parallel converter, Inverse Fast Fourier Transform (IFFT), cyclic prefix and parallel-to-serial converter. The binary streams of data at 1 Mbps are mapped using 4-QAM to form the data symbols. Then a serial-to-parallel converter makes a group of 32, 64 or 128 subcarriers ready for processing by IFFT of size 64, and the data on the subcarriers are then converted to time domain. Then the cyclic prefix of 16 is inserted. The insertion of the cyclic prefix (guard interval) before transmission allows for the removal of ISI. Then the parallel-to-serial converter converts the data streams to a stream suitable for transmission over the frequency selective mobile multipath channel. The receiver consists of serial to parallel converter, cyclic prefix removal, FFT, channel estimation and data detecting technique, parallel-to-serial converter and signal demapper. The receiver ignores the part of the output signal containing the cyclic prefix. The FFT converts the time domain back to frequency domain and single-tap equalization is performed on the received signal restored from FFT. Then the parallel-to-serial converter converts the parallel stream to a serial form, which is demapped using 4-QAM demapper to obtain the received binary signal. The received binary signal was compared with the input binary signal to determine the erroneous bits.

From the system model presented in Figure 1, the number of subcarriers is denoted by N. For each of the OFDM symbols, the modulated data sequence is denoted as s(0), s(1), …, s(N-1). After the IFFT, the time-domain signal can be expressed by [12]:

$$y(n) = \frac{1}{N}\sum_{k=0}^{N-1} S(k)e^{j2\pi kn/N} \qquad (1)$$

where

$n = 0, 1, 2\ldots N-1$
$y(n)$ = OFDM signal
$S(k)$ = OFDM symbols

The channel impulse response of a multipath fading channel is assumed to be modeled as a finite impulse response (FIR) filter with taps h(n), n = 0, 1, …, N-1. The maximum delay is assumed to be L with $L \le N$. That is, h(n) = 0 for n = L, L+1,…, N-1. The frequency domain channel impulse response H(k) is

$$H(k) = \sum_{n=0}^{N-1} h(n)e^{-j2\pi kn/N} \qquad (2)$$

where k = 0,1,…,N-1
Then, the received signal $r(n)$, the output of the FFT processor, becomes

$$R(k) = \sum_{n=0}^{N-1} r(n)e^{-j2\pi kn/N}$$

$$= H(k)S(k) + N(k)\text{, k=0, 1,…, N-1} \qquad (3)$$

where $N(k)$ represents independently identically distributed (i.i.d) complex Gaussian noise components with zero mean and unit variance. Equation (3) shows that each OFDM subcarrier undergoes a flat fading channel denoted by $H(k)$ but the distribution is Rayleigh. The spacing between the subcarriers, related by the factor 1/NT, reduces as N increases. T is the symbol rate.

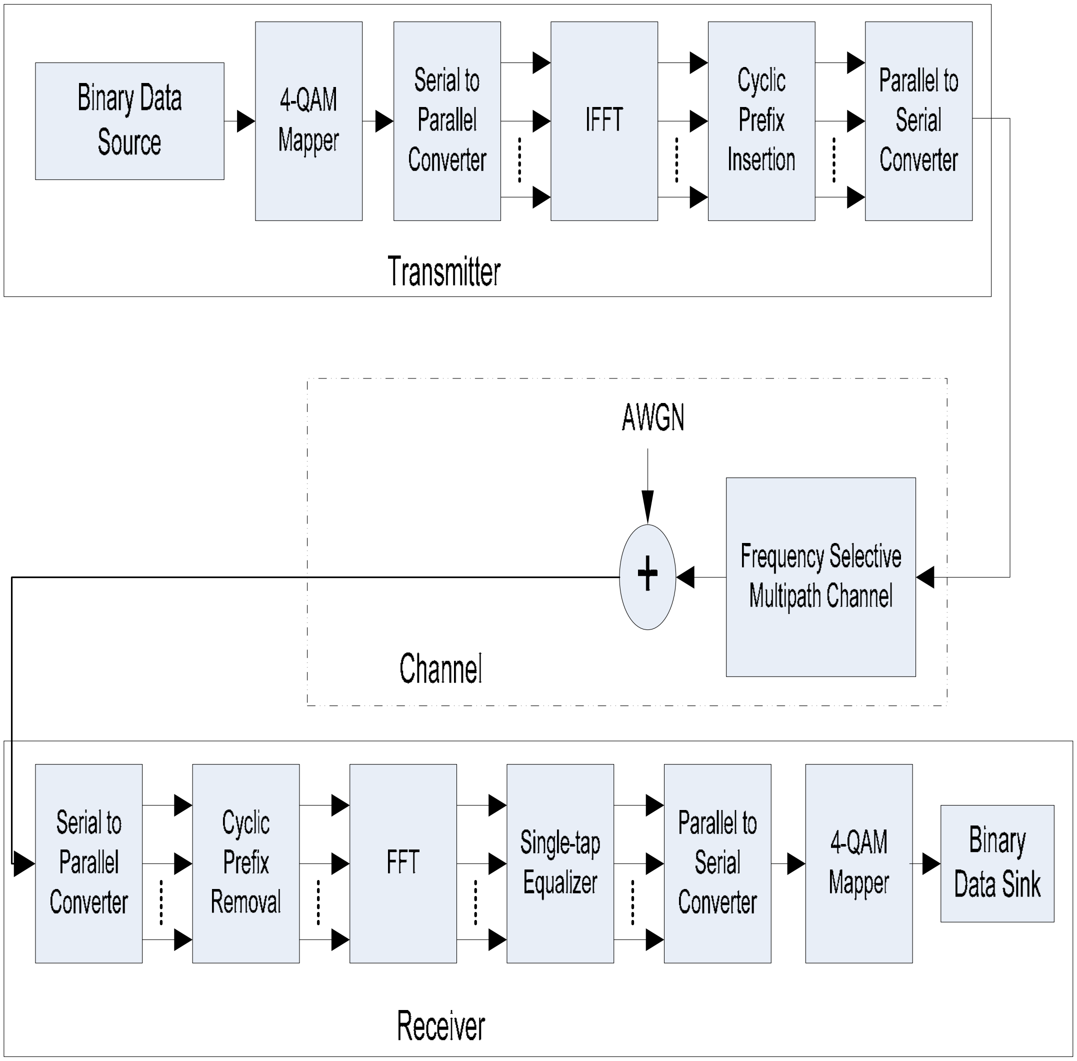

Figure 1: The OFDM System Simulation Model.

2.2 Multipath Fading

When a signal is transmitted over a mobile channel, in most applications, there is no line of sight (NLOS) or specular component between the transmitter and receiver [9], [11]. So the signal arrives at the receiver through many paths due to obstructions which reflect, refract and diffract the signal. The randomly distributed amplitudes, phases and arrival angles of these multipaths may add up constructively to produce a strong signal or destructively to produce a weak signal.

The multipath propagation effects are signal fading, Doppler spread and delay spread, which cause the transmitted signal to undergo frequency- selective fading or flat fading. The Doppler spread causes the channel to vary and determines whether the channel is a slow or fast fading type.

2.3 Delay spread

Delay spread is the spread of the duration of the received signal with respect to the transmitted signal. This is due to different delays associated with the propagation paths [11]. The average delay $\bar{\tau}$ is given by [13]:

$$\bar{\tau} = \frac{\sum_{i=0}^{L-1} |h_i|^2 \tau_i}{\sum_{i=0}^{L-1} |h_i|^2} \quad (4)$$

$$= \frac{\sum_{i=0}^{L-1} P(\tau_i)\tau_i}{\sum_{i=0}^{L-1} P(\tau_i)} \quad (5)$$

where $P(\tau_i)$ = absolute power delay profile and $P(\tau_i) = |h_i|^2$

Then the rms delay spread is defined as

$$\tau_{rms} = \sqrt{\overline{\tau^2} - (\bar{\tau})^2} \quad (6)$$

$$\overline{\tau^2} = \frac{\sum_{i=0}^{L-1} |h_i|^2 \tau_i^2}{\sum_{i=0}^{L-1} |h_i|^2} \quad (7)$$

$$= \frac{\sum_{i=0}^{L-1} P(\tau_i)\tau_i^2}{\sum_{i=0}^{L-1} P(\tau_i)} \quad (8)$$

where $\overline{\tau^2}$ is the second moment for a given power delay profile $(\bar{\tau})^2$ is the square of the mean excess delay.

In the frequency domain, the coherence bandwidth B_c is used to characterize the channel. Coherence bandwidth is the frequency range over which the channel behaves in a correlated manner. Then the coherence bandwidth is defined as the bandwidth over which the frequency correlation is above 90%, the coherence bandwidth B_c is given as

$$B_c = \frac{1}{50\tau_{rms}} \quad (9)$$

When the coherence bandwidth B_c is less than the signal bandwidth or when the maximum delay spread exceeds the symbol period, frequency selective fading occurs.

2.4 Doppler Spread

Doppler spread is the spread of the frequency spectrum of the received signal with respect to that of the transmitted signal when there is a relative motion between the transmitter and receiver. This is due to the different angles of arrival associated with the propagation paths. Since the spectrum of the received signal is wider in frequency than that of the transmitted signal, the multipath propagation channel is clearly a time-varying system [11], [7]. The time interval over which the channel behaves in a correlated manner is known as the coherence time T_c. When the coherence time T_c is less than the symbol period T_s, fast fading occurs. If T_c is defined as the time over which the time correlation function of the channel is above 0.5, it is given as

$$T_c = \frac{9}{16\pi f_d} \quad (10)$$

where f_d is the maximum Doppler frequency shift and it is given by [7]:

$$f_d = \frac{v f_c}{c} \quad (11)$$

where

v = speed of the mobile unit (ms^{-1})
f_c = carrier frequency (MHz)
c = speed of light ($3x10^8$ m)

When T_c is less than the symbol period, fast fading occurs.

2.5 Bit Error Rate (BER)

Bit error rate is a key parameter that is used in assessing systems that transmit digital data from one location to another. BER is applicable to radio data links, Ethernet, as well as fibre optic data systems. When data is transmitted over a data link, there is a possibility of errors being introduced into the system. If this is so, the integrity of the system may be compromised. As a result, it is necessary to assess the performance of the system, and BER provides an ideal way in which this can be achieved. BER assesses the full end to end

performance of a system including the transmitter, receiver and the medium between the two.
BER is defined as the rate at which errors occur in a transmission system. In simple form,

$$BER = \frac{\text{number of bits in error}}{\text{total number of bits sent}}$$

BER expression is given by [7] as

$$BER = \int_0^\infty P_b(E/r)P(r)dr \qquad (12)$$

where, $P_b(E/r)$ = the conditional error probability

$P(r)$ = the pdf of the SNR

2.6 Simulation Method

The input data (random binary data) were mapped unto 4-QAM constellation. An FFT-based OFDM multicarrier transmission was carried out using MATLAB application package. Using the system simulation model of Figure 1, mapped and modulated information data of length 10^4 was transmitted using 32, 64 and 128 subcarriers in turn. Each subcarrier was assigned a particular number of bits and the subcarriers were transmitted in parallel. The mobile speed was implemented in the channel by the use of equation (11) and simple ideal channel estimation was assumed. The received bits were compared with the transmitted bits in order to calculate the BER, in terms of percentages, for each signal-to-noise power ratio (E_b/N_o). The simulation was carried out by varying the number of subcarriers and mobile speed parameters and their BER performances at E_b/N_o of 0 to 12 dB were obtained.

The following parameters and system configurations were used:

Modulation: 4-QAM
Data rate: 1 Mbps
Number of subcarriers: 32, 64 and 128
FFT size: 64
OFDM frame size: 80
Guard interval: 16 (that is, FFT size/4) samples
Guard interval type: Cyclic prefix
Model of channel: Jake’s Rayleigh model
Number of paths: 2
Path delay vector: [0.1 6.2]
Carrier frequency: 900 MHz
Mobile speed: 30 km/h, 60 km/h and 120 km/h

3. RESULTS AND DISCUSSION

The effect of the number of subcarriers in the OFDM system was measured in terms of BER with respect to E_b/N_o ratio at a data rate of 1 Mbps. The simulation results are shown in Figures 2 to 4 at different mobile speeds. Figure 2 shows the BER performance of OFDM-4QAM transmission at a mobile speed of 30 km/h. At E_b/N_o of 6 dB, the BER for 32, 64 and 128 subcarriers were 3.8%, 4.4% and 4.9% respectively. This indicates that as the number of subcarriers increases the BER increases. In Figure 3, a mobile speed of 60 km/h was considered and BER of 5.4%, 6% and 6.8% were obtained for 32, 64 and 128 subcarriers respectively. Figure 4 shows the BER performance at a mobile speed of 120 km/h; the BER incurred were 7%, 7.6% and 8.3% for 32, 64 and 128 subcarriers respectively. The trend shown by the results is that there is an increase in BER as the number of subcarriers increase.

Figure 5 shows the performance of OFDM-4QAM for 32 subcarriers at different mobile speeds. Also taking 6 dB as the reference E_b/N_o, the percentage BER obtained at 30 km/h, 60 km/h and 120 km/h were 3.8%, 5.4% and 7% respectively. For 64 subcarriers, the percentage BER at 30 km/h, 60 km/h and 120 km/h were increased to 4.4%, 6% and 7.6% respectively as shown in Figure 6. It was observed in the result for 128 subcarriers, as shown in Figure 7, that mobile speeds of 30 km/h, 60 km/h and 120 km/h gave BER of 4.9%, 6.8% and 8% respectively. Figures 5 to 7 also show that as the mobile speed increases, the BER also increases.

All the results obtained are justifiable because the more the number of subcarriers, the more the complexity of FFT per subcarrier and hence, more carrier frequency offsets (CFO). Consequently, the frequency errors destroy the orthogonality between the subcarriers thereby increasing the ICI which, invariably, increases the signal degradation. Again, when the mobile speed increases, the Doppler frequency shift increases and hence, the number of fade sec^{-1} increases, which indicates more performance degradation. So, the best performance occurred when the minimum number of subcarriers was employed at a mobile of 30 km/h.

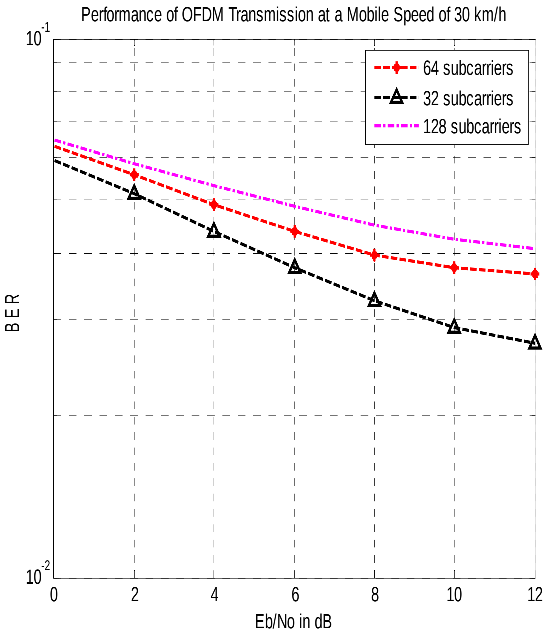

Figure 2: BER performance of the simulated OFDM-4QAM transmission at mobile speed of 30 km/h.

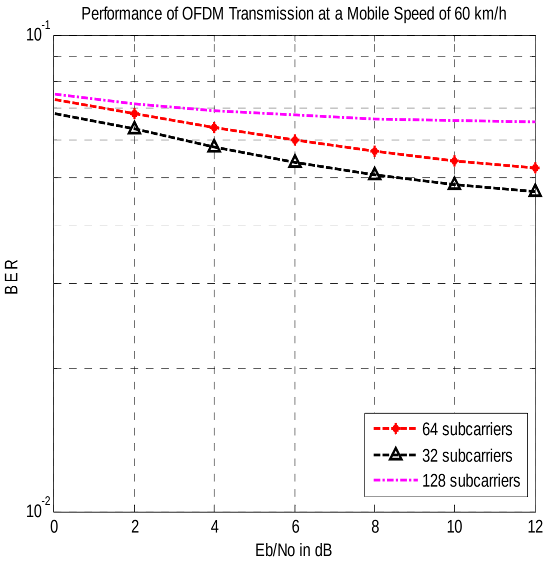

Figure 3: BER performance of the simulated OFDM-4QAM transmission at mobile speed of 60 km/h.

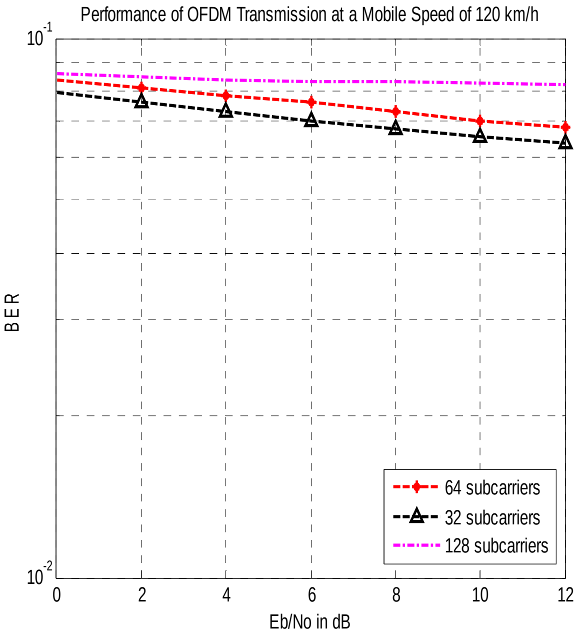

Figure 4: BER performance of the simulated OFDM-4QAM transmission at mobile speed of 120 km/h.

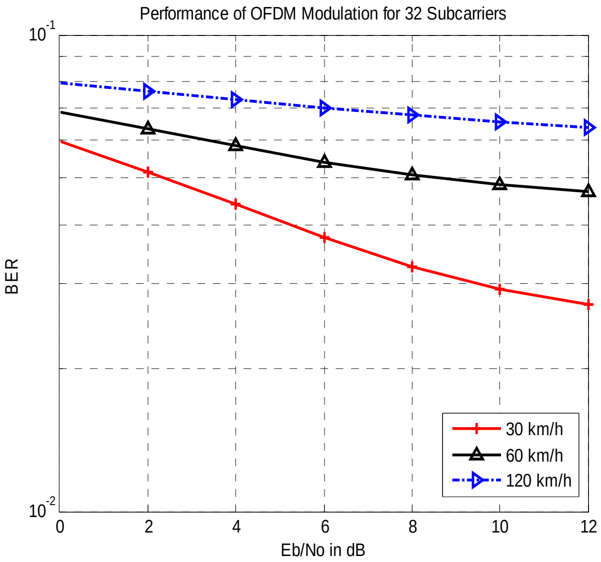

Figure 5: BER performance of the simulated OFDM-4QAM transmission for 32 subcarriers.

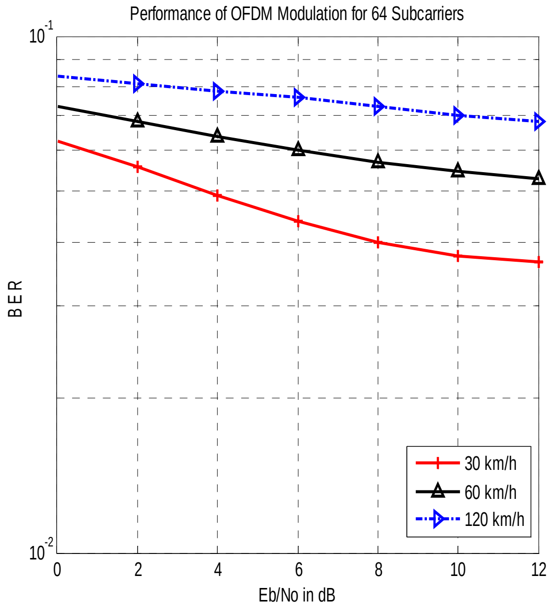

Figure 6: BER performance of the simulated OFDM-4QAM transmission for 64 subcarriers.

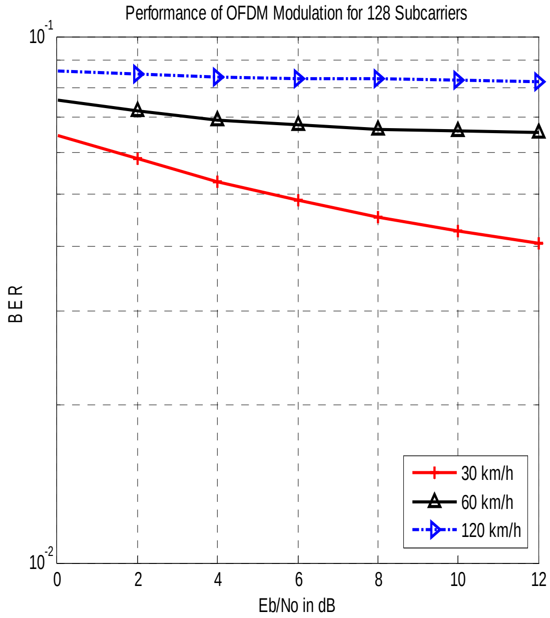

Figure 6: BER performance of the simulated OFDM-4QAM transmission for 128 subcarriers.

4. CONCLUSION

The effect of increasing the number of subcarriers at different mobile speeds in OFDM-4QAM transmission over a frequency selective multipath channel has been investigated. The system model was developed and simulated for 32, 64 and 128 subcarriers at mobile speeds of 30 km/h, 60 km/h and 120 km/h. The input data, random binary bits, were mapped unto 4QAM constellation, processed by OFDM transmitter and propagated over the multipath channel at a data rate of 1 Mbps. The received signal was processed by the OFDM receiver and the resulting received bits were compared with the input binary data to calculate the BER.

The simulation results obtained show that for certain E_b/N_o and multipath effect, the more the number of subcarriers increases, the more the BER also increases. This is caused by intercarrier interference due to loss of carrier orthogonality between the subcarriers, and the loss of orthogonality is as a result of the increase in FFT complexity when the number of subcarriers is increased. Also, there is further degradation in the performance with increase in mobile speed as a result of increase in Doppler spread. The best performance was obtained with 32 subcarriers at a mobile speed of 30 km/h while the worst performance occurred with 128 subcarriers at 120 km/h.

The results obtained in this work will serve as a useful reference for mobile wireless communication systems' designers and researchers working on multicarrier systems for high data rate transmissions.

REFERENCES:

[1] A. Dowler and A. Nix, "Performance Evaluation of Channel Estimation Techniques for a Mobile 4G wide area OFDM System", *Proceeding of the IEEE Vehicular Technology Conference*, *Oct. 6-9*, 2003, *IEEE Xplore press*, *USA*, pp. 1214-1218.

[2] N.L. Heung, *Adaptive Diversity Combining, Equalization and Sequence Decoding for Time-Varying Dispersive Channels*. Unpublished Ph.D. Thesis, 1999, University of California, Los Angeles.

[3] N.D. Jigisha and D.D. Upena, "A Comparative Performance Analysis of OFDM using MATLAB and Simulink with M-PSK and M-QAM Mapping", *International Conference on Computation Intelligence and Multimedia Applications*, 2007.

[4] J. Mehul and M.M. Roja, "Comparison of OFDM with CDMA System in Wireless Telecommunication for Multipath Delay Spread", *The First IEEE and IFIP international conference in central Asia,* 2005.

[5] A.M. Mohammed, A.M. Iman, and E.M. Izz, "Performance of Orthogonal Frequency Division Multiplexing under the effect of Wireless Transmission System Drawbacks", *Sudan Engineering Society Journal* vol. 52, no. 49, 2007, pp. 17-26.

[6] G. Orlandos and H.S. Kamath, "BER Calculation using MATLAB Simulation for OFDM Transmission", *Proceeding of the International Multiconference of Engineers and Computer Scientists*, vol. II, IMECS, 2008, pp. 19-21.

[7] T.S. Rappaport, *Wireless Communication Principles and Practice*, 2nd Edition, 2002, Prentice Hall of India Private Limited, New Delhi.

[8] S.S. Riaz-Ahamed, "Performance Analysis of OFDM", *Journal of Theoretical and Applied Information Technology*, 2008, pp. 23-30.

[9] B. Sklar, *Digital Communications, Fundamentals and Applications*, 2nd Edition, 2001, Prentice Hall.

[10] S.B. Weinstein and P.M. Ebert, "Data Transmission by Frequency-Division Multiplexing using Discrete Fourier Transform", *IEEE Transaction on Communications*, vol. 19, no. 5, 1971, pp. 628-634.

[11] L. Yumin, *Adaptive Equalization and Receiver Diversity for Indoor Wireless Data Communication,* Unpublished Ph.D. Thesis, 1997, Stanford University.

[12] D. Zheng, C. Julian, and C.B. Norman. "Accurate Error-Rate Performance Analysis of OFDM on Frequency Selective Nakagami-m Fading Channel", *IEEE Transaction on Communications*, vol. 54, no.2, 2006, pp. 319-328.

[13] B.K. Zulkeflee and J.T. Haitham. "Performance of Orthogonal Frequency Division Multiplexing System Based on Mobile Velocity and Subcarrier", *Journal of Computer Science*, vol. 2, 2010, pp. 194-198.

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