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Performance Analysis of Multiuser MC-CDMA System for Nakagami-m, Rayleigh and Rician Fading Channel Using a New Set of Spreading Codes

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***Abstract*— The technique of multi-carrier code division multiple access (MC-CDMA) incorporates orthogonal frequency division multiplexing (OFDM) and code division multiple access (CDMA). In 4G systems, the Spread Spectrum technique is used, and MC-CDMA is one of those techniques. Fading channel degrades in data or signal transmission is still a research problem for an effective digital communication device in the mobile radio area. Spreading codes can have as low a cross-correlation value as possible to reduce co-channel and adjacent channel interference. This paper will represent the investigation of bit error rate (BER) and signal to noise ratio (SNR) analysis for multi-user MC-CDMA system using Walsh, PN, and Gold codes as spreading codes. Nakagami-m, Rayleigh, and Rician fading channels are considered transmission channels. We perform all the simulations using MATLAB tools. The performance analysis of BER and SNR are compared based on the code length and number of users. The simulation result provides better performance for all the fading channels when Walsh code is used as spreading code. However, if we consider both SNR and BER, the Nakagami-m channel shows better performance than Rayleigh and Rician fading channels.**

Keywords- MC-CDMA, OFDM, Nakagami-m, Rayleigh, Rician, BER and SNR.

I. INTRODUCTION

Wireless communication is the fastest growing areas in communication engineering. MCCDMA is one ideal alternative for next generation wireless networking systems to achieve fast data rates [1]. It has the benefit of being resistant to frequency-selective fading, narrowband distortion, and inter-Symbol interference (ISI). Each data symbol in the MCCDMA scheme is distributed in the frequency domain [2] and multiplied using spreading sequences. The spreading sequences that are popularly used such as Walsh Codes, Gold Codes and PN sequences. The popularity of these codes stems from the simplicity of which they can be implemented. Walsh codes are ideal for synchronous multi-user interactions because they have a strong auto correlation and low cross correlation. PN sequences have a low correlation property and are statistically random. These sequences are widely used in communication and cryptography. Asynchronous communications prefer gold codes because they are almost orthogonal. Fading is an essential feature of the transmission route between the transmitter and the receiver As a result, various channel fading models (e.g., Rayleigh, Rician, and Nakagami-m) have been developed to aid in the estimation of transmitter-to-receiver channel response. Recently, researchers are attempting to combine the spreading codes with different fading channels. For Rayleigh and Gaussian channel, Walsh and PN codes are implemented the characteristics of multiuser MC-CDMA. After that, increasing number of spreading codes are used with Rayleigh and Additive White Gaussian Noise (AWGN) channel. By changing SNR values characteristics of different fading channels with Gold codes are developed. Some extended features are added like bit error rate performance (BER), modulation techniques and probability density function for different fading channels with single spreading code. In this paper, a new combination of different fading channels and different spreading codes for multiuser MC-CDMA systems is proposed for three fading channels. We consider BER vs SNR characteristics for the performance analyzing. At the same time, we sent more data to the system by increasing the number of users. The next sections of the paper deal with related and proposed work, fading channels, spreading codes and performance analysis of the system.

The rest of the paper is structured like: In section-2 previous related works are being reviewed, Section-3 presents the short description of underwater MAC protocols such as: CW-MAC, RC-MAC, and UW-ALOHA. Research methodology of the paper is discussed in section-4, Section-5 displays the UWSN factors, metrics of interest, and simulation parameters. Section-6 shows the results comparison and performance evaluation. In the end, Section-7 describes the future work & conclusion of the paper.

II. RELATED WORK

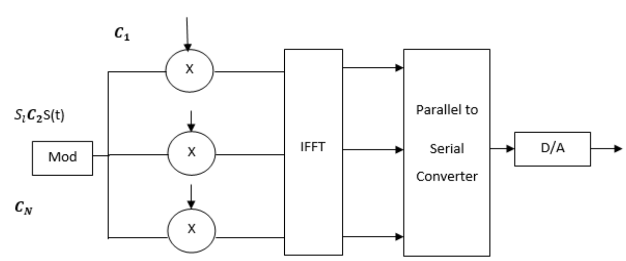
A significant amount of work has been done in the field of multiuser MC-CDMA transmission technique in wireless communication. Maximum works in this area doesn't show the complete combination of different spreading codes with the simulation of different fading channels. The largest portion of papers are deals with less users and insufficient spreading codes with fading channels. This proposed work, three particular spreading codes has been simulated for Additive White Gaussian Noise (AWGN) channel and Rayleigh fading channel. Performances of three different fading channels (i.e., Rayleigh, Rician and Nakagami-m) are jointly simulated with separately three above spreading codes. As well as three spreading codes are also simulated over three separately different above fading channels for increasing number of users.

Shinsuke Hara et al. proposed an overview of MC-CDMA system in 1997. Madhvi et al. proposed performance analysis of MC-CDMA system in later. The performance of Multi-Code CDMA using different code sets in AWGN channels was developed by Sadek Ali et al. [3]. Using those spreading codes, performance analysis of different fading channels was also calculated. Researchers used these spreading codes techniques with different strategies in the field of MC-CDMA transmission systems. Bogucka [4] was trying to develop effectiveness and performance analysis of spreading codes on MC-CDMA. New binary user codes for DS-CDMA communication over Rayleigh fading channel was also proposed [5]. Single spreading code with two different channels [7, 8] (i.e., Walsh and PN code are used with Rayleigh and Gaussian channel) was developed. Bit error rate analysis of MC-CDMA systems overlap- FDE [9] were also proposed by different researchers. An attempt had been taken to generate spreading sequence for MC-CDMA systems by Popovic' [10] and for DS-CDMA and W-CDMA cellular networks by Dinan et al. [11]. Various spreading sequence have been taken into account, analyzed and compared in respect to their applications of MC-CDMA. Gold and Kasami codes as spreading sequences were developed by Turkmani et al. [13]. A proposed orthogonal code was developed with other spreading codes [14]. Using MATLAB, simulation of flat fading channel was shown by Gayatri et al. [15]. In recent time, theoretical and empirical values of BER of Rayleigh and Rician channel at different values of SNR were calculated [16]. Several modulation techniques were proposed in MC-CDMA systems such as BPSK, QPSK, PSK, ASK etc. [17, 18].

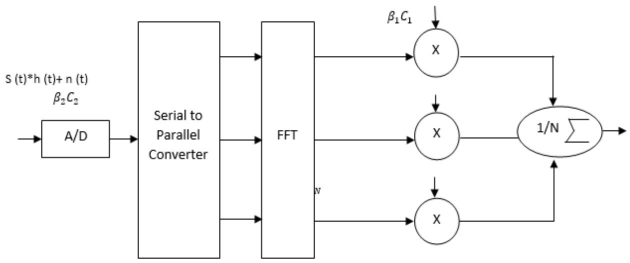
In this work, it has been proposed that simulation results have increasing number of users and comparatively lower BER and higher SNR. It has been observed that the BER and SNR is comparatively lower in Rician fading channel. For the Rayleigh fading channel, BER is increased with SNR. Nakagami-m fading channel gives the average value of BER and SNR corresponding to the Rician and Rayleigh fading channel. Considering BER Rician fading is better to use but considering both SNR and BER, Nakagami-m fading channel is better to use. If the number of users will be increased, the characteristics of proposed work provide better performance than references. For every fading channel Walsh code gives the lower bit error rate compared to PN and Gold codes whereas number of users is greater than references. But in practical applications spreading codes should also be based on the different requirements. Significantly better BER performance to the original MC-CDMA system has obtained and supports more users for the same BER in different fading channels. Hence, this proposed system is more efficient and effective for MC-CDMA transmission technique than the provided references.

III. Overview of MC-CDMA Multiple Access

Multicarrier CDMA (MC-CDMA) blends the benefits of OFDM and CDMA [7]. It works well against ISI as well as allowing many users to use the same channel [17]. Figure 1 shows the fundamental block diagram for a baseband single-user MCCDMA scheme [9, 17]. The data symbol S_l is broadcast through N subchannel. On the N^{th} subchannel S_l is multiplied by the N^{th} chip C_N of a spreading sequence S_C (t), where C_N=±1, the frequency domain is used instead of the time domain for the spreading chain [2]. The frequency spread data ($S_l C_1 S_l C_2 S_l C_3 \dots\dots\dots S_l C_N$) is then multicarrier modulated as normal, the parallel sequence is transmitted via an IFFT, parallel to serial converter [17], and D/A converted to generate the modulated signals *(t)*. Assume that MC-CDMA signal is broadcast over a frequency-selective channel [7] having a channel gain of $\propto_N$ on the N^{th} subchannel and AWGN noise *n(t)*. the receiver reverses the transmitter's operations, transmitting the received signal into an A/D converter, a serial-to-parallel converter, and an FFT [2, 8]. N^{th} subchannel is compounded by the N^{th} chip c_N and a weighting factor β_N, then these terms are added combinedly for the overall symbol calculation $\hat{S}_l$ [2, 8,17]. Each user modulates the signal in a MCCDMA system as seen in figure 1 but with a different spreading code $s_{ck}(t)$ [9, 17], So for this system, user-1 would use the spreading code $s_{c1}(t)$[1, 20] with chips $(c_1^1, \dots\dots, c_N^1)$ that results the transmitted signal $S_1(t)$ and user-2 would use the spreading code $s_{c2}(t)$ with chips $(c_1^2, \dots\dots, c_N^2)$ resulting in a transmitted signal $S_2(t)$ and for N^{th} user would use the spreading code $s_{cN}(t)$ with chips $(c_1^N, \dots\dots, c_N^N)$ resulting in a transmitted signal $S_N(t)$. As two users communicate at the same time, their signals are combined in the air, as seen in Figure 2, where S_l^1 is the symbol corresponding to user-1 over the l^{th} symbol time and S_l^2 the symbol corresponding to user-2 over this symbol time and similarly the symbol S_l^N for user N .



(a) MC-CDMA system Modulator



(a) MC-CDMA system Demmodulator

Fig.1. MC-CDMA system (a) Modulator (b) Demodulator

Each consumer benefits from the frequency-diversity of spreading through individually fading subchannels. As a result, it outperforms traditional spread spectrum in terms of efficiency [16].

IV. Channel Description in Wireless Communication

Tiny scale fading is the fluctuation in the signal amplitude caused by local multipath propagation. Large-scale fading, on the other hand, is a long-term variation in the mean signal frequency. A running receiver will often encounter several fades in a short period of time due to multipath [6]. As a result, various channel fading models have been developed to aid in the estimation of transmitter-to-receiver channel response [6]. The bit error rate (BER) can be calculated based on a signal-to-noise ratio (SNR), channel bandwidth can be calculated, and finally, the optimal channel model for real-time communication scenarios can be determined [8]. In the following pages, we'll look at a few of the several fading channel models available.

A. Rayleigh Fading Channel

One of the models for calculating the influence of the transmission environment on a radio signal is Rayleigh fading. It also means that there is no Line-of-Sight (LOS) contact between the transmitter and receiver, as well as a multipath propagation environment. The transmitted signal is not always received by the mobile station antenna over LOS [6, 15]. As a consequence of multipath propagation, it absorbs a number of absorbed, diffracted, and scattering waves. As a consequence, the phases become unpredictable, and the obtained power becomes a random variable as well. The transmitted signal with a frequency f_c can trigger the receiver over a number of paths, the j^{th} path with an amplitude A_j, and a phase ϕ_j [15]. If no direct path or line-of-sight (LOS) portion is assumed, the received signal *m (t)* can be expressed as,

$$m(t) = \sum_{j=1}^{N} A_j \cos(f_c + \phi_j) \qquad (1)$$

Where N is the number of paths.

That probability density function (PDF) of Rayleigh fading [6, 15] is used to estimate channel efficiency.,

$$PR(r) = \frac{2r}{\Omega}\left[\exp\left\{-\left(\frac{r}{\Omega}\right)\right\}\right],\ r \geq 0 \qquad (2)$$

Where *R* is a random variable with Rayleigh distribution and Ω is given by,

$$\Omega = E(R^2) \qquad (3)$$

Single parameter Ω characterizes the Rayleigh distribution.

B. Rician Fading Channel

Due to the multipath effect, the signal arriving at the mobile consists of a variety of copies of the initial signal [6]. Rayleigh fading is no longer true in this situation since the signal has a clear direct portion at the receiver. In contrast to Rayleigh, the Rician distribution follows a straight Line-Of-Sight (LOS) direction between the transmitter and the receiver, as well as the multipath waves that arrive at the receiver. The probability distribution function is written as [6, 15],

$$p(r) = \frac{r}{\sigma^2}\exp\left\{-\frac{r^2+A^2}{2\sigma^2}\right\} J_o\left(\frac{rA}{\sigma^2}\right),\ r \geq 0 \qquad (4)$$

Bessel function of the first kind is as [33].

$$(z) = \sum_{n=0}^{\infty} \frac{z^{2n}}{n!n!2^{2n}} J_o,\ \text{for } z >> 1 \qquad (5)$$

C. Nakagami-m Fading

Both Rayleigh and Rician distributions can be defined by the Nakagami distribution [15]. Nakagami was the first to note that the Rayleigh distribution struggled to predict channel activity over long distances and at high frequencies. He also proposed a density function based on a parametric gamma distribution to explain the experimental results [6]. In addition, Nakagami offers the perfect match for data from cell communication channels and other deep space communications [19]. The Nakagami distribution, unlike the Rician distribution, does not presume that the transmitter and receiver are in direct line of sight. To define the experimental data and obtain an estimated distribution, it employs a parametric gamma distribution-based density function [15].the PDF of Nakagami distribution is [22]

$$f(r) = \frac{2m^m r^{m-1}}{\Omega^m}\exp\left\{-\frac{mr^2}{\Omega}\right\},\ m \geq \frac{1}{2};\ r \geq 0 \qquad (6)$$

Where *m* is Nakagami scale parameter (fading parameter). It explains the degree of fading caused by scattering and multipath interference processes in propagation media [6, 15]. When $m \rightarrow \infty$ Nakagami fading channel becomes a non-fading channel and Ω is the average power of multipath scatter field, *Γ (m)* is the gamma function [23]. The parameters m and Ω can be estimated as following:

$$m = \frac{E^2[X^2]}{Var[X]} \qquad (7)$$

and

$$\Omega = E[X^2] \qquad (8)$$

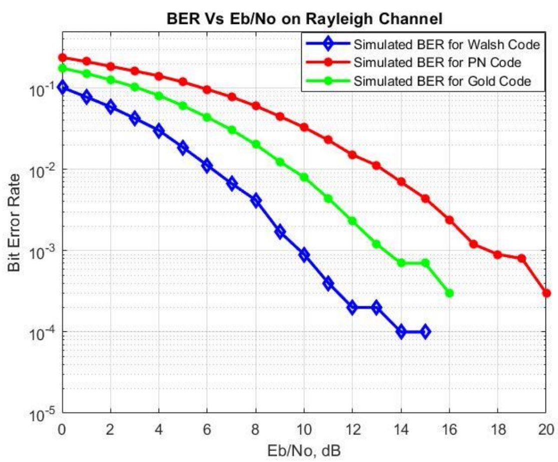
Rayleigh and Rician distribution can be thought as the special cases of Nakagami distribution [21, 22].

V. Experimental Results and Performance Analysis

To find out the result of the proposed system, the default value of Signal-to-Noise Ratio (SNR) is 0dB to 20dB and the number of transmitted bits is 10^4. The modulation technique employed is Binary Phase Shift Keying (BPSK). The channel noise is additive white Gaussian noise (AWGN), and the channel response is created using different distributions as defined previously. For simulation, Rayleigh, Rician, and Nakagami-m fading networks, as well as three spreading codes (Walsh, PN, and Gold) are used. For both fading sources, the Signal-to-Noise Ratio (SNR) is improved linearly. The number of error bits is determined.

A. Analysis of different fading channels performance using Walsh, PN and Gold Codes

Figure 2 shows the effect of bit error rate of Walsh, PN and Gold codes under the Rayleigh fading channel for multiuser MC-CDMA systems.



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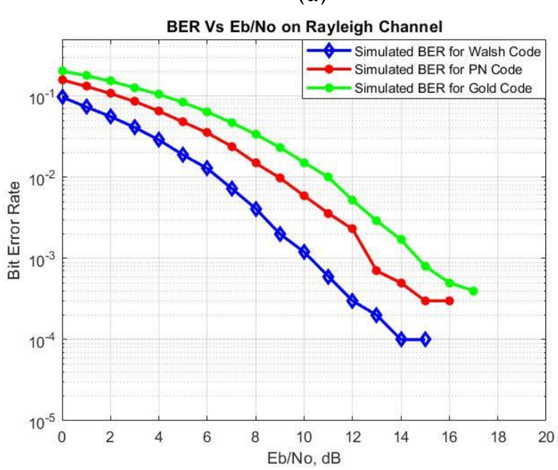

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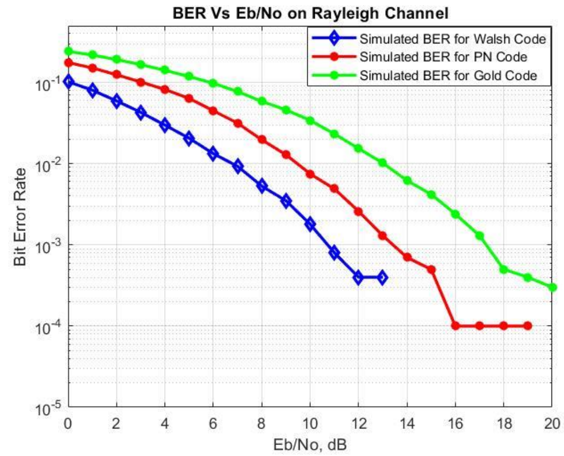
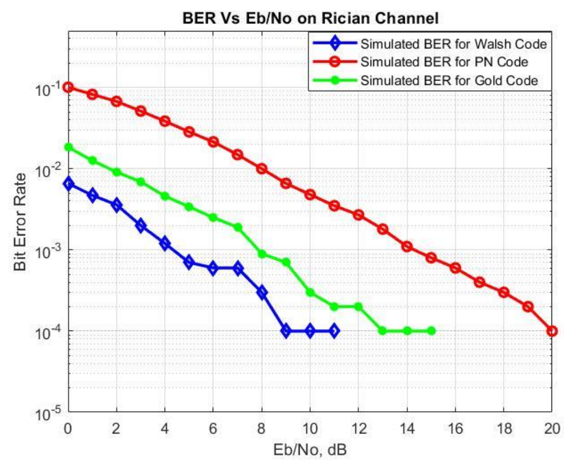


(c)

Fig.2. BER vs. Eb/No on Rayleigh Channel with different spreading codes (a) 8-user (b) 16-user (c) 32-user

The simulation characteristics gives the lower bit error rate for Walsh codes and it omits the output after 15dB for 8 & 16 user (figure a, b) and 13 dB for 32 users (figure c). For PN sequences and Gold codes, channel provides higher SNR value for the same number of users.



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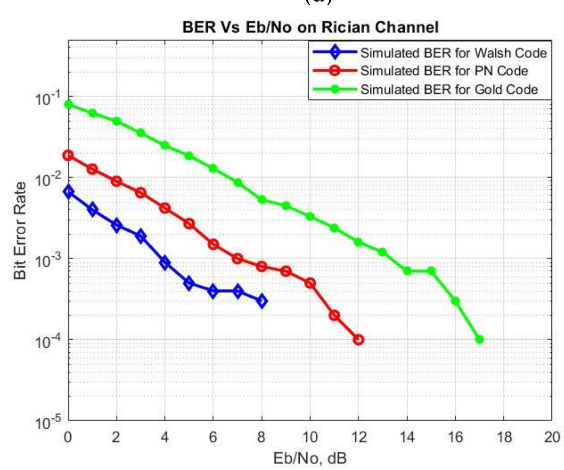

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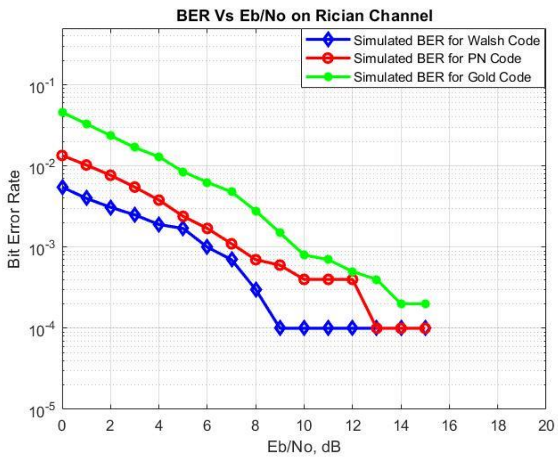

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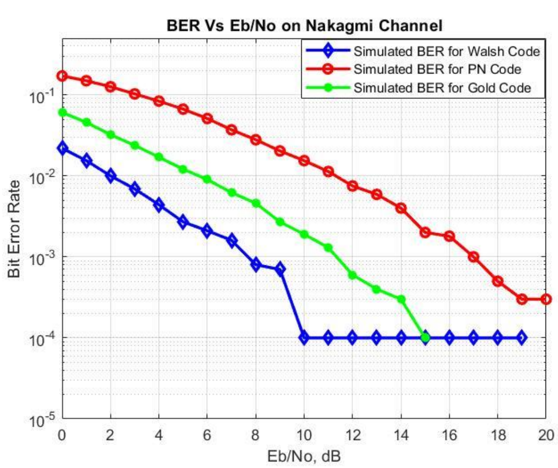
Fig.3. BER vs. Eb/No on Rician Channel with different spreading codes (a) 8-user (b) 16-user (c) 32-user

Figure 3 shows the effect of bit error rate of Walsh, PN and Gold codes under the Rician fading channel for multiuser. The simulation characteristics gives the lower bit error rate for Walsh code and it omits the output after 11dB for 8 user and it increases to 13dB for 32 users. For PN sequences, it omits the fading effect after 12dB for 16 users and 15dB for 32 users. However, bit error effects significantly increase on Gold code for all users.

The effect of bit error rate of Walsh, PN and Gold codes under the Nakagami-m fading channel is shown in figure 4 for multiuser. The simulation characteristics gives the lower bit error rate for Walsh codes and it omits the output after 14dB for 32 users and 16dB for 64 users. For PN sequences, it omits the fading effect after16dBfor 32 users and 20dB for 64 uses. Gold sequences omit the fading effect after 20dB for 32 users and 19dB for 64 users. So, as a spreading code Walsh code provide better performance in channel transmission.



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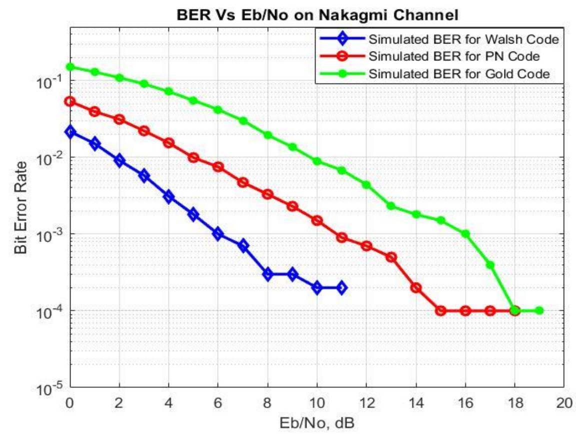

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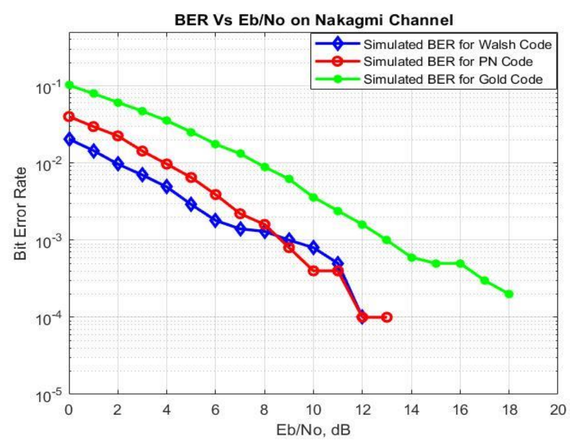
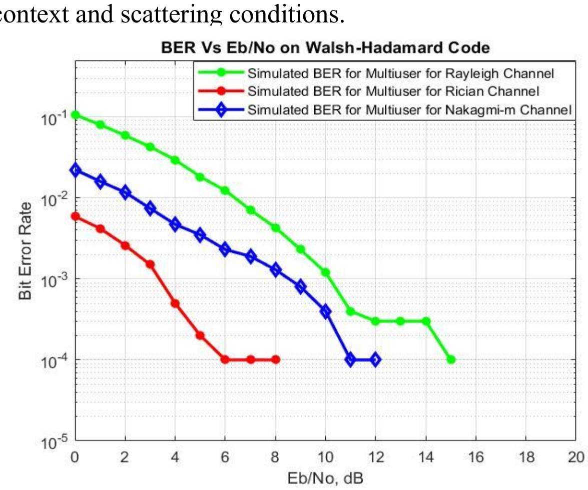


(c)

Fig.4. BER vs. Eb/No on Nakagami-m with different spreading codes (a) 8-user (b) 16-user (c) 32-user

B. Analysis of different spreading codes over Rayleigh, Rician and Nakagami-m fading channel

Figure 5 depicts the effects of Rayleigh, Rician, and Nakagami-m fading channels, where the m component will reflect a variety of different distributions based on the context and scattering conditions.



(a)

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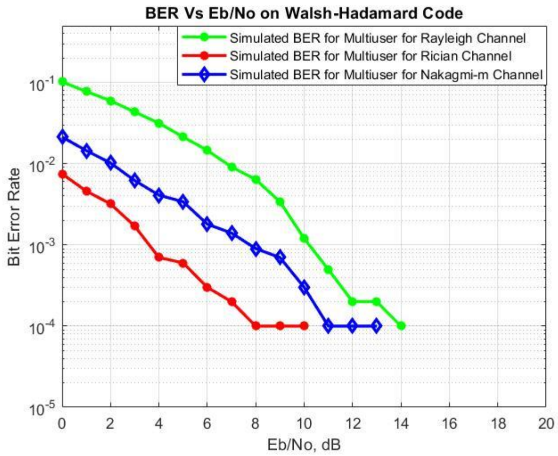

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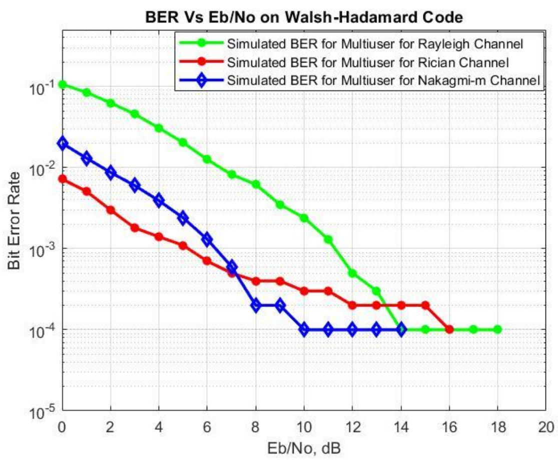
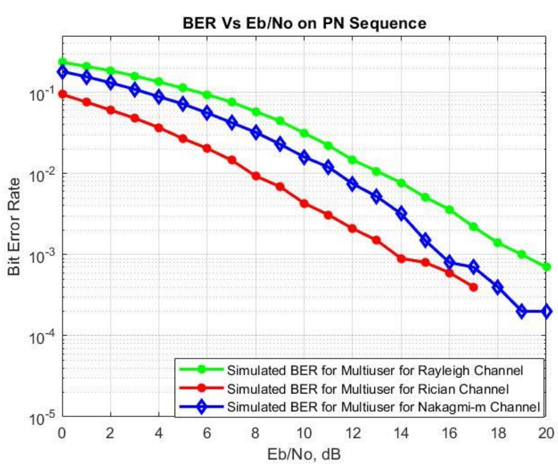


(c)

Fig.5. BER vs. Eb/No for Walsh-Hadamard code with different fading channel (a) 8-user (b) 16-user (c) 32-user

Fading channels on MC-CDMA system having 10^4 bits on the channel. The data were spreaded using 64-bit Walsh codes and 0dB to 20dB SNR.



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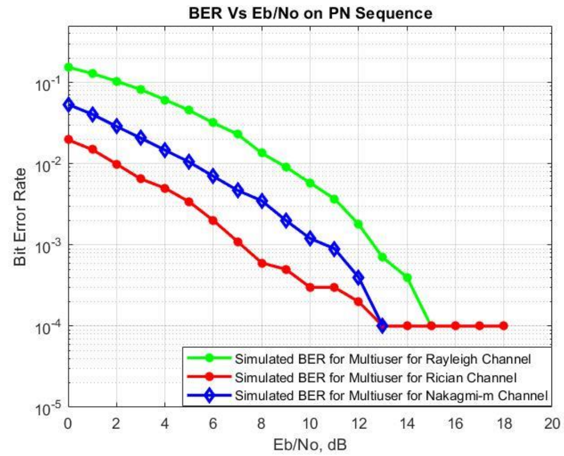

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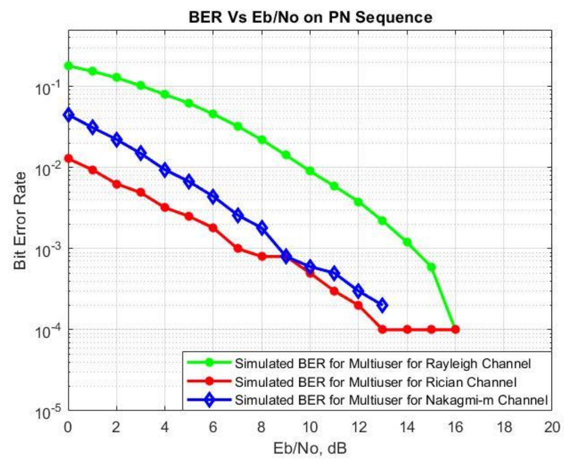

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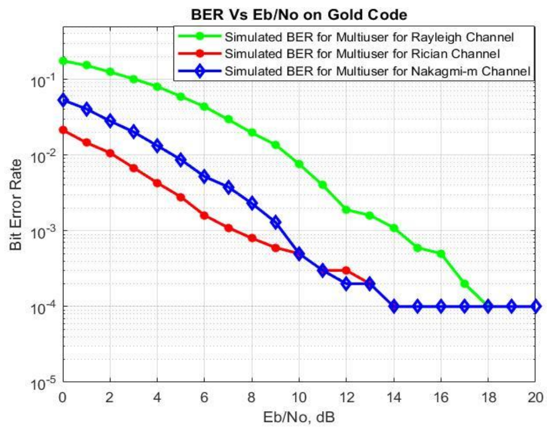
Fig.6. BER vs. Eb/No for PN Sequence with different fading channel (a) 8-user (b) 16-user (c) 32-user

The Rician channel shows the lower bit error rate as well as SNR at the time of transmission. Similarly, the Rayleigh fading channel shows the higher bit error rate and also higher SNR. Nakagami-m channel simulation shows the average bit error rate and SNR value compared to Rician and Rayleigh fading channel.

Figure 6 shows the effect of Rayleigh, Rician and Nakagami-m fading channels using PN sequences. The data were spread using multiple-shift PN sequences and 0dB to 20dB SNR. The Rician channel shows comparatively lower bit error rate and SNR compared to the Rayleigh and Nakagami-m fading channels. However, Rician channel is more feasible to implement if the number user increased.



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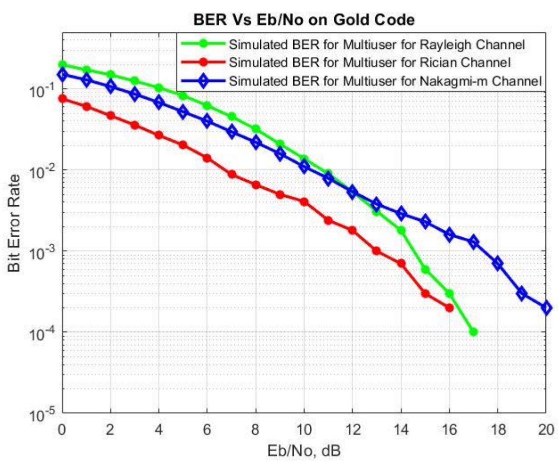

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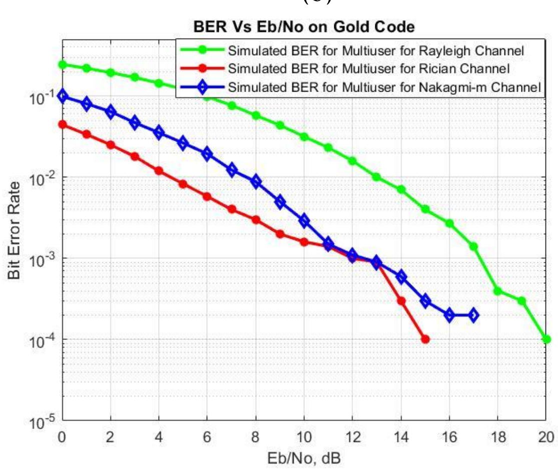

(c)

Fig.7. BER vs. Eb/No for Gold code with different fading channel (a) 8-user (b) 16-user (c) 32-user

From the figure 7, we can observe that if BER is considered for Rician channel, it will always give the lower bit error rate. On the other hand, Rayleigh fading channel will always give the better signal-to noise ratio than Rician and Nakagami-m fading channel if SNR is considered. Nakagami-m fading channel gives the average value of BER and SNR compared to the Rician and Rayleigh fading channel when both BER and SNR is considered, it provides better performance to use.

VI. Conclusion & Future Work

A comparative work has been performed for different fading channels and different spreading codes. In a multi-user setting, the BER outputs of such distributing sequences were also addressed at SNR values ranging from 0dB to 20dB. The experimental results show the better performance for Walsh codes and Rician fading channel in terms of BER. Considering both BER and SNR, the rest of the paper shows that Walsh codes as a spreading code and Nakagami-m channel as a fading channel is better to use. The proposed system has significantly better BER performance and supports more users for the same BER in fading channels. Further research will be aimed at determining the BER performance of the system in fading channel through mathematical analysis and the analysis of the MC-CDMA method in the presence of a nonlinear amplifier with different mapping schemes. Other performance testing criteria for the systems and their behavior through various channels are available. The capacity of the channels can be numerically measured to determine which of the three channels under consideration can better match the data rate for real-time communications.

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