Matlab Simulation Design and performance Comparison of OFDM & FH-OFDM Systems

Ammar Abdul-Hamed Khader
Computer Engineering Dept. / College of Engineering
University of Mosul

Abstract

Single-carrier techniques are vulnerable for fading and multipath propagation. Recently, multicarrier modulation (MCM) or OFDM have received considerable attentions and have made a great deal of progress in world. Also spread spectrum techniques are robust against fading and interference. In this paper a non-coherent FH-OFDM system is proposed to improve the performance of OFDM system in multiuser interference. This system is examined using two different schemes of hopping pattern, namely, Random FH (RA-FH) & Revolver FH (RE-FH). The comparison indicates that RA-FH is more efficient than RE-FH and conventional OFDM for multiuser interference. When compared with previous works that depend on Cluster hopping (CH) Diversity System (DS), the proposed system possesses BER of less than (0.001) for six interferes with high SNR.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Frequency Hopping OFDM (FH-OFDM), Random FH (RA-FH) and Revolver FH (RE-FH).

تصميم و مقارنة أداء منظومتي OFDM & FH-OFDM باستخدام المحاكاة لبرنامج MATLAB

عمار عبد الحميد خضر/ مدرس مساعد
قسم هندسة الحاسوب/ كلية الهندسة / جامعة الموصل

الخلاصة

إن تقنية نظام الحاملة المفردة تكون متحسسة وضعيفة لحالة الخفوت وحالة الإرسال متعدد المسارات. لذا فان الاهتمام العالمي مؤخرا قد اتجه في مجال التضمين المتعدد الحاملات (MCM) أو تقنية الوصول المتعدد للتردد المتعامد (OFDM). ولا يخفى أيضا بان تقنية الطيف المنتشر تعتبر ممانعة للخفوت والتداخل الذي يحصل. في هذا البحث تم اقتراح منظومة FH-OFDM غير المتشاكهة noncoherent لتحسين أداء منظومة OFDM التقليدية تحت ظروف التداخل لعدة مستخدمين. المنظومة المقترحة تم فحصها اعتمادا على أسلوبين مختلفين من نمط توليد القفز الترددي, الأول هو العشوائي (RA-FH) Random FH و الثاني هو الدوار (RE-FH) Revolver FH. لقد أظهرت المقارنة أن RA-FH هو ذا كفاءة أعلى من RE-FH وكذلك OFDM التقليدي عند فحصه بوجود عدد من التداخلات. وكذلك عند مقارنة النظام المقترح مع أعمال سابقة اعتمدت أنماط أخرى من القفز الترددي مثل نظام التنوع Diversity System (DS) و كذلك القفز العنقودي Cluster hopping (CH), كانت نسبة الخطأ في المعلومات الواصلة أقل من (0.001) لحالة ستة تداخلات عند قيم SNR عالية.

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1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a special form of multicarrier modulation, where a single data stream is transmitted over a number of lower rate subcarriers. It is worth mentioning here that OFDM can be seen as either a modulation technique or a multiplexing technique. One of the main reasons to use OFDM is to increase the robustness against frequency selective fading and narrowband interference. In a single carrier system, a single fade or interferer can cause the entire link to fail, but in a multicarrier system, only a small percentage of subcarriers will be affected. Error correction coding can then be used to correct the few erroneous subcarriers [1,2].

MCM is the principle of transmitting data by dividing input stream into several symbol streams, each of which has a much lower symbol rate, and by using these substreams to modulate several subcarriers. Figure (1) compares a single carrier modulation (SCM) and an MCM. Here, B_{SCM} and B_{MCM} denote the bandwidths of transmitted SCM and MCM signals, respectively. For MCM, f_k , $F_k(f;t)$, N_{SC} and Δf denote the frequency of the kth subcarrier, the frequency spectrum of pulse waveform of the kth subcarrier, the total number of subcarriers, and subcarrier separation, respectively. The frequency spectrum of the MCM signal is written as [3]:

$$S_{MCM}(f;t) = \sum_{k=1}^{N_{SC}} F_k(f;t) \qquad (1)$$

A basic multi-carrier transmitter diagram is shown in Fig. (2). Although, the principles are known since early sixties, multi-carrier modulation techniques, especially OFDM, gained more attention in the last ten years due to the increased power of digital signal processors.

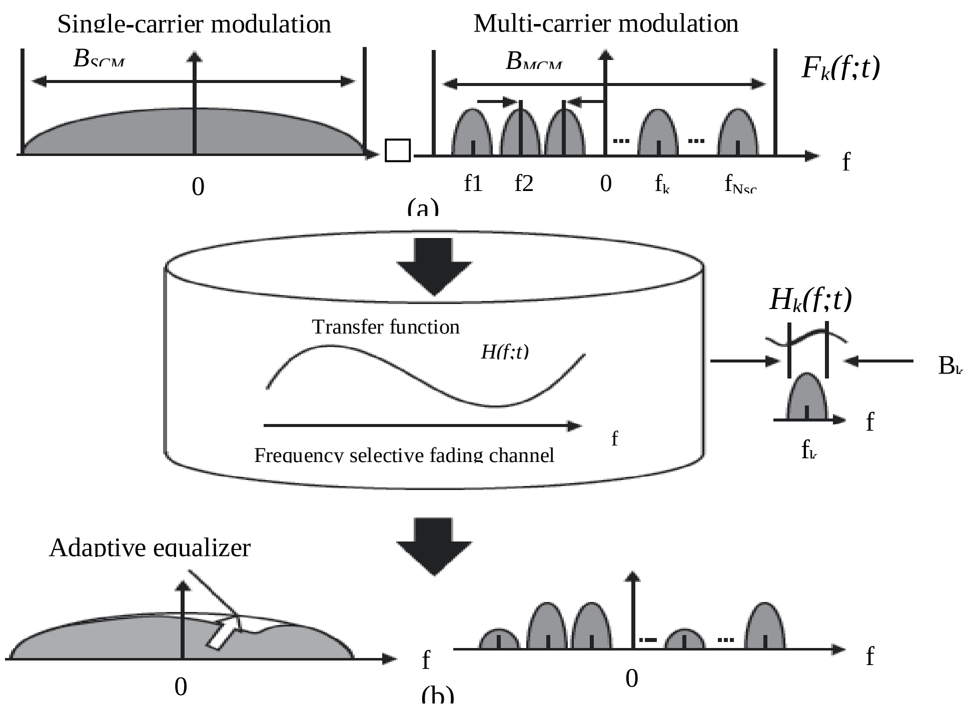

Figure (1): Comparison of SCM and MCM: (a) frequency spectra of transmitted signals; and (b) frequency spectra of received signals.

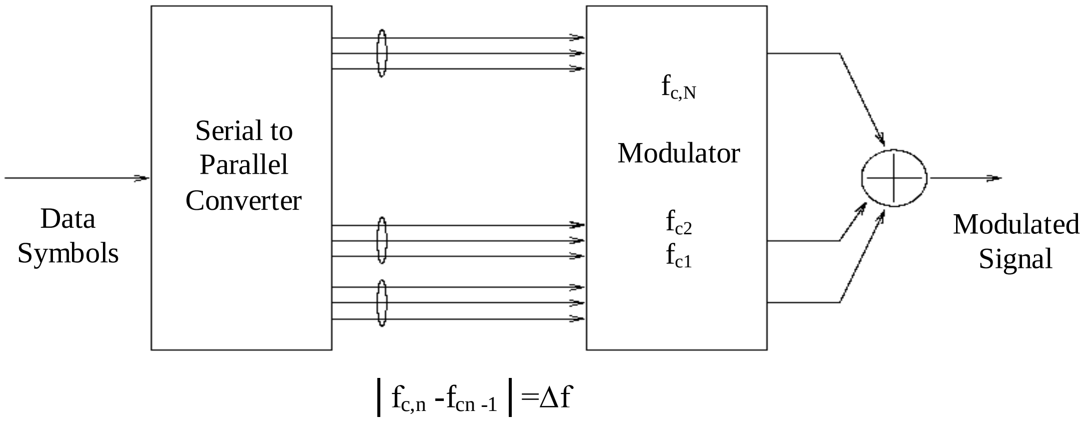

Figure (2): Basic muli-carrier transmitter

OFDM is a technique that can overcome many problems that arise with high bit rate communication, the biggest of which is the time dispersion. In OFDM, the carrier frequencies are chosen in such a way that there is no influence of other carriers in the detection of the information in a particular carrier when the orthogonality of the carriers are maintained. The data bearing symbol stream is split into several lower rate streams and these streams are transmitted on different carriers as in Fig. (3) [4].

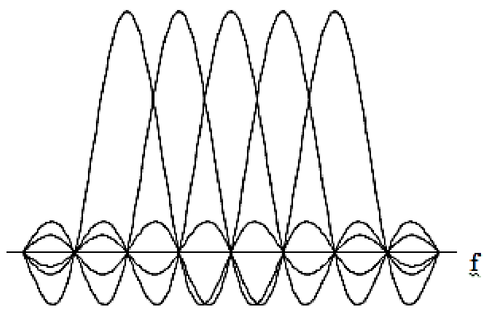

Figure (3): Basic concept for MC- OFDM spectrum

Since this increases the symbol period by the number of non-overlapping carriers (sub-carriers), multipath echoes will affect only a small portion of the neighboring symbols. Remaining ISI can be removed by cyclically extending the OFDM symbol. The length of the cyclic extension should be at least as long as the maximum excess delay of the channel. By this way, OFDM reduces the effect of multipath channels encountered with high data rates, and avoids the usage of complex equalizers. OFDM is used as the modulation method for Digital Audio Broadcasting (DAB) and Terrestrial Digital Video Broadcasting (DVB-T) in Europe, and in Asymmetric Digital Subscriber Line (ADSL). Wireless Local Area Networks (WLANs) use OFDM as their physical layer transmission technique [5].

The multiple access schemes for systems beyond IMT-2000 must be highly flexible and efficient in order to support multimedia services with various Qualities of Service (QoS) requirements. Various methods of combining OFDM with multiple access concepts such as code-division multiple access (CDMA) have been investigated; among them, multi-carrier CDMA (MC-CDMA) and frequency hopping OFDM (FH-OFDM) are two most promising candidates for 4th-generation mobile communications. FH-OFDM also provides the multiple access bases for both the IEEE802.11a local area network (LAN) standard and the IEEE 802.16a metropolitan area network (MAN) standard. Allowing hopping with different patterns for users actually transforms the OFDMA system in a Frequency Hopping CDMA system. This has the benefit of increased frequency diversity, because each user uses all of the available bandwidth as well as the interference averaging benefit that is common to all CDMA variants. Because the interference and fading characteristics change for every hop, the system performance depends on the average received signal power and interference, rather than on the worst case fading and interference power [6]. In this paper, besides the above mentioned on OFDM and FH-OFDM principles and there implementations challenges, section 2 introduces some principles of frequency hopping multiple access (FHMA) briefly. In section 3, FH-OFDM technique is explained briefly with its advantageous performance compared to other multiple access schemes. Sections 4 illustrates the design of a simplified simulink diagram of an conventional OFDM system. In section 5 a results of many interferers on OFDM system are tabulated. Section 6 illustrate the design of a proposed FH-OFDM system. Section 7 elucidate two different methods for generating hopping pattern Random, that is FH and Revolver FH. Section 8 tabulate the results of many interferes in FH-OFDM system. Finally, section 9 concludes the paper.

2. Frequency Hopping Multiple Access (FHMA)

In frequency hopping multiple access (FHMA) systems, the total spread spectrum bandwidth (BW_{SS}) is divided into q sub-bands called frequency slots, with one carrier frequency available in each of these slots. The bandwidth of each sub-band (BW_{slot}) equals the bandwidth of the modulated signal. Due to the difficulty of maintaining phase coherence in FH networks, noncoherent M-ary frequency shift keying (NCMFSK) is the most common modulation scheme used. The main disadvantage of MFSK is its poor bandwidth efficiency that leads to wide slot BW and small q. This problem becomes more severe when error control coding is used. For a constant bit rate, coding requires higher values of M. In MFSK schemes, the slot BW increases exponentially when the number of bits per symbol (k) increases linearly. The minimum tone spacing required for noncoherently detected orthogonal signals is 1/ T_s, where T_s is the symbol duration. For $1/T_s$ tone spacing between the MFSK frequencies, $BW_{slot} = (2^k - 1)R_s$, where $R_s = R_b /k$ and R_b is the bit rate as shown in Fig (4) [7].

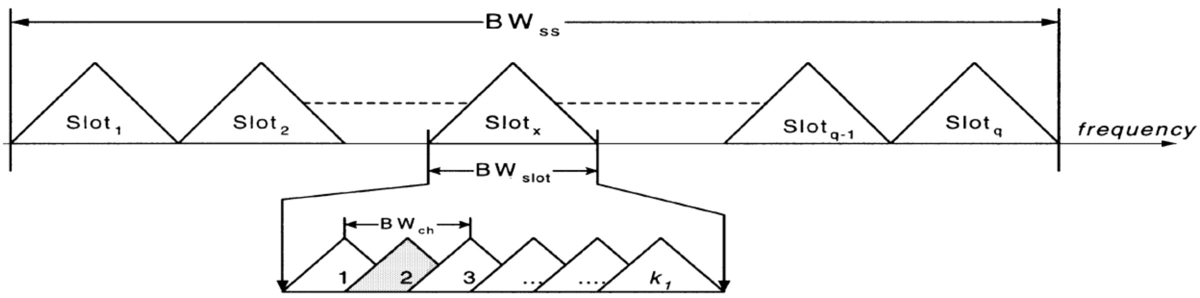

Fig (4): Spectrum of FHMA

3. FH-OFDM

FH-OFDM is a technique that randomize the radio resource allocation in OFDM by performing frequency hopping at subcarrier units or subchannel (which consists of multiple subcarrier) units shown in Fig. (5). This technique realize 1-cell reuse by adopting different hopping patterns for each base station. The advantage of FH-OFDM is, as similar to CDMA, it make inter-cell interference to be regarded as white noise by frequency hopping, and realize 1-cell reuse without requiring any complex processing such as Dynamic Channel Assignment (DCA). Also by making the number of allocated subcarriers variable according to traffic loading, the effects of fractional loading can be achieved, as similar to CDMA [8].

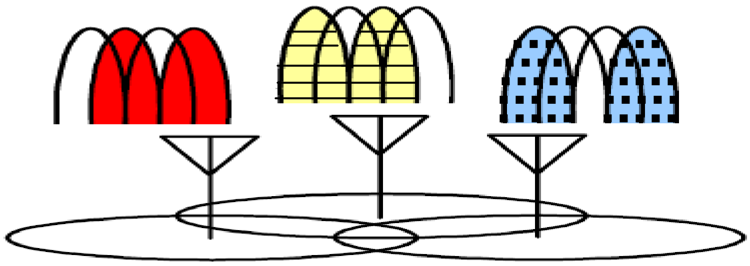

Figure (5): Conceptual diagram of FH-OFDM

4. OFDM Simulink System Design

A simplified simulink design of an conventional OFDM system is shown in Fig. (6). At transmitter, a parallel data generated from Bernoulli Binary Generator each of which will be transmitted on one subcarrier. Individual bits are then grouped properly and mapped into BPSK symbols. An IFFT block transfers the frequency domain symbol set (i.e. BPSK symbols) into a set of time domain samples, called an OFDM symbol. Finally, a cyclic prefix (CP) is added by repeating a portion of the symbol's tail at its head, in order to protect it against inter-symbol interference (ISI) and inter-channel interference (ICI). The transmitted signal (s(t))during any symbol duration can be expressed as

$$s(t) = \sqrt{2P}\sum_{i=1}^{k} x_i \cos(w_i t + \theta_i) \tag{2}$$

where P is the signal power and the data bit x_i is the amplitude for ASK, and θ_i is an arbitrary initial phase. The bandwidth of the signal s(t) will be denoted as the slot bandwidth (BW_{slot}), where $BW_{slot} = (k+1)R_s$. An Additive White Gaussian Noise (AWGN) channel is used to add noise to the transmitted signal. At the receiver, first the CP is eliminated since it carries corrupted data, then the time-domain symbol is converted to a set of noisy BPSK symbols in frequency domain, using FFT algorithm. BPSK symbols are passed through a detector and mapped to the binary space to obtain data bits. Finally, a parallel to serial converter combines the resulted bit streams and restores the original sequence.

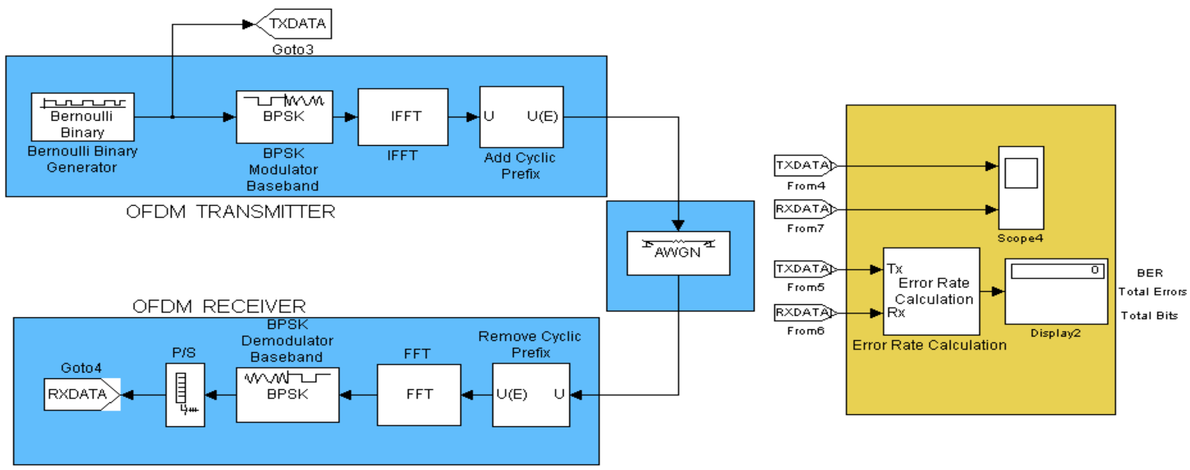

Figure (6): OFDM system

5. Interference in OFDM System

The channel is assumed to be AWGN, with two-sided power spectral density. At any given time, it will be assumed that there is an active user is transmitting through the channel. Let this active user be called the reference user. The reference user signal will be jammed (hit) when any other users transmits on the frequency that the reference user is using during any symbol period; those users are called an interferers. Fig. (7) shows a block diagram for six interferes affect the reference user (OFDM Transmitter2 to OFDM Transmitter7). The results for bit error rate are illustrated in Fig. (8) and compared with Fig. (9) from reference [9] for one user only without interferer in AWGN, where this figure illustrates a comparison between theoretical and simulink results. The results in Fig. (8) for no interferer are close to those in Fig.(9). Figure (8) illustrates that the bit error rate for multi interferer is decreased by increasing the SNR for a finite value, then it stay constant for large values of SNR.

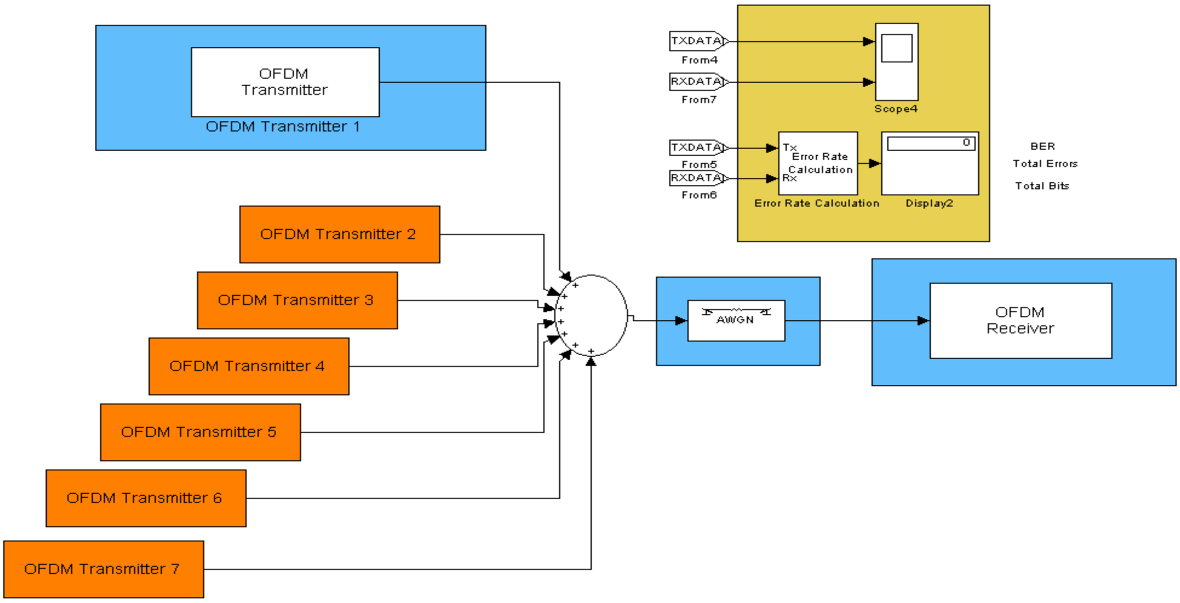

Figure (7): OFDM system with six interferers

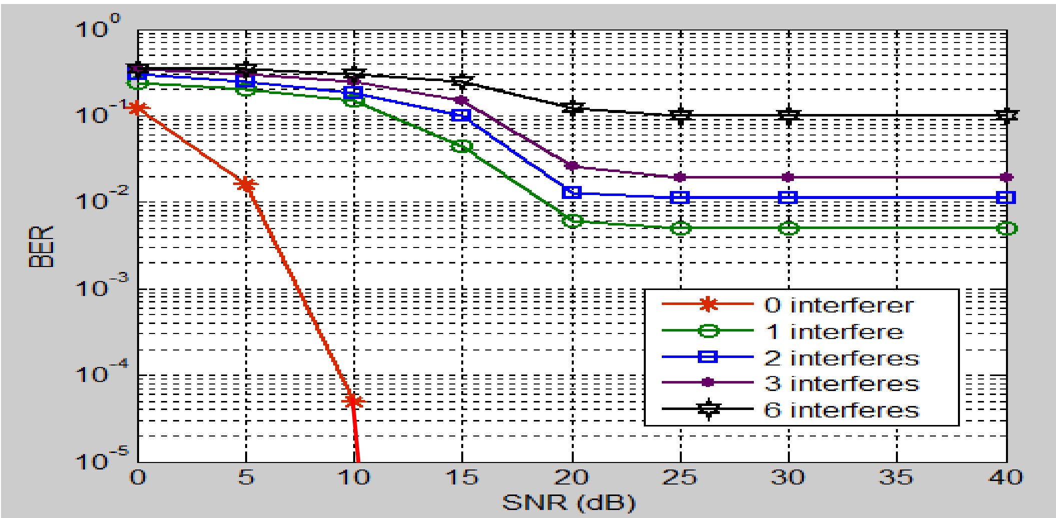

Figure (8): BER vs. SNR (dB) for OFDM system

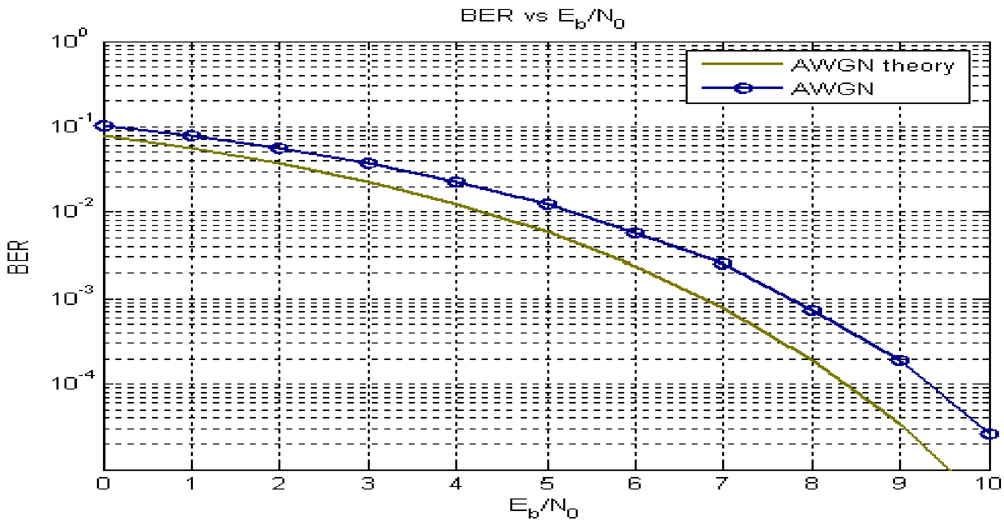

Figure (9): comparison between AWGN theory and simulation for one user

6. Proposed FH-OFDM Simulink System Design

To enhance the performance of OFDM system, a FH-OFDM system is proposed. Fig. (10) shows the transmitter where the important part of frequency hopping is a PN generator and frequency synthesizer. The FH-OFDM signal is generated when mixing the two signal (OFDM & FH). The channel is assumed to be AWGN channel with noise n(t) having two sided power spectral density $N_0/2$. The received noisy signal is applied to the receiver as in Fig. (11) where it consists of two stages. The first stage is the frequency dehopping. This stage has the same structure as the transmitter hopping section (PN generator and frequency synthesizer) besides of other blocks to detect the original signal. In this work it is assumed that there is no loses due to the hopping and the dehopping process. The second stage consists of OFDM receiver as in Fig. (6).

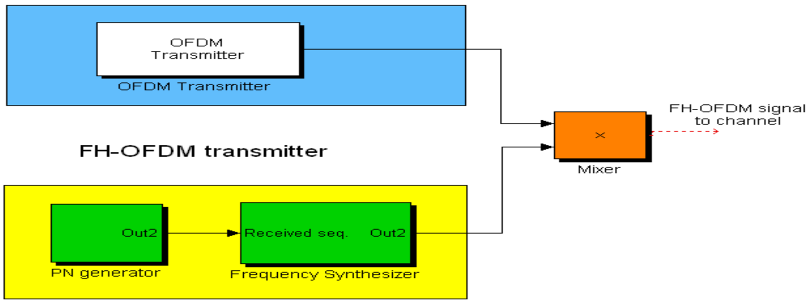

Figure (10): FH-OFDM transmitter

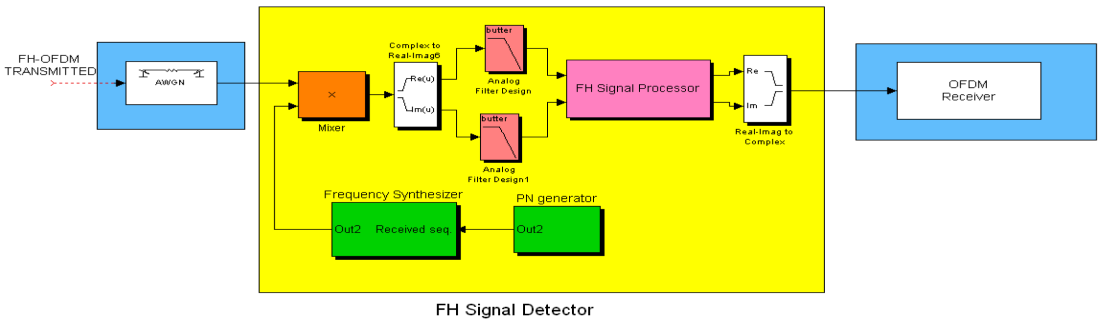

Figure (11): FH-OFDM receiver

7. Generation of Hopping Sequences

Two schemes of hopping pattern are used for generating FH signal; namely (Random FH (RA-FH) & Revolver FH (RE-FH)). They are applied separately to FH-OFDM system when multi-users utilize the same frequency band. The first is based on a central entity which computes the hopping sequences as general. The second scheme is a decentralized algorithm, where each cell decides independently on its next used channel, only based on its local view of the interference and channel occupancy of neighboring cells. The next subsections describes these two schemes.

7.1 RA-FH

In this scheme the individual hopping carriers is randomly selected among 1 to k_1 in $slot_x$. This will done sequentially within $BW_{slot\ 1}$ to $BW_{slot\ q}$ for the case of multy-user as in Fig. (4). Provided reliable communication between the users this always ensures a collision free channel selection.

7.2 RE-FH

The underlying idea of the hopping approach used is a phase shifted operation of neighboring users or cells. The operation (i.e., the channel selection, as well as the jump to a new channel) of two neighboring cells is always time shifted by one quiet time (t_{quiet}). After the maximum transmission time (t_{max}) is over, a cell chooses a new working channel. Since each user's operation period is time-shifted by one or multiple quiet time periods against the operation periods of all neighboring users. Thus, the users coordinate their channel usage by hopping over a cluster of working frequencies. Fig. (12) shows an example of the hopping pattern for 3 neighboring cells or users (i.e. all users are mutually interfering with each other) using 4 channels. As can be seen in Fig. (12) all cells consecutively visit each channel for the maximum allowed data transmission time (t_{max}). In the figure, the sensing slots for the working channel (N_{wf}) of cell or user two are marked [10].

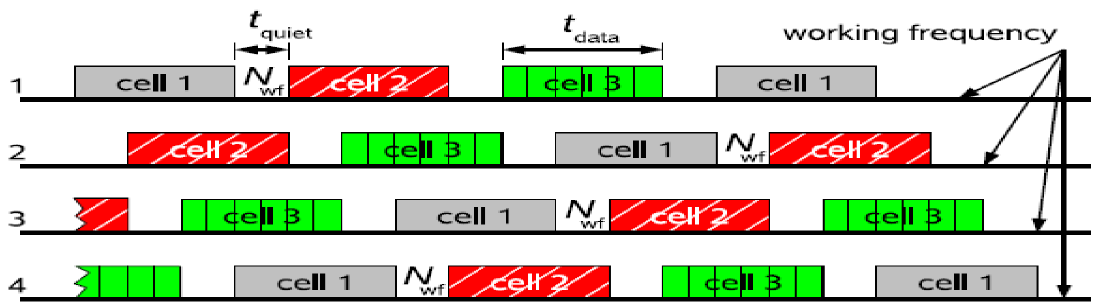

Figure (12): RE-FH for three users

8. Interference in FH-OFDM System

As explained above, the reference user signal will be jammed (hit) when any other users transmits on the frequency band that the reference user is using during any symbol period. As shown in Fig. (13), the two types of hopping pattern (RA-FH & RE-FH) are used and examined under noisy environment. Fig. (14) & (15), respectively illustrate the two cases and their performances separately. A comparison can be made with Fig.(16) via mathematical results for the two cases (Diversity System (DS) and Cluster Hopping (CH)) for 2, 4 and 8 users [11].

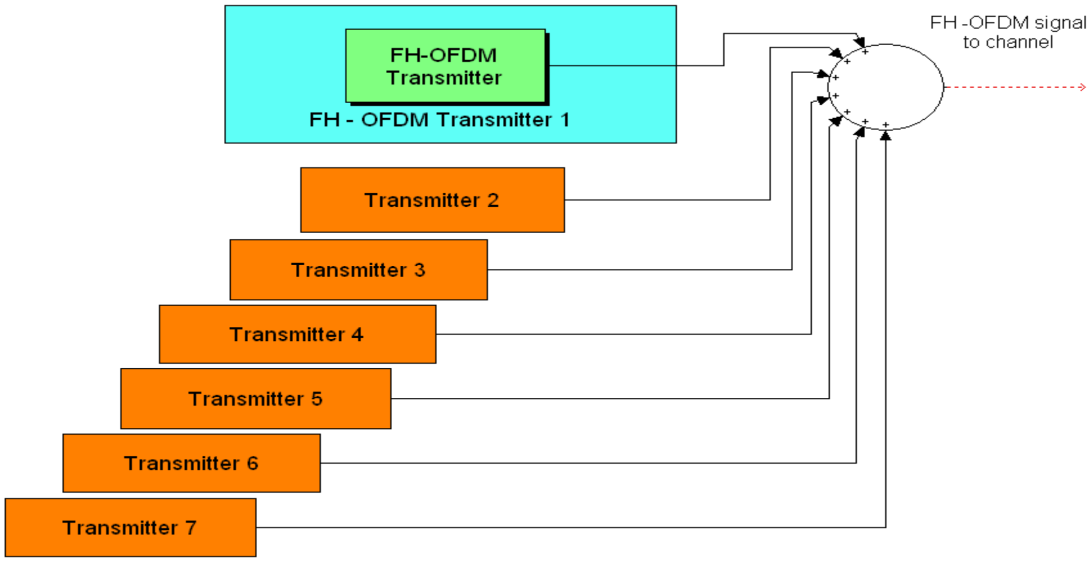

Figure (13): Interferer in FH-OFDM

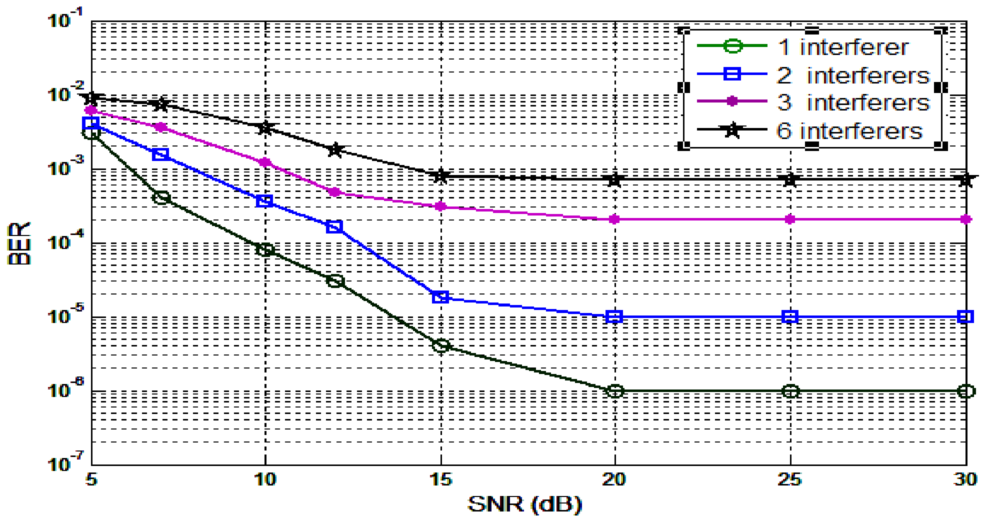

Figure (14): bits error rate vs. SNR (dB) for RA-FH

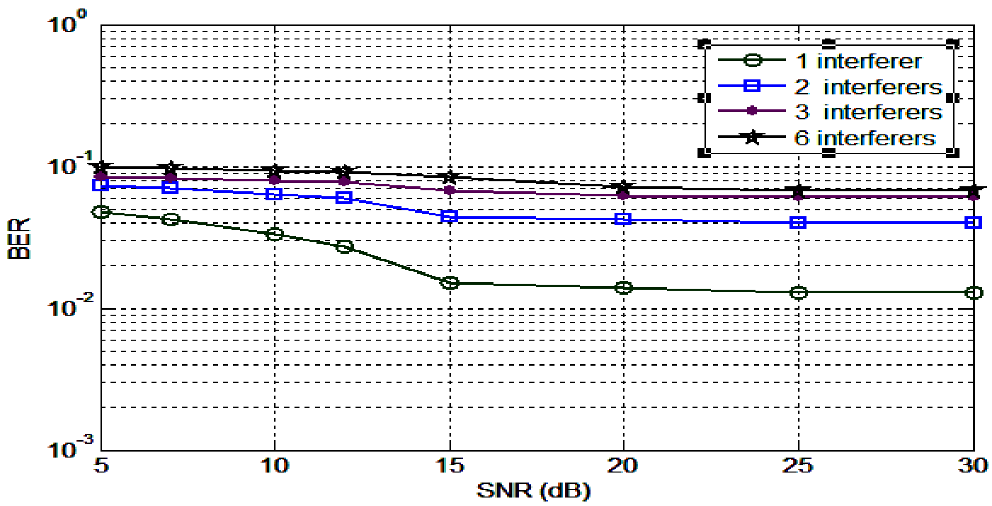

Figure (15): bits error rate vs. SNR (dB) for RE-FH

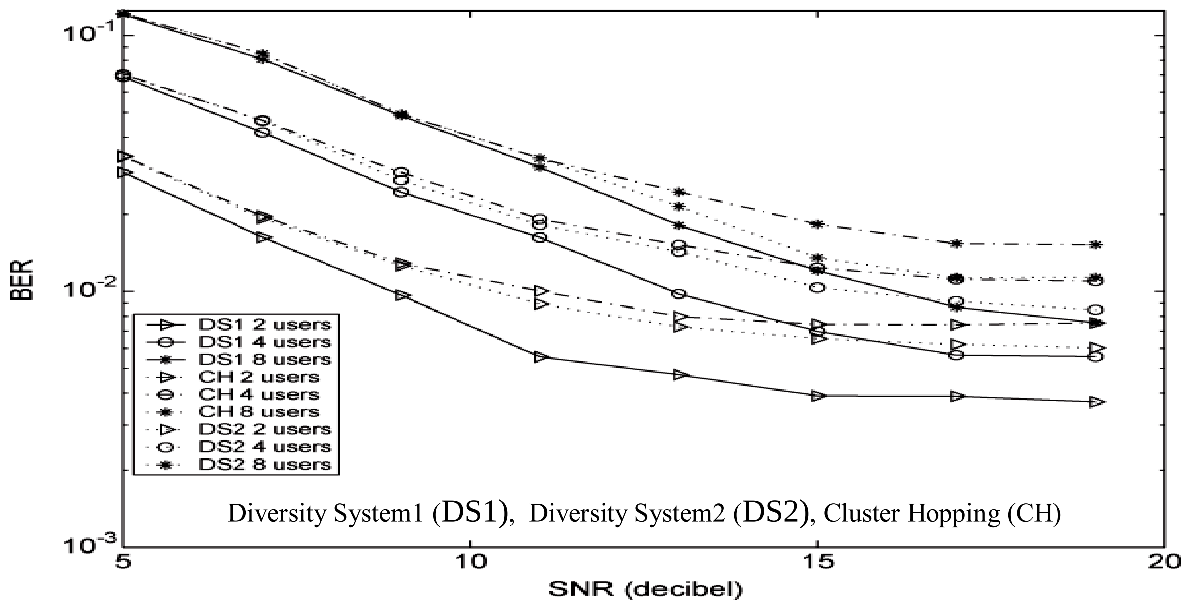

Figure (16): BER vs. SNR for FH-OFDM

9- Conclusion

A FH-OFDM system with both Random Frequency Hopping RA-FH and Revolver Frequency Hopping RE-FH has been examined to check the enhancing of bit error rate occur when muli-user interfere the original signal in OFDM system with noisy channel environment. The results show that the RA-FH scheme gives minimum bit error rate when compared to RE-FH scheme, conventional OFDM, DS and CH.

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The work was carried out at the college of Engineering. University of Mosul