Effect of Multi-tone Jamming on FH-OFDMA System with Orthogonal Hopping Patterns

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***Abstract* — Frequency hopped Orthogonal Frequency Division Multiple Access (FH-OFDMA) is considered as one of the hybrid CDMA-OFDM systems. Data is transmitted through multiple access system which adopt set of frequencies on which signal can hopped. Extending Quadratic Congruence (EQC) orthogonal hopping code is used to provide a protection against multi-user interference (MUI) and extremely generated interfering (jamming) signals with finite power, whether the system is suffering from fading or not.**

***Index Terms* — frequency hopping, OFDM-CDMA, multi-tone jamming, single tone jamming, FH-OFDMA, orthogonal hopping codes.**

I. Introduction

Frequency Hopped Orthogonal Frequency Division Multiple access (FH-OFDMA) is one of hybrid CDMA-OFDM systems that provide the multiple access basis for both the IEEE802.11a [1] local area network (LAN) standard and the IEEE 802.16a [2] metropolitan area network (MAN) standard.

FH-OFDMA system can eliminate multi-user interference (MUI), as well as narrow-band and partial-band interference, by careful code design. 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 will as the interference averaging benefit that is common for all CDMA variants [3],[4].

Hopping Codes that are used in OFDMA system must be orthogonal in order to eliminate MUI, to obtain OFDMA scheme, the Hadamard matrix is replaced by the identity matrix. Note that the spreading and despreading multiplications do not need to be implemented in this scheme since only one position per codeword is nonzero. The OFDMA scheme can therefore be claimed to be of lower computational complexity compared to the schemes that use Hadamard codes [5].

Another example that utilizes orthogonal hopping patterns is the Global System for Mobile Communications (GSM) cellular standard, where each time-division multiple accesses burst is hopped to a different channel [6].

In this paper, FH-OFDMA BER performance will be presented and tested with EQC hopping code under multi-tone jamming in AWGN and Rayleigh fading channels.

II. FH-OFDMA System

The base band block diagram of FH-OFDMA system is given in Fig. 1.

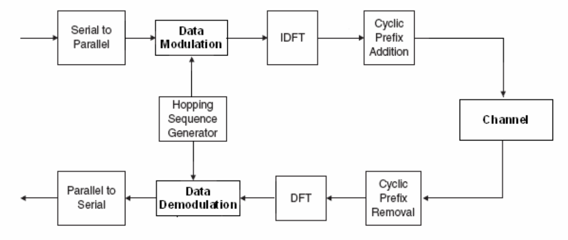

Fig. 1. Frequency-hopping baseband OFDM transmitter and receiver structure.

Data are converted from serial to parallel with block size *M*. Let $X_k(i,n) := X(i, nM+k)$, $k = 0,1,\cdots,M-1$, denote the *k*th symbol of the *n*th data block generated by the *i*th user. Then, the vector

$$x(i,n) = [X_0(i,n)\, X_1(i,n) \cdots X_{M-1}(i,n)]^T \qquad (1)$$

represents the *i*th user's *n*th data block. Every user transmits over *M* sub-carriers, which are assigned or selected as pattern determined by hopping sequence generator. Let

$$C_i(n) = \{ f_{i,n,0}, f_{i,n,1}, \cdots, f_{i,n,M-1} \} \qquad (2)$$

be the set of sub-carriers that make up user *i* transmits its *n*th block where the ordering of sub-carriers is according to EQC hopping code.

Thus $C_i(n) \subset \{1, e^{j2\pi/N}, \cdots, e^{j2\pi(N-1)/N}\}$ has cardinality *M* for all *i* and *n*. The transmission sub-carriers in $C_i(n)$ are altered for all *i* at each symbol block time as dictated by hopping sequence generator

Define the $M \times 1$ vector

$$f_{i,n}^{m} = [e^{j2\pi f_{i,n,0}m} e^{j2\pi f_{i,n,1}m} \cdots e^{j2\pi f_{i,n,M-1}m}]^T \tag{3}$$

for $m = 0, 1, \cdots, M-1$. Then the modulation of the sub-carriers set produces the OFDM symbol

$$s(i,n) = [S_0(i,n) S_1(i,n) \cdots S_{M-1}(i,n)]^T \tag{4}$$

Where

$$S_m(i,n) = \frac{1}{M} x^T(i,n) f_{i,n}^{m} = \frac{1}{M} \sum_{k=0}^{M-1} X_k(i,n) e^{j2\pi f_{i,n,k}m} \tag{5}$$

A cyclic prefix (CP) is appended to each block before transmission, where the last P symbol of the OFDM stream are added to the beginning in order to combat the inter-carrier interference, creating

$$\begin{aligned} s_{CP}(i,n) = [&S_{M-P}(i,n) \cdots S_{M-1}(i,n) S_0(i,n) \cdots \\ &S_{M-1}(i,n)]^T \end{aligned} \tag{6}$$

The channel output for user i is

$$y(i,n) = H(i,n) s_{CP}(i,n) + z(i,n) \tag{7}$$

where the discrete-time Fourier transform of the complex Gaussian channel coefficients

$$\{h_k(i,n)\}_{k=0}^{M-1}$$

From the elements of the M×M diagonal matrix $H(i,n)$ for user *i*. The vector $z(i,n)$ represent the aggregate of AWGN as will as, possible MUI to user i.

System will be considered as synchronous frequency hopping, where the hop intervals from all transmitters are aligned at the receiver.

FH-OFDMA system can be considered as a frequency hopped multi-carrier on-off keying FH-MC-OOK, the modulation and demodulation process that FSK noncohorent modulation used in FH-OFDMA system can be based on same operation in FH-MC-OOK [7]. Hopping sequence generator will depend on EQC hopping code to provide orthogonal hopping pattern for every user. This code can be given as [8]:

$$Y_K = \begin{cases} 0 & if\ K = 0 \\ [Y_{K-1} + aK]\mathrm{mod}(N) & if\ 1 \le K \le (N-1)/2 \\ [Y_{K-1} + bK]\mathrm{mod}(N) & if\ (N+1)/2 \le K \le N-1 \end{cases} \tag{8}$$

where *a* and *b* are some integers members of the set $J_N = [1, 2, \cdots, N-1]$ and *N* is assumed to be an odd prime.

Equation (8) can be rewritten in closed form as [8]

$$Y_k = \begin{cases} [a.k(k+1)/2]\mathrm{mod}(N) & 0 \le k \le (N-1)/2 \\ [b.k(k+1)/2 + (a-b).(N^2-1)/8] & (N-1)/2 \le k \le N-1 \end{cases} \tag{9}$$

The sequence of the integers Y_K defined in (9) is permutation for the set $J_N = [1, 2, \cdots, N-1]$ if and only if *a* and *b* are not both, quadratic residues (QR) or quadratic non-residues (QNR) for the odd prime *N*. each permutation is uniquely defined by the ordered pair (a, b).

In the case of odd primes, Gauss show that α is QR if and only if:

$$[\alpha^{(N-1)/2}]\mathrm{mod}(N) = 1 \tag{10}$$

And that β is QNR if and only if

$$[\beta^{(N-1)/2}]\mathrm{mod}(N) = -1 \tag{11}$$

The number of QRs is equal to (N-1)/2 and the number of QNRs is also equal to (N-1)/2, therefore the numbers of extended quadratic code word are exactly equal to

$$N_{code} = 2((N-1)/2)^2 \tag{12}$$

In this work, synchronous frequency hopping system is considered, where the hop intervals from all transmitters are aligned at the receiver.

III. INTERFERENCE REJECTION

Frequency-Hopping technique that used by FH-OFDMA system can be viewed as performing interference avoidance [9]-[11. The frequency hopping receiver has bandwidth matched to the data modulation, and follows the transmitter as it jumps around the band. If one of those jumps encounters a narrowband interferer, then the communications on that channel can be jammed if all three interference conditions are met which they are [12]:

1. An interfering signal exists at the demodulation frequency.
2. This interfering signal exists at the time demodulation is attempted.
3. The interference is strong enough to corrupt the demodulation.

For multiple access systems that used frequency hopping technique, it is not always advantageous for a noise jamming to jam the entire bandwidth. That is, for a given jamming power P_J , the jammer can often increase its effectiveness by jamming only a fraction of the total bandwidth. This is termed partial band jamming. If it is assumed that the jammer divides its power uniformly among f_j slots, where a slot is the region in frequency that the FH signal occupies on one of its hops, and if there is a total of Y_K slots over which the signal can hop, the average probability of error can be given as [11]:

$$P_e = \frac{(Y_k - f_j)(Y_k - f_j - 1)}{2\,Y_k(Y_k - 1)}\exp\left(-\frac{1}{2\,SNR}\right) + \frac{f_j(Y_k - f_j)}{Y_k(Y_k - 1)}\exp\left(-\frac{1}{\frac{2}{SNR}+\frac{1}{SJR}}\right) + \frac{f_j(f_j - 1)}{2\,Y_k(Y_k - 1)}\exp\left(-\frac{1}{\frac{2}{SNR}+\frac{2}{SJR}}\right) \qquad (13)$$

Where *SNR* is the ratio of the signal power to thermal noise power and *SJR* is the ratio of signal power to jamming power per slot and it is given by:

$SJR = P_s/(P_j/f_j)$, where P_s is signal power and P_J jamming power.

IV. COMPUTER SIMULATION

FH-OFDMA system have been implemented using Matlab 7. This system is implemented with four users and 5 hopping slot for every user and different hopping pattern determined by EQC hopping code, this system have been tested under AWGN, one path Rayleigh fading and multi-tone jamming in case of AWGN and fading channels.

A. EQC Hopping Code Auto and Cross-correlation Properties

FH-OFDMA signal shows good auto and cross-correlation properties with EQC code as shown in Fig. 2 and Fig. 3. The normalized sidelobe level is very low and the peak of cross-correlation is less then 0.1 which means that no cross talk between users can occur.

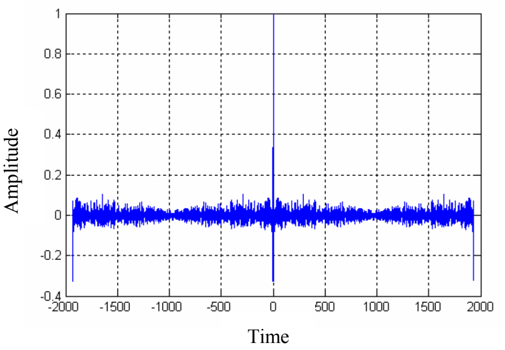

Fig. 2. Auto-correlation function of EQC code.

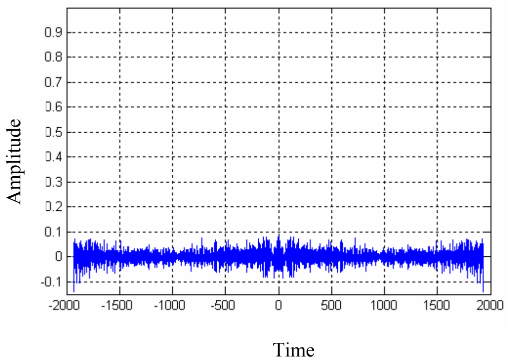

Fig. 3. Cross- correlation function of EQC code.

B. FH-OFDMA under AWGN & Rayleigh Fading

BER performance of FH-OFDMA system under AWGN, one path fading and perfect compensation are shown in Fig.4. From this figure, clear picture can be gotten for the performance of this system. Where it is clear how much this system suffers from fading as comparing with the performance under AWGN, and how perfect compensation can reduce the fading in the received signal so data can be recovered.

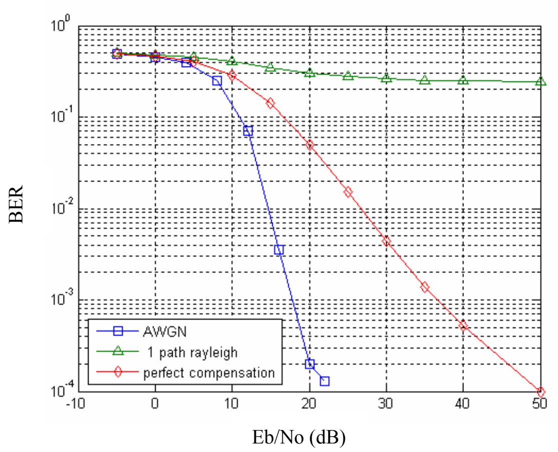

Fig. 4. Comparison of FH-OFDMA BER performance under AWGN, one path fading and perfect compensation.

Perfect compensation is applied to the system to reduce BER performance occurs due to Rayleigh fading [13].

Less fading means that less power has to be transmitted, and hence less interference is generated, which gives an improvement in the capacity of the system.

Comparison of BER performance of FH-OFDMA system under AWGN with tow different wordlengths is shown in Fig. 5.

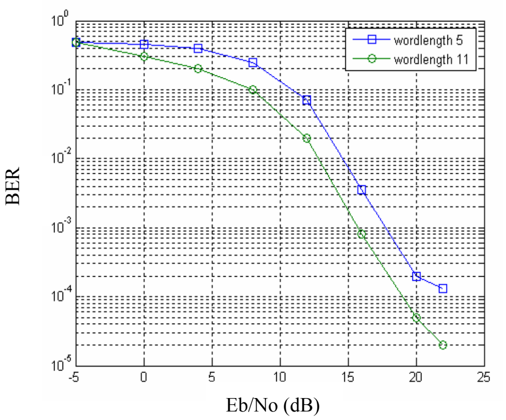

Fig. 5. BER performance of FH-OFDMA under AWGN.

C. FH-OFDMA with Multi-tone Jamming

BER performance of FH-OFDMA in AWGN with single tone is shown in Fig.6.

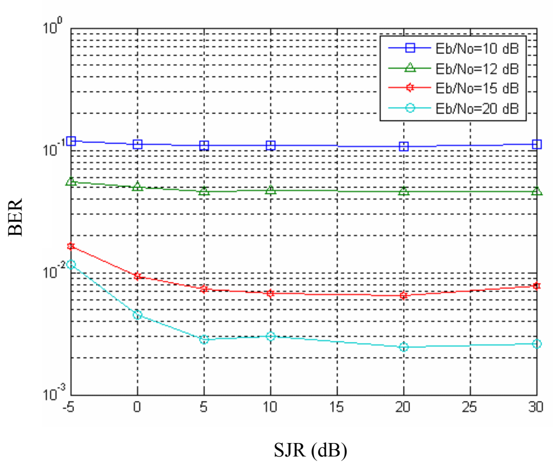

Fig. 6. BER performance of FH-OFDMA under AWGN and single tone jamming.

Single tone jammer shows small effect on FH-OFDMA system according to the results above and those results can be improved as number of slots *N* is increased.

FH-OFDMA system has been tested under multi-tone jamming and its performance is shown in Fig.7.

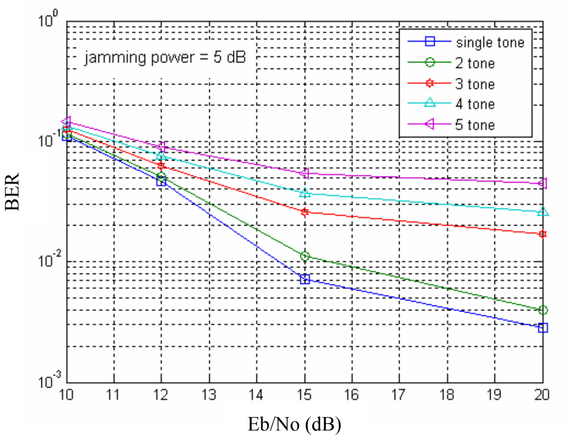

Fig. 7. BER performance of FH-OFDMA in AWGN channel with multi-tone jamming.

From this figure, BER increased as number of jamming tones are increased. BER can be decreased as the number of slots over which the signal can hop is increased to value that making the percentage of jammed tons as comparing to the non jammed tons is very small. BER performance of FH-OFDMA in Rayleigh fading channel with multi-tone is shown in Fig.8.

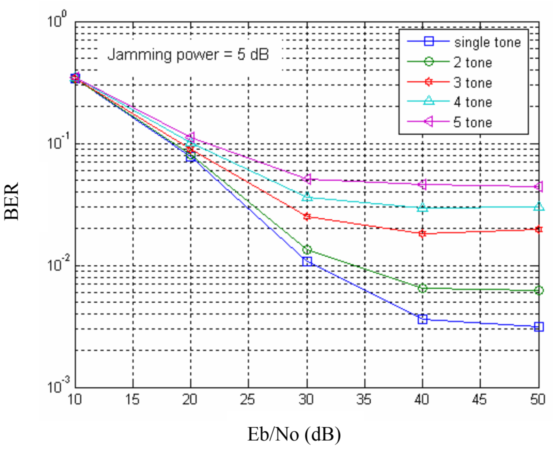

Fig. 8. BER performance of FH-OFDMA in Rayleigh fading channel with perfect compensation and multi-tone jamming.

Comparing Fig. 8 and Fig. 4, it can be noted that the effect of jamming on BER will be worst as number of jamming tone increased.

From Fig. 7 and Fig.8., it can be noted that the effect of jamming has the same effect on the system no matter whether the system is suffering from fading or not.

V. CONCLUSION

FH-OFDMA system had been tested using EQC hopping code that provide orthogonal hopping pattern for each user, this code shows a good performance in multiple access systems that using hopping technique. The orthogonaltiy in hopping patters protect the system against MUI and enhance BER performance of FH-OFDMA under AWGN and one path fading with perfect compensation. Also protection against Multi-tone jamming signals was achieved whether the system suffering from fading or not.

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REFERENCES

[1] Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High-Speed Physical Layer in the 5 GHz Band, *IEEE Standard 802.11a*-1999.

[2] Local and Metropolitan Area Networks—Part 16, Air Interface for Fixed Broadband Wireless Access Systems, *IEEE Standard IEEE 802.16a*.

[3] Jeroen, T., Frank, H.P.F. and Carl, W.," Multihopping for OFDM based Wireless Networks", *Technical Report, Center for TeleInFrastruktur (CTiF), Aalborg University*, June 2004.

[4] John, B.G. and Lawrence, E.L. ," CDMA Mobile Radio Design", Artech House, 2000.

[5] Anders, P., Tony O., and Erik, G.S.," Comparison of Coded OFDMA and OFDM-CDMA in a frequency reuse one system", Jan. 7, 2004.

[6] Morinaga, N., Kohno, R., Sampei, S.,"Wireless Communication Technologies: New Multimedia System", Kluwer Academic Publishers, 2000.

[7] Seung, H.K. and Sang, W. K.," Frequency-Hopped Multiple-Access Communications with Multicarrier On–Off Keying in Rayleigh Fading Channels", *IEEE Transaction on Communications*, Vol. 48, No. 10, pp. 1692-1701, oct. 2000.

[8] Jerome, R. B. and Edward, L.T., "Time Frequency Hop Codes Based Upon Extending Quadratic Congruence (EQC) Construction", *IEEE Transaction on Aerospace and Electronic Systems*, Vol. 24, No. 6, pp. 726-742, Nov. 1988.

[9] Simon, H.," Communication Systems",4th Edition, JOHN WILEY&SONS ,2000.

[10] Robert, C.D., "Spread Spectrum Systems", 2nd Edition, JOHN WILEY&SONS, 1984.

[11] Don, J. T.," Principles of Secure Communication System", Artech House, 1985.

[12] Earl, M.," DSSS vs. FHSS narrowband interference performance issues", *RF signal processing*, pp. 90-104, Sep. 2000.

[13] Hiroshi, H. and Ramjee, P., "Simulation and Software Radio for Mobile Communications", Artech House, 2002.