Performance Analysis of Two-Level FH-CDMA Scheme with OFDM

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***Abstract*— In this paper a Two-level frequency hopping code-division multiple-access (FH-CDMA) scheme with OFDM for wireless communication system has been proposed. This method provides flexibility in the range of modulation codes and FH models. By separating the modulation codes two-level scheme can be modified to carry more possible users without increasing the number of FH models. The simulation results show that the divided two-level FH-CDMA scheme supports higher data rate and greater spectral efficiency than frequency-shift-keying FH-CDMA scheme. Further the Bit error Probability is reduced by implementing OFDM over two level scheme. The results of two-level scheme with and without OFDM are compared.**

Keywords — code division multiple access, code modulation, frequency hopping, spectral efficiency, OFDM.

I. INTRODUCTION

Frequency Hopping Code Division Multiple Access (FH-CDMA) provides frequency range and helps ease multi-path fading and vary intervention. The advantages of FH-CDMA over Direct-Sequence DS-CDMA include better resistance to multiple access interfering. By conveying a unique FH models to each user a FH-CDMA system allows multiple users to share the same transmission channel concurrently. MAI occurs when more than one simultaneous user make use of the same carrier frequency in the same time slot. M-ary frequency-shift-keying (MFSK) atop FH-CDMA scheme is used in order to enlarge data rate by transmitting symbols instead of data bits.

In addition the uses of prime and Reed-Solution (RS) sequences as modulation codes atop FH-CDMA were represented by non-orthogonal sequences, rather than orthogonal MFSK. These prime FH-CDMA and RS FH-CDMA methods supported higher data rate than MFSK FH-CDMA scheme at the expense of the modulation codes and FH models needed to be the same in both methods confining the choice of suitable modulation codes and FH models to use. The only condition is that the weight of the FH models is at least equal to the length of the modulation codes, which is usually true in modulation FH-CDMA methods because each element of the modulation codes needs to be conveyed by an element of the FH models. Therefore two-level FH-CDMA method is more flexible in the selection of the modulation codes and FH models in order to meet different system operating requirements. The prime FH-CDMA and RS FH-CDMA methods are special case of the new method. Partitioning method on the modulation codes such that modulation codes with lower cross-correlation values are grouped together are proposed. The usage of different groups of modulation codes as an additional level of address signature allows the assignment of the same FH model to multiple users, thus maximizing the number of possible users. As the Bit error probability is a key factor in determining the performance of the system, it can be minimized by introducing OFDM over two-level scheme. The Bit error probability is minimized by providing further orthogonality to the system.

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II. DESCRIPTION OF TWO-LEVEL FH-CDMA SCHEME

In two-level FH-CDMA scheme, the available transmission bandwidth is divided into M_h frequency bands with Mm, carrier frequencies in each band giving a total of M_h Mm carrier frequencies. In the first level a number of serial data bits is grouped together and represented by a symbol. Each symbol is in turns represented by a modulation code of dimension $M_m \times L_m$ and weight W_m, where M_m the number of data bits that can be represented by a symbol depends on the number of available modulation codes.

If there is ϕ_m available modulation codes, each symbol can be represent up to [log2ϕm] data bits, where [.] is the floor function. In the second (FH) level, each user is assigned a unique FH pattern of dimension $M_h \times L_h$ and weight W_h, where M_h is the number of frequencies and L_h is the number of time slots. The elements in the modulation codes and FH models conclude the carrier frequencies of the final FH-CDMA signals. While an element of modulation code define the carrier frequency used in a frequency band in a given time slot, an element of the FH pattern determines which frequency band to use.

Table I
Twenty-Five (4 × 5, 4, 0, 1) Prime Equences, Which Can Beorganized Into Five Groups
With $\Lambda^{'}C = 0$ Within Each Group.

	Group 0	Group 1	Group 2	Group 3	Group 4
i_2	i_1=0	i_1=1	i_1=2	i_1=3	i_1=4
0	0000x	0123x	02x13	031x2	0x321
1	1111x	123x0	1302x	1x203	10x32
2	2222x	23x01	2x130	203x1	210x3
3	3333x	3x012	302x1	31x20	3210x
4	xxxxx	x0123	x1302	x2031	x3210

In proposed method families of ($M_m \times L_m$, W_h, $\lambda_{a,m}$, $\lambda_{c,m}$) modulation codes are chosen and ($M_h \times L_h$, W_h, $\lambda_{a,h}$, $\lambda_{c,h}$) FH models as long as $W_h \geq L_m$ prime sequences in Table I as the modulation codes. Fig.1 shows the encoding process of three simultaneous users. The data symbols of these users are $S_1=S_{3,0}$=(0,3,1,x,2),$S_2=S_{2,2}$=(2,x.1.3.0),$S_3=S_{1,1}$(1,2,3,x,0).

Elements of $S_{i1,i2}$ determines which carrier frequency of a frequency band in a given time slot to use. $S_{i1,\ i2,1}$ = i2⊕p(i_1 ⊙p $_1$) [⊕ - modulo p addition, ⊙ -modulo p multiplication]. If the number of available carrier frequencies is restricted or the sequence weight needs to be varied in order to achieve certain method performance, the sequence weights are adjusted to be $W_m \prec P$ by dropping the largest p-Wm. elements in $S_{i1,i2}$. As a result the construction algorithm gives $\phi_m=P_2$ – P +Wm prime sequences of weight $W_m \leq P$ and length L_m = P with, $\lambda_{c,m}$ =1. Using these prime sequences as the modulation codes, at most twenty four symbols are supported and each symbol represents [$\log_2$24.]=4 data bits. FH models can be chosen for the second level of bi-level FH-CDMA method as long as $W_h \geq L_m$. To illustrate this ($M_h \times L_h$, W_h, $\lambda_{a,h}$, $\lambda_{c,h}$) = (5 x 7, 5,0,1) prime sequences as the one-hit FH models are transmitting signal. Where $\lambda_{a,\ m}$, $\lambda_{a,\ h}$ and $\lambda_{c,\ m}$,$\lambda_{c,\ h}$ denotes the maximum autocorrelation and cross-correlation values of the modulation codes, respectively. To illustrate the main concept of bi-level FH-CDMA method, the prime sequences as the modulation codes are used, other codes, such as the RS sequences, quadratic congruence code (QCCs) and multilevel prime codes can also be used. The carrier frequency used in each frequency band in a time slot is determined by superimposing all W_m=4 elements of S1 on top of this first Wm non-X elements of H_k and the X elements of Si produce empty frequency bands in the final two level FH-CDMA signal, where K={1,2,3} the shaded columns in the transmitting signal, T_k of Fig 1 represent the frequency bands specified by the corresponding FH models, H_k for K={1,2,3}.

In review two level frequency hopping CDMA can be represented by T_k=($T_{k,0}$,$T_{k,1}$…….T_{kj},…..$T_{kL,h-1}$=S_k), where $T_{k,j}$ represents frequency used in ith time slot and Δ denotes super impose operation for example two level FH CDMA signal of first user is found to be T_1=(0+, 0*4, 3+2*4, 1+4*4,x,x,2+3*4,x)=(0, 11, 17, x, x, 14, x) after super imposition similarly other two simultaneous users have T_2=(2,x,5,x,11,x,12) and T_3=(13,6,x,19,x,0,x).. Although the prime sequences can only support up to $\lfloor \log2(p2 - p + wm) \rfloor$ bit/symbol, it is important to point out that our two-level FH-CDMA scheme allows the use of other codes, such as the RS sequences ,QCCs ,and MPCs ,as the modulation codes. For example, the MPCs have pn+1 sequences of weight $w_m = p$ and length $L_m = p$ with $\lambda c' = n$ (i.e., symbol interference), where n is a natural number. If the MPCs are used as the modulation codes, the date rate can be increased because the MPCs can support up to $\lfloor \log_2 Pn+1 \rfloor$ bit/symbol at the expense of worsened symbol interference.

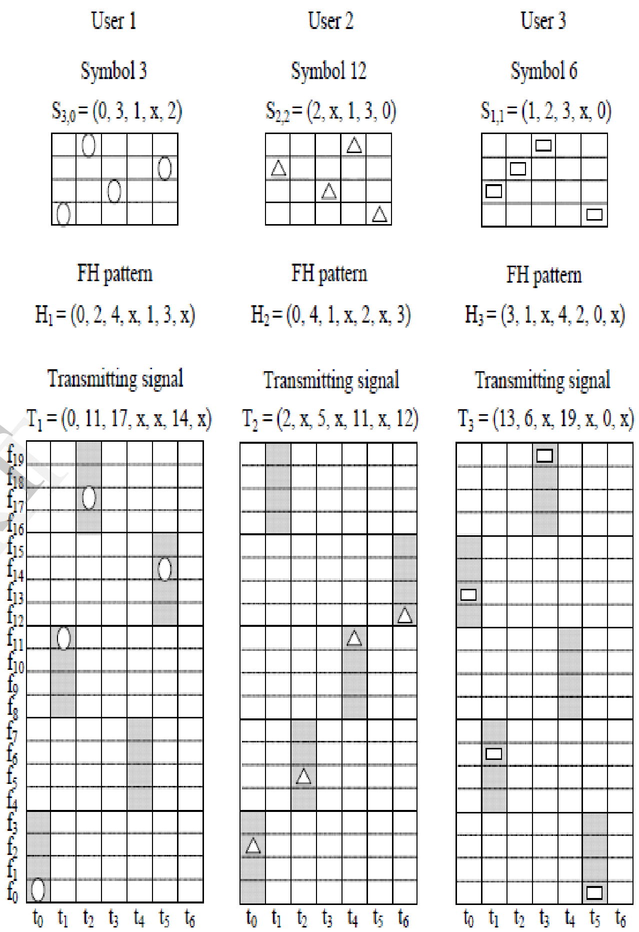

Fig. 1. Example of the encoding process of the two-level FH-CDMA scheme with three simultaneous users.

In the above figure the shaded columns in the transmitting signals, T_k, represent the frequency bands specified by the corresponding FH patterns, H_k, for k={1,2,3} .

III. IMPLEMENTING OFDM OVER TWO-LEVEL FH-CDMA

The OFDM block is added after the second level encoder. OFDM is implemented in order to introduce further orthogonality to the system. The encoded bits of Two-level FH-CDMA are given as the input to the OFDM system .

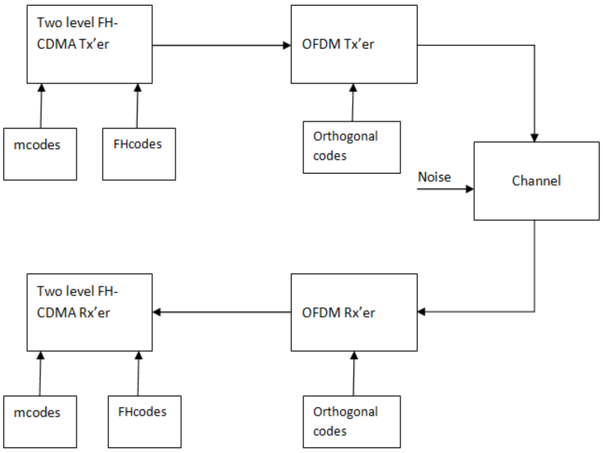

Fig. 3: Two-Level FH-CDMA scheme with OFDM system Model

IV. PERFORMANCE ANALYSIS

In this FH-CDMA system MAI depends on the cross correlation values of FH patterns. For our two level FHCDMA scheme, the cross-correlation values of the modulation codes impose additional interference and need to be considered. Assume that one-hit FH patterns of dimension M_h *L_h are used and the transmission band is divided into Mm *Mh frequencies, in which Mm frequencies are used to carry the modulation codes of weight Wm the probability that a frequency of an interferer hits with one of the frequencies of the desired user is given by

$$q = \frac{{w_m}^2}{M_m M_h L_h} \quad (1)$$

Assume that there are K simultaneous users, the probability that the dehopped signal contains n entries in an undesired row is given by

$$P(n) = \binom{w_m}{n} \sum_{i=0}^{n} (-1)^i \binom{n}{i} \left[1 - \mathrm{q} + \frac{(\mathrm{n-i})\mathrm{q}}{\mathrm{w_m}}\right]^{\mathrm{K-1}} \quad (2)$$

Over AWGN, and Rayleigh and Rician fading channels, false alarms and deletions may introduce detection errors to the received FH-CDMA signals. A false-alarm probability, P_f is the probability that a tone is detected in a receiver when none has actually been transmitted. A deletion probability 'P_d', is the probability that a receiver missed a transmission tone.
For these three types of channels, the false-alarm probability is generally given by [5]

$$p_f = \exp\left(-{\beta_0^2}/{2}\right) \quad (3)$$

For an AWGN channel, the deletion probability is given by [5]

$$p_d = 1 - Q\left(\sqrt{2(E_b/N_o).(k_b/w_m)}.\beta_o\right) \quad (4)$$

Where 'β_o' denotes the actual threshold divided by the rootmean-squared receiver noise, 'k_b'is the number of bits per symbol.
To minimize the error probability, the optimal 'β_o' of an AWGN channel should be a function of the signal-to-noise ratio (SNR), and can be more accurately written as [13]

$$\beta_o = \sqrt{2 + \frac{(E_b/N_o).(k_b/w_m)}{2}} \quad (5)$$

Rather than an inaccurate constant value (i.e., β_o = 3).For a Rayleigh fading channel, the deletion probability is given by [13]

$$p_d = 1 - \exp\left\{\frac{-\beta_0^2}{2+2(E_b/N_o).(k_b/w_m)}\right\} \quad (6)$$

Similarly, the optimal 'β_o' of a Rayleigh fading channel can be more accurately written as [13]

$$\beta_o = \sqrt{2 + \frac{2}{(E_b/N_o).(k_b/w_m)}} \times \sqrt{\log[1 + (E_b/N_o).(k_b/w_m)]} \quad (7)$$

Finally, for a Rician fading channel, the deletion probability is given by [13]

$$p_d = 1 - Q\left(\sqrt{\frac{2\rho(E_b/N_o).(k_b/w_m)}{1+\rho+(E_b/N_o).(k_b/w_m)}}, \beta_1\right) \quad (8)$$

Where the Rician factor 'ρ' is given as the ratio of the power in specular components to the power in multipath components. Similarly, 'β_o' and 'β_1'can be more accurately written as [13]

$$\beta_o = \sqrt{2 + \frac{(E_b/N_o).(k_b/w_m)}{2}} \quad (9)$$

$$\beta_1 = \frac{\beta_o}{\sqrt{1+(E_b/N_o).(k_b/w_m)/(1+\rho)}} \quad (10)$$

Including the noise or fading effect, the probability that the dehopped signal contains n entries in an undesired row is given by [13]

$$p(n) = \sum_{j=0}^{n} \sum_{r=0}^{\min[n-j, w_m-n]} \left[P(n-j)\binom{n-j}{r} \times (1-p_d)^{n-j-r}(p_d)^r \binom{w_m - n + j}{r+j} \times (1 - p_f)^{w_m-n-r}(p_f)^{r+j}\right] + \sum_{j=1}^{w_m-n} \sum_{r=j}^{\min[n+j, w_m-n]} \left[P(n+j)\binom{n+j}{r} \times (1-p_d)^{n+j-r}(p_d)^r \binom{w_m - n - j}{r+j} \times (1-p_f)^{w_m-n-r}(p_f)^{r-j}\right] \quad (11)$$

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It is because the nonzero cross-correlation values of the modulation codes add extra undesired entries. To account for this, let A^{z}_{t} denote the conditional probability of the number of hits (seen at any one of the incorrect rows) being increased from *z* to *z+i*, where i ϵ [1,λcm],we derive a new probability of having a peak of *z* as [9]

$$P_s^{'}(z) = A^{z}_{\lambda_{c.m}} P_s(z-\lambda_{c.m}) + A^{z}_{\lambda_{c.m}-1} P_s(z-(\lambda_{c.m}-1)) + \cdots \ldots \ldots + A_1^{z} P_s(z-1) + \left(1-\sum_{t=1}^{\lambda_{c.m}} A_t^{z+t}\right) P_s(z) \qquad (12)$$

Where A^{z+t}_{t} when $z+t>w_m$ .If there are 2^{kb-1} incorrect rows, the probability that *n* is the maximum number of entries and that exactly t unwanted rows contain n entries is given by [9]

$$P_r(n,t) = \binom{2^{k_b}-1}{t} [P_s^{'}(n)]^{t} [\textstyle\sum_{m=0}^{n-1} P_s^{'}(m)]^{2^{k_b}-1-t} \qquad (13)$$

Over a noisy or fading channel, the probability of having an entry in a desired row is 1-P_d Therefore, the probability that there exist *n* entries in a desired row is given by [9]

$$P_e(n) = \binom{w_m}{n} (1-p_d)^{n} (p_d)^{w_m-n} \qquad (14)$$

The desired symbol is detected wherever the maximum number of entries in the *t* incorrect rows is less than *n*. As the receiver decides which symbol (out of 2^{kb}symbols) is recovered by searching for the modulation code with the largest matching entries, the bit error probability (BEP) is finally given by [17]

$$P_b(k) = \frac{2^{k_b}}{2(2^{k_b}-1)}\left\{1 - \sum_{n=1}^{w}\left[P_c(n)\sum_{t=0}^{2^{k_b}-1} \frac{1}{t+1} P_r(n,t)\right]\right\} \qquad (15)$$

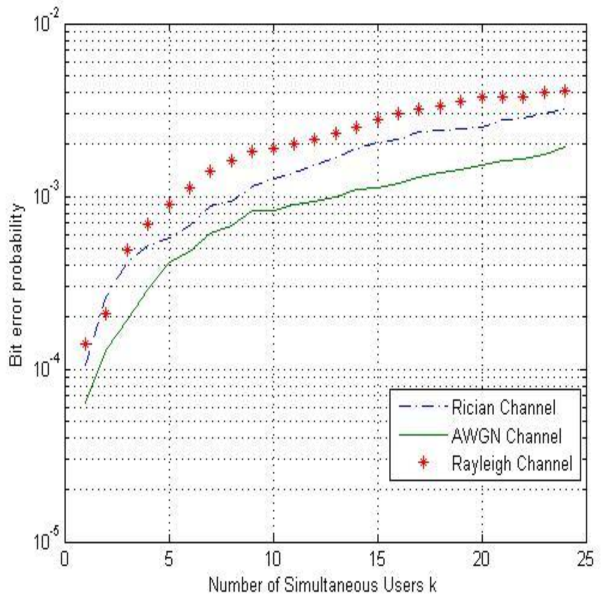

Fig.4. BEPs of Two level FH-CDMA over Rician,AWGN,Rayleigh Channels versus Number of imultaneous users k.

As expected the AWGN curve performances good and Rayleigh curve performance worse, while the Rician curve is in between. The BEP is between 10^{-4} and 10^{-2} which is better than MFSK FH-CDMA with wm=4,$M_m \times L_m$ =4×11, $M_h \times L_h$ =11×47, βo ={3.4633, 3.5148}, kb=3 and E_b/N_o=25db.

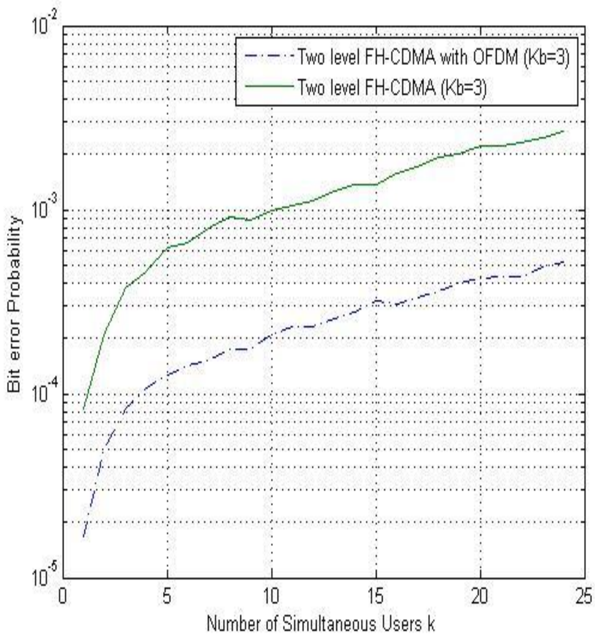

Fig. 5. BEPs of Two level FH-CDMA with and without OFDM versus Number of simultaneous users k over AWGN channel.

As we can see clearly the BEP is less while OFDM is implemented over Two level FH-CDMA by which the spectral efficiency is also increased with W_m=4,$M_m \times L_m$ =4×11 ,$M_h \times L_h$ =11×47, β_o ={3.4633, 3.5148}, k_b=3, Eb/No=25db and number of sub carriers=52 using 16-QAM and similarly the performance is evaluated in Rayleigh channel which is shown below.

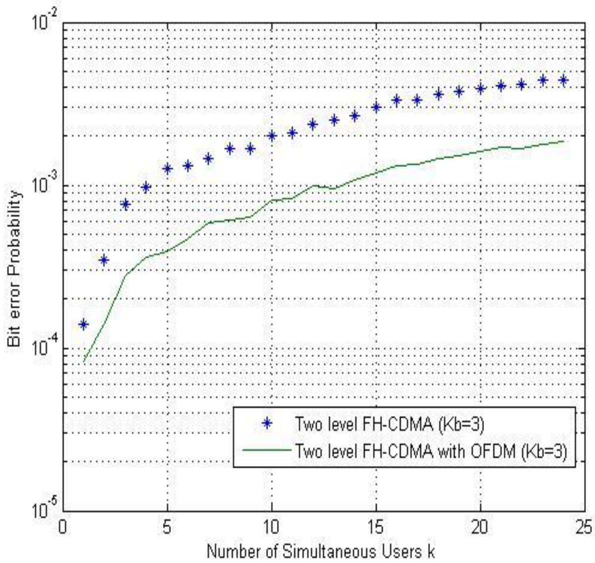

Fig. 6. BEPs of Two level FH-CDMA with and without OFDM versus Number of simultaneous users k over Rayleigh channel.

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There is no much difference in the performance of OFDM in Rayleigh channel compared to AWGN channel and also the parameters used are similar, which are W_m=4,M_m×L_m =4×11 ,M_h×L_h =11×47, β_o ={3.4633, 3.5148}, k_b=3, Eb/No=25db and number of sub carriers=52 using 16-QAM.

V. CONCLUSION

In this paper, we proposed a two-level FH-CDMA scheme with OFDM. The prime/FH-CDMA and RS/FH-CDMA schemes were special cases of our scheme. The performance analysis showed that the two-level FH-CDMA scheme provided a trade-off between number of users and data rate. The partitioned two-level FH-CDMA scheme increased the number of possible users and exhibited greater spectral efficiency. In addition to this, OFDM minimizes the BEP by providing further orthogonality to the system making more reliable.

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