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Wireless Communication Systems over Fading Channels using Bi-Level FH-CDMA Method

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Abstract-In this work, a "bi-level" frequency hopping code-division multiple-access (FH-CDMA) scheme for wireless communication systems has been proposed. The new method provides flexibility in the range of modulation codes and FH models. By dividing the modulation codes, bi-level scheme can be modified to carry more possible users without increasing the number of FH models. The performance and spectral efficiency of the scheme are examined. The results show that the divided bi-level FH-CDMA scheme supports higher data rate and greater spectral efficiency than Frequency-shift-keying FH-CDMA scheme.

***Index Terms*—Code Division Multiple Access, Modulation Codes, Frequency Hopping, Spectral Efficiency.**

I. INTRODUCTION

Frequency Hopping Code Division Multiple Access (FH-CDMA) provides frequency range and helps ease multi-path fading and vary intervention [1], [2]. The advantages of FH-CDMA over Direct-Sequence DS-CDMA [3], [4] include better resistance to multiple access interfering (MAI), less rigorous power control, and reduced "near-far" problem and multi-path interfering. By conveying a unique FH model to each user, a FH-CDMA system allows multiple users to share the same transmission channel concurrently [5], [6]. MAI occurs when more than one simultaneous user make use of the same carrier frequency in the same time slot. "One-hit" FH models have been designed in order to minimize MAI [7], [8].

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-Solomon (RS) sequences as modulation codes atop FH-CDMA were proposed [9], [10], in which the symbols were represented by non-orthogonal sequences, rather than orthogonal MFSK. These prime FH-CDMA [9] and RS FH-CDMA [10] methods supported higher data rate than MFSK FH-CDMA scheme [5], at the expense of worse performance. However, the weights and lengths 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.

A new Bi-level FH-CDMA scheme has been proposed in which both modulation codes and FH models do not need to have the same weight/length anymore. 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 modulated FH-CDMA methods because each element of the modulation codes needs to be conveyed by an element of the FH models. Therefore, bi-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 cases 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, the divided bi-level FH-CDMA method allows the assignment of the same FH model to multiple users, thus maximizing the number of possible users. The performance of bi-level FH-CDMA method over additive white Gaussian noise (AWGN), and fading channels are analyzed algebraically. While previous analyses [5], [9], [10] used a constant βo to approximate the "false-alarm" and removal probabilities caused by additive noise or fading, we include a more accurate model of βo better reflecting the actual effects of "false alarms" and deletions to the method performance. The new method with MFSK/FH-CDMA method in terms of performance and a more meaningful metric, spectral efficiency (SE) has been compared. Numerical examples show that bi-level FH-CDMA method provides a trade-off between performance and data rate. In the comparison of SE, the divided two-level FH-CDMA method displays better system efficiency than MFSK/FH-CDMA method under some constraints.

II. NARRATION OF BI-LEVEL FH-CDMA METHOD

A. *Bi-level FH-CDMA Method*

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

TABLE I

	Group 0	Group 1	Group 2	Group 3	Group 4
I2	i1=0	i1=1	i1=2	i1=3	i1=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

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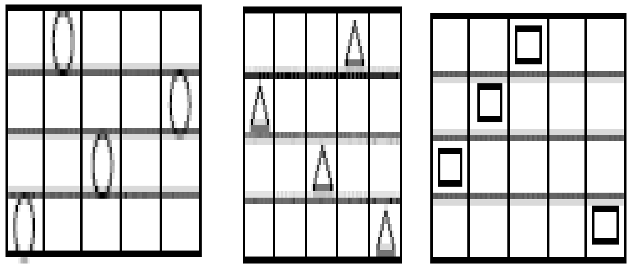
If there is Φ_m available modulation codes, each symbol can represent up to [$\log_2 \Phi_m$] data bits, where [.] is the floor function. In the second (FH) level, each user is assigned a unique FH pattern of dimension $M_h \times L_h$ and weight W_h, where M_h is the number of frequencies, L_h is the number of time slots (i.e., pattern length). The elements in the modulation codes and FH models conclude the carrier frequencies of the final FH-CDMA signals. While an element of a modulation code defines 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. In proposed method families of ($M_m \times L_m, W_m, \lambda_{a,m}, \lambda_{c,m}$) 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. If the data symbols of these users are S1=S3,0 = (0,3,1,x,2),S2= S2,2 = (2, x, 1, 3, 0) ,S3= S1,1 = (1, 2, 3, x,0)

Symbol 3 symbol 12 symbol 6

S3,0 = (0,3,1,x,2) S2,2 = (2, x, 1, 3, 0) S1,1 = (1, 2, 3, x,0)



FH Pattern FH pattern FH pattern

H1= (0, 2, 4, x, 1, 3, x) H2 = (0, 4, 1, x, 2, x, 3) H3 = (3, 1, x, 4, 2, 0, x)

Element of $S_{i1,i2}$ determines which carrier frequency of a frequency band in a given time slot to use. $S_{i1,i2,l} = i_2 \oplus_p (i_1 \otimes_p l)$ [$\oplus$ – Modulo p addition, $\otimes$ -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 $W_m < P$ by dropping the largest p - W_m elements in $S_{i1,i2}$. As a result, the construction algorithm gives $\Phi_m = P^2 - P + W_m$ prime sequences[1] of weight $W_m \leq P$ and length $L_m = P$ with, $\lambda_{c,m} = 1$ (i.e., symbol interference).For example, with P = 5 and Wm. = 4, TableI shows twenty-four($M_m \times L_m, W_m, \lambda_{a,m}, \lambda_{c,m}$)=(4×5,4,0,1) prime sequences , where "x" denotes the drop of the fifth element in order to have a code weight of four. 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 × 7, 5, 0, 1) prime sequences as the one-hit FH models are Transmitting signal Transmitting signal transmitting signal

where , $\lambda_{a,m}$, $\lambda_{a,h}$ and $\lambda_{c,m}$, $\lambda_{c,h}$ denote the maximum autocorrelation and cross-correlation values of the modulation codes (FH models), respectively. To illustrate the main concept of bi-level FH-CDMA method, the prime sequences [8] as the modulation codes are used; other codes, such as the RS sequences [7], quadratic congruence codes (QCCs) [11], and multilevel prime codes (MPCs) [12], can also be used. The prime sequences are constructed in Galois field GF (p) of a prime number p. Each prime sequence of weight W_m. =p. is denoted by $S_{i1,i2}$. = ($S_{i1,i2,0}$, $S_{i1,i2,1}$…., $S_{i1,i2,l}$…., . . . , $S_{i1,i2,p-1}$). These prime sequences are used as the modulation codes, each chosen and the top sixteen ($M_m \times L_m, W_m, \lambda_{a,m}, \lambda_{c,m}$)

T1 = (0, 11, 17, x, x, 14, x) T2 = (2, x,5,x, 11, x,12) T3 = (13, 6, x, 19, x, 0, x)

The carrier frequency used in each frequency band in a time slot is determined by superimposing (element by element) all Wm=4 elements of S1 on top of this the first Wm non-"X" elements of Hk, 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 coloums in the transmitting signals, Tk of Fig 1 represent the frequency bands specified by the corresponding FH models , Hk, for K={1,2,3,}. In review two level frequency hopping CDMA can be represented by Tk=(Tk,0, Tk,1……Tkj, …TkL,h-1= Sk (Mm Hk), where Tk,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 T1=(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 T2=(2,x,5,x,11,x,12) and T3=(13,6,x,19,x,0,x)

In receiver , received two level FH CDMA signals of all users and effects of MAI, fading and noise (i.e., hits , deletion, false alarms) are hard limited , dehopped and finally decoded in order to recover transmitted data symbols. Fig 2 illustrates decoding and detection process of user 1. received signal is first hard limited and then dehopped by user 1's FH pattern to give a dehopped signal R1 of dimension 4*5 .The role of the dehopping process simply brings the frequency bands in each time slot of *back* to the base band, according to the frequency bands specified by H1. The elements of R1 are compared with the elements of all modulation codes in use. The modulation code (e.g., S3,0, with its elements shown as circles in Fig. 2) with the minimum distance from the shaded slots of ..1 is chosen as the recovered symbol.

Although the prime sequences can only support up to $\log_2(p^2 - p + w_m)$ 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 [11], and MPCs [12], as the modulation codes. For example, the MPCs have p^{n+1} sequences of weight $w_m = p$ *and* length = Lm = p with $\lambda_{c,m}$. = *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

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to $[\log_2 p^{n+1}]$ bit/symbol at expense of worsened performance.

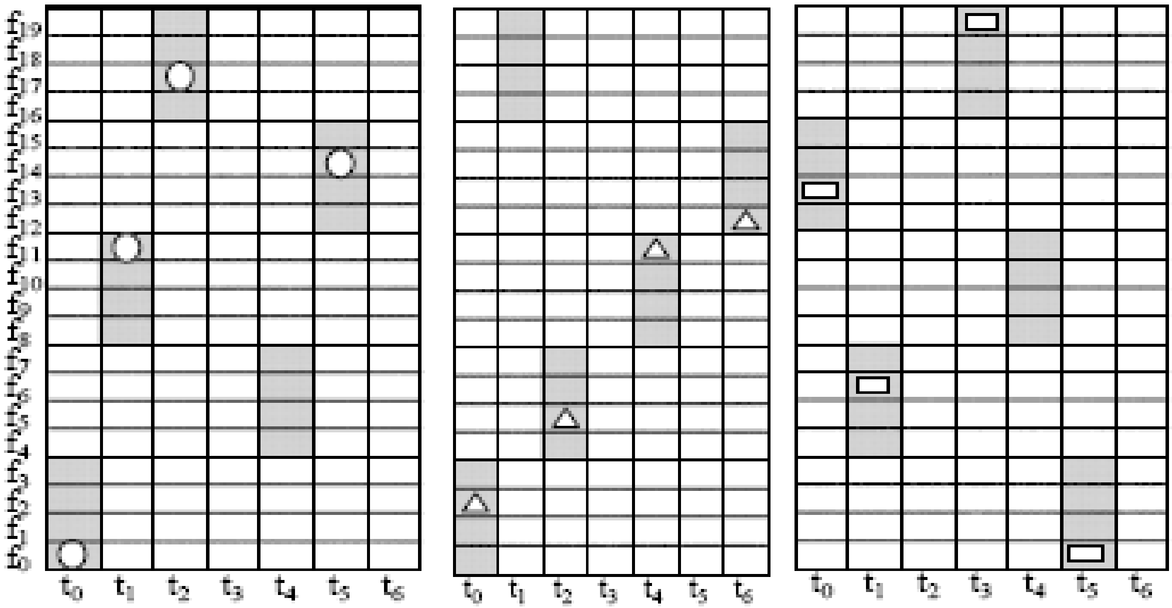

Figure-1 Encoding Process of Bilevel FH CDMA

to t1 t2 t3 t4 t5 t6 respectively. Let the one-hit FH models of these three users be $H_1 = (0, 2, 4, X, 1, 3,)$, $H_2 = (0, 4, 1, 2, X, 3)$ and H3= (3, 1, X, 4, 2, 0) Figure 2 is shown in Appendix.

(***Partitioned Two-level FH-CDMA Scheme***)

In general, the number of possible users in a FH-CDMA system is limited by the number of available FH patterns. However, our two-level FH-CDMA scheme can flexibly increase the number of possible users by trading for lower data rate through a reduction of symbol size. It is done by partitioning the modulation codes into several groups and each group contains reduced number of modulation codes with a lower $\lambda_{c,m}$ each user can now only use one group of modulation codes for symbol representation. In addition to the unique FH pattern assigned to a user, the group of modulation codes that the user can use adds another degree of user address signature. The same FH pattern can now be reused by multiple users as long as they have different groups of modulation codes. Let say there are ϕ_h FH patterns and ϕ_m modulation codes with $\lambda_{c,m}$. If the modulation codes are partitioned into t groups of codes with $\lambda^1_{c,m}$. (Usually, the partition results in $\lambda^1_{c,m} = \lambda_{c,m} - 1$.) We can then assign each user with one FH pattern and one of these t groups of modulation codes, thus supporting a total of t. ϕ_h possible users. The tradeoff is that each group now has at most ϕ_m/t *modulation* codes and thus the number of bits per symbol is lowered from log $_2\,\phi_m$. to .log $_2\,(\frac{\phi_m}{t})$. For example, the twenty-four $\lambda_{c,m}$ = 1 prime sequences in Table I can be partitioned into five groups of prime sequences of $\lambda^1_{c,m}$ = 0 and assigned to five different users with the same FH pattern. Although the number of bits represented by each symbol decreases from .log $_2$ 24. to .log $_2$ 5., the number of possible users is now increased from ϕ_h to 5 ϕ_h. We can also choose the MPCs of length *p* and $\lambda_{c,m}$. =n as the modulation codes. As shown in [12], the MPCs can be partitioned into p^{n-n^1} groups and each group has $\lambda^1_{c,m}$ = n^1 and $\phi_m = p^{n+1}$, where $n > n^1$. The number of possible users is increased to $\phi_h\, p^{n-n^1}$, but the number of bits per symbol is reduced to .log $_2\, P^{n^1+1}$

III. PERFORMANCE ANALYSIS

In FH-CDMA systems, 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 (symbol) 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 $M_m * M_h$ frequencies, in which M_m frequencies are used to carry the modulation codes of weight w_m The probability that a frequency of an interferer hits with one of the frequencies of the desired user is given by

$$q = \frac{w}{M_m M_h L_h} \rightarrow \quad (1)$$

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Volume 2, Issue 3, September 2012

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

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 [14]

$$\rightarrow \quad P_f = \exp\left(\frac{-\beta_0^2}{2}\right) \quad \rightarrow (3)$$

For an AWGN channel, the deletion probability is given by [15]

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

Where β_0 denotes the actual threshold divided by the root mean- squared receiver noise,.... is the number of bits per symbol, E_b/N_0 is the average bit-to-noise density radio, $Q(a,b) = \int_b^{\infty} x.*.\exp[-(a^2 + x^2)/2] I_0(ax)*dx$ is Marcum's Q function, and $I_0(\cdot)$ is the modified Bessel function of the first kind and zeroth order. To minimize the error probability, the optimal β_0 of an AWGN channel should be a function of the signal-to-noise ratio (SNR), E_b/N_0 and K_b/w_m can be more accurately written as [14]

$$\beta_o = \sqrt{2 + \frac{(E_b / N_0).\left(\frac{k_b}{w_m}\right)}{2}} \quad \rightarrow (5)$$

rather than an inaccurate constant value (i.e. $\beta_0 = 3$, used in [5], [9], [10]).

For a Rayleigh fading channel, the deletion probability is given by [14]

$$p_d = 1 - \exp\left\{\frac{-\beta_0^2}{2 + 2(E_b / N_0).(k_b / w_m)}\right\} \quad \rightarrow (6)$$

Similarly, the optimal β_0 of a Rayleigh fading channel can be more accurately written as [14]

$$\beta_0 = \sqrt{2 + 2/\left(\frac{E_b}{N_0}\right) * \left(\frac{K_b}{w_m}\right)} * \sqrt{\log\left[1 + \left(\frac{E_b}{N_0}\right) * \left(\frac{K_b}{w_m}\right)\right]} \quad \rightarrow (7)$$

Finally, for a Rician fading channel, the deletion probability is given by [14]

$$p_d = \left[1 - Q\left(\sqrt{\frac{2p(E_b / N_o) * \left(\frac{k_b}{w_m}\right)}{1 + p + \left(\frac{E_b}{N_o}\right) * \left(\frac{k_b}{w_m}\right)}} * \beta 1\right)\right] \quad \rightarrow (8)$$

Where the Rician factor p is given as the ratio of the power in specular components to the power in multipath components [16]. Similarly β_0 and β_1 can be more accurately written as [14]

$$\beta_o = \sqrt{2 + \frac{(E_b / N_0).\left(\frac{k_b}{w_m}\right)}{2}} \quad \rightarrow (9)$$

$$\beta_1 = \frac{\beta_0}{\sqrt{1 + (E_b / N_o).(k_b / w_m) / (1 + \rho)}} \quad \rightarrow (10)$$

Including the noise or fading effect, the probability that the dehopped signal contains.. Entries in an undesired row is given by [5], [8], [15]

$$P_s(n) = \sum_{j=0}^{n} \sum_{r=0}^{\min[n-j, w_m - n]} \left[P(n-j)\binom{n-j}{r} * P_d^r (1-P_d)^{n-j-r} \binom{w_m - n + j}{r+j}\right] * p_f^{r+j} (1-p_f)^{w_m - n - r}$$
$$+ \sum_{j=1}^{w_m - n} \sum^{\min(n+j, w_m - n} \left[P(n+j)\binom{n+j}{r}\right] X\, p_d^{r} (1-p_d)^{n+j-r} \binom{w_m - n - j}{r - j}$$
$$X\, p_f^{r-j} (1-p_f)^{w_m - n - r} \quad \rightarrow (11)$$

In FH-CDMA systems, an error occurs when interference causes undesired rows in the dehopped signal to have equal or more entries than the desired rows. In addition, an error may still occur in our two-level FH-CDMA scheme even when the undesired rows have fewer entries than the desired rows. It is because the nonzero cross-correlation values of the modulation codes add extra undesired entries. To account for this, let A_i^z 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 $i \in [1, \lambda_{c,m}]$. To account for the effect of $\lambda_{c,m} \neq 0$, we derive a new probability of having a peak of z as

$$P_S^1(z) = A_{\lambda c,m}^z P_S(z - \lambda_{c,m}) + A_{\lambda_{c,m}}^z - 1 * P_S(z - (\lambda_{c,m} - 1)) +$$
$$\ldots. + A_1^z P_S(z-1) + (1 - \sum_{t=1}^{\lambda_{c,m}} A_t^{z+t}) P_S(z) \quad \rightarrow (12)$$

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Where $A_t^{z+t} = 0$ when $z + t > w_m$.

If there are 2^{k_b} -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 [5], [8], [15]

$$p_r(n,t) = \binom{2^{kb-1}}{t}[p_s^1(n)]^t\left[\sum_{m=0}^{n-1} p_s^1(m)\right]^{2^{K_b}-1-t} \rightarrow (13)$$

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

$$p_c(n) = \binom{w_m}{n}(1-p_d)^n(p_d)^{w_m-n} \rightarrow (14)$$

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^{K_b} symbols) is recovered by searching for the modulation code with the largest matching entries, the bit error probability (BEP) is finally given by [5], [8], [15]

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

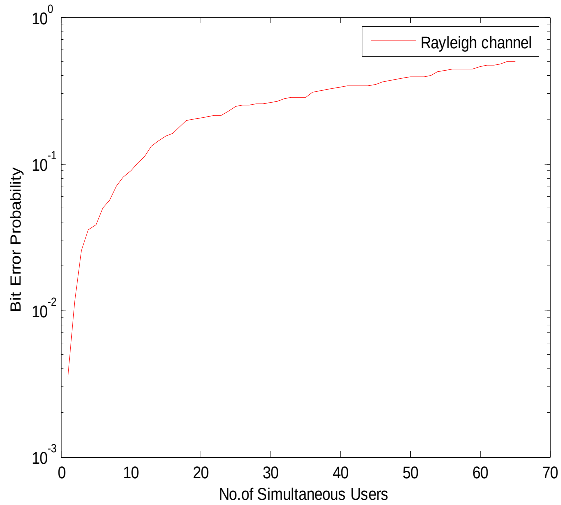

Fig 3, BEP of Rayleigh Channel Using Bi- Level FH CDMA for No. Of Simultaneous Users

IV. PERFORMANCE AND SE COMPARISONS

In this section, we compare the performances of the new two-level FH-CDMA and Goodman's MFSK/FH-CDMA schemes under the condition of same transmission parameters: *Mg* =Mm*M*h*, Lg =Lh, and $w_g = w_h$, where Mg, Lg and w_g are the number of frequencies, number of time slots and weight of FH patterns utilized by Goodman's MFSK/FHCDMA scheme, respectively.

As illustrated in [17], the prime sequences may give at most two hits in Goodman's MFSK/FHCDMA scheme under a symbol-asynchronous assumption. The main difference is that Goodman's MFSK/FH-CDMA scheme supports Mg. modulation symbols (represented by the orthogonal frequencies), while the two-level FH-CDMA scheme supports p^2-p+w_m symbols with the symbol interference level $\lambda_{c,m}$ = 1 if the prime sequences in Section II are used as the modulation codes. This symbol interference is accounted for by the probability term $P_s^1(z)$ in (12). In Fig. 3, the BEPs of Bi level FH-CDMA scheme is plotted against the number of simultaneous users .. over a Rayleigh fading channel, based on the condition of same transmission parameters, where M*g.*× Lg = 44×47, $w_g = w_m$ = 4,Mm×Lm = 4×11, Mh ×Lh = 11×47, and Eb/No. = 25 dB. Using p = 11, our two-level FH-CDMA scheme supports Kb = 6 bits/symbol, while Goodman's MFSK/FH-CDMA scheme supports Kb = 5 bits/symbol. Based on (7) and Kb. = *{*5, 6*}*, we more accurately calculate β_0 = *{*3.4633, 3.5148*}*, respectively, instead of the constant β_0 = 3 used in [5], [9], and [10]. In general, the performance of our scheme is worse than that of Goodman's scheme because of the additional symbol interference created by the prime sequences. In our partitioned two-level FH-CDMA scheme, the modulation codes (e.g., the prime sequences) are partitioned into *P* groups and the cross-correlation values of each group are zero (i.e. zero symbol interference). We then have A_c^z = 0 and $P_s^1(z)$=Ps(z) . In Goodman's MFSK/FH-CDMA scheme, we can also partition Mg frequency bands into P sub bands to achieve the same number of possible users as our partitioned two-level FH-CDMA scheme. However, the number of data bits per symbol in Goodman's scheme is decreased to Kb = $\log_2$ (Mg/P) In Fig. 4, the BEPs of both schemes over a Rayleigh fading channel are plotted against the number of simultaneous users based on the conditions of same number of possible users and same transmission parameters, where Mg ×*Lg.* = 44 × 47, $w_g = w_m$ = 4, Mm×Lm = 4×11, Mh ×Lh = 11×47, and Eb/No. = 25 dB. Our partitioned scheme supports Kb = 3 bits/symbol, while Goodman's scheme supports Kb = 2 bits/symbol. Based on (7) and Kb = *{*2, 3*}*, we more accurately calculate 0 = *{*3.1943, 3.3154*}*, respectively, instead of the constant β_0 = 3 used in [5], [9], and [10]. The performance of our partitioned scheme is very comparable to that of Goodman's scheme.

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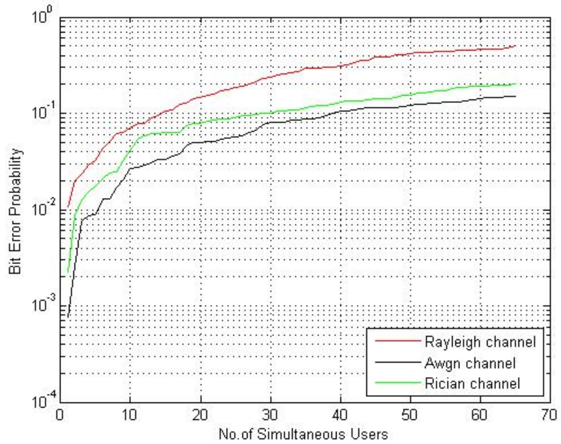

Fig. 4, BEPS of Our Two-Level FH-CDMA Scheme under AWGN, Rayleigh and Rician Fading Channels

Table II Spectral Efficiency (Se) Comparison Of Both Schemes With Pe = {10^{-2}, 10^{-3}}, Based On The Parameters.

Bit error probability	$Pe=10^{-2}$	$Pe=10^{-3}$
Goodman's FH-CDMA (kb = 2)	K=144 SE=13.93%	K=56 SE=5.42%
Two-level FH-CDMA (kb = 3)	K=126 SE=18.29%	K=56 SE=5.42%

plotted against the number of simultaneous users K, where w_m = 4, Mm×Lm = 4×11, Mh ×Lh = 11×47, p = 13, Kb= 6, and Eb/No. = 25 dB. Based on (5), (7), (9), and (10), we more accurately calculate β_0 and $\beta 1$, which are given in Fig. 5. As expected, the AWGN curve always performs the best and the Rayleigh curve performs the worse, while the Rician curve is in between. To compare our partitioned two-level FH-CDMA and Goodman's MFSK/FH-CDMA schemes,

$$SE=Kb*K/M*L \qquad \rightarrow (16)$$

is another figure of merits, which considers the number of bits per symbol Kb, number of simultaneous users K, number of carrier frequencies M, and number of time slots L as a whole, for a given performance (i.e., BEP) [18]. Our goal is to get the SE as large as possible for better system efficiency or utilization. Table II compares the SEs of both schemes with fixed Pe. = {10^{-2}, $Pe=10^{-3}$}, based on the parameters from Fig. 4. In our partitioned two-level FH-CDMA scheme, we can always increase the number of possible users by partitioning the modulation codes, thus resulting in a larger Kb than Goodman's FH-CDMA scheme for the same bandwidth expansion (i.e ML). While the number of simultaneous users K of our partitioned two-level FH-CDMA scheme is only slightly less than that of Goodman's FH-CDMA scheme in Fig. 4, the larger Kb results in a net gain in the SE, as shown in Table II.

Combining with higher data rate, greater SE, and Flexible selection of modulation codes and FH patterns, our two-level FH-CDMA scheme is a better choice in meeting various system operating criteria.

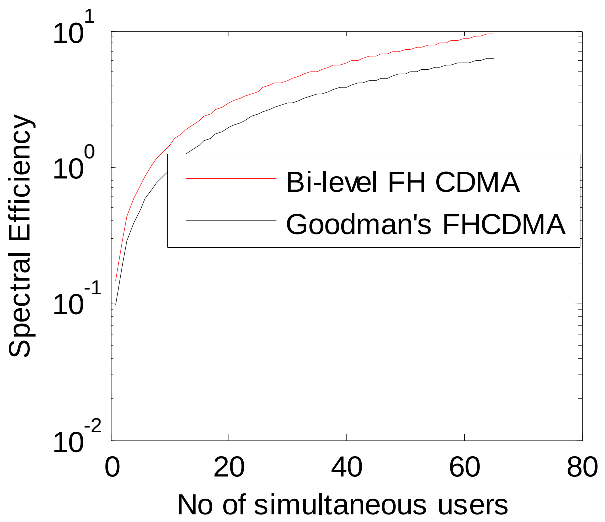

Fig 5, Spectral Efficiency Plot of Bi level FH CDMA & Goodman's FHCDMA

V. CONCLUSION

In this paper, we proposed a new two-level FH-CDMA scheme. The prime/FH-CDMA and RS/FH-CDMA schemes were special cases of our scheme. The performance analyses showed that the two-level FH-CDMA scheme provided a trade-off between performance and data rate. The partitioned two-level FH-CDMA scheme increased the number of possible users and exhibited higher data rate and greater SE than Goodman's MFSK/FH-CDMA scheme. In summary, the new scheme offered more flexibility in the design of FH-CDMA systems to meet different operating requirements.

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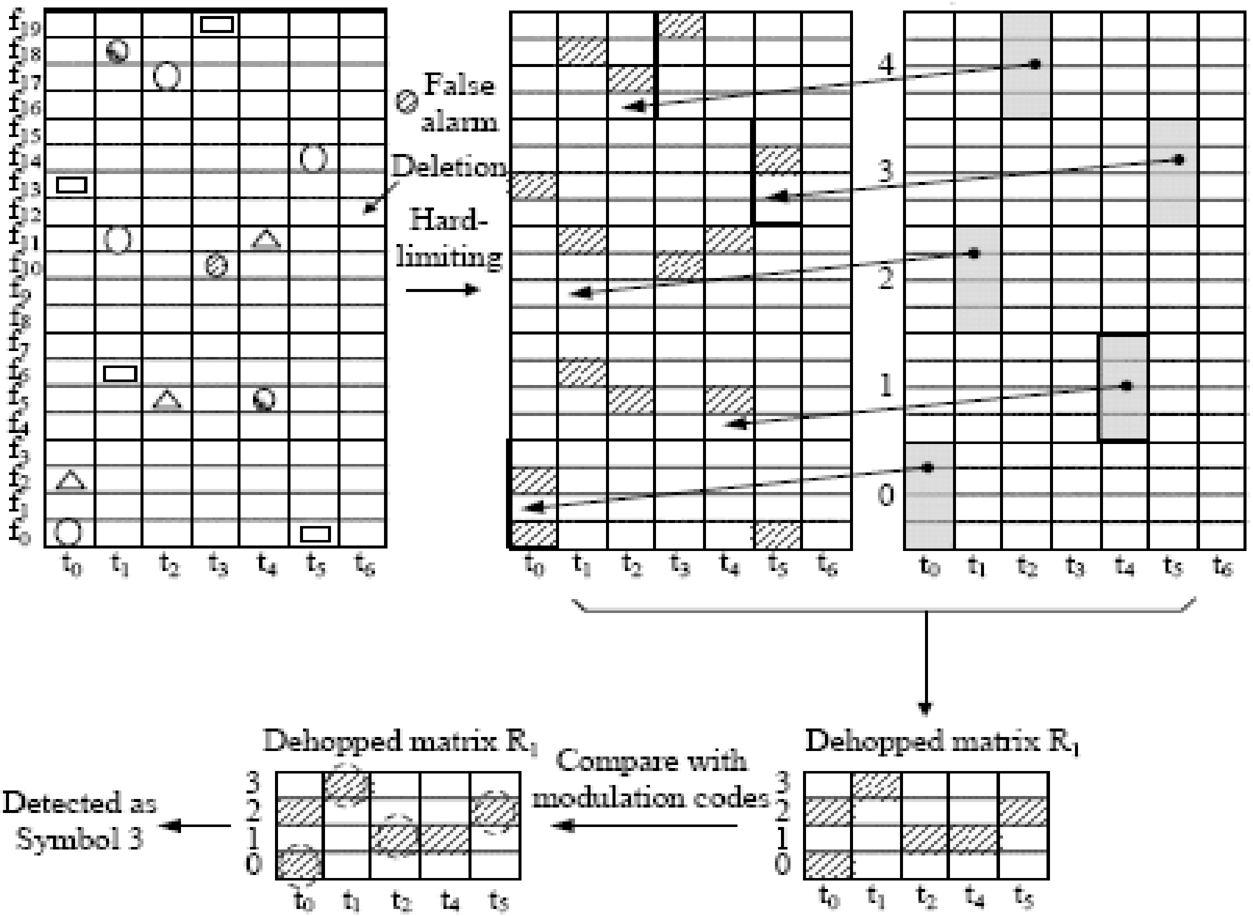

Fig.2. Decoding process of Bi-level FH CDMA