연판정 리미터와 결합된 FH/MFSK 시스템의 다중사용자 검출 방법

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Multiuser Detection Combined with Soft Limiter in FH/MFSK System

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요 약

본 논문에서는 FH/MFSK(Frequency-Hopping Multilevel FSK) 시스템의 다중사용자 검출 방법으로서 경판정 리미터 대신 연판정 리미터를 사용한 변형된 Fiebig의 REC(REduction of the number of Candidate symbols) 알고리즘을 제안하였다. 이 변형된 REC 알고리즘의 성능은 전산 실험으로 확인되었다. 고려한 시스템 변수에 대하여 시스템 용량은 같은 오류확률에서 기존 알고리즘에 비해 약 5% 내외로 증가되었다.

ABSTRACT

In this paper, we proposed a simple modification on Fiebig's REC algorithm for multiuser detection of FH/MFSK systems replacing hard limiter with soft limiter. The performance improvement of our modified REC algorithm has been confirmed with computer simulations. For the parameter of interest, the capacity could be increased about 5% or more without degrading the reliability.

Ⅰ. Introduction

Since multiuser interference in a spread spectrum multiple access (SSMA) system seriously limits the capacity, several algorithms have been developed to reduce this interference. In case of FH/MFSK (Frequency-Hopping Multilevel FSK)[1], maximum likelihood joint detection was proposed for an optimal multiuser detection method irrespective of hopping patterns[2], while Timor's multistage decoding takes advantage of RS code hopping pattern structure[3]. The former algorithm, however, takes too much time to decode symbols for large system parameters. This problem could be resolved by Fiebig's REC (REduction of the number of Candidate symbols) algorithm[4].

In the presence of Rayleigh fading, it is well known that a FH/MFSK receiver with soft limiter gives better performance than one with hard limiter provided the conventional detection scheme is used[5]. When Timor's multistage decoding algorithm is appended after hard-limited decoding in this channel, some small changes are needed because of deletions of transmitted signals and additional detections induced by channel impairment[6]. For Fiebig's REC algorithm, similar modification might be needed. However, since information from soft-limited decoding has never been used in multiuser detection algorithms, we tried to utilize this elaborate information by modifying REC algorithm.

In the following section, we describe the FH/MFSK system model briefly. Then the

modified REC algorithm is represented. It was also shown by computer simulations that the proposed modification increased the capacity about 5% or more in terms of the number of users at a given bit error rate 10^{-3}, compared with the existing REC algorithm.

II. System Description

The FH/MFSK system model in this paper is referred to Goodman et al[1]. The address assignment scheme throughout our simulation is to use shortened RS codes as hopping patterns, which are known to be optimal[7]. Since FSK modulation is used, the receiver has to detect signal energy noncoherently in all frequency slots for each chip, and then, combine these chip energies after despreading with respect to each user's address. Before combining, hard limiter or soft limiter can be used to improve performance. Figure 1 represents the FH/MFSK receiver where M is the number of hopping frequency slots corresponding to the number of message symbols and L is the number of symbol repetitions.

A detected slot i and chip l with energy R_{il} passes the nonlinear function f which is either $f_H(R)$ or $f_S(R)$ according to the type of limiters, hard or soft, as follows.

$$Z_j = \sum_{l=0}^{L-1} f(R_{jl}) \quad , \hat{Z}_m = Max\, Z_j$$
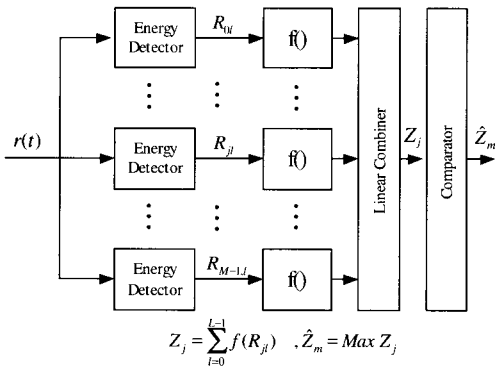
Fig. 1. FH/MFSK receiver model

$$f_H(R) = \begin{cases} 1 & R > T_H, \\ 0 & otherwise \end{cases} \quad (1)$$

$$f_S(R) = \begin{cases} T_s & R > T_S, \\ R & otherwise \end{cases} \quad (2)$$

In the presence of Rayleigh fading, hard limiter's theoretical threshold value T_H can be derived as in [8]

$$T_H = E_t \cdot N_0/2, \quad E_t = 2(1 + \frac{1}{\gamma_c}) \ln(1 + \overline{\gamma_c}) \quad (3)$$

where $\overline{\gamma_c} = \overline{E_c}/N_0 = (\overline{E_b}/N_0)(k/L)$ is the average received signal-to-noise ratio per chip. Soft limiter's threshold value T_S is known to be a good choice when it is approximately twice the hard limiter's T_H, that is $T_S \approx 2T_H$, as long as it is used without multiuser detection[5].

III. Multiuser Detection

At the receiver, two stage decoding can be used to accommodate more users. The first stage decoder is the conventional decoder with hard limiter or soft limiter, and the second is interference canceller or multiuser detector such as REC algorithm. Since it is well known that soft limiter performs better in the first stage we tried to use the soft-limited result in the second stage, hoping for some improvement. Before describing our modified REC algorithm, Fiebig's original REC algorithm using hard limiter in the interference only (IO) channel is reviewed[4][9].

[STEP 1] Generate all despread matrices D_k, $k = 1, 2, \cdots, K$ and identify all $n_k^{(0)}$ full rows in D_k; thus, there are $n_k^{(0)}$ candidate symbols for m_k.

[STEP 2] Apply sth iteration, $s = 1, 2, \cdots, s_{max}$:
step 2-1: For each user: Generate $n_k^{(s-1)}$ candidate transmit matrices $T_{k,i}$, $1 \le i \le n_k^{(s-1)}$ corresponding to the $n_k^{(s-1)}$ candidate symbols for m_k.

step 2-2: Generate matrix $B^{(s)}$ whose elements $b_{ml}^{(s)}$ are obtained as

$$b_{ml}^{(s)} = \sum_{k=1}^{K} \sum_{i=1}^{n_k^{(s-1)}} t_{ml}^{(k,i)}$$

where $t_{ml}^{(k,i)}$ is the element of the mth row and lth column of $T_{k,i}$.

step 2-3: For each user with $n_k^{(s-1)} > 1$: Based on $B^{(s)}$, generate the despread matrix $D_k^{(s)}$ and check those rows of $D_k^{(s)}$ which have been identified as ambiguity rows in D_k. If one of these rows contains an element valued 1, decide for the corresponding symbol and set $n_k^{(s)} = 1$; otherwise no symbol decision is made and set $n_k^{(s)} = n_k^{(s-1)}$.

[STEP 3] No further iteration has to be carried out if either all ambiguities have been resolved - type-1-stop of the algorithm providing ML joint detection - or if the last iteration has resolved none of the remaining ambiguities - type-N-stop of the algorithm. The latter case requires further processing: Either conventional detection where a random decision is carried out among the remaining candidate symbols, or straightforward ML joint detection.

Now, we propose the modified REC algorithm using soft limiter in the Rayleigh fading channel with AWGN noise. The messages of soft-limited decoding which are thought to be more reliable than those of hard-limited decoding can be used additionally in Fiebig's REC algorithm to enhance the performance. In the IO channel, the hard-limited received matrix R has at least one complete row. However, when the effect of fading and thermal noise is taken into account, the probability of both chip deletion and chip insertion will not be zero. Therefore, we can not be sure whether each user's D_k has a candidate corresponding to one's transmitted message. Since more reliable candidates we can select less errors will occur in REC algorithm, the information of soft-limited decoding is additionally used in selecting candidate symbols for the second stage. The following M_STEP 1 is our modification of

STEP 1.

[M_STEP 1]

step 1-1: Make the received matrix R using a soft limiter as shown in (2) and generate each user's despread matrix D_k, $k = 1, 2, \cdots, K$, composed of soft-limited values from this matrix R. Then, perform soft-limited decoding and determine each user's candidate messages.

step 1-2: Regenerate the binary matrix D_k by hard-limiting all the elements in D_k, and identify all $n_k^{(0)}$ maximum rows in D_k.

step 1-3: Only when there is unique maximum row in step 1-2 without ambiguity i.e., $n_k^{(0)} = 1$, compare this candidate with the maximum row in step 1-1. If two maxima are different, add the maximum row in step 1-1 to the candidate list; thus, which make $n_k^{(0)} = 2$.

In step 1-3, we have observed that in a non-negligible amount of cases two maxima turned out to be different. Since it has low probabilities that one of two or more candidates in the hard-limited despread matrix does not agree with the maximum row in the soft-limited despread matrix, we consider in step 1-3 only the case where the number of maximum rows in the hard-limited despread matrix is one. When our modified REC algorithm is followed after conventional soft-limited decoding and hard-limited decoding, it could be noticed using computer simulation that a soft-limiter's threshold value should be almost equal to hard-limited one i.e., $T_S \approx T_H$. This may make implementation somewhat easy.

In the Rayleigh fading channel, such falsely detected or undetected chips make STEP 2 of REC algorithm to be changed as the following M_STEP 2. This step can also be used for the IO channel without any performance degradation.

[M_STEP 2] Apply sth iteration, $s = 1, 2, \cdots, s_{max}$:

step 2-1: The same as step 2-1 of STEP 2.

step 2-2: The same as step 2-2 of STEP 2.

step 2-3: For each user with $n_k^{(s-1)} > 1$: Based on $B^{(s)}$, generate the despread matrix $D_k^{(s)}$ and count the value '1' for each of those rows of $D_k^{(s)}$ which have been identified as ambiguity rows in D_k. if only one of these rows contains the largest element valued '1', determine this row for user number k's correct symbol and set $n_k^{(s)} = 1$; otherwise no symbol decision is made and set $n_k^{(s)} = n_k^{(s-1)}$.

Next, we consider M*_STEP 2 to reduce the complexity of M_STEP 2 in the Rayleigh fading channel, This alternative step will not degrade the system performance at moderate SNR with less complexity. In the IO channel, however, this modification results in bad performance, which is presented in the next section.

[M*_STEP 2] Apply sth iteration,

$$s = 1, 2, \cdots, s_{\max}:$$

step 2-1: Only for users with the number of candidates $n_k^{(s-1)} = 1$, $n_k^{(s-2)} \neq 1$: for users whose message are uniquely determined in $D_k^{(s-1)}$, generate a transmit matrix T_k.

step 2-2: Update matrix $B^{(s)}$ whose elements $b_{ml}^{(s)}$ are obtained as

$$b_{ml}^{(s)} = b_{ml}^{(s-1)} + \sum_{j=1}^{J_s} t_{ml}^{(k_j)}, \qquad b_{ml}^{(0)} = 0$$

where J_s is the number of users with candidates selected in step 2-1, k_j is the corresponding jth user index, and $t_{ml}^{(k_j)}$ is the element of the mth row and lth column of T_{k_j}.

step 2-3: The same as step 2-3 of M_STEP 2.

Since J_1 in the first iteration of M*_STEP 2 is almost equal to the number of the active users K when K is large with moderate SNR, the first iteration of M*_STEP 2 is little faster than that of M_STEP 2. But, J_s in the sth iteration

$s \geq 2$ of M*_STEP 2 is only a few, which means that the delay in the second iteration and after is much less than that in the first. Therefore, the delay in M*_STEP 2 can be reduced significantly after the first iteration compared to M_STEP 2.

Another modification of STEP 3 could be tried as the following. It, however, was proved to provide little gain compared with the previous step.

[M_STEP 3] If more than one candidate still remain, select the maximum row in the soft-limited despread matrix among the remainders.

The next section shows our simulation results for each modification and for those combination. Based on these results, best modification steps will be proposed over Rayleigh fading channel for FH/MFSK multiple access system.

Ⅳ. Simulation Results

We used RS code address assignment scheme over frequency non-selective Rayleigh fading channel whose variance is one with no Doppler effect and with AWGN noise. For simplicity, we assumed chip and word synchronous transmission. In such a noisy channel, we should use M_STEP 2 or M*_STEP 2 instead of STEP 2 of REC algorithm. If there is no comment about the second step, M_STEP 2 is assumed to be used throughout this section. All the threshold values throughout our simulation were determined by computer search to give best performance at BER= 10^{-3}.

First, we investigate the effect of M_STEP 1: STEP 1 of the existing REC algorithm is compared with M_STEP 1. Figure 2 shows their BER curves by varying the number of users when the number M of frequency slots is 256 and the number L of chips per symbol is 19 at Eb/No=25dB. The result for $M = 512$ and $L = 11$ is shown in Fig. 3 at the same Eb/No. These system parameters are selected according to [10]

and for the comparison with the results in [9].

It should be noted that ML joint detection in STEP 3, compared with random choosing, has little gain that is negligible when the parameters of Fig. 2 and 3 are considered.[4][9] In STEP 3 of our simulation, therefore, random choosing was used. In each figure, "hard CD (conventional decoding)" means that only hard-limited decoding without REC algorithm is used, similarly for "soft CD." "REC M1" means STEP 1 was replaced with M_STEP 1. Those figures show that the newly added candidates in M_STEP 1 make it possible to accommodate more users at a given error rate.
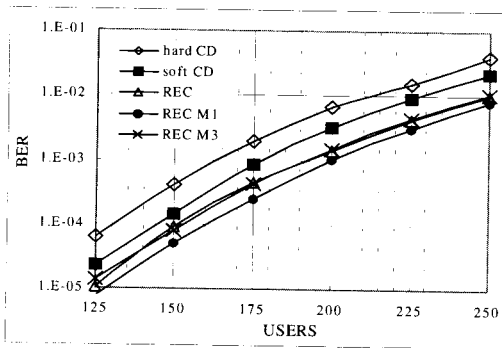

Fig. 2. The modification effects of M_STEP 1 and M_STEP 3 in the Rayleigh fading channel when M=256, L=19, Eb/No=25dB and RS code address assignment scheme is used.
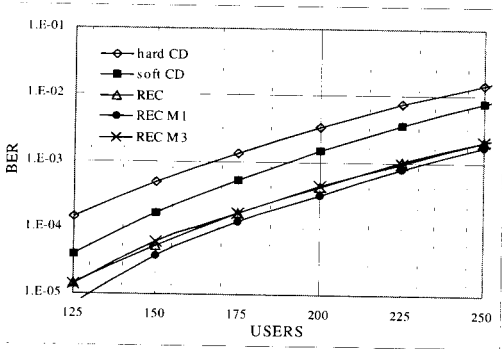

Fig. 3. The modification effect of M_STEP 1 and M_STEP 3 in the Rayleigh fading channel when M=512, L=11, Eb/No=25dB and RS code address assignment scheme is used.

The effect of M_STEP 3 is also given in Fig.

2 and 3 as "REC M3", where "REC" and "REC M3" show the almost same performance. Thus, it can be noticed that candidates remained after the candidate reduction steps cannot be resolved by soft-limited values. Therefore, M_STEP 3 will not be considered from now on.
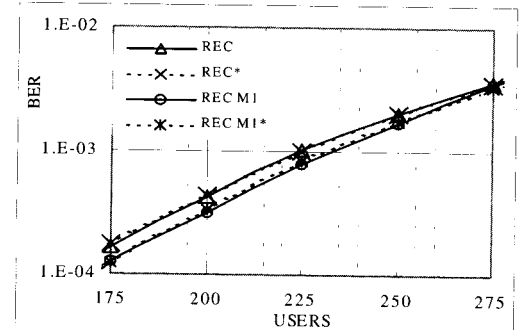

Fig. 4. The comparison of M_STEP 2 and M*_STEP 2 in the Rayleigh fading channel when M=512, L=11, Eb/No=25dB and RS code address assignment scheme is used.
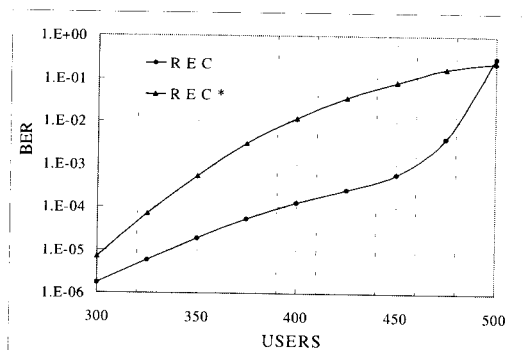

Fig. 5. The comparison of M_STEP 2 and M*_STEP 2 in the IO channel when M=512, L=11 and RS code address assignment scheme is used.

Next, we show that M*_STEP 2 can be replaced with M_STEP 2 without performance degradation. Figure 4 shows BER curves with the same system parameters as Fig. 3. "REC" and "REC M1" in these figures use basically M_STEP 2 as previously mentioned, "REC*" and "REC M1*" imply that M*_STEP 2 is used instead of M_STEP 2. "REC" and "REC*" curves can hardly be discriminated each other, similarly for "REC M1" and "REC M1*." This confirms that

M*_STEP 2 can reduce the complexity of M_STEP 2 with little degradation. In the IO channel, however, the performance of M*_STEP 2 will degrade severely compared with that of M_STEP 2, which is shown in Fig. 5. Since one of each user's candidates must correspond to one's transmitted message in the IO channel, it may be more preferable to use all candidates as in M_STEP 2. The steep increase of "REC" in Fig. 5 between 425 and 475 users represents THR event as mentioned in [4].

Consequently, our modified REC algorithm can be summarized as followings for Rayleigh fading channel.

M_STEP 1
M_STEP 2 or M*_STEP 2
STEP 3

Figure 6 shows the performance comparison at different Eb/No values. Table 1 shows the number of users that can be accommodated at Eb/No= 20dB and at Eb/No=25dB at BER= 10^{-3}. Table 2 shows the average number of iterations for $M = 512$ and $L = 11$.
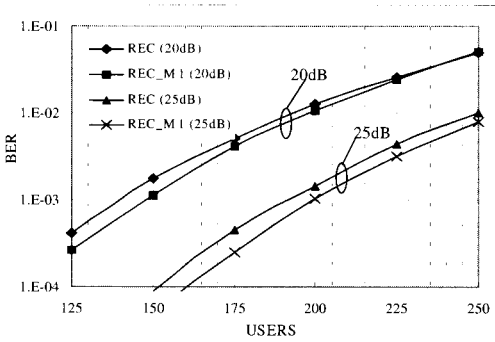

Fig. 6. The comparison of "REC" and "REC_M1" at Eb/No=20dB and at Eb/No=25dB in the Rayleigh fading channel when M=256, L=19, and RS code address assignment scheme is used.

Table 1. The number of users at BER=10E-3

System parameter	M=256, L=19		M=512, L=11	
Eb/No	20dB	25dB	20dB	25dB
hard CD	119	164	122	167
soft CD	138	178	148	190
Fiebig's REC	140	191	163	224
modified REC	148	199	177	232

Table 2. Average iteration number (M=512, L=11)

IO channel			Rayleigh fading channe at Eb/No=25dB		
Users	BER	Average Iteration #	Users	BER	Average Iteration #
300	1.75E-6	2.0	150	5.09E-5	1.2
325	5.81E-6	2.0	175	1.59E-4	1.6
350	1.91E-5	2.3	200	4.37E-4	1.9
375	5.33E-5	2.8	225	1.01E-3	2.0
400	1.28E-4	3.1	250	2.01E-3	2.0
425	2.90E-4	3.9	275	3.59E-3	2.1
450	5.88E-4	5.3	300	6.46E-3	2.3
475	4.05E-3	10.3	325	1.05E-2	2.8
500	3.08E-1	3.75	350	1.62E-2	3.1

Ⅴ. Conclusion

In this paper, we proposed the modified REC algorithm to increase the capacity of FH/MFSK multiple access systems and to reduce the computational complexity in the Rayleigh fading channel. The first modification is based on the fact that soft-limited decoding shows better performance than hard-limited one. The second modification could reduce the complexity with a slight degradation in the Rayleigh fading channel although it degraded severely in the IO channel.

Reference

[1] D.J. Goodman, P.S. Henry, and V.K. Prabhu, "Frequency-hopped multilevel FSK for mobile radio," *Bell Syst. Tech. J.*, vol. 59, pp. 1257-1275, Sep. 1980.

[2] T. Mabuchi, R. Kohno, and H. Imai, "Multiuser detection scheme based on cancelling cochannel interference for MFSK/ FH-SSMA system," *IEEE J. Select. Areas Commun.*, vol. 12, pp. 593-604, May 1994.

[3] U. Timor, "Multistage decoding of frequency-hopped FSK system," *Bell Syst. Tech. J.*, vol. 60, pp. 471-483, Sep. 1981.

[4] U.C.G. Fiebig, "On the performance of joint detection in MFSK/FFH systems," *Proc. of the IEEE ICC'96*, pp. 90-95, 1996.

[5] O.C .Yue, "Maximum Likelihood Combining for Noncoherent and Deferentially Coherent

Frequency Hopping Multiple Access Systems." *IEEE trans. Inform. theory*, vol. IT-28, pp. 631-639, July 1982.

[6] Y.T. Su, C.Y. Hsiao, and C.P. Hung, "Multiuser detection for MFSK frequency-hoped multiple access systems," *Proc. VTC'96*, pp. 387-391, April 1996.

[7] H.Y. Song, I. Reed, and S.W. Golomb, "On the non-periodic cyclic equivalence classes of RS codes," *IEEE trans. Inform. theory*, vol. IT-39, pp. 1431-1434, July 1993.

[8] M. Swchwartz, W.R. Bennet, and S. Stein, *Communication Systems and Techniques*, McGraw -Hill, 1966.

[9] U.C.G. Fiebig, "Iterative interference cancellation for FFH/MFSK MA systems," *IEE Proc. -commun.*, vol. 143, no. 6, pp. 380-388, Dec. 1996.

[10] G. Einarson, "Coding for a Multiple-Access Frequency Hopped system," *IEEE trans. Comm.*, vol. COM-32, pp. 589-597, May 1993.

교수
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