페이지 환경에서 Soft Limited Detection을 이용하는 다중 사용자 FH/MFSK 시스템의 성능

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1. FH/MFSK concept

<Advantage>
• Resistant to Frequency selective fading, Near-far problem
• Anti-jamming, LPD, LPI
• High spectral efficiency

<Method>
• \( M \) frequency slots for \( M \) symbols (\( M = 2^k \) for \( k \)-bit word)
• \( L \) chips per a symbol (Fast FH)
• \( 1 \times L \) dimensional hopping vector

\[
X = a + m 1 \quad \text{where} \quad a \text{ is a address vector}
\]

\[
1 \text{ is a all 1 vector.}
\]
\[ X = m \cdot 1 + a \]
\[ = 4 \cdot (1,1,1,1,1) + (1,2,3,4,5) \]
\[ = (5, 6, 7, 0, 1) \]
\[ m \cdot 1 = X - a \]
\[ = (5, 6, 7, 0, 1) - (1, 2, 3, 4, 5) \]
\[ = (4, 4, 4, 4, 4) \]

- Optimal Hopping Pattern (RS-code)

\[ X = \gamma \beta + m \cdot 1 \quad \text{where} \quad \beta = (1, \beta, \beta^2, \beta^3, \ldots, \beta^{(L-1)}) \]

\(\beta\) is a primitive root over \(\text{GF}(2^k)\)

\(\gamma\) is a user index,

\(m\) is a message symbol
for $L < 2^k$, $[L, 2, L-1]$ shortened RS-code

2. Detection Scheme for Multiuser Environment

figure 4 Detector for FH/MFSK Receiver
(1) Hard limiter:  
\[ f_H(R) = \begin{cases} 
0, & 0 \leq R \leq T_H \\
1, & T_H < R < \infty 
\end{cases} \]

(2) Soft limiter:  
\[ f_S(R) = \begin{cases} 
R, & 0 \leq R \leq T_S \\
T_S, & T_S < R < \infty 
\end{cases} \]

* The performance of soft limiter is better than hard limiter
3. Interference Cancellation

3.1 REC (Reduction of the number of Candidate) algorithm by U.-C. G. Fiebig

< STEPS >

(1) Generate all despread matrix $D_k$, $k = 1, 2, 3, \ldots, K$ users.

   Identify all $n_k^{(0)}$ candidate rows in $D_k$

(2) Apply $s$-th iteration, $s = 1, 2, 3, \ldots, s_{\text{max}}$:

   ① For each use, generate transmit matrices $T_{k,i}$, $1 \leq i \leq n_k^{(s-1)}$

   ② Generate $B^{(s)}$ whose elements $b_{ml}^{(s)}$ are

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

   ③ For each user with $n_k^{(s-1)} > 1$, generate $D_k^{(s)}$ from $B^{(s)}$ if candidate row has '1', which will be regarded as correct one, if any $D_k^{(s)}$ has no '1' in candidates, choose randomly and exit.
A example for REC algorithm
Figure 5 Visualization of the REC algorithm
< Main idea for REC algorithm >

"Among all ambiguity rows, only the correct row may provide elements valued 1."

< After Reaction of the number Candidate >

- REC+CD (Conventional Decoding):

- REC+MLJD (Maximum Likelihood Joint Detection)
3.2 Proposed Soft-limited REC algorithm

<Modified STEPS>

(1) If one candidate row from conventional hard limiter is different to soft-limited detector output, **Add this as a candidate.**

(2) If the iteration ends with an ambiguous matrices,  
**Select a candidate whose soft-limited output is maximum.**
4. Simulation Results

<assumption>

- Synchronous Transmission for Chip and Symbol
- Frequency Selective Fading
- No Doppler Effect

<System Model>

- Bandwidth 20MHz
- Bit rate 32Kbps
- RS code hopping pattern.
- REC+CD
(1) Hard limiter VS. Soft limiter

- For $P_b \leq 10^{-3}$, Eb/No=25dB
  
  Hard-limiter: 167 users
  Soft-limiter: 190 users

  => 14 % increase

- The performance of 25dB soft-limited detector is similar to 30dB hard-limited one.

그림 6 M=512, L=11 일 때 hard-limited 검출기와 soft-limited 검출기를 사용하는 수신기의 성능 비교
(2) Hard-limited REC+CD VS. Soft-limited REC+CD over M=512, L=11

\[ P_b \leq 10^{-3} \]

\[ P_b \leq 10^{-4} \]

- For \( P_b \leq 10^{-3} \), Soft-limited REC accommodate about 7 users more
- For \( P_b \leq 10^{-4} \), about 10 users more
(3) Hard-limited REC+CD VS. Soft-limited REC+CD over $M=256, L=19$

- For $P_b \leq 10^{-3}$, Soft-limited REC accommodate about 15 users more
- For $P_b \leq 10^{-4}$, about 20 users more
<table>
<thead>
<tr>
<th></th>
<th>M=512, L=11</th>
<th>M=256, L=19</th>
</tr>
</thead>
<tbody>
<tr>
<td>hard CD</td>
<td>167</td>
<td>163</td>
</tr>
<tr>
<td>soft CD</td>
<td>190</td>
<td>177</td>
</tr>
<tr>
<td>hard REC+CD</td>
<td>220</td>
<td>191</td>
</tr>
<tr>
<td>hard+soft REC+CD</td>
<td>227 (220+7)</td>
<td>206 (191+15)</td>
</tr>
</tbody>
</table>

- M=256, L=19 system has more increasing ratio between hard REC+CD and hard+soft REC+CD.

- M=512, L=11 system shows better performance in every aspect.
(4) The ratio of new candidate insertion.

그림 9. M=256, L=19, Eb/No=25dB, soft+hard REC
방식의 BER과 새로운 후보행렬 발생비율

- Conventional REC candidate : Ambiguity Row Event from hard-limited detector
- Added REC candidate : Added Candidate Event from soft-limited detector
5. Conclusion

- Soft-limited detector can accommodate more users than hard-limited detector without users information.

- Modified REC algorithm increase reliable candidates with soft-limited detector
  \[ \rightarrow \text{More Users} \]

- More sophisticated candidate selection & reduction have to be studied.