# Diversity Combining for FFH System with Worst-Case Partial-Band Noise Jamming*

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Abstract: Two novel noliner combining algorithms, namely, dual nonliner diversity combining (DNDC) and multi-threshold clipper combining (MTCC) are presented in this paper. In particular , DNDC with the envelope detector samples of each dehopped signal are weighted by the inverse noise powers and then clipped with a soft-limiter. The results are finally accumulated in the combiner. Likewise with MTCC, the receiver adaptively adjusts the clipper's threshold with an estimation of the power of jammer and the number of corrupted frequencies. The performance evaluation under worst-case partial noise jammer for different diversity combining algorithms is given to comfirm that substantial diversity gain in terms of reduced error rate can be achieved by the use of the proposed algorithms.

## I. Introduction

Spread spectrum (SS) technology has attracted considerable worldwidely in the past few decades. In particular, multi-hops/bit frequency-hopped spread spectrum modulation schem is a powerful technique which provide effective protection against jamming. This is due to the inherent time and frequency diversity of the fast frequecy hopping (FFH) system. On the other hand, the enhancement in system performance depends heavily upon the algorithm of divesity combining used at the receiver.

Many researchers have studied the effect of intentional or non-intentional interference on the performance of various FFH diversity-combining techniques[1]-[4]. The performance of square-law linear combining with soft decision receiver was investigated in [1]. Likewise, an adaptive gain controlled (AGC) receiver and a clipper receiver were both presented in [2]. In [3], the model of product combining receiver (PCR) was introduced and its performance under a patial band noise jammer was analyzed. A diversity combining technique employing a ratio-threshold test was proposed in [4]. It is noted that, however, all these developed techniques are likely suitable for certain applications, and are normally far from optimized. Therefore, more and better combining algorithms are quite demanding, but very challenging.

In this paper we consider a FFH system with a binary frequency shift keying (BFSK) modulation schem and a noncoherent detection. The carrier frequencies are pseudorandomly hopped over the bandwidth $W_{SS}$, and the FFH/BFSK transmitter is assumed to perform $L$ hops per data bit with $L \geq 1$ being the diversity level. Specifically, two novel diversity combining receivers called DNDCR and MTCCR are presented and their performance under the worst-case partial band noise jammer(WPBNJ)[1] is analyzed. Also, the performance comparison between different diversity combining techniques is undertaken with the aid of various numberical results.

## II. System Receiver Models

A Transmitter model

This work was supported by the National Fundamental Research Program (G1998030410)

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The transmitter block diagram of an FFH/BFSK SS communication system is shown in Fig. 1. The conventional BFSK modulator selects one of two baseband frequencies $f_1$ and $f_2$ according to the incoming data sequence $\{d_n\}$ of rate $R_b = 1/T_b$, where $T_b$ is the bit duration. The frequency separation between $f_1$ and $f_2$ is equal to $R_h = 1/T_h$, where $T_h$ is the hopping duration. Moreover, assuming that $L$ hops are performed for each bit duration, then $T_h = T_b/L$. Without loss of generality, we choose $f_1 = 1/T_h$ and $f_2 = 2/T_h$. The output of the BFSK modulator is then mixed with a signal from the frequency synthesizer which is controlled by the pseudonoise (PN) code generator. The resultant signal finally passes through the bandpass filter (BPF), the radio-frequency(RF) oscillator, and then transmits out.

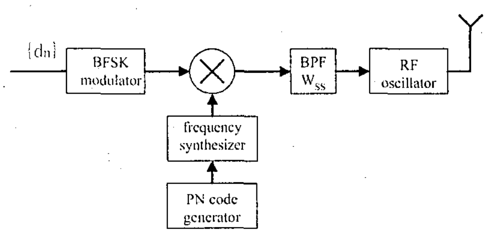


Fig. 1 FFH/BFSK System Transmitter

B Receiver model

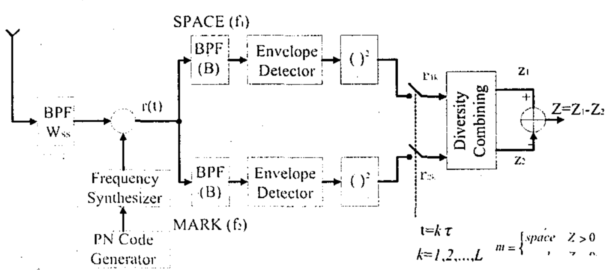


Fig. 2 FFH/BFSK System Receiver

The receiver block diagram is shown in Fig. 2. The dehopped signal $r(t)$ is fed into two channels with different frequencies of interest, i,e., $f_1$ and $f_2$. The outputs of square-law envelope detectors are sampled once very hop period, $\tau = T_b/L$ to produce quantities $r_{1k}$ and $r_{2k}$, $k = 1, 2, \ldots, L$. These output samples are then fed into the diverstiy combining module to form the decision argument, $z_1$ and $z_2$. Finally, difference between $z_1$ and $z_2$ is compared with a pre-set threshold to make a bit decision. It noted here that enhancement in system performance depends heavily upon the algorithms used in the divesity combining module.

## III. Partial-Band Noise Jammer (PBNJ)

The transmitted waveform of $L$ hops/bit FFH/BFSK system is assumed to be subject to a partial-band noise jammer, which is quite typical in practice. Specifically, PBNJ distributes its total available power $J$ watts uniformly over a fraction, $r$, of the total spread-spectrum system bandwidth $W_{SS}$ as depicted in Fig. 3. Then, each hopping symbol is subject to jamming with a probability of $r$, while to jamming free with a probability of 1-$r$. Furthermore for simplicity, we assume that the two adjacent frequencies of the modulation band are simultaneously jammed or out of jamming. Finally let $l$ , $l = 0,1,\ldots, L$, be the number of jamming frequencies, and then define $P(e/l)$ to be the probability of error, conditioned on that $l$ of L symbols are jammed. Then, the probability of bit error is given by

$$P(e) = \sum_{l=0}^{L} \binom{L}{l} r^l (1-r)^{L-l} P(e/l).$$

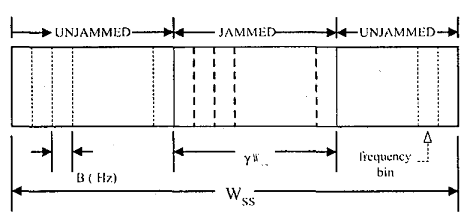


Fig. 3 Partial-band noise jamming model

Specifically, if the value of $r$ could be adjust to make the performance of receiver be the worst, We refer such jammer to the worst-case partial-band noise jammer (WPBNJ)[1][2].

## IV. Proposed Diversity Combining

## Algorithms

As mentioned above, the peroformance enhancement of the FFH/BFSK system is quite dominated by the algorithms used for divesity combining. In the sequel, we put forward two nolinear combining algorithms and describe their structures in detail.

### A Dual Nonlinear Diversity Combining (DNDC)

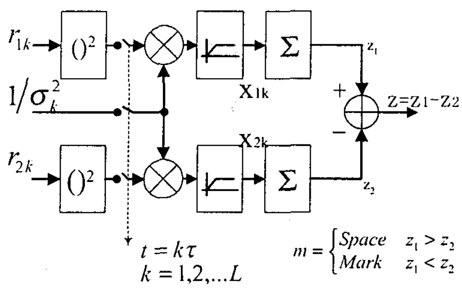


Fig. 4 Dual nonliner diversity combining algorithm

The block diagram of DNDC is shown in Fig. 4. Besides the two channels in Fig. 2, there is a "noise-only" channel which performs noise power measurement. The output of this noise-only channel is also sampled, producing estimates of the noise power, $\sigma_k^2$, $k = 1, 2, \ldots, L$. Then, the output signal samples, $r_{1k}$ and $r_{2k}$, are weighted by the $1/\sigma_k^2$ in the space and mark channels, respectively. Consequently, the weighted samples are further weighted by the soft-limited clippers to produced $x_{1k}$ and $x_{2k}$. Since both the square-law envelope detectors and the clippers are nonlinear elements, this algorithm is referred to as so called DNDC. Finally, the summation of $x_{1k}$ and $x_{2k}$ in a bit period form the decision statistics $z_1$ and $z_2$, respectively. The clipper threshold is set as the value which yields the minimum error probability given values of $E_b/N_0$ and $L$ under jamming free condition. The value of $z_1$-$z_2$ is then compared with the threshold to make a bit decision.

### B Multi-Threshold Clipper Combining (MTCC)

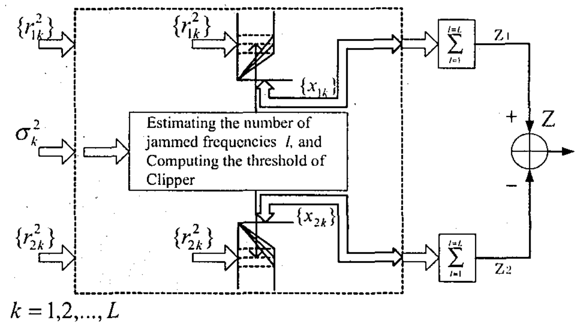


Fig. 5 Multi-threshold Clipper combining Algorithm

In a traditional clipper receiver, the clipper threshold is set as the value which provides the minimum error probability for given values of $E_b/N_0$ and $L$ under jamming free condition. That is , the threshold is set without taking the system thermal noise into account. On the other hand, the jammer is often a stationary band-limited white Gaussian noise, we can actually not distinguish the thermal noise and the jammer noise when setting the threshold of the clipper. Specifically, in our proposed MTCC, the clipper threshold is set as the value which produces the minimum error probability for given values of the minimum $S/\sigma_k^2$, $k = 1, 2, \ldots, L$, and the number of the jammed frequencies $l$, $l = 0,1,2,\ldots, L$. In this sense, the threshold could have different levels in terms of varying jamming condition received.

In practice, the number of the jammed frequencies $l$ and the maximal noise power $\sigma^2_{max}$ can be estimated on the basis of the vector $\{\sigma_k^2\}$, $k = 1, 2, \ldots, L$. Then, the optimal threshold can be computed accordingly. Consequently, with the optiminged threshold, the vectors of $\{r_{mk}\}$, $m = 1,2$ $k = 1, 2, \ldots, L$, are weighted to produce $x_{1k}$ and $x_{2k}$ in the space and mark channels, respectively. Similar to the DNDC, the resultant $\{x_{1k}\}$ and $\{x_{2k}\}$ are simply combined with summation, and then employed to make a bit decision in terms of a comparsion between the threshold and value of $z_1$-$z_2$.

## V. Numerical Results

In this section, the numerical results of BER versus $E_b/N_J$ for a noncoherent FFH/BFSK communication systems under the WPBNJ are given with a diversity level of $L=2$. The signal-to-noise ratio is fixed at $E_b/N_0=13.35$ dB, which corresponds to a BER of $10^{-5}$ for an ideal BFSK system under jamming free condition.

In Fig. 6, the performance curves of several diversity combining receivers such as DNDC receiver (DNDCR), square-law linear combining receiver (SLCR), AGC receiver (AGCR) and clipping combining receiver (CCR) are given for a comparsion. It is shown the proposed DNDCR achieves the best performance, and specifically gets 2dB gain against the AGCR.

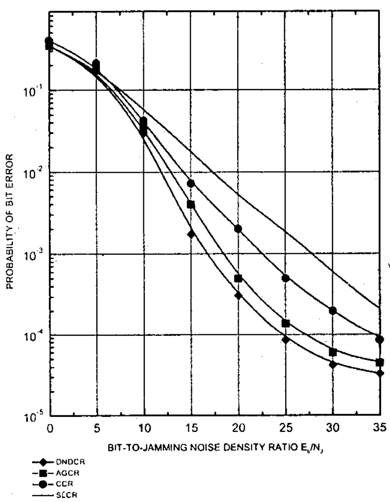


Fig . 6 BER Performance comparsion between DNDCR and other receivers

Likewise, Fig. 7 shows a performance comparison between MTCC recevier (MTCCR) and several other diversity combining receivers such as square-law linear combining receiver (SLCR), AGC receiver (AGCR) and clipping combining receiver (CCR). Again, the MTCCR has the best performance. This is because the power of jammer and the number of jammed frequencies are estimated and used to adjust the clipper threshold adaptively in MTCCR. Thereby, the performance improvement is quite expective.

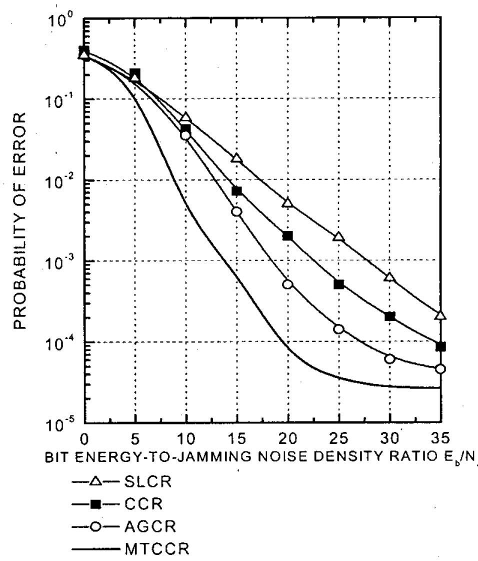


Fig.7 Comparsion between MTCCR and several other diversity combining receivers

# VI. Conclusions

Two new nonlinear diversity combining receivers namely DNDCR and MTCCR are introduced in this paper. Their structures are discribed and numberical results of BER performance are given. Comparsion with previously proposed diversity combining receivers, such as SLCR, CCR, and AGCR, clearly indictates that the developed tedchniques in this paper can substantively improve the jamming resilient capability of the FFH system.

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