BEP Performance Analysis of Multi-Node Self Encoded Spread Spectrum – Cooperative Diversity in Rayleigh Fading Channel

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***Abstract*--**Self-encoded spread spectrum (SESS) is a novel modulation technique that acquires its spreading sequence from the random input data stream rather than through the use of the traditional pseudo-noise code generator. It has been incorporated with multi node cooperative diversity systems as a means to combat fading in wireless channels. In this paper we analyze the cooperative SESS for Amplify and Forward CD links (MSESS-AFCD) and SESS for Decode and forward CD links (MSESS-DFCD) in Rayleigh fading channels. The BEP expressions are derived in closed form, and the veracity of the analysis is confirmed by numerical calculations that demonstrate excellent agreement with simulation results.

Keywords: *Multi node SESS-CD, MSESS with AFCD, MSESS with DFCD, Rayleigh fading.*

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I. INTRODUCTION

Spread spectrum is a digital modulation technology and a technique based on principles of spreading a signal among many frequencies to prevent interference and signal detection. As the name shows it is a technique to spread the transmitted spectrum over a wide range of frequencies. It started to be employed by military applications because of its Low Probability of Intercept (LPI) or demodulation, interference and anti-jamming (AJ) from enemy side. The idea of Spreading spectrum is to spread a signal over a large frequency band to use greater bandwidth than the Data bandwidth while the power remains the same.

Conventional direct sequence spread spectrum system employs pseudo-noise (PN) code generators which generate maximal length or allied sequences. The need for PN code generator was obviated by deriving its spreading sequence from the source (user data) stream which has stochastic nature, so Self-encoded spread spectrum (SESS) provides a viable implementation of random-coded spread spectrum and has a number of sole features such as the potential for enhanced transmission security and anti-jamming capability, multi-rate applications and inherent time diversity [1-7]. SESS modulation was exploited by using iterative detection to significantly improve the system performance over time-varying fading channels [3] and to attain a momentous gain. The combination of cooperative diversity and iterative detection (SESS-CD: Self-Encoded spread spectrum-Cooperative Diversity) has been proposed to provide spatial and temporal diversity, and thus reduce the effect of fading.

The reminder this paper is organized as follows. SESS-CD system with multiple node cooperative transmission through iterative detection is described in the next section. Section III presents the BEP analysis of the SESS-CD system for both amplify and forward (AF) and decode and forward (DF) in cooperative mode. The BEP performance of the correlation and diversity detectors is analyzed in closed form, and a lower bound for the iterative detector is derived. Section IV presents the simulation results to validate the analysis, and Section V concludes the paper.

II. SYSTEM MODEL

Fig.1 represents multi node self encoded spread spectrum-cooperative diversity (MSESS-CD) network. All nodes are assumed to be equipped with single antennas, equal transmission power, operating in half duplex mode and all the transmission links are mutually independent and subject to flat Rayleigh fading.

In the transmitter section, blocks with T_d represent one delay register which are constantly updated from M-tap serial delay of the data to generate spreading sequence of length M, and T_d is the bit duration. The source information d is assumed to be bipolar values of ±1. The bits are first spread by self encoded spreading sequence $s(k)$ of length M at a rate of $1/T_d$. The spreading sequence is constructed from random source stream stored in the delay registers. It is assumed that the delay registers at the transmitter and receiver section have been initialized by a sequence of stochastic nature. Spreading sequence of k^{th} bit *s(k)*, is given as

$$s(k) = \left[d(k-1), d(k-2), \ldots\ldots\ldots d(k-M)\right]^T \qquad (1)$$

And the spreading n^{th} chip of the k^{th} bit can be expressed as

$$c(k,n) = d(k)s(k,n) = d(k)d(k-n) \qquad (2)$$

In the general cooperative phenomenon, source broadcasts the information to *l* relays and destination [D] in phase 1. The received spreading sequence at the destination and at the i^{th} relay (in both AF and DF mode), are modeled respectively, as

$$y_{sd}(k,n) = \sqrt{P d_{sd}^{-\beta}}\, h_{sd} c(k,n) + \eta_{sd} \qquad (3)$$

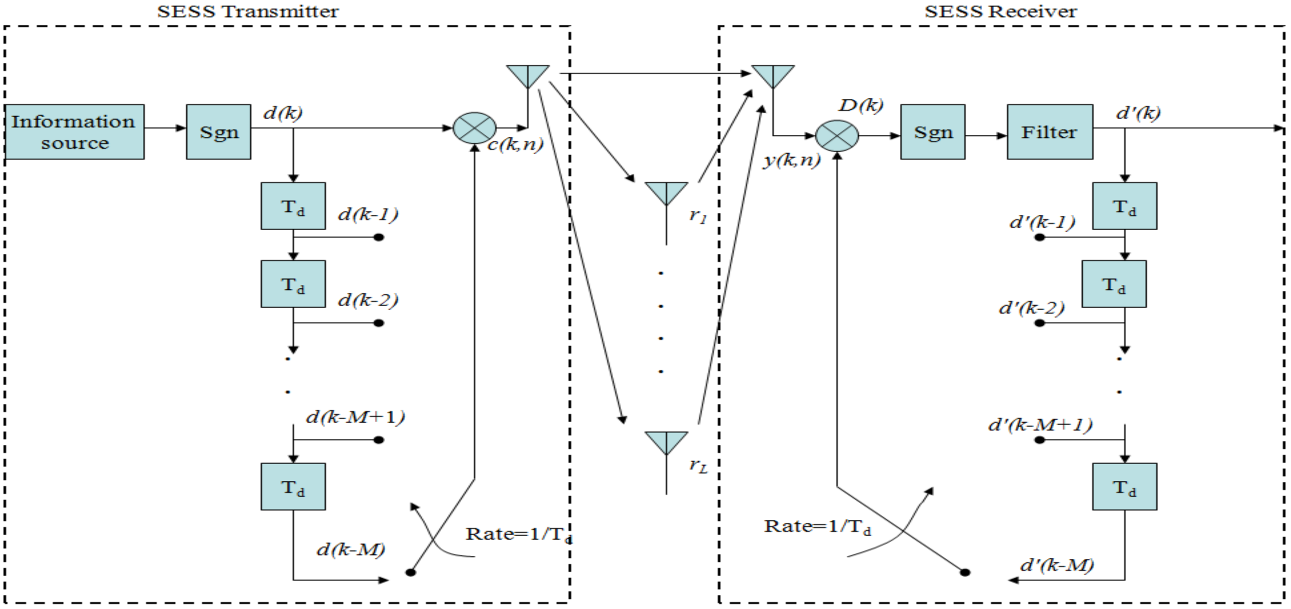

Figure 1. Multi node self encoded spread spectrum - cooperative diversity (MSESS-CD) network

$$y_{sri}(k,n) = \sqrt{P d_{sri}^{-\beta}}\, h_{sri} c(k,n) + \eta_{sri} \qquad (4)$$

Where *c(k,n)* is the spreading sequence at the transmitter end, *P* is the transmitted source power, h_{sri} and h_{sd} are the channel coefficients of source to i^{th} relay link and source to destination link respectively and the terms η_{sd} and η_{sri} denote the additive white Gaussian noise (AWGN) with zero-mean and variance $\sigma_{\hat{\eta}}^2$ and The term $d_{sd}^{-\beta}$ represent the distance between source node and destination with a degradation factor β.

From phase 2, relays retransmit the information to the destination. The received spreading sequence at the destination from i^{th} relay in AF and DF mode can be formulated as eq. (5) and (6) respectively.

Where *C(k,n)* bespoke (decoded and succeeding encoded) spreading sequence with the channel fading coefficient between i^{th} relay and destination is h_{rid}. With knowledge of the channel coefficients (between the source and the destination) and (between the relay and the destination), the destination detects the transmitted symbols by jointly combining the received signal from the source and from the relay. The received signal at the destination can be written as

$$y_d(k,n) = h_{sd} y_{sd}(k,n) + \sum_{i=1}^{L} h_{rid} y_{rid}(k,n) \qquad (7)$$

III. BEP PERFORMANCE ANALYSIS

In this section, we present BEP performance analysis for Multi-node Self Encoded Spread Spectrum Cooperative Diversity (MSESS-CD) scheme in two fundamental cooperative modes.

1) AF Mode:

In MRC cooperative scheme, information bits are repeated in relay paths. Therefore, the bit error probability of error at k^{th} relay branch with high SNR is given by:

$$P_{e_k}^{af} = \frac{(N-1)^2}{12\log_2 N}\,\frac{\eta_0^2}{P\sigma_{s,d}^2}\left(\frac{1}{P\,\sigma_{s,ri}^2} + \frac{1}{P\,\sigma_{ri,d}^2}\right) \qquad (8)$$

Thus, the bit error probability with *L*-relay branches can be defined as follows:

$$P_e^{af} = \frac{(N-1)^{L+1}}{3(L+1)\log_2 N} \frac{\eta_0^2}{P\sigma_{s,d}^2} \prod_{l=1}^{L} \left(\frac{1}{P\sigma_{s,ri}^2} + \frac{1}{P\sigma_{ri,d}^2} \right) \tag{9}$$

The BEP performance of SESS-CD can be considered as

$$P_e^{af} = \int_0^{\infty} Q\left(\sqrt{M.\gamma}\right) P_\gamma(\gamma) d\gamma \tag{10}$$

Where $P_\gamma(\gamma)$ is the probability density function of γ. In this cooperative SESS performance analysis, we do not consider the self-interference that comes from the erroneous dispreading sequences due to the incorrect bit decision at the receiver. (Self-interference has been shown to be dominant only at low SNR or with small spreading factors [8-10]). With L-cooperating relay branches, the bit error probability of SESS-CD with N-QAM can be tightly approximated as equation (11),

$$y_{rid}(k,n) = \frac{\sqrt{P d_{rid}^{-\beta}}}{\sqrt{P d_{sri}^{-\beta} |h_{sri}|^2 + 2\sigma_{sri}^2}} h_{rid} \left[\sqrt{P d_{sri}^{-\beta}} h_{sri} c(k,n) + \eta_{sri} \right] \tag{5}$$

$$y_{rid}(k,n) = \sqrt{P d_{rid}^{-\beta}} h_{rid} \bar{c}(k,n) + \eta_{rid} \tag{6}$$

$$P_e^{af} = \frac{\left(\sqrt{\frac{2}{\pi}} \exp(-2)\right)^{L+1} (N-1)^{2(L+1)}}{3(L+1)! N^{2(l+1)} \log_2 N} \frac{\eta_0^2}{P\sigma_{s,d}^2} \prod_{l=1}^{L} \left(\frac{1}{P\sigma_{s,ri}^2} + \frac{1}{P\sigma_{ri,d}^2} \right) \tag{11}$$

2) DF Mode:

Exact BEP expressions of this scheme is provided for DF systems utilizing N-QAM modulation can approximated as eq.(12).

In which $X_{l,L}[i]$ takes values 1 or 0 and determines whether the i^{th} relay has decoded correctly or not, $b = \frac{3}{N-1}$ and $F_l(\bullet)$ is defined as (13) shown at the bottom of this page.

The BEP formulation in (12) consists of the product of two quantities. One of them is the conditional SER (probability of error) at the destination $p_e[\bullet]$ and another one is probability of the network being in that state $p(X_{l,L}[i])$. At high SNR, we can assume that $1 - p_e[\bullet] \approx 1$. Thus the first term in (12) can be approximated as

$$p_e\left[\left(1 + \frac{bP\sigma_{s,d}^2}{\eta_0 \sin^2(\theta)}\right)\left(1 + \frac{bX_{l,L}[i]P\sigma_{ri,d}^2}{\eta_0 \sin^2(\theta)}\right)\right]$$

$$\approx \frac{f(1+k)}{\gamma b^{1+l} \sigma_{s,rl}^2 \sigma_{rl,d}^2} \tag{14}$$

Where k denotes the number of node which decoded correctly, the function $f(\bullet)$ in (14) is specified as (15)

$$f(x) = \frac{4C}{\pi} \left[\int_0^{\pi/2} \sin^{2x}(\theta) d\theta - C \int_0^{\pi/4} \sin^{2x}(\theta) d\theta \right] \tag{15}$$

in which $C = \frac{\sqrt{N}-1}{\sqrt{N}}$. Thus the bit error probability at the k^{th} node can be determined as follows:

$$P_{e_k}^{df} = \frac{2}{\log_2 N} \left(\frac{1}{\gamma b}\right)^L \frac{1}{\sigma_{s,d}^2} \frac{C^{2k} f(L-l+2)}{\pi^k \sigma_{s,rl}^2 \sigma_{rl,d}^2} \tag{16}$$

Summing (16) over the L channels, we can further determine the approximate expression for the bit error probability as

$$P_e^{df} = \frac{2}{\log_2 N} \left(\frac{1}{\gamma b}\right)^L \frac{1}{\sigma_{s,d}^2} \sum_{l=1}^{L} \frac{C^{2(l-1)} f(L-l+2)}{\pi^{(l-1)} \sigma_{s,rl}^2 \sigma_{rl,d}^2} \tag{17}$$

$$P_e^{df} = \frac{2}{\log_2 N} \sum_{l=0}^{L+1} p_e \left[\left(1 + \frac{bP\sigma_{s,d}^2}{\eta_0 \sin^2(\theta)}\right) \left(1 + \frac{bX_{l,L}[i]P\sigma_{ri,d}^2}{\eta_0 \sin^2(\theta)}\right) \right] F\left(X_{l,L}[i]\right) \tag{12}$$

$$F_l(x) = \begin{cases} p_e \left[\left(1 + \frac{bP\sigma_{s,d}^2}{\eta_0 \sin^2(\theta)}\right) \left(1 + \frac{bX_{l,L}[i]P\sigma_{ri,d}^2}{\eta_0 \sin^2(\theta)}\right) \right] & if \quad x = 0 \\ 1 - p_e \left[\left(1 + \frac{bP\sigma_{s,d}^2}{\eta_0 \sin^2(\theta)}\right) \left(1 + \frac{bX_{l,L}[i]P\sigma_{ri,d}^2}{\eta_0 \sin^2(\theta)}\right) \right] & if \quad x = 1 \end{cases} \tag{13}$$

IV. SIMULATION RESULTS

This section presents a comparison of the analytical and simulation results of the performance parameters discussed in Section III. The results for average BEP is presented for two elementary cooperative modes (AF and DF). A three-relay self encoded spread spectrum-cooperative network with parameters used in the simulation are indicated in Table-I.

TABLE I. SIMULATION PARAMETERS

Parameters	Specifications
Length of spreading sequence	256
No of bits per iterations	50,000
Iterations per SNR	500
Transmission power (P)	10dBm
Path loss exponent (β)	2-4
No of relay nodes (L)	3
Signal constellation	N-QAM

Figure 2 shows the comparative results of PNSS with SESS in non-cooperative and cooperative environments (with 3 relay nodes). It can be seen by comparing the performance of PNSS-CD in Rayleigh fading channel that SESS-CD can provide nearly 5.5dB gain over N-QAM at lower bound.

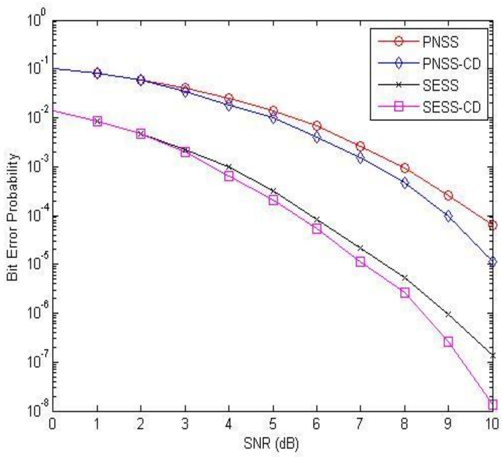

Figure 2. Comparison between PNSS and SESS with and without CD

Bit error probability of the system is depicted in Figure 3; it shows the comparison between PNSS-CD and SESS-CD with AF and DF modes. From the result we clearly observe that the performance of SESS-CD is 4.1dB higher than that of the PNSS-CD with DF relay protocol.

Figure 4 gives the BEP performance of SESS-CD for different modulation index (N) in Rayleigh fading channel. The average bit error probability of the proposed system (SESS-CD) in DF mode for 16-QAM with multiple nodes can be seen in Figure 5. It can be observed that the performance increases with no of intermediate nodes.

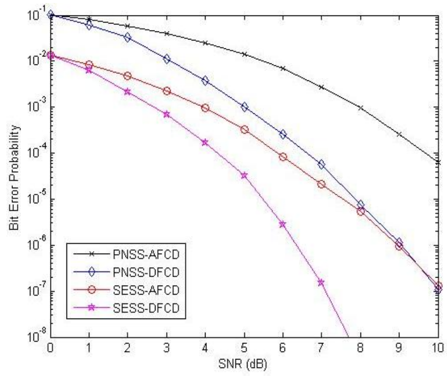

Figure 3. Comparison between PNSS-CD and SESS-CD with AF, DF modes

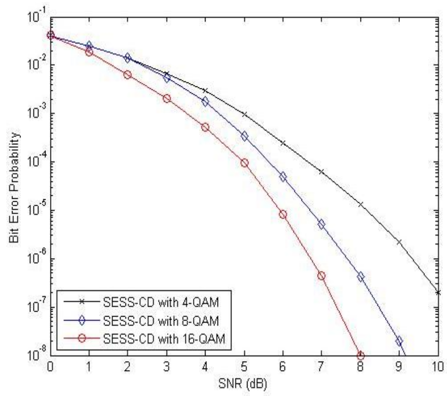

Figure 4. Performance of SESS-CD for different modulation index (N)

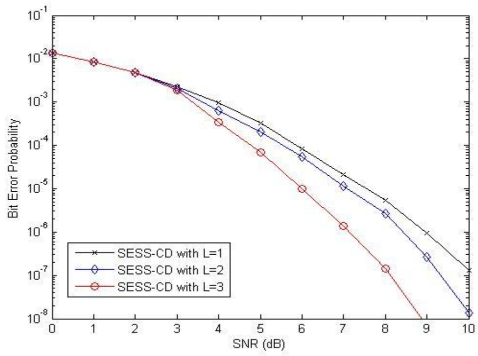

Figure 5. Performance of SESS-CD with multiple number nodes (L).

V. CONCLUSION

In this paper, we presented the analytical study of the BER performance of multi node SESS-CD over Rayleigh fading channels in two fundamental cooperative modes. We derived the closed-form bit error probability expressions for

SESS-CD with iterative detector in AF and DF modes. The linear iterative detection is based on soft estimates that converge hastily, making it plausibly proficient for practical implementation. Form the simulation results it is observed that the performance of the system can be improved by increasing intermediate nodes and modulation index. Thus SESS combined with CD can be a promising CD technique for the future generation of wireless communications

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