Comparative Study of Self-Encoded Spread Spectrum and PN Coded Spread Spectrum in Cooperative Communication

Zohaib-Ur-Rehman, Adnan Ahmed Khan and Ibrahim Khalil
Military College of Signals, National University of Science and Technology, Rawalpindi, Pakistan, Electrical Engineering Dept.
1 Zohaibrehman@mcs.edu.pk, 2 Adnankhan@mcs.edu.pk, 3 ibrahim@mcs.edu.pk

Abstract— In this paper, we propose Self-Encoded Spread spectrum combined with cooperative diversity to combat against the effects of fading in wireless channel. Cooperative diversity technique is employed with the intention of achieving spatial diversity gain using relay nodes. After introducing iterative decoding in SESS we exploit its inherent temporal diversity, by this we gain performance improvement of 3 dB in terms of SNR at BER of $10^{-3}$ with respect to PN-coded spread spectrum.

Keywords-component; SESS, Iterative decoding, Cooperative communication, PNSS, Spatial Diversity, Temporal Diversity

1. Introduction

Self-encoded spread spectrum (SESS) and multiple access communications have been proposed and exhibit some unique characteristics such as low probability of detection (LPD) and inherent memory [1, 2]. It has been demonstrated that the inherent temporal diversity in SESS modulation can be exploited by using iterative detection to significantly improve the system performance over time-varying fading channels [3]. SESS derives its spreading sequences from the stochastic nature of the source stream so it provides a feasible implementation of random-coded spread spectrum and potentially enhances the transmission security [1]. In order to reduce the fading effect, we are using cooperative diversity combined with SESS. The reason for using SESS is that it not only provides multipath diversity like PNSS but also provide inherent temporal diversity. We combine cooperative diversity with iterative detection to provide spatial and temporal diversity respectively. We determine the bit error rate (BER) performance of SESS-CD (Self-Encoded spread spectrum-Cooperative Diversity) system over Rayleigh fading channels and show that its effects can be reduced by exploiting both spatial and temporal diversities.

The contents of rest of the paper are as follow. In Section 2, we give introduction of the original SESS system and Iterative decoding. Cooperative diversity is explained in Section 3. The proposed model of SESS-CD with iterative detection is described in Section 4. Section 5 presents the simulation results and compares the proposed system to a PN-coded spread spectrum in the similar cooperative environment. Finally, in section 6, we conclude the paper.

Notations and abbreviation: Superscript T is used for transpose in whole paper. { } Represent the series, [ ] represent mean of the elements in the brackets symbol and \( \eta \) represent Gaussian noise. SESS-CD and PNSS-CD stands for self-encoded spread spectrum in cooperative diversity and PN coded spread spectrum in cooperative diversity respectively.

2. Self Encoded Spread Spectrum
Basic model of self encoded spread spectrum and iterative decoding extracted from [1, 3] will be explained below in this section.

2.1. Transmitter

A block diagram of SESS system is shown in Figure 1, where each D-block is a representation of one delay register, \( N \) denotes the length of spreading sequence, and \( T \) is the bit duration. The source stream \( e \) is assumed to be bipolar values of \( \pm 1 \). The bits are first spread by the spreading sequence \( d(k) \) of length \( N \) at a chip rate of \( N/T \). This sequence is constructed from the source information stored in the delay registers that are updated after every time interval \( T \). Spreading sequence of k-th bit \( e(k) \) is given as:

\[
d(k) = (e(k-1), e(k-2), \ldots, e(k-N))^	op
\]

Hence the spreading sequence is random and time varying as the bits change from one to another, when a random input source stream is feeded. It is assumed that the delay registers have been initialized by a sequence of stochastic nature (it is also assumed that the initial sequence is known at the receiving end). This randomness is achieved by source coding the bits to the near maximum entropy. The transmission of spread spectrum sequence at transmitter end is represented as:

\[
c(k, n) = e(k)d(k, n)
\]

![Figure 1. Self encoded spread spectrum block diagram](image)

From (3) we can see that it is clear that memory depth of modulation of SESS is \( N \):

\[
c(k, n) = e(k)d(k, n) = e(k)e(k - n).
\]

2.2. Receiver

Channel assumed by us is that fading on each bit period is constant and independent from the other bits. Transfer function of channel is ‘\( f \)' and effect on k-th bit is represented by \( f(k) \), k-th input at receiver is \( y(k,n) \) and is given by:

\[
y(k,n) = f(k)c(k,n) + \eta(k,n)
\]

Where \( \eta(k,n) \) is zero-mean and No/2 variance (where \( N_0 \) is the power of the noise ), additive white Gaussian noise.

\[
\hat{e}(k) = \frac{1}{N}\sum_{n=1}^{N} y(k,n) \hat{d}(k,n)
\]

Normal decoding function is represented by:

\[
\hat{e}(k) = \frac{1}{N}\sum_{n=1}^{N} f(k)c(k,n) \hat{d}(k,n) + u(k)
\]

Where \( u(k) \) is represented by:

\[
u(k) = \sum_{n=1}^{N} \eta(k,n) \hat{d}(k,n)
\]

\( \hat{d}(k,n) \) is nth chip of spreading sequence \( \hat{d}(k) \) generated by delay registers these chips are estimated from the received signal here we assume that first sequence is known at receiver end.

2.3. Iterative decoder

As we have shown in previous sub-section that despreading sequence is estimated from received signal so if there is an error in received signal estimation then it will propagate through the next \( N \) sequences, where \( N \) is the length of spreading sequence. Therefore to reduce the propagation of error and exploitation of inherent
time diversity in self-encoded spread spectrum, we use Iterative decoding. Iterative decoding can be described as a decoding technique utilizing a soft-output decoding algorithm that is iterated several times to improve the bit error performance of a coding scheme (for this paper we are using only one iteration), with the goal of obtaining true maximum-likelihood decoding, and less decoder complexity \[4\].

From (3) we can see that there is memory in SESS system so the natural candidate for decoding method is Maximum Likelihood Sequence Estimation (MLSE) detection based on the Viterbi algorithm. However number of states increases exponentially with increase spreading sequence \[4\]. An iterative detection scheme can be used in place of MLSE to reduce the complexity to a linear order of the spreading factor, which renders the performance very close to that of the MLSE detector. Model of Iterative detector is shown in Fig 3.

From the (8) it can be seen that \(e_t\) not only is related to the \(N+1\) previous bit, it is also used to spread next \(N\) bits. From this we conclude that we can use next \(N\) bits to derive information about \(e_t\) as well.

3. Cooperative Diversity

The crux of Cooperative relaying is to make most of the broadcast nature of radio and to reap benefits of multiple devices, such as spatial diversity gain over wireless fading channels \[5, 6\]. Cooperative communications gained popularity due to its ability to mitigate the fading effects of wireless multipath transmission. Due to the wide areas the radio signals are commonly distributed across, intermediate relay nodes, which cooperatively re-transmit signals and thereby increase spatial diversity for the receiver end.

Amplify and Forward (AAF) and Decode and Forward (DAF) are the two most commonly employed relaying protocols used in cooperative communications \[5, 6\]. In this paper we have used AAF because in the case of DAF, we have to decode received signal at relay which will increase the complexity of the system. However, with AAF noise amplification at relay nodes occurs, limiting the potential gain.

In AAF, the intermediate relay amplifies the power of the received signal and then forwards it to the receiver after amplification process. To remain within its power constraint, an amplifying relay must use gain \[7\]:

\[
\beta_r \leq \sqrt{\frac{P_{R_1}}{f_{R_2,R_1}^2 P_{R_2} + N_o}} \tag{9}
\]

Gain is allowed to depend upon the fading coefficient \(f_{R_2,R_1}\) between the source \(R_1\) and the relay \(R_2\). Here channel estimation is used to find \(f_{R_2,R_1}\)
\( P_{R_1} \) is transmission power of the source
\( P_{R_2} \) is the transmission power of the relay

4. System Model

Consider the cooperative network where information is communicated between a source (S=R₁) and a destination (D=R₀) over a complex channel with fading parameter \( f_{i0} \). Relay node, R₂, cooperate to provide repeated signals through the complex channels with flat fading channel parameters \( (f_{12}) \) from (R₁) to (R₂), and \( (f_{20}) \) from (R₂) to (R₀).

The SESS frames are transmitted through the direct and relay paths simultaneously with different fading coefficients as shown in Fig 3. The self-encoding operation at the transmitter is reversed at the receiver. The recovered data is fed back to the N-tap delay registers to provide the estimate of spreading sequence sent from the transmitter, required for signal de-spreading. The SESS-CD receiver employs iterative detection. The receiver thus exploits the additional time diversity of SESS system while we have the spatial diversity gain due to the use of cooperative communication. The function of relay here is to only amplify the data and forward it to receiver, the amplification factor of relay from (9) is denoted by \( '\beta_r' \).

Signal at destination from source is:
\[
y_1(k,n) = f_{i1}(k)c(k,n) + \eta_1
\]  
(10)

Signal received at relay is:
\[
y_{r2}(k,n) = f_{i2}(k)c(k,n) + \eta_{r2}
\]  
(11)

Signal at destination from relay is
\[
y_2(k,n) = f_{20}(k)(f_{i2}(k)c(k,n) + \eta_{r2}) + \eta_2
\]  
(12)

Here \( \eta_1 \) is the noise received on receiver and \( \eta_{r0} \) is noise received on the relay. Both noises are statistically independent white Gaussian noise. We assume that noise power is same at relay and receiver which is \( \sigma^2 \).

So whole signal is:
\[
y(k,n) = f_{20}(k)(f_{i2}(k)c(k,n)) + f_{i0}(k)c(k,n) + \eta
\]  
(13)

Where \( \eta \) is:
\[
\eta = f_{20}(k)\eta_{r2} + \eta_1 + \eta_2
\]  
(14)

Figure 3. Structure of SESS in Cooperative environment
5. Matlab Simulation and Results

In this section, performance of SESS-CD is determined with single relay node and is compared with PNSS-CD. For simulation purpose, length of the spreading sequence for both PNSS and SESS was set to N=16, number of bits per iteration were set to 50,000, and number of iteration per SNR value was 100.

In Fig. 4, we compare the results of PNSS-CD with SESS-CD in same environment, with both having one relay and as we see in results that there is nearly 3.5 dB gain in terms of SNR at BER $10^{-3}$. Also at 1dB BER is nearly $10^{-2}$ for single iterative decoder. In above simulation we have used single iteration of iterative decoder. Drawback of using iterative decoder is that it increases the complexity of system at but BER is reduced in the process.

![Figure 4. Results of simulation](image)

6. Conclusion

In this paper, we have formulated a new way of SESS-CD with iterative detection as a means to provide temporal and spatial diversities for wireless communications to reduce the effect of fading channels. The results show that we have achieved the gain of 3.5 dB by using an iterative decoder with single iteration. The linear iterative detection is based on soft estimates that converge quickly, making it reasonably efficient for practical implementation.

It is expected that the spectral efficiency of the system can be further increased by integrating QAM with SESS and by performing self encoding across multiple QAM symbols. This could be the future work for SESS-CD.

7. References


