

Performance Analysis of Dual-Hop UWB System with Non-regenerative Relaying Scheme

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Abstract— In this paper, we intend to improve the performance of IR-UWB system by cooperative dual-hop scheme and the BER of the two-hop DS-BPAM UWB system over indoor multipath fading channels is studied. We employ non-regenerative relaying scheme in the relay node instead of regenerative relaying to avoid the performance degradation. To study the system performance, the end to end SINR analysis of the dual-hop scheme is provided, along with a BER analysis. At last, the BER performance of the cooperative dual-hop UWB system under IEEE 802.15.3a indoor multipath fading channel is obtained and it shows the efficiency of the cooperative dual-hop scheme.

Keywords— Ultra wideband, cooperative technology, non-regenerative relaying, multipath channel, direct sequence.

I. INTRODUCTION

Ultra wideband (UWB) Radio has been considered as one of the possible candidates for future high-rate, low cost and short range wireless communications [1]. It has numerous advantages over other short range wireless communication systems, such as low power consumption, low interference to other existed systems for its small power spectrum density (PSD), high data rate and excellent time resolution. However, the low PSD limits the coverage of the UWB system and the high data rate also can be influenced by the extension of the coverage. In order to solve these problems, the cooperative technology has been applied into UWB systems.

Cooperative communication as a new technology in wireless networks where the cooperative nodes or users can help each other and improve the overall system performance is introduced in [2]. One simple and typical cooperative network is relay network. The cooperative relaying scheme has been widely employed in modern communication systems to provide higher quality of service (QoS), extend communication coverage, and improve transmission reliability. The relaying scheme can be divided into two categories, regenerative relaying and non-regenerative relaying. For the first scheme, the relay node decodes, encodes and forwards the processed signals into the destination. For the second one, it just forwards the received signals to the destination after the procession of correlator and integration-and-dump unit. The

non-regenerative relaying has the advantages in system complexity and the real time performance. In this paper, we employ amplify-and-forward (AF) relaying scheme, a typical non-regenerative technology, into direct sequence bipolar pulse amplitude modulation (DS-BPAM) UWB system which was investigated in [3].

Recently, there have been some research works focusing on the combination of the cooperative relaying technology with UWB system. In [4][5], C. AbouRjeily et al. investigated the DF and AF scheme with IR-UWB system and they mainly considered the structure and the construction of the space time codes employed in the UWB system. The performance of MB-OFDM UWB system with typical cooperative protocols, AF and decode-and-forward (DF), was studied in [6][7]. The authors in [8] analyzed the BER performance of TH-UWB system using DF relaying protocol based on the characteristic function of the decision variable at the destination. In [9], the authors employed the differential encoder into cooperative UWB system. Although it can limit the inter-symbol interference (ISI) efficiently, the system complexity in practical realization will be increased. K. Maichalernnukul et al. introduced multiple-antenna relay with antenna selection in dual-hop UWB relay system [10][11]. This scheme improves the system performance, but the requirements for multiple-antenna in the terminal can not be realized easily for the limitations in terminal size, system cost and complexity. With regard to the practical realization, in this paper, we consider the relay node equipped with single antenna and direct transmission of the received signals to the destination with a proper amplification coefficient.

Currently, the research of cooperative UWB relaying system focuses on the performance analysis of the different cooperative UWB relaying schemes and the practical realization. To our knowledge, the BER performance of the cooperative DS-BPAM UWB system with AF protocol has not been considered in the literature. Specially, we take IEEE 802.15.3a channel model into consideration and provide a thorough end to end SINR analysis of the dual-hop scheme along with an approximated BER like [3].

The rest of this paper is organized as follows. Section II presents the cooperative dual-hop non-regenerative relaying

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scheme and the channel model. In Section III, the end to end SINR of the proposed scheme and an approximated BER are analyzed according to the signal model. According to the signal model, the end to end SINR of the proposed scheme is derived in Section III along with a approximated BER. The simulation results are obtained in section IV. Finally, conclusions are drawn in Section V.

II. TWO-HOP COOPERATIVE RELAYING SCHEME AND THE CHANNEL MODEL

A. Two-hop cooperative relaying scheme

We consider the cooperative relaying DS-BPAM UWB system with non-regenerative relaying scheme and the system block diagram is shown in Fig.1. In the first hop, the source node broadcasts the data to the relay node which works with a Rake combiner. Then, the received data will be normalized in energy after Rake combining instead of Rake decision. In the second hop, the relay node will retransmit the energy-normalized signal output of the Rake combiner to the destination node with a constant transmission power. At the last step, the destination node will make the decision of the recovered information bits according to the outputs of the Rake combining.

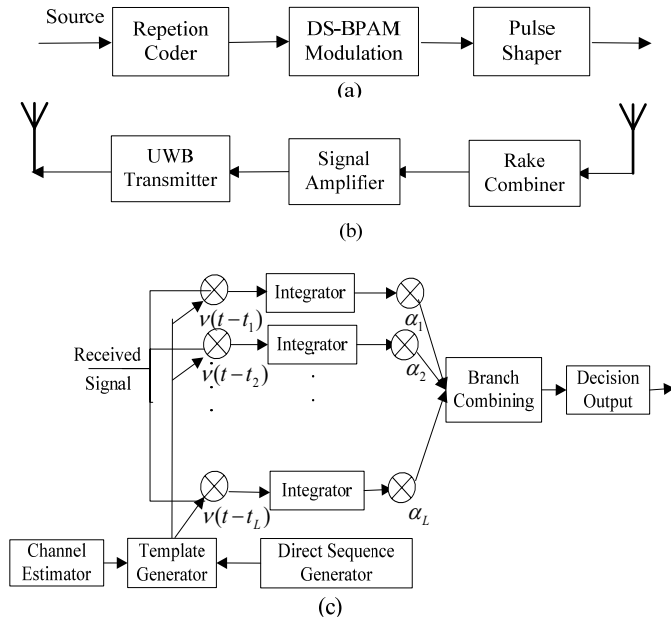


Figure 1. Transceiver diagram of the cooperative relay DS-BPAM UWB system (a) DS-BPAM UWB transmitter, (b) AF relay node (c) Rake receiver in the destination node.

B. Channel model

The antenna in the receiver side will make differentiation to the transmitted pulse $w_{tr}(t)$ and convert it to the received pulse $w_{rec}(t)$ at the output of the receiver antenna. In this paper, we will consider the standard UWB multipath channel model (CM), such as CM1 and CM2, described by IEEE in [12]. In

this multipath channel environment, for each transmitted pulse in each frame, we will receive several corresponding pulses with different attenuation and delays. The channel impulse response can be expressed in a simple way as,

$$h(t) = \sum_{l=0}^{L-1} \alpha_l \delta(t - \tau_l) = \sqrt{G} \sum_{l=0}^{L-1} \phi_l \delta(t - \tau_l), \quad (1)$$

where α_l and τ_l are the channel gain and the time delay of the l th path, respectively. L denotes the number of the resolvable multipath components. G is the total multipath gain and ϕ_l is the energy-normalized channel gain, and we have $E \left[\sum_{l=0}^{L-1} \phi_l^2 \right] = 1$ in common.

The coefficient ϕ_l is generated by the modified Saleh-Valenzuela model proposed by IEEE 802.15.3a working group. For more details about the channel model and the corresponding parameters, the readers are suggested to refer to [12].

III. PERFORMANCE ANALYSIS OF THE DUAL-HOP COOPERATIVE RELAYING UWB SYSTEM

The performance of the dual-hop DS BPAM UWB system using non-regenerative AF relaying scheme is analyzed in this section.

In the first hop, the source will transmit the binary information bit b to the relay by $x_s(t)$ as,

$$x_s(t) = b \sqrt{E_p} \sum_{i=1}^{N_f} w_{tr}(t - (i-1)T_f), \quad (2)$$

where E_p is the pulse energy and T_f is the frame time.

We assume that the impulse response of the channel between the source and the relay and that of the channel between the relay and the destination have the same expression as,

$$h(t) = \sum_{l=0}^{L-1} \alpha(l) \delta(t - \tau_l). \quad (3)$$

Through UWB multipath fading channels, the received signal $r(t)$ at the relay node from the source is expressed as,

$$r(t) = x_s(t) * h(t) = b \sqrt{E_p} \sum_{i=0}^{N_f-1} \sum_{l=0}^{L-1} \alpha(l) w_{rec}(t - iT_f - \tau_l) + n(t), \quad (4)$$

where $n(t)$ is the additive white Gaussian noise (AWGN) with mean value 0 and variance $\sigma^2 = N_0/2$.

The template signal for the Rake receiver at the relay node can be set as,

$$\begin{aligned} v_{bit}(t) &= \sum_{i=0}^{N_f-1} \sqrt{E_p} w_{rec}(t - iT_f) * h(t) \\ &= \sqrt{E_p} \sum_{i=0}^{N_f-1} \sum_{l=0}^{L-1} \alpha(l) w_{rec}(t - iT_f - \tau_l) \end{aligned} \quad (5)$$

We assume that the period $[0, T]$ is the time interval includes the selected L paths. The output signal after the Rake combining can be obtained as,

$$\begin{aligned}
Z_R &= \int_0^T r(t) v_{bit}(t) dt \\
&= \int_0^T r(t) \sqrt{E_p} \sum_{i=0}^{N_f-1} \sum_{l=0}^{L-1} \alpha(l) w_{rec}(t - iT_f - \tau_l) dt \\
&= \sum_{i=0}^{N_f-1} bE_p \int_0^T \left[\sum_{l=0}^{L-1} \alpha(l) w_{rec}(t - iT_f - \tau_l) \sum_{k=0}^{L-1} \alpha(k) w_{rec}(t - iT_f - \tau_k) \right] dt \\
&\quad + \sum_{i=0}^{N_f-1} \sqrt{E_p} \sum_{l=0}^{L-1} \alpha(l) \int_0^T n(t) w_{rec}(t - iT_f - \tau_l) dt \\
&= \sum_{i=0}^{N_f-1} bE_p \left[\sum_{l=0}^{L-1} \alpha^2(l) + \sum_{l=0}^{L-1} \sum_{k=0, k \neq l}^{L-1} \alpha(k) \alpha(l) R(\tau_k - \tau_l) \right] \\
&\quad + \sum_{i=0}^{N_f-1} \sqrt{E_p} \sum_{l=0}^{L-1} \alpha(l) \int_0^T n(t) w_{rec}(t - iT_f - \tau_l) dt
\end{aligned} \quad (6)$$

where $R()$ is the auto-correlation function of the received pulse.

Let $\alpha_{\pm 1}$ and $\sigma_{\pm 1}^2$ be the mean and variance of the Rake combining output. We can calculate the values of $\alpha_{\pm 1}$ and $\sigma_{\pm 1}^2$ as follows,

$$\alpha_{\pm 1} = N_f E_p \left(\sum_{l=0}^{L-1} \alpha^2(l) + \sum_{l=0}^{L-1} \sum_{k=0, k \neq l}^{L-1} \alpha(k) \alpha(l) R(\tau_k - \tau_l) \right), \quad (7)$$

$$\sigma_{\pm 1}^2 = N_f E_p \cdot \frac{N_0}{2} \left(\sum_{l=0}^{L-1} \alpha^2(l) + \sum_{l=0}^{L-1} \sum_{k=0, k \neq l}^{L-1} \alpha(k) \alpha(l) R(\tau_k - \tau_l) \right). \quad (8)$$

Assume $\varepsilon_1 = \sum_{l=0}^{L-1} \alpha^2(l) + \sum_{l=0}^{L-1} \sum_{k=0, k \neq l}^{L-1} \alpha(k) \alpha(l) R(\tau_k - \tau_l)$, the useful signal energy of the Rake combining output can be represented as,

$$E_R = \alpha_{\pm 1}^2 + \sigma_{\pm 1}^2 = N_f E_p \varepsilon_1 \left(N_f E_p \varepsilon_1 + \frac{N_0}{2} \right). \quad (9)$$

Through the above analysis, we can find that,

$$SNR = \frac{N_f E_p}{N_0/2} \varepsilon_1 = \frac{2E_b}{N_0} \varepsilon_1. \quad (10)$$

In our work, the Rake combining output in the relay node is normalized to unity energy instead of using it to make the decision, which can reduce the complexity of the relay node, short the delay time and also reduce the final system decision error probability. After this process, the energy-normalized received signal version is transmitted to the destination node with reassigned transmission power $\sqrt{E_{q,R}}$ as,

$$x_R(t) = \overline{Z_R} \sqrt{E_{q,R}} \sum_{i=1}^{N_f} w_{rec}(t - (i-1)T_f), \quad (11)$$

where $\sqrt{E_{q,R}}$ is the transmitted power for each pulse in the relay node and $\overline{Z_R} = Z_R / E_R$.

With the same process as in the first hop as the relay node, we can acquire the decision variable at the destination as,

$$\begin{aligned}
Z_D &= \int_0^T r(t) v_{bit}(t) dt \\
&= \int_0^T r(t) \sqrt{E_p} \sum_{i=0}^{N_f-1} \sum_{l=0}^{L-1} \beta(l) w_{rec}(t - iT_f - \tau_l) dt
\end{aligned}$$

$$\begin{aligned}
&= \sum_{i=0}^{N_f-1} \overline{Z_R} E_p \int_0^T \left[\sum_{l=0}^{L-1} \beta(l) w_{rec}(t - iT_f - \tau_l) \sum_{k=0}^{L-1} \beta(k) w_{rec}(t - iT_f - \tau_k) \right] dt \\
&\quad + \sum_{i=0}^{N_f-1} \sqrt{E_p} \sum_{l=0}^{L-1} \beta(l) \int_0^T n(t) w_{rec}(t - iT_f - \tau_l) dt \\
&= \sum_{i=0}^{N_f-1} \overline{Z_R} E_p \left[\sum_{l=0}^{L-1} \beta^2(l) + \sum_{l=0}^{L-1} \sum_{k=0, k \neq l}^{L-1} \beta(k) \beta(l) R(\tau_k - \tau_l) \right] \\
&\quad + \sum_{i=0}^{N_f-1} \sqrt{E_p} \sum_{l=0}^{L-1} \beta(l) \int_0^T n(t) w_{rec}(t - iT_f - \tau_l) dt
\end{aligned} \quad (12)$$

Now, we substitute $\overline{Z_R}$ into (12) and the SINR at the destination can be represented as,

$$\begin{aligned}
SINR &= \frac{S}{N} = \frac{N_f^2 E_q^2 \varepsilon_2^2 \frac{\varepsilon_1^2 N_f^2 E_p^2}{\varepsilon_1^2 N_f^2 E_p^2 + N_f E_p \frac{N_0}{2} \varepsilon_1}}{N_f E_p \frac{N_0}{2} \varepsilon_1} \\
&\quad + \frac{N_f E_q^2 \varepsilon_2^2 \frac{N_f E_p \frac{N_0}{2} \varepsilon_1}{\varepsilon_1^2 N_f^2 E_p^2 + N_f E_p \frac{N_0}{2} \varepsilon_1} + N_f E_q \frac{N_0}{2} \varepsilon_2}{\varepsilon_1^2 N_f^2 E_p^2 + N_f E_p \frac{N_0}{2} \varepsilon_1} \\
&= \frac{E_{bR} \varepsilon_2 E_{bs} \varepsilon_1}{E_{bR} \varepsilon_2 \frac{N_0}{2} + \frac{N_0}{2} \left(\varepsilon_1 E_{bs} + \frac{N_0}{2} \right)} = \frac{\gamma_1 \gamma_2}{1 + \gamma_1 + \gamma_2}, \quad (13)
\end{aligned}$$

where we assume $\varepsilon_2 = \sum_{l=0}^{L-1} \beta_l^2 + \sum_{l=0}^{L-1} \sum_{k=0, k \neq l}^{L-1} \beta(k) \beta(l) R(\tau_k - \tau_l)$,

$$\gamma_1 = \frac{2E_{bs} \varepsilon_1}{N_0} \text{ and } \gamma_2 = \frac{2E_{bR} \varepsilon_2}{N_0}.$$

The total SINR can be approximated by its upper bound γ_b , which is a tight bound than others at medium and high SNR values. Now we can acquire a more tractable SNR as in [13]-[15] and it can be expressed as,

$$\gamma \leq \gamma_b = \min\{\gamma_1, \gamma_2\} \quad (14)$$

The PDF γ_b can be obtained with the probability theory as,

$$f_{\gamma_b}(x) = f_{\gamma_1}(x) [1 - F_{\gamma_2}(x)] + f_{\gamma_2}(x) [1 - F_{\gamma_1}(x)]. \quad (15)$$

In [15], the PDF and CDF of ε_1 and ε_2 has been derived. Since $2E_{bs}/N_0$ and $2E_{bR}/N_0$ are both constants for this system, the PDF and CDF of γ_1 and γ_2 can be obtained easily. Substituting them into (15), we can obtain the PDF of γ_b .

The system BER is conditioned on the instantaneous SNR γ_b and it can be achieved as

$$P_e(\gamma_b) = Q(\sqrt{\gamma_b}), \quad (16)$$

where $Q(\cdot)$ is the Gaussian probability integral.

IV. SIMULATION RESULTS

In this section, the computer simulation results about the dual-hop DS-BPAM UWB relaying system over multipath fading channel are presented. The transmitted pulse is modeled as the second derivative of a Gaussian pulse which

can be expressed as $w_{\alpha}(t) = \left[1 - 4\pi \left(\frac{t}{\tau_m} \right)^2 \right] \exp \left[-2\pi \left(\frac{t}{\tau_m} \right)^2 \right]$

where $\tau_m = 0.2877ns$, $T_w = 0.7ns$. To avoid the ISI effects, the frame time is chosen as $T_f = 70ns$. Selective Rake (SRake) receiver with 5 branches in the relay and the destination node is employed in this paper in order to deal with the multipath attenuation. The direct link between the source and the destination is chosen to be 8.0 meters. And the relay is located in the half way of the direct link. As a common case, the relay scheme will be employed only when the direct link is poor. In the simulation, E_b/N_0 is the SNR at the transmitter. According to IEEE 802.15.3a channel model, the coverage for Case A (CM=1) and Case B (CM=2) are both within 0~4m.

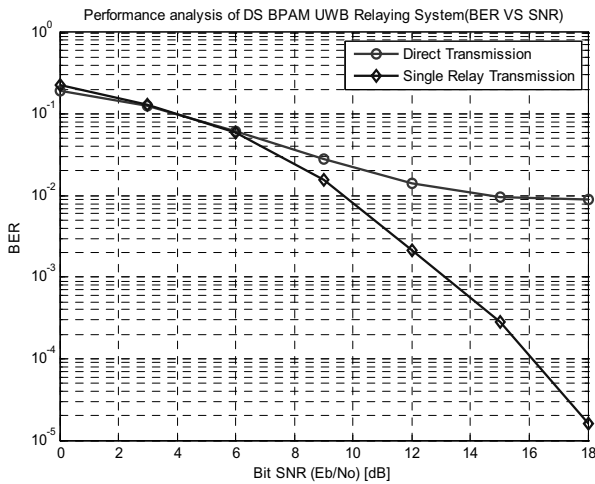


Figure 2. BER performance of the dual-hop relaying UWB scheme and the direction transmission (source-relay channel and relay-destination channel: CM1, source-destination channel: CM3)

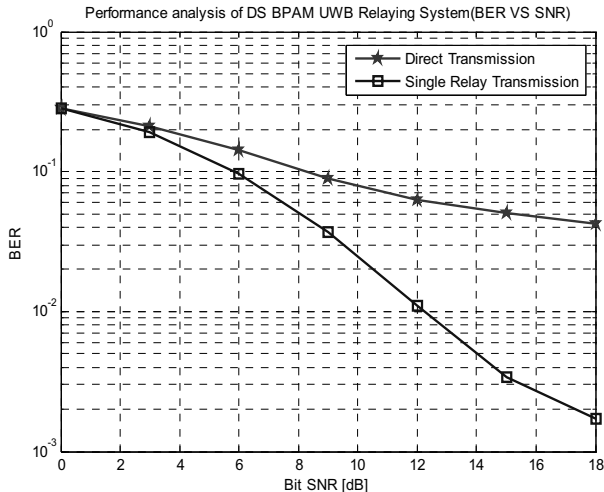


Figure 3. BER performance of the dual-hop relaying UWB scheme and the direction transmission (source-relay channel and relay-destination channel: CM2, source-destination channel: CM4)

At first, we employ channel model CM=1 to model the source-relay channel and the relay-destination channel, and the channel from the source to the destination is modeled by channel model CM=3. As we can be see from the simulation results in Figure 2 that the BER performance of the dual-hop scheme outperforms the direct transmission system significantly with the increase of SNR. Compared with the direct transmission system, the single relay dual-hop system can obtain about 2.6dB gains when BER is 10^{-1} .

Then, we will use channel model CM=2 to model the channel between the source to the relay and the channel between the relay to the destination since the distances of them are both about 4.0m. As illustrated in Figure 3, the performance of the single relay system, the dual-hop relay UWB system, over channel model CM=2 (NLOS scenario) also outperforms the direct transmission system, the conventional DS-BPAM UWB system. We can have more than 6.0dB gains compared with the direct transmission when BER is 10^{-1} . The SNR gains will also be increased greatly with the requirement of better BER like what happens in Figure 2.

V. CONCLUSIONS

We investigate the performance of UWB system by employing cooperative dual-hop non-generative relaying scheme. The theoretical BER is derived. Our simulation results show that the dual-hop UWB system outperforms the direct transmission UWB system. And it improves the performance significantly by the assistance of the relay node in a proper location and scenario. Generally, the result implies that the cooperative relaying scheme, especially non-generative relaying scheme, is an ideal choice for UWB system to extend the coverage and improve the performance.

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