Enhancing the Performance of UWB-Based WPANs Using Cooperative PNC Relaying

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SUMMARY In this letter, a cooperative Piconet Coordinator (PNC) relay scheme is proposed based on a MB-OFDM system. For time domain diversity, the MB-OFDM UWB system transmits the same symbol twice in different time slots over different bands. Devices (DEVs) that are close to the PNC use it as a relay in the second transmission time. Additionally, a symbol transmission schedule is proposed to provide a sufficient time interval for cooperation. During the first transmission of the symbol, the PNC listens in on the signal from the Source Device (SDEV) to the Destination Device (DDEV) and decodes and re-encodes it with the same data rate. The PNC then transmits the signal in the second transmission as well as the SDEV. Our simulation results demonstrate the proposed cooperative PNC relay scheme can significantly improve the bit error rate (BER) performance, which translates into a power savings capability.

key words: MB-OFDM, MAC, cooperative PNC

1. Introduction

Cooperative communication is a novel technique for future communication systems. Although general methods for cooperative communication such as amplify-forward and decode-forward schemes have been introduced in [1], problems related to relay assignment and management have seen relatively little attention. In the IEEE 802.15.3 MAC protocol [2] the Piconet Coordinator (PNC) is usually AC-powered and has larger memory size and better calculating ability than other DEVs. As a centralized controller, the PNC is in charge of assigning Channel Time Allocation (CTA) to each pair of DEVs based on TDMA, i.e., only a pair of DEVs can communicate during a single CTA. The relay scheme in [3] opts to use DEVs within the piconet rather than relays in UWB systems. By using suitable DEVs as relays, the power consumption can be distributed from the PNC to other DEVs and thereby prevent the PNC from consuming its battery too rapidly. When AC power is used by the PNC in a home network, the power issue of PNC is comparatively not serious.

A MB-OFDM system [4] of mode 1 DEV uses a repeater to transmit each symbol for mandatory data rates such as 53.3, 106.6, 200 Mbps; i.e., every symbol is transmitted twice in different time slots over different frequency bands. In the proposed scheme the PNC decides whether it can act as a relay, based on the channel condition and position information [5]. If it decides to be a relay (herein, called a cooperative partner), the PNC will listen in on the signal and decode and re-encode it with the same data rate after the first transmission of the symbol from SDEV to DDEV. In the second transmission, the PNC will transmit the re-encoded signal together with the SDEV. Because the signal from the SDEV to DDEV contains the same original information as the signal from the PNC to the DDEV, both diversity gain and power gain can be achieved, which is analogous to the receiver diversity. Simulation results show that the proposed scheme can achieve better BER performance within an effective range, where lower power consumption can be achieved.

This letter is organized as follows. Section 2 describes the proposed cooperative PNC relay scheme. In Sect. 3 the proposed scheme is valuated by intensive simulations. Finally, Sect. 4 notes the benefits of the suggested approach and provides conclusions.

2. Proposed PNC Relay Scheme

Figure 1(a) illustrates exemplary transmission schemes based on Time-Frequency Code (TFC) for channel number 1. There are 3 symbols in a single schedule and each symbol is transmitted twice from the SDEV to DDEV us-
ing different bands, i.e., symbol 1 on band $f_1$ and $f_2$, to obtain time domain diversity. However, in the case of the proposed scheme, when the DEVs are close to the PNC, as in Fig. 1(b), the SDEV can choose the PNC as a cooperative partner. During the first transmission from the SDEV to DDEV, the PNC listens in on the signal from the SDEV. The PNC then decodes and re-encodes the signal with the same data rate. Based on the timing of the superframe, the PNC will send out the encoded signal together with the SDEV in the second transmission. The DDEV will then use the Maximum Ratio Combiner (MRC) to detect the received signal. Because the signal from the SDEV to DDEV contains the same original information with the same data rate as the signal from the PNC to DDEV, additional diversity gain as well as power gain can be achieved with analogous receiver diversity.

In order to provide sufficient time for the PNC to decode and re-encode the received signal, we propose modification of the symbol schedule as outlined in Table 1. There is 1 symbol duration margin between two transmissions in the worst case, e.g., symbol 2 (S2) and symbol 3 (S3). Even when the PNC does not act as a cooperative partner, the proposed symbol schedule is still effective in the MB-OFDM system.

## 3. Simulation Results

The performance of the proposed scheme was evaluated by intensive simulations in terms of bit error rate (BER) and average probability for using the PNC as relay.

First, the BER performance was observed when the distance between the SDEV and DDEV is fixed and the PNC moves around the SDEV. From this simulation, the effective range, where the proposed scheme is superior to the original MB-OFDM system in terms of BER, can be obtained. However, the PNC is usually located in the middle of the piconet and the positions of the SDEV and DDEV are unpredictable. Therefore, second, we fix the position of the PNC, generate the DEVs uniformly over the PNC coverage, and calculate the average probability of using the PNC as a relay.

### 3.1 BER Performance

For the original MB-OFDM system, all of the simulation assumptions are the same as in [6]. In the case of the proposed scheme, we assume the received signal in the second transmission is composed of the signal from the SDEV to DDEV and the signal from the PNC to DDEV. Since the spatial correlation length has been found negligible within the piconet [8], different channel realizations are considered for direct route and PNC-relayed route. As a centralized controller, the PNC knows the perfect channel condition within its coverage. In the simulations, DDEV and SDEV are placed on the X-axis with fixed positions, while the PNC moves around SDEV. The simulation parameters are listed in Table 2.

![Fig. 2 BER and effective range for using PNC cooperation (Reference Distance = 14 meters).](image)

Figure 2 compares the proposed scheme with the original MB-OFDM system in terms of BER with an SDEV-DDEV distance (reference distance) of 14 meters, where the SDEV is located in (0, 0) and the DDEV is in (14, 0). The reference BER is defined as the BER obtained in the original MB-OFDM system with the same SDEV-DDEV distance. Compared with the original MB-OFDM system, due to the cooperative gain by PNC relaying, the proposed scheme can achieve better performance. However, as the distance between PNC and SDEV increases, the path loss between them becomes larger. Then, the PNC can decode the received signal correctly with a lower probability, which translates into worse performance of the cooperative PNC relaying scheme. By comparing the PNC relaying scheme and the original MB-OFDM system with different PNC-SDEV distances, the effective range can be drawn, where it is beneficial to use the PNC as a relay in term of BER.
In order to determine the impact of the reference distance on the effective range, we increased the reference distance from 14 meters to 20 meters. The effective range is found to be kept nearly the same. Compared to the effective range with 14 meters, the origin of the effective range with 20 meters has a parallel shift of about 0.2 meters to the right side with a circular shape, while the area of effective range with 20 meters is almost the same as that with 14 meters. Hence, the effective range is not dependent on the reference distance.

Figure 3 shows the effective ranges for different reduction of transmitting power in the SDEV in the 2nd transmission with reference distance of 14 meters.

![Effective range in AWGN](image)

![Effective range in CM1](image)

**Fig. 3** Effective ranges for different reduction of transmitting power in the SDEV in the 2nd transmission with reference distance of 14 meters.

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The probability of using the cooperative PNC as a relay in CM1 channel with a code rate of 1/3 within the piconet area is obtained by the simulation model described above. When the distance between the PNC and SDEV increases, path loss between them also becomes larger. This implies that the probability of the PNC correctly detecting the received signal decreases and, therefore, additional transmission by the cooperative PNC is no longer beneficial. Thus, the probability of using the PNC as a relay decreases as the distance between the PNC and SDEV increases. The PNC relaying scheme is beneficial at a distance between the PNC and SDEV from 0 to 6.8 meters. When the distance between the PNC and SDEV is longer than 6.8 meters, the PNC can operate with the original MB-OFDM scheme, i.e., no PNC relay scheme, to satisfy the required BER performance.

The average probability to use the PNC as a relay $P_{\text{average}}$ is calculated by
\[ P_{\text{average}} = \sum_{n=0}^{N} \frac{\pi (r_{n+1}^2 - r_n^2) p_{n+1}}{\pi R^2_{\text{radius}}}, \quad r_0 = 0. \]  

(1)

\( R_{\text{radius}} \) is the radius of the piconet coverage. The piconet area is subdivided into \( N \) rings. \( r_n \) is the outer radius of the \( n \)-th ring. DEVs are assumed to be uniformly distributed over the whole coverage of a piconet. \( p_n \) is the probability of using the PNC as a relay in the \( n \)-th ring. We found that the average probability to use the PNC relay is about 32\%. Hence, a centralized PNC can determine whether to act as a relay and whether lower power consumption can be realized for power savings, based on the channel condition and position information. When the DEVs are close to the PNC, the proposed PNC relaying scheme is superior in terms of BER. Additionally, due to the cooperative gain, DEVs can decrease the transmitting power in the second transmission for longer battery life, especially for short distances between the SDEV and PNC.

4. Conclusions

In this letter we proposed a cooperative PNC relay scheme. Based on the channel conditions and position information, the PNC can choose whether to acts as a relay. By using the modified symbol schedule, the PNC can have at least one symbol margin for decoding and re-encoding of the received signal. Simulation results have shown that the proposed scheme has better BER performance than the original MB-OFDM system. With the same target BER of the MB-OFDM system it is possible to decrease the transmitting power of DEVs in the second transmission in the proposed cooperative PNC relay scheme, which can extend the battery life. The average probability to use the PNC as a relay is about 32\% with a code rate of 1/3. A centralized PNC can support the proposed scheme adaptively based on the channel conditions and position information to achieve better BER performance as well as longer battery life.

References