Energy Efficient Cooperative Communication for UWB Based In-Body Area Networks

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ABSTRACT

In this paper, we study the energy efficiency of single relay cooperative transmission for ultra-wideband (UWB) based in-body area networks (IBANs). A simple relay-based cooperative IBAN system model is introduced first. With a target threshold of the received signal-to-noise ratio (SNR), outage probabilities for direct and cooperative transmissions are derived respectively. Afterwards, the average energy consumption per bit is given for both transmission schemes. The optimal relay location for cooperation is also derived and analyzed to minimize the average bit energy consumption. Simulation verifies the analysis and shows that cooperative transmission can achieve a satisfactory improvement on energy efficiency compared with direct transmission over a range of relay locations for UWB based IBANs. The improvement is more significant with a higher SNR threshold or with the implanted sensor having a deeper depth inside the body.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous; D.2.8 [**Software Engineering**]: Metrics—*performance measures*

General Terms

Theory

Keywords

Energy efficiency, Cooperation, UWB, In-body area networks

1. INTRODUCTION

Wireless body area network (WBAN) is a promising technology that can improve healthcare quality with several lightweight sensors on/in the human body [1]. Ultra-wideband (UWB) technology has great potential for applications in WBAN, particularly for medical implanted devices, owing to its simple electronics and low power consumption, which is less likely to affect human tissue and causes interference to other medical equipments. For UWB based in-body BANs (UWB IBANs), energy consumption is one of the most critical performance parameters as replacing implanted batteries is impractical or causes discomfort to the patient [1][2]. On the other hand, relay assisted cooperative communication has drawn much attention in WBANs currently which can achieve a diversity gain that improves link reliability and energy efficiency [3][6][7][8]. However, the energy efficiency of cooperative communication is still an open issue for UWB based IBANs.

For the energy efficiency of the relay assisted communications, considerable studies have been conducted in wireless sensor networks (WSNs) [4][5]. In [4], the energy-efficient communication techniques to minimize the total energy consumption between clusters have been proposed. In [5], an analytical framework for the energy efficiency trade-off in cooperative transmission was presented. It reveals that, for a large distance separation between the source and the destination, cooperative transmission is more energy efficient than direct transmission.

Due to the unique properties of WBANs with distinct channel characteristics and very small network scale compared with WSNs, the aforementioned existing analysis and results on the energy efficiency in WSNs may be inadequate if they are applied to WBANs directly. To this end, the energy efficiency of the relay assisted cooperative communications for WBANs has been studied recently [6][7][8]. In [6], authors analyzed packet size optimization to improve the energy efficiency of cooperative WBANs. In [7], the energy efficiency of cooperative transmission was studied with the constrained targeted outage probability, which demonstrates that the posture state information can help to reduce the energy consumption when designing an efficient power allocation scheme for WBANs. In [8], the energy efficiency of cooperative transmission was considered from a relay selection perspective for UWB based on-body BANs. Results show that direct transmission is more preferable for energy saving when the transmitter and receiver are located on the same side of the human body. In contrast, at a suitable relay location and with large transmission distance, cooperative transmission can achieve a significant improvement on energy efficiency compared with direct transmission when the transmitter and receiver are located on the different sides of the human body.

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However, to the best of our knowledge, research on the energy efficiency of relaying cooperation for UWB based IBANs has not appeared in the literature so far. For this reason, we provide a preliminary study of this case in this paper. Firstly, a typical relay-based cooperative IBAN system model is introduced. With a target threshold of the received signal-to-noise ratio (SNR) for each link, outage probabilities for direct and cooperative transmissions are then derived respectively. Afterwards, the average energy consumption per bit based on the outage probability is investigated for both transmission schemes. The optimal relay location for cooperative transmission is also given and analyzed to minimize the average bit energy consumption. Simulation results verify the analysis and show that direct transmission for UWB based IBANs is very inefficient due to the significant in-body path loss. However, with the aid of a relay node on the body surface, cooperative transmission can achieve a satisfactory improvement on energy efficiency compared with direct transmission over a range of relay locations for UWB based IBANs. The improvement is more significant with a higher SNR threshold or with the implanted sensor having a deeper depth inside the body.

The remainder of this paper is organized as follows. Section II describes the system model including the channel models, energy consumption model and outage probability. In Section III, the average energy consumption per bit for cooperative transmission is presented and the optimal relay location is derived accordingly. Simulation results are presented in Section IV. Conclusion is given in Section V.

2. SYSTEM MODEL

In this paper, we consider a general UWB based IBAN system model consisting of an implanted sensor node inside the chest, several wearable sensor nodes and a body network coordinator on the body surface. The implanted node (Source: S) monitors the physiological states of a person periodically and transmits information bits towards the coordinator (Destination: D). Then, D can send them to the personal server wirelessly for further processing. As shown in Fig. 1, we consider the single relay cooperative case where an adjacent on-body node R (relay) can assist S in delivering its message to D. With the depth of d_r [mm] from S to the body surface and the distance d_{sd} [mm] between S and D, we denote d_1 and d_2 ($d_2 < d_{sd}$) as the distance from D to R and the one from S to R, respectively, where $d_2^2 = d_1^2 + d_{sd}^2 - 2d_1 d_{sd}\cos\theta$, θ is the angle between d_1 and d_{sd}. For simplicity, we only consider the case that $\theta = \arcsin(d_r/d_{sd})$ in this paper.

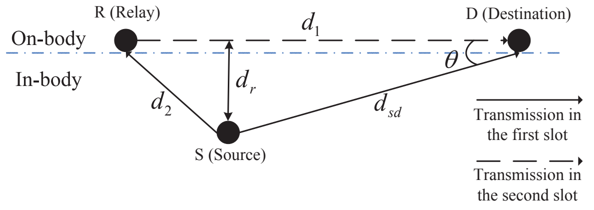

Figure 1: System model for IBANs.

The cooperation protocol is a typical time division multiple access (TDMA) protocol shown in Fig. 1. It consists of two time slots with equal duration. During the first time slot, S broadcasts its signal to D and R, and during the first time slot, R always forwards its received signal to D independently of the results of the transmission in the first time slot, when a feedback is not available from D to R. This protocol can achieve a maximum degree of broadcasting and exhibit no receive collision. It is noted that in practice the amplify and forward (AF) relay, when compared with the decode and forward (DF) relay, requires significantly lower implementation complexity since no decoding is required at R. Thus we only consider the AF relay in UWB based IBANs.

In the following, we will describe the UWB based wireless BAN channel models for on-body and in-body cases. The definition of system outage probability is also presented.

2.1 Channel Models

For cooperative transmission, two types of channel models need to be considered in UWB based IBANs, namely on-body path loss model and in-body path loss model. Table 1 below summarizes the corresponding parameters for these two models [9] [10], where N and N_1 are normally distributed variables with zero mean and standard deviation σ_0 and σ_1, respectively.

Table 1: UWB based BAN Path Loss Models for On-Body and In-Body Cases

On-Body channel model	$PL(d) = a \cdot \log_{10}(d) + L_{on} + N(0, \sigma_0)$
a	19.2
L_{on}[dB]	3.38
σ_0	4.40

In-Body channel model	$PL(d) = a_1 \cdot (d/d_0)^n + L_{in} + N_1(0, \sigma_1)$
a_1	0.987
n	0.85
d_0	1 (mm)
L_{in}[dB]	10
σ_1	7.84

Fig. 2 compares the path loss [dB] for in-body and on-body based on the given channel models. We can see that the in-body path loss is much stronger compared with the on-body case, which indicates that cooperative transmission should be very helpful in improving energy efficiency compared with the in-body direct transmission.

With the given channel models, the received signal to noise ratio (SNR) [dB] for a direct transmission can be given by

$$\gamma = P_t - PL(d) - P_N, \qquad (1)$$

where P_t is the transmit power, d is the transmission distance and P_N is the additive white Gaussian noise (AWGN) power.

2.2 Energy Consumption Model

In this paper, a typical energy consumption model for a direct transmission according to [4] is adopted, which can

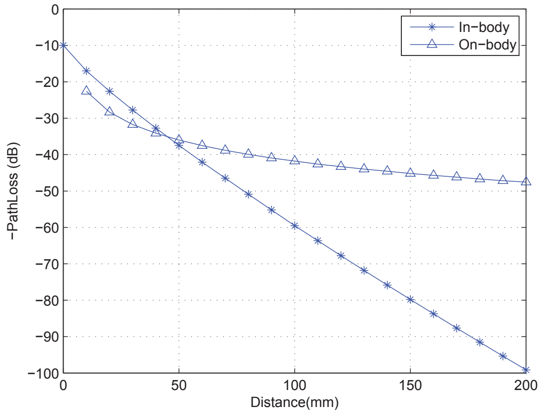

Figure 2: Path loss [dB] versus distance (mm) for in-body and on-body.

be expressed as

$$\begin{aligned} E &= E_t + E_{ct} + E_{cr} \\ &= \frac{P_t}{R_0} + E_{ct} + E_{cr}, \end{aligned} \tag{2}$$

where $E_t = P_t/R_0$, R_0 is transmission bit rate (bits/s). E_{ct} and E_{cr} are the transmitter and receiver circuit energy consumption per bit, respectively. Without loss of generality, we assume that all nodes have the same E_{ct} and E_{cr}.

2.3 Outage Probability

To evaluate the energy efficiency of cooperative transmission and make a fair comparison with direct transmission counterpart, the specific quality-of-service (QoS) requirements should be taken into account. In this paper, to guarantee a reliable transmission, we consider outage probability for each transmission link, which is defined as the probability of the received SNR (γ) falling below a certain threshold, i.e.,

$$p = P(\gamma < SNR_t), \tag{3}$$

where SNR_t is the predefined SNR threshold for UWB based IBANs and the value of SNR_t relies on the system QoS requirements for each transmission link. In fact, bit error rate (BER) is a monotonically decreasing function of SNR with different modulations such as pulse-position modulation (PPM), pulse-amplitude modulation (PAM), etc [11]. Hence the setup of SNR_t is equivalent to guaranteeing the link BER constrained by system QoS. For analytical simplicity, it is assumed that each transmission link in UWB based IBANs has the same SNR_t.

2.4 Average Energy Consumption for Direct Transmission

Energy efficiency is one of the most critical performance parameters for designing UWB based IBANs. In this paper, we consider the average energy consumption per bit to evaluate the energy efficient performance of cooperative transmission. For direct transmission from S to D, signal is affected by the in-body path loss. When the S-D link is in outage, D sends a negative acknowledgement (NACK) back to S to indicate the failure reception and S will retransmit until a successful bit delivery is achieved at D (we omit the energy consumption for NACK since it is negligible compared with the total transmission energy consumption).

The outage probability for S-D link can be given by

$$\begin{aligned} p^{sd} &= P(\gamma_{sd} < SNR_t) \\ &= P(P_t^d - a_1 d_{sd}^n - L_{in} - P_N - SNR_t < N_1) \\ &= Q(\frac{P_t^d - a_1 d_{sd}^n - L_{in} - P_N - SNR_t}{\sigma_1}), \end{aligned} \tag{4}$$

where P_t^d is the transmission power of S-D link and $Q(\cdot)$ is the Q-function which can be expressed as

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-t^2/2} dt.$$

With P_t^d, we have the energy consumption for S-D link

$$E_{sd} = \frac{P_t^d}{R_0} + E_{ct} + E_{cr}.$$

Then, the average energy consumption per bit for direct transmission can be obtained with p^{sd} and E_{sd},

$$\begin{aligned} \xi^{sd} &= E_{sd} \sum_{m=0}^{\infty} (m+1)(p^{sd})^m (1 - p^{sd}) \\ &= \frac{E_{sd}}{1 - p^{sd}}, \end{aligned} \tag{5}$$

In next Section, the average energy consumption per bit for cooperative transmission is investigated and the optimal relay location for cooperation is given and analyzed accordingly to minimize the bit energy consumption.

3. ANALYSIS OF ENERGY CONSUMPTION FOR COOPERATIVE TRANSMISSION

In this Section, based on the property of the cooperative protocol, we first calculate the average energy consumption per bit for cooperative transmission, then the optimal relay location is derived accordingly with the given d_{sd} and d_r to minimize the average energy consumption.

3.1 Average Energy Consumption for Cooperative Transmission

In cooperative transmission, with the assumed AF cooperative protocol, D and R first receive the signal from the transmitter S in the first time slot, and then R, as a transmitter, forwards its received signal to D in the second time slot. Thus, the total energy consumption of cooperation can be separated into three parts: 1) direct transmission energy consumption from S to R; 2) direct transmission energy consumption from R to D; 3) the receiver circuit energy consumption at D. As a result, the total energy consumption for cooperation is given by

$$\begin{aligned} E_{srd} &= \frac{\beta P_t^d}{R_0} + E_{ct} + E_{cr} + \frac{(1-\beta)P_t^d}{R_0} + E_{ct} + 2E_{cr} \\ &= \frac{P_t^d}{R_0} + 2E_{ct} + 3E_{cr}, \end{aligned} \tag{6}$$

where βP_t^d and $(1-\beta)P_t^d$ are the transmission power of S-R link and R-D link, respectively. It is assumed that the total transmission power for cooperation is fixed to P_t^d [3] and β is the system parameter depending on the property of UWB based IBANs. Without loss of generality, β is set to be 1/2.

The outage probability of cooperative transmission p_o^{srd} can be calculated as follows [7]

$$\begin{aligned} p_o^{srd} &= p_c^{sd} p_c^{sr} + p_c^{sd}(1-p_c^{sr})p_c^{rd} \\ &= P(\gamma_{sd}^c < SNR_t)P(\gamma_{sr}^c < SNR_t) \\ &+ P(\gamma_{sd}^c < SNR_t)P(\gamma_{sr}^c \geq SNR_t)P(\gamma_{rd}^c < SNR_t), \end{aligned} \tag{7}$$

where p_c^{sd}, p_c^{sr} and p_c^{rd} are the outage probabilities of S-D link, S-R link and R-D link in cooperative transmission, respectively. It is reasonable to assume that $p_c^{rd}, p_c^{sr} \ll 1$. γ_{sd}^c, γ_{sr}^c and γ_{rd}^c are the received SNR of S-D link, S-R link and R-D link in cooperative transmission, respectively.

Similar to Equation (4), we have

$$\begin{aligned} p_c^{sd} =& P(\gamma_{sd}^c < SNR_t) \\ =& P(P_t^d/2 - a_1 d_{sd}^n - L_{in} - P_N - SNR_t < N_1) \\ =& Q(\frac{P_t^d/2 - a_1 d_{sd}^n - L_{in} - P_N - SNR_t}{\sigma_1}), \end{aligned} \tag{8}$$

$$\begin{aligned} p_c^{sr} =& P(\gamma_{sr}^c < SNR_t) \\ =& P(P_t^d/2 - a_1 d_2^n - L_{in} - P_N - SNR_t < N_1) \\ =& Q(\frac{P_t^d/2 - a_1 d_2^n - L_{in} - P_N - SNR_t}{\sigma_1}), \end{aligned} \tag{9}$$

where $d_2 = \sqrt{d_1^2 + d_{sd}^2 - 2d_1 d_{sd}\cos\theta}$ and

$$\begin{aligned} p_c^{rd} =& P(\gamma_{rd}^c < SNR_t) \\ =& P(P_t^d/2 - a\log_{10}(d_1) - L_{on} - P_N - SNR_t < N) \\ =& Q(\frac{P_t^d/2 - a\log_{10}(d_1) - L_{on} - P_N - SNR_t}{\sigma_0}). \end{aligned} \tag{10}$$

Substituting Equation (8) - (10) into (7), p_o^{srd} can be obtained. Then, the average energy consumption per bit for cooperative transmission takes the form

$$\xi^{srd} = \frac{E_{srd}}{1 - p_o^{srd}}, \tag{11}$$

3.2 Minimization of Cooperative Energy Consumption

With the given d_{sd}, d_r and P_t^d, we can derive the optimal relay location d_1 to minimize ξ^{srd}. Since ξ^{srd} is a strictly increasing function of p_o^{srd}, minimizing ξ^{srd} is equivalent to calculating the optimal d_1^o to minimize p_o^{srd}.

Following Equation (7), we can rewrite p^{srd} as

$$\begin{aligned} p_o^{srd}(d_1) &= p_c^{sd}(p_c^{sr}(d_1) + p_c^{rd}(d_1) - p_c^{sr}(d_1)p_c^{rd}(d_1)) \\ &\approx p_c^{sd}(p_c^{sr}(d_1) + p_c^{rd}(d_1)) = p_c^{sd}\mathrm{F}(d_1), \end{aligned} \tag{12}$$

where p_c^{sd} is a constant with the given P_t^d and d_{sd}, and $\mathrm{F}(d_1) = p_c^{sr}(d_1) + p_c^{rd}(d_1)$. With Equation (9) and (10), we can see that $\mathrm{F}(d_1)$ is a convex function of d_1. Thus the optimal d_1^o can be achieved by setting the first order derivative of $\mathrm{F}(d_1)$ to zero.

Based on the approximation of Q-function given by [13], we have

$$Q(x) \simeq \frac{1}{12}e^{-x^2/2} + \frac{1}{4}e^{-2x^2/3}. \tag{13}$$

Thus, the first order derivative of $Q(x)$ can be expressed by

$$\begin{aligned} Q^{'}(x) &\simeq \frac{-x}{12}e^{-x^2/2} - \frac{x}{3}e^{-2x^2/3} \\ &= -x\left(Q(x) + \frac{e^{-2x^2/3}}{12}\right) \end{aligned} \tag{14}$$

With Equation (13) and (14), we can derive the first order derivative of $\mathrm{F}(d_1)$ as

$$\begin{aligned} &\mathrm{F}^{'}(d_1) \\ &= C_0(d_1)\left(d_1 - d_{sd}\cos\theta\right) \\ &\underbrace{+ C_1\frac{1}{d_1}f_1(d_1)\left(Q(f_1(d_1)) + \frac{e^{-2f_1^2(d_1)/3}}{12}\right)}_{W(d_1)}, \end{aligned} \tag{15}$$

where $C_0(d_1) = \frac{na_1 d_2^{n-2}(d_1)}{\sigma_1}f_0(d_1)\left(Q(f_0(d_1)) + \frac{e^{-2f_0^2(d_1)/3}}{12}\right)$ and $f_0(d_1) = \frac{P_t^d/2 - a_1 d_2^n(d_1) - L_{in} - P_N - SNR_t}{\sigma_1} > 0$ considering $p_c^{sr}(d_1) = Q(f_0(d_1)) \ll 1$. Hence $C_0(d_1) > 0$. $C_1 = \frac{a}{\sigma_0 \ln 10}$ is a constant and $f_1(d_1) = \frac{P_t^d/2 - a\log_{10}(d_1) - L_{on} - P_N - SNR_t}{\sigma_0}$. From Equation (15), we can see that it is not easy to get the close form of the optimal d_1^o by setting $\mathrm{F}(d_1) = 0$. For this reason, an approximate solution is considered in this paper. Considering Equation (13) and the upper bound of Q-function [13], we have

$$\frac{1}{3}e^{-2x^2/3} < Q(x) < \frac{1}{x\sqrt{2\pi}}e^{-x^2/2}. \tag{16}$$

Thus, it yields after some manipulations based on Equation (16)

$$\begin{aligned} W(d_1) &< \frac{5C_1}{4}\frac{1}{d_1}f_1(d_1)Q(f_1(d_1)) \\ &< \frac{5C_1}{4\sqrt{2\pi}}\frac{1}{d_1}e^{-f_1^2(d_1)/2}. \end{aligned} \tag{17}$$

Considering Q-function is a strictly decreasing function and $p_c^{rd}(d_1) = Q(f_1(d_1))$ is very close to zero over a range of d_1 since the on-body path loss is not significant, it is reasonable to assume that $f_1(d_1) \gg 1$. Hence we can assume the coefficient $\frac{1}{d_1}e^{-f_1^2(d_1)/2}$ is small enough which can be ignored. Further, we can assume $W(d_1) \approx 0$.

As a result, the optimal d_1^o is approximately given by

$$d_1^o \approx d_{sd} \cos\theta. \tag{18}$$

Interestingly, we can find that $d_1^o = \sqrt{d_{sd}^2 - d_r^2}$, which means the optimal relay location is right over S on the body surface where it is closest to S. It can be explained that for a relaying cooperation in IBANs, R-D link transmission takes the advantage of experiencing much lower path loss compared to S-R link. Thus p_c^{rd} is much smaller than p_c^{sr}. In other words, p_c^{sr} dominates the value of p_o^{srd}. With the shortest distance from S to R ($d_2^o = d_r$), the minimum p_o^{srd} and ξ^{srd} can be achieved.

In next Section, we compare the average energy consumption between direct transmission and cooperative transmission and the energy efficient performance of cooperative transmission is assessed by simulation in UWB based IBANs.

4. SIMULATION

To assess the energy efficient performance of cooperative transmission in UWB based IBANs, numerical results are conducted by Matlab in this Section. Simulation parameters [6][12] for UWB based IBANs are given in Table 2.

Table 2: Parameters Values

Parameter	Value
P_N	-100dBm
P_t^d	0dBm
E_{ct}	18.75nJ/bit
E_{cr}	18.75nJ/bit
R_0	100Kbps

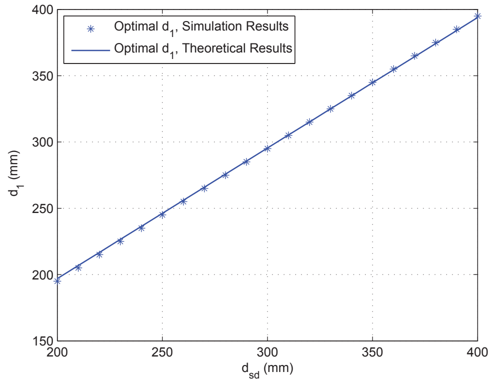

Figure 3: Optimal relay location by simulation and theoretical analysis with $\theta = \pi/18$ and $SNR_t = 15$dB.

In Fig. 3, both the optimal distance d_1^o by simulation and theoretical analysis are plotted with respect to the distance d_{sd} with fixed $\theta = \pi/18$ and $SNR_t = 15$dB. As shown in Fig. 3, the theoretical analysis curve nearly coincides with the simulation results, validating the analysis proposed in the last Section. In Fig. 4, p_o^{srd} versus d_1 with various depth of S (d_r) are given, where $SNR_t = 15$dB with fixed $\sqrt{d_{sd}^2 - d_r^2} = 200$mm. It is shown that the minimum p_o^{srd} exists for all curves corresponding to the same point at $d_1 \approx 200$. It is because that the optimal relay location d_1^o is equal to $\sqrt{d_{sd}^2 - d_r^2}$ based on the theoretical analysis. Thus, $d_1^o = \sqrt{d_{sd}^2 - d_r^2} = 200$ stands for all the scenarios. It is also observed that with the same d_1, p_o^{srd} increases significantly as the depth of S increases, which is a clear evidence that the in-body path loss is so strong that even a few millimeters increase of depth can affect the in-body transmission. Furthermore, we see that $p_o^{srd} \ll 1$ for a wide range of d_1 which centres around d_1^o. With Equation (11), it can be concluded that $\xi^{srd} \approx E_{srd}$ since $1 - p_o^{srd} \approx 0$ for a wide range of d_1. This fact reveals that the average energy consumption of cooperative transmission is approximately equal to a constant over a proper range of d_1 for UWB based IBANs.

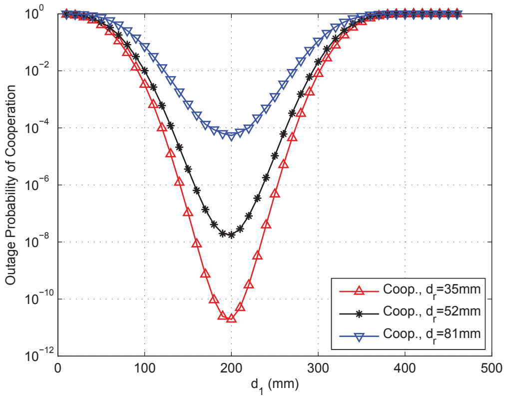

Figure 4: p_o^{srd} versus d_1 with various depth of S, $SNR_t = 15$dB.

In Fig. 5, the average energy consumption of direct transmission and cooperative transmission are compared with respect to d_1 with various SNR_t. We set $\theta = \pi/18$, $d_{sd} = 200$mm and d_1 varies from 10mm to 400mm. As shown in this figure, the the average energy consumption of direct transmission is invariant under d_1 since d_{sd} is fixed. At the same SNR_t, we can see that cooperative transmission is more energy efficient than direct transmission over a range of d_1 which centres around $d_1 = d_{sd}\cos\theta \approx 200$mm. It is also observed that the direct transmission scheme has to consume more energy to achieve higher SNR_t requirement. In contrast, the average energy consumption of cooperative transmission exhibits a weak dependence upon SNR_t which indicates that the cooperation in UWB based IBANs is very helpful for the robustness against the in-body path loss and adaptive for meeting various QoS requirements. Thus, its energy efficient improvement compared with direct transmission is more significant as SNR_t increases.

In Fig. 6, the average energy consumption of direct transmission and cooperative transmission are compared with respect to d_1 with various depth of S. We set $SNR_t = 10$dB and fix $d_1^o = 200$mm. It illustrates that as the depth of S increases, more energy needs to be consumed to overcome the stronger path loss for direct transmission. However, similar to Fig. 5, the average energy consumption of cooperative transmission exhibits a weak dependence upon d_r thanks to its robustness to the path loss and the energy efficient improvement compared with direct transmission is still more significant as SNR_t increases.

In conclusion, direct transmission for UWB based IBANs is very inefficient due to the significant in-body path loss. Compared with direct transmission, a single relay based cooperative transmission scheme is more suitable to be applied in UWB based IBANs due to its robustness to the path loss. It is very helpful in improving the energy efficiency with various scenarios. Furthermore, from the perspective of relay selection, a wide range of the relay locations can be chosen to achieve almost the same energy efficient performance as the optimal relay location.

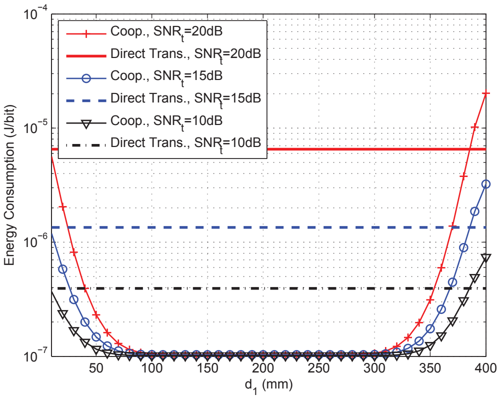

Figure 5: Average energy consumption versus d_1 with various SNR_t, $\theta = \pi/18$ and $d_{sd} = 200$mm.

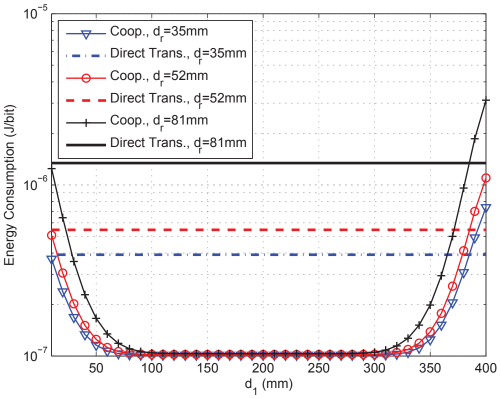

Figure 6: Average energy consumption versus d_1 with various depth of S, $SNR_t = 10$dB.

5. CONCLUSIONS AND FUTURE WORK

In this paper, we investigated the energy efficiency of single relay cooperative transmission for UWB IBANs. A typical relay-based cooperative IBAN system model was briefly described first. Then outage probabilities for direct and cooperative transmissions were calculated respectively with a target threshold of the received SNR. Afterwards, the average energy consumption per bit was derived for both transmission schemes. The optimal relay location for cooperation was also given and analyzed to achieve the minimized energy consumption. Theoretical derivations and numerical results verify our analysis and show that direct transmission for UWB based IBANs is very inefficient due to the significant in-body path loss. However, with the aid of a relay node on the body surface, cooperative transmission can achieve a significant improvement on energy efficiency compared with direct transmission over a range of relay locations under various scenarios. Our future work will focus on a more general UWB based IBANs system model and the optimal power allocation between S and R will also be investigated.

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