Minimum Power Allocation Cooperative Communication based on Health-Care WBAN

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Abstract. Energy is a limited resource in the Wireless Body Area Network (WBAN). Finding optimal and minimum required transmission power that can achieve a certain level of utility while utilizing as little power for transmission as possible plays an important role in reducing energy consumption. In this paper, we found the required transmission power of four transmission modes: the direct transmission mode, the dual-hop transmission mode, and two incremental cooperative transmission modes with Rayleigh channel fading.

Index Terms—WBAN, power allocation, cooperative communication.

1. Introduction

The WBANs usually comprised of a set of sensors with limited-energy source that are in-vivo or non in-vivo, with wireless transceivers that work in the proximity of a human body. These sensors are located in, on, or around the body, and they can monitor the vital and physical signs of the human body [1] [2] [3].

Sensors in WBAN utilize wireless medium to exchange their data, where existence of the human body could effect the transmission between sensors because sensors usually utilize the wireless medium for exchanging and transferring their data, such interruption cause a certain and special radio propagation, which should be appropriately considered in the designing an algorithms for the WBAN systems. In addition, the necessity for efficient power consumption shall be addressed through power control solutions due to repeated battery replacing not practical, which is very hard job for implanted sensors node [4] [5] [6].

WBAN are consist of PHY and MAC layers only, while, traditional networks are supplied with network, transport, application layers [7]. thereby, the physical layer is the most appropriate layer that is dealing with WBAN challenges. To improve the network performance, there are many techniques in physical layer, such as modulations, channel coding, channel estimation, virtual diversity [8] [9]. Plug and play technique is considered in this work which represented later one. cooperative communication achieves virtual diversity, the coordinator node (CN) receives the data efficiently delivering by sensors that work together on the body. there are many papers published on cooperative communication but in WBAN a few work is published.
To date, a few number of researches have been performed on the finding or evaluating a power transmission over cooperative transmission in WBANs. In [10], the authors introduced a cooperative compressed sensing (CCS) approach, which takes into account the energy efficiency of WBANs by exploiting the benefits of random linear network coding (RLNC). An energy harvesting method and cooperative communication are combined together to make helper node recharge their battery and accomplished the cooperative phase [11]. Their proposed protocol is cooperative energy harvesting (CEH)-MAC which achieved better performance in the terms throughput, delay and energy efficiency. In [12] developed two schemes Link-Aware and Energy Efficient protocol for wireless Body Area networks (LAEEBA) and Cooperative Link-Aware and Energy Efficient protocol for wireless Body Area networks (CoLAEEBA) routing schemes that achieved better throughput. The error performance, outage probability, and energy efficiency for the cooperative space-time-coded has been considered in [13]. They have made a comprehensive analysis under Rayleigh and Rician fading channels in either identically or non-identically distributed fading scenario. Recently, combination of the aggregative allocation (AA) mechanism in MAC layer and the Analog Network Coding (ANC) technique in PHY layer is investigated in [14]. Their proposed protocol named as A3NC and it is achieved significant improvement in upload throughput and energy efficiency. Along the same lines, [15] proposed Network Coding-based Fault-tolerant Mechanism (NCFM) which is based on the greedy grouping algorithm. The goal was to minimize the probability of packet loss and average delay, linear Acceleration based Transmission Power Decision Control (LA-TPDC) algorithm is introduced linear Acceleration based Transmission Power Decision Control (LA-TPDC) algorithm is introduced in [16], four parameters are evaluated in this proposed algorithms for all the participated nodes such as the signal to noise ratio (SNR), Bit Error Rate (BER), Packet Delivery Ratio (PDR) and transmission offset. An MI-ICC protocol is proposed in [16] to improve residual energy and network life. In this proposed, several on-body relay nodes and one coordinator are attached to the clothes of a patient. In [17], proactive relays selection for both on-body and in-body WBANs is proposed. where, three-relay, incremental cooperative communication is used in this proposed to improve the energy in term of the probability error rate (PER). A network coding over two-way relay cooperative communication, the authors considered and improved the energy efficiency (EE) and packet error rate (PER) [18]. In [19] introduced a joint relay selection and power control scheme (JRP) to enhance transmission reliability. A good tradeoff between reliability and energy consumption is achieved in this proposed. The critical data index is investigated and studied in the [20], where the authors proposed Critical Data-based Incremental Cooperative Communication (CD-ICC), based on the IEEE 802.15.6 CSMA standard. The design objective of the CD-ICC reduced the end-to-end delay, the duty cycle, and the average power transmission. In [21] two master nodes based cooperative protocol (TMNCP) is proposed. The proposed objective is the retransmission process and average power transmission. In [22][23] a novel Two Master Nodes – Cooperative Network Coding (TMN-CNC) protocol is proposed, based on the IEEE 802.15.6 CSMA policy under log-normal shadowing channel model, for the wireless body area network (WBAN). The design objective of the TMN-CNC is to increase throughput and maximise energy efficiency. In [24] proposed an emergency-based cooperative communication protocol for WBAN, named as Emergency Data Transmission using Transmission Mode Selection (ED-TMS) protocol based on the IEEE 802.15.6 CSMA. The design objective of the ED-TMS is to reduce end-to-end delay and enhance the throughput of direct transmission and traditional cooperative communication. In [25] proposed inter-WBAN cooperation for the IoMT system, which is also known as inter-WBAN cooperation in an IoMT environment (IWC-IoMT).

This research is motivated by the importance of power consumption and saving in the WBAN, and to the best of our knowledge, none of the previous works investigated, analyzed and studied the performance of various transmission modes in the WBAN systems. In this work, various transmission modes (i.e., direct transmission, dual-hop cooperative transmission, incremental relay transmission, and incremental cooperative transmission modes) have been investigated and analyzed in the term of outage probabilities, successful transmission probabilities and minimum required transmission power. In addition, we derived minimum required transmission power of each of these modes by taking into account the desired transmission rate.
The rest of the paper is organized as follows: transmission mode description and the propagation with link analysis are presented in Section II. Then, the outage, successful transmission probabilities and the required transmission powers are derived in Section III and the evaluated numerical results for performance analysis of the transmission modes are presented in Section IV. In Section V, the novel proposed Efficient-Power Transmission Mode Selection-Based Algorithm is explained, and this paper is finally concluded in Section VI including the future work.

Figure 1: transmission mode description

2. Transmission Modes Description
Considering the transmission modes given in figure 1 for any given sensor – CN pair $(S, CN)$, where $S$ is the source sensor and $CN$ is the coordinator node (destination). The definition those transmission modes for WBAN are given as:

- Source-Destination transmission mode: it is direct transmission (DT) mode, where the $S_3$ transmits data packet directly to a CN in a single time slot which mean no intermediate nodes are involved in the transmission.
- Source-relay-destination mode: it is dual-hop transmission mode (dHTM), where the $S_6$ doesn't transmit data packet directly to the CN, but it transmits to the intermediate node ($S_5$) at first time slot then the $S_5$ forwards the received data to CN at the second time slot.
- Source-relay, source-destination, and relay-destination: it is incremental relay transmission mode (iRTM), where the $S_4$ transmits its data directly to both the CN and the $S_2$ at first time slot, and if the CN does not received data from the $S_4$ correctly, the CN sends back NACK to the $S_2$, then $S_2$ forwards the received data to CN at second time slot.
- Source-relay, source-destination, and relay-destination: it incremental cooperative transmission mode (iCTM), where the $S_1$ transmits data directly to the CN and $S_2$ at first time slot, and if the CN
does not receive data from the $S_1$ correctly, the CN sends back NACK to the $S_2$, then $S_2$ forwards the received data to CN at second time slot, and CN combined what received from $S_1$ and $S_2$ via maximal ratio combing (MRC).

3. Propagation Model and Link analysis

The propagation model and the link analysis between two nodes are described in this section. Where, the signal-to-noise ratio ($\gamma_{sd}$) from source sensor to node $CN$ is given as [26]:

$$\gamma_{sd} = \frac{P_t \delta_c}{P_N + P_I} X_{sd}$$

(1)

where, $P_t$ is the transmission power, $\delta_c$ is multiplication of all antennas gain, $P_N$ is the noise power and $X_{sd}$ is a complex Gaussian random variable with unit variance. Hence, the channel gain $|X_{sd}|^2$ is an exponential distributed random variable with the mean value, $1/\lambda_{sd} = E[|X_{sd}|^2] = d_{sd}^{-\alpha_1}$ where $E$ denotes expectation. Where, $d_{sd}$ is the distance between sensor and CN, $\alpha_1$ is the pathloss factor which varies from 2 to 6. The $P_I$ is the received interference power at $CN$ that generated from nearby WBAN sensors, and it can be express as

$$P_I = \sum_{n=1}^{K} P_n d_{nd}^{-\alpha_2}$$

(2)

Where, $n$ is an integer value which represent number of sensors that generate interference at $CN$, $n = 1, 2, 3, \ldots, K$. $P$ is the power generated by interfere nodes or interferer power, $d_{nd}$ is the distance the $nth$ interferer and the $CN$, and $\alpha_2$ is the path-loss factor of interfere nodes. In what follow, The transmission rate between source sensor and CN is given as

$$\beta_{sd} = B \log_2 \left( 1 + \frac{P_t \delta_c}{(P_N + P_I)} X_{sd} \right)$$

(3)

where $B$ is transmission channel bandwidth base on the PHY layer of IEEE 802.15.6 [6], where the channel divided into three categories: human body communication (HBC), Narrow band communication (NB) and Ultra-wide band communication (UWB), as shown in the table I.

| Table I | Frequency band and bandwidth of different PHY layers of IEEE 802.15.6 |
|---------|---------------------------------------------------------------|
| Human-Body Communication | frequency | Bandwidth |
| 16 MHz | 4 MHz |
| 27 MHz | 4 MHz |
| Narrowband communication | frequency | Bandwidth |
| 402-405 MHz | 300 MHz |
| 420-450 MHz | 300 MHz |
| 863-870 MHz | 400 MHz |
| 902-928 MHz | 500 MHz |
| 956-956 MHz | 400 MHz |
| 2360-2400 MHz | 1 MHz |
| 2400-2438.5 MHz | 1 MHz |
| UWB communication | frequency | Bandwidth |
| 3.2-4.7 GHz | 499 MHz |
| 6.2-10.3 GHz | 499 MHz |
The outage probability is the probability that given the transmission rate is less than the required transmission rate ($\beta_0$) and it is calculated as [27]:

$$Out_{sd} = P(\beta_{sd} \leq \beta_0) = 1 - \exp\left(-\frac{U_t}{P_t} \frac{d_{sd}^{-a}}{\delta_c}\right) \quad (4)$$

Where, $U_t = \frac{(P_N + P_r)(2^{\beta_0} - 1)}{\delta_c}$, consequently, the successful transmission probability is given as

$$SU_{sd} = 1 - Out_{sd} = \exp\left(-\frac{U_t}{P_t} \frac{d_{sd}^{-a}}{\delta_c}\right) \quad (5)$$

The probability of successful transmission defines as the probability of successfully received bit at the destination. Then, the required transmission power from $S$ due to transmission to $CN$ or the required transmission power of DT is given as

$$P_t = \frac{U_t \cdot d_{sd}^a}{\log(SU_{sd})} \quad (6)$$

4. Required Transmission Power for the various cooperative transmission modes

A. Dual-Hop Transmission Mode (dHTM)

The first mode is dual-hop transmission mode and it is described as follow: if the sensor and CN are not in the same transmission range or the direct link is too weak, then the sensor transmits the data packet to the relay sensor and it is forwarding what received from the source sensor to the CN. As such, the outage probability of dHTM is given as

$$Out_d = Out_{sr} + Out_{rd} (1 - Out_{sr}) \quad (7)$$

Where, $Out_{sr}$ is the outage between source sensor and relay sensor, $Out_{rd}$ is the outage between relay sensor and CN. with help of (4), the outage probability is given as

$$Out_d = 1 - \exp\left(-\frac{U_t}{P_d} \frac{d_{sr}^{-a}}{\delta_{sr}}\right) + \left(1 - \exp\left(-\frac{U_t}{P_d} \frac{d_{rd}^{-a}}{\delta_{rd}}\right)\right) \exp\left(-\frac{U_t}{P_d} \frac{d_{sr}^{-a}}{\delta_{sr}}\right) \quad (8)$$

Where, $d_{sr}$ and $d_{rd}$ are the distance between the source sensor and the relay sensor, the relay sensor and CN, respectively. Exponential function is computed by using its Taylor series and it’s approximated as exp($-x$) $\approx 1 - x$ [28]

and with help of (5), the successful transmission probability is given as

$$SU_{d} \approx 1 - \left(\frac{U_t}{P_d} \frac{d_{sr}^{-a}}{\delta_{sr}} + \left(1 - \frac{U_t}{P_d} \frac{d_{sr}^{-a}}{\delta_{sr}}\right) - \left(1 - \frac{U_t}{P_d} \frac{d_{sr}^{-a}}{\delta_{sr}} - \frac{U_t}{P_d} \frac{d_{rd}^{-a}}{\delta_{rd}}\right)\right) \quad (9)$$

In this paper, the $d_{sr}^{-a} = d_{rd}^{-a}$, hence we rewrite (9) as

$$1 - SU_{d} \approx \frac{U_t}{P_d} \frac{d_{sr}^{-a}}{\delta_{sr}} + \frac{U_t}{P_d} \frac{d_{rd}^{-a}}{\delta_{rd}} \quad (10)$$
Inserting the value of $U_t$ in (10), the required transmission power of the dHTM is evaluated as

$$P_d \approx \frac{2(P_N + P_t)(2^\beta - 1)}{\varepsilon_c} \left(1 - SU_{d} \right)^{-1}$$  \hspace{1cm} (11)$$

**B. Incremental Relay Transmission Mode (iRTM)**

In this subsection, the incremental relay transmission mode is described and formulated. The iRTM is summarized as follow: if the CN does not received the data packet correctly, then the CN sends back NACK and relay retransmit what was sent by the source to the destination, otherwise relay keep silent. As such, the outage probability of iRTM is given as

$$Out_r = Out_{sd} + Out_{rd}.Out_{sr}.$$  \hspace{1cm} (12)$$

With helping of (5) and (12), the successful transmission probability of the iRTM is given as

$$SU_C_r = \exp \left( \frac{-U_t}{P_r d_{sd}^{-a}} \right) + \exp \left( \frac{-U_t}{P_r d_{rd}^{-a}} + \frac{-U_t}{P_r d_{sr}^{-a}} \right) - \exp \left( \frac{-U_t}{P_r d_{rd}^{-a}} + \frac{-U_t}{P_r d_{sr}^{-a}} + \frac{-U_t}{P_r d_{sr}^{-a}} \right)$$ \hspace{1cm} (13)$$

It is difficult to get an exact expression of $P_r$. Thus, we obtain an upper bound via a worst-case scenario by neglecting the third term in (13). Hence, we obtain (13) as

$$SU_C_r \approx \exp \left( \frac{-U_t}{P_r d_{sd}^{-a}} \right) + \exp \left( \frac{-U_t}{P_r d_{rd}^{-a}} + \frac{-U_t}{P_r d_{sr}^{-a}} \right)$$ \hspace{1cm} (14)$$

With help of the approximation of the $\exp(-x) \approx 1 - x$ [24]. Therefore, the (14) is obtain as

$$SU_C_r \approx \left(1 - \frac{-U_t}{P_r d_{sd}^{-a}} \right) + \left(1 - \frac{-U_t}{P_r d_{rd}^{-a}} + \frac{-U_t}{P_r d_{sr}^{-a}} \right),$$ \hspace{1cm} (15)$$

let assume $U_t/P_r = U_r$, and $U_r$ is obtained from (15) as

$$U_r \approx \frac{2 - SU_C_r}{d_{sd}^{-a} + d_{sr}^{-a} + d_{rd}^{-a}}$$ \hspace{1cm} (16)$$

Inserting the value of $U_t$ in (16), the required transmission power of the iRTM is obtained as

$$P_r \approx \frac{(P_N + P_t)(2^\beta - 1)}{\varepsilon_c} \left(2 - SU_C_r \right) \left(\frac{2 - SU_C_r}{d_{sd}^{-a} + d_{sr}^{-a} + d_{rd}^{-a}} \right)^{-1}$$ \hspace{1cm} (17)$$

In the iRTM, the probability that the source sensor transmits to CN without the need to relay sensor transmission is given as

$$P_{dir}^{r} = (1 - Out_{sd}) + Out_{sr} \cdot Out_{rd},$$ \hspace{1cm} (18)$$

Inserting (4) in (18), we can rewrite (18) as

$$P_{dir}^{r} = \exp \left( \frac{-U_t}{P_r d_{sd}^{-a}} \right) + \left(1 - \exp \left( \frac{-U_t}{P_r d_{sd}^{-a}} \right) \right) \left(1 - \exp \left( \frac{-U_t}{P_r d_{sr}^{-a}} \right) \right) \left(1 - \exp \left( \frac{-U_t}{P_r d_{rd}^{-a}} \right) \right)$$ \hspace{1cm} (19)$$

with help of the $\exp(-x) \approx 1 - x$ [23], and $U_r = U_t/P_r$, then we can rewrite (19) as
The total required transmission power of the iRTM is given as

\[
P^{r\text{tot}} \approx P^{r\text{dir}} \cdot P_r + 2P_r \left(1 - P^{r\text{dir}}\right) \approx P_r \left(2 - P^{r\text{dir}}\right) \tag{21}\]

\(P^{r\text{dir}}\) represents the direct transmission power term, \(2P_r \left(1 - P^{r\text{dir}}\right)\) represents the cooperative transmission power term. Inserting (17) and (20) in (21), we can obtain the total required transmission power for iRTM

\[
P^{r\text{tot}} \approx \frac{(P_N + P_l)}{\delta_c} \left(2^\beta_o - 1\right) \left(1 + U_r d^\alpha_{sd} + \frac{(U_r^2 d^\alpha_{sr} d^\alpha_{rd})}{\delta_c^\alpha + d^\alpha_{sr} + d^\alpha_{rd}}\right) \tag{22}\]

**C. Incremental Cooperative Transmission Mode (iCTM)**

In this subsection, the incremental cooperative transmission mode is described and formulated. The iCTM summarized as follow: if the CN does not receive the data packet correctly, then it sends an ACK to the source sensor and the relay sensor drop what received from the source. Otherwise, it sends a NACK that allows the relay sensor retransmit what was transmitted from the source, then the destination combines what received from the source sensor and the relay sensor via MRC. As such, the successful transmission probability of iCTM is given as

\[
\text{Out}_c = \text{Out}_{sd} \cdot \text{Out}_{sr} + \left(1 - \text{Out}_{sr}\right) \cdot \text{Out}_{rd+sd}, \tag{23}\]

With help of (5) and (19), the successful transmission probability of iCTM is given as

\[
\text{SUC}_c = \exp \left(-\frac{U_t}{P_c} d^{-\alpha}_{sd}\right) \exp \left(-\frac{U_t}{P_c} d^{-\alpha}_{sr}\right) \\
+ \left(\exp \left(-\frac{U_t}{P_c} (d^{-\alpha}_{sd} + d^{-\alpha}_{rd})\right) - \exp \left(-\frac{U_t}{P_c} d^{-\alpha}_{sr} + \frac{-U_t}{P_c} (d^{-\alpha}_{sd} + d^{-\alpha}_{rd})\right)\right) \tag{24}\]

It is difficult to get an exact expression of \(P_c\). Thus, we obtain an upper bound via a worst-case scenario by neglecting the third term in (24). Hence, we obtain (24) as

\[
\text{SUC}_c \approx \exp \left(-\frac{U_t}{P_c} d^{-\alpha}_{sd} + \frac{-U_t}{P_c} d^{-\alpha}_{sr}\right) + \exp \left(-\frac{U_t}{P_c} (d^{-\alpha}_{sd} + d^{-\alpha}_{rd})\right) \tag{25}\]

With help of \(\exp(-x) \approx 1 - x\) [28][29], we obtain (25) as

\[
\text{SUC}_c \approx 1 - \left(\frac{U_t}{P_c} \left(\frac{1}{d^{-\alpha}_{sd}} + \frac{1}{d^{-\alpha}_{sr}}\right)\right) + 1 - \frac{U_t}{P_c} \left(\frac{1}{d^{-\alpha}_{sd} + d^{-\alpha}_{rd}}\right) \tag{26}\]

Let assume \(U_t/P_c = U_c\), we rewrite (26) as

\[
2 - \text{SUC}_c \approx U_c \left((d^\alpha_{sd} + d^\alpha_{sr}) + \frac{1}{(d^{-\alpha}_{sd} + d^{-\alpha}_{rd})}\right) \tag{27}\]
Then, $U_c$ is obtained from (27) as

$$
\frac{U_t}{P_c} = U_c \approx \frac{(2 - SUC_c)}{(d_{sd}^a + d_{rd}^a)(d_{sd}^a + d_{rd}^a) + 1}
$$

(28)

Inserting the value of $U_t$ in (28), the required transmission power of the iCTM is obtained as

$$
P_c \approx \frac{(P_d + P_f)(2\beta_o - 1)}{\delta_c} \left( \frac{(2 - SUC_c)}{(d_{sd}^a + d_{rd}^a)(d_{sd}^a + d_{rd}^a) + 1} \right)^{-1}
$$

(29)

In the iCTM, the probability that the source sensor transmits to CN without the need to cooperative ($P_{dir}^c$) is obtained in the same procedure of (20). Then, the $P_{dir}^c$ is given as

$$
P_{dir}^c \approx 1 - U_c d_{sd}^a + (U_c^2 d_{sr}^a d_{rd}^a)
$$

(30)

The total required transmission power of the iCTM is given as

$$
P_{r}^{tot} \approx P_{dir}^c \cdot P_c + 2 P_c (1 - P_{dir}^c) \approx P_c (2 - P_{dir}^c)
$$

(31)

Inserting (29) and (30) in (31), we can obtain the total required transmission power for iCTM

$$
\frac{P_{r}^{tot}}{P_c} \approx \frac{P_d}{\delta_c} \left( \frac{(2 - SUC_c)}{(d_{sd}^a + d_{rd}^a)(d_{sd}^a + d_{rd}^a) + 1} \right)
$$

(32)

5. Performance Analysis of Direct, Dual-hop, incremental Relay, and Cooperative Transmission Modes

In this section, the performance of various transmission modes is considered. The transmission modes have been examined under different parameters such as inter nodes distances which is denoted as $d_o$, successful transmission probabilities, pathloss exponent, number of interfere nodes and transmission rate.

![Figure 2: The total required transmission power for each mode versus inter-node distance. For all cases, the number of interfere nodes is 10, and the ratio $\beta_o/B$ is 0.5.](image)
Next, the performance of the various transmission modes is described through graphical representation. From the figure 2 to 6, the successful transmission probability, $SUC$, is 0.7, the path-loss factor, $\alpha_1$, 4, power of the interferer nodes is $10\, mW$, the path-loss factor of the interferer nodes, $\alpha_2$, is 3, the distance of interfere nodes to CN, $d_d$, is $4\, m$, the $\delta_c$ is 1 and noise power, $P_N$, is $-174\, dBm$.

Figure 2, shows total required transmission power for the DT, dHTM, iRTM, and iCTM versus internode distance, $d_o$. In the shown figure, the internode distance $d_{sd}$ is equal to $d_o$, which is represent the x-axis of the figure 2 and varying from 1 to 3 m, while $d_{sr}$ and $d_{rd}$ are set to 0.5$d_o$. We noticed from the figure:

It is clear that as the distance between nodes increases, the total required transmission power also increases. The reason is that, with the increase of the inter-node distance, all the transmission modes need to increase the transmit power to overcome the attenuation due to increasing in inter-node distance and to guarantee certain level of the transmission rate.

The dHTM outperforms DT, this is because the signal sent over independent paths and shorter distance compared to $d_{sd}$.

The dHTM outperforms iRTM and iCTM, it is because the required transmission power of the iRTM and iCTM are govern by three links (see (22) and (29)), the $d_{sd}$, $d_{sr}$ and $d_{rd}$.

The total required transmission power of the iRTM approaches the iCTM. Figure 3, shows the total required transmission power for DT, dHTM, iRTM, and iCTM versus inter-node distance, $d_o$. In the shown figure, the internode distance $d_{sd}$ is equal to $d_o$, which is represent the x-axis of the figure 3 and varying from 1 to 3 m, while $d_{sr}$ and $d_{rd}$ are set to 0.75$d_o$. The DT outperforms dHTM, while the iRTM and iCTM outperform the DT. In addition, the iCTM outperform the iRTM.

![Figure 3: The total required transmission power for each mode versus inter-node distance. For all cases, the number of interfere nodes is 10, and the ratio $\beta_o/B$ is 0.5 (b/s/Hz).](image)
Figure 4: The total required transmission power for each mode versus inter-node distance. For all cases, the number of interfere nodes is 10, and the ratio $\beta_o/B$ is 0.5 (b/s/Hz).

Figure 5: Total required transmission power for each mode versus number of interfere nodes, $n$. For all cases, the ratio $\beta_o/B$ is 0.5 (b/s/Hz).

Figure 4, shows the total required transmission power for DT, dHTM, iRTM, and iCTM versus inter-node distance, $d_o$. In the shown figure, the internode distance $d_{sd}$ is equal to $d_o$ which is represent the x-axis of the figure 4 and varying from 1 to 3 m, while $d_{sr}$ and $d_{rd}$ are set to 1.5$d_o$. The DT outperform the dHTM, iRTM and iCTM, it is because the $d_{sr}$ and $d_{rd}$ are greater than the distance of the $d_{sd}$ by 1.5 times. In addition, the worst transmission mode apparent in the figure 2 is dHTM.
Figure 5 shows the total required transmission power for DT, dHTM, iRTM, and iCTM versus number of the interfere nodes, \( n \). In the shown figure, the internode distance \( d_{sd} \) is equal to \( d_o = 1 \) m, while \( d_{sr} \) and \( d_{rd} \) are set to \( 0.5d_o \), and the ratio \( \beta_o/B \) is 0.5 (b/s/Hz). The total required transmission power increases as the number of interfere nodes increase. The reason is that, with the increase of the number of interfere nodes, all the transmission modes need to increase the total transmit power to guarantee a certain transmission rate, \( \beta_o \).

Figure 6 shows the total required transmission power for DT, dHTM, iRTM, and iCTM versus \( \beta_o/B \) and it vary from 0.1 to 1. In the shown figure, the internode distance \( d_{sd} \) is equal to \( d_o = 1 \) m, while \( d_{sr} \) and \( d_{rd} \) are set to 0.5\( d_o \), and the number of interfere nodes is 10. The total required transmission power increases as the \( \beta_o/B \) increases. The iRTM approaches the iCTM, while the dHTM outperform the DT.

![Graph showing transmission power vs. \( \beta_o/B \).](image)

Figure 6: The total required transmission power for each mode versus \( \beta_o/B \). For all cases, the number of interfere nodes is 10.

6. Conclusion
This paper investigated and analyzed the performance benefits of various cooperative transmission modes to determine the total required transmission power in WBANs. The minimum end-to-end total required transmission power is determined while guaranteeing certain transmission rate. In addition, we provided an analytical model for each transmission modes such as outage probability, successful transmission probability and the total required transmission power. The evaluated total required power transmission under various parameters, the dHTM, iRTM and iCTM did not alway outperformed the DT.

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