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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Achieving Longevity in Wireless Body Area Network by Efficient Transmission Power Control for IoMT Applications

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DOI: https://doi.org/10.30880/ijie.2022.14.03.009
Received 16 June 2021; Accepted 04 June 2022; Available online 20 June 2022

Abstract: The application of tiny body sensors to collect, process, store, analyze, and retrieve medical information from a human body is a part of the Internet of Medical Things (IoMT). IoMT helps to monitor and track human vital health parameters, predict disease, notify the patients and the health care professionals with relevant data for analyzing the problems before they become severe and for earlier invention. By 2022, more than 60 % of IoT applications will be health-related. The convergence of biomedical sensors, wireless body area networks (WBAN), Information technology, and bioinformatics will help improve the efficiency of saving human lives. In a WBAN, network longevity is challenging because of the limited supply of low power battery energy in tiny body sensor nodes. Here, we proposed an energy-efficient *transmission power control (TPC) algorithm* to extend the network lifetime in IoMT networks for healthcare applications by *eliminating the transceiver overhearing problem*. In TPC, human tissue resistivity properties are considered to adjust the transmission power, which reduces the communication power and extends the network lifetime. The simulation results show that network power consumption is reduced by 35%.

Keywords: Wireless Body Area Networks (WBAN), low power sensors, transmission power control, transmission range, Internet of Medical things (IoMT), human tissues dielectric

1. Introduction

The Internet of Things (IoT) is one of the significant current technological, social, and economic subject matter. The Internet of Medical Things (IoMT) has many use cases [1], ranging from remote patient monitoring to smart Nano sensors

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and medical device combination. IoMT has the ability not only to keep monitor the patient’s safety and healthy but also accelerates the paradigm shifts of the global pharmaceutical sector. IoMT can accurately track and analyze the data captured from individuals, equipment, specimens, supplies, or even service animals [2]. Also, IoMT may be used to monitor equipment like oxygen tanks, which require being refilled or calibrated and alerting the medical workers in those situations. There are transformative IoT healthcare developments aimed at enhancing patient experience, improving efficiency, resource optimization and achieving substantial cost reductions [3]. But these advancements are constrained by concerns related to technology, safety and protection, privacy and trust.

The healthcare sector continues to be one among the fastest to adopt to the Internet of Things [4]. The reasoning for this move is that the adoption of IoT technology into medical devices significantly increases the efficiency of the medical service and its efficacy, bringing high value to elderly people, patients with chronic disorders, and those who need regular care. Diminishment of sensors electronics has influenced health management in wireless sensor technology and made substantial improvements. These deployed tiny sensors sense, communicate and coordinate with one another and create a Wireless Body Area Network (WBAN). It helps patients with continuous professional remote healthcare facilities during an emergency.

According to the analysis of administration on aging, it observed a significant increase in people's average lifetime [5], which is saddling the health care system to maintain more old age people. This scalability in older people requires advanced technology to monitor their health conditions remotely. Likewise, this technology assists in tracking the actions and health of the baby. WBAN is dedicated to intensifying the healthcare services for the elderly, patients, and infants. More number of health care items are being created today for making the life of patients and healthcare professionals simpler.

The advancements in the design and manufacturing of microelectronics and wireless communications, also interest in WBANs has increased. [6] – [9].

In November 2007, IEEE Task Group TG6 was formed to introduce a standard explicitly developed for WBANs, namely IEEE 802.15.6, its final standard was released in February 2012. Three different layers, Layer 1- Narrowband (NB) PHY, Layer 2- Ultra-Wide Band (UWB) PHY, and Layer 3- HBC PHY [10] is defined. In that standard, for different PHY solutions, only a single MAC protocol is provided. A BAN coordinator manages the other nodes placed within the human body and interacts with the external receiver.

Since the WBANS are heterogeneous [10] [11], one node with better computing speed and power supply serves as the body coordinator or as cluster head of that sensing area to acquire data from other low power sensor nodes. In BAN, the in-body sensor nodes are very tiny related to the nodes in general WSN, also packed with more constraints. BAN nodes subject to shortcomings in terms of transmission range, battery power, computing power, and diminished memory compared with WSN node. In WSN, the use of redundant nodes may solve the data loss issues, but it raises complexity in ensuing QoS and real-time data delivery in WBANs. It is essential to maintain energy consumption with the required degree of consistency for the better working performance of the BAN.

The proposed work is aimed to reduce the transmission power consumption used for communication, increasing the network's lifetime, which is achieved by an algorithm to control the transmission power based on node position and dielectric property of the channel medium (blood, bone, skin, and fat).

The contributions in this paper are (i) An extensive analysis of wireless body area network in medical and its related sector (ii)The overhearing problem (i.e., receive packets destined to other nodes) is eliminated by optimizing the distance between the nodes using the Friis equation. (iii) The TDMA MAC protocol is being used since it is energy efficient. When the channel medium is a good conductor, then an optimized distance is defined. At the same time, the medium is a poor conductor, then a maximal coverage distance is proposed. However, both 1-hop and multiple-hop transmission will reduce the network's lifetime.

2. Literature Review

There are several works proposed for the energy-efficient routing and node placement in WBAN in the literature. These proposals were on energy-efficient routing for within-body, out-body, and within-body to out-body communications [12]. But, most of them did not consider the power consumption at sensors placed inside the tissues. The transmission power control based on the body tissue medium also has not been discussed in detail.

Weilin Zang and et al, attained the energy efficiency in WBAN communication by the transmission power control [13]. Link quality and body movement, using the local accelerometer for the on-body WBAN are observed. Here, the transmission power is calculated based on the receiver’s feedback information. Seunghu Kim and Doo-Seop Eomalso proposed an antenna power control protocol to enhance the network life time, which investigates the characteristics of the link states using Received Signal Strength (RSSI) [14]. They also suggested a rationale transmission power control protocol using short- and long-term link estimations to enhance the link reliability.

Fernandes [15] and team, investigated a reduced overhead TPC, by computing the fixed and the pre-defined transmission power level to optimize the energy consumption of the on-body WBAN networks [15]. The proposed a hybrid approach of posture and motion of the resources to achieve energy efficiency. Ali Hassan Sodhro and team suggested the energy conservation of wearable devices considering node's size and weight. They studied in-body communication inside the human body nevertheless considering the medium properties.

Taiyang Wu and Fan Wu [17] also attempted to design a solar and Bluetooth Low Energy (BLE)combined wearable sensor node and deployed on various parts of human body to measure vital physical parameters like body temperature and HR.

Considering a human body as a sensing field, the conducting capacity of the antenna varies with respect to the body tissues [18]. Also, the sensing and communication range in WBAN is limited within a restricted range across the human body in which the source nodes, intermediate nodes and data sink are almost at closer proximity, which induces the overhearing of data which may ends in data Collison. Thus, in this proposed work, the dielectric properties of the tissues are taken in account along with the distance between the nodes to optimize the TPC of the antennas.

3. Proposed Method

The WBAN standard considered in this paper is defined under 801.15.6 by IEEE as a communication standard specification for tiny, low-powered, wearable, embedded devices which operates around, on, or inside a human body to perform a wide range of vital medical observations. These devices packed with relatively low computing power, tiny weight and size, with better fault-tolerance. The protocols used must be adaptive for energy scavenging with a small form factor for the antenna, processor, and the power supply system.

The aim is to design and develop an energy efficient protocol by controlling the voltage level used by the transmitting antennas. The explicit assumption is that the field to be covered will be limited to the nearby nodes around and within a person's body. Thus, optimizing the TPC inside the human body and prolonging the network lifetime. In implantable WBAN, the sensors placed inside the body, and the transmission medium is the human body. This medium might be a fluid, tissue, fat, or bone. Here, the dielectrics of these body parts are significantly considered. The proposed algorithm optimizes the distance to overcome the overhearing problem, reducing the power utilization for transmission shown in Fig. 1.

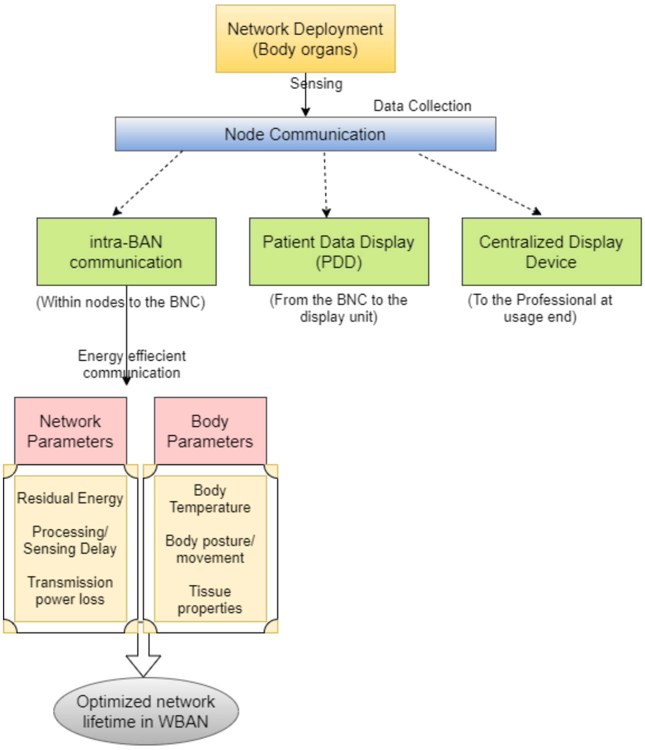

Fig. 1 - Representation of the proposed TPC

Fig. 1 describes the proposed architecture and types of nodes deployed. The following section describes the system model that has been analyzed.

Here, we considered an IoMT network as a graph, $G(u, v)$ where u denotes the sensor nodes placed in the body organs and v represents the communication channel (or) the human body channel that connects the network nodes of the graph G. The network model represents the star topology, where a single node acts as a BNC or Sink collecting data from all the other nodes and communicate it to the controller or monitor outside the human body. A fixed WBAN architecture consisting of source body nodes or BN and a coordinator BNC, is displayed in Fig. 2.

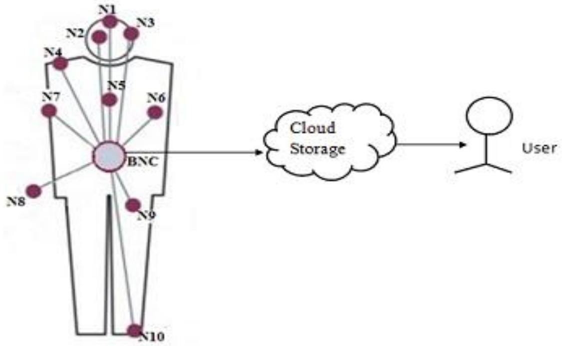

Fig. 2 - In-body WBAN setup

Due to the energy-constraints and limited electromagnetic exposition, radio unit of the BN plays a critical role in WBANs. Many modified medium access control approaches were proposed for WBAN to handle the energy constraints. The most energy-efficient technique was based on the TDMA [15] [19] which is used in our proposed work.

This paper focuses on the BAN for both implantable and wearable body sensors. These sensors are tiny in size with limited battery power, which is one of the bottle neck in performing sensing and communication in body area networks. In general, the battery depletion is mostly due to the communication. As the nodes are placed inside the human body, it is not easy to replace them often. Therefore, there is a need to prevent the energy depletion of the sensor nodes to extend the nodes life time, in turn the networks.

The following section describes the power consumption at the sensor nodes and the medium of transmission.

As per the network theory and practice most of the nodes power is utilized for the antenna's communication. In multi-hop routing, the energy of the intermediate nodes also used. The power consumed in the receiver mode is given by,

$$P_r = P_{RO} + P_{PR} \qquad (1)$$

where P_r is the sum of power used by the processor.

The power consumed by the transmitting antenna is given by,

$$P_T = P_{T0} + P_{PA} \qquad (2)$$

where P_{TO} is the power for the microcontroller and the front-end circuit of the transmitter, and P_{PA} is the power usage of the power amplifier (PA).

Power consumption of the PA for signal propagation is given as

$$P_A = \frac{1}{\eta P_{tx}} \qquad (3)$$

where η is the coefficient of power efficiency, and P_{tx} is the output power of RF.

The efficiency of a conventional RF power amplifier is proportional to its output amplitude,

The efficiency is given by

$$\eta = A\left(\frac{P_{tx}}{P_{max}}\right)^{\beta} \qquad (4)$$

where, Pmax is the maximum output power of RF.

The transmit mode's power consumption using (2), (3), (4) can be rewritten as,

$$P_T = P_{T0} + CP_{tx}^{B} \qquad (5)$$

where, $C = \frac{P_{max}^{B}}{A}$ and $\beta = 1 - B$.

Table 1 – Tissue properties of human body

Human body medium	Dielectrics [S/m]
Blood	Highly Conductive; σ=0.7, ε=3*103
Bones	Highly Resistive; σ=8e-9, ε=7*105
Skin	Highly Conductive; σ=0.3, ε=4*104
Fat	Insulated; σ=0.03, ε=2*105

The Friis path loss equation,

$$P_{\alpha} = \frac{P_{tx}G_{t}G_{t}\lambda^{2}}{(4\pi)^{2}d^{\alpha}} \tag{6}$$

where α and λ is path loss constant and wavelength respectively, and G_t and G_r denotes antenna gain of the transmitter and receiver, respectively.

Equation (6) can be re-written as,

$$P_{tx} = S\{\frac{GtGt\lambda^{2}}{(4\pi)^{2}d^{\alpha}}\}^{-1} \tag{7}$$

where S is the level of receiver sensitivity.

For WBAN, the antenna's transmit power P_{max} and the range covered relation is given by,

$$d_{max} = \left\{\frac{G_{r}G_{t}\lambda^{2}P_{max}}{(4\pi)^{2}\,S}\right\}^{1/\alpha} \tag{8}$$

From equations (5) and (7) the power consumed is given by,

$$P_{source} = P_{T0} + \gamma^{d\alpha\beta} \tag{9}$$

where γ is given by,

$$\gamma = \mathrm{C}\left\{\frac{(4\pi)2\ \mathrm{S}}{\mathrm{GtGr}\lambda 2}\right\}^{\beta} \tag{10}$$

The efficiency per unit is given by the equation,

$$E_{Source} = \frac{d}{P_{T0}\gamma^{d\alpha\beta}} \tag{11}$$

When $\alpha\beta \leq 1$, the transmission energy efficiency (11), increases monotonically with the transmission range d, suggesting that the most energy-efficient one is to use the maximum power to transmit to the furthest point.

If $\alpha\beta > 1$, then there is an optimal distance d^{*} that maximizes the energy efficiencies.

The optimal distance is found as

$$d* = \left\{\frac{P_{T0}}{\gamma(\alpha\beta-1)}\right\}^{1/\alpha\beta} \tag{12}$$

Then the $d*$ optimal distance to be attained.

In the optimal distance,P_{min} is used for the minimum coverage, and P_{max} is used for the maximal coverage.

Experimental observations show that the path loss is the function of frequency and distance. Moreover, the path loss of the human body medium varies with respect to the organs and its tissues.

When the medium is highly conducting, the path loss is minimized and vice versa. From the above, an optimized distance is proposed when the medium is highly conducting, and a maximal coverage or range is defined when the medium is a poor conductor. The following table gives the conductive and non-conductive nature of those body medium.For the above derivation, the path exponent is substituted based on the following discussions.Path loss is defined as as$PL(f, d)$.

3.1 Frequency

UWB (Ultra-Wide Bandwidth) was proposed for in-body communications [20]-[22]. The frequency band inside the human body is determined to be from 402MHz-405MHz by the U.S FCC and the ETS Institute [23]. The UWB communications power level is well below the noise threshold, which implies that it is harmless to people.

$\sqrt{PL(f)} \alpha f^{-k}$, where k denotes the frequency dependence factor.

3.2 Distance

$$PL(d) = PL_o + 10_n \log_{10}(d/d_o) + X_\sigma \qquad (13)$$

where d_o is reference distance, PL_o is the assumed path loss. Here for free pace , n=2 and X_σ is the Shadowing or fading coefficient.From [24], the path loss exponent is varied between and 5 and 7.4 for the human body medium.

From the equations, it is evident that there is an immediate need to control the power loss in transmission. The following defines the proposed algorithm considering the node position and the dielectric property. The flow diagram of the algorithm is represented in Fig 3. It classifies the node deployed inside the human body as a single BNC and the clustered sensor nodes.

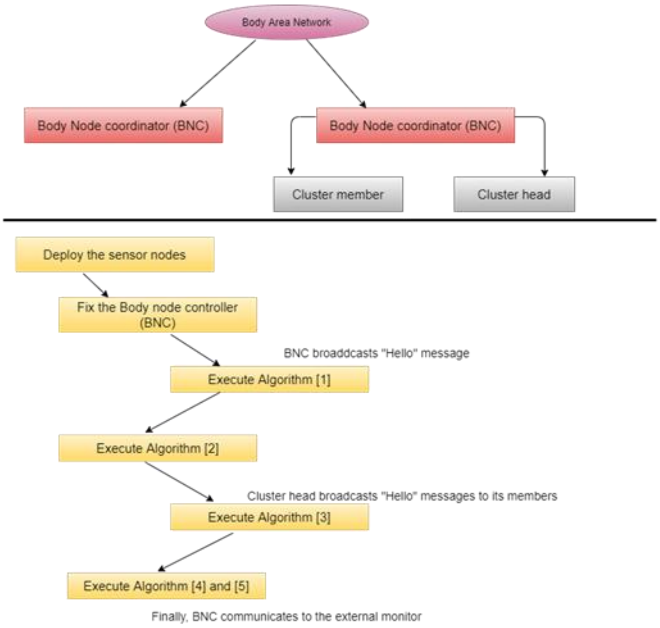

Fig. 3 - Execution flow of the algorithm

ALGORITHM 1: (In-Body WBAN Topology deployment)

```
Step1: Deploy N nodes
Step 2: Fix the Body Node Controller(BNC)
Step 3: For Nodes i=1 to all N
Step 3.1: Node[i].cl_flag
Step 3.2: Node[i].Transmission_Range($d_{max}$)
Step 3.3: Node[i].Initial_Energy
Step 4: For each node i, BNC sends a "HELLO" msg
Step 5: For i=1 to N  [Calculate]
Step 5.1: Node(i,BNC)   //$d_{i,BNC}$
Step 5.2: E = Initial Energy-lost energy   //Remaining energy(E)
Step 5.3: Node Connectivity // Neighbor table(C)
Step 5.4: Signal Strength     //Link Quality (SNR)
Step 5.5: Buffer Length (B)
Step 6: Execute Algorithm 2.
Step 7: Cluster Head (CH node) broadcasts messages to all nodes in the cluster
Step 8: Execute Algorithm 3.
```

```
Step 9: Execute Algorithm 4.
Step 10:  BNC Communicates to the External monitor.
Step 11: End.
```

Initially, the body sensors are labeled with an id, transmission range, and initial energy. A flag parameter is used to mark it as either the cluster member or the cluster head. A BNC is fixed to collect and communicate the information from all the source sensor nodes to the external sink. The body sensors are grouped into clusters, and the cluster head interacts with the BNC. This is achieved by Algorithm 2. Since there is a need to optimize the power consumption in the sensors placed inside the body, Algorithm 3 and Algorithm 4 aims to decide the transmission power, medium, and the range.

ALGORITHM 2 (Cluster Head Selection)

```
Step 1: For each $node_i$, Construct the neighbor table
Step 2: Weight calculation,
$W= W_1*C+W_2*E+W_3*d+W_4*SNR-W_5*B$
Step 3: Broadcasts $W_i$ toall neighbors of i
Step 4: if>$W_{min}$
Step 4.1 : Set Node[i].cl_flag to TRUE.
Step 5: Go to Step 7 in Algorithm 1.
```

Algorithm 2 explains the Cluster head Selection phase. Weighted Clustering technique is used for cluster head selection. The factors like Connectivity(c), Remaining energy in the sensor node(E), distance from the BNC(d), the signal strength (SNR), and the buffer length(B). The weight is calculated by defining w1 to w5 in the range 0-1, resulting in a total of 1. The calculated weight is broadcasted and compared to and by every neighbor node, and the node with top weight is chosen as the cluster head, setting the cl_flag to true. Again, it continued with Step 7 in Algorithm 1.

ALGORITHM 3 (Data Transfer)

```
Step 1: if $Node_i$ is CH ($Cl\_flag_i$==TRUE)
Step 1.1: Send the data packet directly to BNC
Step 1.2: Execute Algorithm 4.
Step 2: Else
Level 2.1: Send the data packet to CH
Step 2.2: Execute Algorithm 5.
```

Algorithm 3 decide the whether the data sink is a BNC or CH. If the sender is a CH, it delivers the package to the BNC. Else, the packet is sent to the CH and then to the BNC.

ALGORITHM 4(Transmission Type)

```
Step 1 : if $d_{max}$(CH) >$d_{CH\_BNC}$
Step 1.1: Execute Algorithm 5. // Single Hop
Step 2: Else
Step 2.1: Find $Node_i$= >$d_{max_i}$>$d_{i,BNC}$  Multi Hop
Step 2.2: Execute Algorithm 3.
```

Algorithm 4 defines whether the data transmission can be a one hop or multiple hop transmission which is based on the distance between a source node to the BNC and the node's maximal transmission distance. Comparing them, the transfer is decided as either single-hop or multi-hop.

ALGORITHM 5 (Power and Range Estimation)

```
Step 1 : If  is highly conductive
Step 1.1 : Power ,P= $P_{min}$
Step 1.2 :$T_{range}$=$d^*$
Step 2: Else
Step 2.1 : Power, P=$P_{max}$
Step 2.2 :$T_{range}$ =$d_{max}$
Step 3: Execute Step 10 in Algorithm 1.
```

In Algorithm 5, the optimal distance and the minimum power are decided considering the tissues' dielectric properties. By optimizing the transmission range, the overhearing problem can be controlled. This issue describes a node losing its energy in transmitting data to the neighbor, considering its distance difference. This proposal compares the distance and the transmission range, along with the dielectrics of the human-body medium.

4. Results and Analysis

The performance of the proposed TPC protocol is evaluated using OMNeT++ simulator with the network setup parameters described in Table 2 shown below.

Table 2 - Network setup

Settings	Value
Wireless channel model	WBAN
Located area of node(m2)	60X60
Number of deployed nodes	10
Mote type	Neural dust mote
Transport layer	UDP
Network layer	IPv6 + 6loWPAN
MAC layer	TDMA + Beacon Superframe

Wireless sensor nodes were deployed using the OMNeT++ simulator. Each node is defined with parameters like id, transmission range, power, energy, and a flag to set its role. Algorithms were executed over the nodes, to control the transmission power of these nodes. It retains the energy of the sensor nodes, thus increasing their lifetime. Similarly, the lifetime of the network is extended. The results showed that the maximum power is utilized when the transmission range is maximum, where the medium is poor conducting. The power is minimum for the optimal range of transmission where the medium is highly conducting.

The subsequent sections describe the power consumption during the transmission and reception of data inside the human body medium.

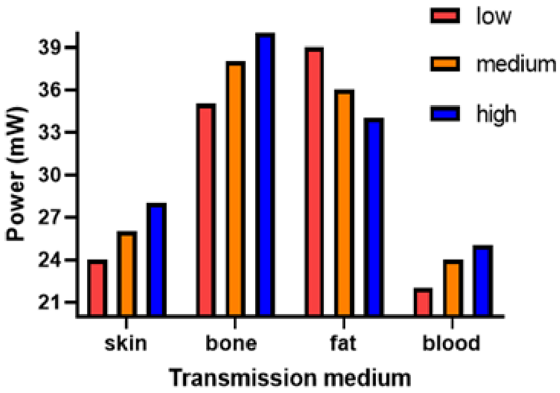

Fig. 4 - Power consumption at different body medium

Fig 4 displays the minimum, average and maximum power consumption when the medium is conductive and non-conductive. From the power algorithm, it is evidenced that the change in path loss exponent will bring a change in power consumed. The above results showed that, even with the exponent shift, the power consumption is maximum in the non-conducting medium.

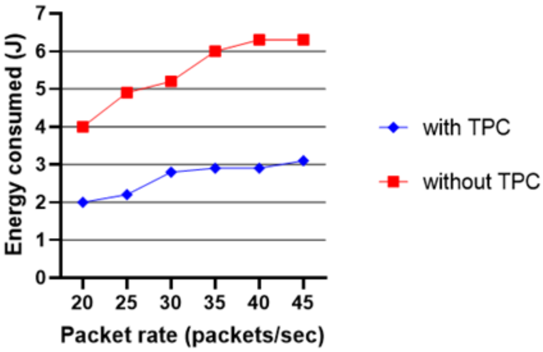

Fig. 5 - Energy utilization with and without TPC

Fig 5 describes the energy utilization with and without TPC respective to the packet transmission rate. Here, the packet transmission rate is specified as the number of packets successfully transmitted by a sender per unit time through the medium or channel. The energy consumption is maximum when the transmission control is not employed.

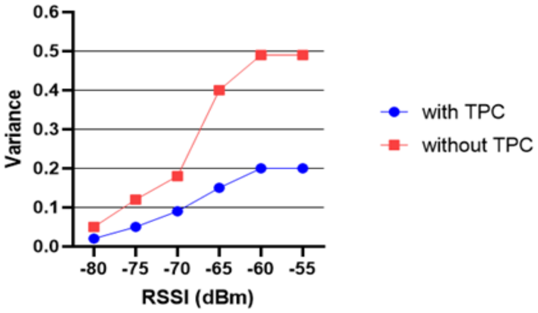

Fig. 6 - RSSI distribution for the network with and without TPC

Fig 6. Represents RSSI distribution in the body area networks when the Transmission power control methods are employed and vice versa. This figure shows that the transmission power control protocol uses the received signal strength indicator to characterize the channel. The RSSI levels in blue have high variance, and the RSSI values in red have less difference. The mean power consumption is reduced by 35%.

5. Conclusion

The radio signal propagation by a WBN inside the human body was studied in this project by analyzing the dielectric properties and the range of transmission covered by the sensor nodes. The issue of overhearing is tackled in our article. A cluster-based strategy has been applied to optimize the network 's lifespan, allowing the body nodes to switch from cluster-based transmission to either direct or multi-hop transmission, depending on the available battery capacity. The simulation results show the expansion of the overall network lifetime by controlling the transmission power in the sensor node. The total mean power consumption is reduced by up to 35% by using conducting mediums as transmission channels. The energy consumption when TPC is used is less by 2% when compared to that without TPC. In the future, we extend the on-body loss model to perceive the energy consumption of a WBAN more realistically, storing and retrieving the patient data in cloud storage.

Acknowledgment

The authors would like to thank to Department of Information Technology for providing the facilities and support this research work.

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