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Hop-Count Aware Wireless Body Area Network for Efficient Data Transmission

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ABSTRACT

This work focuses on the clustering in Wireless Body Area Network (WBAN). Recently, it was found that less attention was given to Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) clustering in WBAN. Past works on LoS clustering WBAN consider the problem of enhancing the network throughput and end-to-end delay of the network. However, the problem of necessary hop count for packet transmission has not been considered. The non-consideration of necessary nodes hop count degrades the performance of cluster-based WBAN as throughput of the network is reduced in addition to high end-to-end delay. This work develops a hop count aware WBAN for enhancing the performance of body nodes called improved Dual Sink Approach using Clustering in Body Area Network (iDSCB). The simulation results depicted that the hop distance criterion of iDCSB improved the performance of WBAN in terms of end-to-end delay and throughput by 3.16% and 6.59%, respectively.

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1. INTRODUCTION

The technology associated with Wireless Sensor Networks (WSNs) is still under development. WSNs are a network of sensor nodes that are used to measure certain environmental parameters which are now used to deduct a conclusion concerning such environment. However, the main problem is that most research on WSN those not carter for the problems associated with the human body (Javaid, 2015). To tackle this challenge, WBAN have been introduced in recent years to study the body condition of users (Singh, 2016).

In the physiological biosensor technology, the introduction of BAN has led to a paradigm shift in terms of the existing routing protocols, Media Access Control (MAC) layer, energy efficiency models, etc (Ibrahim & Mahmood, 2019). BAN is defined as a type of network that is Radio Frequency (RF) based used to connect sensor nodes in the human body for carrying out health analysis of patients. Thus, physicians that are connected to the BAN can get the health data of their patients and give necessary recommendations (Ayatollahitafti *et al.,* 2016). The BAN is made up of sensor nodes that can be attached or fixed on or in the human body without affecting the daily routine of its users. These sensors have proven to be very effective in the detection of chronic health challenges which include heart attack, cancer, kidney problems (Qu & Zheng, 2019). With better detection procedures, the doctors can provide appropriate solutions to the detected problems. (Sharma, 2018). The star topology is the most effective in WBAN due to the nature of the human body. As compared to the WSN, the WBAN has restricted topologies that suites effective detection.

In the star topology, the nodes are placed to ensure that data are collected from several parts of the human body. This body information is collected from nodes that are 1.5 meters from the access points. In the BAN, the access point is usually a Personal Digital Assistant (PDA) device that has a high energy source, memory, and speed in carrying out computations (Javaid *et al.,* 2013). The activities that exist between the sensor nodes and the access points are well organized to ensure effective energy management. These access points or the sensor nodes act as the CH which is the master node (Sharma, 2018). Thus, ensuring efficient energy management is of great importance in BAN and as such most researchers are working on improving the energy-efficiency (Ahmad, *et al*., 2014).

A lot of research work has been done to improve the quality of service of WBAN using several transmission protocols. The following are some of the related works.

Ha (Ha, 2016) proposed an improved routing protocol for effective data transmission in WBAN. The proposed protocol was composed of phases for carrying out initialization, routing processes, activity scheduling, and data processing phase. During the initialization stage, a “Hello” message is broadcast to all nodes, including the number of hop counts. The number of hop counts is estimated by calculating the distance of sink nodes and adjacent nodes. Additionally, in the process of scheduling, a time slot is allocated for each node in the network to transmit the packets. In the routing phase, routing algorithms for all nodes in the network as well as energy-efficient models for lifetime maximization are developed. The energy of the node is taken into consideration in the transmission phase. In the developed protocol, the energy of nodes and their corresponding routing protocol took into consideration. This considerably improved the network lifetime of sensor nodes in the body network. However, using a single sink node subjected the network to congestion when all source nodes transmit their packets simultaneously, especially in the case of critical packets. Also, the use of only energy-related parameters as a criterion subjected the nodes to high packet admission without minding the buffer size of the node. During critical moments of the network, the intermediate nodes would want to process more packets based on their residual energy but not minding their buffer capacity. This led to network delay and packet drop which degrades the performance of the network.

Smail (Smail *et al.*, 2016) presented an Energy-aware and Stable Routing protocol (ESR) for WBAN networks. The ESR algorithm takes into consideration the residual energy of all nodes and their corresponding stability factor is used in the selection of routes for data transmission. In the route discovery phase, the source nodes initiate the process of route discovery which will be used for packet forwarding in a BAN. The selection of the best path for packet forwarding in the route selection phase was done based on route stability and node energy. Two cost functions which include energy and path stability was used in the work. Simulation result reveals that the ESR protocol improved the network performance in terms of overhead and network lifetime. However, the choice of a single coordinator node makes the ESR protocol prone to congestion occurrences at the sink node when all sensor nodes send data simultaneously, especially in the case of critical data. This situation on its own increases network overhead in the network. Also, the criteria for route selection was energy-based which subjected intermediate nodes to the danger of processing more packets based on their energy and not taking note of their current buffer capacity. This led to low network throughput and low network lifetime.

Ullah (Ullah, 2017) designed a routing protocol that incorporates two sinks. The algorithm was a dual sink cluster-based type of network. The dual sink-based clustering method adopted in the work was more reliable due to the close proximity offered by the use of two sink nodes. One of the sink nodes was placed in front of the human body while the other was placed at the back of the human body. The adoption of the clustering method was to avoid the problem associated with congestion as seen when a single sink node is adopted in BAN. In their work, 10 sensor nodes with two sink nodes were implanted in the human body for data collection. The two sink nodes had better energy value, battery power, memory and buffer size as compared to other nodes in the network. During the scheduling phase, the source node sent 'Hello' packets which includes node IDs, node position, node energy and Signal-to-Noise Ratio (SNR). In the topology, four nodes were placed on the front and the back with their corresponding sink nodes (Cluster Head or CH). During, the routing process, LoS and NLoS communication were taken into consideration due to the motion of the human body. Thus, an efficient path loss model was adopted for efficient data transmission. However, the use of node residual energy and hop count resulted in more consumption of energy as the current buffer traffic of the node was not considered. This made a node to attempt process more packets from other nodes due to its current energy without considering its current traffic and buffer size. The non-consideration of node buffer traffic led to high consumption of node residual energy which resulted in low throughput and network lifetime. Also, in the initial timing of DSCB there was serious energy consumption. The reason for the consumption of more energy in the initial timings stage was due to the use of SNR.

Adhikary (Adhikary *et al.*, 2016) proposed a routing scheme that improves power utilization and the lifetime of the network. In their work, the authors established the variance, in routing schemes WBAN and that of the wireless sensor network, since WBAN schemes at times, have been characterized by thermal aware, and the rate of packets delivery must be dependable. Although with respect to their work, several WBAN protocols have been previously proposed, none is able to fully impart health packets dependably due to energy efficiency.

As discussed in related works above, the hop count were not considered in WBAN. This motivates us to evaluate a multi-hop protocol in WBAN which is efficient in Packet Delivery Ratio (PDR), Transport Protocol (T.P) and network lifetime. The main contributions of this work are the analysis of the Hop count for WBAN and the development of a hop count model to improve the transmission of packets in a BAN.

Fastened sensor nodes were attached to the WBAN that can be utilized as forwarder sensor node, using a cost function such as T.P, velocity rate of the vector receiver, residual energy with reference to sink node. The result depicts that the proposed scheme improves the lifetime of the network and data delivery. However, non-consideration of hop-count during packets routing caused more energy depletion in the network.

2. RESEARCH METHODOLOGY

The system models used in the course of this work are presented. The following steps were adopted in the development of a hop count-based algorithm for choosing forwarder node in WBAN:

- Initializing node deployment
- Forming clusters with sink as CH
- Allocating time slot to CH
- Checking data status
- Developing Hop Distance Criterion for Forwarder Node

2.1. Initializing node deployment

Initialization of nodes on the human body depends on the health area of interest. Here, two sink nodes S1 and S2 which have better resources (i.e memory, battery power, and transmission power) than other body nodes are considered. These sink nodes are also referred to as the cluster nodes in this work. Four sensor nodes are deployed on both the front and backside of the human body with SI and S2 being the cluster head nodes respectively. S1 and S2 nodes are placed on the waist and lumbar region respectively. Also, Line of Sight (LOS) communication is used during communication for nodes that are placed on the hands and legs. The nodes that are placed on the legs and the hands relatively change their distance with respect to other nodes in the network.

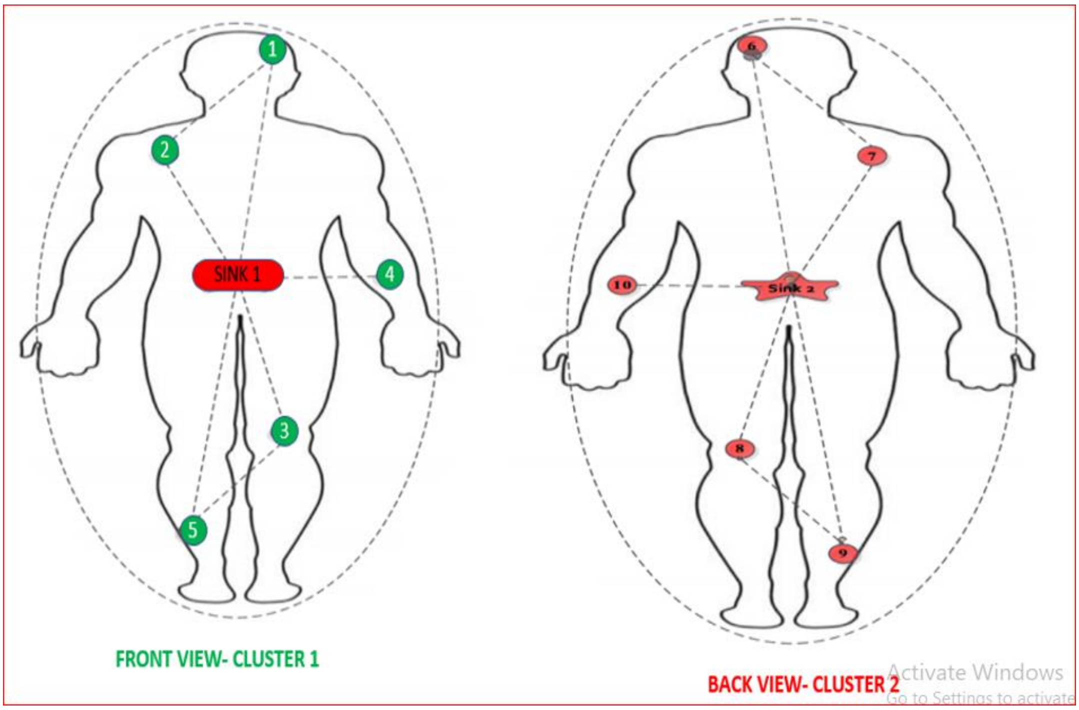

Figure 1. Sample Schematic Diagram for Node Placement

2.2. Forming Clusters with Sink as Cluster Head

Ensuring maximum body coverage is paramount in WBAN. Thus, the use of more sensor nodes is usually used by most researchers to ensure maximum coverage. However, the use of the cluster approach helps in creating load on a single node. Here, nodes that are located at the frontal path of the body form the first cluster. While the nodes at the backside of the human body form the second cluster. This is shown in **Figure 1**. During transmission, CH broadcast "HELLO" packets which have their locations and IDs. Upon reception, all sensor nodes send "REPLY" messages, which also contain their IDs and residual energies.

2.3. Allocating Time Slot by Cluster Head

The allocation of time slots for transmission amongst contending sensor nodes has drawn a lot of attention. In this work, after cluster formation, time slot allocation to all cluster members is carried out by the CH using TDMA protocol. After aggregation of the sensed data from cluster members, the CH nodes forwards the aggregated data to a nearby Access Point (AP). A TDMA-based protocol is flexible and efficient in terms of quality of service and bandwidth allocation. The use of sleep modes was evident due to the advantage offered by the possibility of synchronization of nodes in time. In TDMA, a one-time slot is allocated to a single channel. In WBAN, the size of the time slot is based on signal synchronization which determines the number of channels that can be connected at a given time slot. **Figure 2** shows the process of transmitting health data in a scheduled slot- based on the synchronization signal of a CH. Here, the CH transmits a synchronization signal to all neighbouring nodes in the first slot of the period. The cluster member nodes on receiving the synchronization signal, buffer the sequence information of the current data based on the signal and send the message, which includes the health data and the sequence number to the CH. This process is repeated for each node in the cluster. The number of connectable channels is given as (Hwang *et al*., 2018):

$$N_c = \frac{T}{t_{slot}} - 1 \quad (1)$$

where N_c is the number of allocated channel, t_{slot} represents the length of time slot, and T stands for the length of` one cycle time.

2.4. Checking Data Status

During the data sensing phase, sensor nodes in the cluster are been activated in their assigned time slot. In the active state, the node begins to sense data. The sensed data is first checked for criticality. If the sensed data is critical, it will be directly sent to the CH, else, the data is sent to the CH via multi-hop. In this work, the probability of a data being critical is given as:

$$P(C) = P(\Gamma \geq \Gamma_{th}) \quad (2)$$

where Γ is the normal random data variable with zero mean and unity variance and Γ_{th} represents the threshold that gathered data that is critical.

The threshold for testing the degree of criticality of sensed data is given as:

$$\Gamma_{th} = \left| \frac{\Gamma_{\min} - \Gamma_{\max}}{\Gamma_{\max}} \right| \quad (3)$$

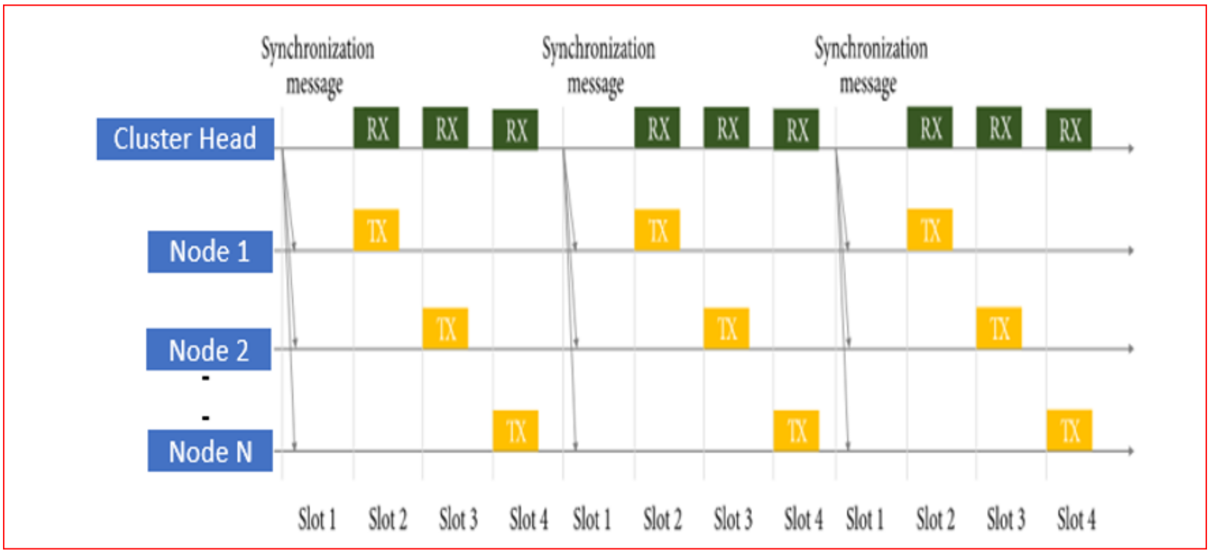

Figure 2. Time Slot Allocation by Cluster Head Node

where $\Gamma_{\max}$ is the maximum critical data index and $\Gamma_{\min}$ stands for the minimum critical data index which varies between O and $\Gamma_{\max}$.

The minimum critical data index ($\Gamma_{\min}$) depends on the gathered data from the part of the human body. If the data is critical, $\Gamma_{\min}$ assumes a high value.

2.5. Developed Hop Distance Criterion for Forwarder Node

During transmission, the distance between any sensor node and its neighbor sensor node or sink node is calculated using Equation (4) (Ullah, 2017).

$$d(s, Dst) = \sqrt{(X_s - X_{Dst})^2 + (Y_s - Y_{Dst})^2} \qquad (4)$$

where X_s is the horizontal coordinate of the source node, X_{Dst} denotes coordinate of the destination node, Y_s represents a vertical coordinate of the source node, and Y_{Dst} is the vertical coordinate of the destination node.

The developed model equation for forwarding packets based on hop count is derived as follows:

Let i be the number of a given hop between two nodes, di be the distance of a given hop from the previous node towards a given destination node DN, SN denotes the source node, and di+1 be the distance of the next hop from the previous node towards a given destination node DN. This is illustrated in **Figure 3**.

It is assumed that the distance between each hop in a given route is known by each node during the forwarding process after route search. Nodes that are placed on the movable path of the body vary the distance from a prospective forwarder node.

The distance of the second hop will be compared with that of the previous hop, and this will be used as a conditioned parameter for forwarding data. If the distance of the next hop is less than half the distance of the previous hops, the packet will be transmitted to the node in the *i+1+1* hop. The model is given in Equation (5):

$$d_{i+1} \leq \frac{d_i}{2} \qquad (5)$$

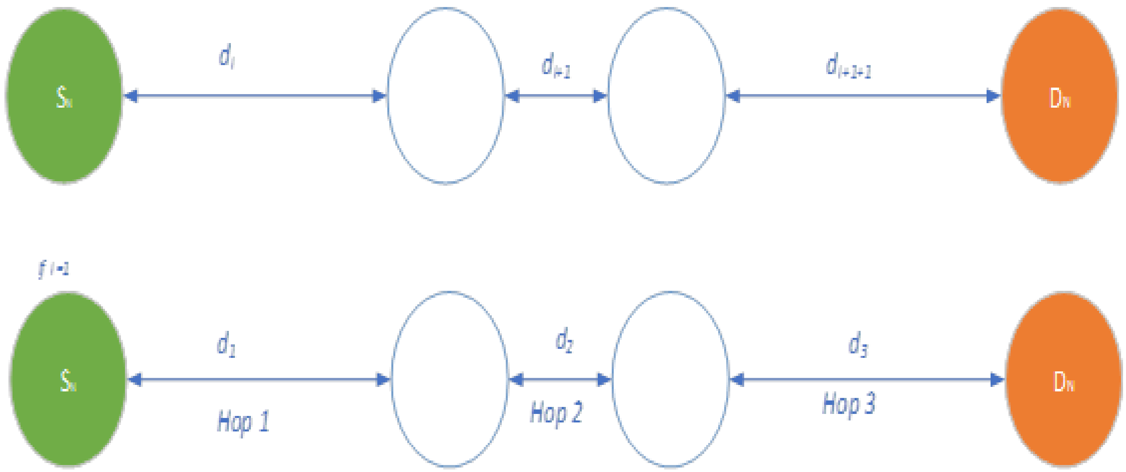

Figure 3. Framework for Developed Hop Distance Algorithm

In order to ensure that the method is valid, simulation is performed using parameters shown in **Table 1**.

Table 1: Simulation Parameters

Parameter	Value
Simulator	MATLAB 2017
Initial Energy	0.6 J
Minimum supply voltage	1.8 V
Channel Frequency (f)	2.4GHz
$E_{Tx\text{-}amp}$	1.98nJ/bit
$E_{Tx\text{-}CCT}$	16.7nJ/bit
$ER_{x\text{-}CCT}$	36.3nJ/bit
DC current (TX)	10.6 mA
DC current (RX)	17mA
Wavelength (λ)	0.138m
Γ_{max}	7

In WBANs, one of the most limiting factors of sensor nodes is energy- efficiency in the network for the continuity of network operation activities after a prolonged task, hence well-organized and efficient management of the energy utilization in the system must be adhered to (Karunanithy & Velusamy, 2012), due to limited node's processing capacity, lesser energy, and so on because of their size as compared to the Sink node whose processing capacity, storage, power, and so on are higher.

When routing packets in the network, hop-count techniques are employed using the model equation given in Equation (2) to hop-eliminate some nodes that are in close proximity to themselves during routing packets and save the energy of those individual nodes who are in close proximity (Raja & Kiruthika, 2020). This energy saved in the individual nodes that are in close proximity accumulates to the entire network system energy for its continuous operation. Hence, in the selection of forwarder nodes, the developed distance criterion is a candidate parameter to ensure throughput efficient data transmission (Bouldjadj & Aliouat, 2020).

3. RESULTS AND DISCUSSION

In this section, the end-to-end delay and throughput of WBAN were analyzed. **Figure 4** shows the result of the performance of DSCB and iDSCB in terms of end-to-end delay against network processing or simulation time. In this work, end-to-end delay is referred to, as the time lag between sender nodes and Cluster Head (CH) node or sink nodes. The on-time collection of data of member nodes by the CH node will ensure quick communication of information between the medical server and the CH node.

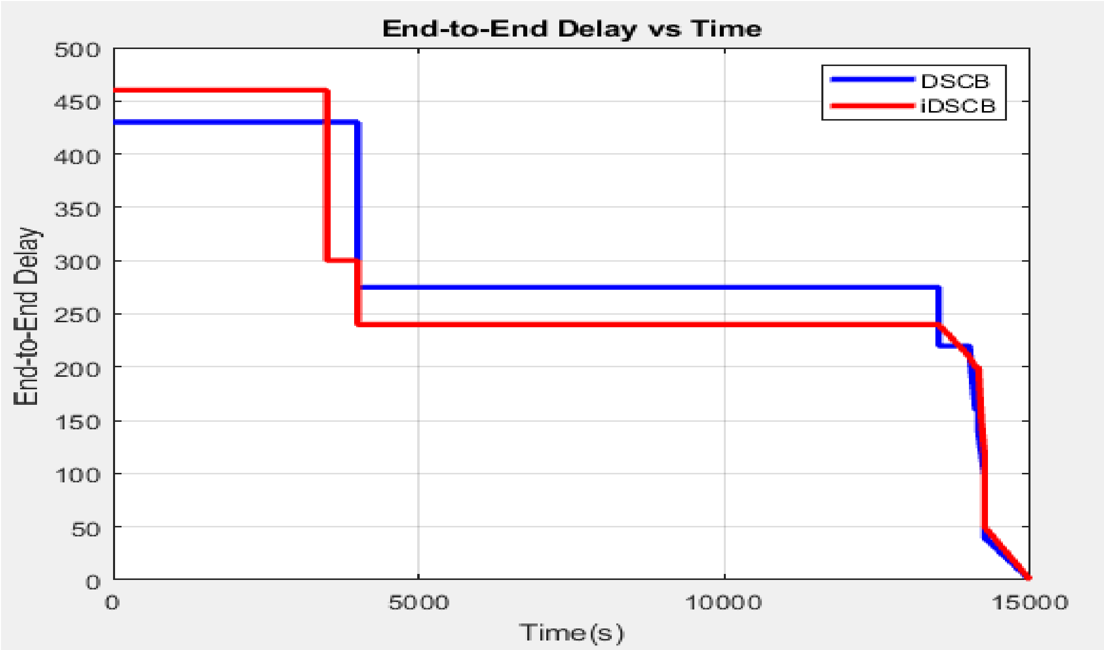

Figure 4. Plot of End to End delay against Network Processing Time

It can be observed that as the network processing time increases, the end-to-end delay also decreases. This is due to the presence of two sink nodes which ensured on-time direct communication between the member nodes and the sink node. The occurrence of direct communication lessens the distance, which results in a low end-to-end delay. It can also be observed that at simulation times ranging from 0 to 4000 seconds, the iDSCB suffered more delay. This is due to the more initial time taken to implement the developed hop distance criterion.

In addition, the initial calculation of the network SNR, T.P, and cost function consumes time. However, as the network processing time increases beyond 4000s, the iDSCB algorithm performs better than the existing DSCB algorithm. This is due to the use of the developed hop distance criterion which ensured quick transmission of data packets to sink nodes. Simulation result showed that the iDSCB algorithm showed an end-to-end delay improvement of 3.16% over the existing DSCB algorithm.

3.1. Throughput Against Network Processing Time

In this study, the successful delivery of data packets from the source node to the sink node in unit time is referred to as throughput. **Figure 5** shows the throughput performance of the developed algorithm against the existing DSCB algorithm. It is observed from **Figure 5** that the throughput increases as the network processing time increase for both algorithms. This is due to the use of dual sink nodes that enable more transmission of packets to the CH at a given time. However, the iDSCB algorithm shows better throughput than the existing algorithm. This is because the developed algorithm has a system that manages energy for the continuity of packets transmission operation of the network. The iDSCB algorithm shows an improvement of 6.59% when compared with the existing algorithm. For future further improvement of its percentage, another parameter like Buffer traffic state will be considered, whose effect will reduce the number of dead nodes in the network.

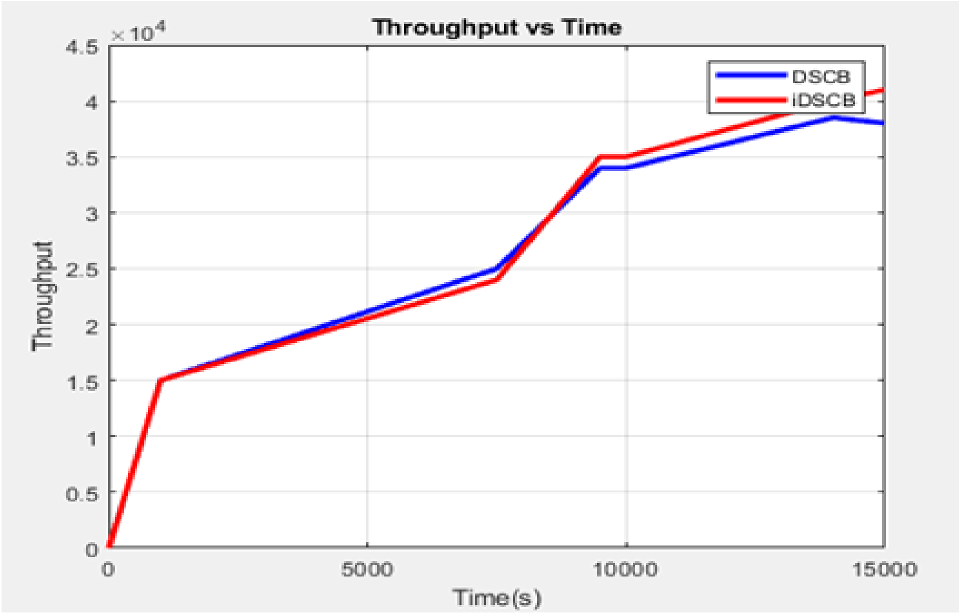

Figure 5. Plot of Throughput against Net work Processing Time

4. CONCLUSION

Due to data transmission inefficiencies in WBAN, this research developed an improved iDSCB routing algorithm WBAN. The node hop distance criterion was used to ensure a reduced end-to-end delay of packets during transmission. Also, the improved algorithm enhanced the performance of WBANs when it was developed using clustering scheme along side with TDMA scheme in dual sink scenario. Simulation results depicted that, the improved algorithm performs better than the existing algorithm in terms of End-to End delay, and Throughput.

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