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Analyzing and reviewing cumulative cost functions of simple protocol in wireless body area network

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K E Y W O R D S

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A B S T R A C T

Wireless Body area network (WBAN) has become an area of special interest for the researchers due to its vast applications in the medical field. The major components of WBAN are sensors and gateway where sensors are responsible for collecting and transmitting physical and biological status of human body. The gateway is responsible for linking sensors with any external server for valuable output. As it has been always challenging to enhance network performance, energy efficiency, higher throughput and longer stability time in WBAN. To overcome such issues many routing protocols initiated, SIMPLE protocol is one of them. Till now there are 6 cost functions modified from the SIMPLE Protocol, It is also challenging to tell which one has the better ability to work well under certain condition. In this paper, we have compared and analyzed all the cumulative CF's of SIMPLE protocol for the following parameters, a) throughput, b) packet sent to the sink, c) packet drop, d) packet received at the sink, e) residual energy, f) path loss and e) delay. The simulations are performed for the rounds ranges from 0-8000 in MATLAB simulator. The efficient cost function is also categorized on the basis of electing the parent node to measure the performance.

1. Introduction

WBAN is playing a vital role in the field of medical science. Either the patient is stable or mobilized; WBAN continuously monitors the activities through sensor nodes. Every node has the capability of sensing, sampling, processing, storing and transferring the data to the neighbored nodes or a WBAN server. The sensors may be implanted on the human body as shown in Fig. 1. Various examples like electrocardiogram (ECG) for measuring heart activity, electromyogram (EMG) for muscle activity in which sensor nodes need to be connected with the main server through a network. The other applications where WBAN being use are sports, wireless audio, video device, military, security, gaming and entertainment [1].

In WBAN, firstly the sensors collect the information in the form of physical or biological data of the human body and then these data is send to the terminal via any electronic device which is manipulated to give a valuable response [2].

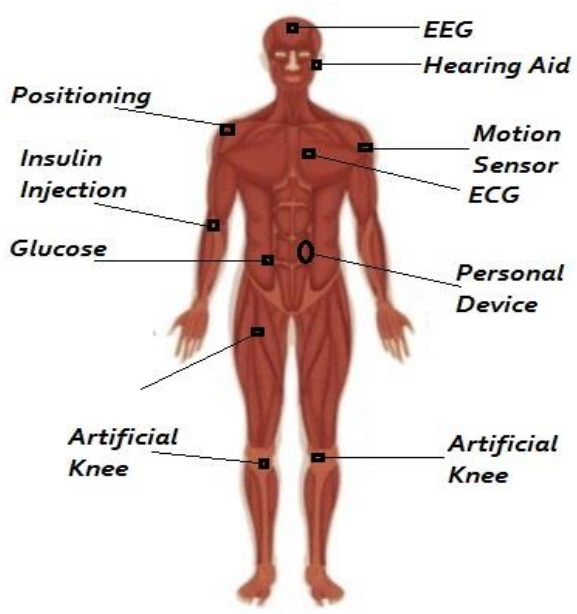

Fig. 1. Sensors implantation on human body

The routing protocol in WBAN plays a vital role for an effective communication. SIMPLE protocol is one of them in which cost functions is manipulated for electing forwarder / parent node for direct in direct communication with sink In this paper, an effort is made to analyze the behavior of different cost functions using certain parameters, mention below;

- Throughput
- Packet sent to sink
- Packet dropped
- Packet received at sink
- Residual Energy
- Path loss
- Delay

2. Parameters

2.1 Throughput:

It represents the packets of sensed data successfully delivered from nodes to forwarder node then to sink.

2.2 Packet Sent To Sink:

It represents the total number of data packets send to sink.

2.3 Packet Dropped:

It represents the total number of data packet drop while sending to sink.

2.4 Packet Received At Sink:

It represents the total number of data packet received at sink.

2.5 Residual Energy:

It represents the consumption of energy used throughout network.

2.6 Path Loss:

It represents the signal attenuation between a nodes and sink.

2.7 Delay:

It represents the difference between time of send the data packets and time of received the data packets.

The objective of this research is to analyze and review all the cost function for various parameters as discussed below in table no 2. The progress or status of various cost functions is determined, described the efficient cost function and acknowledged which area is needed to be modified further to maintain stability in WBAN.

3. WBAN Obstacles:

WBAN performance can be maintained or stabilized through making enhancement in its components and parameters. These are listed below.

3.1 Energy:

Energy is the main and primary source of WBAN that should be balanced. As we know that recharging of batteries is the main obstacle or drawback in WBAN. Therefore, there should be mechanism which should avoid these drawbacks and balanced the energy consumption**.** [3]

3.2 Quality Of Services and Reliability:

In WBAN it is important to send sensed data of patient to the sink without any delay or loss, so network should be reliable and able to monitor the critical and emergency cases. [4]

3.3 Co-Existence:

The sensors or nodes send data to the server via an electronic device. Therefore, it is essential that the network should be operative without any interruption.

3.4 Secure And Confidentiality:

WBAN holds patient sensed data, if any kind of tempering with it may cause a hazardous state such as patient death. So, there must be an authentication or confidential section which secures the data for causing malfunction.

3.5 Validation:

The data validation is an important factor regarding the efficient network. Network failure may cause wrong data transmission which can affect serious issues. So, data should be verified in a proper manner at the receiver sides.

3.6 Network Lifetime:

Network lifetime is also necessary in WBAN. All the sensors or nodes should stay alive for longer period of without any disturbance whether it is normal or critical situation.

4. Background Motivation

Researchers are involved to optimize the network efficiency in terms of better stability, energy efficiency and prolonging the network lifetime in WBAN. Several parameters in SIMPLE protocol are investigated to produce remarkable results. The contribution of the researchers in this field are listed as follows.

Nadeem Javaid et al initiated SIMPLE protocol, it utilized multi hop communication of data to the sink, a Cost function is used for selecting parent node with high residual energy and minimum distance to sink, whereas high residual energy balance the consumption of energy between nodes and sensors and minimum distance provide easily successfully packet delivery to sink, by doing this author takes these as an integer linear program [5].

Narendra Kumar Yadavproposed the modification in SIMPLE protocol to increase the throughput. They are discriminating not to select that node which is away from the sink, and acknowledged that the most of the nodes (as compared to SIMPLE and ATTEMPT) have same energy Level E0, thus they eliminated residual energy from the cost function. Then they compared proposed Protocol with SIMPLE Protocol and 11.78% raised throughput as compared to SIMPLE Protocol [6].

Neelam Sharma et al discriminating the enhancement of SIMPLE protocol is necessary for stable and constantly measuring patient health, as we know in SIMPLE protocol we have to select forwarder node to send packet or data to sink for patient strategic report, in this paper author proposed protocol in which distance from node to sink and residual energy of nodes itself selecting the parent node for reducing throughput among various nodes, where all the sensors transmitting packets to the sink then sink will transmit to server. After simulation 12.46% better than SIMPLE protocol [7].

Javaid, Nadeem et al initiated IM-SIMPLE protocol which is the enhancement of SIMPLE, it support mobility and selects forwarder node on the basis of cost function. Also present linear programming based mathematical model for energy consumption minimization. The proposed protocol; iM-SIMPLE, has reduced path loss in comparison to M-ATTEMPT and SIMPLE protocols, Also Simulation result shows the enhancement in network stability period and number of successful packet delivered to sink [8].

Utkarsh Shukla et al acknowledged that WBAN being using everywhere it is based on small sensors, presenting the enhancement in SIMPLE protocol along with empathizing on distance and residual energy, for selecting forward node, author proved with simulation result that the mean placement of node is best placement of selecting sink or server [9].

Dwivedi, Nidhi, et alfurther modified SIMPLE Protocol cost function which elect parent node for transmitting all sensed data to sink, this cost function consider that the energy lost which is the disparity between initial energy and remaining energy in each round. 11.64% improved throughput after the simulation results [10].

S. Ahmed et al discriminated the concept of path loss in medium access control (MAC) and initiating LAEEBA protocol for reducing path loss and providing high throughput in WBAN, beside single and multi-hop transmission used for prolonging network lifetime. A cost function proposed that select parent node regarding residual energy and shortest distance to sink [11].

Adhikary, S., Choudhury, S., and Chattopadhyay proposed cost function to elect forwarder node to minimized network lifetime on the basis of metrics like transmission power of the node and at the end enhancing network packet delivery [12].

Bin Liu and Zhisheng Yan acknowledged that in WBAN numerous data transmitting by sensors and delivered to server or head of node, which may cause loss of data and traffic loads, therefore a CA-(Channel aware) MAC, Polling and schedule approaches introduced to overcome this issue [13].

Essafi Sarra et al described interference problems and effect on channel access in WBAN, packet collision also may cause, in this paper author initiated IEEE 802.15.4 protocol with the availability of WI –FI transmitters, also improved capacity, successfully packet delivery via no cost and convenient parameters. In WBAN minimum number of nodes gives best result instead of maximum number of nodes [14].

Raju Sharma et al initiated cluster based network in WBAN, that reduce the energy consumption in sensor

nodes, in CBR eight nodes sited on human body for measuring and sending data to sink, the electing of forwarder node based on the value of threshold, if the previously energy level higher than threshold level then the same cluster head elected for next stage and if the energy level lower than threshold level then previous cluster head will be replaced [15].

A genetic algorithm-based clustering processing method for reduction in computation complexity and improving lifetime of network is discussed also in [16].

Xiaoyuan Li et al introduced R-coefficient, greedy channel search to maximize the expected residual energy for every pair of sensor channel and also optimized model presented for maximize total expected residual energy [17].

Mohammed Abdulrahman Dawood Al-obaidi and Abdullahi Abdu Ibarahim introduced R-SIMPLE protocol in which author added smart sleep mode in SIMPLE protocol and divided sensors into critical and non-critical sensors according to schedule time report given by doctor in which sensor wake up and send the data to neighbor cluster head then to sink and again put it into sleep. Authors also introduced receipt mode where if the server received the data it acknowledged before sensor go to sleep mode [18].

Wenjing Guo et al, designed a kinetic energy harvestion device to stabilized node energy also proposed energy level classification (ELC) protocol for energy efficiency, it has 3 phases, initial phase where the sink ensure its location to all neighbors nodes, second phase routing algorithm where each node calculated its distance and residual energy higher than E_{th} toward sink and finally third phase transmission phase where the best routing path determined for transmitting data [19]

In table -1 summary of the literature review is presented. An effort is done to present the published work in terms of various parameters used for the performance enhancement of throughput, network lifetime along with minimizing the path loss.

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Table 1

Summary of the literature review

S.No	Name of Author	Year	Analysis / Focal points	Remarks
1	(NademJavaid et al) [5]	2013	In this paper author proposed SIMPLE Protocol in WBAN. It depends on three major stages including primary, forwarder selection and time scheduling process. Author compared proposed protocol with ATTEMP on the basis of throughput, R.E, dead nodes and path loss Parameters.	0.4% network lifetime improved
2	Ahmed S, Javaid N, Akbar M, Iqbal A, Khan ZA, Qasim [11]	2014	In this paper authors, proposed LAEEBA protocol for minimized path loss in MAC in WBAN. It is Multiple hop communication network which lead to prolong network lifetime and stability time as well.	2 GHz freq used
3	Shukla, Utkarsh [9]	2014	In this paper authors acknowledged that the mean position of node considers good to put sink on it. As CF5 is the difference between initial energy and consumption energy (R.E). After simulation results CF5 achieved 14.12% improved in throughput.	14.12%. rise in throughput throughout network
4	Javaid, N., Ahmad, A., Nadeem, Q., Imran, M., andHaider, N [8]	2015	In this paper authors proposed IM-SIMPLE which support mobility and also minimized energy consumption by implementing linear based programming mathematical model even also reduced path loss. At the end it compared with M-ATTEMP which improved network stability 14%.	14% network stability improved
5	Adhikary, S., Choudhury, S., et al [12]	2016	In this paper author proposed a routing protocol "cost function" to elect forwarder node in WBAN to enhanced network lifetime on the basis of metrics like transmission power of the node, also enhancing network packet delivery. The cost function used for electing forwarder as under; $\mathrm{C.F\ (i)} = \frac{d(i) - v(i)}{R.E(i)}$ In which d(i) represent distance, v(i) represent magnitude of the velocity of node toward coordinator and R.E(i) represent remaining energy of node	Proposed cost function was compared with M-ATTEMP protocol and proposed function better performed and enhance network lifetime
6	(Narendra Kumar Yadav, PushpendraDwivedi et al) [6]	2017	In this paper Authors further modified SIMPLE Protocol. The node which is far away from server or Sink should not consider as CH. So, author only consider distance and eliminate R.E from the cost function.	11.78% improved throughout, from comparing with CF1
7	Sharma, N., Singh, K., and Singh, B [7]	2018	In this paper authors, modified SIMPLE Protocol by assuming cost function CF4 as E1 and CF5 as E2 with the assumption p>2. At the end these protocols compared with IM-SIMPLE, ATTEMP and SIMPLE Protocols, where 6.7% throughput improved with E2 (CF5).	6.7% improved throughput
8	Dwivedi, Nidhi, and Hari Om Sharan [10]	2019	In this paper authors, modified SIMPLE Protocol cost function for electing CH. As CH in SIMPLE Protocol elects by cost function having minimum R.E and minimum distance to sink. After simulations 11.64% throughout increased throughout network.	11.64 % throughput enhanced
9	Mohammed Abdulrahman Dawood Al-obaidi and Abdullahi Abdu Ibarahim [18]	2020	In this paper authors, introduced R-SIMPLE (Reliable Stable Increased Multi Hop Protocol for Link Efficiency), in which they initiated smart sleep mode, critical and non critical sensor mode, schedule report time from patient doctor and receipt acknowledgment request (RAR) from server to node.	R-SIMPLE protocol enhance throughput.
10	Wenjing Guo et al [19]	2021	In this paper authors, designed a kinetic energy harvestion device ELC (Energy Level Classification) protocol for energy efficiency of nodes in WBAN. It has 3 main phases, 1st is Initial phase, 2nd is Routing algorithm and 3rd is Transmission.	ELC protocol enhance node energy efficiency

5. Simple Protocol Overview

In this section, overview of SIMPLE protocol is presented. In WBAN it is necessary to establish a network having high throughput, longer lifetime, proper stability, and high energy efficiency. SIMPLE protocol not only provides stability to the network but also saves the energy of the nodes. SIMPLE protocol has the following phases.

a. Primary Phase:

In this phase, the sink broadcast the massage in the form of packets containing its position to all neighbor nodes. Each of the nodes saves sink position and broadcast packet to sink which include node ID, location and energy status

b. Forwarder/Parent Node Phase:

Forwarding function is based upon the selection of a forwarder node among all nodes by implementing cost function. Forwarder node is responsible for collecting all sensed data from neighbor nodes and sends them directly to the sink.

c. Scheduling Process Phase:

In this phase, the time division multiple access (TDMA) approach is used by the forwarder/parent node for allocation of specific time period over neighbored nodes. Each node sends the sensed data to the forwarder/parent node within that specific time duration. These nodes will be in idle state when no data is sent which minimized the energy.

6. Importance of Simple Protocol and its Cost Function

As WBAN provides medical health care services. To make it further reliable, efficient and providing high throughput, we need routing Protocols. SIMPLE Protocol is one of them which elect parent node by its Cost function with two assumptions like minimum distance to sink and maximum residual energy (remaining energy) among nodes. So, that node would be elect whose distance should be minimum to sink and energy level (R.E) should be maximum among nodes.

Now many authors worked on this cost function for making it more efficient and reliable.

The Table no 2 shows the cost function along with their dependency (assumptions). The mentioned cost function which started from CF1to CF6 till date. Their dependency factors distance, dissipated energy and remaining energy (R.E) is also shown in the right most column.

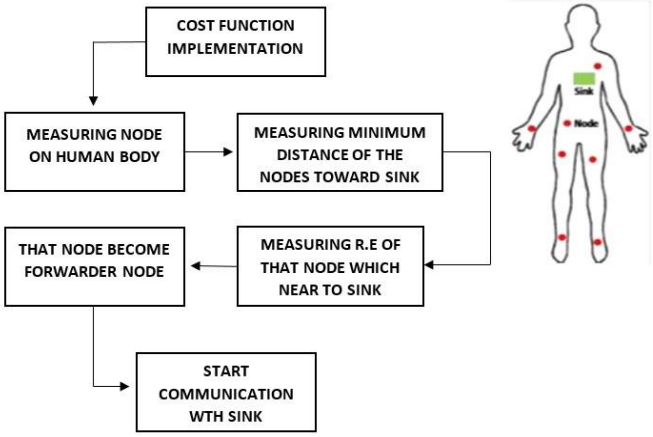

Fig. 2. Cost function selection

7. Analyzing Cumulative / Cost Functions

In SIMPLE protocol, the cumulative/cost functions elect parent node among several nodes for fetching the sensed data from the rest of the nodes and send them directly to the sink or main server for reasonable output as shown in Fig. 2. The parameters required for maintaining the stability in WBAN are listed below.

a) Prolong Network Lifetime:

It represents consistency in the network till the last node die.

b) Stability:

It represents the time period of the network operation

c) Throughput:

It represents the data which is successfully transmitted to the BS.

d) Remaining Energy R.E:

It represents consumption of total energy in per round for nodes; also represents the parameter for measuring energy consumption of the network.

Table 2

Cumulative Cost Functions. [12]

CF's	Forwarding Function	Dependency
CF1	$C.F(i) = \frac{d(i)}{R.E(i)}$	Distance andR. E
CF2	$C.F(i) = \frac{1}{d(i)}$	Distance Only
CF3	$C.F(i) = \frac{1}{R.E(i)}$	R.E Only
CF4	$C.F(i) = \frac{1}{d(i)[R.E(i)]^p}$	Distance and R.E
CF5	$C.F(i) = \frac{1}{d(i)[E - R.E(i)]^p}$	Distance and Dissipated Energy
CF6	$C.F(i) = Min\ [\frac{\sqrt{d(i)}}{[Eo-E(i)]}]$	Distance and R.E difference

a. Cost Function 1 (CF1):

$$C.F(i) = \frac{d(i)}{R.E(i)} \quad (1)$$

In this cumulative function, the d(i) represents the distance between the node and the sink whereas RE(i) represents the residual energy of the node (i).It also minimizes the present energy from the total energy of node. In this function, the minimum cost function becomes the forwarder. Whereas the rest of the nodes send the data to the forwarder node where forwarder node transmits data to the BS. As the forwarder node has the maximum residual energy and minimum d to BS. So, it consumes less energy to move data to BS. ECG and Glucose are the nodes 1 and 2 which directly communicate with BS. It has higher stability span depends upon the distance and residual energy.

b. Cost Function 2 (CF2):

$$C.F(i) = \frac{1}{d(i)} \quad (2)$$

This cumulative cost function is only dependent upon the d(i). Therefore, the parent node is elected by distance only.

c. Cost Function 3 (CF3):

$$C.F(i) = \frac{1}{R.E(i)} \quad (3)$$

This Cumulative/Cost function determines only residual energy which is the worst attempt, because nodes consume higher energy when sink is placed far away from them. Therefore parent node should be elect which is nearest to the sink.

d. Cost Function 4 (CF4):

$$C.F(i) = \frac{1}{d(i)[R.E(i)]^p} \quad (4)$$

This Cumulative/Cost function depends on the distance and scaled residual energy. Where d(i) represents distance from sink and R.E(i) represents remaining energy of the nodes, where p is the scaled energy index value which is greater or equal to 2.

e. Cost Function 5 (CF5):

$$C.F(i) = \frac{1}{d(i)[E-R.E(i)]^p} \quad (5)$$

In this Cost function we assume that those nodes which have less amount of initial energy and residual energy as compared to other nodes should not be considered. The forwarder node should be elected which has higher residual energy and nearest to the sink.

f. Described Approach Cost Function 5 (CF5):

So, CF5 approaches developed for electing parent node like CF1, CF2, CF3 and CF4 with given function

$$C.F(i) = \frac{1}{d(i)[E-R.E(i)]^2} \quad (6)$$

This Cumulative/Cost function depends on distance and dissipated energy; through this approach we minimized the dissipated energy which consumes energy among nodes and sensors.

It is further modified as,

$$C.F(i) = \frac{1}{d(i)[E-R.E(i)]^2} P \geq 2 \quad (7)$$

In this function where p is the index value which is greater or equal to 2, we assume that energy lost is the difference between initial energy and remaining energy in each round. Those nodes having less amount of energy should not be considered to become forwarder node.

g. Cost Function 6:

$$C.F = Min\ [\frac{\sqrt{d(i)}}{[Eo-E(i)]}] \quad (8)$$

This above cost function is based on minimum distance and difference of initial energy and remaining energy, even the node which has lesser energy will not be selected as parent node.

8. Methodology

In this section, the methodology for reviewing cost functions in SIMPLE protocol is discussed. The parent node which is selected from the implanted nodes gathers all the data from neighbored node and send to the sink immediately. The SIMPLE protocol elects the parent node using the cost function as defined in Table 2. In this work all the cost functions have been analyzed for the parameters throughput, packet sent to the sink, packet drop, packet received at the sink, residual energy, path loss and delay. Simulations have

been performed in Matlab R2009a and results have been generated for the above mentioned parameters.

9. Simulation Results and Analysis

In this section, we analyzed all the cost functions discussed above; the results of these cost functions for various parameters are manipulated. The simulations are performed for the rounds ranges from 0-8000.

Fig. 3 shows the throughput comparison in terms of the number of dead nodes. It is mentionable that CF6 has the minimum number of dead nodes till 7300 rounds. The minimum number of dead nodes is zero for CF3 at 5300 rounds.

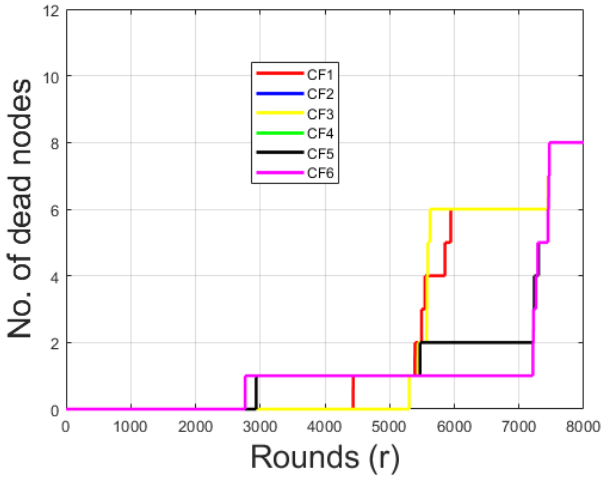

Fig. 3. Throughput comparison

In Fig. 4, results of packets sent to the sink are shown, in Fig. 5, results of packet drop are shown and in Fig. 6, results of the packet received at the sink are shown. It is evident to mention that the CF1 has minimum number of packets sent and received while the maximum number of packets dropped is also of CF1. The maximum number of packets sent and received is of CF6 while the minimum number of packet drop is of also CF6.

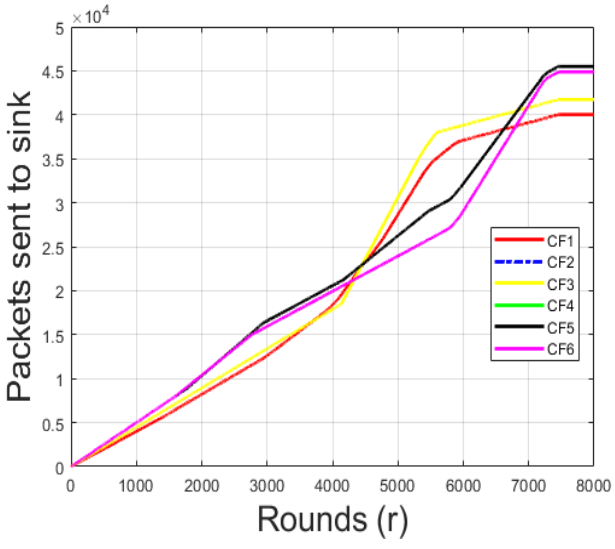

Fig. 4. Packets Sent to Sink

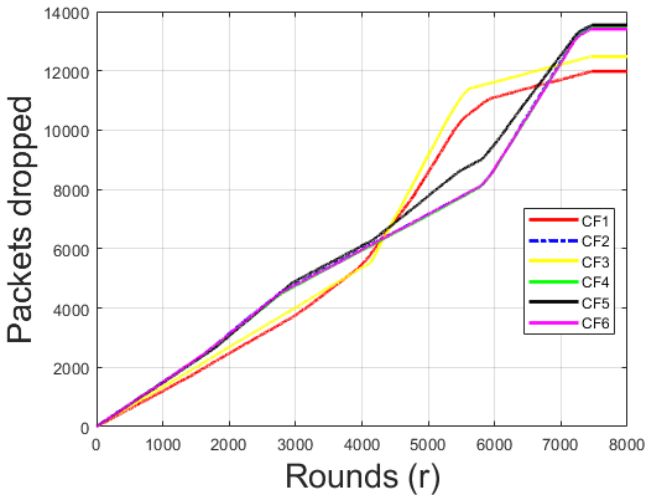

Fig. 5. Packets dropped

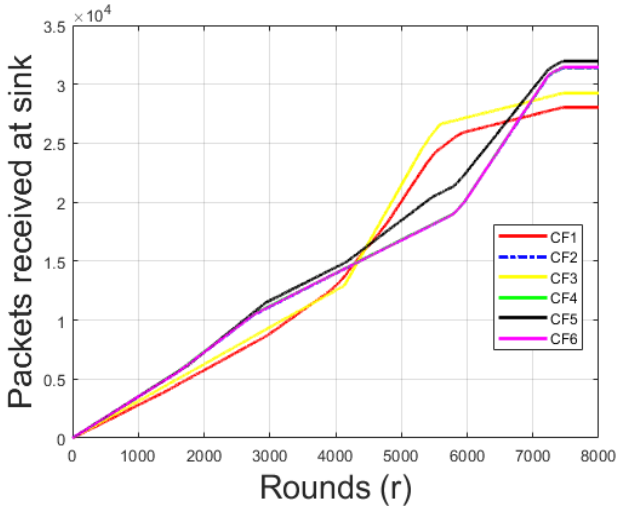

Fig. 6. Packets received at sink

Fig. 7 shows the result of residual energy. It is mentionable that the energy loss for CF1 and CF3 starts earlier than the other cost functions and reached to zero 7200 rounds. The energy for the other cost functions reaches to zero at 7300 rounds.

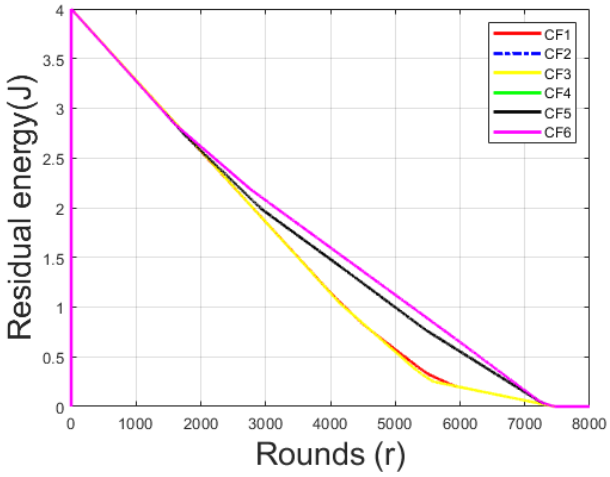

Fig. 7. Residual energy

Fig. 8 shows the result of path loss in dB for all the CF's. The path loss CF6 has the minimum path loss at 7500 rounds. Fig. 9 shows the delay for all CF's. The

delay is above 0.8sec till round 2100 while the delay is noticed to be 0.5 sec till round 7000.

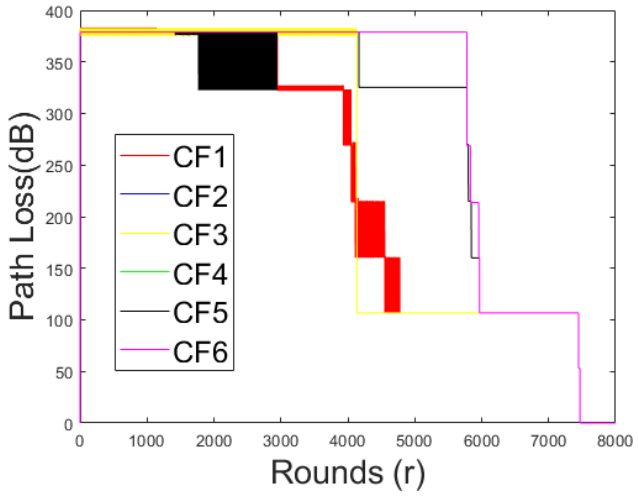

Fig. 8. Path loss

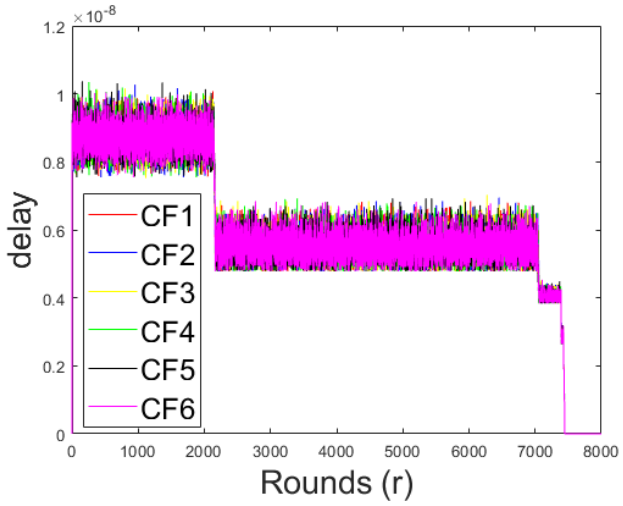

Fig. 9. Delay

9. Conclusion

In this paper we have compared and analyzed all various CF's of SIMPLE protocol for till date in WBAN is performed. SIMPLE protocol is categories on the basis of the CF's. We have compared and analyzed all the CF's in terms of throughput, packet sent to the sink, packet dropped, packet received at the sink, residual energy, path loss and delay. Simulation Results performed in MATLAB R2009a Simulator that shows the CF5 and CF6 have better performance results when compared with the other CF's as clearly seen in graphs. It is evident to mention that the CF5 and CF6 perform better while electing the parent node in SIMPLE Protocol.

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11. Future Work

In near future we will "propose" our own cost function, which will "be responsible" for selecting efficient forwarder node with minimum distance to sink and having higher residual energy. We must have to acknowledge that nodes should utilize less energy, if node utilizes less energy it will enhance throughput, which means if nodes are stable for longer period of time so they can communicate longer with sink.

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