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Design Energy Efficient Fuzzy-Based Clustering Routing Protocol for Wireless Body Area Networks (WBANs)

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Abstract: Wireless Body Area Networks (WBANs) are the most important area emerged from Wireless Sensor Networks (WSNs) to measure different vital signs of human body in term of remote healthcare monitoring. It comprises from tiny, intelligent and limited power sensors organized in/on or around the patient's body for diagnosis and long monitoring. Due to WBANs sensor nodes have limited battery power, so, the main challenge that airs with those networks are the battery power consumption and network life time. This research focuses on design and implement a reliable, high throughput and power efficient, fuzzy-based clustering routing protocol for WBANs. The proposed protocol combines many effective techniques (like clustering, routing, TDMA, single-hop and multi-hop techniques). The fuzzy logic concept is presented with two effective techniques: clustering: fuzzy logic used to select a cluster head based on two effecting parameters (residual energy and distance to sink). Routing: fuzzy logic used to choice the best route from many different possible routes between the sender sensor node and the receiver (sink), depended on three reliable parameters (route length, path loss and end-to-end delay). The proposed system utilizes a Time Division Multiple Access (TDMA) scheme in order to scheduling transmission of sensor nodes to the cluster heads and avoid data packets collisions at the sink. The performance of the proposed protocol was compared with the performance of SIMPLE and M-ATTEMPT. The performance analysis and comparison of the results which obtained after simulations in Java V(8) R(2018) Software, shows that the proposed protocol consumes minimum energy till 80% of simulation time (has the highest remaining energy) as compared with other selected protocols. Also, the results obtained shows that the proposed protocol improved the network life time more by 12, 22%, respectively and sends 20, 26%, respectively, more packets to base station as compared to SIMPLE and M-ATTEMPT protocols.

Key words: WBAN, clustering, routing, fuzzy logic, Java, TDMA, multi-hop, path loss

INTRODUCTION

Recent technological growths in sensors architectures, products small, low power micro-sensors with the capability of radio communication, so, those associated devices will create a Wireless Sensor Network (WSN) which have the capability to monitor continuously and autonomously as well as control of environments. Wireless sensor networks have many promising applications, the most important one is monitoring human health. When number of small wireless sensor devices placed on the body of human, so that, produce a Wireless Body Area Network (WBAN) which has capability of monitoring several vital signs and providing real time feedback to the medical personnel or emergency department (Devi and Nithya, 2014). Two types of WBAN devices can be distinguished: sensor devices and actuators devices. The sensors devices are used to measure vital parameters (such as: heartbeat sign, body temperature, recording a prolonged Electrocardiogram (ECG), etc.) from the human body, either externally or internally (Yahya, 2015). Each sensor device contains three main subsystems: first one, the sensor subsystem which is responsible about the data sensibility. Second, the process subsystem which performs partial processes to collected data. Third, the connection subsystem which is responsible for communications and sending data between neighboring devices. On the other hand, the actuator devices (a PDA or a smart phone which acts as a sink to the sensors data) take some certain actions according to the sensing data that received from the sensor devices where it forwards the gathered sensed data to a medical servers, hospital, dispensary or elsewhere in a real time (Santhosha and Sujatha, 2012). In WBAN, sensors are worked with limited power source. Therefore, it is required to use lowest energy for diffusing

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data from sensors to base station. Lowest power consumption can reserve the battery life-time over longer time where recharging of sensors batteries in WBAN is rare. One of the main difficulty in WBAN is to recharge sensors batteries. Therefore, an efficient clustering routing protocol is always essential to overcome this problem of refreshing sensors batteries (Nadeem, 2013). So, the main focus of this work is to propose a high throughput, reliable and energy efficient fuzzy-based clustering protocol together with routing method in order to enhance the lifetime of WBANs applied in smart healthcare.

Results obtained after simulation by using Java V(8) Software appearances that a suitable of fuzzy-based clustering and routing for extremely lessening the nodes energy consumption and increase the network life time.

Literature review: Ortiz *et al.* (2012) defined an adaptive energy efficient approach for WBANs called Adaptive Multi-hop tree-based Routing (AMR) protocol. The proposed protocol choose the qualified route based on the fuzzy concept with three combine parameters (Residual energy, Hop-count and Received Signal Strength Indicator (RSSI)). After experiments, they concluded that the network energy consumption, network life time and network throughput are improved with the fuzzy logic theory.

Lee and Cheng (2012) used the Network Simulator (NS-2) to simulate a fuzzy logic-based clustering model which used energy predication scheme in order to prolong the WSNs life time by evenly distributing the work load. The main job of the Fuzzy Inference System (FIS) is to compute the chance of each sensors to be selected as a cluster head. Two inputs variables are used in the FIS; Residual energy and expected residual energy. The simulation results showed that the proposed approach is more effective and efficient than other distributed systems.

Chen and Peng (2013) proposed a novel energy effective fuzzy-based routing algorithm in wireless body area networks to prolong the network life time. They used fuzzy logic concept with four suitable parameters (residual energy, traffic load, rate of power utilization and links cost) as inputs to (FIS) in order to optimize the best path for routing. The results showed that the proposed energy efficient fuzzy-based routing protocol decreased the energy consumption when compared with the standard routing protocols.

Abdulalim *et al.* (2013) proposed a fuzzy logic based energy-aware dynamic clustering technique for WSNs which increases the network lifetime in terms of Last Node Dies (LND). They used Fuzzy Inference System (FIS) with two inputs (node centrality and residual energy) to selected preferable nodes as a cluster heads according to the fuzzy cost values (output). The main advantage of this technique is that the optimum number of clusters is formed in every round. Moreover, this protocol has less computational load and complexity than in LEACH protocol (Low-Energy Adaptive Clustering Hierarchy). The simulation result demonstrated that this approach performs better than LEACH in terms of energy saving as well as network lifetime.

Yahya (2015) proposed a new method that combines cluster formation and cluster head selection in heterogeneous Wireless Body Area Networks (WBANs). He was used a single-hop star topology with a multi-hops cluster-based topology for WBANs. Also, he was used fuzzy logic system with two inputs parameters (residual energy and distance to sink), to select the cluster head nodes. The results showed that the suggested model consumes less energy, so that, extended the network life time, improves the stability period of the network and provides more packets delivered to the base station, as compared with the other star topology scheme.

Theory of the work

Fuzzy logic: Fuzzy set theory was formalized by Professor Lofti Zadeh at the University of California in 1965 (Zadeh, 1965) to deal with imprecise or vague problems. Fuzzy logic is derivative from fuzzy set theory and is the superset of conventional (Boolean) logic that has been extended to grip the idea of partial truth-truth values between "completely true" and "completely false". As its name proposes, it is the logic fundamental modes of thinking which are approximate rather than exact. In difference with traditional principle where binary sets have two-valued logic: false or true, fuzzy logic variables may have a truth values that sorts in degree between 1 and 0. That means, the elements of a fuzzy concept are transferred to a universe of membership values using a function-theoretic form. Therefore, the continuous form of elements can be represented by a membership function in a fuzzy sets (Lan *et al*., 2011). Fuzzy logic principle is utilized to knowledge and model human reasoning that do not have well known boundary. While fuzzy concept maps a wide range of techniques and theories, it is essentially based on four concepts: linguistic variables, fuzzy sets, fuzzy IF-THEN-rules and possibility distributions (membership functions) (Belohlavek *et al*., 2009). In general, the Fuzzy Inference Systems (FISs) comprises from knowledge base (database and rule base), fuzzification process, decision-making unit (inference engine process) and finally, the defuzzification process. A fuzzy inference system with its four processes as a blocks shows in Fig. 1.

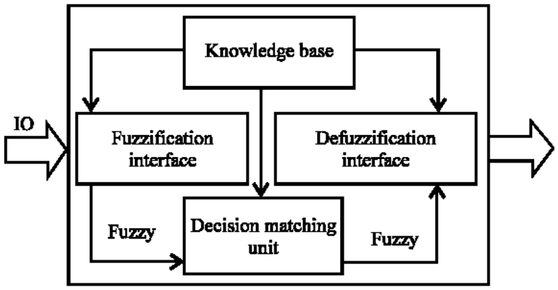

Fig. 1: General form of fuzzy inference system

MATERIALS AND METHODS

The proposed fuzzy-based clustering routing protocol details: The main objective of the proposed protocol is to reduce energy consumption in WBANs by searching about the best cluster head node in each round, choosing the best path for routing between the sender sensors and receiver (sink) and scheduling data transmission to the sink. This objective is achieved based on the Fuzzy Inference Systems (FIS) with suitable fuzzy rules. The proposed protocol used two Mamdani inference systems, one for the suitable forwarder node selection in each round and the other for the best routing path selection. The limited numbers of elements in the WBANs environment give a large chance to relax constraints in the proposed routing protocol. The following subsections give details of the proposed protocol. Algorithm 1 illustrates the general phases for the proposed protocol to reduce energy consumption and prolong network life time in the WBANs.

Algorithm 1; Fuzzy Inference Systems (FIS):

1. Start
2. Construct a WBAN by deploy eight sensors at fixed places on the human body and place the sink on the waist of body
3. Sink broadcast an information packet which contains its coordinate on the body
4. All sensors broadcasts an information packet holds node ID, coordinates of node on the body and node energy level
5. Configure WBAN and sensors begin send their sensing data to the sink. ECG and BP sensor nodes transmit data packets direct to sink (single-hop) and remaining sensors will be consider as a cluster
6. Sink determine the CH based on the Fuzzy_Cost value of every node which find by using FL with two parameters (residual energy and distance to sink)
7. CH (parent node) assigns a Time Division Multiple Access (TDMA) based on time slots to its children
8. Select the best routing path based on the FL with three parameters (route length, path loss and end-to-end delay) as inputs to FIS
9. Select a new CH in each round, until sensor nodes energy equal to or less 0.1 J, so, sensors transmit their data packets direct to sink (single-hop)
10. Calculate performance metrics
11. Compare the performance metrics (results)

Built a WBAN: In this project, we places eight sensor nodes on the human body at appropriate positions and put the base station (sink) on the waist of the body. All heterogeneous nodes in the WBAN and the human body are fixed after deployment, that means, the location of a sensor node in the network does not change. All sensor nodes have the same initial energy equal to (0.5 J) and equal computation capabilities. Single-hop routing is used for the sensors that will sense and transmit critical medical data form the human body (such as Electrocardiography (ECG) and Blood Pressure (BP) sensors). Multi-hop routing is used for other sensors which delivery normal data from the human body. In this research, we utilize the first order radio model (Javaid *et al*., 2013). In this model (d) symbol consider the separation between transmitter node and receiver node while (d^2) represented the cost of energy in the channel during the transmission operation. Details of first order model are given as Javaid *et al*. (2013):

$$E_{Tx}(k, d) = E_{Tx\text{-}elec}(k) + E_{Tx\text{-}amp}(k, d) \quad (1)$$

$$E_{Tx}(k, d) = E_{elec} \times k + E_{amp} \times k \times d^2 \quad (2)$$

$$E_{Rx}(k) = E_{Rx\text{-}elec}(k) \quad (3)$$

$$E_{Rx}(k) = E_{elec} \times k \quad (4)$$

Where:

(E_{Tx}) = Energy required to Transmission operation
(E_{Rx}) = The Energy spent by Receiver
($E_{Tx\text{-}elec}$) and ($E_{Rx\text{-}elec}$) = The Energies necessary to run the electronic circuit of transmitter and receiver, separately
(E_{amp}) = Energy necessary for amplifier circuit
(k) = The packet size

In wireless body area network the communication medium is body of human which contributes diminution to radio signal. So, in this research, we consider path loss coefficient factor (n) in the radio model. Therefore, Eq. 2 transmitter must modified as following Eq. 5:

$$E_{Tx}(k, d) = E_{elec} \times k + E_{amp} \times n \times k \times d^n \quad (5)$$

Figure 2 shows placement of sensor nodes and sink on the human body.

Network set-up phase: Three important tasks are done in this initial phase: the coordinates of sink on the human body will be identified, informed every node with its

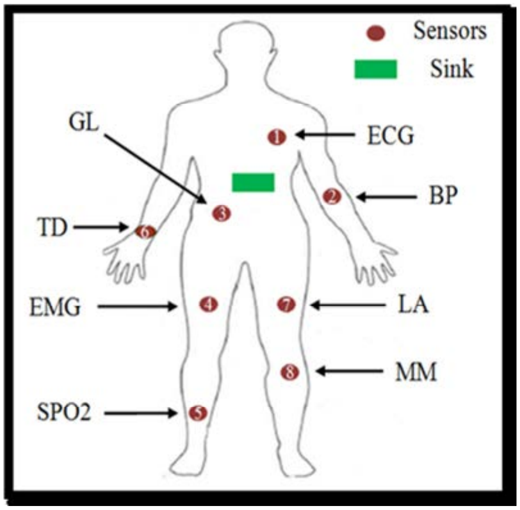

Fig. 2: Sensors deployment

neighbours and identified every possible route to sink. Where, the sink broadcast a HELLO message to all other nodes which holds the coordinates of the sink on the human body. When circumference nodes receiving control packets from sink, each one stores the coordinates position of the sink in its routing table. After that every sensor node broadcasts a HELLO message to other nodes which holds node (ID), node energy level and its coordinates on the human body. According to this style, every sensor updates its routing table with the coordinates of neighbors nodes, sink location and all available routes to the sink.

Cluster head selection phase: Multi-hop scheme was used in this model, to reduce nodes energy consumption and prolong the network life time. So, the proposed model will select a new cluster head in each round in order to distribute energy consumption among the sensor nodes in equally manner and increasing the network balancing. In each round, sink computes and allocates the fuzzy-cost values for each sensor node based on the fuzzy logic concept and its storage information (nodes ID, residual energy and distance to sink). Based on the Fuzzy-cost value of each sensor node, the decision of which one must be selected as a forwarder node will be done. So, the selection of cluster head be done based on the fuzzy inference system with two input parameters (residual energy and distance to sink). Mamdani fuzzy inference style was used to find the Fuzzy_Cost value to each sensor node due to its simplicity in implementation and its outputs are very suitable for the requirements of the proposed system and few calculations are required. This fuzzy inference system was executed on the basis of

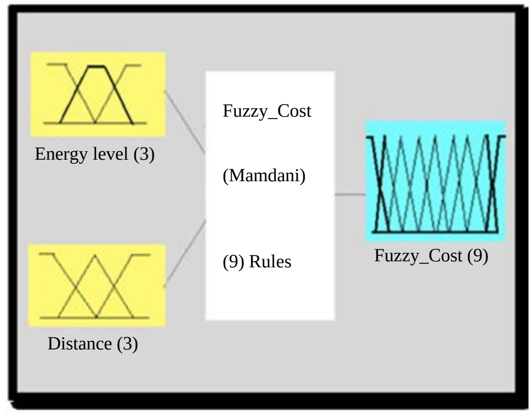

Fig. 3: FIS architecture of CH selection

the best fuzzy rules. Figure 3 provides some details about the general form of the suggested mamdani fuzzy inference system.

The parameters that are used as inputs to the proposed FIS are defined as follow:

Residual energy: It represents the remained energy level of each node after each transmission process. The amount of residual energy to each node can be determined based on the following function (Nadeem *et al*., 2013; Sandhu, 2014):

$$RE_{node} = E_{node} - E_{Tx} \tag{6}$$

Where:
(RE) = Residual Energy of specific node
(E) = Node Energy
(E_{Tx}) = Total Energy cost calculated based on Eq. 5

Distance to sink: It refers to the distance between any sensor node and the sink. Its calculated using the following function (Yahya, 2015):

$$Distance_{(Sink,\ Node)} = \sqrt{(X_s - X_n)^2 + (Y_s - Y_n)^2} \tag{7}$$

where, (X_s) and (X_n) are the points of sink and any sensors node on the (X) axis (Y_s) and (Y_n) are the points of sink and any sensors node on the (Y) axis.

In the proposed fuzzy system, two membership functions (trapezoidal, triangular) are used to map input variables into fuzzy values. Inputs variables are (energy level and distance to base station). Each of this variables contain three membership functions. Table 1 display different membership function of each input variables. The output variable is used nine membership functions. Table 2 displays the output variable membership functions.

Table 1: Input variables with its membership functions

Inputs	---------------Membership functions------------------		
Energy level	Low	Medium	High
Distance to sink	Close	Medium	Far

Table 2: Output functions with its membership

Output	Membership functions
Fuzzy_Cost	Very small, small, rather small Small medium, medium, large medium Rather large, large, very large

Table 3: Production fuzzy rules for best CH selection

Energy levels	Distance to sink	Fuzzy_Cost
High	Close	Very small
High	Medium	Small
High	Far	Rather small
Medium	Close	Small medium
Medium	Medium	Medium
Medium	Far	Large medium
Low	Close	Rather large
Low	Medium	Large
Low	Far	Very large

FIS must apply a set of fuzzy rules to get the output value (crisp). So, the depended knowledge based include (9) best fuzzy rules (Table 3). The form of this fuzzy rules is:

IF X1 is A and X2 is B THEN Y is D

At final step to the offered fuzzy system, the Center of Gravity (COG) approach was utilized as a defuzzification process after evaluating the fuzzy rules in fuzzy inference engine. The mathematical model of the (COG) using the following Eq. 8 (Yahya, 2015):

$$COG = \frac{\sum_{k=1}^{q} x.\mu A(x)}{\sum_{k=1}^{q} \mu A(x)} \quad (8)$$

where, $\mu A(x)$ is membership function of a fuzzy set (A) defined in the universe (x) and (q) is the number of quantization levels of the output.

The FIS output values (crisp values) were got after running the defuzzification process which represent a Fuzzy_Cost values for each sensors node. After that, the sensor node which has minimum Fuzzy_Cost value will be selected as a cluster head. In this way, all the children sensor nodes with its parent node are formed in each round, then, nodes transmit their sensed data to cluster head. Thus, the parent node (CH) aggregates data and transmit it directly to the sink.

Scheduling assignment phase: In this stage, cluster head node assigns Time Division Multiple Access (TDMA) to each children nodes based on time slots. TDMA principle involve allocating time frame in devoted time slots. The parent node (cluster head node) are responsible for telling their children nodes when they can communicate (the synchronization slot is possible). So, each child forwards its sensed data to the parent node in a fast sequential sequence at its own dedicated time slot. With TDMA any sensor with no sensing data to transmit, it will switch to sleep mode but when it has data to forward at allocated transmission time, it will switch to wake up mode. Therefore, sensor nodes scheduling scheme absolutely reduce the energy consumption of each sensor node. TDMA also, avoids any collision or loss of data packets to achieve better network throughput. In this way, data packets are efficiently routed from nodes to sink.

Best route selection phase: Routing optimization is a process of choosing the best routing path between the sender and receiver nodes with consideration of network performance maximization. This process will reduce the path loss rate and avoid any node retransmit its data packets, thus, selecting the best path will reduce the energy consumption of the nodes. The proposed system will choose the best routing path from different passible routes (with each node transmitted process) based on the Route_Cost value which is computed by using fuzzy logic concept. When any node has sensed data to send at its own transmission time, it will estimate the Route_Cost value for each passible route to sink based on the FIS with three inputs parameters (route length, path loss and end-to-end delay). These variables are considered because they have great effect on the amount of energy consuming to send a message towards the sink. Based on the route-cost value of each passible route (between source sensor node and the destination sink), the decision of which one will be selected as a best routing path is done. Figure 4 provides some details about the general form of the suggested mamdani fuzzy inference system. The parameters that are used as inputs to the proposed FIS are defined as follow:

Route length: It refers to the distance between the sender node (source) and the target node (sink), passing through the remaining intermediate nodes. This parameter is calculated on the basis of distance function as it is shown in Eq. 7.

Path loss: Path loss (or path attenuation) is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space. Path loss is usually expressed in (dB). In its simplest form, the path loss can be calculated using in Eq. 9:

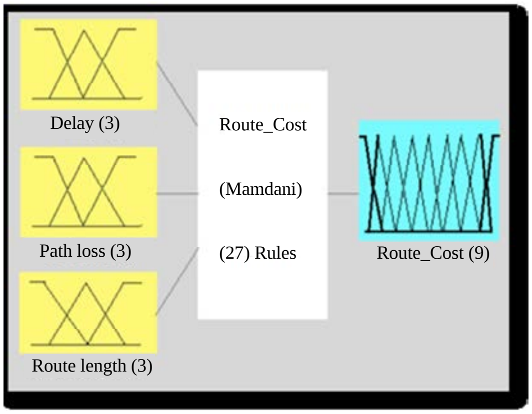

Fig. 4: FIS architecture of best route selection

$$PL(d) = PL_0(d_0) + 10 \times n \times \log_{10}(d/d_0) + X\sigma \quad (9)$$

Where:

$PL(d)$ = The path loss of specific distance between transmitter and receiver nodes
(d_0) = The reference distance
(n) = The path loss coefficient
$PL_0(d_0)$ = The path loss at reference distance
(d_0) = Calculated according the following equation (Sandhu, 2014; Javaid *et al.*, 2013)

$$PL_0(d_0) = 10\log_{10}\left[\frac{4 \times \pi \times d_0}{\lambda}\right]^2 \quad (10)$$

where (λ) is the wavelength of the electromagnetic waves. The standard value of reference distance (d_0) in WBANs is 10 cm.

End-to-end delay: It refers to the time required for the sent data packet to travel across the network from the source node to its destination node, measured by fractions of seconds (Raptis *et al.*, 2009). The delay can be calculated depending on the ratio between the distance traveled and the velocity of sending data packets (typically the speed of electromagnetic waves is considered) as the following equation (Sandhu, 2014):

$$\text{End-to-end delay} = d/c \quad (11)$$

Where:

d = The distance between sink and node
c = The speed of electromagnetic waves (typically the speed of light is considered)

Table 4 display different membership function of each input variables. The output variable is used nine membership functions. Table 5 displays the output variable membership functions.

Table 4: Input variables with its M.Fs

Inputs	---------------Membership functions----------------		
Delay	Small	Medium	Large
Path loss	Low	Medium	High
Route length	Short	Medium	Long

Table 5: Output functions with its membership

Output	Membership functions
Route_Cost	Very small, small, rather small Small medium, medium, large medium Rather large, large, very large

Table 6: Production fuzzy rules for best rout selection

Delay	Path loss	Route length	Route-Cost
Small	Low	Short	Very small
Small	Low	Medium	Small
Small	Low	Long	Rather small
Small	Medium	Short	Small
Small	Medium	Medium	Small medium
Small	Medium	Long	Medium
Small	High	Short	Small medium
Small	High	Medium	Medium
Small	High	Long	Rather large
Medium	Low	Short	Small
Medium	Low	Medium	Small medium
Medium	Low	Long	Medium
Medium	Medium	Short	Small medium
Medium	Medium	Medium	Medium
Medium	Medium	Long	Large medium
Medium	High	Short	Medium
Medium	High	Medium	Large medium
Medium	High	Long	Large
Large	Low	Short	Small medium
Large	Low	Medium	Medium
Large	Low	Long	Rather large
Large	Medium	Short	Medium
Large	Medium	Medium	Large medium
Large	Medium	Long	Large
Large	High	Short	Rather large
Large	High	Medium	Large
Large	High	Long	Very large

The FIS used knowledge based include (27) ideal fuzzy production rules for knowledge representation (Table 6). The form of this fuzzy rules is:

IF X1 is A and X2 is B and X3 is C THEN Y is D

At final step of fuzzy inference system, the Center of Gravity (COG) method also exploited as a defuzzification process after evaluating the fuzzy rules in fuzzy inference engine to get the output function. The mathematical model of the (COG) was shown in Eq. 8. The output values (crisp values) which get after executing the defuzzification process, represent a Route_Cost values for each available route between the sender sensor node and receiver sink. After that, any routing path which has minimum Route_Cost value will be selected as a best route which will be used to transmit data packets to sink.

Data transmission phase: In the data transmission phase, all WBAN sensor nodes except Electrocardiography

(ECG) and Blood Pressure (BP) measuring nodes send their data to the forwarder in multi-hop scheme. Where, nodes transmit data to their respective forwarder nodes in their scheduled time slots. Forwarder nodes receive data from their children nodes, aggregate it and route it to the sink. The initial energy of all sensor nodes is the same (i.e., Eo = 0.5 J). Nodes measuring ECG and blood pressure communicate directly to the sink (using a single-hop scheme) as they have critical data. Sensor nodes sense the vital parameters of the human body and send data packets to the sink continuously. If a node has less distance to the sink than forwarder node, it routes its data directly to the sink. However, after the nodes are left with energy equal to or below a certain threshold (0.1), the proposed protocol uses reactive routing (network sensors send their data packets directly to the sink in single-hop scheme). Therefore, human vital parameters are monitored for long term (increasing network life time).

RESULTS AND DISCUSSION

In this study, the performance of the proposed protocol is evaluated and analysed by consider an extensive set of experiments using Java (R2018) as a simulator. Experiments involves 5 session for each one (8000) round. We display the validation of the performance of the proposed protocol by compare it's results with the results of SIMPLE (Nadeem *et al*., 2013) and M-ATTEMPT (Javaid *et al*., 2013) protocols. The setting parameters with their values are display in Table 7.

Many performance metrics are used to analyze and understand the performance of the proposed protocol after comparing its performance with the performance of SIMPLE and M-ATTEMPT as described in the following sub-sections:

Network life time: Network life time can be defined as a total time required to complete network operations until the last node die. Figure 5 illustrates the rates of network

Table 7: Simulation parameters

Parameters	Values
Number of sensor nodes	8
Simulation area	(100,200) cm
Initial energy	0.5 (J)
Packet size	500 (bytes)
Received Energy ($E_{rx\text{-}elec}$)	36.1 (nJo/bit)
Transmitted Energy ($E_{tx\text{-}elec}$)	16.7 (nJo/bit)
Amplification Energy (E_{amp})	1.97 (J/b)
Wavelength (λ)	0.125 (m)
Human body path loss coefficient (n)	3.38 (dB)
Standard Deviation (σ)	4.1

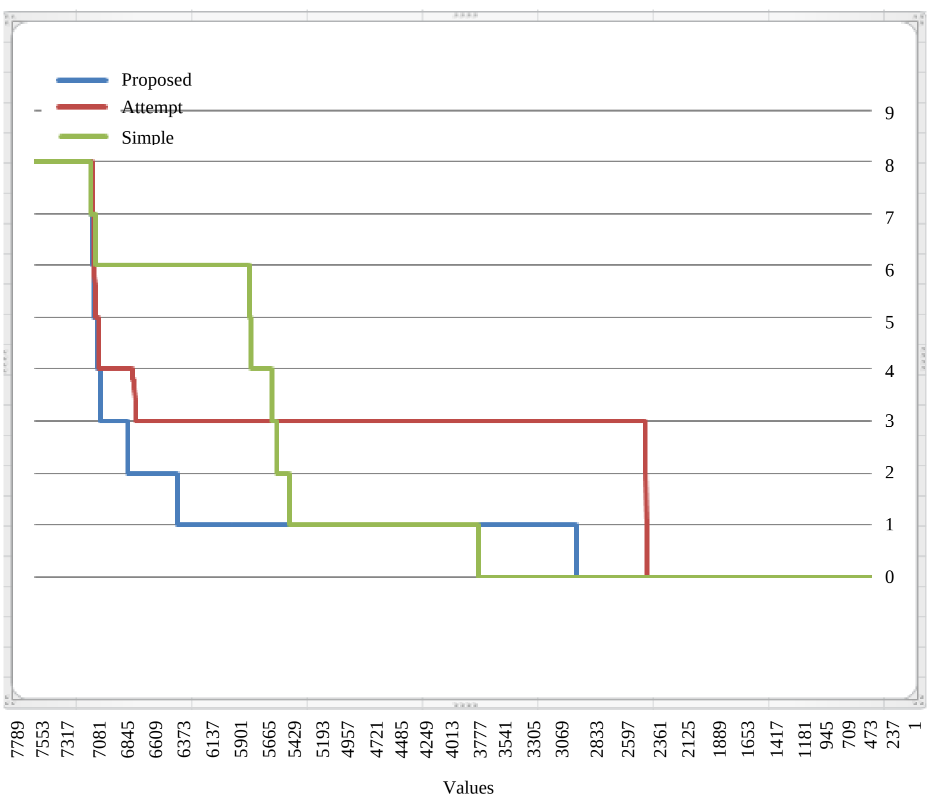

Fig. 5: Analysis of network life-time; No. of dead nodes

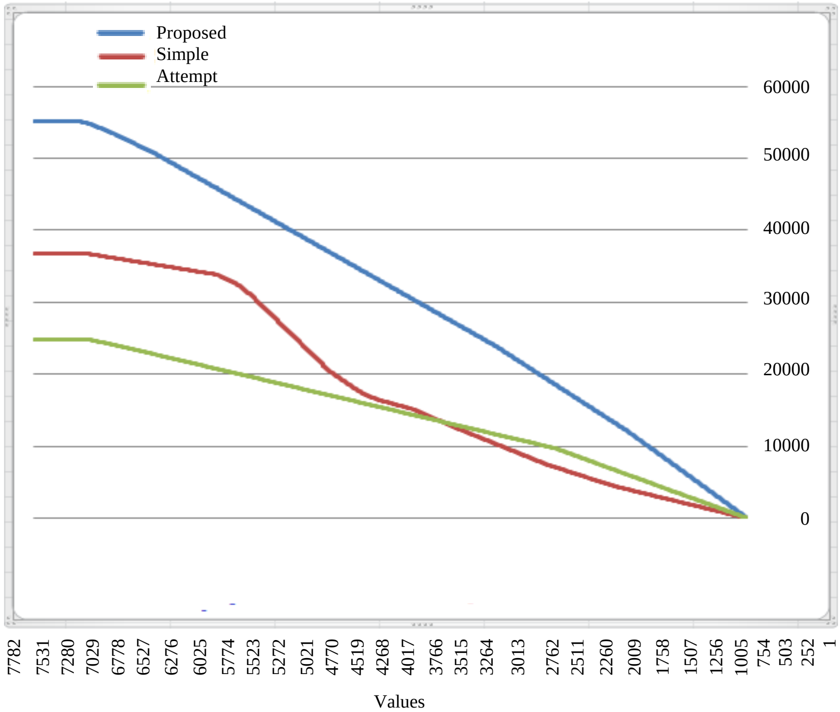

Fig. 6: Throughput analysis; Number packets received at the sink

life time for the proposed, SIMPLE and M-ATTEMPT protocols for 5 sessions (for each one 8000 round). By comparing the graphs of the three protocols together which represents the number of dead nodes, it can be easy observed that the average number of dead nodes of the proposed system is much lower than in the rest protocols for five sessions. Therefore, the network life time of the proposed protocol is more than that in the rest protocols. This is due to the important role of the fuzzy systems by choosing the best forwarder node in each round (thus increasing the balance energy consumption among the nodes) and selecting the best routing path (reducing energy consumption by avoiding retransmitting loss packets). According to Fig. 5, the proposed protocol improved the network life time more by 12% than network life time of SIMPLE protocol and more by 22% than that in the M-Attempt protocol.

Throughput: This measure can be defined as a total number of packets which sent from sources (sensors nodes) across the network and successful access to their destination (sink). Figure 6 shows that the ratio of the packets received at the sink with the proposed protocol is much higher than that achieved by the rest protocols that means, the proposed system has very high throughput (mostly, network throughput depends upon the number of nodes which are alive, that means, more nodes send more packets, so, throughput increases). The proposed system achieved batter performance because it has more a live nodes which produce more delivery packets as well as selecting the best routing path with each transmitting process, thus reducing the number of dropped packets. According to Fig. 6, the proposed protocol achieved average packets received at the sink more by 20% than that achieved by simple protocol and more by 26% than that achieved by M-ATTEMPT protocol. So, the proposed model has better performance in terms of number packets received at the sink node.

Residual energy: Residual energy indicates to the amount of remaining energy in the node which related to the number of data packets that is received, processed, transmitted and the node's life time. Figure 7 shows that all simulation rounds of the offered WBAN, the energy consumption of the proposed protocol is less than energy used in the SIMPLE and M-ATTEMPT protocols that cause increasing network life time of the proposed protocol. Low power consumption of the proposed protocol due to use of several energy conserving methods which combined with the fuzzy inference systems (clustering and routing) as well as selecting a new cluster head node in each round and used TDMA scheme. Simulation results show that the proposed protocol consumes minimum energy till 80% of simulation time (has the highest remaining energy). As a result, the proposed system has more network lifetime and stability period, this means, more live nodes will send more data packets to sink (improves the network throughput).

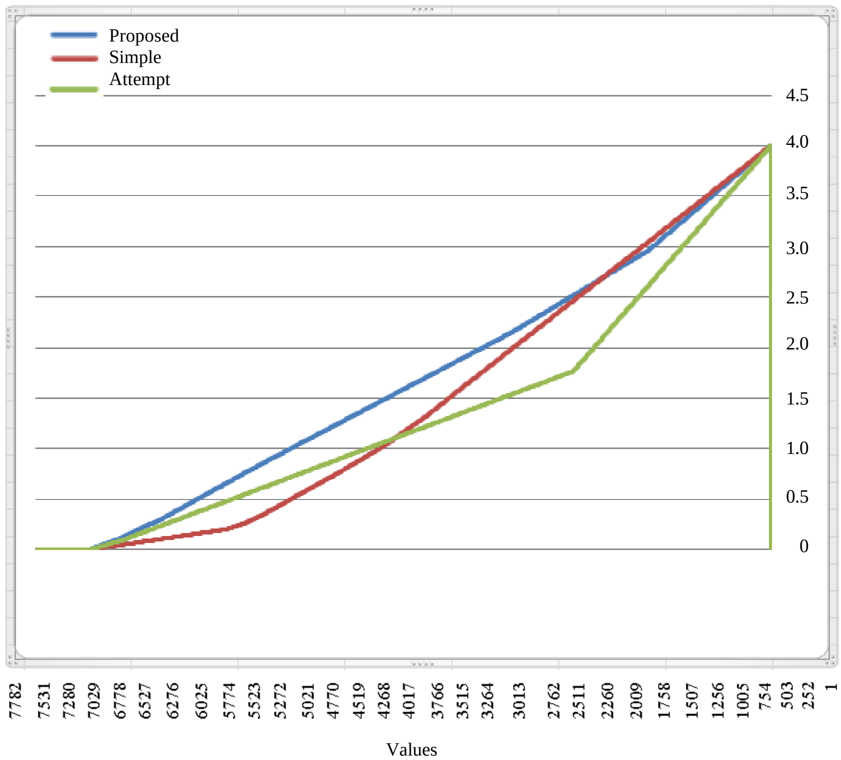

Fig. 7: Analysis of remaining energy; Residual energy

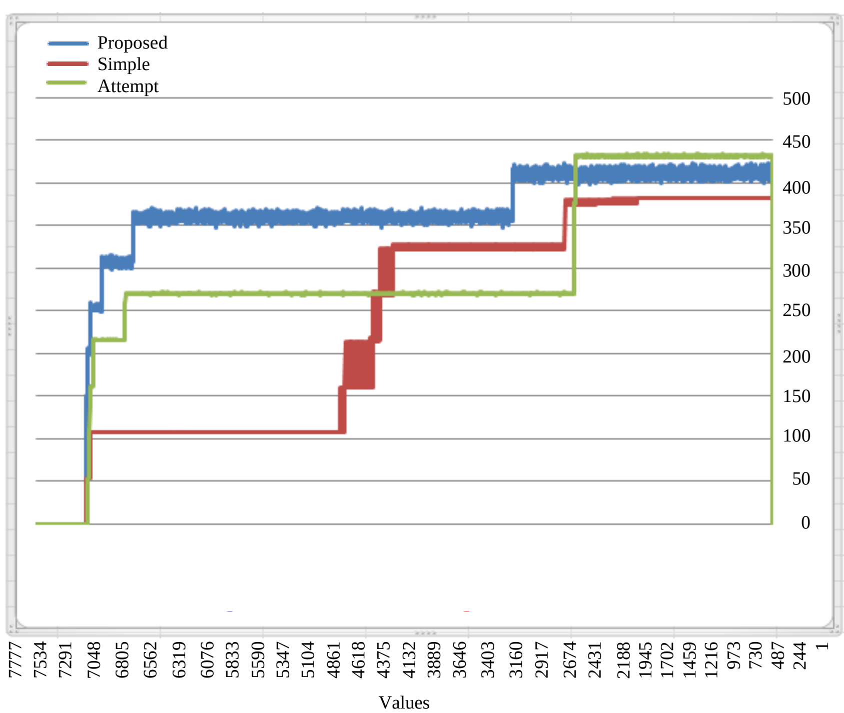

Fig. 8: Network path loss

Path loss: Path loss is the reduction in power density of an electromagnetic signals as it propagates through a medium, calculated in decibels (dB). Figure 8 represents the average path loss of the three protocols (Proposed, SIMPLE and M-ATTEMPT) for 5 sessions. When these results compared together, we can distinguish that the proposed system achieved average path loss higher by 12, 6%, respectively, than that achieved by SIMPLE and M-ATTEMPT protocols. In the initial rounds of simulation, simple protocol performs better performance, also, the path loss accumulative of M-ATTEMPT protocol became decreased after 2000 rounds. The well performance of SIMPLE and M-ATTEMPT protocols in the initially rounds due to there are some nodes in their topologies are died early in the simulation. Where, the smallest number of the live nodes has lowest accumulative path loss. On the other hand, in the initial rounds, the proposed protocol has more a live nodes and achieved longer stability period that lead to more accumulated path loss. However, in the finality rounds (after 6000 rounds), the path loss of proposed model was dramatically decreased, due to the fact that some nodes die after 6000 rounds. So, less number of nodes have lower cumulative path loss.

CONCLUSION

In this study, we proposed an energy effective fuzzy-based clustering routing protocol for WBANs. It combines the advantage of several energy effective techniques like: clustering (based on the fuzzy logic), routing (based on the fuzzy logic), TDMA, single-hop and multi-hop schemes. Our model takes into account more information from the present state of sensor nodes (comprising the remaining energy level of each node, the distance between nodes and the base station) to select the best cluster heads in each round and effective parameters about link state (like route length, path loss and end-to-end delay) to select the best routing path with each multi-hop data transition operation. So, our simulation results shows an improvement of over 12 and 22%, respectively, in terms of the network lifetime as compared to the performance of SIMPLE and M-ATTEMPT protocols. Also, simulation results shows that the proposed protocol improved network throughput more by 20 and 26%, respectively, than that achieved by SIMPLE and M-ATTEMPT protocols. The proposed protocol consumes minimum energy till 80% of simulation time (has the highest remaining energy) as compared with other selected protocols. Our results also proved that the proposed protocol achieved better network residual energy, throughput and life time as the sensor nodes die slowly making it considering an energy efficient clustering routing protocol as compared with other selected protocols.

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