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Using Fuzzy Logic to Enhance Network Lifetime in the Clustered Routing Protocol of Wireless Body Area Network (WBANs)

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Abstract: Large progress in Wireless Sensor Networks (WSNs) technology produce the low-cost and very small electromechanical sensor nodes which has capability of sensing and processing various kinds of certain information as well as wireless communication between them. In recent years, Wireless Body Area Networks (WBANs) emerged as the most important research area from the existing WSNs technology. Its developed mainly for patient health monitoring. A WBAN consist from number of miniature sensor nodes which have capability of sensing data and wireless communication with each other as well as with the base station (Example: mobile phones, PDA) through a radio interface. The main challenge that arise with the WBAN is network life time. When any sensor node associated to the human body are battery operated devices, so, it has limited power and life time. Therefore, design power efficient protocols for WBANs are always needs to reduce energy consumption and prolong network life time. This study presents a new energy-efficient adaptive clustering routing protocol for WBANs which used fuzzy logic to efficiently maximize the network lifetime in term of improve network stable period. The suggested protocol used fuzzy logic concept in two effective places; To select a Cluster Head (CH) nodes in each round, based on three parameters (residual energy, distance to sink and RSSI). To select the optimal path from many different possible routes between sender and receiver nodes, based on three effective parameters (local battery level, traffic load and number of hops). Also, it used multi_hop and TDMA schemes to avoid data packets collisions at the sink. Simulation results in the MATLAB R (2009a) simulator shows that the percentage of energy consumption enhancement is more than 33% that lead to network lifetime improved more than 40% when compared our method with the m-Attempt protocol.

Key words: WBAN, routing, clustering, fuzzy logic, MATLAB, TDMA, Multi_Hop, RSSI

INTRODUCTION

Wireless Sensor Networks (WSNs) are a fault tolerant networks with large scale deployment and redundant communication between thousands of cheap, tiny sensor nodes and one or more sink node (also known as base station) through a wireless medium in the physical space (Potdar *et al*., 2009). One of the wide applications of WSN is healthcare which lead to emergence a new field of research known as Wireless Body Area Networks (WBANs). It is a network created by communication of various sensor nodes attached at the fixed places on the human body to monitor vital signs such as heart beat, temperature, pressure. These sensors are connected primarily with the base station or sink like PDA (Personal Digital Assistant) (Ahmad and Zafar, 2012). Figure 1 show WBAN architecture which consists from few sensor nodes implanted on the human body those sensors can be three types.

Biosensor: These sensor nodes are used to sensing physiological activities like heart rate, particulate matter (such as oxygen degree) in the human blood, body temperature, blood pressure and respiration rang (Tickoo and Gambhir, 2015).

Motion sensor: These sensor nodes are used to sensing and monitoring the current posture of the body like walking, running, standing, sitting, falling, kneeling, crawling and laying (Tickoo and Gambhir, 2015).

Gateway: The gateway (also known as WBAN controller or sink) is an interface between sensor nodes on the human body and the monitoring server. It can be a PDA (personal digital assistant) or a cell phone with one of these wireless technologies like WiFi, Wi-Max, GPRS, UMTS, Zigbee or Bluetooth. It does three main tasks (Suresh and Alli, 2012).

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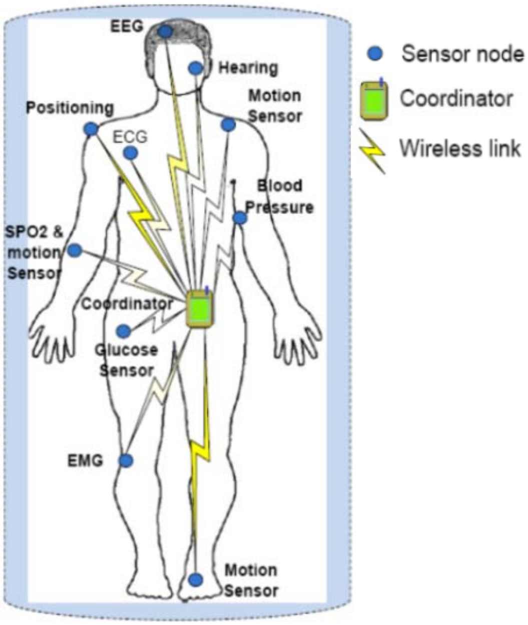

Fig. 1: WBAN architecture

- Gateway collects digitized sensing information from all sensors in WBAN
- Gateway has capability to pre-processes, analyses and takes some action on the varied type of data traffic. It stores this information in its local memory (in case of slow or no internet connection)
- The gateway then forwards this digital information to monitoring server via. ad-hoc network or other communications

Monitoring device: A monitoring device involves processing software and data base. The sensing data received via. internet is analysed and processed according to the implemented software. A monitoring server can be a personal computer, laptop or a display instrument specific for that WBAN application.

When a WBANs consists from small sensor nodes which have limited battery capacity, so, design effective protocols are always important to reduce power consumption and increasing the network throughput with its life time. Many energy efficient routing protocols are designed to maximize the life time of networks (Nadeem *et al*., 2013). An adaptive power control algorithm is presented and implemented in this work to ensure energy-efficient consumption in WBANs. Our algorithm utilized fuzzy logic in two phase: the first one in the clustering phase where we deployed fifteen homogeneous sensor nodes and sink at the fixed places on the human body, two nodes have important data which is transmitted directly to the sink and the remaining nodes sent data through a forwarder. Fuzzy logic used to select the Cluster Head (CH) based on three variables (residual energy, distance to sink and received signal strength indicator) as inputs to fuzzy inference system. The second phase is routing optimization in which the best path to base station is selected on the basis of fuzzy logic with three effective parameters (local battery level, traffic load and number of hops) as inputs to fuzzy inference system. We also utilized Time Division Multiple Access (TDMA) scheme to schedule nodes transmission to a Cluster Head (CH) and avoid data collisions at the sink. Results obtained after simulation by using MATLAB (R2009a) simulator shows that an appropriate master cluster-head election and the optimization routing scheme can extremely decrease the energy consumption of the nodes and improve the network life time. Organization of the article.

Literature review: AlShawi *et al*. (2012) suggested a novel routing protocol for (WSNs) to prolong network lifetime by using a fuzzy logic concept and an A-star method. The suggested scheme select a best path from the source to the destination based on the highest residual battery power, lowest traffic loads and smallest number of hops. They are compared the proposed method with the other A-star search methods which used the same routing principles in two different topographical areas in order to prove the efficiency of the suggested algorithm in terms of enhancing energy consumption and extension of network lifetime. Simulation results shows that the improvement of network lifetime nearly 25% more than existing A-star algorithm and nearly 20% more than other fuzzy approach (AlShawi *et al*., 2012).

A novel clustering algorithm called Fuzzy Chessboard Clustering (FFC) for (WSNs) was suggested by AlShawi *et al*. (2014) in order to solve the bottleneck problem and reduce energy consumption in heterogeneous (WSNs). They also offer an energy-efficient routing approach called Artificial Bee Colony Routing Method (ABCRM) to select the best transitions route for balancing energy consumption and extension of network lifetime. They are compared the proposed method with three approaches (chessboard clustering approach, LEACH and PEGASIS), to prove the efficiency of FCC-ABCRM. Simulation results shows that the improvement of network lifetime nearly 25, 45 and 60% more than that achieved by chessboard clustering, PEGASIS and LEACH, respectively (AlShawi *et al*., 2014).

The performance of hybrid routing protocol for the WBANs was analysed by Sharma and Kumar (2012) when they are proposed a homogeneous energy routing protocol f-Mchel which represent as improve to LEACH protocol. The clusters scheme in the LEACH protocol are made randomly based on threshold values. The suggested protocol used fuzzy logic approach to elect the cluster-head on the basis of two inputs (energy level and distance). After simulation based on MATLAB simulator, results shows that the suggested approach improve the energy consumption and the enhance network stability period as compared to LEACH protocol (Sharma and Kumar, 2012).

Gajjar *et al.* (2014) they are proposed Cluster Head selection method Based on Fuzzy Logic (CHBFL). Fuzzy concept was used to select a cluster head based on the four variables (residual energy, quality of communication path with its neighbourhood, reachability from its neighbourhood and distance to sink) as inputs to FIS. Simulation results shows that CHUFL method achieved up to 20% more residual energy and more than 72% data packets send to base station when compared the proposed method with (CHEF) clustering algorithm (Gajjar *et al.*, 2014).

A new method was proposed by Naggar (2015), she depended on the merge between the cluster head selection and cluster formation in Wireless Body Area Networks (WBANs). She was use the fuzzy logic theory with two inputs parameters in order to elect the cluster head. These two inputs parameters are residual power and distance to the base station. After simulation results shows that the suggested scheme need to less energy that lead to increasing the network life time and improves the stability period of the network and obtain more packets send to the base station when compared with the other star topology idea (Naggar, 2015).

Jiang *et al.* (2013) they are increases the network life time based on fuzzy approach in energy efficient optimized routing algorithm which offered to enhance the degree of network energy balancing. Simulation results shows that the proposed method prolong the network lifetime by improved energy consumption and network balance together when compared with the other similar algorithms (Jiang *et al.*, 2013).

MATERIALS AND METHODS

Theory of the work

Fuzzy logic: Fuzzy set theory is the seed of fuzzy concept, it was presented by Zadeh (1965). This concept refers to any element in the universal set of domain but with the varying membership degree in the range between 0 and 1. That means it can be defined mathematically by assigning to each element in the Universe of Discourse (UOD) a degree refers to its value of membership in the fuzzy set (Lafta and Salman, 2014). The fuzzy sets with Membership Functions (MF) shows as follows definition (Zadeh, 1994): If variable (X) is a group of items indicated generically by (x) then fuzzy set (A) in (X) is known as a set of ordered pairs:

$$A = \{(X, \mu A(x)) \backslash x \in X\} \quad (1)$$

where, μA (x) known as MF for the fuzzy set (A). The MF translates each element of (X) to a membership degree among [0, 1]. The MFs μA (x) was used in the fuzzification steps and defuzzification steps of the fuzzy logic, to converts the crisp input values to fuzzy linguistic terms and vice versa. Fuzzy Inference System (FIS) show in Fig. 2.

The suggested fuzzy-clustering routing algorithm details: We present in this study a suggested clustering routing algorithm for WBANs. Little numbers of sensors in WBAN provide large chance to relax constraints in develop clustering routing model. The main objective of propose method is balancing the energy consumption between network nodes and growing the network life time by using Fuzzy Logic (FL) to select the forwarder nodes (CH) and to optimize the best routing path to sink. Next flowchart provide details about the offered method (Fig. 3).

Network model: In this research, we allocate fifteen sensors on the body of human at suitable places with sink on the waist of body. All sensors with the sink are fixed after deployment on the body and homogenous (all sensors have the same power and computation capabilities). Node 1 represent ECG sensor and node 2 represent glucose sensor this two nodes always have very important sensing data which must transferred to the sink directly. We utilize the first order radio model (Heinzelman *et al.*, 2000). In first order model d symbol refers to separation between transmitter sensor and

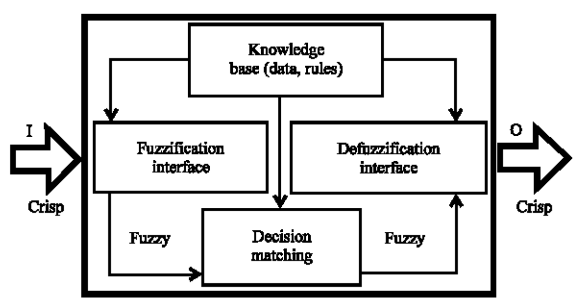

Fig. 2: Fuzzy inference system phases

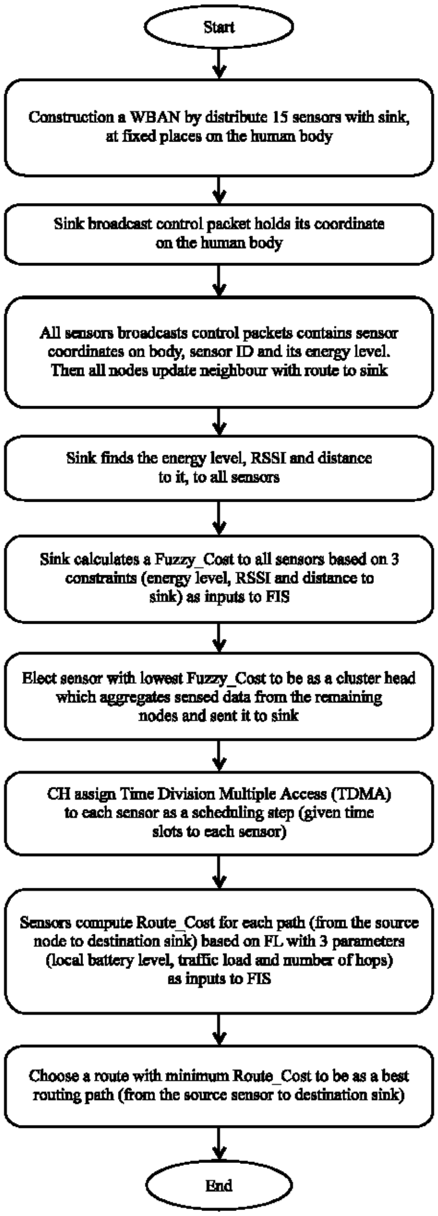

Fig. 3: Proposed method flowchart

receiver nodes while d2 consider the cost of energy in the channel during the transmission operation. More details about first order model are given:

$$ETx(k, d) = ETx\text{-}elec(k)+ETx\text{-}amp(k, d) \quad (2)$$

$$ETx(k, d) = ETx\text{-}elec*k+Eamp*k*d2 \quad (3)$$

$$ERx(k) = ERx\text{-}elec(k)ERx(k)+ERx\text{-}elec*k \quad (4)$$

$$ERx(k) = ERx\text{-}elec*k \quad (5)$$

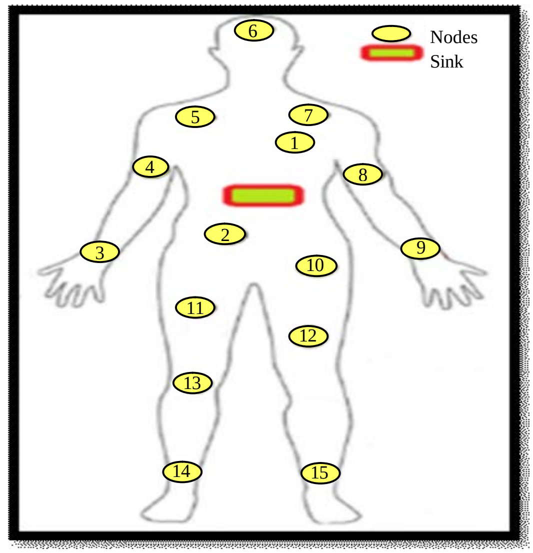

Fig. 4: Nodes deployment

Where:

Etx = Energy required to transmission operation
Erx = The energy spent by receiver
Etx-elec and Erx-elec = The energies necessary to run the electronic circuit of transmitter and receiver, separately
Eamp = Energy necessary for amplifier circuit
k = The packet size

In WBANs the communication medium is body of human which provides diminution to radio signal. So, we consider path loss coefficient factor (n) in the radio model. Therefore, Eq. 5 transmitter must modified as following Eq. 6:

$$ETx(k, d) = Eelec*k+Eamp*n*k*dn \quad (6)$$

Figure 4 shows assignment of sensor nodes and sink on the human.

Network forming phase: In this segment, three different types of tasks are performed: first task coordinator node broadcast control packet to all other nodes this packet contain sink coordinate on the human body. When neighbours nodes receiving control packet from the base station, each one update their routing table by coordinates of the sink position. Then, information packets broadcasts from all sensor nodes which contains node (ID), node energy level and node coordinates on the human body. By this way each node is organized with its neighbours where every node update their routing table with the coordinates of neighbours nodes and with the base station.

Forwarder node election phase: We provide in this phase the selection constraints for a sensor to become as a cluster head (forwarder or parent node), depended on the fuzzy logic in order to balance energy consumption among sensor nodes and improve network life time. In every round, nodes ID, residual energy level and distance to base station are stores in the sink, depended on this information, sink computes the Fuzzy_Cost of all nodes (by using fuzzy inference system) in each round and sent those Fuzzy_Cost to each one. The decision of election a forwarder node is done by always select the node with minimum Fuzzy_Cost. The selection of cluster head done based on the fuzzy logic theory with three parameters (energy level, distance to sink and Received Signal Strength Indicator (RSSI)) as inputs to fuzzy inference system. The received signal strength indicator based on the fact that the strength of transmitted radio signal reductions with the distance. In the same mean, the path loss is the reduction of any signal travelling over a route between two nodes, so, depended on path loss and transmits signal strength, we can find RSSI value. The mathematical model of the path loss can be designed based on the following Eq. 7 (Smolau, 2009):

$$PL(d) = PL(d0)+10n\log(d/d0) \quad (7)$$

Where:

PL(d) = Path loss function on the basis of distance factor in decibels

PL(d0) = Path loss over the reference distance factor close to transmitter

n = Loss exponent which known as a rate at which the loss growths with the distance

The distance between any node and sink is calculated using the following function (De-Carvalho, 2015):

$$Distance_{(Sink, Node)} = \sqrt{(X_S-X_n)^2+(Y_S-Yn)^2} \quad (8)$$

Where:

X_{sink} and X_{node} = The points of sink and any sensors on the X axis

Y_{sink} and Y_{node} = The points of sink and any sensors on the Y axis

We used FL approach presented by Zadeh (1965) to select a CH node. In proposed scheme fuzzy structure has three main parts: fuzzification parameters, a fuzzy inference system (with 27 fuzzy rules) and a defuzzification segment. The architecture of FL system shows in Fig. 5 (MathWorks, 2017).

In our fuzzy inference system, 3 membership functions (triangular, trapezoidal) used to exchange input

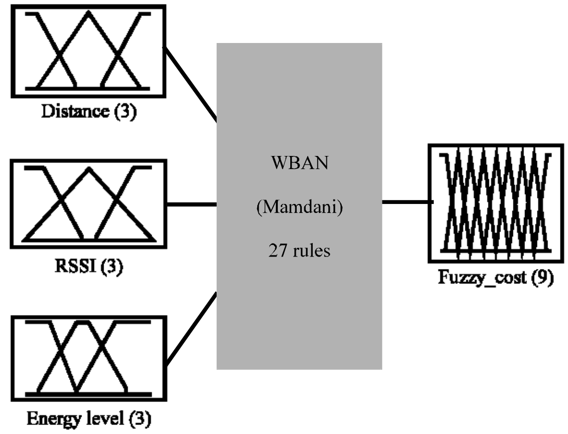

Fig. 5: Fuzzy Inference System (FIS)

Table 1: Input parameters with its membership function

Inputs	Membership function		
Distance to sink	Close	Average	Remote
RSSI	Weak	Medium	Strong
Energy level	Little	Average	High

Table 2: Output functions with its membership

Output	Membership
Fuzzy_Cost	Quite weak, weak, few weak, lower middle, middle, higher middle, few sturdy, sturdy, very sturdy

variables (energy level, RSSI and distance to sink) into fuzzy sets. Each of this parameters has 3 input membership functions, Table 1 shows diverse degree of the input functions.

The output function (Fuzzy_Cost) include nine membership functions. Table 2 shows the Fuzzy_Cost membership functions. The set of fuzzy rules applied in Fuzzy Inference Engine (FIE) to come up with output fuzzy scores. Where the knowledge base used in our model contain (27) rules for the FIE. The form of this fuzzy rules is: if X1 is A and X2 is B and X3 is C then Y is D. Table 3 shows the fuzzy rules.

We apply Center of Gravity (COG) scheme as a defuzzification process after evaluate the fuzzy rules in the fuzzy inference engine. The center of gravity Eq. 9 used as following:

$$COG = \int X\mu_A(X)dx / \int \mu_A(X)dx \quad (9)$$

where, $\mu_A(X)$ is membership function of set A. After defuzzification step, we obtain the crisp value which represent a Fuzzy_Cost for each sensor nodes. Then compare all node's Fuzzy_Cost to select the node with minimum Fuzzy_Cost as a cluster head in each round. In this technique all the children sensors with its parent node (CH) are formed in each round. Then children

Table 3: Fuzzy rules

Energy levels	RSSI	Distance	Fuzzy Cost
Little	Weak	Remote	Quite weak
Little	Weak	Average	Weak
Little	Weak	Close	Few weak
Little	Medium	Remote	Weak
Little	Medium	Average	Few weak
Little	Medium	Close	Lower middle
Little	Weak	Remote	Few weak
Little	Weak	Average	Lower middle
Little	Weak	Close	Middle
Average	Weak	Remote	Few weak
Average	Weak	Average	Lower middle
Average	Weak	Close	Middle
Average	Medium	Remote	Lower middle
Average	Medium	Average	Middle
Average	Medium	Close	Higher middle
Average	Weak	Remote	Middle
Average	Weak	Average	Higher middle
Average	Weak	Close	Few sturdy
High	Weak	Remote	Middle
High	Weak	Average	Higher middle
High	Weak	Close	Few sturdy
High	Medium	Remote	Higher middle
High	Medium	Average	Few sturdy
High	Medium	Close	Sturdy
High	Weak	Remote	Few sturdy
High	Weak	Average	Sturdy
High	Weak	Close	Very sturdy

sensors transmit their sensed data to the parent node (CH). Cluster head node aggregates data and transmit it to sink.

Scheduling assignment phase: In this phase, cluster head sensor (parent node) allocates Time Division Multiple Access (TDMA) to each children sensor nodes on the basis of time slots. TDMA approach refers to allocating certain time frame in dedicated time slots. Therefore, each children node transmit sensed data packets to cluster head in fast sequential sequence in its own devoted time slot. Due to TDMA based on synchronization factor, therefore, any sensor node has no sensed data to transmit, it will exchange to sleep mode but when it has sensed data to forward at its own time slot, it will exchange to wake up mode. So, sensors node scheduling approach completely decrease the energy consumption of each nodes because sensors transmit its data packets only in allocated time slots and all the other time nodes will be inactive state (sleep mode).

Routing election phase: Routing optimization is operation of select the best routing path from the source to destination, with consideration of energy minimization, load distribution policy and network performance maximization, so, there are different optimization techniques used for these purpose in WBANs such as Genetic Algorithm (GA), Ant-Colony Optimization (ASO), Particle Swarm Optimization (PSO)

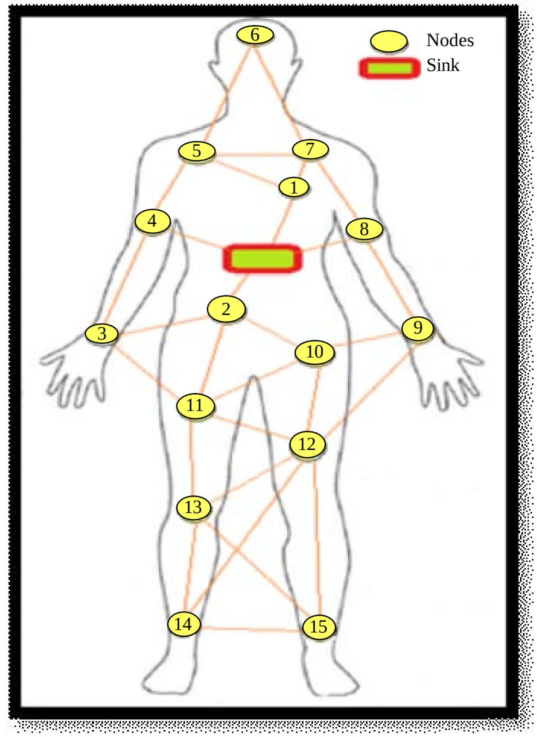

Fig. 6: Different possible routes to sink

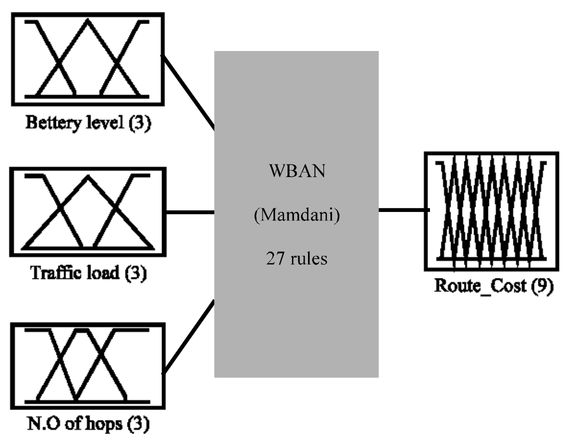

Fig. 7: Fuzzy inference system (FIS)

and other. In this research, we consider Fuzzy Logic (FL) concept to selection the best route from different passible routs between the sender sensor node and the receiver sink as show that in Fig. 6.

Sensors node calculate Route_Cost for each passible route to sink based on the fuzzy inference system with three inputs parameters (local battery level, traffic load and number of hops). We considered these three variables because it have greater effect on amount of energy consuming to send a message toward the sink. The architecture of FL system shows in Fig. 7 (MathWorks, 2017).

In this phase, we also use three input functions to converts the system inputs parameters to fuzzy sets as shows that in Table 4. The output function (Route_Cost) consisted from nine membership functions. Table 5 shows the output functions with its membership functions.

The fuzzy inference engine have knowledge base include 27 rules. The form of the rules is IF X1 is A and X2 is B and X3 is C then Y is D. Table 6 shows the fuzzy rules. After applied the set of rules in fuzzy inference engine, we also used Center of Gravity (COG) scheme Eq. 9 as a defuzzification process. After defuzzification phase we get the crisp value which represent as a Route_Cost for each available routes from the sender node to receiver node (sink). Then compare all route's Route_Cost to select the route with minimum Route_Cost as a best routing path, thus, minimize the energy consumption.

Table 4: Input parameters with its membership function

Inputs	-------------Membership function	-------------	
Local battery level	Little	Average	High
Traffic load	Low	Middle	High
Number of hops	Few	Middle	Large

Table 5: Output functions

Output	Membership
Route_Cost	Quite weak, weak, few weak, lower middle, middle, higher middle few sturdy, sturdy, very sturdy

Table 6: Fuzzy engine rules

Local battery level	Traffic load	Number of hops	Route_Cost
Little	Low	Large	Quite weak
Little	Low	Middle	Weak
Little	Low	Few	Few weak
Little	Middle	Large	Weak
Little	Middle	Middle	Few weak
Little	Middle	Few	Lower middle
Little	Low	Large	Few weak
Little	Low	Middle	Lower middle
Little	Low	Few	Middle
Average	Low	Large	Few weak
Average	Low	Middle	Lower middle
Average	Low	Few	Middle
Average	Middle	Large	Lower middle
Average	Middle	Middle	Middle
Average	Middle	Few	Higher middle
Average	Low	Large	Middle
Average	Low	Middle	Higher middle
Average	Low	Few	Few sturdy
High	Low	Large	Middle
High	Low	Middle	Higher middle
High	Low	Few	Few sturdy
High	Middle	Large	Higher middle
High	Middle	Middle	Few sturdy
High	Middle	Few	Sturdy
High	Low	Large	Few sturdy
High	Low	Middle	Sturdy
High	Low	Few	Very sturdy

RESULTS AND DISCUSSION

Simulation and results analysis: In this study, we evaluated and analysis the performance of WBAN with the proposed algorithm by implemented an extensive set of experiments using MATLAB (R2009a) simulator. Experiments consists from five session for each one (8000) round. We analysis the performance of the suggested algorithm by compare it's results with the m-Attempt (Javaid *et al*., 2013) routing protocol results. The simulation parameters with their values are shown in following Table 7. The performance metrics of the offered algorithm has been measured depended on the following metrics.

Network life time: Network life time denotes the total network process time until the final node dies. Figure 8 shows the comparison of m-Attempt vs. offered protocol according to number of sensor nodes died. As result show the network lifetime of our approach is greater by 40% with stability period 35% more than other protocol and again sharp decrease in the value during last iterations represents larger stability region. Also all sensor nodes of m-Attempt protocol are died very earlier as compared to suggested protocol. So, the network is better load balanced as compared with m-Attempt.

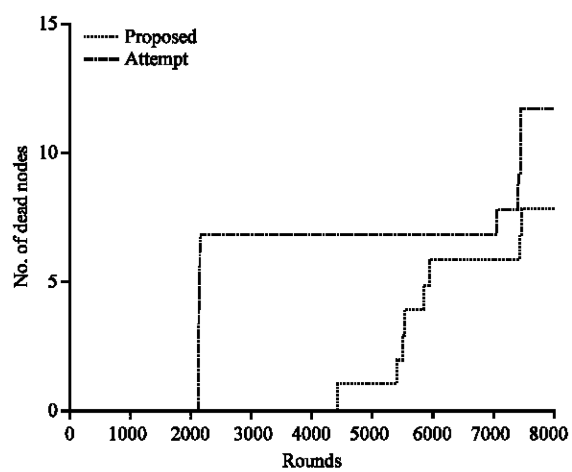

Fig. 8: Analysis of network lifetime

Table 7: Simulation parameters

Parameters	Values
Number of sensor nodes	15
Simulation area	100,100 cm
Initial energy	0.5 J
Packet size	4000 bits
Received Energy ($E_{rx\text{-}elec}$)	36.1 nJ/bit
Transmitted Energy ($E_{tx\text{-}elec}$)	16.7 nJ/bit
Amplification Energy (E_{amp})	1.97 J/b

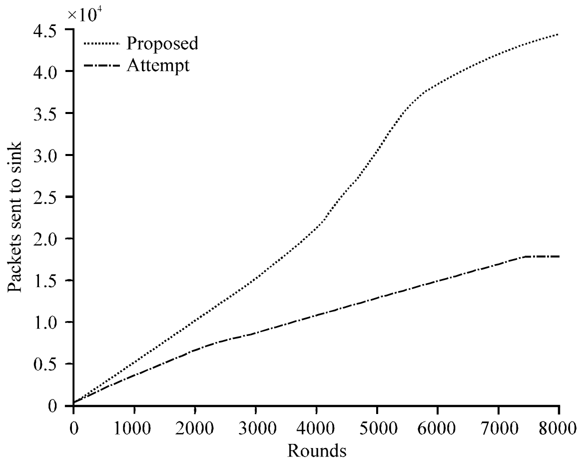

Fig. 9: Throughput analysis

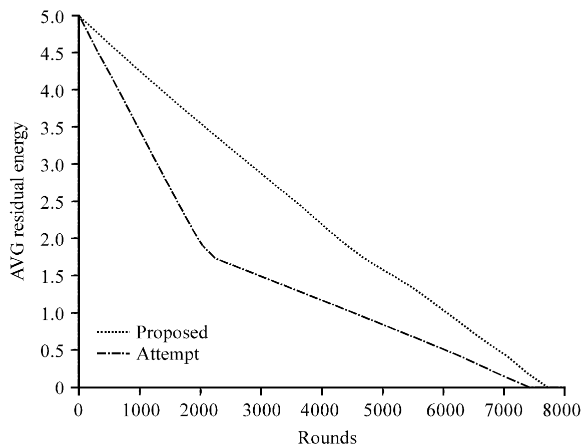

Fig. 10: Analysis of remaining energy

Throughput: It denotes the maximum number of data packets which successfully received at the base station. We can easy see in the Fig. 9 that throughput of the offered method enhance by 42% more than m-Attempt network throughput. It is clear that our algorithm have more numbers of data packets successfully received at the sink when comparison result with m-Attempt protocol. Where increases number of alive sensor nodes and reduce network path loss will provide more data packets transmission to the base station that means extra number of alive sensor nodes send extra number of data packets to the base station that lead to growth network throughput.

Residual energy: In every execution periods of the suggested model, the energy consumption in our system enhancement more than 33% over energy used in the m-Attempt protocol, until the final life time of the formed sensors network that lead to maximize network life time. Figure 10 shows the comparison of m-Attempt

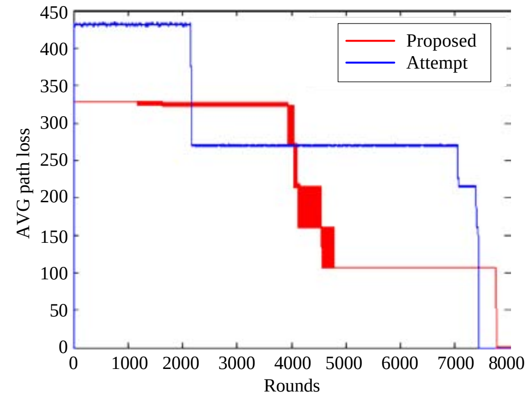

Fig. 11: Network path loss

vs. suggested algorithm according to average network residual energy which consumed in each round. Also, the decreasing of energy consumption in the suggested model for WBANs, due to selected optimal route and elects better cluster head in each round of operations. So, for all previous reasons, the life time of the WBAN is prolong.

Path loss: It refers to the reduction in energy density, so it denotes the difference between the transmitted energy of sending node and received energy at reception node, computed in DeciBels (dB). Path loss is a function of relation between the frequency and the distance to base station. Figure 11 offers the comparison of path loss parameter for diverse sensors between suggested algorithm and m-Attempt algorithm. Figure 11 shows the path loss decrease in the suggested model as a result to used multi_hop topology and selection the optimal routing path in every transmitted operation.

CONCLUSION

In this research, we offered an energy effective clustering routing protocol for wireless body area networks on the basis of fuzzy logic system. Our algorithm take into consideration more information from the present statue of sensors (such as: the remaining energy of nodes, the distance among sensor nodes with base station and the received signal strength indicator) to select the optimal forwarder nodes in each round. Also, it present the optimization routing scheme based on the fuzzy system with effective variables (local battery level, traffic load and number of hops) to select the best routing path to the sink. The offered algorithm guarantees to form balance the energy consumption over the WBANs. Simulation results shows that offered fuzzy-based energy effective clustering routing protocol for WBANs with stationary sensor nodes and fixed sink, improved the network life time more than 40% with stability period more than 35% by reduce number of lost nodes, enhancement energy consumption more than 33% and growth number of successfully transmitted packets (network throughput) more than 42% by reduce network path loss.

RECOMMENDATIONS

In the future, we plan to extend proposed scheme for routing in the networks with mobile sensor nodes and mobile sink.

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