Design and Implement Energy Efficient Routing Protocol for Wireless Body Area Networks (WBANs) by Using Fuzzy Logic

1Fadhil Mohammad Salman and 2Hussein Lafta Atia
1Department of Software, College of Information Technology, University of Babylon, Hillah, Iraq
2Department of Computer Science, College of Sciences, University of Babylon, Hillah, Iraq

Abstract: A Wireless Body Area Network (WBAN) in recent years emerged as the most demanding research area from the existing WSN technology. It comprises from number of tiny devices (sensors) which attach internal or external of human body these sensors has ability to sensing various vital signs such as blood pressure, body temperature, ECG, etc. These sensors also have ability to communication among themselves through inbuilt radio interface which enables them to communicate wirelessly, so, data transfer between them and with special node called the sink or Base Station (BS). When the WBANs consists from battery devices, so, the important challenge that arises in these networks is the battery power consumption where it is very hard and not possible to discharge these batteries from the human body parts in order to charging them at times, so, many techniques are developed to prolonged the network throughput and its life time. Clustering is important efficient techniques using to decreasing nodes energy consumption. In clustering scheme, adjacent nodes are organized into effective groups called (Clusters) then one node from each group is selected to represent as a cluster head and the rest represents as cluster members. This research involves new energy-efficient adaptive clustering protocol based on fuzzy logic concept to efficiently maximize the network life time and to improve the stable period of WBANs. So, we utilize multi-hop scheme, TDMA to avoid data packets collisions at the sink and clustering using fuzzy logic to select a candidate cluster head nodes based on three important variables (residual energy, distance to sink and RSSI). Our simulation results in MATLAB (2009a) simulator shows that network life time with stability period of the suggested algorithm improved by 30, 31%, respectively, more than existing clusters algorithms.

Key words: WBAN, clustering, fuzzy logic, MATLAB, TDMA, multi-hop, RSSI

INTRODUCTION

Wireless Body Area Networks (WBANs) are important class from wireless sensor networks (WSNs) which supports remote observing of different sensors in several environments. Its arisen as a most important techniques to make available real time health monitoring for the human and avoid many diseases which threatening human life based on initial diagnose. WBANs comprises from number of tiny biosensors intelligent devices placed in or around the human body these devices has capability to wireless connected between them, establishing communication network in order to observer various vital signs such as body temperature, blood pressure, heartbeat, etc.

There are two main kinds from WBAN nodes: sensor nodes and actuator nodes. Sensor nodes are used to quantity vital signs (Ex.: human body temperature, heartbeat, Electrocardiogram (ECG), etc.) of the human body, so, attached either internally or externally to the body. The second type called an actuator nodes (or base station) which run some special operations based on the receiving data from the other sensor nodes or by interacted with the users. The interaction with the persons or other users is typically controlled by a personal devices (Ex.: smart phone, PDA) these devices represents as a sink for transmitted data packets of the wireless nodes (Abina et al., 2009).

Technologies from wireless sensor networks or ad-hoc networks could be used for realized communication among these devices. The proposed protocols for WSNs are not always well be suitable to support a WBANs because of its difficult properties. Same explains about variations between a WSNs and a WBANs are shows in the following (Latre et al., 2011):

- The biosensors nodes has limited battery’s power as an energy resources (often <1 cm³). Where it is very hard and not possible to discharge these batteries from the human body parts in order to charging them at times. Therefore, memory available and consequently the computational power and energy resources for these devices will be limited.

Corresponding Author: Fadhil Mohammad Salman, Department of Software, College of Information Technology, University of Babylon, Hillah, Iraq
• Every nodes are similarly important and new nodes (or redundant nodes) are available only when we are needed it for more operations.
• A very low-cost transfer energy per nodes is necessary to reduce the interference and deal with health worries.
• A very loss medium always needed to propagation the waves which takes place in or on the human body in order to the waves are not weakened greatly before the data access to the base station.
• Motion sensor nodes also can be used to sensing data by placed it on the body of human. Therefore, WBANs are very strong to deal with repeated variations in the network topology.
• Greater reliability and low latency are always needed in WBANs to transfer medical information.
• Robust security tools are always needed to ensure the robustly private transmitting to medical data.
• The heterogeneous nodes are often used which may have variant operations with diverse resources from the network in terms of reliability data rates, power consumption and confidentiality.

When a WBAN comprises from tiny sensor nodes, which has limited power resources, therefore, it is very important to decreasing energy consumption in order to increasing the network throughput and life time. Throughput increases be by sending more data packets to the base station. There are various type of energy effective routing protocols are designed to increasing the network life time (Ragesh and Baskaran, 2012). In this research, we suggest a clustering based fuzzy logic routing algorithm which developed by placed eight sensor nodes with the sink at fixed places on the human body. Two sensors transmitted sensing data direct to base station because they have important data and all the remaining sensors well forward packets data to the base station through the cluster head (forwarder). In our algorithm parent node or forwarder is electing in each round based on the fuzzy logic concept with three parameters (residual energy, distance to sink and received signal strength indicator) as inputs variables to fuzzy inference system. We also utilized a Time Division Multiple Access (TDMA) to scheduling transmission of sensor nodes to the cluster head that led to reduce data packets collisions at the base station. Results obtained after simulation by used MATLAB (2009a) simulator shows that a suitably of fuzzy cluster head election for extremely decreasing the energy consumption and improve the life time of the network.

**Literature review:** Sharma et al. (2015) suggested routing protocol based on clustering scheme to improve LEACH protocol of WSNs. The proposed clustering algorithm deployed eight sensor nodes on the body of human at fixed places. After simulation results was compared with the M-ATTEMPT clustering algorithm which using for wireless body area network, so, it shows that suggested algorithm provides best results than that M-ATTEMPT results in terms of improved throughput with network stability (Sharma et al., 2015).

A novel reliable and energy-efficient with greater throughput routing protocol for the Wireless Body Area Network (WBAN) was suggested by Nadeem et al. (2013) they are used a multi-hop scheme to obtain lowest energy consumption and extended the life time of networks. They are developed a cost function for forwarder node election. After simulation based on MATLAB, results shows that suggested algorithm decreasing energy consuming and increasing the network living period (Nadeem et al., 2013).

The performance of hybrid routing protocol for the WBANs was analysed by Sharma and Kumar (2012) when they are suggested a homogeneous energy routing algorithm F-MCHIEL 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 choose 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).

Ran et al. (2010) development the LEACH algorithm based on fuzzy logic concept (LEACH-FL). Fuzzy system utilize distance, energy level and nodes intensity as inputs to FIS. After simulation based on MATLAB simulator, results shows that the suggested approach improve the power consumption (Ran et al., 2010).

A new method was proposed by Nagar (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 let to increasing the network life time and improves the stability period of the network and more packets sent to the base station compared with star topology idea (Naggar, 2015).
MATERIALS AND METHODS

Theory of the work

Fuzzy logic: Fuzzy set theory is the seed of fuzzy logic concept it was offered by Zadeh (1965). He was contributed to improvement the fuzzy logic theories, where he developed a mathematical representation to the ambiguity and imprecision information based on formalized logical tools for coping with the vagueness existing in several real world problems. The main idea can be defined mathematically by assigning to each individual in the Universe of Discourse (UOD) a value represented its degree of membership in the fuzzy set (Lafla and Salman, 2014). So, many features for fuzzy system are outlined by Zadeh (1965), some of it given as follows:

- Each individual in the world have grade of membership
- Precision causes in the fact consist from partials cases of approximate causes
- Inference presented as an operation of spread of elastic constrictions
- Knowledge represented as a group of elastic, fuzzy constrictions on a group of variables
- In the real world all the logical system can be "Fuzzified". Fuzzy Inference System (FIS) contains four major phases

Fuzzification phase, knowledge base (comprise from two phase database and rule base), decision-making phase (Inference engine) and finally the defuzzification phase. A fuzzy inference system with its four phases blocks shows in Fig. 1.

The proposed fuzzy-clustering algorithm details: We present in this unit a suggested routing algorithm for wireless body area networks. Where the little numbers of sensor nodes in wireless body area networks gives large chance to relax constraints in suggest routing algorithm. The major objective of the suggest protocol is balancing the energy consumption between network nodes and increasing the network life time this achieved by using fuzzy logic concept to elect the cluster head. Next subsections give more details about the proposed model with its flowchart (Fig. 2).

Built a WBAN: In this research, we assign eight sensor nodes on the body of human at suitable places and put the base station on the waist of its body. All these nodes with the base station are heterogeneous and be fixed after deployment on the body that means all these sensor nodes have equal power and computation capabilities.

Node (1) represent (ECG) sensor and node (2) represent (Glucose) sensor these two nodes have very important

Fig. 1: Fuzzy inference system phases

Fig. 2: Suggested method flowchart
sensing data which must transmitted to the sink directly. We utilize in this research, the first order radio model (Mitra and Naskar, 2011). In this model, d symbol consider the separation between transmitter node and receiver node while d2 represented the cost of energy in the channel during the transmission operation. Details of first order model are given as follows (Mitra and Naskar, 2011):

$$ETx(k, d) = ETx-elec(k) + ETx-amp(k, d)$$

(1)

$$ETx(k, d) = ETx-elec<k + Eamp<k \times d2$$

(2)

$$ERx(k) = ERx-elec<k \times ERx(k) + ERx-elec<k$$

(3)

$$ERx(k) = ERx-elec<k$$

(4)

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
- $k$ = Symbol refers to 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. 4 transmitter must modified as following Eq. 5:

$$ETx(k, d) = Eelec<k + Eamp<n \times k \times d2$$

(5)

Figure 3 shows placement of sensor nodes and sink on the human body.

**Cluster head selection phase:** We present in this level the selection measures for a node to become forwarder (or parent node) on the basis of fuzzy-cost in each round also using multi-hop scheme for WBAN in order to balance the energy consumption among sensor nodes and enhance network throughput. In each epoch, the node (ID), residual energy state and distance to sink for all circumference nodes are stores in the base station, based on these information, base station calculates the fuzzy-cost of all nodes and forward this fuzzy-cost to each one. Based on fuzzy-cost of each node, the decision of which node must be select to become forwarder node is done. The selection of cluster head done based on fuzzy logic concept with three parameters (Residual Energy, Distance to Sink and Received Signal Strength Indicator (RSSI)) used as inputs to fuzzy inference system. The received signal strength indicator depended on the fact that the strength of transmitted radio signal decreases with the distance. In the same mean, the path loss is the diminution of any signal travelling over a route between two nodes, so, depended on path loss and transmits signal strength we find RSSI value. The mathematical model for path loss can be calculated using Eq. 6 (Bouayad et al., 2014):
Fig. 4: Fuzzy system architecture

\[ PL(d) = PL(d_0) + 10 \log \left( \frac{d}{d_0} \right) \]  

Where:

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

\( PL(d_0) \) = Path loss over the reference distance factor close to transmitter

\( n \) = Loss exponent which known as a rate at which the loss grows with the distance

The distance between any node and sink is calculated using the following function (Eq. 7) (Naggar, 2015):

\[ \text{Distance}_{(\text{Sink, Node})} = \sqrt{(X_s - X_n)^2 + (Y_s - Y_n)^2} \]  

Where:

\( X_s \) and \( X_n \) = The points of sink and any sensors node on the x-axis

\( Y_s \) and \( Y_n \) = The points of sink and any sensors node on the y-axis

We used the fuzzy logic concept suggested by Zadeh (1965) to elect a forwarder node. In offerd scheme fuzzy structure has three main parts: fuzzification inputs, a fuzzy inference system phase (using 27 fuzzy rules) and a defuzzification phase. The architecture of fuzzy logic system shows in Fig. 4.

In our fuzzy algorithm, three membership functions (triangular, trapezoidal) are used to convert input parameters (distance to sink, RSSI and energy level) into fuzzy sets. Each one of this parameters has three input membership functions. Table 1 displays different degree of the input functions.

The output function composed from 9 membership functions. Table 2 shows the output functions. Fuzzy inference system requires the set of rules applied to come up with output fuzzy scores, So, the knowledge base used in our system include 27 rules for the fuzzy inference engine. 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 utilize Centre of Gravity (COG) scheme as a defuzzification process after evaluated the rules in fuzzy inference system. COG function shows as following (Eq. 8) (Naggar, 2015):

\[ \text{Output} = \int X \mu_A(X) dx / \int \mu_A(X) dx \]  

where, \( \mu_A(X) \) is membership function of set A. After runs defuzzification phase we get the crisp value which represent as fuzzy cost for each sensors node. Then any sensor node which have minimum fuzzy cost chosen as a cluster head. In this way all the children sensor nodes with its parent node are formed, then nodes transmit their data to cluster head. Parent node aggregates data and transmit it to base station.
Scheduling assignment phase: In this study, parent sensor (forwarder node) distributes Time Division Multiple Access (TDMA) to each children nodes depended on the time slots.

TDMA principle involve allocating time frame in devoted time slots. So, each children sensor forward sensed data packets to parent node in fast sequential sequence in its own dedicated time slot. When TDMA depended on synchronization factor, so, any sensor has no sensed data to forward, it will switch to sleep mode but when it has sensed data to send at its own transmission time, it will switch to wake up mode. Therefore, sensors node scheduling scheme absolutely reduce the energy consumption of each sensor node because nodes send its packets only in assigned time slots and all the other time nodes will be inactive state.

RESULTS AND DISCUSSION

In this chapter, we evaluate and analyse the performance of suggested model by consider an extensive set of experiments using MATLAB (R2009a) as a simulator. Experiments involves four session for each one (8000) round. We analysis the performance of the suggested algorithm by compare it’s results with the M-ATTEMPT routing protocol results. The simulation parameters with their values are shown in Table 4.

The performance metrics of the proposed algorithm has been measured depended on the following parameters.

Network life time: Network life time represents the total network process time until the final node dies. Figure 5 shows the comparison of M-ATTEMPT vs proposed protocol according to number of nodes died. As can be seen the life time for our given approach more better than other and again sharp decrease in the value during last iterations represents larger stability region. Also all sensor nodes of M-ATTEMPT algorithm are died very earlier as compared with the proposed protocol So, the network is better load balanced as compared with M-ATTEMPT.

Throughput: It represents the maximum number of data packets successfully received at the sink. We can see in Fig. 6, the throughput of our suggested model is better 40% more than M-ATTEMPT network throughput. It is clear that our algorithm produce more numbers of data packets received at the base station when compared with M-ATTEMPT algorithm. Where increases number of alive nodes will produce more data packets transfer to the base station. That means extra number of alive sensor nodes send extra number of data packets to the base station that led to network throughput growth.

Residual energy: In all implementation periods of our algorithm, the energy consumption in our system is fewer than energy used in the M-ATTEMPT protocol that cause increases network life time of our algorithm. Figure 7 shows the comparison of M-ATTEMPT vs. proposed model according to average energy of network consumed in each round. Simulation results show that
residuals energy of our suggested system in each round of execution improved more than 30% remaining energy of M-ATTEMPT protocol after implementation, until the final life time of the formed sensors network, so, energy consumption decreasing in every periods of execution to the suggested scheme when compared it with the M-ATTEMPT protocol energy consumption.

Path loss: It’s the attenuation in energy density, so, it represents the variance between the transmitted energy of sending node and received energy at reception node, calculated in decibels (dB). Path loss is a function of frequency and distance to sink. Figure 8 shows the path loss reduction in the proposed algorithm decreasing 35% more than that resulted with the M-ATTEMPT protocol.

CONCLUSION

In this study, we offered an energy effective routing protocol for WBANs depended on fuzzy logic concept. The model takes into account more information from the present state of sensor nodes (like the remaining energy level of each node, the distance between nodes and sink and the RSSI) to select the best cluster heads in each round. So, our simulation results shows that the percentage of network life time improvement is more than 30% with stability period more than 31% by reduce number of died nodes and enhancement network throughput is more than 40% by reduce network path loss >35%, after compare our results with the M-ATTEMPT protocol results. The results also proved that using fuzzy logic concept can produces an appropriate direction for development effective solutions to many related power effective and network live time problems in WBANs and WSNs.

REFERENCES


