Journal of Engineering and Applied Sciences 12 (23): 7201-7207, 2017
ISSN: 1816-949X

FEELP: Fuzzy-Based Energy-Efficient LEACH Protocol in Wireless Sensor Networks

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Abstract: Wireless Sensor Networks (WSNs) brings a great solution for most of the areas where the infrastructure is not accessible. This motivates the improvement on WSNs and increases the necessity of such networks. The most annoying factor of WSN is that mostly the network is placed in some hostile area and it cannot be able to replace the battery of the nodes. Such problems introduce the need of energy-efficient protocol to extend the lifetime of the network. The group of nodes are formed as clusters and controlled by Cluster Head (CH). The election of CH is a tedious process which gives a lifetime opportunity to the entire network. The Low Energy Adaptive Cluster Hierarchy (LEACH) protocol follows the election using the threshold function. In this model, the threshold function of LEACH is modified to elect a better and high performing CH to extent the network lifetime using residual energy, distance to Base Station (BS) and threshold energy of a node. The node which gets the higher value among the other member nodes is elected as CH. This model also introduces a novel idea to elect Super CH (SCH) among the elected CH which will receive the information from other CH's and forwards it BS. The aggregation will also be done at SCH. The Fuzzy Logic (FL) is been introduced in this approach to elect SCH. The proposed scheme is verified with the latest existing models. The simulation results show that the proposed model performs better than the existing models in terms of average energy, average distance to BS and other empirical metrics.

Key words: Cluster formation, energy-efficiency, LEACH protocol, super cluster head, wireless sensor networks, SCH

INTRODUCTION

WSNs is an emerging area for research in recent years as of the vast growth of new applications. Some of the attractive areas where WSNs is concentrating are military surveillance industrial automation tools, healthcare, natural disaster monitoring, etc. It consists of large number of sensor nodes grouped together to collect the information from the location where it is actually deployed. The collected information is forwarded to the sink or Base Station (BS) for further processes. Sensor nodes are tiny nodes which consists of limited battery power utilised to sense and forwarding the information. As the nodes cannot be recharged and it is actually deployed in an area where the humans are not able to move the need for effective routing protocols is increased. Routing doesnot only involve of identifying routing path, it is also responsible for the improvement of reducing the energy consumption of a node. Energy-efficient routing protocols will obviously increase the performance of a network.

Routing in WSN is not an easy task as of in ad-hoc networks, WSN needs a highly improvised routing methodologies not only comprising the path selection but also includes data aggregation. Aggregation of data is the vital area where the energy efficiency to be improved. For WSNs, address identification, updation and bandwidth transmission is not accessible as it not possible to apply Internet Protocol (IP). As the nodes are dynamic in range and it cannot possible to make a static network the assignment of IP is worthless (Stankovic, 2006).

Sensor nodes are of a tiny particle which senses the information from the location and forwards it to the other nodes to reach the sink which is the final destination of the network. As these nodes are dynamic, it is not at all possible to follow static path. These obstacles clear the need for effective routing protocols for WSNs. Yet, the routing protocols have to concentrate on identifying nodes, sending, receiving and aggregating the data and updating the node's information because the above processes where need battery power to process. Thus, the routing protocol have to aware of developing energy-efficient routing protocols. Some of the common key issues of routing are reliability, mobility, congestion and security. Communication between the nodes in a secured way improves the reliability of the network. The connectivity between the nodes are the pathway to transfer the data between the source and destination such

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connectivity improves the reliability of the network. The data communication between the two edges are reliable in WSN, mostly where the data reaches its destination in the given time slot. This reduces the loss of packet and improves packet delivery ratio. Likewise, some of the security issues such as black hole, denial of service, etc., are to be concentrated for the improvement of the lifetime of the network. Congestion may occur as of a single destination node. To reduce the congestion TDMA schedule is much helpful in allocating time series to each node for communication.

Some of the advantage of WSNs includes convenience, easy setup, less cost, etc. The convenience of WSNs is easy to setup in any environment. Due to the developments in WSNs, the production cost is low. This improves the usability of sensors in most of the applications. The developments in sensor applications drives the needs of security concerns. The development of applications reduces the cost making of sensors.

Some common terms used in WSNs are: sensor nodes, clusters, cluster heads, base station, end user. Sensor node is a node consists of a low-end processor, limited memory and battery. The sensor node is used to sense the data from the environment. Cluster are group of sensor nodes where used to collect the information from the nodes and forward to a node which is act as CH and CH forwards it to BS. Clusters mainly reduce the consumption of energy and conserves the communication bandwidth. This improves the scalability of the network. Base station is responsible for collecting the information from the nodes are forwards to the nearby station where the collected information is used for further processes. This also acts as a bridge to connect the node and end-user. End user is the user who uses the collected data for further works.

The WSNs utilise the battery power for all of it works thus, makes to concentrate in developing more energy-efficient based methodologies to reduce the power consumption of the network. Here, the proposed methodology "Feelp: Fuzzy-based energy-efficient LEACH protocol for WSNs" also tends to concentrate in energy-efficiency of the network by electing CH on the basis of which holds high energy in terms of residual energy, less distance to BS and threshold energy. The performance of the proposed scheme is verified with the latest existing methodologies using NS2 simulation.

Literature review: Most research are carried out in the energy-efficiency protocols in WSNs. The traditional LEACH protocol stands first in this area. Low-Energy Adaptive Clustering Hierarchy (LEACH) introduced by Heinzelman *et al.* (2000, 2002). This model introduces that the election of CH is based on the threshold function in Eq. 1:

$$T(n) = \begin{cases} \dfrac{p}{1\text{-}p\times\left(r \bmod\left(\dfrac{1}{p}\right)\right)} & \text{if } n \in G \\ 0 & \end{cases} \quad (1)$$

Where:
P = The percentage of CHs
r = The number of round
G = The fraction of nodes from 1/P round
n = The number of nodes

LEACH follows that all the nodes are given a threshold value which is obtained using Eq. 1 and each node is requested to choose a value between 0-1 in random. The node which holds lesser random value than the threshold value is elected as CH. The other nodes will act as member nodes to CH for this round. LEACH follows TDMA schedule to send the data to BS in a given period of time which reduces congestion between nodes. This process is continuous in each round.

Razaque *et al.* (2016a, b) introduce H-LEACH which concentrates in energy optimization in election of channel head. It also considers threshold function for election of head. The node which holds maximum residual energy is also considered for election and the node. The head node is chosen between the node holds higher threshold energy and the node considers maximum residual energy. This scheme performs better than LEACH and HEED protocol but still the election process spends more energy of a node which reduces lifetime of the network.

The proposed model collects information from the remote agriculture farms and sends the data to the base station using shortest path algorithm with modified LEACH protocol. This scheme is developed by Subramanian *et al.* (2015). This scheme comprises the features of LEACH protocol and identifies the destination using shortest path algorithm to reduce the consumption of energy of a node. The major flaw in this scheme is energy consumption. The improvement in effective network models will improve the performance of the network.

Energy of power consumption is the main area to be concentrate to increase lifetime of the network. Thus, the P-LEACH (PEGASIS-LEACH) optimal cluster-based chain protocol introduced by Razaque *et al.* (2016a, b) is widely concentrating by developing a novel algorithm to transfer data. This model combines both PEGASIS and LEACH protocol model and identifies a novel approach to reduce the consumption of energy which mainly consumes in sending the data over the network. This scheme introduces new dynamic data transfer model to transfer data between the nodes. Though this scheme improves the lifetime, it lacks in effective CH selection.

Pradhan and Sharma (2016) introduces a novel energy efficient CH selection and rotation mechanism to reduce the energy consumption and repeated cluster forming in each round. This can be obtained by transferring CH from a node to nearest node of the same cluster which can able to communicate all the member nodes based on the signal indicator process. The signal indication is stored in NODE packet which also consists of the node ID which is going to act as CH for next round. Thus, made the rotation of CH without forming the clusters in each round. This scheme reduces the FND (First Node Die) ratio compared to the existing schemes.

Power-Efficient and Fading-aware Clustering based on Cross-Layer (PEAFC-CL) techniques is proposed by Ren and Qian (2016). This model proposes a different sending power on different periods to improve the lifetime of the network using fade margin method. This protocol features on stable network topology and adaptability based on time-varying fading. This scheme increases packet delivery ratio. The implementation of channel fading on node deployment integration of heterogeneous network and QoS (Quality of Service) are the areas where to concentrate to improve the performance of the proposed scheme.

Lee *et al*. (2016) introduces a dual-hop layer: single-hop for short range and multi-hop for long range data transmission. The energy consumption on remote transmission is reduced and thus, increases the lifetime. This also reduces the transmission of data to a huge distance where the energy is wasted for aggregation after reaching a certain default hop-count. The short range transmission also reduces the aggregation process only once. This also increases the scalability of the network. The dual-hop performs better in energy-efficiency on transmission of data but this scheme is not concentrating in the election of CH and formation of clusters which reduce the performance of a network.

MATERIALS AND METHODS

The proposed methodology “Feelp: Fuzzy-based Energy-Efficient LEACH Protocol for WSNs” identifies the energy-efficiency of nodes by introducing the four novel ideas: residual energy of a node, distance to BS, threshold energy and fuzzy logic based technique in election of CH. These two metrics are highly recommended to identify the level of a node to act as CH. Here, level describes the nodes are positioned based metrics used. The levels are described in the coming section. The Residual energy of node is obtained using the Eq. 2:

$$Res_{egy} = \frac{E_{current}}{E_{max}} \tag{2}$$

Where:

Res_{egy} = The Residual energy of a node
$E_{current}$ = The current energy level of a node
E_{max} = The maximum energy of a node which is described at the initial stage of a network

The distance to BS is find through the Eq. 3:

$$Dst = 1\text{-}\frac{distance_{bs}}{distance_{far}} \tag{3}$$

Where:

Dst = The distance of a node
$distance_{bs}$ = The distance between the node and BS
$distance_{far}$ = Gives the farthest distance of the network

The threshold energy is the minimum requirement energy of a node to act as CH. A node needs an extra energy than, the all other nodes to act as CH. CH have to communicate to all other nodes of a cluster and it receives the data from the members, aggregates the data and forward it to the BS. To do so, the CH needs more energy than the member nodes. To maintain such level the threshold energy is to be calculated. Equation 4 gives the threshold energy:

$$Thres_{egy} = E_{init} \times \frac{\sum_{i=1}^{No} E_{current}}{No._{Total}} \tag{4}$$

Where:

$Thres_{egy}$ = The Threshold energy
E_{inint} = The initial energy of a node
$E_{current}$ = The current energy of node
No_{Total} = The total number of nodes

Equation 2-4 are added together to the LEACH’s probability function to find the best CH among the member nodes using Eq. 5:

$$T(n) = \left[\left[\frac{E_{current}}{E_{max}}\right] + \left[1\text{-}\frac{distance_{bs}}{distance_{far}}\right] + \left[E_{init} \times \frac{\sum_{i=1}^{No} E_{current}}{No_{Total}}\right]\right] \times \begin{cases} \dfrac{p}{1 - p \times \left(r \bmod \left(\dfrac{1}{p}\right)\right)} & \text{if } n \in G \\ 0 & \end{cases} \tag{5}$$

Here, the Eq. 5 is used to elects an energy efficient CH among the eligible nodes which can act as CH for that round. The proposed model not only follows a novel idea to elect the CH alone it also develops a new model to elect Super CH (SCH) which is going to receive the data from all of the CH's and forwards the received information to BS. This scheme reduces the energy consumption of CH's in transferring the data to BS from a faraway distance compared to a CH which is nearer to the BS. To improve the energy-efficiency to another level scale SCH is introduced. The election of SCH is proposed by using Fuzzy Logic (FL). It is a better way to handle the situations than using in a probabilistic model using FL (Nayak and Devulapalli, 2016). After the election of CH's using the Eq. 5 of the proposed scheme, the SCH will be find out using the fuzzy mamdani method, which is widely used. Fuzzifier, fuzzy inference engine, fuzzy rules and finally a defuzzifier are the common four modules to use FL. The input will be given in fuzzification, the inference engine takes care about the both fuzzification and fuzzy rule and gives defuzzification which is an output produced. The output is exactly a chance to act as SCH for our methodology. The block diagram of the FL is given in Fig 1.

The triangular member function is used in this methodology for evaluation of mamdani FL. Table 1 shows the membership functions (input).

Table 1: Membership functions (INPUT)

Residual energy	Distance to BS	Threshold energy
Low (0)	Faraway (0)	Less (0)
Medium (1)	Nearby (1)	Adequate (1)
High (2)	Close (2)	Vast (2)

Table 2: Fl rule evaluation

Residual energy	Distance to BS	Threshold energy	Fuzzy chance
Low (0)	Faraway (0)	Less (0)	Very weak (0)
Low (0)	Faraway (0)	Adequate (1)	Weak (1)
Low (0)	Faraway (0)	Vast (2)	Low moderate (2)
Low (0)	Nearby (1)	Less (0)	Weak (1)
Low (0)	Nearby (1)	Adequate (1)	Low moderate (2)
Low (0)	Nearby (1)	Vast (2)	Moderate (3)
Low (0)	Close (2)	Less (0)	Low moderate (2)
Low (0)	Close (2)	Adequate (1)	Moderate (3)
Low (0)	Close (2)	Vast (2)	High moderate (4)
Medium (1)	Faraway (0)	Less (0)	Weak (1)
Medium (1)	Faraway (0)	Adequate (1)	Low moderate (2)
Medium (1)	Faraway (0)	Vast (2)	Weak (1)
Medium (1)	Nearby (1)	Less (0)	Low moderate (2)
Medium (1)	Nearby (1)	Adequate (1)	Moderate (3)
Medium (1)	Nearby (1)	Vast (2)	Low moderate (2)
Medium (1)	Close (2)	Less (0)	Moderate (3)
Medium (1)	Close (2)	Adequate (1)	High moderate (4)
Medium (1)	Close (2)	Vast (2)	Durable (5)
High (2)	Faraway (0)	Less (0)	Low moderate (2)
High (2)	Faraway (0)	Adequate (1)	Weak (1)
High (2)	Faraway (0)	Vast (2)	Low moderate (2)
High (2)	Nearby (1)	Less (0)	Moderate (3)
High (2)	Nearby (1)	Adequate (1)	Low moderate (2)
High (2)	Nearby (1)	Vast (2)	Moderate (3)
High (2)	Close (2)	Less (0)	High moderate (4)
High (2)	Close (2)	Adequate (1)	Durable (5)
High (2)	Close (2)	Vast (2)	High durable (6)

Membership functions (Output):

- Very weak (0)
- Weak (1)
- Low moderate (2)
- Moderate (3)
- High moderate (4)
- Durable (5)
- High durable (6)

Table membership functions with input and output variables. Table 2 produces the chance obtained using FL. The FL chance is obtained using fuzzy rules. The proposed scheme follows 27 rules of fuzzy inference system to select SCH among the elected CH. The results are achieved using the Eq. 6:

$$Fuzzy_{chance} = Res_{egy}+Dst+Thres_{egy} \tag{6}$$

Where:

$Fuzzy_{chance}$ = The Fuzzy chance
Res_{egy} = The Residual energy
Dst = The Distance to BS
$Thres_{egy}$ = The Threshold energy

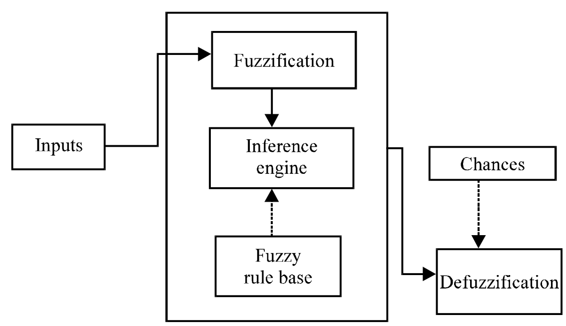

Fig. 1: Block diagram of fuzzy logic

For example, when is Low (0), Faraway (0) and is vast (2) then the holds low moderate (2) by adding:

$$Fuzzy_{chance} = 0+0+2$$

This chance gives a better result than the probabilistic model, the nodes elected as CH are put into the fuzzy inference system and receives it's chance to act as SCH in this round. The node which elects as SCH forwards the SCH election message to all CH's and asks them to forward the data to it. At last, the SCH aggregates the data once again with its own data and forward it to BS. By using the distance to BS as one of the membership function obviously, the node which holds a minimum time to reach BS gets a better chance to act as SCH (Chamam and Pierre, 2010).

RESULTS AND DISCUSSION

To verify the performance of the proposed model, the model is verified with the existing schemes EECF and EACHP (Barati *et al*., 2015). To validate, NS_2 simulator is used (Wei *et al*., 2011) with the metrics such as First Node Dies (FND), Last Node Dies (LND), average energy consumption, average distance to BS and Number of messages received. For this simulation, 100 nodes are randomly deployed within (100×100) area range. BS is deployed static in a position (50, 175) the node 100 is chosen as 100. The remaining nodes (0-99) acts as sensor nodes. Each round is calculated as 20's. The bandwidth is 1 Mbps, data message size is 500 bytes and packet header is 25 bytes long. The simulation is simulated for a period of 20000's and for easy understanding the results are calculated for 200's. the simulation is simulated more than 100 times to verify the effectiveness of the performance of the proposed scheme. Figure 2 shows the average energy consumption compared with the existing schemes EECF and EACHP.

Figure 2 shows that the proposed scheme Feelp holds a high average remaining energy compared to the existing models EECF and EACHP. The proposed model retains an average of 67% energy and existing models retains 39 and 54% by EECF and EACHP, respectively. Figure 3 proves the proposed scheme Feelp consumes less energy than the existing models.

Figure 4 shows the average distance to BS after the completion of 200 rounds. Based on the distance to BS parameter the average energy consumption is calculated. The proposed scheme performs a better than the existing schemes in less consumption of energy. Figure 4 shows the average shows the performance of proposed and existing schemes based on the centrality of CH.

Figure 4 shows the total number of messages received at BS. The Feelp performs well than the existing schemes as it holds a less energy consumption and less distance the life of a node increases and it maintains the scalability of the network. In other terms, Feelp also receives a high number of messages as the nodes are alive for a maximum period of time.

Figure 5 shows the average time taken by each scheme to get all the nodes alive. The time mentioned above is the exact time of first node dies in the network by losing it energy. The FND describes the strength of the network. The simulation results show that the proposed model performs better than the existing models in energy consumption of nodes by holding energy of all of its node for a longer period. Figure 6 shows the LND of the all three schemes. The total lifetime of the network is well established by this network. As of the results of the plots are calculated for 200 rounds, Fig. 6 is exempted as of it have to show the LND of a network. Here, EECF performs as of equal to another existing model EACHP, Feelp records high performance as it elects a better CH using modified threshold function and electing SCH.

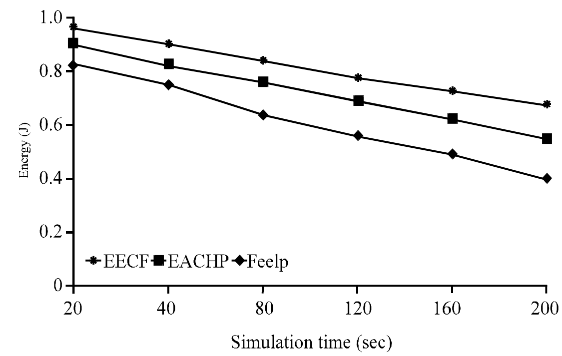

Fig. 2: Average energy consumption

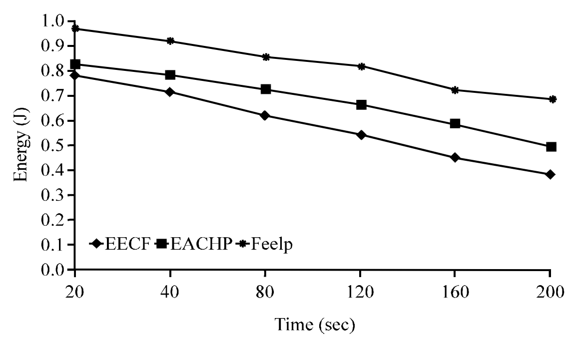

Fig. 3: Average energy consumption impact of distance to BS parameter

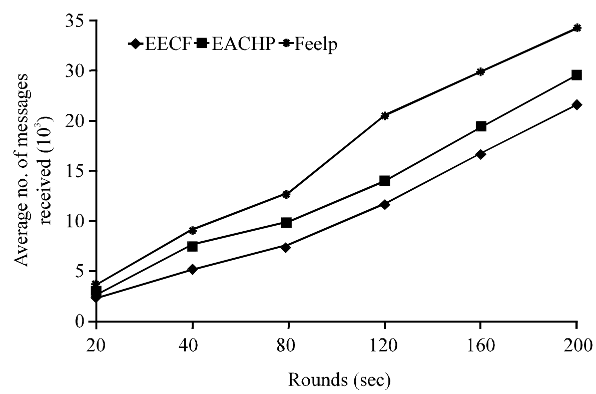

Fig. 4: Average centrality of CH

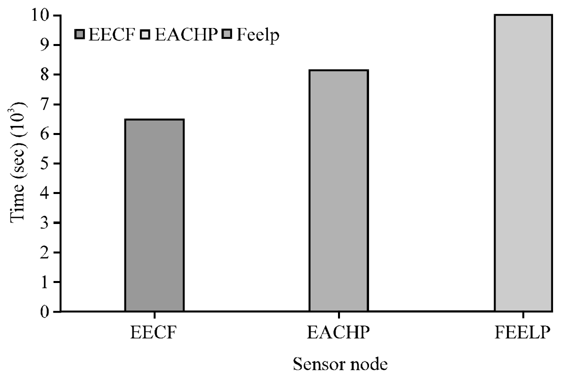

Fig. 5: First node dies

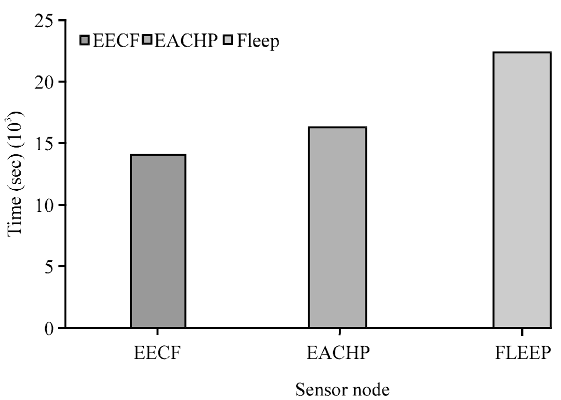

Fig. 6: Last node dies

CONCLUSION

There are more number of modified schemes are existing for LEACH protocol as well as more number of modifications are also applied to LEACH protocol in the past years. The proposed scheme Feelp also modifies the LEACH protocol by modifying LEACH's threshold function into a new one by adding parameters such as residual energy, less distance to BS and threshold energy. The modified function gives a better election of CH among the nodes. The node which elect as CH is by using the modified function is effective in reduction of energy consumption using the above parameters.

The proposed scheme is not satisfied with the election of better CH among cluster nodes, it also implies a novel idea in selection of better CH among CH's which is named as SCH and the communications from the CH's are forwarded to SCH and SCH aggregates and forwards the information to BS. The SCH election is also carried out using the same parameters such as residual energy, less distance to BS and threshold energy. The election of SCH is obtained using FL which is a better approach to identify a better model. With the three parameters 27 rules are framed and all the CH's are lies under a specific conditional frame. The CH which holds a higher frame elects as SCH. The evaluation of the proposed methodology is carried out with the latest other two schemes to verify the performance of the proposed scheme.

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