LEACH-S Enhancement to Ensure WSN Stability

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Abstract. Due to miniaturization of sensor nodes and the ease and low cost of deployment, the use of Wireless Sensor Networks (WSN) has grown rapidly. Several fields are concerned, including environmental monitoring, e-health, precision agriculture, and smart home. These sensor nodes have limited resources, especially energy resource. An efficient management of this resource is necessary for the effectiveness of these networks. Several energy management solutions have been proposed in the literature, including clustering. In this paper, we propose a new approach based on the LEACH-S protocol called Balance Member's Nodes in LEACH-S (BMN-LEACH-S). This approach allows, first to balance the number of member nodes between the different clusters. For this purpose, a fuzzy logic system using as basic metrics the number of nodes in the cluster and the RSSI with the cluster head are used during the construction of the network topology. Second, it allows to allocate a quantum of energy to each Cluster Head (CH) after which the CH gives up its role to another node. This CH selection is done in turn. BMN-LEACH-S reduces instability of WSN due to the frequent change of CHs and increases network lifetime as a result of balancing nodes between clusters.

Keywords: Balance nodes · Energy consumption · LEACH · Fuzzy system · WSN instability

1 Introduction

A sensor network is a set of nodes deployed in a study environment to collect and transmit data to a sink. These sensor nodes are applied in many domains such as smart homes, precision agriculture, e-health to automate and facilitate information gathering and monitoring tasks. These sensor nodes generally run on batteries and their deployment environment often does not allow them to be recharged. Therefore, once a node runs out of energy, it becomes unusable. This has a direct impact on the life of the network. Facing this problem, researchers are working on all layers of the OSI model to propose solutions that optimize energy consumption in these sensor nodes. One of the best known techniques at the network layer is clustering routing. The LEACH protocol and several of its variants are part of this routing approach. LEACH-S [1] is an enhancement to

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LEACH [2] that eliminates the cluster rebuild cycles that consume energy in the network. However, in LEACH-S to elect a new cluster head, the outgoing Cluster Head (CH) compares the residual energy to the average residual energy of the cluster to make a decision. This could lead to instability in the network because the residual energy of the CH quickly falls below the average. This leads to a frequent change of CHs, causing instabilities in the network. Also, in LEACH-S after the initial cycle, clusters are formed. A node remains in the same cluster indefinitely. As a result, the nodes acting as CHs in clusters with more nodes than average deplete faster than others. This cause instability in the cluster due to the rapid change of CHs. To provide a solution to these problems, we proposed a new approach called Balance Member Nodes in LEACH-S (BMN-LEACH-S). This approach consists of balancing different nodes between clusters when building the network. This balancing is done based on a fuzzy logic system using the parameters number of nodes in the cluster and Received Signal Strength Indication (RSSI). Also, BMN-LEACH-S solves the problem of fast CH changes in LEACH-S by assigning a quantum of energy to each CH instead of relying on the average energy of the cluster. At the end of this quantum, the CH could be replaced by another node chosen among nodes not yet elected as CH. The main contributions of our research are:

- Saving energy by avoiding to CH the computation and exploitation of the average residual energy of the cluster.
- Reducing the size of the control message by removing the field used to collect the residual energy of the nodes. This helps to reduce the routing overhead and thus reduce the energy consumption of the nodes.
- Reduced network instability due to frequent CH changes.
- Better traffic distribution and thus better distribution of the CHs' energy consumption. This improves the network lifetime.

The rest of this paper is organized as follows. In Sect. 2, we present related work. Our proposed solution, BMN-LEACH-S, is described in detail and we conduct an analytical performance evaluation of our approach compared to LEACH-S in Sect. 3. We conclude in Sect. 4.

2 Related Work

Please Wireless sensor nodes are very often manufactured with non-rechargeable batteries. These nodes therefore have limited energy autonomy. A sensor network does not work well when some of the nodes run out of energy. Energy conservation and the lifetime aspect of the sensor network are important challenges in the wireless sensor network environment. To address these challenges, many routing techniques have been proposed including those based on clustering.

LEACH protocol [2] is the one cluster-based communication protocol following a hierarchical routing approach. LEACH uses random rotation of clusters to evenly distribute the energy load among network nodes. LEACH improves energy management through a load balancing and data aggregation.

PEGASIS [3] is an improvement of the LEACH protocol. However, unlike LEACH which is based on a cluster formation, the main idea of PEGASIS is that each node receives and transmits to its close neighbours and takes the lead role for transmission to the base station. To achieve these energy conservation goals, PEGASIS performs data fusion at every node except the end nodes of the chain. To do this, a distance threshold is set between neighbours to be a leader. This approach allows the energy load to be distributed equally among the sensor nodes in the network. PEGASIS saves energy compared to LEACH.

In a network of sensor nodes, instead of each node sensing information and sending it to the sink individually, HEED protocol [4] proposes a distributed clustering scheme so that a cluster node head takes care of the transmission to the sink. The HEED protocol, has the task of circulating the server role between all the nodes of the cluster for balance maintenance between the residual energy of all the nodes constituting the cluster. This will increase the lifetime of the network.

LEACH-B [5] is an improvement of LEACH that takes into account the residual energy at the sensor nodes. Thus after the first selection of the cluster head according to the LEACH protocol, a second selection is introduced to modify the number of cluster heads taking into account the residual energy of the nodes. This allows a balanced distribution of clusters in the network. LEACH-B, by favouring nodes with a good energy level in the selection of cluster heads, provides a longer network lifetime compared to LEACH.

To solve the long-range problem between cluster heads and the sink in LEACH, Kaur et al. [6] propose a technique of electing a master node near the sink called Master Cluster Head. The latter will be responsible for aggregating and transmitting data from the different cluster heads to the base station. In sensor networks, most of the energy is consumed during the long distance transmission. The advantage is therefore the reduction of the communication between the cluster heads and the receiving node.

In LEACH, the residual energy and the distance between the base station and the sensor node are not considered in the process of electing the cluster head nodes. The energy efficient cross layer-LEACH model for a wireless sensor network is proposed in [7]. It addresses the problem of collecting correlated sensor data from a sink node in a WSN. CL-LEACH maximizes the network lifetime by considering the routing layer, physical layer and link access to the MAC layer. In addition, the residual energy and the distance between the node and the base station are taken into account for cluster head selection. The energy consumed during data transmission between the cluster head and the base station is directly proportional to the distance between them. After the routing mechanism, the CL-MAC model is processed by taking the threshold value, the remaining energy and the node as input. Initially, the position of the node is updated and the neighbouring node with a distance of one hop is estimated. In addition, it checks whether the node is in the neighbour list or not. If it is, then it checks if the remaining energy is greater than the threshold value. If the condition is met, then the relay node is selected. Once the node is equal to the destination, then the data will be processed and stop at the relay station.

In order to reduce the energy consumption of the sensor nodes, authors proposed a super cluster head [8] (CH) to collect data from the CHs to send to the receiving node. Moreover, these super CHs use fuzzy temporal rules to perform optimal routing. The first cluster head is responsible for data collection and has low mobility. The super CH is static in nature and performs all types of routing and monitoring activities towards the other CHs.

3 Our Solution: BMN-LEACH-S

To cope with the rapid change of CH and its corollaries, we propose a new approach called BMN-LEACH-S. This solution, on the one hand, proposes a technique for balancing the number of cluster member nodes based on a fuzzy logic system exploiting the basic metrics: number of nodes already managed by the CH and the RSSI of the target node with the CH. On the other hand, it proposes a simple and efficient technique to change the CH of a cluster based on the determination of an energy quantum to be used up by each CH before it hands over to another node (new CH). These new mechanisms contribute to balancing traffic load among different CHs and thus reduce the instability of some clusters and increase the lifetime of the network.

Our BMN-LEACH-S algorithm runs in cycles, and each cycle consists of two phases: the configuration phase and the stable phase. The configuration phase of the initial cycle consists of cluster head election process and the cluster choice process by nodes based on a fuzzy system metrics. For the other cycles, the selection of a new CH is performed by the outgoing CH.

3.1 CH Election Process in the Initial Round

As in LEACH-S, in BMN-LEACH-S, the initial cycle begins with a setup phase where each sensor node decides whether or not to act as a CH for that particular round. This decision for a sensor node to act as CH is based on the value of the number (between 0 and 1) randomly selected. A node becomes a cluster head for this first round if this number is below a predefined threshold. It then broadcasts a control message announcing its CH status. Unlike LEACH-S, in our approach, the CH announcement messages include the number of nodes already in the cluster.

3.2 Node Membership Process in a Cluster

When a node that is not a CH receives an announcement message from a CH, it sends its membership request message to the CH. In the case where this node receives an announcement message from several CHs, it calculates the cost associated with each CH using the fuzzy system. The fuzzy system takes as parameters RSSI and the number of member nodes contained in the CH cluster. The process of calculating the cost of the CH by our fuzzy system is presented in Appendix 1. The node will choose the cluster whose CH has the best cost. After that, it sends a membership message to the concerned CH. This message contains its identity information.

3.3 Cluster Heads Change Process

The cluster head function is played in turn. Unlike LEACH-S which averages the cluster energies and compares them with its residual energy, in our new approach, to solve the instability problem in clusters, we define a quantum of energy that the CH node must exhaust before giving up its place to another node. To do this, the outgoing CH node informs the new CH of the list of nodes that have already been elected and also the list of nodes not yet elected. Thus, the cluster head will choose a node from the list of not-yet-elected nodes as its successor and add its identity to the list of already-elected nodes before handing over its role. When all the nodes rotate as cluster head, i.e., when a CH has no more nodes in the not-yet-elected list, then the already-elected list is automatically copied to the not-yet-elected list, then the elected list is emptied, and the process starts again. Thus, member nodes will no longer need to inform the CH of their energy status, thus avoiding burdening the control packet. The approach also helps to avoid the operations of calculating the average of the residual energies of the different nodes of the cluster and its comparison with the CH.

Analytical evaluation of the solution
To highlight the relevance of the proposed solution, we conduct an analytical study. This study consists in describing and comparing the operating process of LEACH-S and BMN-LEACH-S. To do so, we first describe the environment of our study. Then, we present the results of the analytical experimentation. Finally, we analyse and interpret the results from the study.

3.4 Estimation Context

We consider two identical 17-nodes networks, one running with the LEACH-S protocol and the other with the BMN-LEACH-S. We observe the process of these two networks in different communication rounds (T0T1T2…T16). We assume that during a communication round, a member node consumes 0.5 Energy Units (EU) to communicate with its CH and the latter also uses 0.5 EU for the processing of each received message. Therefore, to process messages from N nodes, the CH needs N*0.5UE. A CH chooses a replacement when it exhausts an amount of energy equal to $C = 4$UE. In the experimental phase, the 17 nodes formed 3 clusters named cluster I, cluster J and cluster K. Each node has 20 UE as its initial energy.

3.5 Experimental Results

Experimentation with LEACH-S

In LEACH-S after the initial phase, the network formed 3 clusters I, J and K. These clusters I, J and K contain respectively 9, 7 and 3 nodes. NI1, NJ1 and NK1 are the cluster heads of cluster I, J and K respectively.

In round T1, we have the topology shown in Fig. 1. The cluster head is in blue and the other nodes in green. The links symbolize the direction of the communication.

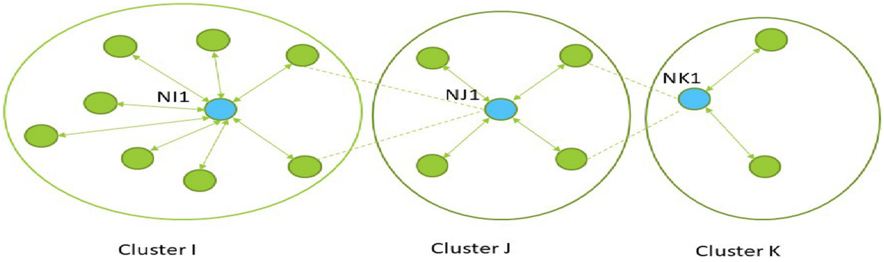


Fig. 1. State of the network at tower T1

The following table shows the energy status of the network nodes after the T1 round (Table 1).

Table 1. Energy status of the network after the T1 round on LEACH-S

	Cluster I									Cluster J					Cluster K		
Node	NI1	NI2	NI3	NI4	NI5	NI6	NI7	NI8	NI9	NJ1	NJ2	NJ3	NJ4	NJ5	NK1	NK2	NK3
E_r	16	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	18	19.5	19.5	19.5	19.5	19	19.5	19.5
Stat	INSTABILITY									STABLE					STABLE		

Nodes periodically send data from their environments to the CH. A round corresponds to the event of sending data to the CH, i.e., a period. We repeat the experiment until round T16 and collect the information to count the number of instabilities on the network. We call INSTABILITY the change of CH. This change generates a specific broadcast of control messages to announce the new CH. We assume that the energy consumed by an ordinary (non-CH) node receiving a packet from a neighbouring node is negligible. A non-CH node destroys this packet at the network access layer.

Table 2 Summarizes the information from rounds T1 to T16.

INSTABILITY Experimentation with BMN-LEACH-S

In BMN-LEACH-S, thanks to our member node balancing process, we end up this time with 7 nodes in cluster I, 5 in cluster J and 5 in cluster k. The CHs for these clusters I, J and K are respectively, NI1, NJ1 and NK1. As a reminder, in BMN-LEACH-S membership in a cluster is a function of the cost that the non-CH node has with the CH. Each node chooses the CH with which it has the highest cost. This cost is computed with our fuzzy logic system presented in Appendix 1.

Table 2. Summarizes the information from rounds T1 to T16 on LEACH-S

LEACH-S																	
Cluster	I									J					K		
Nodes	NI1	NI2	NI3	NI4	NI5	NI6	NI7	NI8	NI9	NJ1	NJ2	NJ3	NJ4	NJ5	NK1	NK2	NK3
T0	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
T1	16	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	18	19.5	19.5	19.5	19.5	19	19.5	19.5
Stat	INSTABILITY									STABLE					STABLE		
T2	15.5	15.5	19	19	19	19	19	19	19	16	19	19	19	19	18	19	19
Stat	INSTABILITY									INSTABILITY					STABLE		
T3	15	15	15	18.5	18.5	18.5	18.5	18.5	18.5	15.5	17	18.5	18.5	18.5	17	18.5	18.5
Stat	INSTABILITY									STABLE					STABLE		
T4	14.5	14.5	14.5	14.5	18	18	18	18	18	15	15	18	18	18	16	18	18
Stat	INSTABILITY									INSTABILITY					INSTABILITY		
T5	14	14	14	14	14	17.5	17.5	17.5	17.5	14.5	14.5	16	17.5	17.5	15.5	17	17.5
Stat	INSTABILITY									STABLE					STABLE		
T6	13.5	13.5	13.5	13.5	13.5	13.5	17	17	17	14	14	14	17	17	15	16	17
Stat	INSTABILITE									INSTABILITY					STABLE		
T7	13	13	13	13	13	13	13	16.5	16.5	13.5	13.5	13.5	15	16.5	14.5	15	16.5
Stat	INSTABILITY									STABLE					STABLE		
T8	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	16	13	13	13	13	16	14	14	16
Stat	INSTABILITY									INSTABILITY					INSTABILITY		
T9	12	12	12	12	12	12	12	12	12	12.5	12.5	12.5	12.5	14	13.5	13.5	15
Stat	INSTABILITY									STABLE					STABLE		
T10	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	08	12	12	12	12	12	13	13	14
Stat	INSTABILITY									INSTABILITY					STABLE		
T11	11	11	11	11	11	11	11	07.5	07.5	11.5	11.5	11.5	11.5	10	12.5	12.5	13
Stat	INSTABILITY									STABLE					STABLE		
T12	10.5	10.5	10.5	10.5	10.5	10.5	07	07	07	11	11	11	11	08	12	12	12
Stat	INSTABILITY									INSTABILITY					INSTABILITY		
T13	10	10	10	10	10	06.5	06.5	06.5	06.5	10.5	10.5	10.5	09	07.5	11.5	11.5	11
Stat	INSTABILITY									STABLE					STABLE		
T14	09.5	09.5	09.5	09.5	06	06	06	06	06	10	10	10	07	07	11	11	10
Stat	INSTABILITY									INSTABILITY					STABLE		
T15	09	09	09	05.5	05.5	05.5	05.5	05.5	05.5	09.5	09.5	08	06.5	06.5	10.5	10.5	09
Stat	INSTABILITY									STABLE					STABLE		
T16	08.5	08.5	05	05	05	05	05	05	05	09	09	06	06	06	10	10	08
Stat	INSTABILITY									INSTABILITY					INSTABILITY		

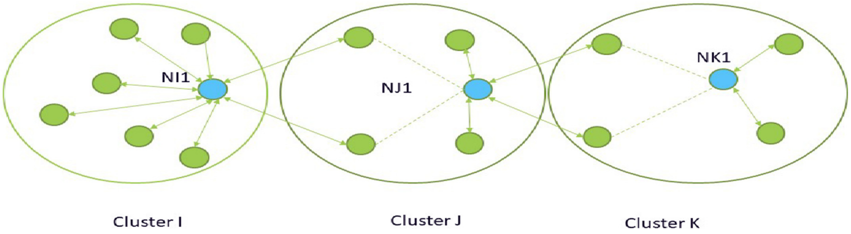


Fig. 2. Fuzzy-based CH selection of nodes in the respective clusters

In round T1, we have (Table 3):

Table 3. Energy status of the network after the T1 round BMN-LEACH-S

	Cluster I							Cluster J					Cluster K				
Nodes	NI1	NI2	NI3	NI4	NI5	NI6	NI7	NJ1	NJ2	NJ3	NJ4	NJ5	NK1	NK2	NK3	NK4	NK5
E_r		19.5	19.5	19.5	19.5	19.5	19.5	18	19.5	19.5	19.5	19.5	18	19.5	19.5	19.5	19.5
Stat	STABLE							STABLE					STABLE				

We repeat the experiment until round T16 and collect the information to count the number of instabilities on the network. Table 4 summarizes information from rounds T1 to T16.

Table 4. Information from the network running on BMN-LEACH-S

BMN-LEACH-S																	
Clus-ter	I							J					K				
Nodes	NI1	NI2	NI3	NI4	NI5	NI6	NI7	NJ1	NJ2	NJ3	NJ4	NJ5	NK1	NK2	NK3	NK4	NK5
T0	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
T1	17	19.5	19.5	19.5	19.5	19.5	19.5	18	19.5	19.5	19.5	19.5	18	19.5	19.5	19.5	19.5
Stat	STABLE							STABLE					STABLE				
T2	14	19	19	19	19	19	19	16	19	19	19	19	16	19	19	19	19
Stat	INSTABILITY							INSTABILITY					INSTABILITY				
T3	13.5	16	18.5	18.5	18.5	18.5	18.5	15.5	17	18.5	18.5	18.5	15.5	17	18.5	18.5	18.5
Stat	STABLE							STABLE					STABLE				
T4	13	13	18	18	18	18	18	15	15	18	18	18	15	15	18	18	18
Stat	INSTABILITY							INSTABILITY					INSTABILITY				
T5	12.5	12.5	15	17.5	17.5	17.5	17.5	14.5	14.5	16	17.5	17.5	14.5	14.5	16	17.5	17.5
Stat	STABLE							STABLE					STABLE				
T6	12	12	12	17	17	17	17	14	14	14	17	17	14	14	14	17	17
Stat	INSTABILITY							INSTABILITÉ					INSTABILITÉ				
T7	11.5	11.5	11.5	14	16.5	16.5	16.5	13.5	13.5	13.5	15	16.5	13.5	13.5	13.5	15	16.5
Stat	STABLE							STABLE					STABLE				
T8	11	11	11	11	16	16	16	13	13	13	13	16	13	13	13	13	16
Stat	INSTABILITY							INSTABILITY					INSTABILITÉ				
T9	10.5	10.5	10.5	10.5	13	15.5	15.5	12.5	12.5	12.5	12.5	14	12.5	12.5	12.5	12.5	14
Stat	STABLE							STABLE					STABLE				
T10	10	10	10	10	10	15	15	12	12	12	12	12	12	12	12	12	12
Stat	INSTABILITY							INSTABILITY					INSTABILITY				
T11	09.5	09.5	09.5	09.5	09.5	12	14.5	11.5	11.5	11.5	11.5	10	11.5	11.5	11.5	11.5	10
Stat	STABLE							STABLE					STABLE				
T12	09	09	09	09	09	09	14	11	11	11	11	08	11	11	11	11	08
Stat	INSTABILITY							INSTABILITY					INSTABILITY				
T13	08.5	08.5	08.5	08.5	08.5	08.5	11	10.5	10.5	10.5	09	07.5	10.5	10.5	10.5	09	07.5
Stat	STABLE							STABLE					STABLE				
T14	08	08	08	08	08	08	08	10	10	10	07	07	10	10	10	07	07
Stat	INSTABILITY							INSTABILITY					INSTABILITY				
T15	07.5	07.5	07.5	07.5	07.5	05	07.5	09.5	09.5	08	06.5	06.5	09.5	09.5	08	06.5	06.5
Stat	STABLE							STABLE					STABLE				
T16	07	07	07	07	07	02	07	09	09	06	06	06	09	09	06	06	06
Stat	INSTABILITY							INSTABILITY					INSTABILITY				

From the analytical study we conducted, during the 16 rounds, according to Tables 2 and 4, we notice that the total number of instability cases in LEACH-S for the whole network is 28 against 24 in BMN-LEACH-S.

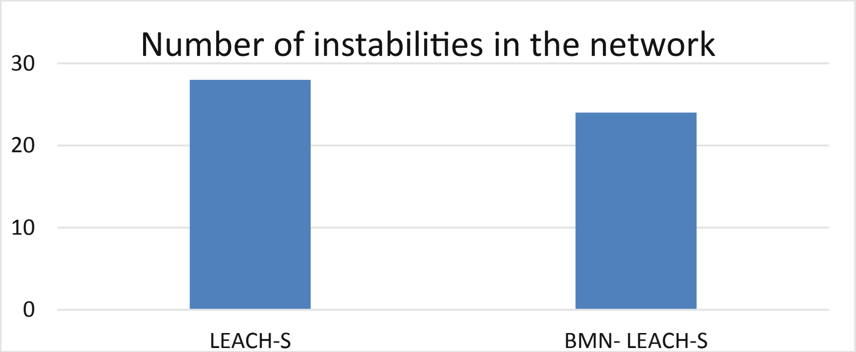


Fig. 3. Number of instability in the network

Looking in detail the number of instabilities per cluster, we notice that in LEACH-S, for clusters I, J and K, we have respectively 16, 8 and 4 cases of instabilities. In the network running with BMN-LEACH-S, with this experiment, we have the same number (8) of instabilities for each of the three clusters I, J, K (see Table 2 and Table 4).

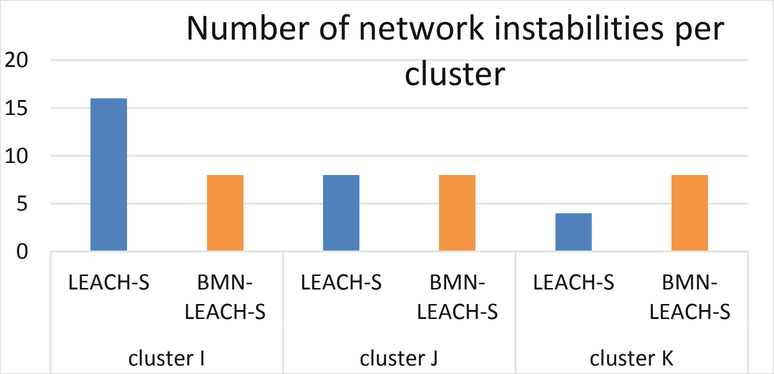


Fig. 4. Number of network instability per cluster

3.6 Analysis and Interpretation

The results of the experiments show that in all the networks, with the LEACH-S protocol we observe 28 instabilities against 24 for BMN-LEACH-S (see Fig. 3.). The use of LEACH produces more instabilities than the use of BMN-LEACH-S. If we analyse the results by cluster, the imbalance is more visible. In cluster I, we see that the CH was changed 16 times with LEACH-S versus 8 for BMN-LEACH-S (see Fig. 4.).

Knowing that each CH change induces special control message broadcast for new CH announcement, we can deduce that BMN-LEACH-S improves the routing load compared to LEACH-S. This leads to the reduction of the overall network energy consumption. BMN-LEACH-S also improved packet loss rate due to topology changes or network overload and average packet transmission delay.

With these experiments, the CH was changed 8 times for each cluster driven by BMN-LEACH-S. We can say that BMN-LEACH balances the traffic load between the different CHs. This increases the lifetime of the network.

4 Conclusion

In this paper, we proposed a new clustering-based routing solution called BMN-LEACH-S. This method is an improvement of the LEACH-S protocol to decrease the instability of some clusters due to frequent CH changes. Also, it solves the problem of unequal distribution of member nodes between clusters. To do this, BMN-LEACH-S allocates a quantum of energy to each cluster head. When the CH exhausts the quantum of energy, it appoints a replacement among the nodes not yet elected. Also, it implements a function based on a fuzzy logic system using the parameters number of nodes in the cluster and the RSSI to estimate the cost of a CH. Each node uses this cost to make its choice of CH. This allows more equitable distribution of nodes in the different clusters. An analytical evaluation of our solution shows that it reduces network instabilities compared to LEACH-S. This improves the lifetime of the network. This performance should be confirmed by extensive simulation and tesbed.

Appendix 1 : The Fuzzy Function for Costing

Our fuzzy node balancing solution works in three steps. The fuzzification of the analog values (number of nodes and RSSI), the inference system and the defuzzification.

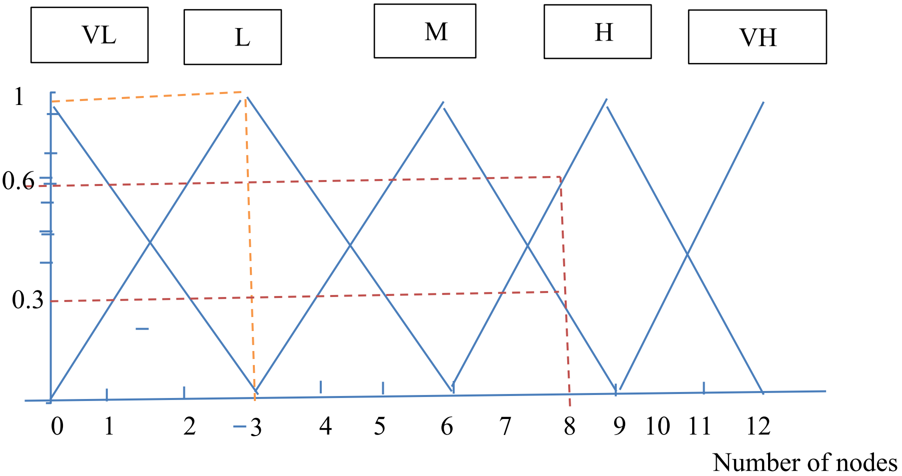
The Fuzzification Phase

In this phase, we translate the analog input parameters (RSSI signal strength and number of nodes in the cluster) into discrete values between 0 and 1. The first parameter is the number of nodes in the cluster. Since our goal is to balance the size of the clusters, it is necessary to take into account the number of nodes (NN) owning each cluster so that the cluster with more nodes has less chance to receive a new node. Also, the second parameter is the signal strength (RSSI) between the node and the CH. We considered the signal strength so that the cluster with a good communication link has a higher chance of receiving the node.

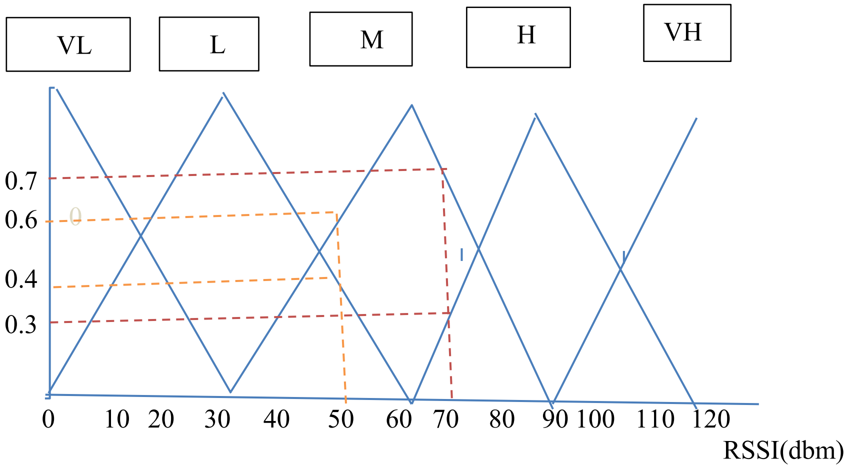
To do this, we use a membership function to translate these analog values. It should be noted that there are several types of membership function, namely the triangular membership function, the sinusoidal function, etc. But we have chosen the triangular membership function. Also, we choose the same linguistic variables to delimit our fuzzy sets (Very low, low, medium, high, Very high) for both parameters.

For example, if a node has the choice between two clusters named I and J. The number of nodes in cluster I is 8 and its RSSI is 70 and the number of nodes in cluster J is 3 and its RSSI is 50.

Cluster I (NN = 8; RSSI = 70) Cluster J (NN = 3; RSSI = 50)



fuzzification process of number of nodes related to CH I and J



fuzzification process of RSSI related to CH I and J

After fuzzification, cluster I has as fuzzy values (NN(0.66 high; 0.34 medium) RSSI(0.3 High; 0.7 medium)). cluster J has as fuzzy values(NN(1 low) RSSI(0.4 low; 0.6 medium))

The Inference System

Once the different parameters have been translated into “fuzzy language”, the inference aims at building decision rules and finding for each of them the rule of belonging of the conclusion. The construction of these rules, mainly based on “AND”, is mathematically translated in the following form.

Rule i	Description (***Ri***)	Output rule (Cluster choice level)
1	NN (very low) AND RSSI (very low)	Medium
2	NN (very low) AND RSSI (low)	Medium
3	NN (very low) AND RSSI (medium)	High
4	NN (very low) AND RSSI (high)	Very high
5	NN (very low) AND RSSI (very high)	Very high
6	NN (low) AND RSSI (very low)	Medium
7	NN (low) AND RSSI (low)	Medium
8	NN (low) AND RSSI (medium)	High
9	NN (low) AND RSSI (high)	Very High
10	NN (low) AND RSSI (very high)	Very High
11	NN (medium) AND RSSI (very low)	Low
12	NN (medium) AND RSSI (low)	Low
13	NN (medium) AND RSSI (medium)	Medium
14	NN (medium) AND RSSI (high)	Medium
15	NN (medium) AND RSSI (very high)	Medium
16	NN (high) AND RSSI (very low)	Very low
17	NN (high) AND RSSI (low)	Low
18	NN (high) AND RSSI (medium)	Low
19	NN (high) AND RSSI (high)	Medium
20	NN (high) AND RSSI (very high)	Medium
21	NN (very high) AND RSSI (very low)	Very Low
22	NN (very high) AND RSSI (low)	Very Low
23	NN (very high) AND RSSI (medium)	Low
24	NN (very high) AND RSSI (high)	Low
25	NN (very high) AND RSSI (very high)	Low

After the establishment of the rule base, We use the truth values associated with the clusters to activate the rules using Zadeh operators.

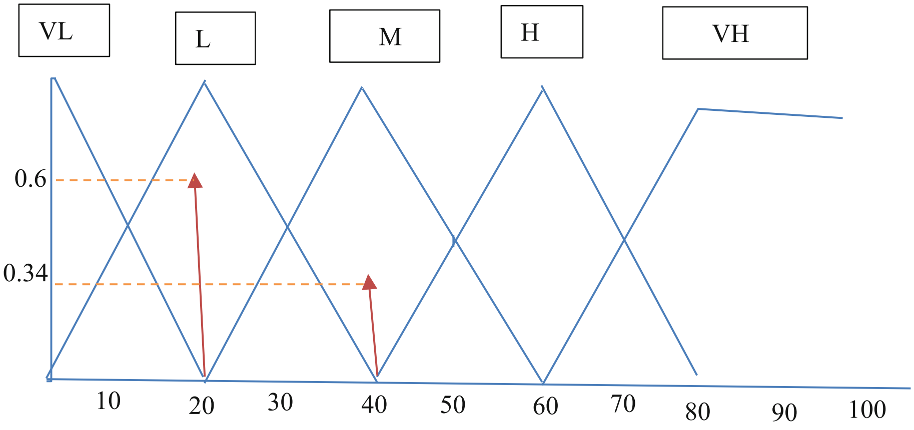
Cluster I		
Rule	Value	Result
NN (high) AND RSSI (medium))	Min (0.66; 07)	0.66 low
NN (high) ET RSSI (high))	Min (0.66; 0.3)	0.3 medium
NN (medium) ET RSSI (medium))	Min (0.34; 0.6)	0.34 medium
NN (medium) ET RSSI (high))	Min (0.34; 0.4)	0.34 medium

Cluster J		
Rule	Value	Result
NN (low) ET RSSI (low))	Min (1; 0.4)	0.4 medium
NN (low) ET RSSI (medium))	Min (1; 0.6)	0.6 high

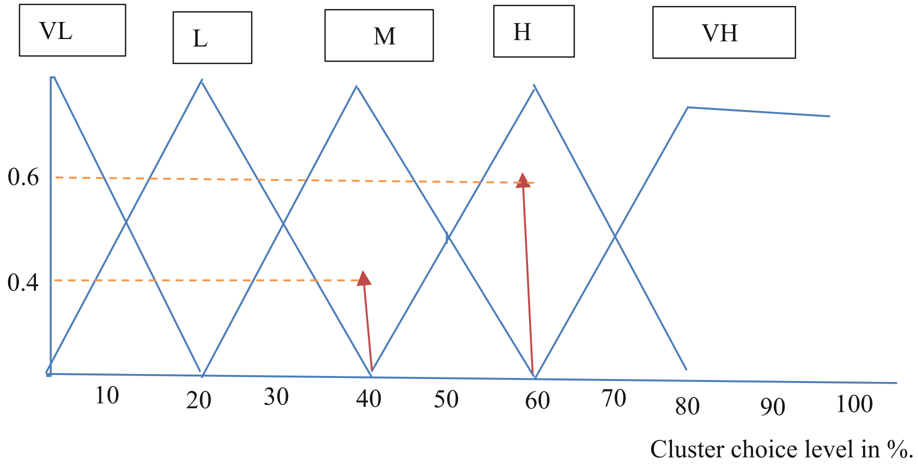
Aggregating the Results

This step of the inference consists in grouping all the rules. This aggregation is therefore done on the basis of logical "Or", which translates into "Max".

Aggregation of the CHI values of Cluster I



Aggregation of CHJ values of Cluster J



Defuzzification

Defuzzification consists in transforming the fuzzy output subset into a non-fuzzy value called the cluster head cost. A node wanting to integrate into a cluster will choose the cluster whose CH offers a better cost. To compute the cost, we will use the weighted average method which consists of averaging the maximums of the output values.

$$\text{CG}= \frac{\sum_{i=0}^{n} \mu_A(K_i).(K_i)}{\sum_{I=0}^{n} \mu_A(K_i)}$$

$$\text{Cost (CHI)} = \frac{30*0.66+ 60*0.34}{0.66+ 0.34} =40.2$$

$$\text{Cost (CHJ)}= \frac{40*0.4+ 60*0.6}{0.6+ 0.4} = 52$$

So the node will choose cluster J because it is the CHJ that offers a better cost.

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