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A Survey on Probabilistic And Fuzzy Based Energy Efficient Clustering Protocols For Sensor Networks

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Abstract - Wireless sensor network (WSN) plays very important role in today's life. The major role of WSN is to sense a particular region and transfer sensed information to a distant base station for further processing. Sensor networks composed of many sensor nodes will be utilized for sensing purpose. The major design issue in this area is to optimize the energy efficiency of a sensor node because the power source of these sensor nodes is limited. Thus, to sustain the lifetime of a sensor network for a longtime, the energy of sensor node must be used in a optimized way. Many solutions are introduced by researchers to prolong the lifetime of a sensor network. In this paper, a survey on these various solutions has been discussed. The major focus on clustering techniques, probabilistic and fuzzy based models has been discussed. The paper concludes with open research issues.

Keywords— Clustering, fuzzy, probabilistic, wireless sensor network, Micro electro mechanical system.

I. INTRODUCTION

Recent advancement in Micro Electro Mechanical Systems (MEMS) permit the manufacturing of small size, low power, on-board processing and communication capable wireless sensor nodes which can be further used for sensing purpose. Wireless sensor network (WSN) are mainly useful in battlefield surveillance, environment monitoring, traffic monitoring etc [2] and [3]. In wireless sensor network sensor nodes are deployed in a random manner and a Base Station (BS) is located far from deployment region. All sensor nodes are accountable for sensing their relevant vicinity and transmit sensed information to the BS. Non-rechargeable batteries are used by these sensor nodes, so optimizing the energy of sensor networks is a major design issue [4]. In wireless sensor network, nodes have to drive in unattended environment for a long time without substitute of power sources, so focus is on optimized use of energy so that the lifetime of the network is enlarged. Energy expenditure is not an issue in traditional wireless network as energy source can be replaced and recharged at any time. But the case is not same in wireless sensor nodes that means the batteries used by sensor nodes cannot be replace and recharge by any means. A number of routing protocols have been proposed to make nodes more energy efficient. There are cases that the nearby nodes sense the same data and transmit it to BS, making network inefficient. It is found that to sustain worthy information at the BS, the nodes must be accountable for data aggregation and fusion. So, a reliable network is the one in which the superfluous information is negligible. To steer clear of redundancy, clustering algorithms were proposed. In clustering the entire network of nodes is divided into a number of clusters; the data aggregation is performed within the cluster and then transmitted to the base station. Clustering helps in reduction of redundancy and upgrading over the lifetime of the network. Recently, a few surveys of clustering routing methods for WSNs have been accessible. These surveys mainly aim at outlining some characters of clustering and summarizing some popular clustering routing algorithms with comparison based on different attributes and performances. In this study, we present a wide-ranging survey of different clustering routing protocols proposed in literature as well as fuzzy logic based clustering protocols for WSNs in recent years. The representative design is low-energy adaptive clustering hierarchy (LEACH) [3] protocol, which uses a probabilistic model to select cluster heads (CHs) periodically in order to balance energy consumption. However in some cases, inefficient clustering could not maximize the lifetime of WSNs so a number of modifications has been done to improve the energy effectiveness of protocol.

II. WIRELESS SENSOR NODE

The basic unit of a wireless sensor network is wireless sensor node which mainly consists of four major components: a sensing unit, a processing unit, a transceiver unit and a power unit. Fig 1 shows the architecture of a wireless sensor node.

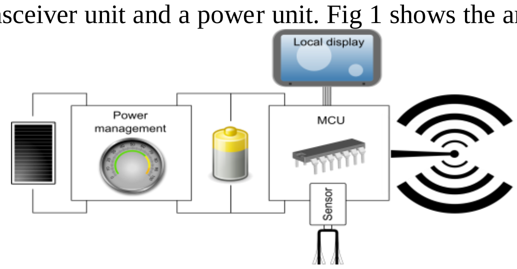

Fig. 1 Architecture of a wireless sensor node

Sensor Unit: Sensing units are usually composed of two subunits: sensors and analog to digital converters (ADCs). Sensor is a device which is used to translate physical phenomena to electrical signals. Sensors can be classified as either analog or digital devices. There exists a variety of sensors that measure environmental parameters such as temperature, light intensity, sound, magnetic fields, image, etc. The analog signals produced by the sensors based on the observed phenomenon are converted to digital signals by the ADC and then fed into the processing unit [1].

Processing Unit: The processing unit mainly provides intelligence to the sensor node. The processing unit consists of a microprocessor, which is responsible for control of the sensors, execution of communication protocols and signal processing algorithms on the gathered sensor data [5]. Commonly used microprocessors are Intel's ARM microprocessor, Atmel's AVR microcontroller and Texas Instruments' MP430 microprocessor. In general, four main processor states can be identified in a microprocessor: off, sleep, idle and active. In sleep mode, the CPU and most internal peripherals are turned on, and can only be activated by an external event (interrupt). In idle mode, the CPU is still inactive, but other peripherals are active [1].

Transceiver Unit: The radio enables wireless communication with neighboring nodes and the outside world. It consists of a short range radio which usually has single channel at low data rate and operates at unlicensed bands of 868-870 MHz (Europe), 902-928 MHz (USA) or near 2.4 GHz (global ISM band). For example, the TR1000 family from RF Monolithic works in the 800–900 MHz range can dynamically change its transmission power up to 1.4 mW and transmit up to 115.2 Kbps [5].

Battery: The battery supplies power to the complete sensor node. It plays a vital role in determining sensor node lifetime. The amount of power drawn from a battery should be carefully monitored. Sensor nodes are generally small, light and cheap, the size of the battery is limited [1]. AA batteries normally store 2.2 to 2.5Ah at 1.5V. However, these numbers vary depending on the technology utilized. Furthermore, sensors must have a lifetime of months to years, since battery replacement is not an option for networks with thousands of physically embedded nodes. This causes energy consumption to be the most important factor in determining sensor node lifetime [5].

III. APPLICATIONS OF WSN

WSN applications can be classified into two categories [6] as shown in Fig 2.

- Monitoring
- Tracking

Monitoring applications include indoor/outdoor environmental monitoring, health and wellness monitoring, power monitoring, inventory location monitoring, factory and process automation, and seismic and structural monitoring. Tracking applications include tracking objects, animals, humans, and vehicles and categorize the applications into military, environment, health, home and other commercial areas. It is possible to expand this classification with more categories such as space exploration, chemical processing and disaster relief.

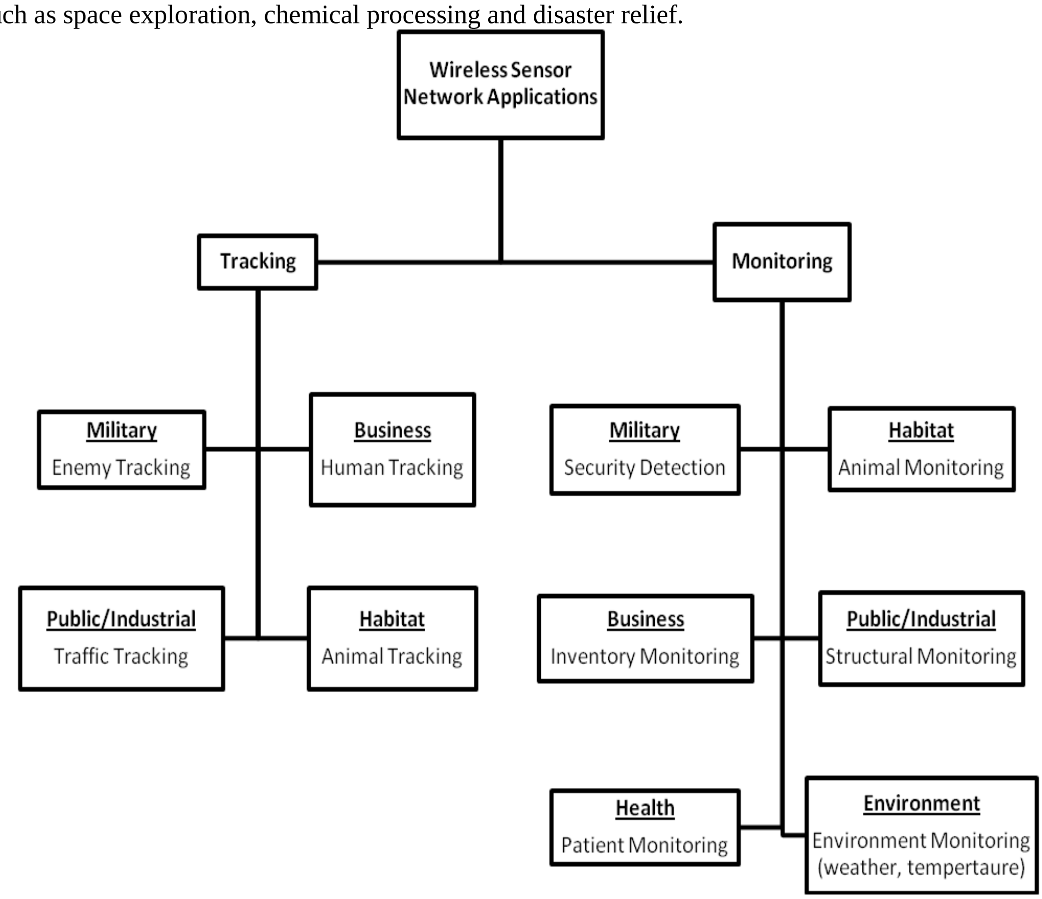

Fig. 2 Applications of wireless sensor networks

IV. CLUSTERING

A WSN consists of large number of sensor nodes which collaborate together to form a communication network to provide reliable networking services. It is likely that data collected from one sensor is highly correlated with the data collected from its neighboring nodes, so in that case data aggregation can reduce the redundant information to be transmitted in the network [6]. Clustering allows splitting the transmission of data into inter and intra-cluster communication, an example shown in Fig 3. This leads to energy saving because radio unit is the main energy consuming unit. Aggregating nodes in clusters has many advantages as mentioned below.

- The size of the routing table stored at each node gets reduced.
- Communication bandwidth can be conserved since inter-cluster interactions become limited to cluster heads and hence avoid redundant exchange of information among sensor nodes.
- Since transmission distance for every node gets reduced, energy consumption is less and hence network lifetime increases.
- Data aggregation performed on cluster heads reduces the number of redundant packets. Energy consumption rate can also be decreased by scheduling activities in the cluster.

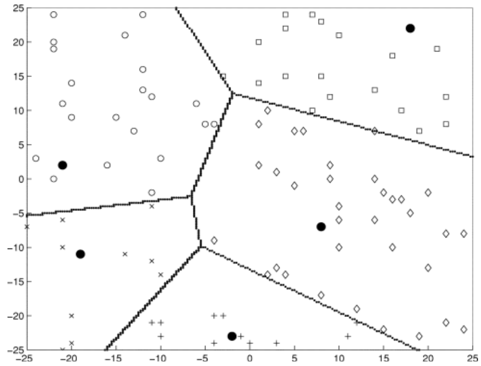

Fig. 3 Clustering example

V. PROBABILISTIC CLUSTERING PROTOCOLS

A. LEACH Protocol

Heinzelman et al. [3] describe Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol. LEACH is a well-known cluster-head election approach that constitutes a basis for many other approaches as stated in literature. It is the first significant protocol that aims to minimize the overall energy used in data gathering operations in wireless sensor networks. LEACH is a distributed algorithm which makes local decisions to elect cluster-heads [4]. If the cluster-heads are selected for once and do not change throughout the network lifetime, then it is obvious that these static cluster-heads die earlier than the ordinary nodes. Therefore, LEACH includes randomized rotation of cluster-head locations to evenly distribute the energy dissipation over the network. LEACH also performs local data compression in cluster heads to decrease the amount of data that is forwarded to the base station. In LEACH, cluster-head election is done periodically to enable randomized rotation of cluster heads. Every round consists of two phases, namely set-up phase and steady-state phase. In set-up phase, cluster-heads are elected and clusters are formed. In steady-state phase, data transfers to the base station are performed through the clustered network. A particular sensor node decides whether it is going to become a cluster-head or not by generating a random number between 0 and 1. If this number is less than the predefined threshold T(n), then the sensor node becomes a cluster-head. G represents the set of sensor nodes that have not been cluster-heads in the last 1 / p rounds where p is the desired percentage of cluster heads; r represents the current round number. Using these parameters, T(n) is formulated as follows:

If the sensor node n belongs to G:

$$T(n) = \begin{cases} \dfrac{p}{1 - p*(r*\text{mod}(1/p)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

If the sensor node n does not belong to G, then the T(n) is set to 0. Thus, n cannot become a cluster-head. At round 0, the probability of becoming a cluster-head for each node is equal to p. However, this situation changes in the following rounds. The cluster-heads of round 0 cannot become cluster-heads during the following 1 / p rounds. This restriction prevents a particular node to become a cluster-head frequently. However, this restriction brings a drawback. It causes rapid decrease in the number of cluster-heads. To handle this drawback, as r increases, the chance of the remaining sensor nodes to be a cluster-head is also increased by adjusting the threshold T(n) for the remaining sensor nodes. This critical balance is a significant property of LEACH. After cluster-heads are elected for a particular round, each cluster-head broadcasts an advertisement message to the remaining sensor nodes. As each non-cluster-head node receives these advertisement messages, they decide the cluster to which they belong. Each non-cluster head joins to the cluster from which it has received the largest signal strength. In order to join to the selected cluster, it transmits a Join Cluster Head Message to that cluster [4]. Once all the cluster-heads are selected and the clusters are formed, data transmission continues up to the next round. The steady-state operation is broken into frames, where nodes send their data to the cluster head at most once per frame during their allocated transmission slot. The duration of each slot in which a node transmits data is constant, so the time to send a frame of data depends on the number of nodes in the cluster. Fig 4 shows the time line for one round of LEACH. We assume that the nodes are all time synchronized and start the set-up phase at the same time. This could be achieved, for example, by having the BS send out synchronization pulses to the nodes.

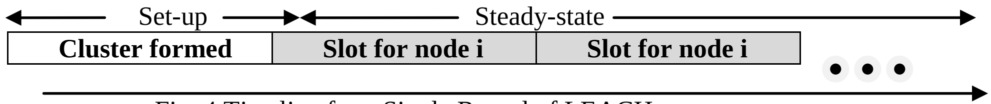

Fig. 4 Timeline for a Single Round of LEACH

The problem with LEACH is poor clustering that means some cluster heads are very near to base station while some are very far so that the CH far away from base station deplete their energy earlier as compared to others.

B. LEACH-C

Heinzelman et al. [4] proposed LEACH-Centralized (LEACH-C) is a centralized clustering algorithm during cluster formation phase, rest is same as LEACH. Base station has global knowledge of location & energy of sensor nodes in the network. During set up phase, each node sends its current location (possibly using GPS Receiver) and energy level to base station. Base station compute average node energy and this average node energy will be utilized as a threshold value for the selection of a Cluster Head. LEACH-C delivers about 40% more data per unit energy than LEACH. The drawback with LEACH-C is that the numbers of nodes in different clusters varying so that more the CH members results in CH overload and early it will deplete its energy [4].

C. Deterministic LEACH

Handy et al. [7] proposed deterministic LEACH. In this protocol instead of using only the probability factor the remaining energy is also considered while selecting the cluster heads. Like in LEACH, it is obvious that a stochastic cluster-head selection will not automatically lead to minimum energy consumption during data transfer for a given set of nodes. All cluster-heads can be located near the edges of the network or adjacent nodes can become cluster heads. In these cases some nodes have to bridge long distances to reach a cluster-head. In this protocol the threshold value of LEACH is multiplied with a factor that represents the remaining energy of the node with respect to its initial energy. Such a modification of the cluster-head threshold can increase the lifetime of a LEACH micro sensor network by 30 % for First Node Dies (FND) and more than 20 % for half of the Nodes Alive (HND) [7].

D. SEP

Smaragdakis et al. [8] proposed Stable Election Protocol. SEP is an energy-aware protocol for heterogeneous wireless sensor networks. SEP is used for electing cluster heads in two-level hierarchical wireless sensor networks. This protocol is based on weighted election probabilities of each node to become cluster head according to the residual energy in each node. SEP improved the stable region of the clustering hierarchy process using the fraction of advanced nodes. Since advanced nodes had more energy than normal nodes, so advanced nodes were made cluster heads more frequently than the normal nodes. This was done by increasing the epoch of the sensor network in proportion to the energy increment. However, SEP cannot be used for multi-level heterogeneous wireless sensor networks.

E. EEHC

Kumar et al [9] proposed Energy Efficient Heterogeneous Clustering (EEHC) approach for wireless sensor networks. The main idea is to introduce heterogeneous nodes in the network on energy basis. This work mainly focuses on selection probability of cluster head. Three types of heterogeneity introduced in this paper as computational, link and energy. In this protocol three different types of nodes are used for sensing an environment such as super nodes, advanced nodes and normal nodes. This approach assigns a weight to the optimal probability. This weight must be equal to the initial energy of each node divided by the initial energy of the normal node. EEHC extend the lifetime of the network by 10% as compared to LEACH.

These are some of the probability based clustering protocols which were developed for the prolongation of the lifetime of wireless sensor network, but the major problem with all probabilistic approaches is that in all these only the random number will be check against a predefined threshold but none of the method consider sensor node parameters such as energy, distance to base station etc. Thus, sometime those nodes become cluster heads which are not suitable or even they don’t have enough energy to run a round. So, this will degrade the throughput of the network results in poor performance. Thus, as an alternative to probabilistic approaches fuzzy logic based clustering protocols got popularity because they consider various parameters related to sensor node on the basis of their membership grades.

VI. FUZZY BASED CLUSTERING PROTOCOLS

As from the above discussion we come to know the importance of fuzzy based clustering protocols for WSN systems. In this section we are discussing various energy efficient approaches for sensor networks. The model of fuzzy logic controller consists of a fuzzifier, fuzzy inference engine, and a defuzzifier shown in Fig 5.

The Fuzzification module performs the following functions:

- Receive the crisp inputs. The input variables are scale mapped that is transferred from the range of values of input variables into corresponding Universe of Discourse.
- Transform the input crisp variables to fuzzy variables. The UOD of fuzzy variables is divided into fuzzy sets. The input variable is mapped into subset with grade of membership.

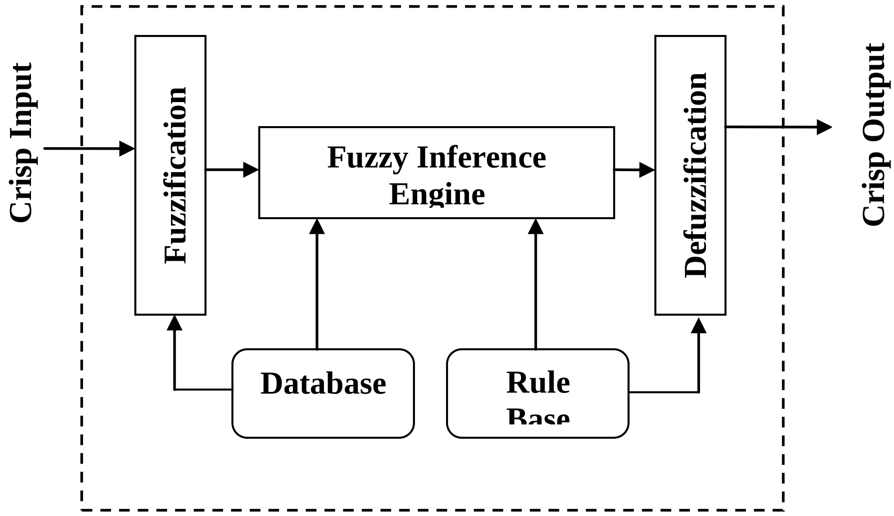

Fig. 5 Fuzzy logic controller

The Rule Base and Database perform the following functions:

- The data base provides the necessary definitions which are used to define Linguistic control rules & Fuzzy data manipulation in FLC there are more than one outputs at a given instant.
- The rule base characteristics the control goals and control policy of the domain experts by a set of linguistic control rules.

Fuzzy Inference Engine: These rules simulate the decision making capabilities of human brain. Based on input from fuzzifier, knowledge and set of control rules the output decisions or the necessary control actions are evaluated in fuzzy domain. Since usually more than one rule fire there are more than one outputs at a given instant. Inference Engine also takes into account this fact by combining these fuzzy outputs into a single fuzzy set. This process of combining fuzzy sets into a single fuzzy set is called as aggregation. Rules form the basis for the fuzzy logic to obtain the fuzzy output [10]. The rule based system is different from the expert system in the manner that the rules comprising the rule based system originates from sources other than that of human experts and hence is different from expert systems. The rule-based form uses linguistic variables as its antecedents and consequents. The antecedents express an inference or the inequality, which should be satisfied. The consequents are those, which we can infer, and is the output if the antecedent inequality is satisfied. The fuzzy rule-based system uses IF–THEN rule-based system, given by, IF antecedent, THEN consequent [11].

Defuzzification: In many instances, it is desired to come up with a single crisp output from an FIS. For example, if one was trying to classify a letter drawn by hand on a drawing tablet, ultimately the FIS would have to come up with a crisp number to tell the computer which letter was drawn. This crisp number is obtained in a process known as defuzzification [11]. Thus defuzzification module transforms fuzzified outputs into corresponding crisp output for suitable action.

A. Fuzzy LEACH

Gupta et al. [12] proposed fuzzy logic in the field of wireless sensor networks. It is based on LEACH protocol. As in LEACH cluster heads are elected using a fixed threshold value but in this proposed approach fuzzy logic used for CH selection process to eliminate the problems face by pure probabilistic approaches like poor clustering. In this scheme fuzzy logic control is implemented using three fuzzy descriptors such as energy, concentration and centrality for improving clustering process. Node centrality variable indicate how central the node is to the cluster can calculated on the basis of the sum of the squared distance of other nodes from the given node. Although this approach increases the lifetime of the sensor network but only limited to stationary nodes.

B. CHEF

Kim et al. [13] proposed Cluster Head Election mechanism using Fuzzy Logic (CHEF) for the selection of cluster head by using two input parameter energy and proximity distance. This approach allows the node with high energy and locally optimal node to elect as a cluster head. The CHEF is 22.7% more efficient than LEACH.

C. F-MCHEL

Sharma et al. [14] proposed Fuzzy based Master Cluster Head Election Leach (F-MCHEL) strategy as advancement in CHEF. Instead of transmission from number of cluster heads this approach select only one cluster head as a master CH on the basis of maximum energy. Like in CHEF, this approach utilizes two input parameter for FIS (Fuzzy Inference System) energy and proximity distance for the selection of cluster head out of these selected CH one Master cluster head will be selected and only this Master CH is responsible for collecting and aggregation data from various cluster heads and then forward to base station. In future this protocol can be implemented with heterogeneous environment.

D. LEACH-ERE

Lee et al. [15] proposed LEACH-Expected Residual Energy (LEACH-ERE) a framework for energy prediction in wireless sensor networks using fuzzy logic. The proposed protocol named as LEACH-ERE (LEACH Expected Residual Energy) Energy Prediction methodology in clustering using fuzzy logic with input fuzzy descriptors as residual energy and expected residual energy. Excepting this protocol, the energy of a sensor node after selecting as a CH and run a full round has never been discussed. This approach outperforms LEACH and CHEF (Cluster Head Election using Fuzzy Logic) [13]. LEACH-ERE is more efficient than LEACH about 42.61%. Although this protocol extend the lifetime of the sensor network as compared to LEACH but only limited to homogeneous stationary nodes which can be further modified for better performance using heterogeneous sensor nodes and mobile sensor nodes.

VII. CONCLUSION AND FUTURE SCOPE

The energy efficiency is the main challenges in the design of protocols for sensor networks due to the limited energy assets of sensor nodes. In this section, above discussed probabilistic and fuzzy based clustering protocols compared on the basis of Table I that shows the First Dead Node (FND) round or the stability period of the network.

TABLE I

Protocol	First Dead Node Round
LEACH	283
SEP	290
EEHC	285
Fuzzy-LEACH	350
CHEF	360
LEACH-ERE	384

Fig 6 shows a comparison of various protocols on the basis of Table I, which clearly reflects how fuzzy logic improve the performance of clustering protocols for wireless sensor networks. It must be noted that by adding heterogeneity to the sensor network the overall network lifetime has been increased. A further improvement has been carried out if energy prediction methodology used.

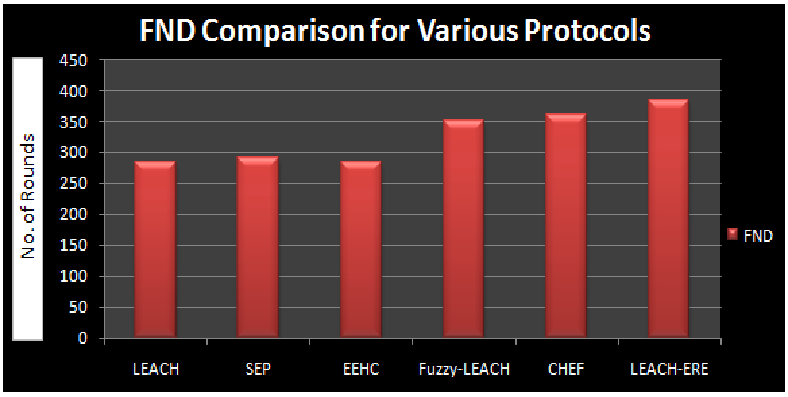

Fig. 6 FND comparison

Two parameters residual energy and distance to the base station can be used for cluster head selection and heterogeneity in terms of energy can be added as a extension of this work. Thus, as a future scope of this work the features of fuzzy logic and heterogeneity can be combined in a single hybrid protocol that can be further prolong the lifetime of the sensor network with a large throughput and energy optimization.

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REFERENCES

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, “Wireless sensor networks: a survey”, *Elsevier Journal of Computer Networks*, Vol. 38, pp. 393-422, 2002.

[2] J. Yick, B. Mukherjee, D. Ghosal, “Wireless Sensor Network Survey,” *Elsevier Computer Networks Journal*, vol. 52, pp. 2292-2330, April 2008.

[3] W.R. Heinzelman, A. Chandrakasan and H. Balakrishnan, “Energy-Efficient Communication Protocol for Wireless Micro sensor Networks,” *IEEE Annual Hawaii International Conference on System Sciences*, pp. 3005-3014, January 2000.

[4] W.B. Heinzelman, A.P. Chandrakasan and H. Balakrishnan, “An Application-Specific Protocol Architecture for Wireless Micro sensor Networks,” *IEEE Transaction on Wireless Communications*, vol. 1, no. 4, pp. 660-670, October 2002.

[5] H. Karl and A. Willig, “Protocols and Architectures for Wireless Sensor Networks”, John Wiley & Sons Ltd, 2005.

[6] J. Yick, B. Mukherjee and D. Ghosal, "Wireless Sensor Network Survey", *Elseveir Journal of Computer Networks*, Vol. 52, pp. 2292-2330, 2008.

[7] M.J. Handy, M. Haase and D. Timmermann, "Low Energy Adaptive Clustering Hierarchy with Deterministic Cluster-Head Selection", *4th IEEE Conference on Mobile and Wireless Communications Networks,* pp. 368-372, 2002.

[8] G. Smaragdakis, I. Matta and A. Bestavros, "SEP: A Stable Election Protocol for Clustered Heterogeneous Wireless Sensor Networks", *Proceedings of the 8th International Workshop SAPNA,* pp. 1-11, 2004.

[9] D. Kumar, T.C. Aseri and R.B. Patel, "EEHC: Energy efficient heterogeneous clustering scheme for wireless sensor networks", *Elsevier Computer Communications Journal*, Vol. 32, Issue 4, pp. 662-667, 2009.

[10] S.N. Sivanandam, S. Sumathi and S.N. Deepa. "Introduction to Fuzzy Logic using MATLAB", *Springer,* pp. 1-30, 2007.

[11] B. Yuan, "Fuzzy Sets and Fuzzy Logic: Theory and Applications", Prentice Hall Inc, 1995.

[12] I. Gupta, D. Riordan and S. Sampalli, "Cluster-head Election using Fuzzy Logic for Wireless Sensor Networks," in *Proceeding of Annual Conference on Communication Networks Services,* pp. 255–260, 2005.

[13] J.M. Kim, S.H. Park, Y. Han and T.M. Chung, "CHEF: Cluster Head Election mechanism using Fuzzy Logic in Wireless Sensor Networks", *Proceeding of International Conference on Advance Communications Technology*, pp. 654-659, 2008.

[14] T. Sharma and B. Kumar, "F-MCHEL: Fuzzy Based Master Cluster Head Election Leach Protocol in Wireless Sensor Network", *International Journal of Computer Science and Telecommunications*, Vol. 3, Issue 10, pp. 8-13, 2012.

[15] J.S. Lee and W.L. Cheng, "Fuzzy-Logic-Based Clustering Approach for Wireless Sensor Networks Using Energy Prediction", *IEEE Sensors Journal,* Vol. 12, No. 9, pp. 2891-2897, 2012.

