Energy Efficient Fuzzy Based Clustering For Cognitive Radio Wireless Sensor Networks

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Abstract-- **The explosive growth of wireless sensor networks have increased demand for radio spectrum which have resulted in spectrum scarcity problem, as the entire spectrum bands are already been allocated to different wireless services and technologies. Cognitive radio has emerged as a promising solution for the inherently resource-constrained wireless sensor networks to opportunistically access the reserved underutilized frequency bands. It adopts artificial intelligence algorithms to enable sensor nodes to avoid crowded unlicensed congested bands by sensing underutilized licensed frequency bands and make decision to adapt their transmission parameters. Clustering is used to decrease energy consumption and support scalability of sensor networks, however current clustering is based on fixed spectrum allocation and cannot deal with the dynamic spectrum allocations needed for next generation networks. This paper proposes an energy efficient spectrum aware clustering that groups neighboring nodes with similar sets of idle channels and optimally form energy efficient clusters based on three fuzzy parameters of residual energy, closeness to base station, and node degree to compute the chance of each node to be a cluster head. The performance is evaluated using data packets sent to base station, number of nodes alive during rounds, number of dead nodes during rounds, and energy consumption as performance metrics. Comparative performance evaluation in different simulation scenarios show that the proposed protocol have outperformed other implemented protocols and prolonged the stability period and the networks' lifetime due to reduction in packet collision and retransmission.**

Index Term-- **Wireless Sensor Networks; Fuzzy Clustering; Energy Efficient, Spectrum Aware, Network Lifetime.**

1. Introduction

Wireless Sensor Networks (WSNs) [1] is an integral part of Internet of Things (IoT) [2], which consists of a set of sensor nodes that are deployed to support a huge number of applications in various environments. Applications include security, smart agriculture, smart homes, smart cities, and smart grid [3]. These applications have specific requirements such as long range, low data rate, low energy consumption, and cost effectiveness [4]. The structure of IoT consists of three layers: sensor layer, network layer and application layer. Sensor layer is used to collect and identify the information, network layer provides access for sensor layer to the public networks, and application layer that satisfies user's requirements. To achieve the full functionality of IoT, intelligent protocols are needed for communication to adapt to different communications scenarios. Designing intelligent protocols for sensor data collection and aggregation is one of the main challenges that IoT is facing [5]. One of the wireless communication technologies for IoT, that operate in sensor layer, is based on IEEE802.15.4 protocols [6], which is used for relatively short distances, with low data rates and low energy consumptions. Currently, several clustering protocols were developed to minimize energy consumption and to prolong WSN's lifetime [7]. These protocols were different in how they improve the communication and transmission of packets in the network [8]. Clustering algorithms create virtual groups of nodes to reduce network communication overhead, provide stability and balance the use of resources [9]. A numerous clustering algorithms have been proposed based on well known "Low Energy Adaptive Clustering Hierarchy (LEACH)" protocol [10]. LEACH organizes nodes into independent clusters, each with a number of Member Nodes (MNs) to collect data from their environment and communicate with a Cluster Head (CH) to aggregate data arriving from nodes at regular intervals to a Base Station (BS). Leach periodically elects CHs randomly from all the nodes in the networks and rotates this role to balance the energy dissipation of sensor nodes in the networks. Network lifetime is divided into discrete and disjoint time intervals called rounds, and every round is composed of two phases, the setup phase and the steady state phase. The setup phase involves forming clusters based on a randomly selected number. The cluster formulation process takes place locally within each node according to a predetermined percentage of the nodes to act as CHs in each round.

In every round, every node picks a random number between 0 and 1 to determine if it will become a CH or not, then compares this number with threshold value that is defined in equation 1.

$$T(n) = \begin{pmatrix} \frac{p}{1-p*\left(r \bmod \frac{1}{k}\right)} & if n \in G \\ 0 & otherwise \end{pmatrix} \quad (1)$$

Where $p = \frac{k}{N}$ is the desired percentage of nodes to become CHs in each round, r is the current round, and G is the nodes that have not been a CH for the last $\left((r \bmod) \frac{N}{k}\right)$ rounds.

After a node has decided to become a CH, it broadcasts an advertisement message to the rest of the nodes. Other nodes decide to join the cluster based on the received signal strength and it informs the CH node that it will be a MN. The CH receives all the messages from these MNs and based on the number of nodes in the cluster, the CH node creates a Time Division Multiple Access (TDMA) in MAC layer to allow nodes to turn off their radio component until their allocated time slots. The schedule is broadcasted back to all MNs in the cluster and it will be fixed for that round. All MNs will use their allocated timeslot in TDMA schedule to send monitored data to CH in the corresponding slot. CHs aggregate data to BS along with its identification. At the end of each round, a new set of nodes becomes CHs for the subsequent round. Therefore, the steady-state stage consists of sensing, and transmission of the sensed data to the CH and then to the BS [11].

Leach-C [12] is a centralized clustering algorithm where all nodes send their residual energy and their location to the BS to compute the probability of each node to be a cluster head [13]. Both leach and leach-C use fixed channel assignment and are not suitable for crowded spectrum.

WSNs usually operate in unlicensed Industrial Scientific and Medical (ISM) band [14], which leads to severe congestion between the various wireless networks. On the same time, licensed spectrum bands are underutilized due to their static spectrum band Allocation. Cognitive Radio (CR) [15] is an intelligent radio that can be programmed and configured dynamically to solve spectrum scarcity problem recently encountered in wireless networks due to rapidly growing demand for new applications and huge amount of generated data expected in most applications. In Cognitive Radio based wireless Sensor Networks (CRSNs) [16], the unlicensed users (Secondary Users (SUs)) can opportunistically access underutilized licensed spectrum whenever the licensed users (or Primary Users (PUs)) are absent. The available idle channels are detected by spectrum sensing and communication channels are determined by spectrum decision [17]. Spectrum aware clustering requires nodes to form clusters that are located within the transmission range of each other and have a common control channel for intra clustering communications to broadcast control messages to all nodes participating in the network. Traditionally this channel is realized as a separate static frequency band dedicated to carry only control traffic which is reserved from unlicensed band. However, in over-utilized frequency bands, there is no guarantee to allocate a fixed frequency band to exchange control messages either locally (one-hop neighborhood), or over multiple hops. Thus a high number of idle channel offers flexibility for channel switching and minimizes re-clustering due to changes in channel states or due to variations of spectrum availabilities [18].

The channel availability parameter must be added as part of clustering in CRSNs where both CH and CM must share a common idle channel to communicate and to form the cluster [19]. Nodes cannot link when they do not shared a common idle channel even though they are closely located to each other. Two types common channel constraints are used: pair-wise [20] and group-wise [21] channel constraints. A pair-wise channel constraint requires a common idle channel between a CH and a particular CM only. In group-wise channel constraint, an identical idle between a CH and all its CM nodes is needed. Therefore, additional constraint of clustering nodes according to similar idle spectrum channels in spatial neighborhood must be considered [22].

CogLeach [23] is an extension to Leach to add spectrum awareness as part of the CH selection criteria. The probability of each node to become cluster head is defined as

$$P_i(t) = \min(K. \frac{C_i}{\sum_{i=1}^{N} C_i}) \tag{2}$$

Where K is the number of CHs in the network, N is the number of nodes in the network, and C_i is the number of idle channels sensed by node i.

CogLeach-C [24] is also centralized cognitive protocol, where all nodes start by sensing the spectrum to identify idle channels. Then, each node sends a message to the BS over a CCC containing its ID, its idle channels, its residual energy level and its position in the network to compute the probability of each node to be a cluster head. Once the BS receives all the information from all the nodes it calculates the total residual energy in the network E_T and the total number of channels sensed idle in the network C_T. Next, the BS determines the probability for each node to become a CH or not using probability that node will be a CH in each round $P_i(t)$ which is formulated as

$$P_i(t) = \min(\frac{C_i * E_i}{E_T * E_T}, 1) \tag{3}$$

Where, C_i represents the number of channels sensed idle by node i, K is the number of clusters in each round, N is the number of nodes in network. Nodes that sense a higher number of idle channels have an increased probability to become CH. The objective is to make $(CHs) = k$, where $E(CHs) = \sum_{i=1}^{N} P_i(t)$. Then multiply by $N\,K$ to make the summation of $P_i(t)$ for the N nodes equal to K, number of CHs in network in each round. Then

$$P_i(t) = \min(k * N \frac{C_i * E_i}{E_T * E_T}, 1) \tag{4}$$

After choosing the K CHs, the BS broadcasts clusters information to the nodes and when a node receives this information, it validates its rule in the current round. If the node is a CH it waits for joining messages from the MNs. Then, it creates TDMA frame. If the node is a MN it sends join message to the CH. These control messages exchanged between the BS and the nodes are short and they are sent over a common communication channel. In addition, each round a node sends two control messages. A message to the BS, which contains its ID, its number of channels sensed idle and its residual energy. Then, it sends another message to the CH that was assigned for it by the BS to join the cluster.

Cogleach-C is an extension to Leach-C to add spectrum awareness as part of the CH selection criteria for further improve network lifetime. Nodes that sense a higher number of idle channels have an increased probability to become CH which improves spectrum utilization. However, nodes with higher number of idle channels and low residual energy can also be elected as CHs, which leads to a faster death of the node.

In Distributed Spectrum-Aware Clustering (DSAC) algorithm [25], each node senses the spectrum to identify the idle channels and compares it with the previously sensed result. If any change in the PU state is detected, the node declares itself as a new cluster by beaconing a new cluster ID. Otherwise, the node stays with the current cluster. The CH updates and beacons the cluster information, including cluster size and common channels. DSAC only needs to determine the local minimum distance through neighborhood information exchange and merges the locally closest pair. The communications consist of intra cluster aggregation and inter cluster relaying. The optimal number of clusters is formulated using the group-wise constrained clustering that requires at least one common idle channel for all nodes in a group to a form the cluster. DSAC requires intensive message exchange for cluster merging which makes it energy inefficient.

Centralized Spectrum-Aware Clustering (CSAC) algorithm [26] is inspired by the constrained complete-link agglomerative clustering algorithm [27] in which each node is treated as an individual cluster at the beginning and then merges the two nearest clusters in each iteration. In the initializing phase, each node senses the spectrum band and determine its available idle channels, then aggregate its own information such as their residual energy and its geographical position to the BS [28]. BS compares the distance between all nodes and finds the global minimum pair to merge first using group-wise constraint to form clusters.

Fuzzy Logic was initially introduced by Lotfi Zadeh [29] to model the vagueness of real world with approximate reasoning rather than exact values. It has proven to be more accurate than the probabilistic models as it is capable of forming clusters based on multiple criteria. The decision making process of Fuzzy logic is described by 3 steps. First is the fuzzification, which converts crisp values into linguistic variables. Second, the fuzzified data is fed into the fuzzy inference system to manipulate linguistic variables and produce the fuzzy output. The fuzzy inference engine apply the predefined rule base to manipulate the linguistic variables taken as the input. The rule base consists of different IF-THEN rule clauses according to the requirement. The output of fuzzy numbers is found, composition of IF-THEN clauses. The number of rules depends on the number of linguistic variables and membership functions. Finally, the third step is the defuzzifier, which converts fuzzy output into crisp values again which is the actual output of the system.

Membership functions are used in both fuzzification and defuzzification to map the non-fuzzy input values to fuzzy linguistic values and vice versa. It is a graphical representation of the magnitude of participation of each input [30]. It associates a weight with each of the processed inputs, defines functional overlap between inputs, and ultimately determines the output response. The rules use the input membership values as the weighting factors to determine their influence on the fuzzy output sets of the final output conclusion. The Mamdani Min-Max inference [31], in which the membership functions for input variables are first combined inside the IF - THEN rules using AND ($\cap$ or Min) operator, and then the output fuzzy sets from different IF - THEN rules are combined using OR ($\cup$ or Max) operator to get the common fuzzy output.

The fuzzy logic clustering proposed by Gupta [32] used a fuzzy inference system that considered three fuzzy parameters to elect CH: energy level, concentration, and centrality. Each parameter is assigned three linguistic values as input, and the output assigned seven linguistic values with a total of 27 if-then rules. This approach have two stages of set-up and steady-state as in LEACH protocol, but in set-up phase, the BS collects energy level and location information of each node, and includes this information in FIS to calculate the chance for each node to become a CH. Then BS selects the node with the maximum chance to become a CH. The disadvantageous of this protocol is the unbalanced cluster size, which leads to high energy consumption of the CH that belong to cluster with dense concentration of nodes.

Fuzzy Logic Leach (LEACH-FL) [33] also proposed to enhance LEACH protocol by considering three fuzzy parameters: energy level, node density, and distance between the CH and the BS. It is similar to Gupta protocol with a set-up stage, and steady-state stage except that in the set-up stage it picks three different fuzzy parameters to apply and to obtain their output for each node. However, the clusters have different sizes and lead to quick energy depletion of the CHs belonging to high density clusters.

The fuzzy logic (CHEF) protocol [34] is also similar to the Gupta fuzzy protocol but it does not have a BS to collect information from all sensor nodes. The protocol is divided into rounds and in every round, each node chooses a random number between 0 and 1. If the random number is less than the predefined threshold similar to equation 1, then that node becomes a tentative CH. Two fuzzy parameters are used to select CH: residual energy of each node and local distance, which is the sum of distances that node has with all other nodes in radius R. These tentative CHs compute their chances to be an actual CH. If the chance of tentative CH is greater than the chance of other tentative CHs' chances in radius R, then this tentative CH becomes CH for the current round. Consequently, it sends an advertisement to all nodes in its proximity. The nodes that have not been selected as CH join the closest CH. Therefore, it is possible that CHs aren't well distributed in the area. Consequently, some nodes will find themselves uncovered, and have to send their data directly to the BS. In addition, the distance between CHs and BS is not considered, which lead to unbalanced energy consumption [35].

This paper considers channel availability as part of spectrum cluster formation process and develop an energy efficient protocol, which is suitable for CRSNs, as inspired from [36]. The fuzzy clustering formation is divided into rounds and each clustering round is composed of a set-up stage and a steady-state stage. The main difference lies in the set-up stage precisely at the period of cluster formation. The non-CH nodes compute a chance value for each CH by applying the FIS, where three descriptors are considered namely Residual Energy (RE), Closeness to BS (C_{BS}) and Node Degree (ND). The rest of the paper is organized as follows. Section 2 focuses on the proposed energy efficient spectrum aware fuzzy clustering protocol. Section 3 provides description of the network model. Section 4 presents simulation environment, performance metrics, simulation scenarios and analyzes the simulation results. Finally, Section 5 provides the conclusion and future work.

2. Proposed Energy Efficient Spectrum Aware Fuzzy Clustering Protocol

The proposed clustering algorithm uses Mamdani fuzzy inference system which is the most commonly used fuzzy method due to its simple structure of 'min-max' or "AND-OR" operations. The fuzzy output is the nodes with the highest chance to become CHs for the current round. Three fuzzy parameters of residual energy, distance to BS and node distribution are used. A candidate CH node calculates the spectrum aware clustering factor which is a composition of spectrum availability (SA) and chance (F) output of the fuzzy logic.

SA value is defined as

$$\boldsymbol{SA} = \frac{\boldsymbol{c_i}}{\boldsymbol{m}} \qquad (5)$$

Where $c_i$number of is idle channels sensed by the candidate CH and m is the total number of channels. Both channel availability and chance values are multiplied and broadcasted to the neighbor nodes in radius R. If the advertised value received by another node is higher than node parameter, then this node resets it status to a CM and join the nearest CH through a pair wise constraint.

The chance (F) is calculated, in setup phase, using the fuzzy rule based on three fuzzy parameters of Residual Energy (RE), Closeness to BS (C_{BS}) and Node Degree (ND). RE is the difference between the initial energy and the consumed energy. C_{BS} is the distance between a node and the BS, which is calculated based on received signal strength and is measured at the node itself (when nodes are static, closeness remains fixed throughout the node lifetime). A CH closer to BS have high chance compared with other faraway CH. Finally, ND describes the closeness of the nearby nodes within a radius R of the candidate CH, which effects energy consumption of that node. These three fuzzy parameters (linguistic variables) are selected because of their importance for the network lifetime and stability period of WSNs. A node is usually aware of the number of alive nodes within the R through a local information exchange. The average radius of a preferred cluster dimension R is evaluated as

$$R = \sqrt{\frac{x.y}{\pi.n.p}} \qquad (6)$$

Where x and y is the dimension of network area and n is the total number of sensor nodes. If all the neighbours are located at the boundary R, then ND will be calculated as the ratio of sum of distances of all neighbours node and the maximum distance of the neigbours node.

$$ND = \frac{\sum_{i=1}^{\#\,of\,neigbors} \sqrt{(x_i - x_{CH})^2 - (y_i - y_{CH})^2}}{\#\,of\,neigbors\,.R} \qquad (7)$$

Where $(x_i\,,\,y_i)$ is the coordinate of n_i. The lower the ND value, the lower the energy consumed for the intra-cluster communication by CH and cluster member nodes.

Each linguistic variable is divided into three levels: low, medium, and high for remaining energy level and node distribution; and Close, medium, and far for the distance to the BS [37]. Many types of membership functions are available in the MATLAB Fuzzy Logic toolbox including Triangle and Trapezoidal membership functions, which are more useful than the other types because their degree is more easily determined [38]. The linguistic variable for middle level is defined as (medium) by a triangle membership function, while both sides levels (low, high, close, and far) are defined by a trapezoidal membership function. The linguistic variable for chance value is divided into 9 levels as: very weak, weak, and little weak, little medium, medium, high medium, little strong, strong, and very strong. The trapezoidal membership function is used to represent both sides, and triangle membership function is used to represent other chance levels. The chance value calculation is evaluated using predefined fuzzy if-then rules to handle the uncertainty. Since there are three fuzzy input parameters each is divided into three linguistic variables, then 27 possible chance values from the fuzzy if-then rules. Centroid defuzzification method is used to calculate the chance value for clustering formation.

3. Network Model

The network consists of 100 nodes that are deployed randomly within the defined network area of 100mx100m. Nodes use single hop transmission in relaying data to the BS, which is located at location (50m, 50m). For the purpose of clustering, each node construct its own view of the topology and spectrum availability based on the information received from its neighbors within radius R. The neighboring nodes are assumed to have highly correlated sets of idle channels, and therefore, clusters are decided primarily by the physical topology as in leach. Furthermore, the optimal number of clusters is defined as the desired ratio of CH, “p” and is set to 0.2 for all simulations, as it produces the most optimal results.

The energy model is based on IEEE 802.15.4-compliant ChipCon CC2420 transceiver [39]. The energy consumption is evaluated based on [8] and all nodes have same initial energy of 0.5 joules. The communication channel between nodes is modeled using a realistic lognormal distribution as a realistic environment for the smart grid applications [9] as defined in equation 8.

$$[\mathrm{PL}(d)]_{\mathrm{dB}} = [\mathrm{PL}(d_0)]_{\mathrm{dB}} + 10\ \ \beta\log\left[\frac{\mathrm{d}}{\mathrm{d_0}}\right] + \ \ [\mathrm{X}_\sigma]_{\mathrm{dB}} \tag{8}$$

Where $\mathrm{PL}(d_0)$ is the path loss at a reference distance d_0 (87 m), and β is the path loss exponent. The shadowing term X_δ is a zero-mean Gaussian random variable.

The traffic model is also based on common data traffic load expected for most smart grid WSN-based applications [8], where sensor nodes generate data packets at one-second intervals. All nodes are assumed to have same packet arrival rate of (packets per second (pkts/s)) and with a Poisson distribution. The packet size is 64 B and nodes have similar data priorities. Lengths of the packets generated by the sensor nodes are generated from a uniform distribution between 64 and 102 bytes.

4. Simulation Environment

MATLAB is used to evaluate performance of a CRSN with a 100 SUs. To simplify the network model, the number and activities of PUs are both assumed fixed during simulations, with number of PUs is 7 and number of sensed idle channels are 5. Nodes are randomly deployed in 100m×100m area for a total number of rounds of 7000. The performance metrics evaluated are: data packets sent to BS, number of nodes alive during rounds, number of dead nodes during rounds, and energy consumption. Data packets sent to the BS is the measure that how many packets are received by BS for each round. Number of nodes alive is a parameter that describes number of alive nodes during each round. These parameters depict stability period, instability period and network lifetime. Stability period is period or round up to which all nodes are alive (from start of network until the death of first node) whereas, instability period is period from the death of first node until last one. Lifetime is the time interval from the start of operation until death of the last alive node due to battery exhaustion. The larger the stability period and the smaller the instability period are, the better the reliability of the clustering process of the WSN is. There is a trade-off between the reliability and lifetime of the WSN. In some cases the last alive node can still provide feedback, but this could in most cases be unreliable. Therefore when assessing the performance of the all protocols, a good balance between the stability and instability periods should be considered.

4.1. Simulation Results and Analysis

The proposed energy efficient and spectrum aware fuzzy based clustering protocol is compared with four protocols. First, the basic non cognitive clustering (inspired by Leach) protocol that computes a probability to become a CH. Second, a centralized leach protocol that takes remaining energy into consideration (inspired by Leach-C). Third, a cognitive spectrum aware (non-fuzzy) clustering protocol that takes remaining energy and spectrum awareness into account (inspired by Cogleach) which uses the number of channels sensed idle by the node to determine node rule in a round. Finally a fuzzy energy efficient protocol (inspired by CHEF and is called here fuzzy leach), which is not spectrum aware.

Fig. *1* depicts the number of data delivered to base station. The proposed protocol delivered more data to BS compared to other protocols. It goes linearly up to 1500 rounds when nodes start to die, as shown in Fig. *2*, and protocol enter unstable period up to 2500 rounds and after that the difference with proposed protocol can be seen. However, Leach protocol causes nodes to die out faster as it is not either energy aware nor spectrum aware and packet loss cause more energy consumption. It is unstable from 1000 rounds up to 1500 rounds where all nodes die with high rate. The Leach-C protocol follows the same behavior with a longer stability period as shown in Fig. *2* and delivers the lowest amount of data to BS because it takes remaining energy into consideration. The fuzzy energy efficient protocol perform well as it consider multiple criteria. The proposed is both energy efficient and spectrum aware protocol that can deliver more data with longer instability period. The proposed protocol perform well and prolong network lifetime and successfully deliver highest number of data to base station because CHs are optimally elected based on all criteria.

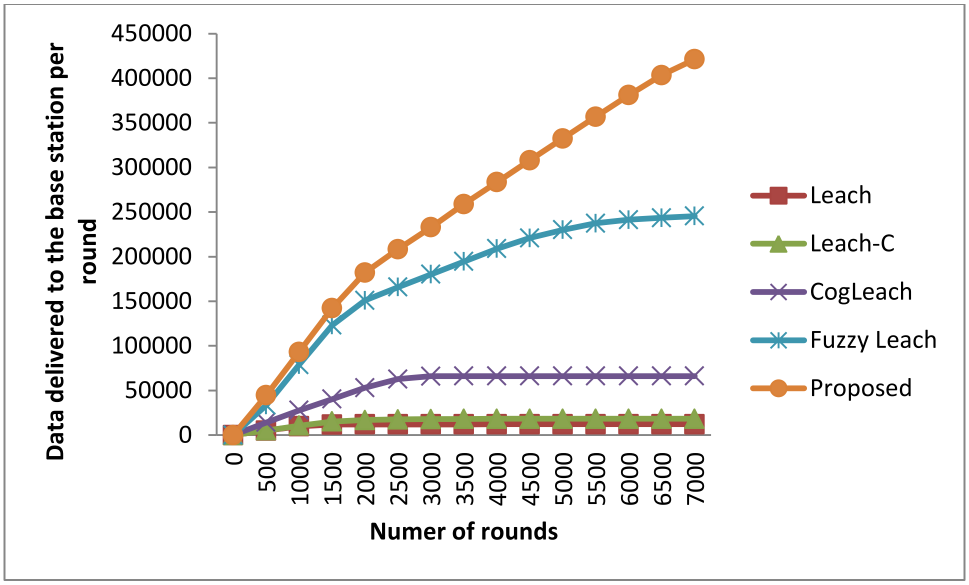

Fig. 1. Number of Data Delivered to Base Station per round

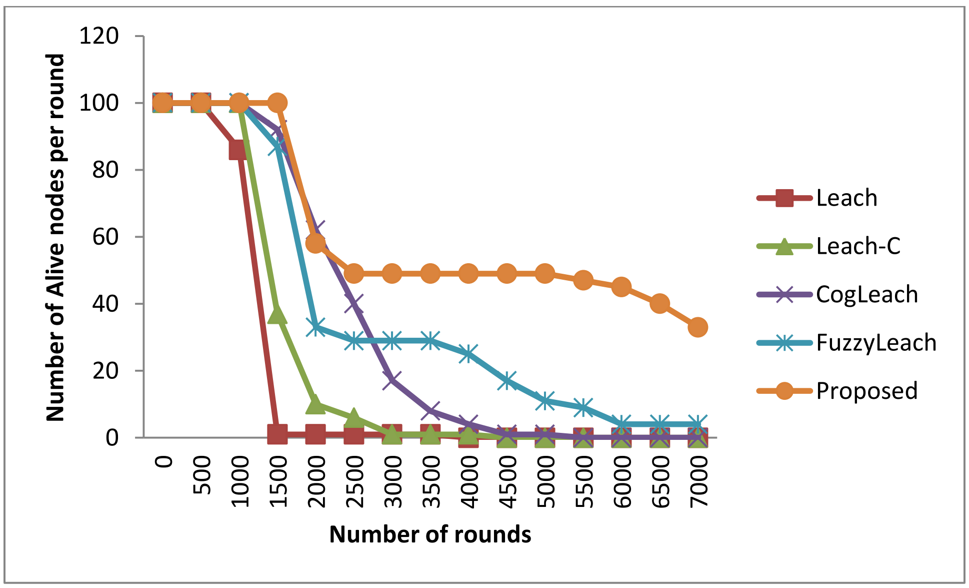

Fig. 2. Number of Alive Nodes per Round

Fig. 2 shows the number of alive nodes over time. The first node start to die at 500 rounds for leach and 1000 rounds for Leach-C, CogLeach and fuzzy leach while it increases to 1500 rounds for the proposed fuzzy protocol. The instability period of Leach is shorter than Leach-C which has few number of CHs to be elected in the region of 1000 and 3000 rounds, after that all nodes are dead. Fuzzy Leach nodes start to die after a higher number of rounds with a slower rate from 1000 to 3000 rounds. It has longer unstable period, from 1000 to 6000 where a few number of nodes can be elected as CHs. The reduction in number of CHs introduces instability in network and CHs election process becomes unreliable. The stability period and lifetime of proposed fuzzy protocol is longer than other protocols with first node dies at 1500 rounds as it elects CHs based on ratio of residual energy of nodes and average energy of the network in respect to the optimum number of CHs.

Fig. 3 clearly shows the number of dead nodes over time to show length of stability period length, which is very distinct from each other. It is observed that the proposed protocol achieves a clear advantage over the others with longer stability period where first node dies at 1500 rounds due to higher initial energy of the network which make the difference between all protocols. For Leach, the first node dies at 500 rounds and continue to dies quickly till 1500 where all nodes are almost dead. Leach performs very poorly in the presence of spectrum scarcity problem compared with other protocols. Leach-C protocol shows longer stability period till 1000 rounds and longer instability period from 1000 to 3000 rounds compared to Leach. CogLeach protocol stability period ends before 1500 rounds and instability period continues to up to 4000 rounds. Fuzzy leach has longer instability period from 1000 to 6000 with few nodes alive at the end of simulation. The proposed protocol has longest stability period and prolonged. Also the instability period is extended but with 33% nodes alive at the end of simulation. This amount of alive nods are suitable for applications with loose reliability requirements, for instance, the proposed protocol allows node death up to 53% of nodes, and still outperform all other protocols and maintaining operation up till around 6000 rounds, compared with round 1800 for same non fuzzy protocol.

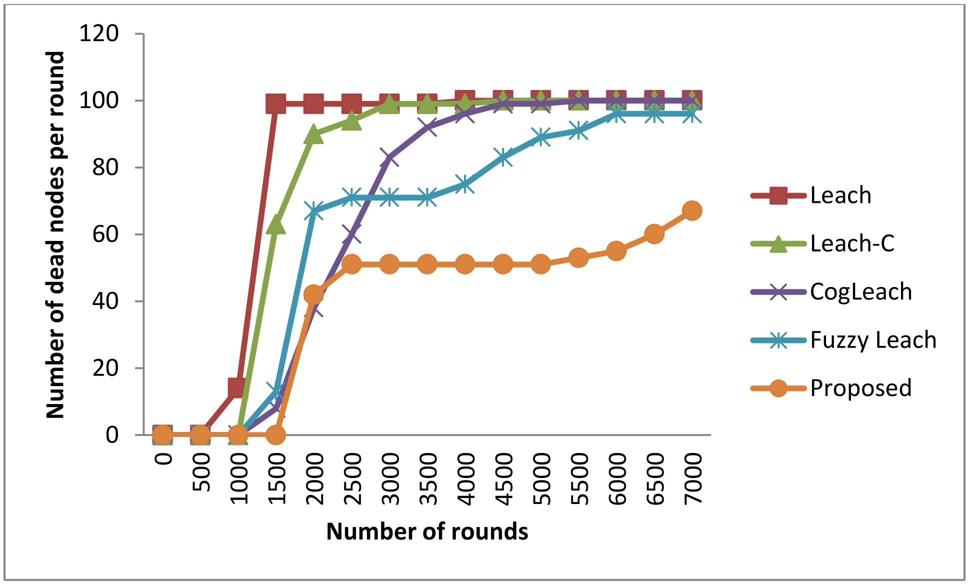

Fig. 3. Number of Dead Nodes per Round

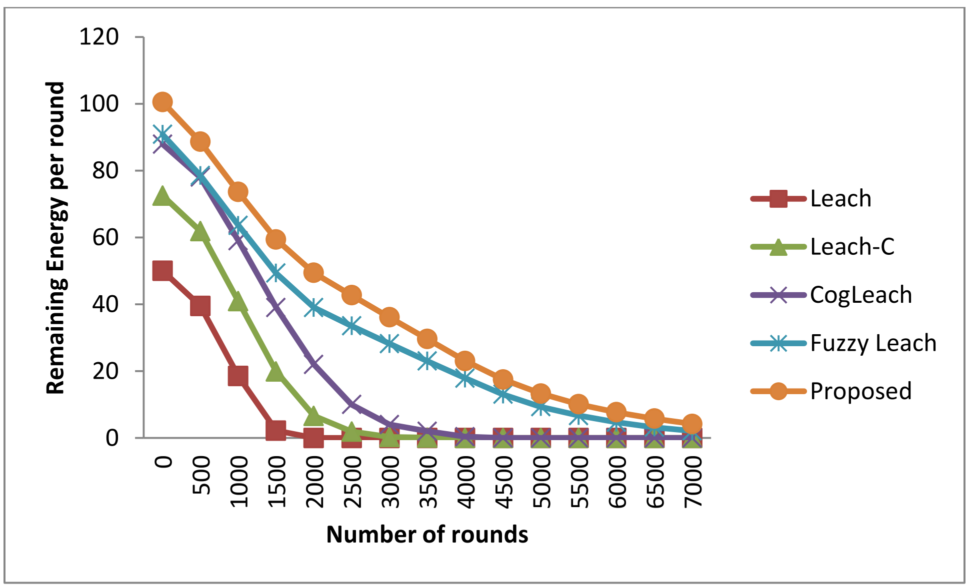

Fig. 4. Remaining Energy Per Round

The superiority of the proposed fuzzy protocol compared with other protocols can also be observed from the remaining energy. Fig. *4* compares remaining energy pattern for all protocols. For the proposed protocol, the energy remaining slope is flatter than others, therefore achieving a prolonged stability period up to1500 rounds. On the other hand, non spectrum aware or non fuzzy protocols consume all of their energy at 1500 rounds. Clearly, the proposed protocol achieves better utilization of all of network resources compared with other protocols, confirming the objective for designing the proposed protocol.

5. Conclusion and Future Work

Intelligent spectrum aware have emerged as a key technology to solve spectrum scarcity problem recently encountered in wireless communications. The existing protocols for WSNs are not specifically designed to solve such problem and are unawareness of functions introduced by cognitive cycle. They do not function properly to achieve the required energy efficient and reliable communications. Energy efficient and spectrum-aware protocols are urgently needed for the success operation of future wireless networks. The objective of spectrum-aware clustering is to adaptively select CHs according to the available spectrum resource. However, dependency on channel availability alone does not guarantee an optimal selection of CH. Therefore, fuzzy logic algorithm is used to minimize energy consumption and extend network lifetime. The proposed energy efficient spectrum aware fuzzy-based clustering elects nodes with maximum chance to become CHs. The chance was based on three fuzzy parameters: residual energy of each sensor node, closeness to base station, node degree which describes the distribution of neighboring nodes. The closer neighboring nodes lead to a smaller intra cluster communication cost and less energy consumed by cluster members which prolonged lifetime and stability period of network. Comparative performance evaluations have been conducted in terms of number of data packets sent to base station, number of alive nodes per round, number of dead nodes per round, and energy consumption. In this paper, an energy efficient fuzzy-based clustering protocol and spectrum aware was implemented in MATLAB and compared with four protocols. Two basic non cognitive clustering protocols, one that uses a probability value to elect CHs (inspired by Leach) and a more energy efficient (leach-C) were simulated, along with one spectrum aware protocol that takes number of available channels into consideration (inspired by Cogleach) and a final fuzzy protocol (inspired by CHEF) were simulated and compared with proposed energy efficient and spectrum aware protocol. The input and output linguistic variables with their membership functions have been defined to Mamdani system to draw inference from inputs using 27 fuzzy-if-than rules. This chance value was multiplied by the spectrum availability parameter.

The results clearly demonstrated that the proposed protocol enhanced network lifetime as compared to other protocols. It also extended stability period of network with a significant improvement in number of data packet delivered to base station. The proposed protocol further improved performance by taking into account multiple parameters to optimally elect CHs based on three fuzzy parameters: residual energy, node degree, and closeness to BS to equally distribute number of nodes in clusters, so that energy consumption can further be more uniform throughout the network. The results indicate that the proposed fuzzy protocol has successfully minimized the energy consumption and increased the lifetime of the network. Thus, it have optimally balanced the energy in the network and enhanced the stability period and lifetime of the network.

Some simulation assumptions were made to avoid excessive overhead and clustering instability such as the number of sensed channels are assumed fixed and the activity of the primary users were not considered. The number of PU were fixed and no new PU appearance during simulation therefore no re-clustering during simulation and it is assumed to takes place at beginning of simulation. In addition, energy model did not consider energy consumed during energy sensing, processing and transmission. All these issues will be addressed in our future works.

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