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An Improvement on LEACH Algorithm with a Fuzzy Processor

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Abstract- **Power dissipation management and hence increasing lifetime in wireless sensor networks (WSNs) is the most critical issue in the design procedure of the modern WSNs. There are many approaches through which power dissipation and lifetime of the WSNs are moderated. In this paper, we present a fuzzy rule based methodology in order to increase the power saving in LEACH algorithm. We propose a fuzzy processor to be in charge of performing fuzzy instructions. This processor is applied to track the best path online for forwarding packets instead of traditional offline table based forwarding process. In addition, this processor is capable of aggregating input data by which the network traffic is extremely reduced. Simulation results show the numerous efficiency of our methodology not only in balancing the power dissipation through network, but also in lifetime improvement, traffic management, and network availability.**

I. INTRODUCTION

WSNs are among the most important developments of the recent decade; their robust behavior allows data recording and transmission in an unreliable and non-moderated environment. These networks are composed of several nodes, which sense, record, and transmit data to the base station(s). Although WSNs provide countless advantages, they are faced with some shortcomings and limitations. Since we are unable to equip the WSNs with endless source of energy, the energy suppliers are confined to small batteries. As a result, less power consumption leads to lifetime improvement. According to this fact, most of the network routing and data aggregation algorithms are concentrated on power consumption optimization. In these algorithms, the power is considered as the most important parameter for decision-making. In many cases, several approaches are gathered to provide better consequences. Among them we can mention the approaches in which fuzzy logic [1, 2] algorithms, artificial neural network decision systems, bio-inspired algorithms, etc, are employed. Among the means which are applied in diverse algorithms, fuzzy reasoning is not only straightforward but also considerably effective. Hence, this methodology is widely used in various applications from time [3] to power constraint [4] ones.

Various methods have been provided which intend to abate the shortcomings of WSNs. These limitations include storage size, power supply, and computation power inadequacy. In order to decline these difficulties, several researchers proposed miscellaneous approaches to utilize different appliance in different layers. Among researches which propose methodologies in application layer we can mention [5, 6]. [7-9, 23] present some algorithms for power management in network layer.

One can divide WSNs routing algorithms into different categories; flat based routing, location based and hierarchical based algorithms. Balanced distribution of the data through the network might seem inefficient at the first glance, although this approach has the capability of spreading data spontaneously throughout the network. Robustness and scalability improvements are other aspects of Directed diffusion [10]. Recording data locally and tracking the pre-detected route is another approach which results in better performance in the models with small number of events [11]. However this approach requires more storage and power in order to set the pre-defined paths. While propagating the data which is obtained from the least cost path is another method with more proper performance, this behavior is extremely power hungry in a shortest path and leads to overhead in computation [12, 24, 25] Dynamical routing, energy consumption balancing and nodes selection for sensing in specific periods are the aspects, considered in information driven sensor query [13].

Cluster based algorithms may be regarded as the most successful method for energy saving in WSNs. Hierarchical algorithms play an important role in network lifetime improvement [14]. Since the first recognition of uncertainty in WSNs, several fuzzy based algorithms have been proposed for handling ambiguity. Fuzzy decision making system perceives the conditions of the environment based on the specific characteristics of the nodes. One of these approaches selects cluster-heads among the nodes of each cluster by fuzzy decision making engine. Clustering and hierarchical communication minimize the energy consumption by restricting data sending of nodes. Hence, transmission process is alleviated and it, therefore, results in less power consumption [15]. It should be mentioned that energy reserve of each node is an important parameter which should be considered in routing algorithms. The efficient routing can significantly improve the energy effectiveness and prolong network lifetime [15-17]. Traffic engineering is another substantial problem in WSNs. A method which can utilize both shortest path model and load-balancing algorithm may perform better in cases of either low or high network loads [17].

In this paper, we use an online fuzzy decision-making algorithm to distribute packet forwarding task through the nodes of the WSN. Meanwhile, the overall network traffic is reduced when an efficient fuzzy data fusion approach is used. Although processing power usage gradually rises due to the more complicated instructions and included fuzzy processor, the dominant energy consumers are transmitting components in the applications which request large amount of data back. In addition, the proposed fuzzy processor is more power efficient in processing fuzzy rules than general processing elements. Considering all of these facts, we claim that our proposed methodology leads to significant improvement in well-known LEACH algorithm. The simulation results demonstrate that our methodology leads to less power dissipation and lifetime improvement.

This paper is organized as follow: Section II contains a high level demonstration of our proposed algorithms. In section III, we have an overview on fuzzy logic and proposed fuzzy processor architecture. Section IV is mainly about our approaches in detail and their effects on the power dissipation. Section V reveals experimental results. In section VI conclusion are drawn from our simulation and both results and our future works are clarified.

II. Our Algorithms

In this section, we demonstrate our proposed algorithms, based on LEACH algorithm, including both routing and data aggregation. We equip each node of the network with a specific fuzzy processor. This processor is in charge of processing fuzzy rules. Our model, according to LEACH [18] algorithm, has two phases: Setup phase and Steady phase; in the former in addition to the actions which are done in LEACH, all cluster-heads which receive advertisement message from other cluster-heads, send their own information as a data message in return; so each cluster-head is aware of its own neighbor clusters. This information is kept by each cluster-head and is used when one cluster-head aims to forward a data packet through the network. After gathering information, each cluster head, via its fuzzy processor, sets the appropriate paths through which it can forward its packets. The path finding process is based on different factors including: distance between the selected neighbor cluster to the base station, distance between the main cluster-head and the selected neighbor cluster-head, the energy level on the main cluster-head and the energy level of the selected neighbor cluster. These parameters are fed into the fuzzy processor and the suitable neighbor cluster is elected. As these parameters change gradually, the processor performs its computation occasionally.

In the steady phase, each cluster performs a fuzzy data aggregation among received data and produces a single data packet and forwards it towards the base station. In this phase, the suitable path is selected randomly from the list of paths which is prepared in the setup phase. The proposed data aggregation algorithm is especially helpful in WSNs with nodes which can sense different parameters (multi-sensor MEMS). In this model we consider that each node can sense and record various types of data. Different types of data can be forwarded to the cluster-head in separate data packets which are labeled according to their contents or in a single packet of data with predefined format. As cluster-head gathers data packets, the fuzzy processor performs a soft computation among received data; thus, it can decide whether one packet is sent from a node which has recently experienced an event or not. The decision is based on different characteristics of the sender nodes and the data packet including: the average data which is received from other nodes, the number of members of the cluster, the previous data packet which has been sent to the base station in the preceding round, and the position of the event. After decision-making procedure, cluster-head compresses the selected data packets and forwards them to the base station. Cluster-head is responsible for forwarding separate compressed data packet for each type of data.

III. Fuzzy Logic and Processor Architecture

The term Fuzzy Logic [1, 2] emerged in the development of the theory of fuzzy sets by Prof. Lotfi Zadeh. It was first invented as a representation scheme and calculus for uncertain or vague notions. It is basically a multi-valued logic that allows more human-like interpretation and reasoning in machines by resolving intermediate categories between notations which represent linguistic variables. This was extended to handle the concept of partial truth or partial false rather than the absolute values and categories in Boolean logic.

Fuzzy inference fundamentally is the process of formulating the mapping from a given input set to an output set. The Fuzzification, Inference, and Defuzzification are the basic functions of each fuzzy inference engine. In Fuzzification operation, a fuzzy set A of a crisp set X is characterized by assigning to each element x of X the degree of membership of x in A. On the other hand, this degree of membership is determined by a membership function shape which is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. In the Inference operation, the fuzzy rules are processed and the output(s) of them are combined by some predefined functions. At last, in the Defuzzification [19] step, the crisp outputs are generated.

In each hardware implementation of fuzzy engines, evidently, power and time efficient processing are major issues. The proposed architecture (Fig. 1) not only is capable of processing time constraint applications, but also is significantly computation and power efficient [21]. The processing starts with active rule detection [22]. This preprocessing performs rule exploration for activation. As a consequence, the active rules are found and therefore, the processor performs its process on the effective rules only. After the recognition of first active rule, the fuzzy operation on inputs and rules are started. The premise

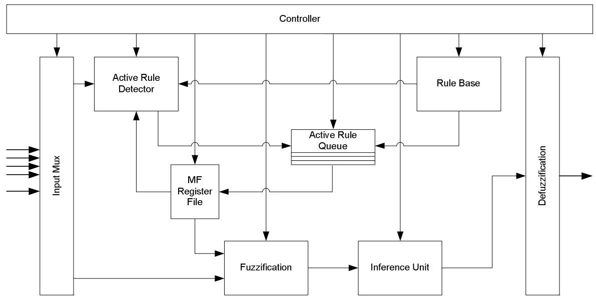


Figure 1. Architecture of the proposed fuzzy processor.

predicate selects appropriate membership function in the MF register file. The MF register file, then, send the selected membership function information to the Fuzzification unit. The degree of membership is calculated by a multiplier and adder in the Fuzzification unit.

In the next step, the Inference unit calculates the minimum value among premise predicates. Since we use Sugeno [20] model, the Deffuzification unit uses the minimum value which is calculated in the prior unit to calculate the weighted average among rules' consequents. A multiplier, two adders, and a sequential divider perform these consequent calculation functions. Due to the sufficient time between productions of divider inputs, the sequential divider is more power and area efficient. In addition, in this pipeline architecture, the controller synchronizes units. Furthermore, it initiates the pipe and halts the operations when neither the rules are ready nor available.

IV. Detail of Improved LEACH Algorithm

A. Fuzzy Routing – LEACH Algorithm

Our proposed routing method based on LEACH algorithm is consisted of two phases. In the setup phase, not only are clusters developed but also are neighbor information schedules assembled and the values of the next nodes are indicated by the fuzzy engine. In the steady phase, the algorithm performs a random selection among values which were processed in the previous phase and forwards both the received and generated packets. The routing algorithm with random value selection among respected nodes shows a better behavior in distributing packets in an uncertain environment. In addition, in each phase, the algorithm dynamically processes path values. Both of these characteristics lead to a flexible behavior in data forwarding.

Our fuzzy inference engine employs three parameters to process next hub value. The first parameter is the distance between node and base station. The second factor is the distance to the next hub which leads to more efficient message forwarding. Nodes, consequently, select the hub with considering both remained energy and distance; therefore, the system shows adaptive behavior and balanced energy consumption. Consequently, we try to exclude low-energy nodes which probably die sooner. We apply three membership functions for these factors: high, medium, and low. The nodes with high energy and low distance to selector node are more likely to be selected as the next hub. In Fig. 2 and 3, the proposed pseudo codes are shown.

One of the critical issues of WSNs is constancy of the networks. Cluster-heads play the most important role in the data transmission procedure; therefore, they are expected to lose all their energy and die. This case is anticipated when the network has already lost most of its energy. When a cluster-head dies, other members of the cluster are not able to forward their packets to the base station.

The worst case happens when members of the cluster are unaware that the head has died; as a result, they

For each H_i in cluster-head collection
Obtain H_i information
If H_i to base station distance < self to base station distance
V_i=Process H_i value using fuzzy inference engine;
$V_i=V_t+V_i$;
$V_t=V_i$;
$V_t= V_t+0.05\ V_t$;

Figure 2. The proposed fuzzy routing algorithm in clustering phase.

For each received or generated packet
Generate a random value between 0 and V_t
Find the H_i which the generated value is in its region
If this node is not found
Send the message directly to the base station
Else forward the message to H_i

Figure 3. The proposed fuzzy routing algorithm in transmission phase.

regularly forward their packets to a death node and lose energy without any outcome. In order to overcome this dilemma, we set a new strategy in the proposed LEACH model. Whenever the cluster-head aims to forward data to the base station, it checks its energy level. If its energy level is less than a threshold value, it broadcasts a message to other members of the cluster and informs them about the unavailability. Consequently, members of the cluster avoid forwarding data to the head; instead, they can wait for the later clustering phase or they can perform their operation. Another important consequence of routing algorithms is the danger of packet-looping condition; in such situations, each packet turns in a loop which is composed of cluster-heads. We avert such dilemma by implementing an avoidance policy in our model. When cluster-heads intend to find paths, the fuzzy processor selects next neighbors according to their distance from the base station.

B. Fuzzy Data Aggregation

Data aggregation is done by the fuzzy engine of the cluster-head. The fuzzy engine tries to combine and fuse sets of data which are correlated to each other. This unification is done based on different features of the network and factors which are considered inside the cluster. One of these factors is the average of the received data in each round by which the processor can become aware of environment noise (for different categories, separated averages are computed). These average values are compared with each data packet obtained from all members. The distance, event position, type, and difference between the average and the last sent data are considered by fuzzy engine to use input data and create output information. Likewise, each cluster-head keeps a copy of the preceding data a packet which is transformed to the base station. Consequently, less data transmission occurs in the network which results in less energy consumption. In Fig. 4, we have shown the fuzzy data

For each input set
Calculate average of received data;
For each received data (D_i)
C_i= received data coefficient using fuzzy engine;
$C=C+ C_i$;
$D_p= D_i*C_i+ D_p$;
$D_o= D_p/C$;
Save D_o for next step;

Figure 4. The proposed data aggregation algorithm.

aggregation pseudo code.

It should be signified that one can alter the range of accuracy; by which one can control the precision of the data. However, forwarding noisy data may not always result in higher precision. The last factor which is used in decision-making policy is the denseness of the cluster. When a cluster is dense, more nodes may sense the same data; therefore, their data might be less noticeable in comparison to the energy which is used for transmitting that packet. All of the above features lead to less energy consumption and on the whole contribute to a long life WSN.

V. EXPERIMENTAL RESULTS

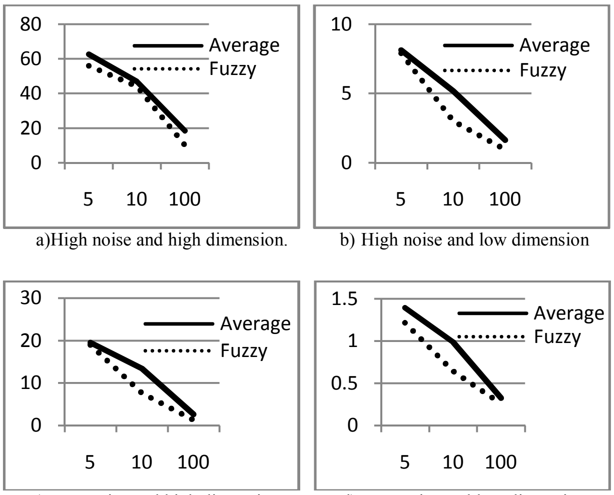
A. *Fuzzy Routing*

With the intention of simulating our routing method, we implemented the C# based model and tested the model changing different parameters; therefore, we claim that the results which are provided by simulation scheme are sensitive towards various parameters including: number of nodes in a WSN, number of clusters and transmission energy load. Based on the fact that our routing scheme is an intra cluster routing method, the number of clusters plays an important role in the results. In other terms, increasing the number of clusters provides us with more opportunities for routing and therefore less power dissipation will be accomplished. In order to present an accurate result and comparison based on the routing method, we compare our results with the outcomes which are acquired by the traditional LEACH algorithm.

We simulate a WSN with 100 nodes and we set the clustering probability at 5%. The nodes are uniformly distributed through the network. According to Fig. 7, that depicts the number of live nodes throughout the simulation time steps, it is clarified that during the time steps, our approach results in more live nodes. It should be mentioned that the shown diagram reveals two important characteristics of our model: first, our model bring about a balanced reduction of energy though the network because the simulation results show that nodes die in a balanced manner. Secondly, the network lifetime is improved. Rules play a crucial role in our system. It is possible to improve network lifetime when balanced power consumption constraint is unnoticed. In this case, the nodes try to forward the packets without considering next hub remained energy; however, this approach leads to more energy consumption in the nodes which are in the shortest path. Furthermore, while in some algorithms lager number of nodes abates the performance, in our model, rise in number of nodes improves our performance due to its highly distributed policy which needs just local information. It should be apparent that the number of clusters grows in WSNs with more nodes, which directly results in more routing options for our model, better routing paths and finally less power consumption.

B. *Fuzzy Data Aggregation Results*

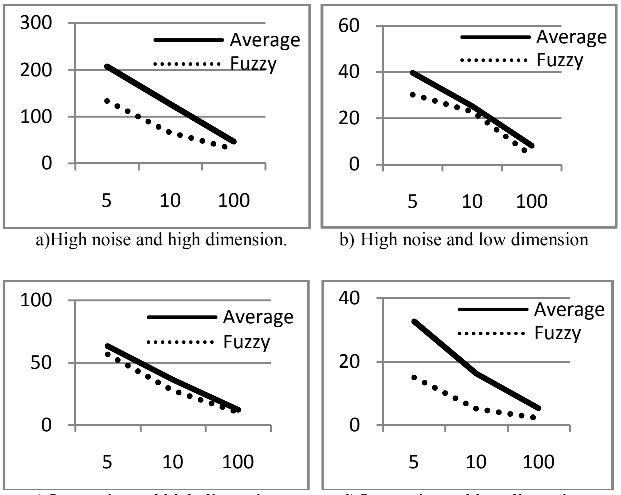
In order to simulate our fuzzy data aggregation algorithm, we provided different kinds of noises like uniform noise, normal noise, etc. With the purpose of testing our data aggregation scheme, we applied two different types of



a)High noise and high dimension. b) High noise and low dimension

c) Low noise and high dimension. d) Low noise and low dimension

Figure 5. Noise percentile versus number of nodes with normal noise.



a)High noise and high dimension. b) High noise and low dimension

c) Low noise and high dimension. d) Low noise and low dimension

Figure 6. Noise percentile versus number of nodes with uniform noise.

noise to the targeted WSNs: uniform noise and normal noise. For each case, we have examined the model with both high and low noise and we studied the effect of dimension enlargement on the WSN. On the other hand, we have intended to specify the effect of number of nodes on the model; therefore, we have analyzed the model with different number of nodes. It should be mentioned that the dimension of WSN and number of nodes in the model plays a considerable role in the performance of our design. All of these parameters are studied through the analyses which are done over the simulation outcomes. Consistent with the Fig. 5 and 6 which are demonstrated in this section, we can state that the fuzzy data aggregation algorithm brings about less error in received data; while, the percent of the latter accuracy is influenced by different factors like dimension, number of nodes and so forth. In an environment with Gaussian noise with different dimensions, the proposed algorithm has an average of 10% better accuracy and less error. In addition, this approach easily leads to lower than 20% average error. The average error in similar environment with lower noise is less than 10%. This error rate would be accomplished by data averaging approach by twice as more node as our proposed algorithm requires. In an environment with lower size, this algorithm leads to better performance. The

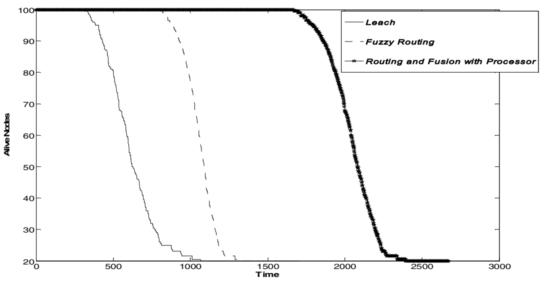


Figure 7. The performance of the proposed methodologies.

Fig. 6 illustrates the performance of the proposed algorithm in a system with uniform noise. As it is shown in this figure, the fuzzy data aggregation algorithm has 8% better data error rate when both the noise of the system and size of it are high. This algorithm leads to lower than 10% error in a high size with low noise environment. Considering all of above facts, our proposed methodology can significantly reduce average error in comparison to data averaging methodology.

C. Results of Running Algorithms on Processor

We amalgamate both of these methods to verify the magnified effects of each of them on power dissipation and lifetime improvement. While the transmission power dissipation is dominate in WSN applications which request large amount of data back, we consider processing power dissipation due to the more sophisticated processing scheme. The bottleneck of fuzzy processing is fuzzy data aggregation. This process is run in each period. The synthesis result of the processor [21, 22] show that the power dissipation of it is negligible in comparison to the other power hungry components such as IO and transmission components. The performance of the improved LEACH algorithm with fuzzy processor is illustrated in Fig. 7.

VI. Conclusion and Future Work

We proposed fuzzy routing and data aggregation algorithms to reduce WSNs power consumption. The proposed fuzzy data fusion algorithm reduces the overall packets needed to be transmitted through the network and the proposed fuzzy routing algorithm distributes packets through the network. The combinations of these algorithms uniformly balances power dissipation of the network and consequently, the network lifetime increased noticeably. According to the fact that, fuzzy processing is a complex function to be run in a general processor or controller of a simple node, we propose a fuzzy processing scheme to be included in WSNs nodes. The simulation results show the efficiency of this methodology. The efficient architecture of the fuzzy processor not only effectively performs complicated fuzzy routing and data aggregation algorithms but also does not cause any significant power dissipation overhead.

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