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Load-Based Fuzzy Logic Approach to Cluster-Head Election for Wireless Sensor Networks

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***Abstract*— The lifetime of Wireless Sensor Networks (WSNs) were limited by the fact that sensor nodes are battery-powered and communication is the main source of energy consumption. Once deployed, the entire network lifetime shows a strong dependency on the battery lifetime of individual nodes. Therefore, WSNs can only subsist on while the battery power is adequate. One of the popular solutions in overcoming this handicap is by using the clustering technique where cluster-heads will be appointed among the sensor nodes with the network divided into several groups. Cluster-heads are responsible to aggregate data collected by its cluster member and transmit it back to the base station. In this paper, we proposed protocol of a centralized cluster-head election mechanism using fuzzy logic since it is capable of exhibiting the situations from the real-world more closely. This protocol uses node' energy, node's centrality and distance as the fuzzy descriptor to elect cluster-head. To justify the efficiency of the proposed protocol, comparisons have been made with protocols proposed by Gupta et al. and Z.W. Siew et al. using the simulator, Matlab. Simulation results demonstrate that the proposed protocol performs better than the other two in terms of network lifetime, residual energy and the number of alive nodes.**

***Keywords*—Wireless Sensor Network, Cluster, Clustering, Fuzzy Logic.**

I. Introduction

Wireless Sensor Networks (WSNs) usually consist of tens to hundreds sensor nodes operated under limited energy supply and computational capabilities [1]. Sensor nodes collaborate among themselves to form a sensing network by means of wireless channel to gather data and cooperative processing. They communicate with one another either directly or through other nodes, accumulate the data and relay it back to the base station [2]. Sensor nodes are usually placed in unattended geographic areas and application domains are diverse in this field ranging from environmental monitoring, military purpose to gathering sensing information for disaster management [3]. Under most circumstances, the environment to be monitored does not have an existing infrastructure for either energy or communication and the sensor nodes are expected to be operating for long periods of time equipped only with battery under harsh terrain. Nevertheless, with large number of physically distributes nodes expected in sensor network and the unpredictable nature of deployment conditions, it increases the difficulty of changing or recharging batteries during operational times. Therefore, to minimize energy consumption the development of appropriate routing strategies must harmonize with the available energy resources.

Clustering is one of the routing approaches than can help in attaining more energy efficient network condition [4]. A typical clustering protocol will requires that certain sensor node to be elected as the cluster-head (CH) and the remainder as its cluster member (CM). CHs are responsible for coordinating the data gathering process from their respective group or cluster and will eventually go through the aggregation process by sending the collective data back to the base station. By partitioning the network into several groups it allows the reduction of a significant amount of traffic overhead because the process of data accumulation are done locally by the cluster head within its own cluster and only the aggregated data will be sent back to the base station.

In this paper, we proposed a protocol of centralized cluster-head election mechanism by using the fuzzy logic approach with three fuzzy variables - energy, centrality and distance. The base station will elect the eligible nodes and appointing them as the cluster-head based on some fuzzy descriptors. Sensor nodes with a higher fuzzy chance will always be given the priority compared to nodes with lower fuzzy chance. Fuzzy logic can be built using a set of linguistic rule by creating a fuzzy system to match any set of input-output data without precise knowledge of its surrounding [5]. Fuzzy logic models, called the fuzzy inference systems, consist of a number of conditional "if-then" rules [5]. Rather than declaring data into standard conditional logic of true and false, a fuzzy inference system takes into accounts the ambiguities of data by giving it a level of confidence [5][6]. Taking the air conditioning unit for example, a fuzzy system is capable of deciding whether a room is "normal" "warm "very warm" or "hot" [6]. Thus, the system can decide to cool down a "little" "a good amount" or "a lot" when the temperature of a room dropped below a certain degree. These terms can be seen as imprecise and yet very descriptive of what must actually happen. Moreover, the fuzzy inference system can be used to blend different types of environment parameters to supply as many rules as necessary in order to describe the system adequately.

The proposed protocol will be compared to Gupta et al. [7] that used concentration, energy and centrality as the fuzzy variable and Z.W. Siew et al. [8] that also utilized fuzzy variable of energy and distance into the cluster-head election.

The rest of this paper is organized as follows. In section II, both protocols Gupta et al. [7] and Z.W. Siew et al. [8] will be briefly discussed. Section III introduces the proposed protocol while section IV will further explain the simulation model along with two sub-topics which are the radio model and simulation results. Finally, in section V, are the summarizations of the overall paper.

II. Related Work

A. Cluster-Head Election using Fuzzy Logic for wireless sensor networks

Gupta et al. [7] introduced a centralized protocol using fuzzy logic for cluster-head election. They presented three fuzzy variables which are the energy, concentration and centrality to prolong the network lifetime. The fuzzy variable energy is referring to the power resides in each node, concentration is the amount of neighbour nodes and centrality is a value based on how central the node to the cluster. To find the node centrality, the base station selects each node and calculates the sum of the squared distance of other nodes from the selected node [7]. The disadvantage of this protocol resides in the fuzzy variables. Both concentration and centrality are focusing heavily on having the maximum connectivity and neglected the possible workload that shall be managed by the cluster-head selected. By focusing merely on node with high connectivity can only drain the node's energy faster due to the amount of traffic received by that particular node.

B. Fuzzy Logic based Cluster Head Election for wireless sensor networks

Similar to Gupta et al. [7], Z.W. Siew et al. [8] also proposed a centralized protocol that requires that the cluster-head election process being performed centrally at the base station. They offered energy and distance as the fuzzy variable where energy stands for node's energy and distance as the distance between the node and the base station. This protocol avoids creating early coverage holes by not selecting sensor nodes that are closer to the base station as cluster-head. But even so, the lifetime of the network can only be extended for a certain time as no consideration has been made regarding the amount of workload one sensor can take.

III. The Proposed Load-based Fuzzy Logic Approach

Fuzzy inference is the process of formulating the mapping of a given input to an output using fuzzy logic. The most commonly used fuzzy inference technique is the Mamdani method due to its straightforwardness. It is consists of four steps: fuzzification of the input variables, rule evaluation, aggregation of the rule outputs and defuzzification [9]. In the first step, fuzzification is the process of determining the degree to which the crisp input variables: energy, centrality and distance belong to the appropriate fuzzy sets via membership functions. Subsequently, during the rule evaluation processes it will take the fuzzified inputs and evaluate them to the antecedents of the fuzzy rules. Third stage involved aggregation of the rule outputs by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Lastly, defuzzification will transform the aggregated output of fuzzy set into a single crisp value of final output. One of the defuzzification methods are the centroid technique. It finds the point where a vertical line would slice the aggregated set into two equal masses [9]. Mathematically, centre of gravity (COG) can be expressed in (1) with $\mu_A(x)$ as the membership function of the fuzzy sets [9].

$$\text{COG} = (\Sigma\mu_A(x)*x)/\Sigma\mu_A(x) \qquad (1)$$

Three of the important descriptors that directly influence the process of fuzzy controls are the energy, node centrality and distance. Energy can be defined as the energy level available within one's node while node centrality prioritises on node with low values of betweenness centrality or participate less in shortest path. The descriptor distance is described as the distance between the node and the base station. Reasonably, sensor node with high energy level will always be in favour. Meanwhile, node centrality targets at identifying nodes with low participation in the number of shortest paths. This method helps by distributing the workload among sensor nodes and avoids overloading nodes with high connectivity. Using the base station as a mark, nodes that are medium range away from the base station will be given the priority as oppose to closer range. The logic behind this set up is to relieve nodes that are nearer to the base station to be elected as cluster-head and creating coverage hole in the early stage of network lifetime.

The set of decompositions for the linguistic variables of energy can be outlined as high, medium and low. Naturally, node with higher amount of energy will be preferred follow by medium range and finally lower energy. For node centrality, the linguistic variables are defined as high and low with the latter being set as priority to achieve a more load balancing network. On the other hand, the linguistic variables for distance are close, medium and far with medium ranking first followed by close then far. The detailed fuzzy sets variables energy, node centrality, and distance are described in Table I. All sensor nodes will be compared based on chances and the node with higher chance is then elected as the cluster-head. The output to represent the node cluster-head election chance was divided into nine levels which are very high, high, rather high, medium high, medium, medium low, rather low, low and very low.

TABLE I. FUZZY IF-THEN RULES

	Energy	Centrality	Distance	Chance
1	High	Low	Medium	vHigh
2	High	Low	Close	High
3	High	High	Medium	High
4	High	High	Close	High

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	Energy	Centrality	Distance	Chance
5	High	High	Far	rHigh
6	High	Low	Far	rHigh
7	Medium	Low	Medium	mHigh
8	Medium	Low	Close	mHigh
9	Medium	High	Medium	Medium
10	Medium	High	Close	Medium
11	Medium	High	Far	mLow
12	Medium	Low	Far	mLow
13	Low	Low	Medium	rLow
14	Low	Low	Close	rLow
15	Low	High	Close	Low
16	Low	Low	Far	Low
17	Low	High	Medium	vlow
18	Low	High	Far	vlow

Legend: vHigh = very high, rHigh = rather high, mHigh = medium high, mLow = medium Low, rLow = rather low, vLow = very low

IV. Simulation Model

In this simulation environment, assumptions have been made that all sensor nodes will always have data to send to its cluster-head. The cluster-head will aggregates the collected data and eventually transmits the aggregated information back to the base station. All sensor nodes are homogeneous and are expected to be quasi-stationary once deployed. The base station is assumed to have an unlimited power resource, processing power, and storage capacity and is located in the middle of the sensor's field with no mobility. It is also presumed that the channel is symmetric so that the energy spent on transmitting from node i to node j is the same as transmitting from node j to i. An upper bound on the number of cluster-head available is fixed and is known a priori which will be referred to as the cluster-head probability throughout this paper. Based on the simulator seeds provided by the random number generator, sensor nodes will have a random level of initial energy to imitate the harness of energy available. The same random seeds were used to generate an identical simulation environment for all three protocols. Finally, at the beginning of each cycle a new set of cluster-heads shall be elected and clusters are formed. There is an equal period of time called round where sensor nodes forward the sensed data back to its respective cluster-head.

A. *Radio Model*

The first order radio model illustrated in Figure 1, is a very simple and frequently used energy dissipation model to compute the expected energy consumption rate in the transmission and the reception of data in a sensor network [10]. Based on Table II, E_{elec} represent the energy spent per bit in transmitting and receiving data for a sensor and ε_{amp} is the energy dissipated per bit in the amplifier. Accordingly, a sensor node consumes energy while receiving and processing a message. Therefore, the amount of energy spend is also proportional to the number of bits in the message.

TABLE II. SPARAMETERS FOR FIRST ORDER DISSIPATION MODEL

Parameters	Value
Energy for radio transmission, ε_{amp}	100pJ/bit/m^2
Electronic energy, E_{elec}	50 nJ/bit

Thus, to transmit k-bit packet from the sender to the receiver over the distance d, the amount of energy consumes can be obtained from (2). Where else the amount of energy consume during receiving k bits can be calculated using (3).

$$E_{Tx}(k,d) = E_{elec}\, k + \varepsilon_{amp}\, k(d^2) \tag{2}$$

$$E_{Rx}(k,d) = E_{elec}\, k \tag{3}$$

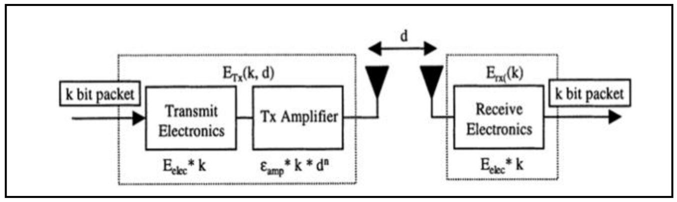

Figure 1. The first order energy dissipation model. [10]

B. *Simulation Results*

The comparison between Gupta et al. [7], Z.W. Siew et al. [8] and the proposed protocol were implemented using Matlab. The simulation network consists of 100 sensor nodes that are randomly distributed in a square field between (0, 0) and (200,200) meter.

TABLE III. PARAMETER SETTINGS

Parameter	Value
Network Grid	From (0,0) to (200,200)
Base Station Position	(100,100) m
Number of nodes, n	100
Initial Energy, E_0	1 J
Data Packet Size, k	4000 bits
Sensor radius	30 meter
Energy of data aggregate, E_{DA}	5nJ/bit/signal
Aggregation Ratio	10%
ε_{amp}	100pJ/bit/m^2
E_{elec}	*50 nJ*/bit

As previously described in Figure 1, the first order energy dissipation model will be used as the communication model for sensor nodes. The rest of the parameter settings used for the network are described in Table III. In this simulation, energy is consumed when a node sends and receives a packet or aggregate data. Evidently, when a node depletes its energy it can no longer sends, receives packet or aggregates any data. The simulation will also include the energy consumption of aggregation process where the aggregation ratio is 10% and the energy used per bit is 5nJ/bit/signal. If the cluster-head received 5 packets from its cluster member and each length of the message is 100bits, then the length of aggregated message is (100 + 10 x 5) bits.

To evaluate the efficiency of the proposed protocol, it had been tested under 50 different kinds of network seeds with the average being measured out. Each of the routing protocols was tested under cluster-head probability of 0.05, 0.10, 0.15 and 0.20 in respective to the remaining alive nodes. Therefore about five nodes per round becomes cluster-head for the probability of 0.05 in the initial stage but the number of cluster-heads elected will decrease in relevance to the decreasing of alive nodes. This will also apply to the probability of 0.10, 0.15 and 0.20. All three protocols were compared and evaluated for their overall network lifetime obtained until the simulation ends, the network lifetime achieved during first node die and half node die, the number of alive node remains during first node die and the total residual energy remained during first node die as well as half node die.

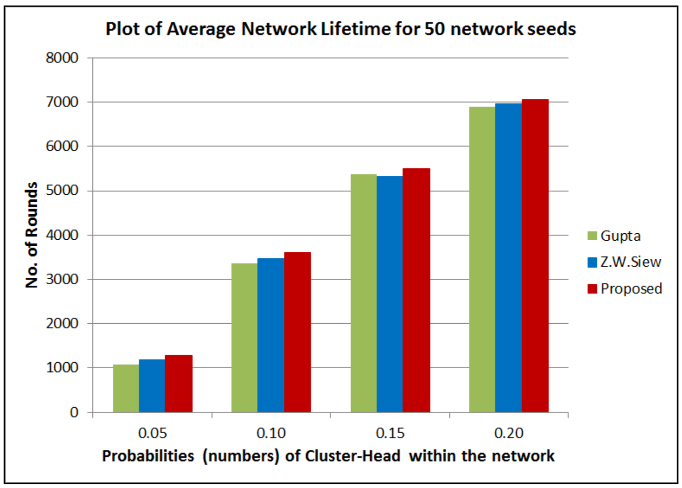

Figure 2. Average network lifetime for 50 network seeds.

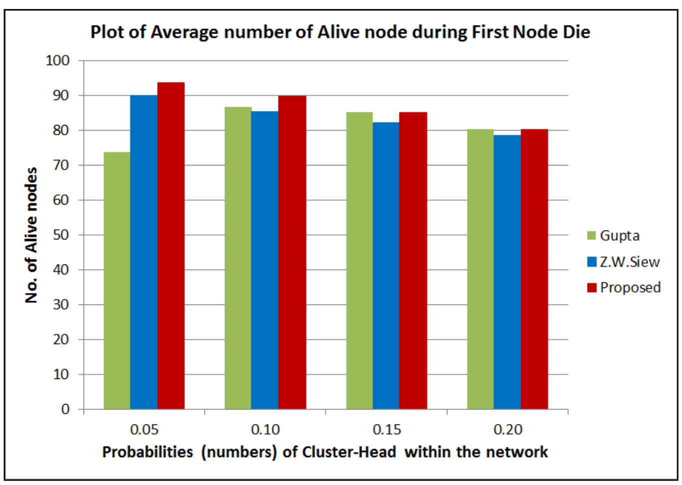

Figure 3. Average number of alive node during first node die.

Figure 2 shows the graph of average network lifetime achieved by the proposed protocol, Gupta et al. and Z.W. Siew et al. under 50 different network seeds. For cluster-head of 0.05 probabilities, Gupta et al. manage to achieve 1073.8 rounds while Z.W. Siew et al. with 1187.9 rounds. The proposed protocol outdo both by gaining 1275.2 rounds As for the probability of 0.10, Gupta et al. manage to achieve 3362.7 rounds and Z.W. Siew et al. with 3458.9 rounds. The proposed protocol exceeds with 3605.7 rounds. For probability of 0.15, the average network lifetime achieved by the proposed protocol is 5489.7 rounds while Gupta et al. with 5365.8 rounds and Z.W. Siew et al. only with 5324.4 rounds. Finally, with the probability of 0.20, the proposed protocol manages to gain 7054.3 rounds; Gupta et al. with 6885.6 rounds and Z.W. Siew et al. with 6954.7 rounds. Under four scenarios, the proposed protocol continually outdoes the other two protocols. Table IV shows the percentage increase of network lifetime of the proposed protocol in comparison to the other two.

TABLE IV. PERCENTAGE INCREASE OF NETWORK LIFETIME IN COMPARISON WITH THE PROPOSED PROTOCOL

Percentage Increase				
Protocol	**Cluster-head probability**			
	0.05	***0.10***	***0.15***	***0.20***
Gupta et al.	18.8%	7.2%	2.3%	2.4%
Z.W. Siew et al.	7.3%	4.2%	3.1%	1.4%

Figure 3 shows the average number of alive nodes during first node die for the cluster-head probability of 0.05, 0.10, 0.15 and 0.20. Under four different scenarios of cluster-head probabilities, the number of alive nodes remains in the proposed protocol surpass the other two protocols except for the probability 0.15 and 0.20 where the number of alive nodes in Gupta et al. is the same as the proposed protocol. Even so, referring to Table V, the proposed protocol manages to achieve significantly higher network lifetime regardless the same number of alive nodes remained in the network. Moreover, for the probability of 0.05 and 0.10 the number of alive nodes remains in the proposed protocol were higher yet the network lifetime still outdo the other two protocols with lower alive nodes. This shows that the proposed protocol is able to choose the best candidate as cluster-heads by balancing the workload and thus help in prolonging the network lifetime.

TABLE V. NETWORK LIFETIME ACHIEVED DURING FIRST NODE DIE.

Network Lifetime achieved during First Node Die				
Protocol	**Cluster-head probability**			
	0.05	***0.10***	***0.15***	***0.20***
Gupta et al.	360.2	773.58	1382.84	2285.24
Z.W. Siew et al.	242.82	858.94	1494.54	2357.48
Proposed	375.52	927.5	1779.68	2618.26

In Table VI, the network lifetime of all three protocols are defined as the time until half node die. Evidently the proposed protocol performs better than Gupta et al. and Z.W. Siew et al. in all cluster-head probability scenarios. Gupta et al. performed the poorest because it does not consider the amount of traffic that may encumbrance the overall network by focusing on node with high connectivity. Z.W. Siew et al. in the other hand performed slightly better than Gupta et al. yet cannot outdo the proposed protocol. Under different definitions of network lifetime, results obtained by the proposed protocol exceeded the other two.

TABLE VI. NETWORK LIFETIME ACHIEVED DURING HALF NODE DIE.

Network Lifetime achieved during Half Node Die				
Protocol	**Cluster-head probability**			
	0.05	***0.10***	***0.15***	***0.20***
Gupta et al.	894.88	2918.8	4529.9	6297.8
Z.W. Siew et al.	1052.9	2933.7	4636.2	6358.6
Proposed	1098.2	3086.6	4694.1	6455.2

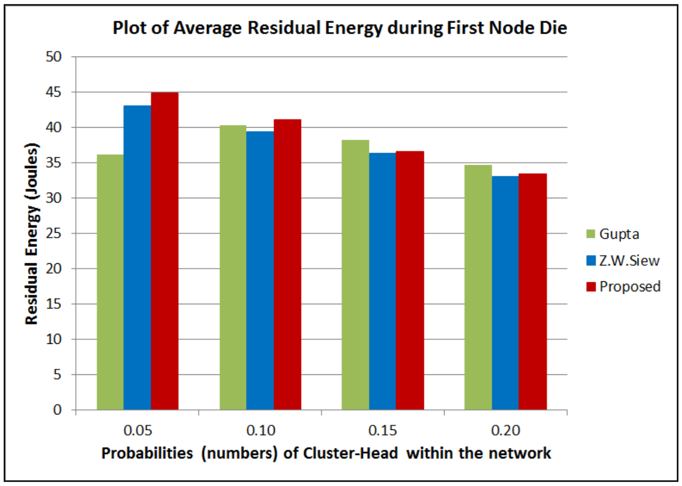

Figure 4. Average residual energy remained during first node die.

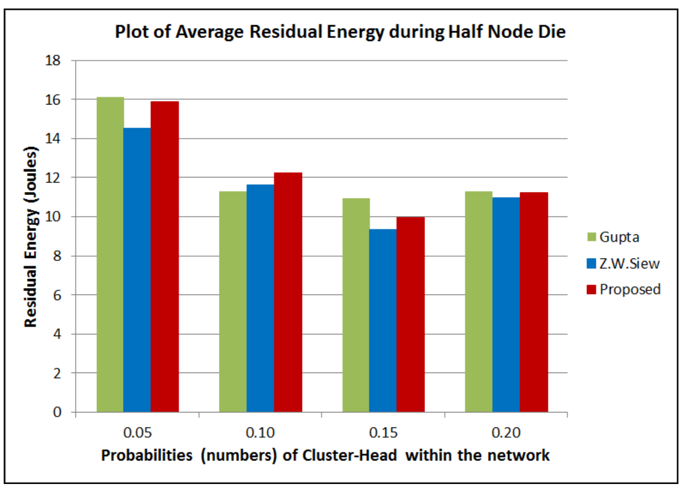

Figure 5. Average residual energy remained during half node die.

Figure 4 and Figure 5 show the average residual energy remained during first node die and half node die. Referring to Figure 4, the residual energy remained for the proposed protocol are not necessarily high comparing to Gupta et al. in exchange of achieving higher network lifetime during first node die specifically the probability of 0.15 and 0.20. Under the probability of 0.15, the network lifetime achieved by the proposed protocol is 28.6% more than Gupta et al. and for probability 0.20 the proposed protocol performed with 14.5% more than Gupta et al. Meanwhile, based on Figures 5 with half of the sensor node considers as incapable of routing; the proposed protocol manages to achieve higher network lifetime referring to Table VI irrespective to the residual energy remained. This shows that the proposed protocol can utilize the energy more efficiently compare to the other two by performing better and achieving higher network lifetime.

V. Conclusion

In this paper, a protocol of centralized cluster-head election mechanism using the fuzzy logic approach has been proposed. By using three fuzzy descriptors of energy, centrality and distance the objectives of prolonging the network lifetime and efficiently utilize the energy resource has been accomplished. Further enhancement of this study is to find the optimal fuzzy set and to compare it with other clustering algorithms.

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References

[1] J. L. Hill, “System architecture for wireless sensor networks,” Ph. D. Dissertation, Computer Science Program, University of California, Barkeley, California, United States. 2003.

[2] Nandini. S. Patil, and P. R. Patil, “Data Aggregation in Wireless Sensor Network”, IEEE International Conference on Computational Intelligence and Computing Research, 2010.

[3] D. Puccinelli and M. Haenggi, “Wireless Sensor Networks-Applications and Challenges of Ubiquitous Sensing,” IEEE Circuits and Systems Magazine, 5:19-29, Aug 2005.

[4] A. A. Abbasi and M. Younis, “A survey on clustering algorithms for wireless sensor networks,” Computer Communications, vol. 30, no. 14-15, pp. 2826–2841, 2007.

[5] Fuzzy logic introduction. (n.d.). Retrieved from http://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol2/jp6/article2.html

[6] Introduction to fuzzy control systems. (n.d.). Retrieved from http://libaray.thinkquest.org/29483/fuzzy_cntrl.shtml

[7] I. Gupta, D. Riordan and S. Sampalli, “Cluster-head Election using Fuzzy Logic for wireless sensor networks,” Communiction Networks and Services Reearch Conference, pp.255-260, May 2005.

[8] Z.W. Siew, C.F. Liau, A. Kiring, M.S. Arifianto and K.T.K. Teo, “Fuzzy Logic based cluster head election for wireless sensor network,” Proceedings of the 3rd CUTSE International Conference Miri, Sarawak, Malaysia, 8-9 Nov,2011.

[9] Alan Holland. (2010). Lecture 5: Fuzzy System. Retrieved from http://www.4c.ucc.ie/~aholland/udg/Girona_Lec5.pdf

[10] M. A. Labrador and P. M. Wightman, “Topology Control in Wireless Sensor Networks,” Springer Science + Business Media B.V. 2009.