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A Comparative Study on the Topology Control Mechanism Using GAHCT and FLHCT for an N-Tier Heterogeneous Wireless Sensor Network

S. Emalda Roslin[a,*], C.Gomathy[b,1]

Abstract - **Topology control targets to achieve an energy efficient network with limited number of communication links between the sensor nodes. One way to attain a reduced topology is via a cooperative technique. In this paper, a new methodology GAHCT: Genetic Algorithm based Hierarchical Cooperative Technique is proposed and implemented for a N-tier architecture with different node densities. Obtained results prove the effectiveness of our proposed GAHCT for two tier architecture. Also a fuzzy logic based hierarchical cooperative technique (FLHCT) is proposed towards achieving an efficient topology control.**

Index Terms **– Topology control, GAHCT, FLHCT, N-tier architecture**

I. Introduction

Wireless Sensor Network (WSN) comprises of small complex sensors with limited battery as the energy resource. The effective utilization of the battery leads to the maximization of the network lifetime which is a crucial factor. Usage of minimum transmission range for communication between the nodes produces maximum power savings and enhanced network lifetime. This also results in a reduced network topology. The foresaid process is called topology control.

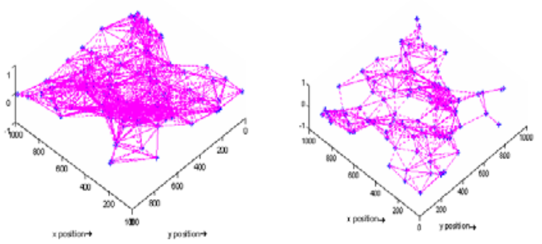

Figure 1. Network Topology with maximum and minimum transmission ranges

Figure 1 depicts a network of 100 nodes with maximum and minimum transmission ranges. The complexity and the region of interference becomes more for a network with maximum transmission range. Thus results in increased collision and number of retransmissions. One solution to avoid these circumstances is applying a topology control technique. The art of coordinating nodes' decisions regarding their transmitting ranges, in order to generate a network with the desired properties is called Topology control. Many topology control algorithms are presented in the literature [1-12]. Widely used applications of sensor networks incorporate large number of sensors. The data collected using these sensors must be transmitted to the sink using direct long distance communication or short multi hop communication. Longer communication distance between the sensors and the sink makes energy consumption more. By making the distance short, the overall energy consumption is reduced. One of the effective mechanisms for short distance communication is clustering. The literatures also showed the drastic increase in network lifetime using clustering [11-15]. Using an energy efficient clustering schema in a topology control algorithm leads to the enhancement of network capacity and network lifetime. In one tier architecture the data forwarding from source to sink is via multihop communication through the neighboring nodes. For a two tier architecture, the lower tier involves clustering of sensor nodes which forms cluster slaves for the purpose of data gathering. The second tier comprises of cluster heads, which are responsible for transferring data from cluster slaves to sink. In three tier architecture, in addition to the lower and the second tier of the previous a third tier comprising of super heads is formed. Data gathered by the cluster slaves were sent to the cluster heads. The cluster heads forwards the data to the near by super heads. From the super heads the data is forwarded to the sink. Cluster head selection and super head selection are critical processes in N-tier architecture. So an effective optimization tool has to be used for cluster head and super head election from the randomly deployed sensor nodes. Genetic Algorithm (GA) is one such tool.

In this paper, a genetic algorithm based hierarchical cooperative technique which considers the nodes bandwidth, residual energy and memory capacity for cluster head selection and super head selection is proposed. It has also been implemented on N-tier architecture with various network densities. The impact on the network topologies and the total energy consumption over a N-tier architecture is studied. Also a fuzzy logic based hierarchical cooperative technique which takes care of nodes distance, residual energy and Received signal strength indicator (RSSI) for head selection has also been proposed.

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Emalda Roslina,*,
Research Scholar,
Sathyabama University,
E-mail: roemi_mich@yahoo.co.in
C.Gomathy b,1,
Prof. & Head/
Dept. of E & C,
Sathyabama University

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The paper is organized as follows. In section 2, discussion on the various existing works on GA based and fuzzy based clustering is done. The proposed methodology is illustrated is section 3. Results and discussions on the proposed work were made in section 4. Section 5 concludes our work with a future work.

II. Overview of Clustering

A. Survey Based on Genetic Algorithm

The GAs' ability for searching, fast convergence and fast evaluation distinguish themselves from other decision and optimization algorithms. A Genetic Algorithm (GA) is a stochastic search technique based on the mechanism of natural selection and recombination. It starts with an initial *population* of individuals, i.e. a set of randomly generated candidate solutions. The solutions are represented by *chromosomes*, which are collections of numbers or symbols that map onto parameters of the problem. Individuals are evolved from generation to generation, with *selection*, *crossover* (*mating)*, and *mutation* operators. These operations provide an effective combination of exploration of the global search space and pressure to converge to the global minimum. The solution quality is measured by a *fitness* function.[12][15-20].

In [12] G. Ahmed et. al., explained the procedure of using evolutionary computing for the selection of the CHs. The CH selected using any algorithm should be powerful, closer to the cluster-centroid, less vulnerable and low mobility. The above said factors are involved in forming a fitness function. The BS periodically runs the proposed algorithm for a certain time period to select new CHs. Results showed that using evolutionary computing, the network life time is drastically increased.

In [16] Mohamed et. al., proposed the use of GAs to minimize the communication distance in a sensor network by dividing it into K-clusters. The total transmission distance is the main factor used in the fitness function that is to be minimized. The algorithm starts to find an appropriate number of cluster-heads and their locations by adjusting cluster-heads based on fitness function. Once cluster-heads are selected, each regular node connects to its nearest cluster-head. Each node in a network is either a cluster-head or a "member" of a cluster-head. Each regular node can only belong to one cluster-head. Each cluster-head collects data from all sensors within its cluster and each head directly sends the collected data to the sink. It has also been proved that the total distance is minimized as the number of heads is decreased.

In [19] Jenn-Long Liu et. al., proposed a GA-based adaptive clustering protocol (LEACH-GA) to determine the optimal thresholding probability for cluster formation in WSN.The fitness function involves energy dissipation for aggregating data , number of Cluster Candidate Head (CCH) , number of cluster members and the transmitter electronics. Initially all the nodes perform cluster head selection process and decides whether to become CCH or not. This status along with the geographical position is send to the base station. The base station then searches for an optimal probability of nodes being cluster heads via a genetic algorithm by minimizing the total energy consumption required for completing one round in the sensor field. Thereafter, the base station broadcasts an advertisement message with the optimal value of probability to the all nodes to form clusters. Simulation results showed that the proposed algorithm produces optimal energy consumption resulting in an extension of network lifetime of WSN.

a) Survey Based on Fuzzy Logic Controller

Fuzzy logic is capable of making real time decisions, even with incomplete information. Conventional systems rely on an accurate representation of the environment, which generally does not exist in reality. Fuzzy logic systems, which can manipulate the linguistic rules in a natural way, are hence suitable in this respect. Moreover it can be used for context by blending different parameters - rules combined together to produce the suitable result. Any Fuzzy Interface System (FIS) has four parts. *Fuzzification module:* Transforms the system inputs, which are crisp numbers, into fuzzy sets. This is done by applying a fuzzification function. *Knowledge base:* Stores IF-THEN rules. *Inference engine:* Simulates the human reasoning process by making fuzzy inference on the inputs and IF-THEN rules. *Defuzzification module:* Transforms the fuzzy set obtained by the inference engine into a crisp value [21][22][23][24].

In [21] Indranil Gupta et. al., proposed a fuzzy cluster-head election scheme (FCHES) based on three descriptors – node concentration, energy level in each node and its centrality with respect to the entire cluster. The operation of this fuzzy cluster-head election scheme is divided into setup and steady state phase similar to LEACH. During the setup phase the cluster-heads are determined by using fuzzy knowledge processing. In the steady state phase the cluster-heads collect the aggregated data and sent the composite signal to the base station. With this system model a substantial increase in the network lifetime is accomplished.

Ge Ran et. al., proposed a new methodology LEACH-FL [22] that improves LEACH protocol using Fuzzy Logic and chooses battery level, distance and node density to be the attributes of the cluster heads selection. LEACH depends on a probability model in which there is a possibility that the selected Cluster heads may be very close to each other or it may be located in the edge of the WSN. In such case they could not maximize the energy efficiency. So more calculations and communications is done in the proposed method to get the data of the node density and the distance. The probability of a node to be selected as a CH is increased with the increase of the battery level and node density. While with the increase of the distance between the node and the BS, the probability of a node to be selected as a CH is decreased. The energy consumption of the proposed system is much lower than that of LEACH.

Ting Jiang et. al., proposed a novel transmission power control algorithm based on fuzzy logic (TPC-FL) using Link Quality Indicator, Received Signal Strength Indicator, Signal To Noise Ratio and data transmission rate [23]. In a clustering formation WSN system model, a fuzzy logic controller is used to adjust transmission power adaptively. The proposed methodology considers three modules in the Sending Node and four modules in the Receiving Node. In the Sending Node Transmission Module sends data packets with reference transmission power delivered by History Power Module. Adjust Value Receiving Module is used to update history power level in real-time. In Receiving Node, Receiving Module works in physical layer to receive signals. QoS Extraction Module collects several receiving QoS parameters and Fuzzy Computing Module calculates adjust-value with fuzzy logic controller. The result is delivered to Adjust Value Feedback Module which is in charge of sending adjust-value to Sending Node with a transmission power the same as Sending Node. The proposed fuzzy algorithm realized reliable data transmission with low power consumption.

III. Proposed Methodology

Energy, Bandwidth and Memory Capacity are the limited resources for a WSN. Taking these factors into consideration, the Genetic Algorithm based hierarchical Cooperative Technique is proposed. Using this methodology an efficient network can be generated. As the initial step, best nodes called Cluster Head (CH) nodes are to be selected. Remaining nodes used for collection of data are called Cluster Slaves (CS). The resource rich nodes among the cluster heads are elected as Super Heads (SH) for data forwarding to the sink node.

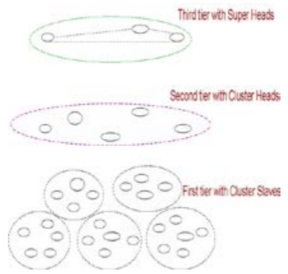

Figure 2. N-Tier Architecture

Initially nodes are deployed in a random fashion. Every node launches and receives "Hello" messages from its neighbors with its minimum transmission range and wait for a random amount of time. On receiving the "Hello" message each node will calculate its residual energy, bandwidth and memory capacity. These details are sent along with the "Ack" message. Based on the residual energy values in the "Ack" message, nodes are categorized in to normal Nodes (residual energy > 20%), warning nodes (residual energy between 10 – 20 %), and danger nodes (residual energy <10 %). The danger nodes are not eligible for involving in the communication. So these nodes are moved to sleep state for a predefined time period. After considering the residual energy of the neighbors, the bandwidth and memory capacity of the normal nodes and warning nodes are considered and compared. The node with higher bandwidth and memory at a particular time is elected as cluster heads and the other nodes are listed as cluster slaves. After a predefined time, cluster heads with maximum residual energy, bandwidth and memory capacity are elected as super heads. These super heads form the communication subnet, through which data is forwarded to the sink node. The data transmission between the super nodes takes place using minimum transmission power to reach the sink node.

<u>GAHCT Algorithm</u>

Step 1: Randomly place nodes as initial population
Step 2: Calculate the fitness function for all individual nodes which uses Remaining energy, Bandwidth and Memory capacity
Step 3: Select nodes with best fitness value as cluster heads for reproduction
Step 4: Recombine between individual nodes
Step 5: Mutate individual nodes
Step 6: Calculate the fitness for the modified individual nodes
Step 7: Repeat till a good new population of cluster heads are obtained
Step 8: The above steps are repeated for the cluster heads to select super heads among them

B. System Model For FBHCT

The three important parts of a fuzzy logic controller are fuzzification functions, an inference engine (conclude 27 rules) and a defuzzification module. The system architecture connects three input parameters and one output parameter using mamdani interference engine and is shown in figure 3. Each of the three input parameters namely Residual energy, RSSI and Distance uses three membership functions. The output parameter is the neighbor status which also uses three membership functions.

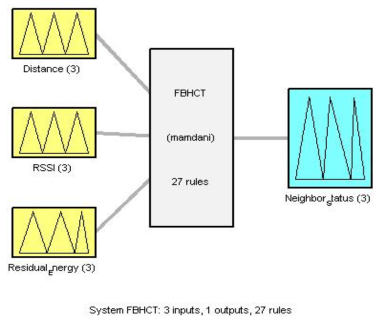

Figure. 3. Fuzzy System Architecture

For cluster head selection three main attributes of the nodes like distance, RSSI and residual energy are needed. These three attributes are represented as three input functions that transform the system inputs into fuzzy sets. Each of the input functions has three membership functions that show the different degree of the functions. The membership functions for the different input and output attributes are shown in table 1. The degree of membership for the input functions and the output function is given in figure 4, figure 5, figure 6 and figure 7.

TABLE 1: INPUT AND OUTPUT FUNCTIONS

Input Function	**Membership**		
Residual Energy	Good	Better	Poor
RSSI	Max	Mid	Min
Distance	Near	Medium	Far
Output Function	**Membership**		
Node Status	Select	Partial Select	Reject

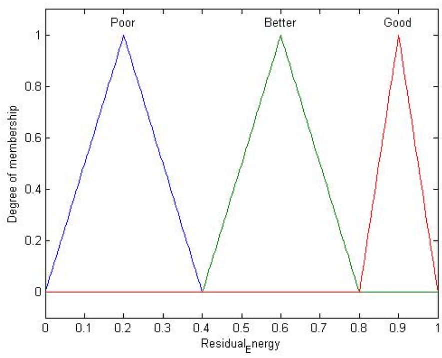

Figure 4. Membership function for the Input attribute Residual energy

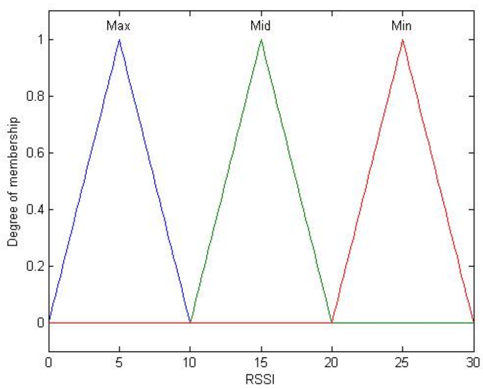

Figure 5. Membership function for the Input attribute RSSI

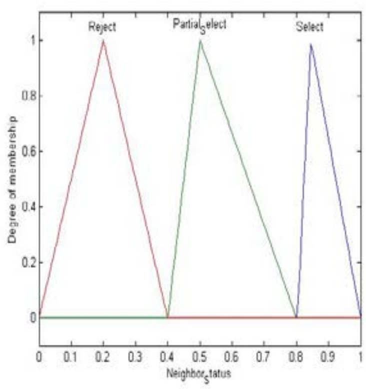

Figure 7. Membership function for the Output attribute Node status

TABLE 2: RULES

Distance	RSSI	RE	Node_Status
Near	Max	Poor	Reject
Near	Max	Better	Select
Near	Max	Poor	Reject
Near	Mid	Poor	Reject
Near	Mid	Better	Select
Near	Mid	Good	Partial-Select
Near	Min	Poor	Reject
Near	Min	Better	Reject
Near	Min	Good	Select
Medium	Max	Poor	Reject
Medium	Max	Better	Select
Medium	Max	Good	Partial-Select
Medium	Mid	Poor	Reject
Medium	Mid	Better	Select
Medium	Mid	Good	Select
Medium	Min	Poor	Reject
Medium	Min	Better	Reject
Medium	Min	Good	Partial-Select
Far	Max	Poor	Reject
Far	Max	Better	Select
Far	Max	Good	Select
Far	Mid	Poor	Reject
Far	Mid	Better	Partial-Select
Far	Mid	Good	Partial-Select
Far	Min	Poor	Reject
Far	Min	Better	Reject
Far	Min	Good	Partial-Select

IV. RESULTS AND DISCUSSIONS

The proposed GAHCT is implemented for a N-tier architecture with network densities of 25 nodes and 50 nodes. A network scenario with 25 sensor nodes and 1 sink node, whose x, y and z coordinated were known, is deployed and the scenario is termed as Network Deployment #1. Another network scenario with 50 nodes is deployed and is named as Network Deployment #2. Using NS-2.34, network deployments #1 and #2 were simulated with the parameters given in table 3. For both the scenarios the energy consumed by all the nodes in the network were calculated. The energy consumed to transmit k bits message over a distance d is given by,

$$E_{TX}\ (k,d) = E_{Elec}*k + €_{amp}*k*d^2 \qquad (1)$$

Where E_{Elec} is the radio energy dissipation and $€_{amp}$ is transmit amplifier dissipation. Using the above equation, the energy consumed to transmit data in a N-tier architecture using the simulation parameters in table 1 for our proposed GAHCT is calculated.

TABLE 3: THE SIMULATION PARAMETERS

Parameters	Value
Deployment Region	1000 m x 1000 m
Number of Nodes for Deployment #1	25
Number of Nodes for Deployment #2	50
Sink Node Id	25
Sink Node Position	800 , 800 , 0
Number of Bits transmitted	500
Transmission Power	0.8 mW
Receiving Power	0.2 mW
Idle Power	0.003 mW
E_{Elec}	50 nJ/bit
€ $_{amp}$	100 pJ/bit/m^2
Simulators	NS-2.34, Matlab

The total energy consumed by individual nodes for both the deployments were compared in figure 8 and figure 9. Figure 10 proves the effectiveness of our proposed GAHCT, for a two tier architecture by comparing the total energy consumption for a N-tier architecture using different node densities.

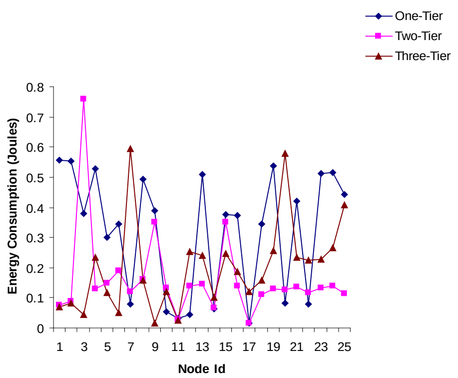

Figure.8. Comparison on the energy consumed by the individual nodes for deployment #1 in a N-tier architecture using GAHCT

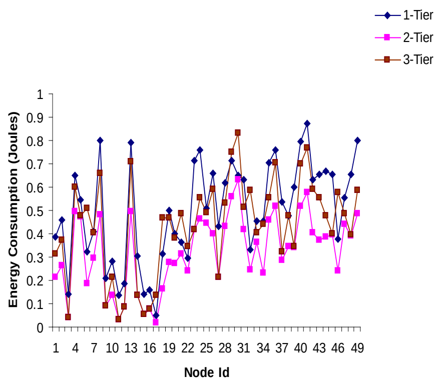

Figure 9. Comparison on the energy consumed by the individual nodes for deployment #2 in a N-tier architecture using GAHCT

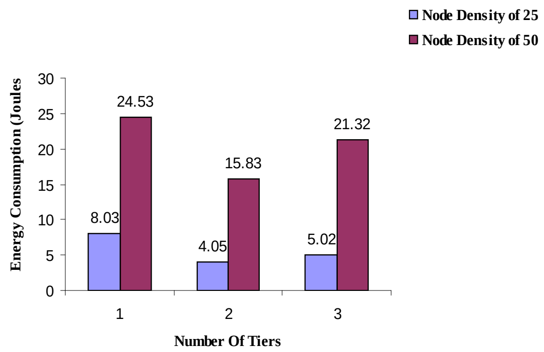

Figure 10. Comparison on the Total Energy Consumption for a N- tier Architecture for various node densities

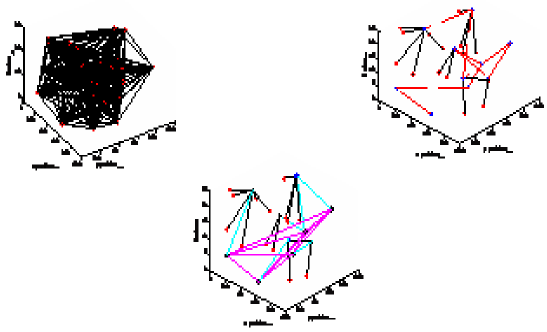

Figure 11. Network topologies of deployment #1 for One tier, Two tier & Three tier Architecture

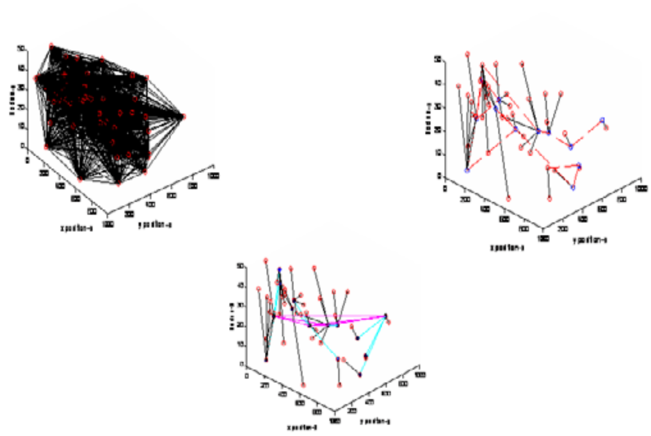

Figure12. Network topologies of deployment #2 for One tier, Two tier & Three tier Architecture

The network topology diagrams of deployment #1 and #2 for a N-tier architecture using the proposed methodology is shown in figure 11 and figure 12. From the figures, it is very clearly seen that implementation of a topology control algorithm reduces maximum number of communication links thereby reducing the overall network complexity.

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B. Discussions on FBHCT

Based on the hierarchy of the node parameters, the rules were framed to find out the neighbor status and are listed in table 2. The rule discussed in table 2 is entered in the rule editor of fuzzy interface system toolbox in matlab and is shown in figure 13. The relation between the input attributes and output attribute are shown in the rule viewer of fuzzy interface toolbox and is shown in figure 14. Figure 15, 16 and 17 shows the surface viewer obtained using FIS for the given set of input and output membership functions

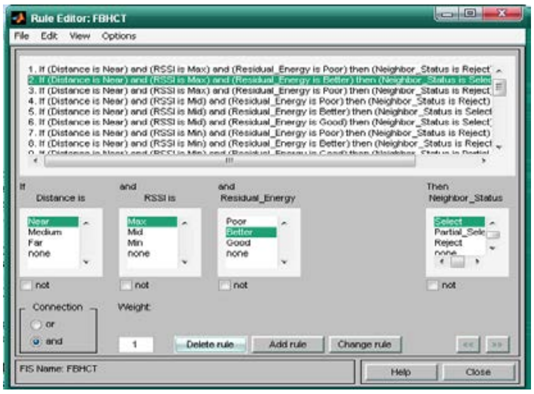

Figure 13. Rule Editor of FIS

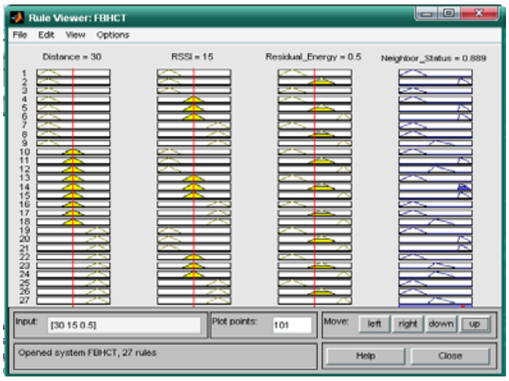

Figure 14. Rule Viewer of FIS

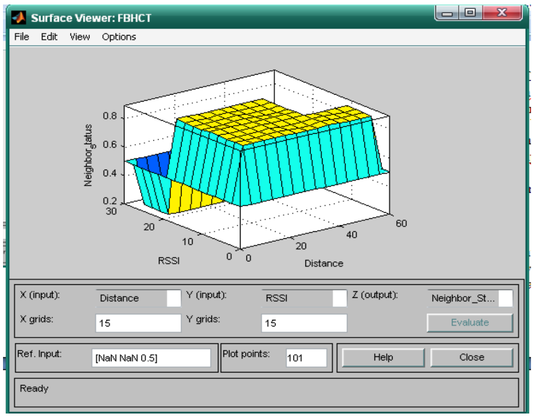

Figure 15. Surface viewer for RSSI and Distance

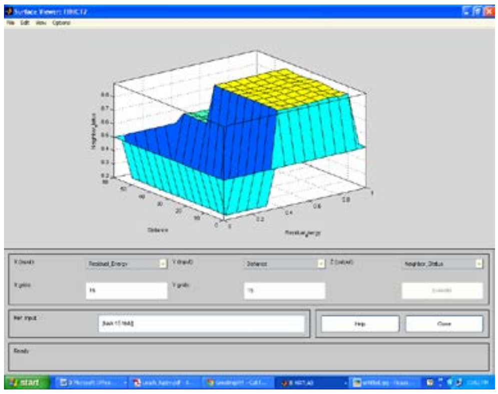

Figure 16. Surface viewer for Residual Energy and Distance

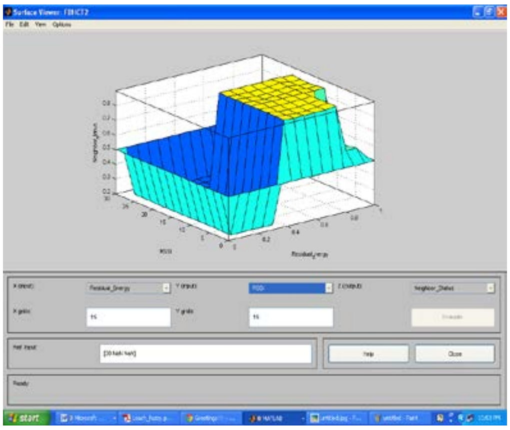

Figure 17. Surface viewer for Residual Energy and RSSI

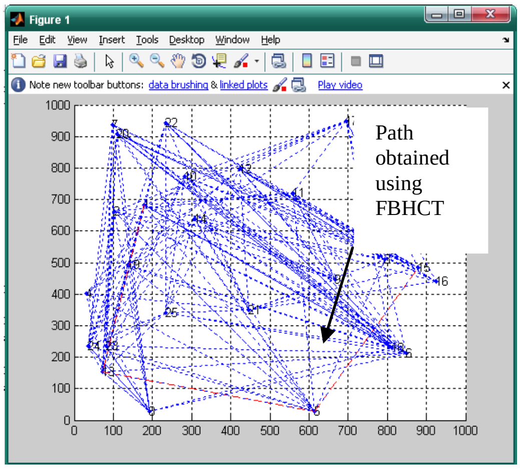

Figure 18. Network Topology obtained using the proposed FBHCT

The proposed methodology using fuzzy logic controller is proposed and implemented for a network topology of 25 nodes. Best set of nodes got selected as heads using the given input attributes with the help of fuzzy interface system. The reduced data forwarding path is shown by a red color line in figure 18.

V. Conclusion & Future Work

A new methodology, genetic algorithm based hierarchical cooperative technique is used for the election of cluster heads and super heads for a N- tier architecture. Since GA is used and the fitness function includes residual energy, bandwidth and memory capacity, a best set of super heads and cluster heads were selected. The study on the impact of total energy consumption over N-tier architecture for various node densities of a wireless sensor network is performed. From the comparison it is well proved that two tier architecture gives a better performance when compared to others in case of a N- tier architecture. Fuzzy logic controller based technique for cluster head election has also been proposed and implemented for node density of 25 nodes.

The hardware implementation on the proposed algorithm can be done to prove the effectiveness on the real time scenario. As an enhancement of this work, a methodology using fuzzy which uses residual energy, bandwidth and memory capacity can be proposed. The results can be compared with GA based methodology.

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BIOGRAPHY

S. Emalda Roslin acquired a B.E. degree in Electronics and Communication Engineering from St. Josephs College of Engineering , Chennai in 2000 and a M.E. degree in Applied Electronics Engineering from Sathyabama University, in 2004. She is pursuing Ph.d in Sathyabama University, Chennai. She has published over 20 research papers in National conferences, International conferences and Journal. Her areas of interest include wireless sensor networks and Communication Networks.

C. Gomathy acquired a B.E. (with honors) degree in Electronics and Communication Engineering from Government College of Engineering, Tirunelveli, in the year 1986, and an M.S. degree in Electronics and Control Engineering from Birla Institute of Technology and Science, Pilani, in 1992. She also obtained an M.S. (by research) degree from Anna University in 2001. She obtained her Ph.D. in the area of Mobile Ad hoc networks from Department of Electronics and Communication Engineering, College of Engineering, Anna University, Chennai, India, in the year 2007. She has published over 80 research papers in National and International conferences and journals. Her areas of interest include mobile ad hoc networks, high-speed networks, and wireless sensor networks.