AN QUANTITATIVE STUDY ON THE IMPACT OF N -TIERS IN THE PERFORMANCE OF TOPOLOGY CONTROL ALGORITHMS FOR WIRELESS SENSOR NETWORK S

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Abstract

Recent years showed a wide range of applications in Wireless Sensor Networks (WSN). For a WSN, Topology Control is crucial to obtain an energy efficient network without affecting the connectivity and other properties. In this paper the sequence of strategies carried out to obtain a better scheme for a topology control in terms of energy is discussed. An quantitative study is also done on the impact of N-tiers in the performance of the various proposed algorithms. Comparison on one tier , two tier and three tier architecture using the proposed methodology is also made. The results showed the effectiveness of the different approaches proposed. The future works discussed also gives a wider vision on the probabilities of the various schemas for the forthcoming years.

Keywords

Wireless Sensor Network, Topology Control, Energy, Network Property.

1. INTRODUCTION

Wireless Sensor Network (WSN) is a collection of tens to thousands of small battery powered devices called sensor nodes with limited communication, processing and computational capabilities. These autonomous sensor nodes work cooperatively to achieve a desired goal. Due to its low cost, reduced size and easy to manufacture characteristics, they are used widely in various military and civilian applications. Each sensor node depends on small low capacity battery as energy source, and cannot expect replacement [1][2][3][4]. This makes the energy factor of the sensor node a critical one. Hence for any WSN, both energy and capacity are limited resources. The network designer should strive for reducing energy consumption of nodes but by maintaining network capacity. A suitable compromise for this is Topology Control. Topology Control (TC) refers to maintaining a topology with certain properties (e.g., connectivity) while reducing energy consumption and/or increasing network capacity. Figure 1 shows the pictorial representation of a network before and after applying TC. By implementing a TC, maximum

DOI : 10.5121/ijasuc.2011.2302

number of communication links in the network has been reduced. This leads to minimum energy consumption and maximum network capacity [5] [6].

Topology Control can be broadly categorized in to any of the two approaches. They are power Control mechanism and power management mechanism [1]. Adjusting the transmitting power of each node dynamically is termed as power control [7][8][9][10]. Power management is switching off the redundant nodes that are not involved in transmission nor reception [11][12][13][14][15]. By integrating power control and power management algorithms it is possible to increase the energy efficiency of a wireless sensor network.

The flow of this paper is as follows. Some of the related works on Power Control, Power Management and Genetic Algorithm is discussed in section 2. The effect of using maximum transmission range is given in section 3. Section 4 deals with the various approaches proposed for getting an efficient network. The discussion on the results obtained using the proposed methodologies are given in section 5. Conclusion is dealt in section 6.

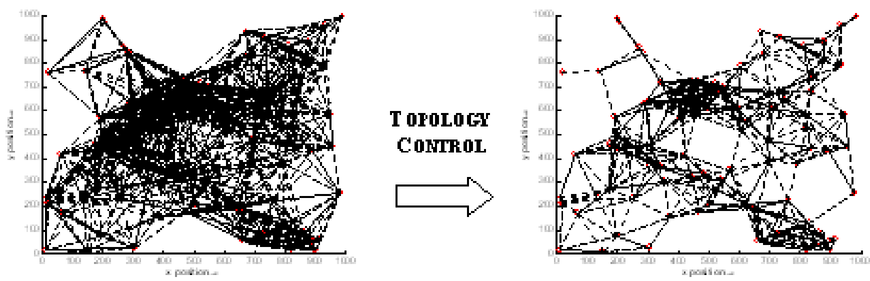

Figure 1. Network Topology

2. RELATED WORKS

Shan Lin, Jingbin Zhang et al. [8] employed a feedback based adaptive transmission power control algorithm (ATPC) to dynamically maintain individual link quality over time. In ATPC algorithm, each node broadcasts a beacon at different transmission power levels in the initialization phase, and its neighbors measure RSSI/LQI values corresponding to these beacons and send these values back by a notification packet. After the notification packet is received, the beaconing node determines the optimal transmission power level by the least square approximation method. In the runtime tuning phase, the transmission power level is adjusted based on their feedback mechanism. The result of applying ATPC is that every node knows the proper transmission power level to use for each of its neighbors by dynamically adjusting the transmission power through on demand feedback packets. ATPC maintains above 98% end to end communication quality while saving transmission power significantly.

Junseok Kim; Sookhyeon Chang et al. [9] proposed an efficient transmission power control algorithm for wireless sensor networks, namely, the on-demand transmission power control (ODTPC) algorithm. This new algorithm attempts to reduce the initialization overhead in determining the optimal transmission power level while providing good link qualities. There are two main differences between the related works and ODTPC. First of all, ODTPC is an on-demand scheme, i.e. a link quality between a pair of nodes is measured after the sender and the receiver exchange data-ACK packets rather than measuring link quality to every neighbor in the initialization phase. Secondly, there is no additional packet exchange to maintain good link quality and to adjust the transmission power level. Therefore, because of its simplicity, ODTPC can be easily implemented.

Ya xu, Solomon Bien et al. [13] Proposed two protocols, Geographic Adaptive Fidelity (GAF) and Cluster Based Energy Conservation (CEC) , to conserve energy by identifying redundant nodes and turning their radios off. In GAF the network area is divided in to virtual grids. Inside each grid, nodes collaboratively work to play different roles. GAF conservers energy by identifying redundant nodes by their physical location using GPS system and turn their radios off. More accurate mobility prediction is possible using GAF. But dependency of global location information limits GAF's usefulness in indoor applications and in dense forests application where GPS does not work. This motivates CEC, which, unlike GAF, does not rely on location information. CEC directly and adaptively measures network connectivity and thus can find network redundancy more accurately so that more energy can be conserved. In CEC nodes are organized into overlapping clusters. A cluster is defined as a subset of nodes that are mutually reachable in at most 2 hops. A cluster can be viewed as a circle around the cluster head with the radius equal to the radio transmission range of the cluster head. Each cluster is identified by one cluster head, a node that can reach all nodes in the cluster in 1 hop.

Marcel busse et al. [14] present a novel timer based topology control algorithm to conserve energy in WSN. The algorithm works in three phases and in a distributed and localized fashion. Cluster heads are determined in phase 1. Gateway nodes are added to directly connect two or more cluster heads in phase2. Intermediate nodes will join the topology and become a bridge node in phase 3. All other nodes are redundant and go to sleep with their radio transceiver turned off. Using this algorithm the networks operational lifetime can be extended about ten times compared to a single sensor node that never goes to sleep.

In [22] 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.

In [10] Amol P. Bhondekar et. al., demonstrated the use of genetic algorithm based node placement methodology for a WSN**.** Design parameters such as network density, connectivity and energy consumption are taken into account for developing the fitness function. A fixed WSN of different operating modes was considered on a grid deployment and the GA system decide which sensors should be active, which ones should operate as cluster-in-charge and whether each of the remaining active normal nodes should have medium or low transmission range. It has also been concluded that it is preferable to use more number of sensors and achieve lower energy consumption for communication purposes than having less active sensors with consequently larger energy consumption for communication purposes.

3. IMPACT OF TRANSMISSION RANGE ON WSN PERFORMANCE

From the various literatures surveyed, it is a well know fact that reducing the maximum transmission range increases the network lifetime. To start up with the work in reaching a minimum energy consumption we first investigated the factors affected by maximum transmission range. In a dense network, increasing the transmission range is undesirable because it leads to a higher channel interference, collision, decreased throughput and high energy consumption. So in order to increase the performance it is desirable to decrease the transmission range. It is illustrated with the following network scenario. Figure 2 shows a sample network of four nodes. When node 1 communicates using a maximum transmission range, all the adjacent nodes comes under its range. And if the adjacent nodes also start communicating, then the area of interference becomes more. On the other hand if node 1 has used minimum transmission range such that it is reachable only to node 2 interference area becomes less.

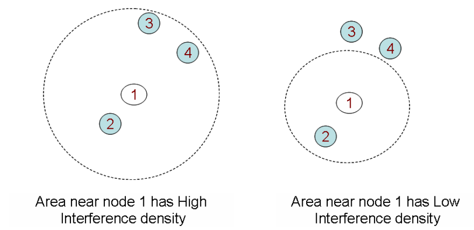

Figure 2. Network using minimum and Maximum Transmission Ranges

From the literatures surveyed various transmission range reduction algorithms are done using cooperative approach [16]. However cooperative approach fails miserably, when the critical neighbors are at the same distance, as it leads to oscillation problem. Hence to overcome the oscillation problem, a Hierarchical Cooperative Technique (HCT) based on nodes usage is initially proposed.

4. HIERARCHICAL COOPERATIVE APPROACH (HCT)

The mechanics of exchanging information regarding their transmission power among the nodes in the network is said to be cooperative technique. In HCT, every node maintains a best set of neighbors which leads to the desirable connected network.

4.1. HCT based on Nodes usage

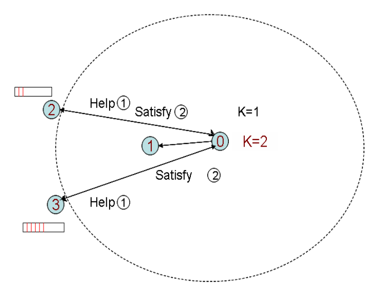

Figure 3. HCT based on Nodes usage

The algorithm of HCT is discussed below.

Hierarchical Cooperative Technique (HCT) based on nodes usage
Step 1: Neighbor table is maintained
Step 2: If number of neighbors less than critical value K, HELP packet is sent
Step 3: Neighbors receiving HELP , sends back SATISFY, naming themselves as critical neighbors
Step 4: Bandwidth details of the critical neighbors is sent along with SATISFY Packet
Step 5: For critical neighbors at the same distance, priority is given for nodes with maximum unused bandwidth

The proposed algorithm is explained using figure 3. In this sample of 4 nodes, K is assumed to be 2. Consider node 0 is with one neighbor (K =1). To satisfy the connectivity property, the transmission range is increased and exchanging of Help and Satisfy packets takes place. Since nodes 2 and 3 are at a same distance, an oscillatory behavior is encountered. To overcome this, along with the Satisfy packet, nodes 2 and 3 send their bandwidth details to node 0. Based on the hierarchy a node with lesser bandwidth is considered as neighbor. Since a node with maximum unused bandwidth is selected congestion is avoided. Average energy consumption has reduced but not significantly. Hence to further reduce the energy consumption, HCT based on Received Signal Strength Indicator (RSSI) and Residual Energy (RE) is proposed and implemented.

4.2. HCT based on RSSI and RE

From the set of neighbors maintained using the above algorithm (HCT based on nodes usage) the best node for data forwarding is to be elected. Data forwarding through the neighboring nodes with higher RSSI is present in the literatures [8]. RSSI always depends on the distance. So when a node is at a nearer distance then the RSSI takes a higher value. And if the node with higher RSSI always gets elected for forwarding, then maximum energy drain occurs in that node. This leads to a disconnected network. To overcome this problem data forwarding node election based on RSSI and RE is proposed. The proposed algorithm is given below.

Hierarchical Cooperative Technique (HCT) based on RSSI and RE

Step 1: RTS packets were sent. RSSI metric and Residual Energy were calculated and is sent back along with the CTS packet

Step 2: Neighbor table with the neighbor node id , RSSI value and RE value is maintained

Step 3: Nodes with higher RSSI and RE value is given higher priority

Step 4: Nodes not satisfying the threshold conditions were made to sleep

Step 5: Overall Energy Consumption for sleep and idle states were calculated

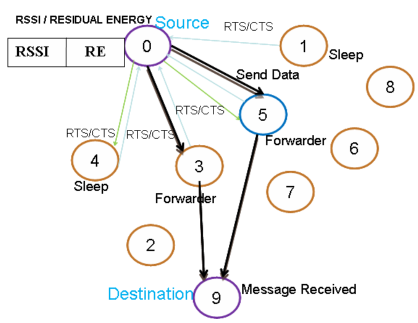

Figure 4. Sample Network using HCT based RSSI and RE

Figure 4 illustrates the proposed algorithm. In figure 4, node 0 is the source node which tends to send packets to destination node 9. Now it's the job of the source to elect a suitable neighbor as a forwarder node. This election is based on a hierarchy formed based on the RSSI and RE of the neighbors. The other neighbors other than forwarder node are made to sleep. Thus a maximum amount of energy can be saved.

3.3. Genetic Algorithm based HCT (for two tier architecture)

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. Genetic Algorithm (GA) is an evolutionary tool that is used to solve different varieties of problem that are not easy to solve using normal methodologies [17][18][19][20][21]. Using this methodology an efficient network can be generated. As the initial step, best nodes which are named as Cluster Heads (CH) is to be selected for data forwarding, and the remaining nodes used for collection of data are termed as Cluster Slaves (CS). The network with CHs and CSs forms two tier architecture. The proposed algorithm is given below. Figure 5 depicts the network diagram using the proposed algorithm.

Genetic Algorithm based Hierarchical Cooperative Technique

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

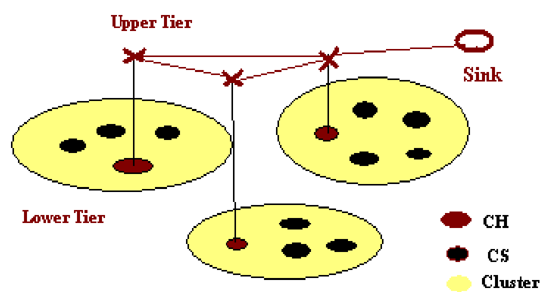

Figure 5. GAHCT for Two tier Architecture

3.4. Genetic Algorithm based HCT (for three tier architecture)

In this a three tier architecture is developed. The lower tier forms with cluster slaves, the middle tier with cluster heads and the upper tier comprises of super heads. The cluster slaves gather the data and forward it to their cluster head. The cluster head receives data from the slaves and pass it to their near by super head. The upper tier forms a communication subnet, where the data forwarding to the sink takes place via super heads. Genetic algorithm based Hierarchical Cooperative Technique is used for the selection of cluster heads and super heads. Once the cluster heads were elected, the same steps were followed to elect the resource rich nodes among them as super heads. Figure 6 shows a three tier architecture.

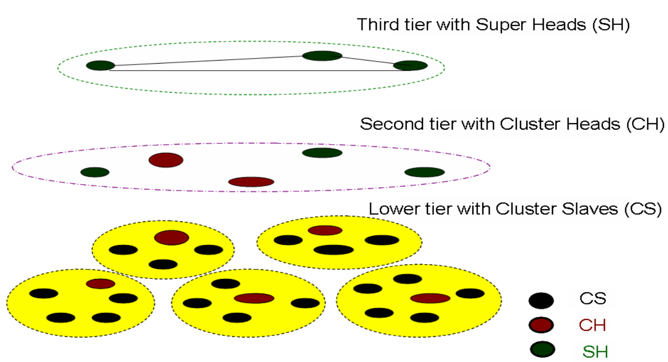

Figure 6. Three tier Architecture

4. RESULTS AND DISCUSSIONS

4.1 Relationship between Interference and Transmission Range

In order to study the impact of transmission range on Interference and Packet Delivery Ratio (PDR), a network is created with 20 nodes. There are two source nodes (green) and one sink node (yellow). Sink node has two neighbors (magenta). The simulation parameters are given in Table 1. The network for the given simulation parameters is visualized in figure 6. Interference and PDR are calculated for four transmission ranges viz 150m , 250m, 350m and 450m and are plotted in figure 7 and figure 8. The path with lesser interference is selected between the source and the sink. The intermediate nodes between them are represented by red color. The intermediate nodes keep on changing for different transmission ranges.

Table 1. The Simulation Parameters

Software Version	: NS 2.27
Operating System	: Fedora 7.0
Network Topology	: Mesh
Number of Nodes	: 20
Transmission ranges:	150m, 250m, 350m ,450m
Sink Node	: Yellow color
Source Node	: Green color
Intermediate Node	: Maroon color

The network animator of the given simulation parameters is visualized in the below screenshot.

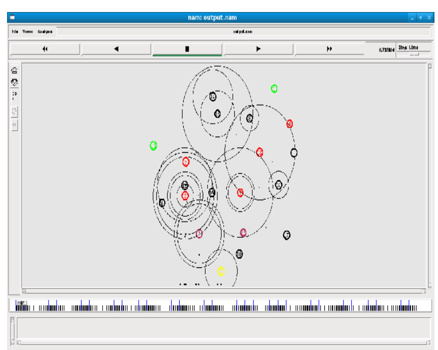

Figure 7. Network Animator Screenshot

From the figures 8 and 9, it is clear that increase in the transmission range increases the interference and decreases the packet delivery ratio.

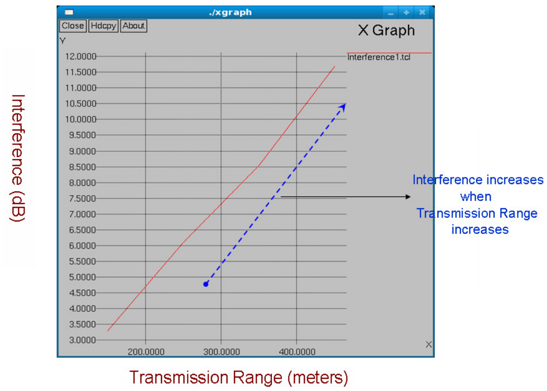

Figure 8. Transmission Range Vs Interference

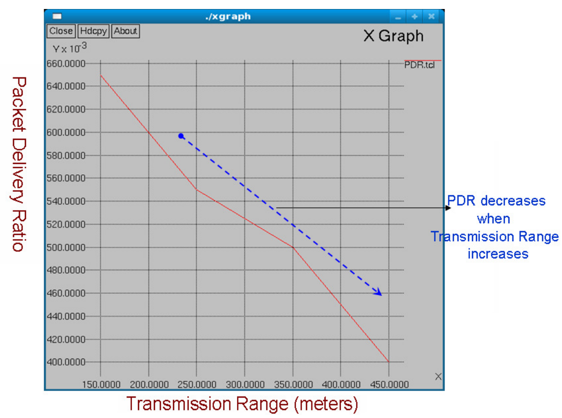

Figure 9. Transmission Range Vs PDR

4.2. HCT based on Nodes usage

The existing cooperative approach and HCT based on nodes usage are implemented using the following simulation parameters (Table 2). A network with 10 nodes is deployed. Labels were given for source and the destination nodes. The critical nodes identified by this algorithm are circled with red color. The network animator screenshot given in figure 10.

Table 2. The Simulation Parameters For HCT Based On Nodes Usage

Software Version	: NS 2.27
Operating System	: Fedora 7.0
Network Topology	: Mesh
Number of Nodes	: 10
Source Node	: Node 6
Destination Node	: Node 3
Critical Nodes	: Nodes 2 and 5

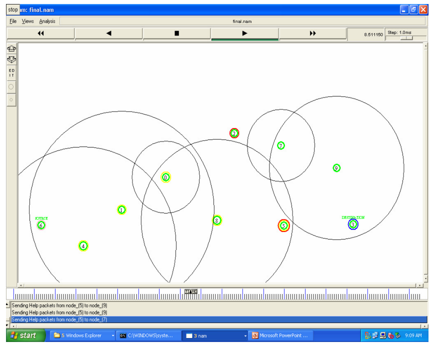

Figure 10. Network Animator Screenshot For HCT Based on Nodes Usage

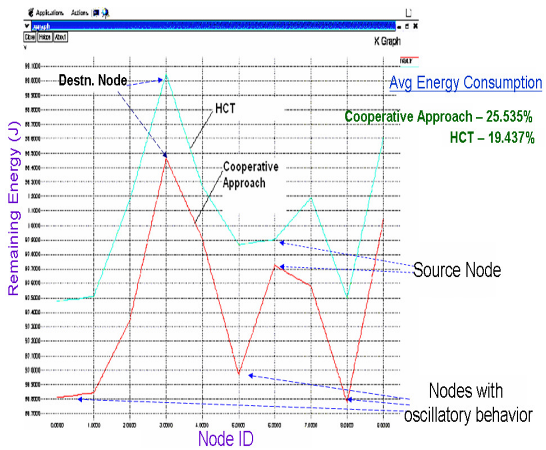

Figure 11. Energy consumption using cooperative approach and using HCT based on Nodes usage

The remaining energy present in each node is calculated and is plotted for both cooperative approach and HCT based on nodes usage. The average energy consumption is also calculated and the results were compared in figure 11. In the existing cooperative technique due to the oscillatory behavior, more amount of energy is spent by the critical nodes. This can be seen by the dip in the remaining energy calculated. The dip occurred in the existing method gets overcame by the proposed HCT based on nodes usage. The Average Energy consumption calculated for a network of given parameters using Cooperative Approach is 25.535% and using Hierarchical Cooperative Approach is 19.437%. Thus overall energy consumption is reduced by 6.098% using HCT based on Node usage.

4.3. HCT based on RSSI and RE

The proposed HCT based on RSSI and RE is implemented using the following simulation parameters (Table 3). A mesh topology of 10 nodes is randomly deployed in a region of 1000 x 1000 m. Nodes 0 and 8 are labeled as Source and destination. For the critical nodes 4 and 5, the proposed methodology is implemented. Table 4 shows the sample neighbor table maintained for node 0. It shows the neighbor list for node 0 along with the RSSI and the RE values received for those neighbors. Initially all the nodes are configured with a constant RE value. So during the initialization phase, forwarder node election only depends on the RSSI value. After a defined period of time (i.e. after nodes started spending energy for forwarding) both RSSI and RE were considered for election.

Table 3. The Simulation Parameters For HCT Based On RSSI And RE

Software Version	: NS 2.27
Operating System	: Fedora 7.0
Network Topology	: Mesh
Number of Nodes	: 10
Source Node	: Node 0
Destination Node	: Node 8
Critical Nodes	: Node 4 and 5

Table 4. Neighbor Table Of The Source Node

NODE	NEIGHBOR NODE	RSSI	RE
0	1	-53.23	100
0	3	-42.68	100
0	4	-49.08	100
0	5	-42.76	100

The RSSI values calculated for the source node 0 with respect to all other nodes in the network is listed and is graphically shown along with its distance metric in figure 12. As the distance increases the RSSI get decreases. This is seen in the above Figure From the list of all neighbors, a best set of nodes (RSSI > Threshold) were considered for forwarder node election. The neighbor table maintained is shown in figure 13. The figure 14 shows the RSSI calculated for node 3 with respect to all other nodes in the network.

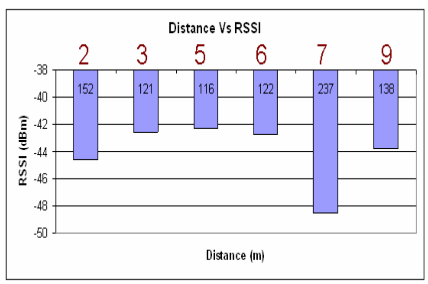

Figure 12. Inverse Nonlinear Graph for Distance Vs RSSI

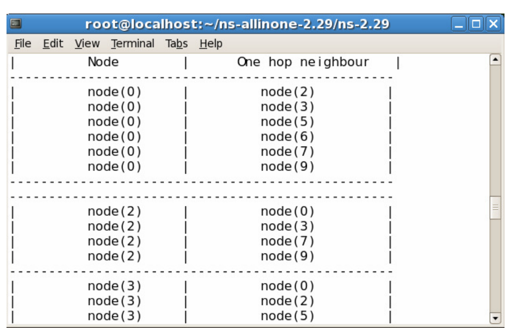

Figure 13. Neighbor Table

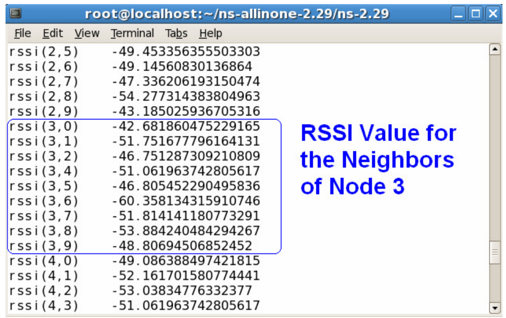

Figure 14. RSSI calculation

The redundant nodes (not used for forwarding) can be in any one of the two states namely idle and sleep states. Energy consumption is calculated for both cases and is plotted in figure 15. The graph proves hibernating idle nodes to sleep state gives less energy consumption. The average energy consumption calculated for a network using HCT based on RSSI and RE with idle nodes is 18.84%, and with sleep nodes it is 10.86%. Thus overall energy consumption is reduced by 7.98% using HCT based on RSSI and RE with sleep nodes.

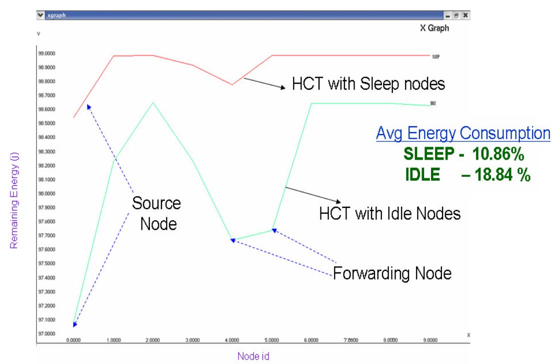

Figure 15. Energy consumption of HCT based on RSSI and RE with idle nodes and sleep nodes

Comparisons on the average energy consumption using the different approaches proposed are done and are shown in figure 16. The figure shows the effectiveness of the proposed methodologies compared to the existing cooperative approach. It is also proved HCT based on RSSI and RE with sleep nodes provides a lesser energy consumption compared to the others.

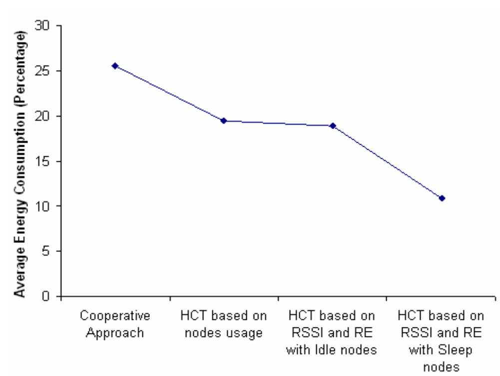

Figure 16. Comparison on various methodologies for a one tier architecture

4.4. Genetic Algorithm based HCT (GAHCT for two tier architecture)

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. Since a random initial population has been generated, the number of cluster heads in every iteration is going to be different. More number of iterations is done. Average of cluster heads and cluster slaves is taken and is shown in figure 17. Using NS-2.34, network deployment #1 is simulated with the parameters given in table 5. For this scenario the energy consumed by all the nodes in the network is calculated.

Table 5. The Simulation Parameters For GAHCT

Parameters	Value
Deployment Region	1000 m x 1000 m
Number of Nodes	0 - 25
Sink Node Id	25
Sink Node Position	800 , 800 , 0
Number of Bits transmitted	500
E_{Elec}	50 nJ/bit
$€_{amp}$	100 pJ/bit/m^2
Simulator	NS-2.34, Matlab

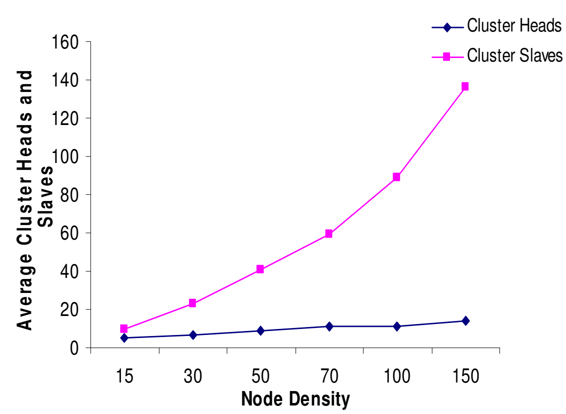

Figure 17. Average Number of Cluster Heads and Cluster Slaves for various network densities

The energy consumed through a one tier architecture for the same simulation parameters is calculated and is compared with the proposed GAHCT. Figure 19 gives the average energy consumed for the network of deployment #1 using a one tier architecture and using the proposed GAHCT. The average energy consumed using one tier architecture is 32.12 mJ and using

GAHCT it is just 16.20 mJ. Thus maximum energy gets saved using the proposed GAHCT. This further increases the network lifetime and network capacity, leading the network to a better performance. The network topology for deployment #1 for a one tier architecture and a two tier architecture using GAHCT is shown in figure 20 and figure 21.

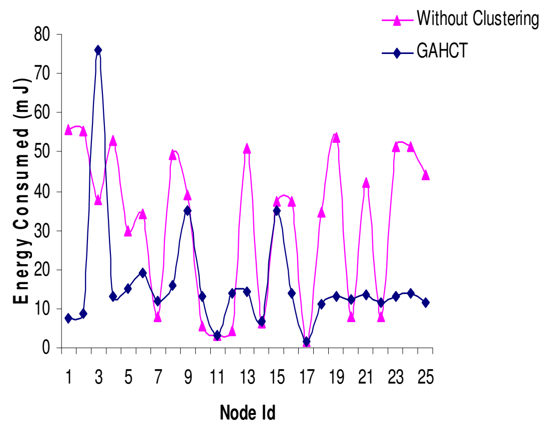

Figure 18. Comparison on the Energy Consumed by the individual nodes using GAHCT and One-tier architecture

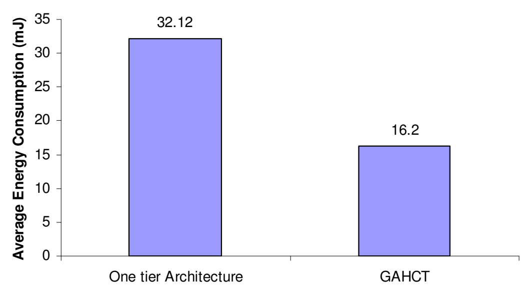

Figure 19. Comparison On The Average Energy Consumed For A One-Tier Architecture And GAHCT

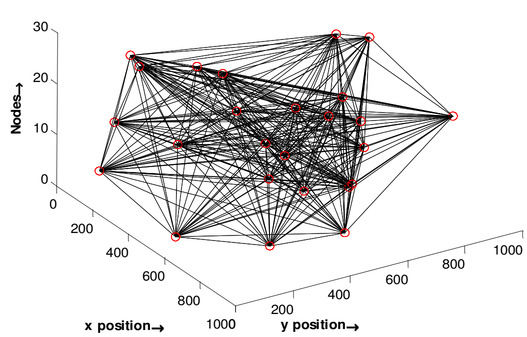

Figure 20. Network Topology of a One – tier architecture

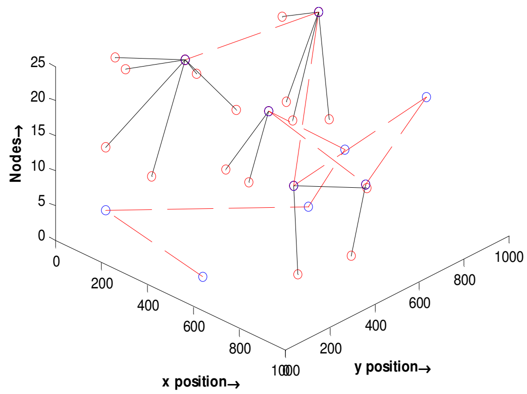

Figure 21. Reduced Network Topology using GAHCT

4.5. Genetic Algorithm based HCT (GAHCT for three tier architecture)

Same network deployment #1 is considered, and the proposed GAHCT algorithm (for 3 tier) is implemented. Since a random initial population has been generated in a GA, the number of cluster slaves, cluster heads and super heads in every iteration is different. More number of iterations is done. Average of super heads, cluster heads and cluster slaves is taken and is plotted in figure 22. From the figure, it is inferred that cluster slaves are more in number when compared to the cluster heads and super heads. This also leads to an effective data gathering process.

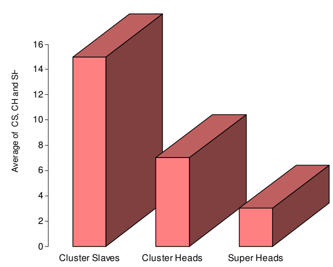

Figure 22. Average of CS, CH and SH

The network animator screenshot using NS-2.34 is shown in figure 23. During the time of simulation the super head nodes are identified by yellow color, cluster heads by red color and cluster slaves by green color. Using the parameters given in Table 5, the energy consumed by all the nodes in the network is calculated. A comparison on the energy consumption of the individual nodes for a N –Tier architecture is plotted in figure 26. The total energy consumed using deployment #1 for a N- Tier is shown in figure 27. The proposed GAHCT proves better performance for a two tier compared to that of one tier and three tier architecture.

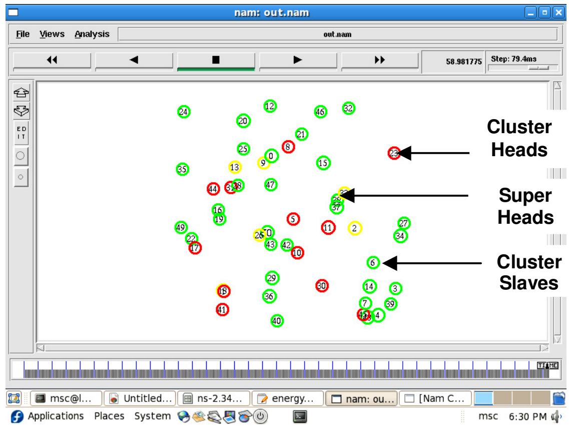

Figure 23. Network Animator screenshot for GAHCT (3- tier)

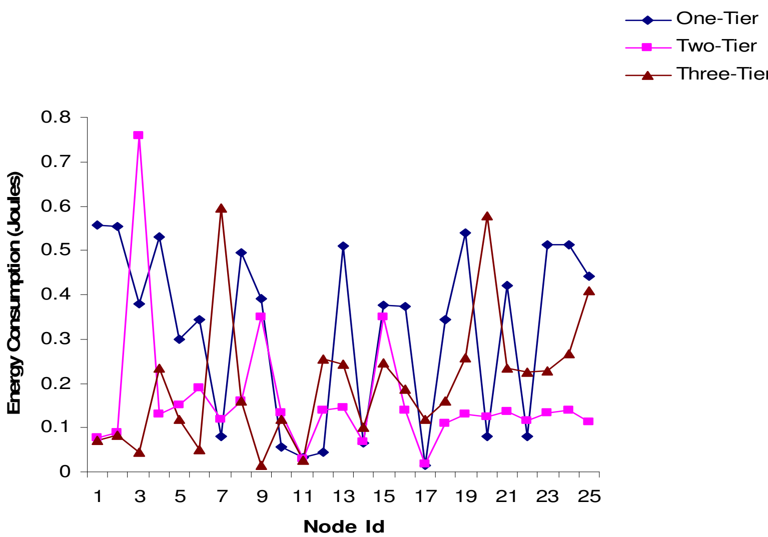

Figure 26. Comparison on the Energy Consumed by the individual nodes for a N-Tier architecture

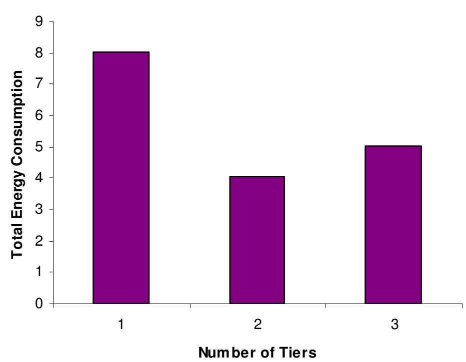

Figure 27. Comparison on the Total Energy Consumed for a N-Tier Architecture

The network topology of one tier architecture (before applying GAHCT) is shown in figure 28. In this a mesh topology each node gets connected to all the nodes in the network leading to a more complex network. The topology obtained after applying GAHCT for three tier architecture is shown in figure 29, 30, 31 and 32. On comparing figure 28 and figure 32, it is well proved that GAHCT reduced the number of links between the nodes in the network to the maximum. Thus reducing the number of links leads to a more energy efficient network.

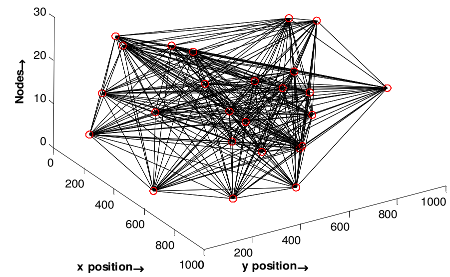

Figure28. Network Topology of One – tier architecture

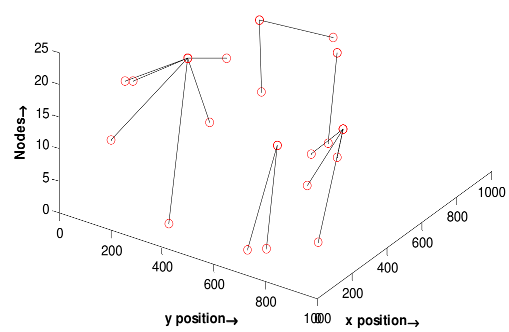

Figure 29. Cluster formation (lower tier) using GAHCT for a Three –tier architecture

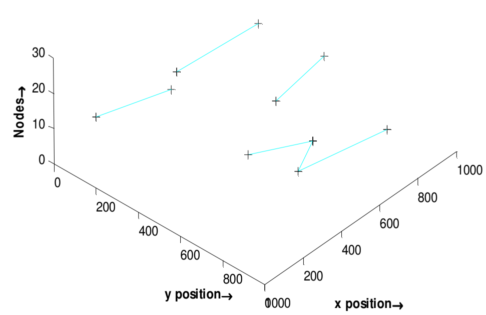

Figure30. Cluster Heads (middle tier) using GAHCT for a Three –tier architecture

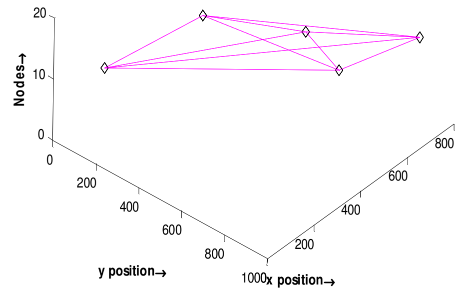

Figure31. Super Heads forming Communication Subnet (upper tier) using GAHCT for a Three –tier architecture

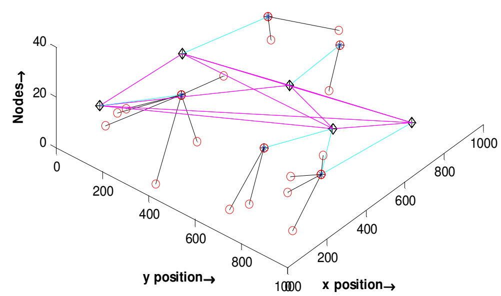

Figure32. Network Topology of a Three – tier architecture

5. CONCLUSION AND FUTURE WORK

A new topology control algorithm called HCT based on nodes usage and HCT based on RSSI and RE is proposed and implemented for a one tier architecture. It has overcome the oscillatory behavior faced in the conventional cooperative approach. HCT based on nodes usage is used to select a best set of neighbors to form a connected network topology. Compared to the existing method, HCT based on nodes usage brings out a overall reduction in the average energy consumption by 6.098% . HCT based on RSSI and RE is implemented in order to select a best forwarder out of all the selected set of neighbors. The unused neighbors are put on to sleep state to further reduce the energy consumption. The overall energy consumption is reduced by 7.98% by hibernating the idle nodes to sleep state using HCT based on RSSI and RE.

A two tier architecture comprising of cluster heads and cluster slaves is developed using GA based on Bandwidth, Memory Capacity and RE . Using the proposed GAHCT , for a two tier architecture the overall energy consumption has been reduced by 15.92 mJ compared to a one tier. As an enhancement of this work, a three tier architecture which forms with Super heads, cluster heads and cluster slaves is developed and the results are compared with a two tier and one tier architecture. It has also been proved that using the proposed GAHCT, for a network density of 25 nodes a two tier architecture consumes lesser energy compared to a one tier and three tier network. The proposed work can be extended by increasing the value of N and the node density.

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