A COMPARATIVE STUDY OF PROPOSED TOPOLOGY CONTROL ALGORITHMS FOR ENERGY EFFICIENT WIRELESS SENSOR NETWORK

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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. The results showed the effectiveness of the different approaches proposed. Comparison on one tier architecture and two tier architecture using the proposed methodology is also made. 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

A Network of complex sensor nodes equipped with limited sensing, computing, and radio communication capabilities is called a Wireless Sensor Network (WSN). It is classified in to two ways. One is the homogenous network and heterogeneous network. The main requirement for various applications is to prolong the lifetime of the sensor network. 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 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. The effect of using maximum transmission range is discussed in section 2. Section 3 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 4. Conclusion and future work are dealt in section 5.

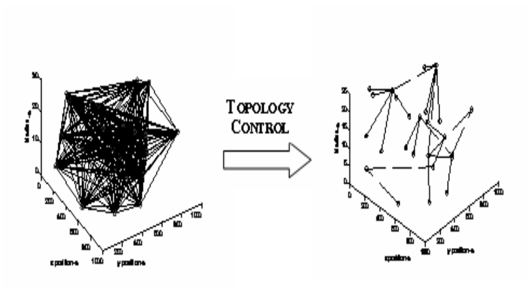

Fig. 1. Network Topology

2. 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.

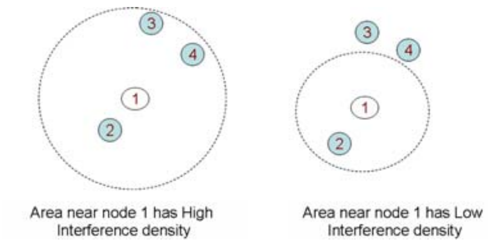

Fig. 2. Network using minimum and Maximum Transmission Ranges

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.

3. 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.

3.1.HCT based on Nodes usage

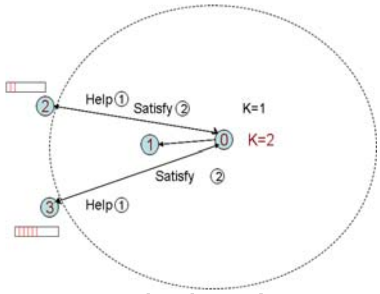

Fig. 3. HCT based on Nodes usage

The algorithm of HCT is discussed below.

<u>Hierarchical Cooperative Technique (HCT) based on nodes usage</u>
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.

3.2. 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. Figure 4 illustrates the proposed algorithm.

<u>Hierarchical Cooperative Technique (HCT) based on RSSI and RE</u>
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

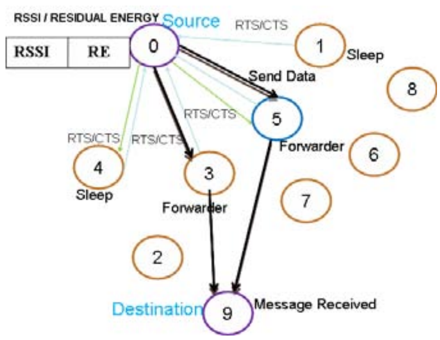

Fig. 4. Sample Network using HCT based RSSI and RE

In figure 6, 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

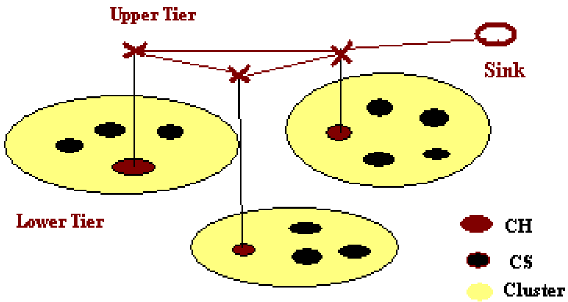

Fig. 5. GAHCT for Two tier Architecture

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.

Fig. 6. 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.

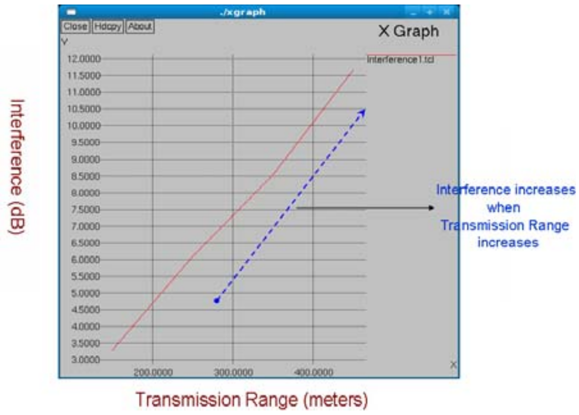

Fig. 7. Transmission Range Vs Interference

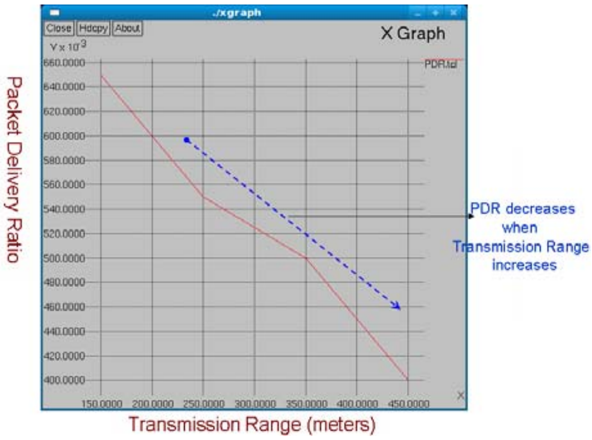

Fig. 8. Transmission Range Vs PDR

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 9.

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

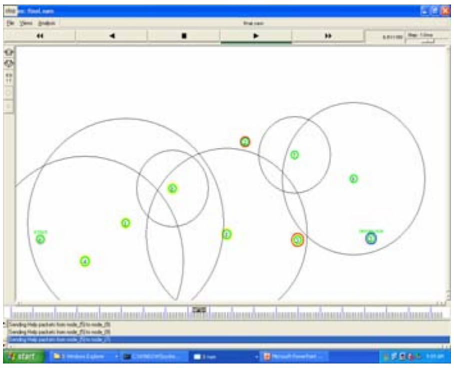

Fig. 9. Network Animator Screenshot For HCT Based on Nodes Usage

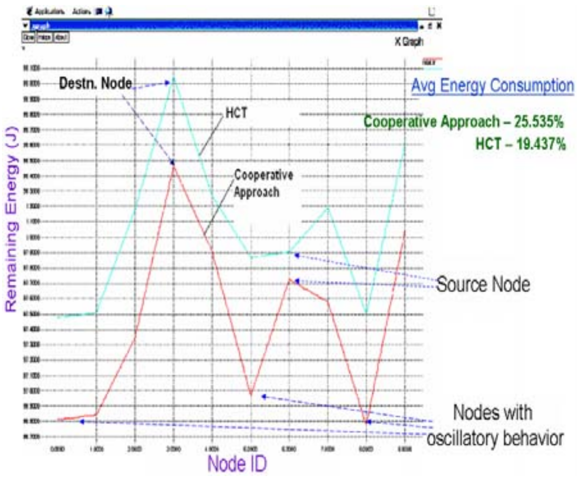

Fig. 10. Energy consumption using cooperative approach and using HCT based on Nodes usage

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 10. 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 11. As the distance increases the RSSI get decreases. This is seen in the above Fig. 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 12. The figure 13 shows the RSSI calculated for node 3 with respect to all other nodes in the network.

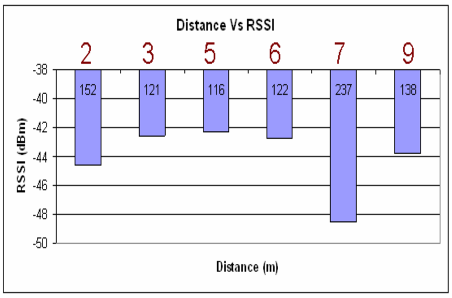

Fig. 11. Inverse Nonlinear Graph for Distance Vs RSSI

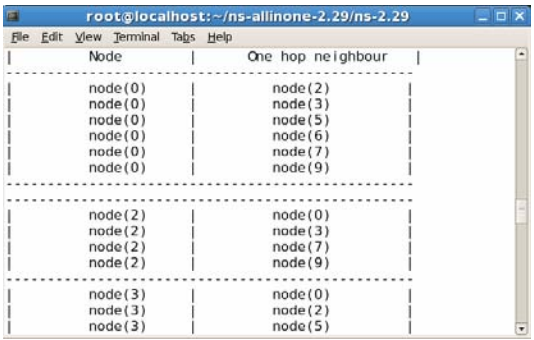

Fig. 12. Neighbor Table

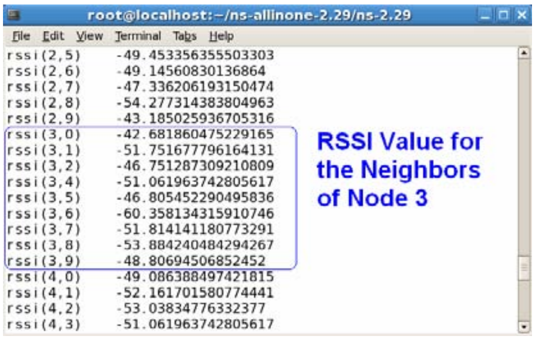

Fig. 13. RSSI calculation

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 14. 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.

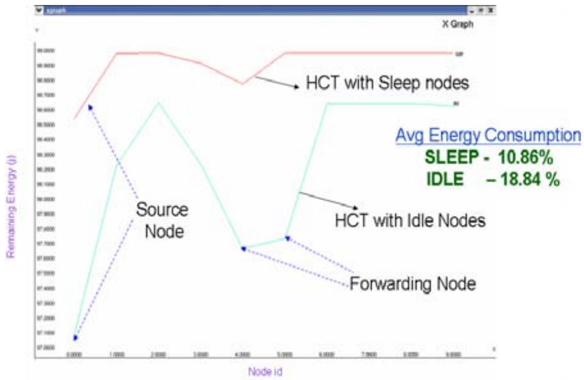

Fig. 14. Energy consumption of HCT based on RSSI and RE with idle nodes and sleep nodes

Comparisons on the average energy consumption using the different approaches proposed are done and are shown in figure 15. 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.

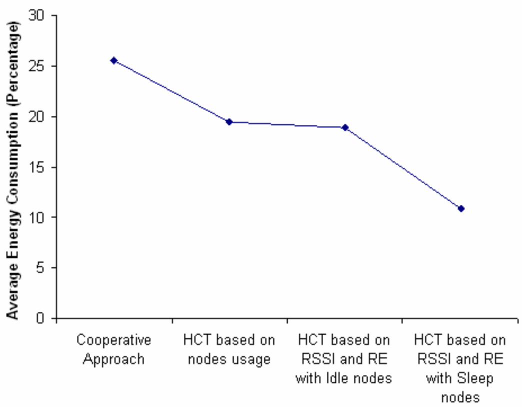

Fig. 15. Comparison on various methodologies for a one tier architecture

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 16. 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 Number of Bits transmitted E_{Elec} $€_{amp}$ Simulator	800 , 800 , 0 500 50 nJ/bit 100 pJ/bit/m^2 NS-2.34, Matlab

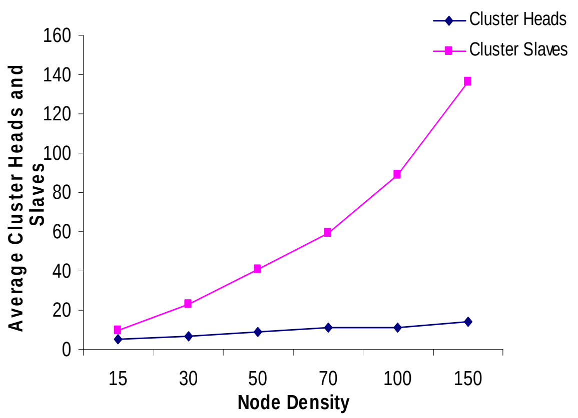

Fig. 16. Average Number of Cluster Heads and Cluster Slaves for various network densities

The energy consumed through a one tier architecture for the same simulation parameters is calculated and is compared with the proposed GAHCT. Figure 18 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 19 and figure 20.

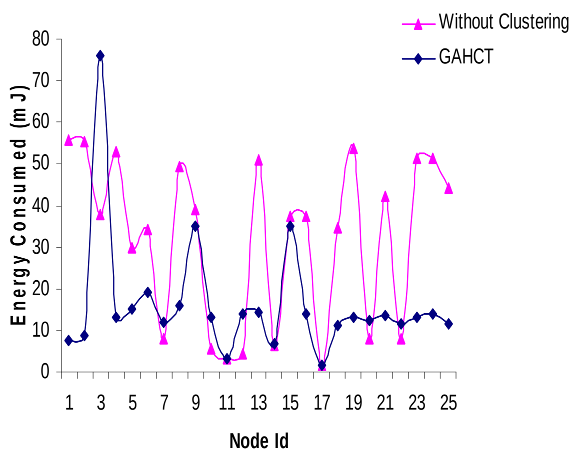

Fig. 17. Comparison on the Energy Consumed by the individual nodes using GAHCT and One-tier architecture

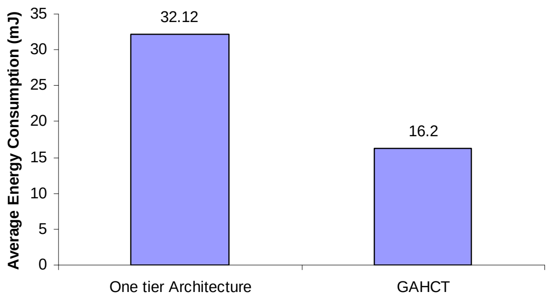

Fig. 18. Comparison On The Average Energy Consumed For A One-Tier Architecture And GAHCT

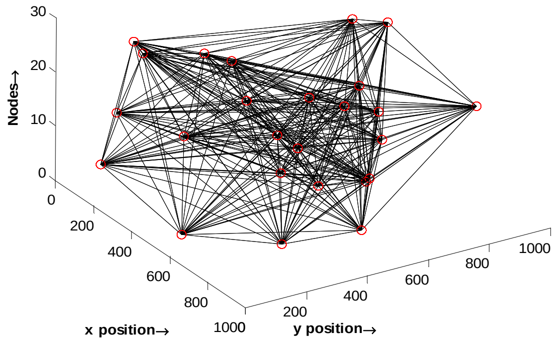

Fig. 19. Network Topology of a One – tier architecture

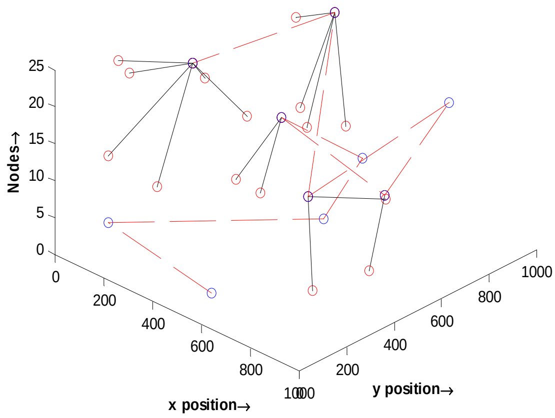

Fig. 20. Reduced Network Topology using GAHCT

5. Conclusion and Future Work

A new topology control algorithm called HCT is proposed and implemented. It has overcome the oscillatory behavior faced in the conventional cooperative approach.

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 and the results are compared with the one tier architecture. The overall energy consumption is reduced by15.92 mJ using GAHCT based on Bandwidth, Memory Capacity and RE. As an enhancement of this work, an efficient algorithm for selection of best cluster heads in three tier architecture can be developed and the results can be compared with a two tier architecture. An efficient algorithm for data forwarding in the upper tier can also be developed.

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