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Control the Topology and Increase the Tolerance of Heterogeneous Wireless Sensor Networks

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Abstract: Heterogeneous wireless sensor networks consist of sensor nodes with different capabilities including different computing power, amount of energy, and sensing range. In this paper the issue of fault tolerance in heterogeneous wireless sensor networks is stated and two methods of resolving this are provided. Considering the fact that the sensor nodes are operating in an independent manner, the method of k-path topology control is proposed and the minimization of the necessary energy needed to transfer data from one point to another is addressed.

Keywords: Topology Control, Fault Tolerance, Power Increase, Heterogeneous Wireless Networks Sensor Network, Energy Consumption

I. INTRODUCTION

Wireless Sensor Networks provide a technology which is consisted of several nodes that enables the monitoring and control of physical and environmental variables, such as temperature, sound, light, vibration, pressure, movement, and pollution [1]. These networks firstly designed for military applications but later their civilian applications became common. A variety of wireless sensor networks are used for environmental monitoring, blood pressure monitoring [2], plant control, monitoring of traffic, roadway safety warning [3], industrial sensor [4], remote patient monitoring [5], habitat monitoring [6], smart classroom [7], etc.

Wireless sensor networks generally are divided in to two types; symmetric and heterogeneous networks [8]. In symmetric wireless sensor networks all sensor nodes are the same, but in heterogeneous networks some of the sensor nodes have a different characteristics and attributes. In this paper it is supposed that heterogeneous wireless sensor networks include two types of wireless sensor nodes: ordinary wireless sensor nodes which are distributed randomly in an environment and super nodes which are located in special areas.

Super nodes provide a better service in power, communication links, energy amount, radio range, processing capacity than sensor nodes. Super nodes have two types; transmitter and receiver, that one of them is designed to connect to wireless sensor network and the other for rapid sending of data from sensor nodes.

With these assumptions, collection of information in Heterogeneous wireless sensor networks is in a way that sensor nodes transmit and distribute data in multi hop paths. Figure.1 shows this process that data from sensor nodes reach to super nodes then by the use of existing relationship between super nodes this data transferred to user.

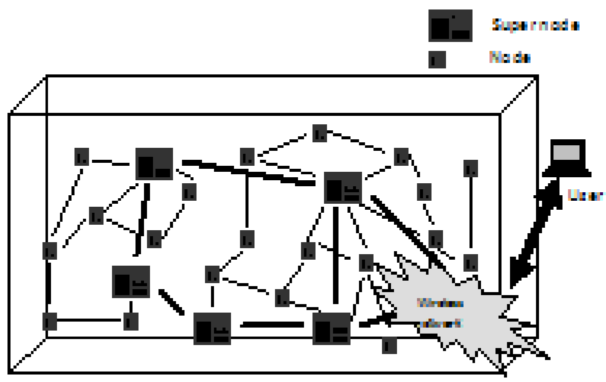

Figure: 1Heterogeneous Wireless Sensor Networks

The rest of the paper is organized as follows: Section 2 provides an overview of related work. Section 3 briefly describes the Heterogeneous wireless sensor network architecture. Section 4 describes the topology control problem in Heterogeneous wireless sensor network. Next, the network model is presented in Section 5. The Proposed Methods are presented in section 6. The simulation results are provided in Section 7. We conclude the paper in Section 8. Finally references are provided in the last section.

II. RELATED WORKS

In this section related works are briefly explained. In [9] a new method to increase the life time of wireless sensor networks is presented. In [10] a new method for problem of two connections and four costs is presented. In [11] one new method to control of the fault tolerance in ad-hoc networks has been introduced. The algorithm which is presented in [12] creates neighborhood graph and its generalizing around topology control that increase tolerance of ad-hoc networks. In [13] also greedy methods are used for fault tolerance topology control. In [14] two local and central algorithms for topology control with the aim of reduction of energy consumption are presented. In [15], the authors propose the power aware dynamic source routing protocol for enhancing the traditional method with power awareness. In [16] a new consumed energy type aware routing method was introduced which discourage some active node in participating in routing process in order to save their energy. T. Kim and et al. in [17] present a distributed low power scheduling algorithm for wireless sensors to determine their active time slots in a TDMA scheme operating on a slotted CSMA network. In [18] the authors propose the Particle Swarm Optimization (PSO) method to classify a sensor node field into groups of equal sized groups of nodes. This method enables the network to balance the energy consumption of cluster heads; but is not applicable to some where nodes are not evenly distributed. In [19] a framework for managing the QoI offered by a shared WSN using negotiation techniques between application tasks and network resources and real-time estimates of the network's total QoI capacity is presented. The energy optimization with multi-level clustering algorithm for wireless sensor networks is presented in [20]. In [21] the results show that when the network lifetime is over, up to 90% of the total initial energy of the nodes is left unused if the nodes are usually distributed in the network. There are other extensive researches on energy aware routing [22-25] and improvement in lifetime [26-30].

In the next section heterogeneous wireless sensor networks are briefly reviewed.

III. HETEROGENEOUS WIRELESS SENSOR NETWORK ARCHITECTURE

Wireless sensor networks include the large number of sensor nodes. In this network when data are sent to destination without super nodes, their transfer in wireless networks lead consume the sensor nodes power that cause low and uncertain results. One solution which recently attracted more attention is the use of heterogeneous wireless sensor network which consist of components with different hardware capabilities. Three conventional types of hardware heterogeneity are; Computational heterogeneity that some nodes have high computational power, link heterogeneity that some nodes have reliable communication links with long range and energy heterogeneity that some nodes have unlimited energy sources.

Proposed architecture includes two types of wireless components which are shown in figure 1; sensor nodes and super nodes. Sensor nodes have weight limitations, low cost, limited battery power, short range communication, low rate of data, and short life. The main duties of sensor nodes are data sensing, data processing, and data casting. The upper layer is consisting of super nodes with many sources which are located on wireless sensor network. Super nodes consist of two transmitters; one for communication with sensor nodes and the other for communication with super nodes. Super nodes have much more allocated energy, processing and storage capabilities than sensor nodes. One of the main works which is done by super nodes is to transfer data from sensor nodes to destination. The other duties that super nodes are collection of data, complex computations and decision making. Next section describes the topology control problem in heterogeneous wireless sensor network.

IV. TOPOLOGY CONTROL PROBLEM NETWORK MODEL

In this paper, an heterogeneous wireless sensor network which includes super nodes and nodes is considered. Super nodes are distributed in an environment and connect to each other and their main duty is data cast from sensor nodes to user programs. In other hand, sensor nodes are distributed randomly in the environment. It is assumed that sensor nodes can maximize their own radio range up to R_{max}. If each sensor node uses R_{max} radio range, there is at least k path from each sensor node to the set of super nodes.

In this paper the aim is providing reliable substructure for transmitting data from sensor nodes to super nodes. In this problem model there is distinct k-connected communication path from any sensor node to super nodes that this condition guaranty that when k-1 sensor node is damaged, at least there will be one path from any sensor node to super node and consumed energy by all sensor nodes is minimized to guarantee that there is optimal design for energy consumption. also, the communication between nodes are ignored and it is assumed that when one packet of data transmitted from one sensor node to super nodes, data will be casted with distinct and optimal super node.

In this problem, instead of reliance on communication between any couple of sensor nodes, the aim is creation of communication path from any sensor node to one or several super nodes. If the distance between sensor nodes less or equal to communication range of sensor nodes, a sensor node will be able to have a communication with other sensor nodes or one super node. Thus an heterogeneous wireless sensor network consists of *M* super node and *N* node with limited power to control their sending range to R_{max}. Figure 2 illustrates an example of heterogeneous wireless sensor network that each sensor node contains 3 distinct paths to super nodes. For example n_6 node has three distinct path to super nodes which are (n6,n1), (n6,n5,n1) and (n6,n4,n3,n4). In all of these paths there is not any duplicated node, because in this case by distorting of a node two paths will be eliminated.

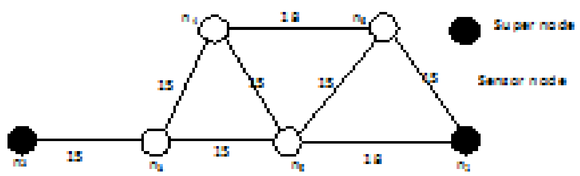

Figure 1. Sensor Network Graph

Sensor nodes are susceptible of error due to physical dangers or lack of energy.

V. NETWORK MODEL

A heterogeneous wireless sensor network consists of *M* super node and *N* sensor node that the size of *M* is much less than *N*. In this mode communications between two sensor nodes and the communication between sensor node and super node is considered. It means communication between super nodes is ignored. Topology of network is shown by Non-directional weighted graph *G=(V,E,c)* that

$V=\{n_1,n_2,\ldots,n_N,n_{N+1},\ldots,n_{N+M}\}$ is a set of nodes and E is a set of edges. A set of edges is defined by $E=\{(n_i,n_j)|dist(n_i,n_j)\leq R_{max}\}$ in which $dist(n_i,n_j)$ is a distance function.

Function of (u,v) represents the required cost for u and v nodes to establish one way communication between them. It is also assumed that each node has an identified address and each node can find its own information by one of routing techniques for wireless networks [13].

Also, in this model accessible neighbor is a set of nodes n_i can have an access to certain nodes by maximum sending range R_{max}. For example in figure2 accessible nodes for n_5 are $\{n_1,n_3,n_4,n_6\}$.

VI. PROPOSED METHODS

In this section two solutions for this problem are provided. To solve this problem, the graph should be reduced and reduced directional graph should be defined.

a. ***Reduced graph:*** in this graph all super nodes are replaced by a node which is titled root and edges between sensor nodes are the same as previous but the edges between sensor nodes and super nodes is reduced to an edge between sensor nodes and root. The weight of the edge in reduced graph is the same as G. figure 3 shows reduced graph of the graph in figure 2. If a sensor node is connected to more than one super node, then just one edge is added to reduced graph because the goal is sending data of sensor nodes to at least one super node that its cost is distinct to the nearest super node.

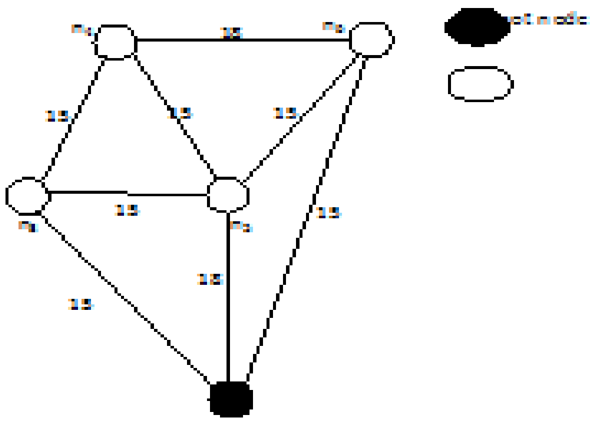

Figure 2. Reduced Graph

b. ***Reduced directional graph:*** each nondirectional edge (n_i,n_j) in reduced graph between two sensor node n_i and n_i becomes directed and an edge between sensor node and root in reduced graph is replaced by directional edge from sensor node to root. The reason is that in this problem we are just engaged with sending data to sensor nodes and any communication external to super nodes is not considered. In the other hand for all communications between sensor nodes we considered two way communications that each sensor node can transfer data to other sensor nodes. Figure 4 illustrates reduced directional graph of the graph in figure 2.

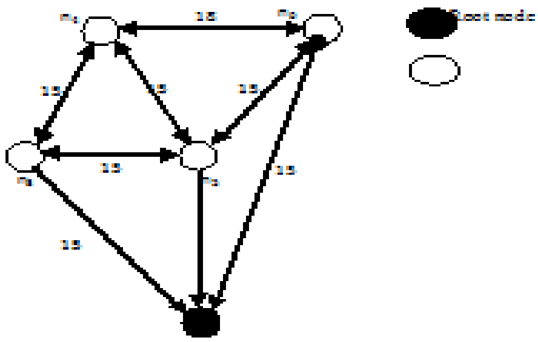

Figure 3. Reduced Directional Graph

c. ***K-path connection in reduced graph:*** Reduced graph has k connection to root, if in each sensor node the number of paths from n_i to root equals to k distinct path. So the reduced graph is k-connection if elimination of k-1 sensor node and all related communication paths do not lead to network partitioning. A heterogeneous wireless sensor network is k-connected vertex if related reduced graph of it connected to root in k vertex form.

Next subsection presents the general fault tolerance topology control to solve this problem.

A. General Faulttolerance Topology Control:

In this subsection one greedy algorithm is presented that k vertex of super node is connected to sub graph and then all nodes initialize the least required power to establish communication with nearest neighbors by one hop. In this algorithm the maximum transmission power of all sensor nodes among other k vertex of super node is minimized. This attribute is very important to balances power consumption among all nodes.

This algorithm begins from k connected vertex of super node of G, then makes reduced graph and convert the graph to directional graph. This algorithm checks all edges in directional graph and cleans one (u,v) edge in order to G remains k connected to root. Then algorithm computes the power of each sensor node in order to n_i super node have an ability to have direct connection with other nodes.

Next sub section describes the distributed fault tolerance topology control.

B. Distributed Fault Tolerance Topology Control:

This method is a distributed and casted algorithm that allocate effectively power levels to each sensor node in such a way that one k vertex super node remains. Each node begins with making its neighbors that is based on massage switching between neighbors and starts with R_{max} communication range. Each sensor nodes began to distributed process until determines its own maximum power. Sensor node finds required power to have an access to furthest neighbor and required power to make a relation with first neighbor. Each sensor nodes makes a use of one repetitious process to establish the ultimate power. For this purpose it starts from the required power to have an access to furthest neighbor. After this, sensor node put its own power in such a way between required power to have an access to furthest neighbor and required power to have an access to relation with first neighbor that the network stay connected in k path form.

If G be a connected form super node of k edge, in that case the level of allocated power by an *n* algorithm ensures *k* edge connected topology.

In the next section the simulation results are provided.

VII. SIMULATION RESULTS

In this section, the simulation results are presented. It is assumed that sensor nodes are deployed in an environment of $120m^2$ areas. Super nodes are deployed uniformly in this environment and power consumption is considered as the sum of each sensor node power.

Figure5 illustrates the result of simulation for a network with nodes between 10 and 60 and *k* is equals 3 with fault tolerance public topology control.

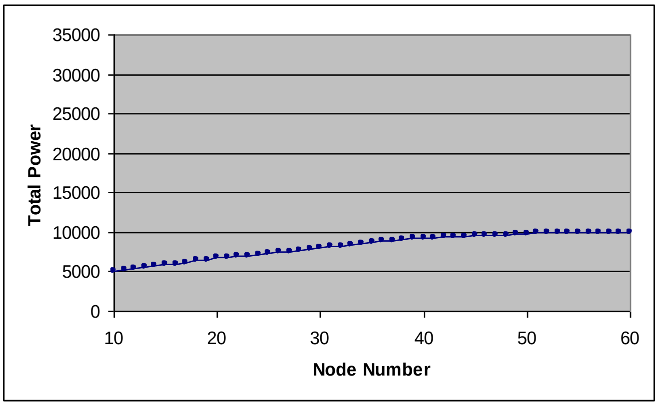

Figure 4. the simulation result with public fault tolerance topology control

Figure 6 represents the obtained result of simulation with fault tolerance distributed topology control for a network with nodes count between 10 and 60, *k* is equal to 3.

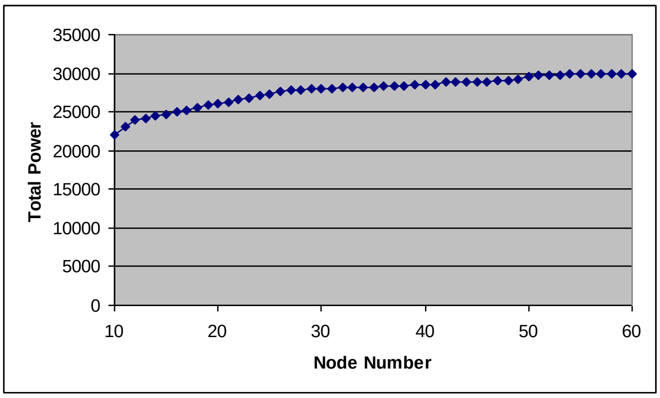

Figure 5. the simulation result with distributed fault tolerance topology control

As illustrated in figure6 distributed fault tolerance topology control has very low power consumption than public fault tolerance topology control. Also due to its distributed nature it can be used in sensor networks.

VIII. CONCLUSION AND FURTHER WORKS

In this paper the topology control problem in the heterogeneous wireless sensor network with the goal of minimizing total power consumption in a state that the count of distinct paths from sensor nodes to super nodes equals to *k* is introduced. This topology results in fault tolerance in k-1 node.

In this paper to solve the topology control problem two solutions is introduced; one solution is public and the other is distributed. Distributed solution has an attribute that can reduce maximum power between all sensor nodes. Also, simulation results showed this superiority. By considering distributed nature of this method, this algorithm has more applicable in sensor network.

For further works, it is possible to develop this problem in a state that there is two-way (fully duplex) communications between sensor nodes and super nodes and vice versa.

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