One Dominant Graph Topology for Heterogeneous Wireless Sensor Networks

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Abstract - The integration of different wired and wireless access technologies constitute the next-generation heterogeneous network. A typical wireless sensor network configuration consists of sensors sensing and transmitting their observation values to some control center, the so-called sink node, which serves as a user interface. Due to the limited transmission range, sensors that are far away from the sink deliver their data through multihop communications. As sensor devices are resource constrained, extending the network life time is very crucial to the functioning of the system. In this paper it is proposed to identify a one dominant node based topology in heterogeneous set up. The topology management is proved to be highly energy efficient.

Keywords - Sensor, Sink, One dominant node, Topology, Heterogeneous

I. INTRODUCTION

Sensor networks are low power, low cost devices equipped with wireless communication and having limited processing capabilities [1]. These networks have found innumerable applications recently especially in healthcare, automation, industry, traffic management and so on. The sensors are resource constrained devices and thus they have very limited life time. Sensor networks introduce new challenges that need to be dealt with as a result of their special characteristics. This requirements lead to the innovative and dynamic algorithms that particularly paid attention to energy conservation. More specifically a number of proposals have been made related to the topology of the network. The key challenge in wireless sensor networks is maximizing network lifetime [16]. The appropriate communication mode will significantly reduce energy consumption of communication and prolong networks lifetime. Therefore, many researchers are currently focusing on the design of power-aware protocols for wireless sensor networks. Regardless of communication protocol, researchers must choose communication mode: single hop or multi hop. Using a single hop communication mode, each sensor sends its data directly to the base station. In multi hop mode, each node sends its data destined ultimately for the base station through intermediate nodes [14].

The life time of WSN depends on connectivity of a WSN which is related to the positions of nodes. The positions of the nodes are heavily affected by the method of sensor deployment. In general, there are two types of approaches to deploy sensors in a WSN: deterministic deployment, where sensors are placed exactly at pre-determined positions, and the random deployment, where nodes are deployed at random positions [8]. For the deterministic deployment, networks are carefully planned, and nodes are placed at desired positions. If specifications of nodes are known, it is not difficult to determine whether the network is connected, and if not, to add relay nodes where needed. This topology suits certain applications like under water monitoring and building monitoring. This is unlike dense forest fire detection, habitat monitoring and vehicular networks systems. The deployment is mostly random and there is no structural topology. Although deterministic deployment has many advantages, in order to reduce installation costs, it has often been proposed that large WSNs which contain very large numbers of nodes be deployed randomly. Nodes may be dispersed by a moving vehicle or artillery shell. Mobile sensors also add to the dynamic nature of the network. Therefore, sensors often have nondeterministic positions, and the analysis of connectivity depends on the random topology.

Base station placement has significant impact on sensor network performance. Despite its significance, results on this problem remain limited. The authors in [3, 17] focus on the important problem of base station placement such that certain network performance objectives can be optimized. Indeed, the location problems for base stations have been very difficult to analyze and is shown to be NP complete. A very few special cases have been investigated for optimal placement, e.g., single-hop communication between sensor node and base station [17] or special grid topology.

In [7] the authors proposed to find the nearest base station for efficient routing in heterogeneous networks. In this paper it is proposed to construct a one dominant graph based topology based on the protocol discussed in [7]. In a given region, if all the nodes can communicate with a node which is either a sink node or a powerful mobile node, the node is said to be one dominant. The one dominant cluster head solves the problem of multiple hops and thus guarantees energy efficiency. If there is a base station or a dominant node exists within the transmission range of a node, the node is said to be covered. In this paper an efficient topology management is discussed which improves the network life time.

II. RELATED WORK

Due to the limited transmission range, sensors that are far away from the sink deliver their data through multihop communications. Although there is active research on maximizing network lifetime or network capacity most of these work consider a sensor network under a given physical topology. The survey of various topologies and their effectiveness can be found in [13].

Random graphs are often applied to model communication networks to highlight their randomness. Mathematically, a random graph is a graph that is generated by a stochastic process. A natural candidate for random network modeling is the class of Random Geometric Graphs [4, 12]. With node set V , a geometric graph G = (V, r) is equivalent to a graph G1 = (V, E), in which the vertex set V is embedded in a metric space, and $E = \{ (u, v) \mid \forall\ u, v \in V, \|u - v\| < r\}$. The authors in [5, 6] have studied the application of random geometric graph to wireless sensor networks. Chen Avin in [4] had investigated the property of random geometric graphs that has implication for routing and topological control in sensor networks. In [2, 12] the authors studied the topology and connectivity properties of random geometric graphs.

The challenges and solutions of topology control for wireless sensor networks are discussed in [8, 10, 11]. The optimal solution for the topology problem had been studied by the authors in [9]. An exhaustive survey of topologies and their qualitative assessment were studied by the author in [13]. It was discussed that the chain based topology would be the ideal topology for WSN. The topology control and management for WSN had been studied with respect to the static networks. The random deployment of sensors and the topology management is an active research area. Also none of the existing work has considered a heterogeneous setup where the sensors would coexist with other powerful nodes. In this paper a one dominant graph based topology is suggested for heterogeneous WSN.

III. TOPOLOGY MANAGEMENT

Base station placement problem has significant effect on network life time as in [17]. Most of the topology construction algorithms have assumed stationary sensor networks. The topologies that are studied for WSN are tree, cluster, chain and random. In a tree based topology as in figure 1, the roots are identified and the sensor nodes send the data to the root node. The only optimization that can be done on root based topology is that the nodes can decide to send the data only if there is significant change in data. The cluster based topology as in figure 2 is based on choosing a leader node which will be responsible for sending the data to the base station. There is a number of optimization done on this topology. Election of the leader node by energy level, rotating the leader nodes are some examples of optimization on this topology. The chain based topology as in figure 3 is based on efficient routing protocols. The routing protocol determines the path as chosen by the quality of service parameters and the path is followed. This topology has higher success rate as the path is determined dynamically. All these topologies have been studied for static sensor networks and random sensor networks. The random deployment is illustrated in figure 4.

But in real world, apart from stationary sensors, base stations, there may exist more powerful sensors, sink nodes, dominant nodes within a region. Typically a topology is constructed as a graph. The mathematical modeling of WSN can be represented by random geometric graphs. A one dominant graph is a graph where there exists a node which is reachable by all the other nodes in the graph. Connectivity is a significant factor in WSN as it ensures that the data is received by the base station. Taking advantage of the heterogeneous model, it is proposed to identify a dominant node in every region. When a sensor wishes to send the data, it identifies the high energy node and passes the data to it instead of sending it to another sensor. .

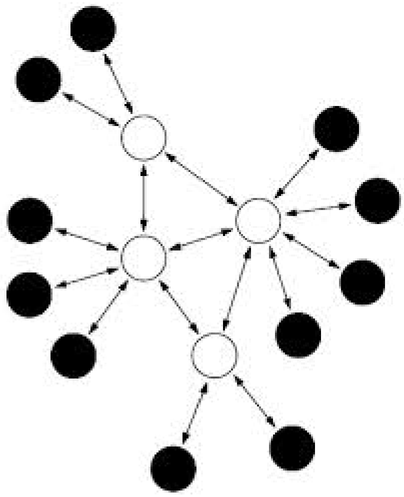

Figure 1 – Tree Topology

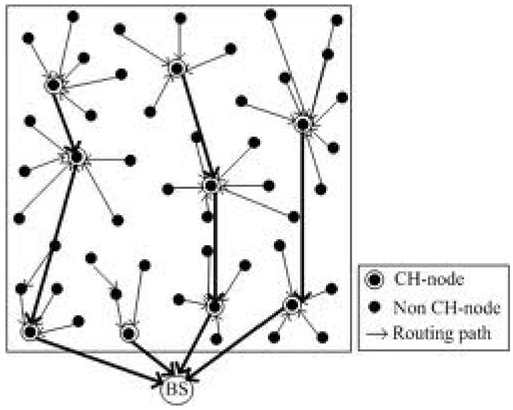

Figure 2 – Cluster Topology

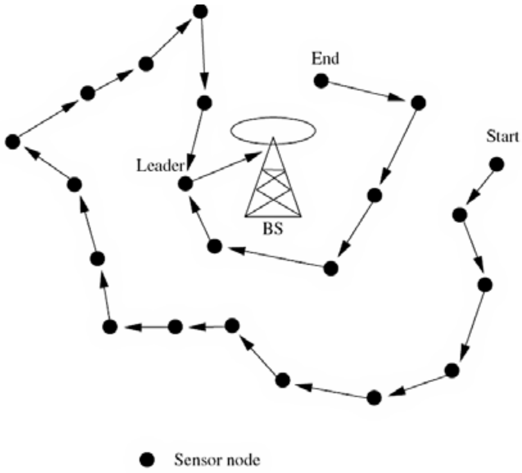

Figure 3 – Chain Topology

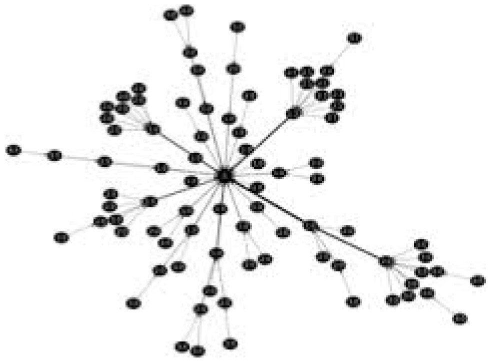

Figure 4 – Random Topology

IV. SYSTEM MODEL

The arrangement of sensors is called topology. In heterogeneous networks, the deployment of the sensors is random. This paper proposes a model that suits the random topology and is highly energy efficient. The sensors are assumed to be distributed over an area. In a heterogeneous setup, both wired and other wireless devices would coexist. Since sensors have multihop fashion communication, they tend to send the data to the nearest neighbour and eventually to the base station. All sensors are also assumed to be having various transmission powers. The transmission range of one node is different from another. Also they coexist with other mobile nodes and powerful sink nodes. Traffic monitoring systems, building monitoring systems are some examples of this set up. Apart from the sensors installed to monitor the present/absence of some phenomena there would be a number of mobile phones, laptops, wired computers and other communication devices. The wireless devices have a feature called wireless broadcast advantage. All the wireless devices will be able to see the presence of other devices. Thus it is possible for a sensor to know the presence of other powerful nodes around it. Every node broadcasts its identification, energy level and location. The sensors have a wake up – sleep schedule. When a node wakes up, it listens for high energy nodes. When a node receives such broadcast, it updates its routing table. The node periodically updates the table by discarding the old ones and adding new entries. It maintains a maximum of three entries for reliability. This is done so as to maintain two alternate paths to the base station. If the node does not receive any broadcast, it goes off to sleep. So it is possible for some nodes without having any entries in the routing table. The topology is assumed to be random and so it is highly dynamic in nature. Some nodes may have more than 3 powerful nodes around them and some may not even have a single powerful node. The scheme is designed in such a way that it is energy efficient. The assumption made here is that when an event occurs, it is likely to be detected by all the sensors in the region and so even if some nodes do not have neighbours, it will not affect the functioning of the system. In continuous monitoring systems, the sensors in the region would be sensing the same data and so even if some nodes do not have neigbours, the system produces more or less accurate results.

The nodes which can not directly communicate to any of the cluster heads are called orphaned nodes. Till the time these nodes identify a cluster head, the transmission is stopped. The nodes will not send any information to the base station. If the base station specifically queries the sensor, the transmission would start. Even then if it does not have a cluster head, it would send the information in a typical multihop fashion. In this algorithm, the usage of intermediate nodes is discouraged and only on certain circumstances, the sensors would be used as multi hops.

Algorithm

A. Initialization

- The sensor nodes periodically wake up and listen to the broadcast.
- If there is a high energy node, the sensor keeps a track of the details of the node.
- A sensor keeps a maximum of three entries to ensure reliability.
- For the next round of wake up, if the sensor does not hear from any of the already stored node, it removes it from the table and waits for another entry. The dynamic topology is maintained using wireless broadcast advantage.

B. Event monitoring systems

1. The user queries the base station through an interface.
2. The base station sends interest propagation to the sensor nodes.
3. The node that has detected the event checks its routing table for a neighbor.
4. If the node does not have any neighbor, the node just ignores the request.
5. If the node has a neighbor i.e, the node has one or more entries in the routing table, it picks the most promising node based on the time of updation. It is believed to be the last node in the entry table would still be reachable.
6. The node sends a request packet to the high energy node.
7. If it receives the reply within the set time period, the node sends the event data to the high energy node.
8. If not, the node picks next high energy node from the table and repeats the process.
9. If none of the route table entries send a reply packet, then the node ignores the request and continues in the wake up – sleep mode.

C. Continuous monitoring systems

1. The node monitors the phenomenon and checks with the previous reading
2. If there is significant change (>0.3), the node checks its routing table.
3. If the node does not have any neighbor, the node goes off to sleep
4. If the node has a neighbor i.e, the node has one or more entries in the routing table; it picks the most promising node based on the time of updation. It is believed to be the last node in the entry table would still be reachable.
5. The node sends a request packet to the high energy node.
6. If it receives the reply within the set time period, the node sends the data to the high energy node.
7. If not, the node picks next high energy node from the table and repeats the process.
8. If none of the route table entries send a reply packet, then the node continues in the wake up – sleep mode.

V. IMPLEMENTATION RESULTS

The proposed topology is implemented and an analysis with the existing topologies is done. The other topologies considered are cluster, chain and tree topologies. Table 1 shows the parameters used for simulation. The simulation is done for different CBR traffic. The location data is taken from [15].

Table 1: Assumed Parameters

Parameters	Value
Transmission range	250 m
Simulation Time	5M
Topology Size	2000m x 2000m
Number of sensors	55
Number of sinks	16
Mobility	Trace File
Traffic type	Constant bit rate
Packet rate	8 packets/s
Packet size	512 bytes
Radio range	350m
Node Placement	Node File

For the evaluation of the model the following metrics have been chosen. Each metric is evaluated as a function of the topology size, the number of nodes deployed, location and the data load of the network.

- Latency – This is a measure of execution time. It is time taken for different topologies for the given CBR traffic to complete within the simulation time.
- Remaining Energy – This is measured in terms of signals received and transmitted. The difference between the total energy and the energy spent on each node clearly shows the energy efficiency of the system.
- Number of sensors used - The number of nodes used in the transmission is also an indication of energy conservation at each node. The less the number of sensors used, the more the energy conservation. This is an indication of good network life time.

A. Simulation Results

Figure 5 shows the transmission range of the various sensors considered. All the sensors have different transmission power. They are heterogeneous in nature. This set up suits most of the real world applications. Figure 6 shows the latency for different topologies. The proposed model has better latency compared to other models. This is because of the fact that the sensor node always tries to find the high energy node as the next hop neighbour. Other models do not differentiate between high energy nodes and sensor nodes when selecting the next hop neighbour. Almost every node participates in the communication and thus latency is high in other models. In the one dominant model, if there is no high energy node around, the sensor will not participate in transmission. Figure 7 shows the remaining energy level of the network. The proposed system has better energy conservation than the other topologies. This is because the one dominant model spares the sensors as much as it can to conserve energy. This will prolong the network life time.

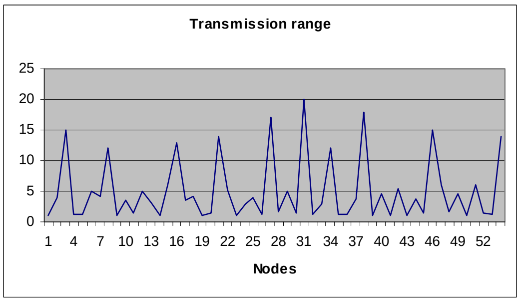

Figure 5 – Transmission range

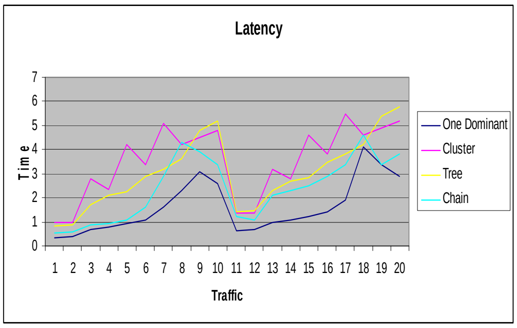

Figure 6 – Latency

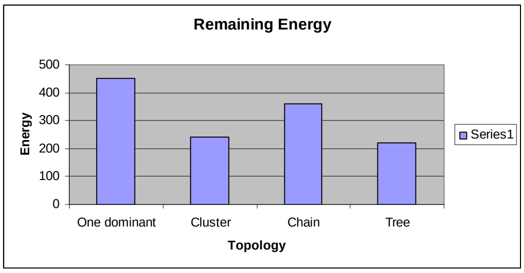

Figure 7 – Remaining energy level

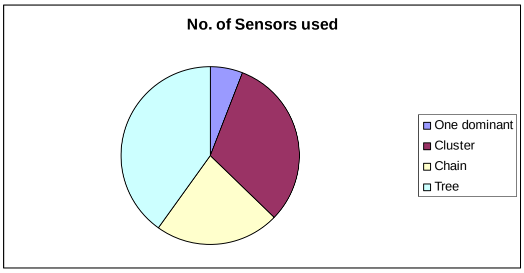

Figure 8 – Number of sensors used

Figure 8 shows the number of sensors used and the one dominant model uses the least number of sensors. This is because the sensors are never chosen as next hop neighbours. This conservative approach is proved to be suitable for real world applications and also prolongs the network life time.

VI. CONCLUSION

The broadcast communications of the wireless sensor networks and the dynamic infra-structure of the network, pose a different challenge in topology management. The traditional topologies are not suitable due to random deployment and the heterogeneous nature of the sensors. Also the main objective of WSN is to conserve energy so as to maximize the network life time. In this paper a one dominant graph based topology for heterogeneous WSN is suggested. This topology tries to spare the sensor nodes and thus conserve maximum energy. Each node tries to identify a dominant node as a next hop neighbour. The simulation results indicate that this model is well suited for heterogeneous setup. However, the suggested model will not work well in a static set up. Also it is possible to miss some events and data if there are no high energy nodes around the region.

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