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Energy Efficient Routing Mechanism for the Mobile Sink in WSN with Obstacles

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Abstract In Wireless Sensor Networks (WSNs), the benefits of exploiting the sink mobility to prolong network lifetime have been well recognized. In physical environments, all kinds of obstacles could exist in the sensing field. Therefore, a research challenge is the determination of efficient dispatch of the mobile sink to find an obstacle-avoiding shortest route. This research article presents an energy-efficient routing mechanism based on the cluster-based method for the mobile sink in WSNs with obstacles. According to the cluster-based method, the nodes selected as cluster heads collect data from their cluster members and transfer the data collected to the mobile sink. In this work, the mobile sink starts the data-gathering route periodically from the starting site, then directly collects data from these cluster heads in a single-hop range and finally returns to the starting site. However, due to the complexity of the scheduling problem in WSNs with obstacles, the conventional algorithms are difficult to resolve. Simulation results verify the effectiveness of the method.

Keywords WSN, LEACH, TDMA, CDMA, TSP, RLT, WCV, TCP, UDP, CBR

Introduction

Wireless Sensor Networks (WSNs) have been applied in many areas, including health monitoring, environmental monitoring, and military surveillance and also as Internet of Thing (IoT). Energy efficiency has become the most key issue for WSNs. However, power supplies for sensor nodes are limited and hard to replace. In addition, compared with other nodes, nodes near the base station (also called the sink) consume more energy, since the nodes relay the data collected by sensor nodes far away from the sink. Hence, once these sensors near the sink fail, the data collected by other sensors cannot be transferred to the sink. Wireless sensor networks (WSNs) have been broadly studied in ubiquitous computing environment because of its widespread utilization. The application area of WSNs includes environmental management, health-care services, and military monitoring [1–3].

WSNs are composed of many sensor nodes equipped with processors, memory, and short-range wireless communication. In real applications, the sensor nodes are distributed in the areas of interest and they sense data from surrounding environments. The sensor nodes co-operate with each other to transmit the sensed data to the central base station called sink node. A routing protocol determines the path between a source node and destination (i.e., sink node) for sensed data transmission. The efficiency of WSNs is highly dependent on routing protocol that directly affect the network lifetime. The main objective of routing protocol is to enhance both reliability and lifetime of WSNs by considering the capability of a sensor node with resource constraints such as limited power, slow processor and low communication bandwidth. Hence, the challenging issue of routing protocol is to reduce the communication overhead for data transmission by determining an optimal path. Clustering is one of the most popular techniques for routing protocols. The cluster-based routing is an efficient way to reduce energy consumption within a cluster by decreasing the number of transmitting messages to the sink node. Hence, there have been many researches on cluster-based routing protocols. A popular cluster-based protocol called LEACH proposes a two-phase operation based on a single-tier network using clusters. LEACH randomly selects a portion of nodes as cluster headers and they gather the neighbouring nodes to construct clusters. Each node forwards the sensed data to a cluster header which collects and delivers data to the sink node. There are several extensions of the LEACH protocol to increase energy efficiency but the existing protocols have some limitations. First, it is assumed that all sensor nodes can transmit data to the sink node with enough power and network capability. However, the entire network becomes disconnected although most of the nodes still have a lot of energy. Therefore, to extend the network lifetime, minimizing the energy consumption of sensor node is the key challenge for WSNs. Different approaches are proposed to prolong the lifetime of WSNs. Recent work shows that one can use mobile node to reduce the energy expenditure of WSNs to a large extent. Consequently, the lifetime of WSNs is prolonged. When compared with static nodes, mobile nodes possess more energy and powerful capabilities.

Mobile nodes are usually mounted on a mobile vehicle equipped with enough energy and can collect data from all static nodes by moving across the sensing field. The mobile nodes are used as the mobile sink which moves across the sensing field to collect data. On one hand, the mobile sink reduces the communication overhead for sensor nodes close to the base station or the sink leading to the uniform energy consumption. On the other hand, with the movement of the sink, one can handle better the disconnected and sparse network. Therefore, the network lifetime can be significantly extended by the optimum control of the route of the mobile sink. In physical environments, the sensing field could contain various obstacles. Hence, to prolong the network lifetime, a research challenge is to determine an obstacle-avoiding shortest route for the mobile sink.

Low-energy adaptive clustering hierarchy ("LEACH") is a TDMA-based MAC protocol which is integrated with clustering and a simple routing protocol in wireless sensor networks (WSNs). The goal of LEACH is to lower the energy consumption required to create and maintain clusters in order to improve the lifetime of a wireless sensor network. LEACH is a hierarchical protocol in where most nodes transmit to cluster heads and the cluster heads aggregate and compress the data and forward it to the base station (sink). Each node uses a stochastic algorithm at each round to determine whether it will become a cluster head in that round. LEACH assumes that each node has a powerful radio to directly reach the base station or the nearest cluster head but using this radio at full power all the time would waste energy. Nodes that have been cluster heads cannot become cluster heads again for P rounds, where P is the desired percentage of cluster heads. Thereafter, each node has a $1/P$ probability of becoming a cluster head again. At the end of each round, each node that is not a cluster head selects the closest cluster head and joins that cluster. The cluster head, then creates a schedule for each node in its cluster to transmit its data. All nodes that are not cluster heads only communicate with the cluster head in a TDMA fashion, adhering to the schedule created by the cluster head. This is accomplished using the minimum energy required to reach the cluster head and needs only to keep their radios on during their time slot. LEACH also uses CDMA so that each cluster uses a different set of CDMA codes to minimize interference between clusters.

In the past, one could only utilize static sensor nodes to collect the environment information. With technical progress, one can introduce mobility to WSNs. For example, one can use mobile sensor nodes to collect information. Compared with static nodes, mobile nodes have more energy and are more convenient for usage. However, in physical environments, the sensing field may be uneven and contain various obstacles.

In the existing methods, a hybrid WSN, static sensors monitor and collect environmental information. Once events happen, each static sensor can sense only one attribute of events. Compared with static sensors, a mobile sensor can evaluate multiple attributes of events. According to the sensing data from static sensors, mobile sensors move to corresponding hot locations for more in-depth analysis. To minimize the energy consumption, the authors present a two-phase heuristic algorithm to dispatch mobile sensor for hot locations. In the first phase, the authors dispatch MAM sensors to hot locations in a one-to-one approach. In the second phase, according to unassigned hot locations, the authors present a spanning-tree construction algorithm for the displacement of MAM sensors. Due to similar capabilities of sensors, a research challenge is how to dispatch mobile sensors to these hot locations. However, in [8-14], the authors don't consider that the sensing field may contain various obstacles. In fact, the route for mobile nodes in sensing field containing obstacles is more complex than sensing field without obstacles.

In the proposed cluster based routing mechanism, it is assumed that the mobile sink could be a vehicle or a mobile robot with enough energy. When compared with other operations, communication is the most critical energy consumption of sensor nodes which includes transmission and reception. A radio energy dissipation model for the sensor node includes the transmitter energy dissipation model and the receiver energy dissipation model as shown in Figure.1. In the transmitter energy dissipation model, the operations for radio electronics and power amplifier consume energy. In addition, in the receiver energy dissipation model, the operation for radio electronics consumes energy. Obviously, the transmitter consumes more energy than the receiver. According to the cluster-based algorithm, all sensor nodes in the network are divided into two categories: cluster heads and cluster members. Cluster heads collect data from their cluster members which collect environment information and then forward the data to the sink either directly or via relaying across other cluster heads [6]. Due to movement of the sink, the mobile sink can move nearest to the cluster heads and consume less energy. One can balance energy consumption of sensor nodes by using the cluster-based algorithm. Therefore, the network lifetime will be prolonged significantly. To solve the scheduling for the mobile sink, one uses the Low-Energy Adaptive Clustering Hierarchy (LEACH). Once cluster heads are determined by the LEACH, the mobile sink can move closest to the cluster heads for gathering data. Hence, sensor nodes consume less communication energy which is the most critical energy consumption of sensor nodes. Here, the mobile sink mounted on a mobile vehicle is equipped with enough energy.

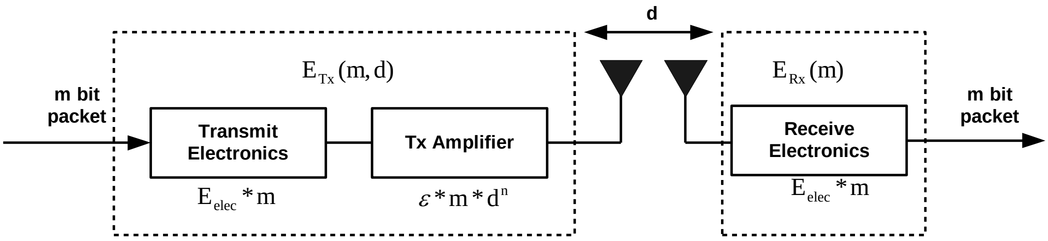

Figure 1: Block Diagram of Energy Model

In essence, the obstacle-avoiding the shortest route problem is similar to the Traveling Salesman Problem (TSP) which is a classical problem. One can utilize the minimum spanning tree to solve the TSP. Hence, according to the minimum spanning tree, one can also find an obstacle-avoiding shortest route for the mobile sink. The obstacle-avoiding spanning graph is the set of edges that can be formed by making connections between terminals and obstacle corners. Once a spanning graph is constructed, the infinite possible sites for the mobile sink movement will be reduced to a finite set of sites. Therefore, the algorithm based on the spanning graph makes it more efficient to schedule for the mobile sink.

Literature Survey

Recent work depicts that the advantage of utilizing the mobility of nodes. By using the mobility of nodes in WSNs, one can ease the traffic burden and enhance energy efficiency. Hence, the network lifetime is extended significantly. Many articles have proposed several different approaches.

In [8], the authors present a VGDRA scheme for the mobile sink to minimize the communication cost. The sensor field is divided into a virtual grid containing the same sized cells and the nodes near the center are chosen as the cell-header nodes. In addition, a virtual backbone structure consisting of the cell header nodes is constructed The mobile sink moves across the sensor field and collects the sensing data by communicating with the border cell header nodes. To reduce the overall communication cost, the routes reconstruction process includes only a subset of cell-header nodes.

In [9], the authors propose a mixed integer programming framework for base station to mitigate the suboptimal energy dissipation. To reverse the suboptimal energy dissipation trends, the base station mobility is introduced to WSNs [7]. The network lifetime is finally extended by using mobility patterns for base station. The research article [10] utilizes the support vector regression technique to construct a convex optimization model where the optimal trajectory of the mobile sink can be determined. The network lifetime is affected by the trajectory called

COT. To maximize the network lifetime, the mobile sink in the event-driven is used to collect the captured data of events. In [11], the authors propose a mobile data-gathering tour for different sensor networks. An M-collector similar to a mobile base station is introduced to collect sensing data from static sensors. The MDC begins its periodical movement from the base station and finally returns for transferring the data to the base station. For some applications in large-scale networks, the authors take a divide-and-conquer strategy and use multiple M-collectors, each of which moves through a shorter data-gathering tour. In [12], the authors adopt a wireless energy transfer technology for charging sensor nodes. The Wireless Charging Vehicle (WCV) starts a periodical tour from the service station, moves across the network for charging some sensor nodes wirelessly and finally returns. According to the novel Reformulation-Linearization Technique (RLT), the authors design a near-optimal solution for the optimization problem.

In [13] and [14], the authors consider the dispatch of mobile sensors as a multi-round and multi-attribute sensor dispatch problem. In a hybrid WSN, static sensors monitor and collect environment information. Once events happen, each static sensor can only sense one attribute of events. Compared with static sensors, a mobile sensor can evaluate multiple attributes of events. According to the sensing data from static sensors, mobile sensors move to corresponding hot locations for more in-depth analysis. Many researchers have proposed different protocols for energy-efficient routing in WSNs. In general, the routing protocols for WSNs can be divided into flat-based routing, cluster-based (hierarchical-based) routing, and location-based routing [9–12], based on the network structure. In flat-based routing, all nodes are typically assigned equal roles or functionality. In cluster-based routing, however, nodes play different roles in the network. In location-based routing, sensor nodes' positions are exploited to route data in the network. Among the existing protocols, the cluster-based routing protocol is particularly more suitable for continuous data transmission in WSNs. In this section, an abbreviated overview of the well- known cluster-based routing protocols for WSNs, along with their limitations is presented. Heinzelman et al. [4] introduced a hierarchical clustering algorithm for sensor networks called Low Energy Adaptive Clustering Hierarchy (LEACH). The idea is to randomly select a few sensor nodes as cluster headers and rotate this role to evenly distribute the energy load among the sensors in the network.

The LEACH protocol includes two stages of operation: node clustering and information transmission. A node that produces the random number being smaller than threshold is selected as cluster header. The other nodes are allocated to the cluster header closest to them. Second, in the information transmission stage the cluster headers aggregate the data received from their cluster members and send the aggregated data to the base station by single hop communication. LEACH outperforms traditional clustering algorithms by using adaptive clusters and rotating cluster header, that can distribute energy consumption among all the sensor nodes. In addition, LEACH can perform local computation so the amount of transmitted data can be reduced. However, LEACH assumes direct communication between a node and a base station. This is a high-power operation and shortens the lifetime of the network. Moreover, the random selection of headers does not guarantee optimal cluster construction and may cause rounds of communication when cluster headers are not available. Heinzelman et al. [4] presented Low Energy Adaptive Clustering Hierarchy-Centralized (LEACH-C) in order to distribute cluster headers evenly over the network and reduce energy dissipation. During the initial stage, each node sends to the sink node information about its current location and energy level. Therefore, sensor nodes whose remaining energy is below the average energy are excluded from becoming a cluster header. For each round, the sink node runs an optimization algorithm to determine cluster headers and the network is divided into clusters. Since LEACH-C requires the position of each node at the beginning of each round, an expensive global positioning system (GPS) is required for sending the position information. In addition, the number of nodes for each cluster is not guaranteed during formation of clusters.

Farooq et al. [15] proposed a Multi hop Routing with Low Energy Adaptive Clustering Hierarchy (MR-LEACH). MRLEACH partitions the network into different layers of clusters based on the distance between a sensor node and a sink node. Cluster headers are chosen by the LEACH protocol and transmit the aggregated data to a sink node by using multi hop routing. Therefore, significant improvement is achieved on energy consumption compared with the LEACH protocol. The problem of MR-LEACH is the selection of a cluster header in a layer, solely depends on the energy residue of a sensor node without considering distances among cluster headers.

NS2 – Network Simulator Tool

NS2 [5] is simply an event-driven simulation tool that has proved useful in studying the dynamic nature of communication networks. It implements network protocols TCP and UDP, traffic source behavior of FTP, Telnet, Web, CBR and VBR, router queue management mechanism of Drop Tail, RED and CBQ, routing algorithms Dijkstra and more. NS also implements multicasting and some of the MAC layer protocols for LAN simulations. NS2 has gained popularity in the networking research community since its birth in 1989.

The Figure.2 shows the simplified user's view of NS. NS is Object-oriented Tcl (OTcl) script interpreter that has a simulation event scheduler, network component object libraries and network setup (plumbing) module libraries (actually, plumbing modules are implemented as member functions of the base simulator object). To setup and run a simulation network, an user should write an OTcl script that initiates an event scheduler, sets up the network topology using the network objects and the plumbing functions in the library and instructs traffic sources when to start and stop transmitting packets through the event scheduler. When an user wants to make a new network object, he or she can easily make an object either by writing a new object or by making a compound object from the object library and plumb the data path through the object.

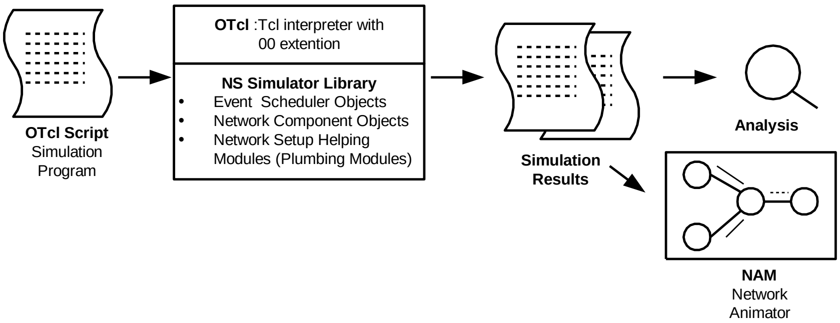

Figure 2: Simplified User's View of NS

NS2 consists of two key languages: C++ and Object-oriented Tool Command Language (OTcl). C++ is used to define the internal mechanism of the simulation objects, OTcl is used to set up simulation by assembling and configuring the objects as well as scheduling discrete events. The C++ and OTcl are linked together using TclCL.

NS2 provides a large number of built-in C++ objects. It is advisable to use these C++ objects to set up a simulation using Tcl simulation script. After simulation, NS2 outputs either text-based or animation-based simulation results. To interpret these results graphically and interactively, tools such as NAM (Network AniMator) and XGraph are used.

NS2 supports multiple protocols which is a positive factor in demand and popularity of the simulator. Due to this feature of NS2, it is an appropriate simulator for many networks. NS2 supports protocols of TCP/IP at different OSI layers. Some of the protocols such as TCP, UDP, CBR, and FTP are application layer of OSI model protocols.

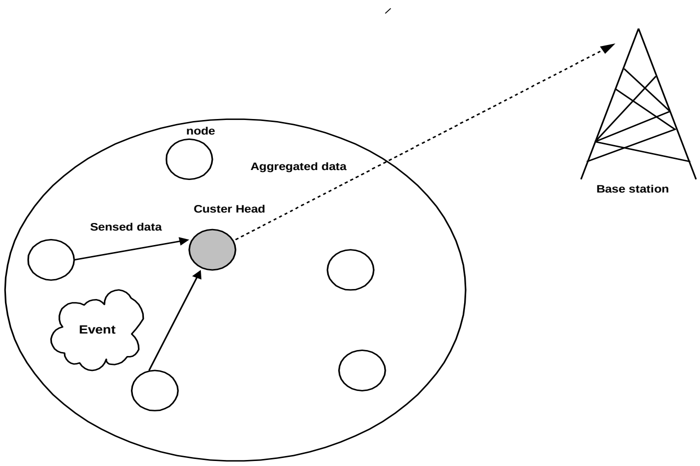

Figure 3: Overall Process Mechanism of Cluster Based Routing

Proposed Work

In this research work, Figure 3 shows the Cluster-based routing mechanism for mobile sinks with obstacles represent the cluster based routing for every event of nodes are sensed and data transmission between these nodes are tracked by cluster head. All the data are gathered by the cluster head and transmitted to base station.

The proposed system is divided into four modules namely Nodes Partitioning, Obstacle Avoidance Clustering, Construction of Spanning Graphs and Performance Evaluation

Nodes Partitioning

In this module, all sensor nodes in the network are divided into two categories: cluster heads and cluster members. Cluster heads collect data from their cluster members who collect environment information, and then forward the data to the sink either directly or via relaying across other cluster heads represented in Figure.4. Due to movement of the sink, the mobile sink can move nearest to the cluster heads and consume less energy. We can balance energy consumption of sensor nodes by using the cluster-based algorithm. Therefore, the network lifetime will be prolonged significantly. To solve the scheduling for the mobile sink, Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is used. Once cluster heads are determined by the LEACH, the mobile sink can move closest to the cluster heads for gathering data. Hence, sensor nodes consume less communication, energy which is the most critical energy consumption of sensor nodes. Here, the mobile sink mounted on a mobile vehicle is equipped with enough energy.

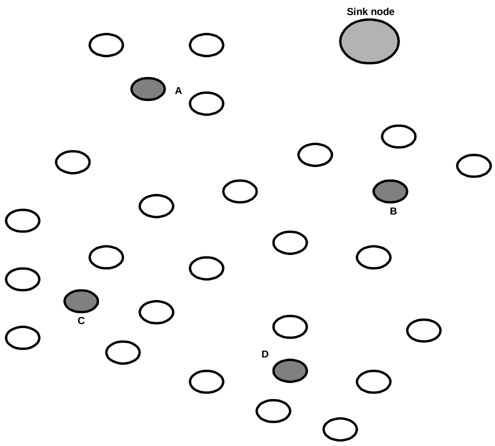

Figure 4: Nodes Partitioning

Obstacle Avoidance Clustering

In this module, a heuristic algorithm is presented to find an obstacle-avoiding shortest route for the mobile sink. In order to better solve the dispatch problem of the mobile sink, one uses the algorithm to construct the spanning graph of the network model represented in Figure. 5. According to the spanning graph, one can obtain all obstacle-avoiding paths. Furthermore, the obstacle-avoiding shortest route for the mobile sink can be acquired from these obstacles avoiding paths.

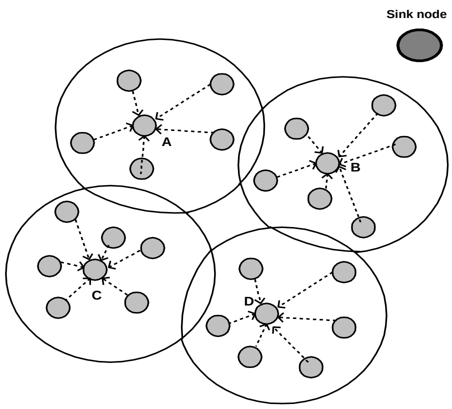

Figure 5: Formation of Clusters to Avoid Drops during Obstacles

Construction of Spanning Graphs

In this module, the obstacle-avoiding the shortest route problem is similar to the Traveling Salesman Problem (TSP) which is a classical problem. One can utilize the minimum spanning tree to solve the TSP. Hence, according to the minimum spanning tree, one can also find an obstacle-avoiding shortest route for the mobile sink. The obstacle-avoiding spanning graph is the set of edges that can be formed by making connections between terminals and obstacle corners. Once a spanning graph is constructed, the infinite possible sites for the mobile sink movement will be reduced to a finite set of sites. Therefore, the algorithm based on the spanning graph makes it more efficient to schedule for the mobile sink is represented in Figure.6.

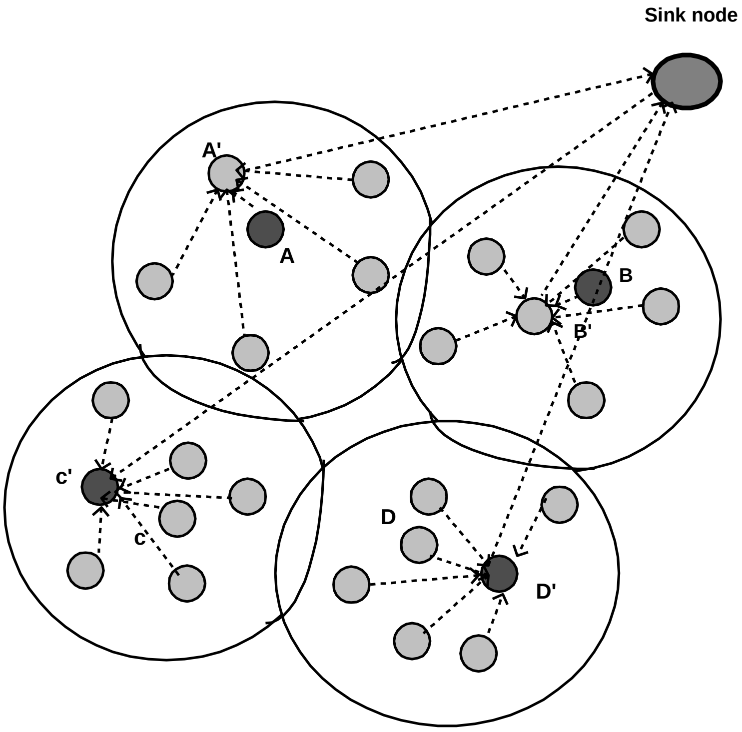

Figure 6: Construction of Spanning Graphs for Effective Communication

Performance Evaluation

The performance of the network will be measured by Throughput, Delay and Packet Delivery Ratio. Throughput is defined here as the number of data bits successfully delivered to the sink, per second. This is expressed as where N_p is the total number of packets produced and T_t is the total deployment time of the network. The expression shows how the throughput is largely affected by the number of packets generated and the number of packets lost.

$$TP = \frac{L_{data} \cdot E\, N_p \cdot PDR}{T_t}$$

The Packet Delivery Ratio (PDR) is defined as the fraction of created packets that are successfully received by the sink the TDMA MAC layer is contention free, hence there will be no packet loss from collisions. It is also assumed that the network is well connected and as such nodes will not become disconnected. For this reason the main cause of packet loss will be through link breakages on the path of a packet.

$$PDR = \frac{P_{rx}}{P_{tx}}$$

Delay is a function of the packet's length and has nothing to do with the distance between the two nodes. This delay is proportional to the packet's length in bits, It is given by the following formula:

$$D_T = N/R \text{ second}$$

Results and Discussion

The performance of Cluster based routing mechanism using LEACH is analyzed using network simulator. The experimental model is built with 21 nodes distributed randomly on square surface of 600 x 600 m^2. The following Figure 7 represents the network formation of mobile sensor nodes and deployment in wireless Environment.

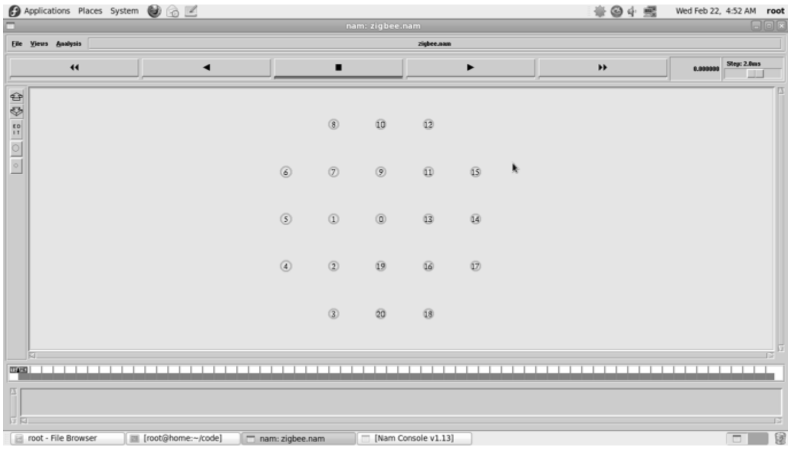

Figure 7: Network Formation

Figure 8 represents the active devices in network and transmission of messages from sensing nodes to cluster head.

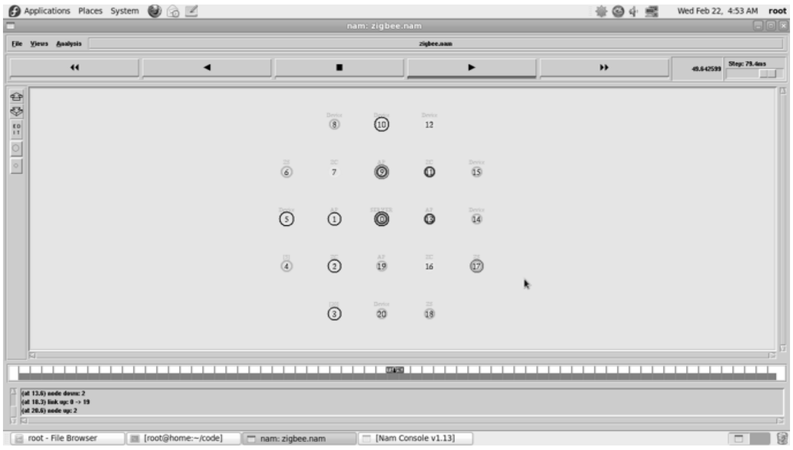

Figure 8: Active Devices in Network Transmission

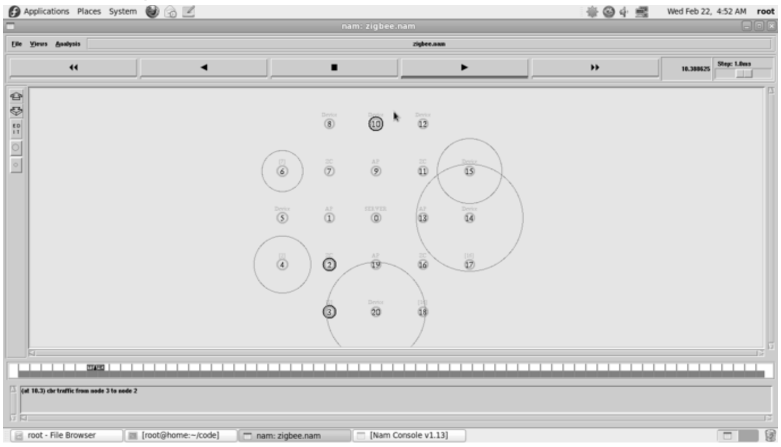

Figure 9: Communication between Cluster Head

The above Figure.9 represents the communication between cluster head and co-ordinator to transmit message delivered successfully. Figure.10 represents the synchronization between the channel and co-ordinator for successful data request and successful data delivery.

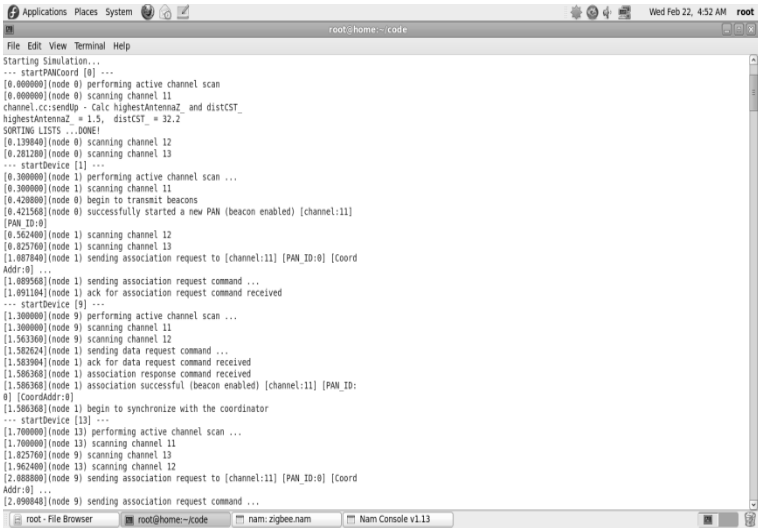

Figure 10: Transmission From Client To Co-ordinator

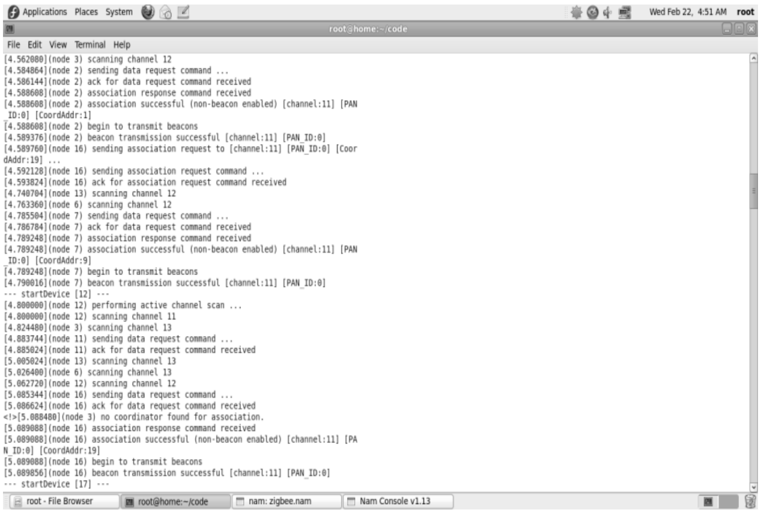

Figure 11: Data Transmission Through Co-ordinator

The above Figure.11 represents the scanning of channel and co-ordinator and successful association between the nodes in network. The Delay, Packet Delivery Ratio and Throughput are shown in following figures.

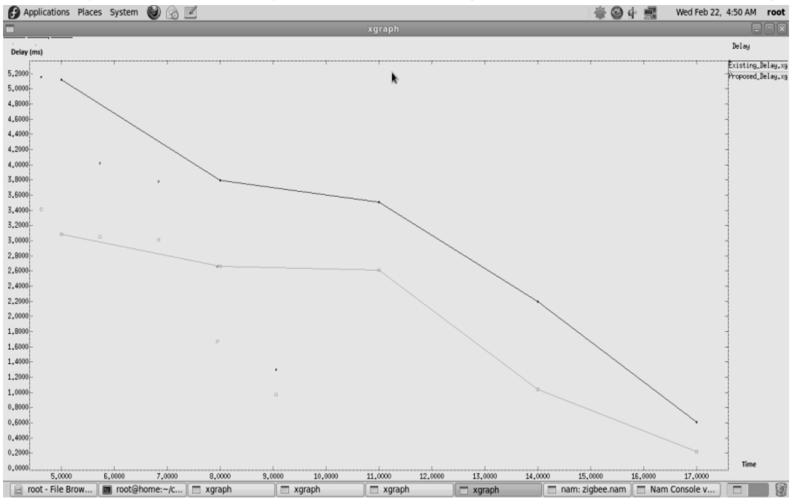

Figure 12: Delay

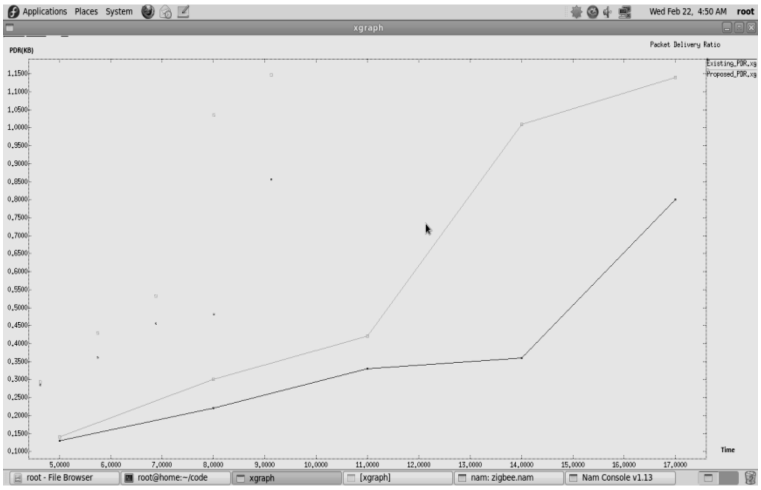

Figure 13: Packet Delivery Ratio

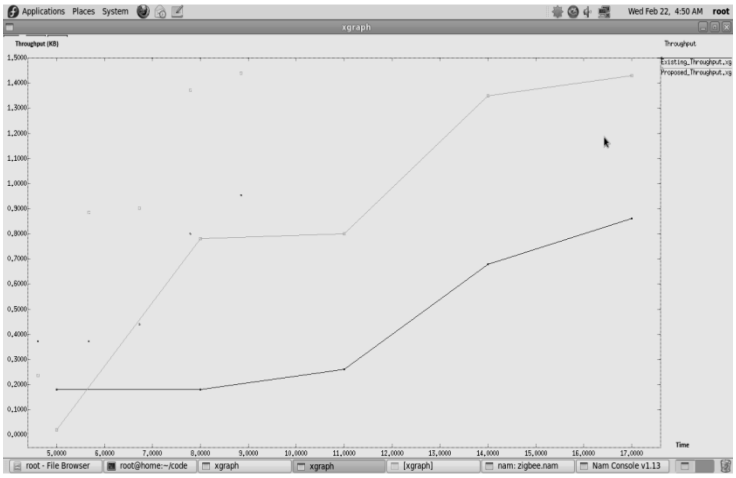

Figure 14: Throughput

Conclusion and Future Work

In physical environments, the sensing field could contain various obstacles. To simplify the scheduling for the mobile sink, the grid-based technique has been introduced to the WSN with obstacles. At the same time, the spanning graph has been constructed for the mobile sink to find an obstacle-avoiding shortest route. Based on the cluster-based method, the heuristic obstacle-avoiding algorithm has been applied to dispatch the mobile sink. Simulation was also conducted by using NS2 simulator and experimental results depict the cluster-based approach is feasible for the dispatch of the mobile sink. Finally, an obstacle-avoiding shortest route was found for the mobile sink and the network lifetime was prolonged.

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