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ON ENERGY EFFICIENT DATA DISSEMINATION IN WIRELESS SENSOR NETWORKS USING MOBILE SINKS

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ABSTRACT

We illustrate the effectiveness of using mobile sinks to obtain potential energy savings for the sensors during data dissemination in wireless sensor networks. The entire wireless sensor network is divided into two layers: the resource-constrained sensor nodes forming the bottom layer and a mobile ad hoc network of resource-rich sink nodes forming the top layer. Each sink node is assigned a particular cluster of sensors to monitor and collect data. A sink node moves to the vicinity of the sensor nodes (within a few hops) to collect data. The collected data is exchanged with peer mobile sinks and can also be transferred to a control center through multi-hop sink-to-sink data propagation. The energy loss due to multi-hop data propagation in disseminating the data from a sensor to the control center can be accounted to the sinks and not to the sensors. We also illustrate the effectiveness of using just one mobile sink to reduce energy consumption at the sensors in scenarios where one cannot afford to use multiple mobile sinks. In such scenarios, the mobile sink directly transfers the collected data to the control center.

Keywords: *Energy Consumption, Mobility, Sensor Networks, Two-layer Architecture, Simulation, Mobile Sinks*

1. INTRODUCTION

A wireless sensor network (WSN) is a distributed system of smart sensor nodes interconnected by a wireless communication network. The self-organizing ability of WSNs permits one to access data from dangerous and hostile environments which otherwise would not be possible. Some potential applications of WSNs include [1]: habitat monitoring, border patrol, battle field surveillance, remote health monitoring, early warning of natural disasters like forest fire, wild-life tracking, smart transportation, industrial process control and etc. With all the opportunities and promises, WSNs possess their own set of resource constraints [2] like limited on-board sensor battery power, network communication bandwidth, processing power, memory capacity and etc.

Each sensor node is equipped with one or more sensing devices to monitor the ambient environment and collect data. The sensor node is also equipped with a processor to process the collected data and communication hardware to exchange data with other local sensor nodes within its radio range. Data collected at the sensor nodes is propagated to control centers called sinks where the information is required. Traditionally, the sinks have been static and the data collected is disseminated to the sinks using sensor-to-sensor multi-hop data propagation. This approach normally incurs significant energy consumption at the energy-constrained sensors. Sensor nodes spend lot of energy in coordinating and transmitting data through multi-hop paths to reach the sink. Nodes near the sink fail relatively earlier due to repeated relaying of data from nodes that are farther away. The lifetime of a sensor network is often defined as the first time the network gets disconnected due to the failure of certain sensor nodes that keep the network connected. Sensor nodes are not often rechargeable and redeployment may be next to impossible in certain scenarios.

The idea of voluntarily introducing sink mobility for effective and energy-efficient data collection was explored for the first time very recently in [3]. In [4], we proposed a novel two-layer wireless sensor network architecture called Mobile Sinks and Static Sensor Network (MSSSN), with a motivation to lower the burden of data-dissemination at the sensors. According to the MSSSN architecture model, the entire wireless sensor network is divided into two layers: the resource-constrained sensor nodes forming the bottom layer and a mobile ad hoc network of resource-rich sink nodes forming the top layer. Each sink node is assigned to monitor and collect data from a cluster of sensors (in a particular region). Using multi-hop sink-to-sink propagation, the sink nodes can exchange the collected data and also forward to a control center of the sensor network. The MSSSN architecture assumes the sink nodes have significantly more energy compared to the sensors and may even possess replenishable energy resources. By being mobile, the sink nodes can move inside the area of deployment of the sensor network and collect data from the vicinity of the sensors. After disseminating data to a mobile sink, a sensor need not be involved at all in propagating the data to the control center or to the other sensors. Some of the potential applications that have emerged to use mobile sinks are: battle field surveillance, wild-life monitoring, locating parking spots, mobile hotspot tracking and pollution control.

In this paper, we implement the MSSSN architecture to illustrate the effectiveness of using mobile sinks to collect and disseminate data. Through extensive simulations, we show that tremendous energy savings can be obtained by (i) Letting the sink move to the vicinity of the sensors rather than remaining static and collecting the data (ii) Transferring the data collected from a mobile sink to a control center through multi-hop sink-to-sink data propagation. We run our simulations under two different types of wireless sensor networks: (a) Networks that permit the use of multiple sinks and (b) Networks that permit the use of just one mobile sink to collect and disseminate data to the control center. We show that by using mobile sinks to collect and disseminate data to the control center, the energy consumption overhead incurred at the sensors in transferring the data from the point of origin to the control center can be significantly reduced.

The rest of the paper is organized as follows: In Section 3, we discuss some of the existing literature work that has considered the use of mobile sinks in wireless sensor networks. Section 4 describes the MSSSN architecture and its potential advantages. In Section 5, we describe the simulation environment, the simulation models and the results obtained in a wireless network comprising multiple sinks. In Section 6, we describe our simulations in a wireless network with only one sink. Section 7 concludes the paper, also lists the open research problems and the future work planned with the MSSSN architecture.

2. RELATED WORK

Data dissemination protocols like Directed Diffusion [5], Declarative Routing Protocol [6] and GRAB [7], suggest that each mobile sink should continuously propagate its location information throughout the sensor field to enable a sensor node to send future data reports. However, frequently updating the locations of the mobile sinks can rapidly consume the battery power of the sensors and cause increased collisions during wireless transmissions.

In the Two-Tier Data Dissemination (TTDD) approach [8], each source sensor node of the data proactively constructs a grid structure such that the sensor nodes at the grid points (called dissemination nodes) forward the data from the source to the sink node. The sink node within a grid, issues a query for the data and the query is routed by the sensors within the grid to the dissemination node for the grid. The query is further propagated only by the dissemination nodes and the source now responds back through the reverse path of the dissemination nodes. Considerable overhead would be involved in establishing the grid structure for each source sensor node. The dissemination nodes at the grid points are bound to run out of battery power quickly. A variant of TTDD called the Energy Efficient Data Dissemination (EEDD) approach [9] divides the entire sensor field into virtual grids of size $R_{trans} / 2\sqrt{2}$. Each grid has a grid head, most likely to be the node with the highest energy among the nodes in the grid. The grid heads are responsible for forwarding the data from the source node to the sink. The grid heads have to be frequently changed in order to maintain fairness for each sensor node. As a result, more latency will be incurred in propagating the data from a source to the sink.

In [10], the authors propose to explicitly construct a multicast tree rooted at the data source. A mobile sink associates itself with a fixed sensor node (called the access node), which acts as its proxy in the multicast tree. The proxy node is normally the node closest to the sink or the node with the maximum energy in the nearby neighborhood. In the latter case, the multi-hop path between the sink and its proxy might have to be frequently updated as the sink moves. When the sink moves far away form its proxy, a new proxy has to be selected. The method is not scalable as it requires construction of an explicit multicast tree rooted at each sensor node that becomes a data source. The tree will have one proxy node for every sink in the network. With geographically distributed sink nodes in a large sensor network, the multicast tree will include many sensor nodes to span all the proxy nodes.

The Sensor Information Networking Architecture (SINA) [11] lets the mobile sink to issue a query to a particular, dedicated sensor node called the query resolver. The query resolver searches for the reply to the query either in its local cache or by interacting with the peer sensor nodes. When the reply becomes available, the resolver node forwards the reply to the mobile sink if the latter is in the neighborhood. Otherwise, the reply is forwarded through progressive footprint chaining – a sequence of logical links established from the resolver to the mobile sink as the latter moves away from the former after placing the query. It would be highly complex for the different functionalities to be implemented at the resolver node and there would be high latency involved in transferring the data from the resolver node to the mobile sink through the sequence of logical links.

All the previous work discussed so far consider sink mobility as a "necessary evil" and something that has been imposed by the application on the sensor network. The idea of voluntarily introducing sink mobility for effective and energy-efficient data collection was explored for the first time very recently in [3], where the authors propose different sink mobility models for effective data collection. They propose purely random walk, biased random walk and deterministic walking models. Under the purely random walk model, the mobile sink moves chaotically towards all directions at varying speeds. Three models have been proposed for biased random walk: (i) the sink node has been assigned some predefined areas and the node performs random transitions from one area to another depending on their connectivity (ii) the sink gives more priority in visiting less frequently visited areas and (iii) the sink gives priority in visiting areas populated with more sensor nodes. In the deterministic walk model, the mobile sink moves along a predefined trajectory within a small area. The trajectory is a circle of length l, the sink is initially on the circumference of the circle and moves around this circle of radius $l/2\pi$. The deterministic mobility model cannot execute complex movements. Also, there would be high overhead on the part of the sensors to constantly update the multicast trees involving the sink.

3. MSSSN ARCHITECTURE

The MSSSN has a mix of static sensor nodes and mobile sink nodes. Each sink node is assigned a particular region (also called cluster) of sensor nodes to control and monitor. Physically, the sensors and sinks are in the same plane. MSSSN proposes a logical two-layer architecture: the lower sensor network layer and the upper mobile sinks layer. The architecture can be implemented with the currently available IEEE 802.11 [12] devices that only use a single half-duplex transceiver.

3.1 Sensor Network Layer

This layer comprises the energy-constrained, battery powered sensors that collect information about the environment and pass it to the mobile sinks. The sensors are static and the battery power is non-replenishable once exhausted. Energy is the most critical resource of the sensor nodes and hence these devices often operate at a very limited transmission range and sensing range. The underlying sensor network is normally a homogeneous network of sensors: all sensors are from the same manufacturer and have the same transmission and sensing range.

3.2 Mobile Ad hoc Network of Sinks

This layer is comprised of sinks whose main characteristic is mobility. The sinks self-organize to form a mobile ad hoc network (MANET) among themselves and the communication protocols applicable in a typical MANET are applicable for this layer. Sinks (devices like Personal Digital Assistants - PDAs) are relatively less energy-constrained (compared to the sensors in the WSN) and their main purpose is to go to the vicinity of the sensors and collect data at a reduced energy cost and then disseminate the collected data. The transmission range of a mobile sink could be 5-20 times to that of a sensor node. In a huge network field, a single mobile sink cannot effectively and efficiently cover the entire the sensor network. Hence, MSSSN advocates use of multiple mobile sinks, each assigned to cover a certain region of the network. The mobile sinks are assumed to be GPS (Global Positioning System) [13] enabled and hence when deployed over the MSSSN architecture, each mobile sink will delineate the region of sensor network it is supposed to monitor.

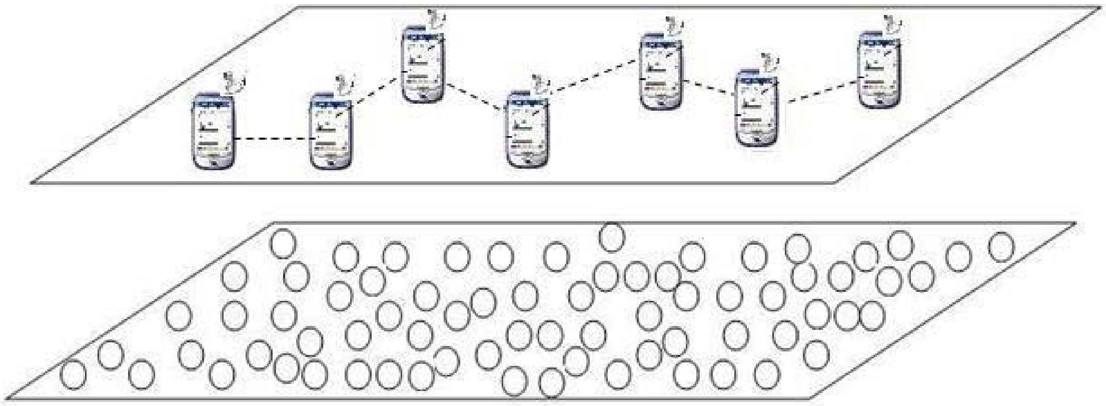

Figure 1: *MSSSN Architecture*

A mobile sink collects the data from the region assigned to it, processes the data and periodically shares an aggregate of the collected data with its peers. The sink will handle localization, addressing, resource allocation and time synchronization for the sensor nodes in its assigned region. The mobility of the sinks in the sensor network field will be facilitated through a range of techniques: from simple hand-carrying to as far as automated vehicles.

A remote user could send a query to a mobile sink. The mobile sink on receiving the query checks whether it is the appropriate sink node to respond to the query. If so, it collects the required data from its region and replies to the user. Otherwise, the mobile sink determines the appropriate sink node to answer the query. It does this by broadcasting the query to all the mobile sinks. This would be similar to the route discovery process in MANETs, except that the destination mobile sink node is not known before route discovery. The appropriate mobile sink node will then collect the data from its assigned region and if required, will co-ordinate with other mobile sink nodes. An appropriate reply is then sent back on the path that was traversed by the query packet. The mobile sink that originated the query will then receive the reply and forward it to the remote user.

3.3 Multi-Channel MAC Protocol

IEEE 802.11 standard for Wireless local area networks (WLANs) [12] supports multiple channels (14 channels) for use at the physical layer. The channels are 5 MHz apart in frequency. However, only 3 channels (channels 1, 6 and 11) are used in current implementations because for the channels to be totally non-overlapping, the frequency spacing must be at least 30MHz. With multiple channels, one can obtain a higher network throughput than using one channel, as multiple transmissions can occur without any interference. Unfortunately, the IEEE 802.11 Medium Access Control (MAC) Distributed Coordinate Function (DCF) protocol is designed to use only a single channel.

To use multiple channels for improving throughput, several MAC protocols like the Dual Busy Tone Multiple Access [14], Hop Reservation Multiple Access [15], Receiver Initiated Channel Hopping with Dual Polling [16], Dynamic Channel Assignment (DCA) protocol [17] and multi-channel MAC (MMAC) protocol [18] have been proposed in the literature. All of these protocols except the MMAC protocol require multiple transceivers per host and when used with the current IEEE 802.11 devices, equipped with only one half-duplex transceiver, these protocols face the multi-channel hidden terminal problem [18]. However, the MMAC protocol requires only one transceiver per host and also solves the multi-channel hidden terminal problem. With MMAC, packets transferred on two different channels do not interfere with each other.

A brief description of the assumptions and the principle of the MMAC protocol are as follows: All channels have the same bandwidth. Hosts have prior knowledge of the number of channels available. As a host has only one half-duplex transceiver, the host can listen (i.e., carrier sense) or transmit on only one channel at a time. A host can switch channels dynamically with the time to switch a channel being 224μsec [12]. Clocks across all nodes are assumed to be synchronized to facilitate the beacon interval at each node to begin at the same time. At the beginning of each beacon interval, the ATIM window, each node listens onto a common channel to negotiate the channels. After the ATIM window, a node switches to its agreed channel and exchanges data on that channel for the remaining duration of the beacon interval.

3.4 Advantages of the MSSN Architecture

Low operational cost: With MSSSN, we can handle sparse and disconnected networks at lower operational cost. The entire wireless sensor network need not be connected. In each region, it is sufficient for the sensors to be reachable with the mobile sink assigned to that region. A mobile sink can move into regions with fewer sensor devices and collect data by being in close proximity with such devices. Also, mobile sinks can navigate through or bypass around obstacles that block the data propagation path involving sensors alone. The mobile sinks can then co-ordinate among themselves and collect data about other regions.

Increased throughput: The sensors can operate at the lowest transmission range required to just reach the mobile sinks and hence the collisions at the link level could be reduced. Also, as data propagates through fewer hops all the way from the sensor to the application user across the Internet, the probability of packet drops due to transmission error could be reduced. Hence, the network throughput could be increased.

Scalability and Reduced Energy Consumption: The twin objectives of the two-layer architecture are to achieve scalability and to maximize network lifetime. Sensor networks normally employ hundreds to thousands of nodes and MSSSN supports a scalable architecture without any need for maintaining global information at the sensors. The sensor nodes are involved in multi-hop data propagation only for data originating within a narrow region and not for the entire sensor network field. Also, sensors do not need to use a larger transmission power for data packets addressed to the sink nodes. Sink nodes could be contacted with the same transmission power used to contact a neighboring sensor node. These two factors help to reduce the energy consumption at the sensors.

Fault Tolerance: The carrier housing the mobile sinks could be equipped with unused, fully-battery powered sensor nodes that will be deployed in regions devoid of the required number of sensors to maintain network connectivity. In case, a mobile sink fails, the application user monitoring the network from remote can instruct a neighboring mobile sink to take control of the region devoid of mobile sink.

Increased data fidelity – Communication among the mobile sinks could be protected using standard secure routing protocols for wireless networks. The number of sink nodes would be manageable and there will not be any scalability problem to employ the secure routing protocols in the MANET layer. Since, communication in the WSN layer is only for short-range, limited number of hops, data may not propagate through potentially compromised sensor nodes that could forward data to an adversary.

4. SIMULATIONS WITH MULTIPLE SINKS

In this section, we consider a wireless sensor network (refer Figure 2 for the network architecture) of 36 sensors and 9 sinks with the sensors located in a grid whose co-ordinates are known. There are 9 clusters, with a sink monitoring and collecting data from 4 sensors in a cluster. Thus, we have a mobile ad hoc network of 9 sinks that can communicate with each other through one or more hops. The sinks forward the data collected from their cluster to a coordinating sink (Sink 4) that is near the control center. Data propagation from the sink in a cluster to the coordinating sink is along the shortest path (path with the minimum hop count) comprising of zero or more intermediate sinks. We assume the sinks use the Dynamic Source Routing (DSR) protocol [19] to determine the shortest paths. The simulations are conducted in a discrete event simulator implemented in Java. Its functionality is similar to ns-2 [20].

The size of each cluster is a square of dimensions 100m x 100m. The transmission range of each sensor is fixed at 100m and the transmission range of the sink is 450m. When the sink is mobile, we assume the sink moves closer to the sensor and collects data within a distance of 20m. The sensors in the network are assumed to continuously sense the data in the region around. We assume a simulation time of 4000 time slots.

4.1 Multi-Channel MAC Protocol

We use the multi-channel MAC (MMAC) protocol [18] as the MAC layer protocol for our simulations. We use the MMAC protocol for sensor-to-sink and sensor-to-sensor (channel 1), sink-to-sink (channel 6) and sink-to-control center (channel 11) communications. The channel bandwidth is 2 Mbps. The main objective would be to maximize the throughput and at the same time minimize the interference between sink-to-sink communication spanning long distances and sensor-to-sensor communication spanning short distances.

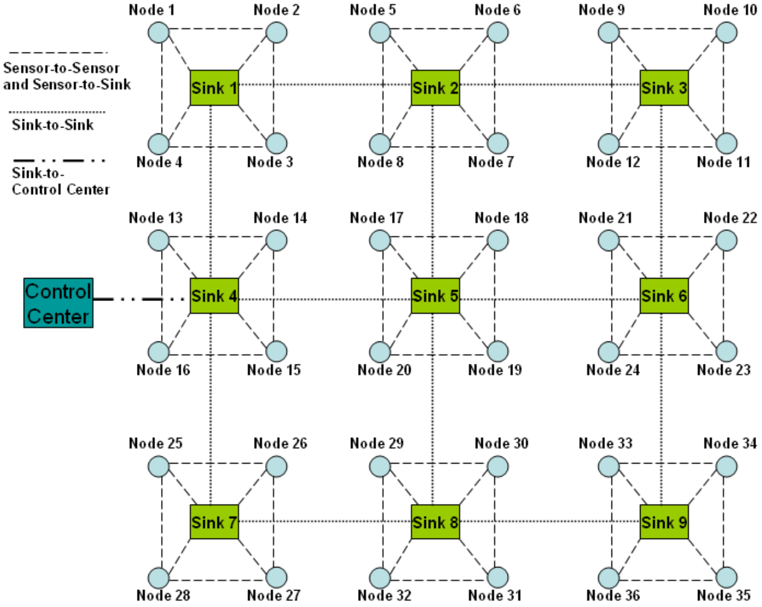

Figure 2: *MSSSN Architecture with Multiple Sinks*

We assume all our wireless devices are equipped only with a half-duplex transceiver. The sensors operate using only one frequency. But, we assume the sinks can operate at more than one frequency, though with only one frequency at a given time. The sinks collect the data from the sensor nodes on one frequency; transmit data to the coordinating sink on another frequency. The coordinating sink communicates with the control center on another different frequency.

4.2 Data Collection Model

During each time slot, the sink in each cluster collects data from a randomly selected sensor in the cluster by remaining static at the center of the cluster or moving closer to the selected sensor. In either case, the sink first sends a query to the selected sensor, which responds back with the data. The other sensor nodes in the neighborhood discard the query and the data response packets (when not addressed to them) after listening only to the header of these packets. The size of the data packet is 50 bytes and the query packet is of size 16 bytes [21]. The header size for the query and data packets is assumed to be 8 bytes [22].

4.3 Sensor Energy Consumption Model

Each sensor node is assumed to be of initial battery charge 1 Joule. The sensor node senses the data at a rate of 8 bits/sec and loses 1000 nJoules/second [23] due to sensing. Energy lost at a sensor node due to transmission of a packet [24] is [50 nJoule/bit * (*packet size*)] + [100 pJoule/bit/m^2 * (*packet size*) * (*distance of propagation*)^2]. Energy lost at a sensor node due to receiving [24] is 50 nJoule/bit * (*packet size*). When a sink moves close to the sensor to query and get the response, we assume the *distance of propagation* of the query and response packets is 20m. On the other hand, when the sink is static and located at the center of the cluster, the *distance of propagation* of the query and response packets is $100/\sqrt{2} = 71$m.

4.4 Sink Energy Consumption Model

Each sink is assumed to be of initial battery charge 50 Joules, far more than the battery charge of an individual sensor node. During each time slot, each sink node sends the data collected from a sensor in the cluster to the coordinating sink (sink 4 in Figure 2). The sink nodes in each cluster run the DSR protocol to determine the path to the coordinating sink. The energy lost at a sink due to transmission and reception is modeled according to [25][26]. The energy lost due to transmission is [1.1182 + (7.2*10^{-11})*(*distance*)^4**delay*] Joules and due to receiving is 1**delay* Joules, where *distance* is the distance from the transmitter sink to the receiver sink and *delay* is the time spent in transmitting or receiving the data packet and is given by *packet size* / *channel bandwidth*. The *packet size* is assumed to be 100 bytes, large enough to hold the source routing information and other control information in addition to the sensor data. Sink nodes lose energy while sending their own data packets and also while forwarding the data packets for their peer sinks.

4.5 Results

Figures 3 and 4 respectively show the energy consumed at each sensor as a result of data collection by using the static sink and mobile sink approaches. For each case, summing up the energy lost at the sensor nodes, we find the total energy lost at all the sensors due to data dissemination to a static sink to be 8.29 Joules and due to data dissemination to a mobile sink to be 1.39 Joules. This shows the effectiveness of having a mobile sink compared to a static sink as the energy savings at the sensors due to data dissemination is 1 – (1.39/8.29) = 83%.

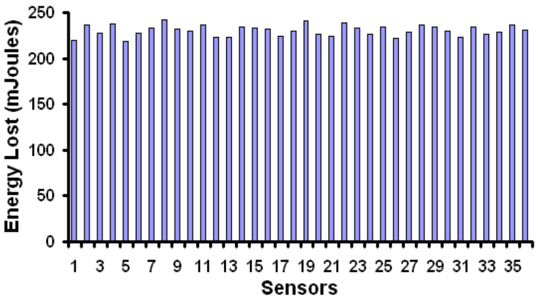

Figure 3: *MSSSN: Energy Lost at the Sensors (Static Sinks Scenario)*

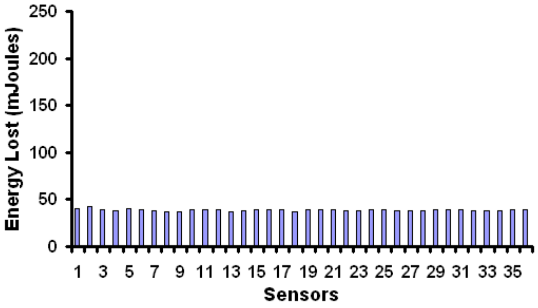

Figure 4: *MSSSN: Energy Lost at the Sensors (Mobile Sinks Scenario)*

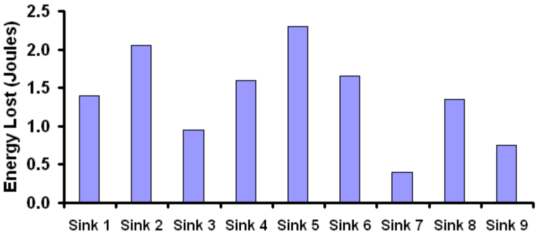

Figure 5: *MSSSN: Energy Lost at the Sinks for Sink-to-Sink Multi-hop Data Propagation*

Figure 5 shows the energy consumed at the individual sinks for the simulation time of 4000 time slots. The sum of the energy lost across all the sinks is equal to 12.5 Joules. This quantity is the same for both the static and mobile sink scenarios as the sink-to-sink communication happens in the top layer and the sensor-to-sink communication happens in the bottom layer. The sensors would have lost this much of additional energy if they were involved in the multi-hop data propagation instead of the sinks.

The above results illustrate the effectiveness of the two-layer MSSSN model, sink mobility and sink-to-sink multi-hop data propagation. The energy consumed at the sensors is 67% of the energy consumed at the sinks when data is disseminated to a static sink and is only 11% of the energy consumed at the sinks when data is disseminated to a mobile sink. With the two-layer model, if we employ mobile sink nodes with appreciable amount of battery charge, the energy consumption overhead incurred due to multi-hop data propagation from the region of the sensors to the control center can be effectively taken care of by the sinks and the sensors can be relieved of this overhead. Thus, the two-layer architecture model will help us to prolong the lifetime of the sensor networks.

The above are the initial results of our simulation of the two-layer architecture model. We are planning to go for a real-time implementation of the proposed architecture in the near future. In Section 5, we show simulation results obtained in a wireless network with only one sink.

5. SIMULATIONS WITH ONE SINK

In this section, we consider a wireless sensor network of 36 sensors and only one sink with the sensors located in a grid whose co-ordinates are known. There are 9 clusters, with 4 sensors forming a cluster. When being static, the sink will be at the center of the network. When being mobile, the sink will be in the vicinity of a randomly selected sensor located in a cluster that is visited either randomly or in a round-robin fashion. The size of each cluster is a square of dimensions 100m x 100m. The default values for the transmission range of the sensors and the sink are assumed to be respectively 100m and 450m. When required to communicate directly, a sensor and the sink can dynamically adjust their transmission range depending upon the distance between them. The sensors in the network are assumed to continuously sense the data in the region around. When the sink is mobile, we assume the sink moves closer to the sensor and collects data within a distance of 20m. We assume a simulation time of 36000 time slots.

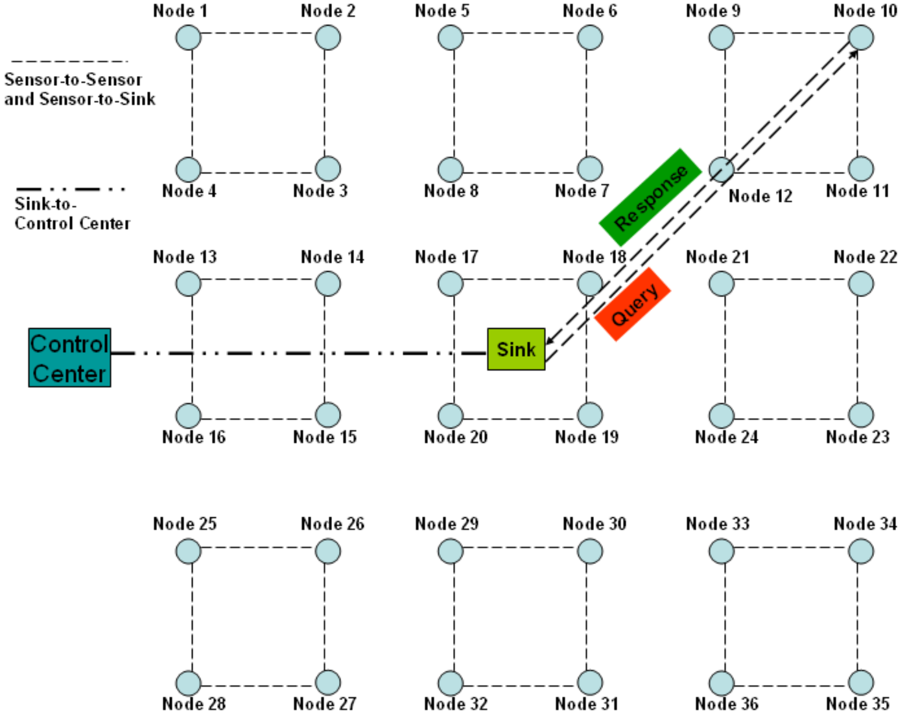

Figure 6: *Network Architecture with Static Sink and Direct Querying*

We use the IEEE 802.11 MAC protocol [12] for sink-to-sensor, sensor-to-sink and sensor-to-sensor communications. All these communications use a given frequency. We assume the sink could report the data to the control center, whenever required, on a different frequency. The channel bandwidth is 2 Mbps. When not required to receive and/or forward the packets, the sensors nodes discard the query and the data response packets after listening only to the header of these packets. The size of the data packet is 50 bytes and the query packet is of size 16 bytes [21]. The header size for the query and data packets is assumed to be 8 bytes [22]. In Scenario 1 (Static Sink and Direct Querying), the sink can dynamically adjust its transmission range to send the query packet depending on the distance to the selected sensor node and similarly, the sensor can dynamically adjust its transmission range to send the reply packet depending on its distance to the sink node. The energy consumption models for the sensor and sink are similar to that in Section 4. The initial energy available at the sensors is assumed to be 6 Joules. The simulations are again conducted in the discrete-event simulator implemented in Java.

5.1 Simulation Scenarios

Scenario 1: Static Sink and Direct Querying – The sink node is static and located in the center of the network. During each time slot, the sink queries a randomly selected sensor node and obtains direct reply from it.

Scenario 2: Static Sink and Multi-hop Query/ Response Propagation – The sink is static, located in the network center and queries a randomly selected sensor node for every timeslot. The query is sent along the shortest multi-hop path determined by the sink and the queried sensor node sends back its response along the reverse path.

Scenario 3: Mobile Sink with Random Cluster Selection – The sink is mobile and for each time slot, selects a random cluster to visit. After entering the cluster, the sink randomly selects a sensor to collect the data and moves to the vicinity of the sensor to collect the data.

Scenario 4: Mobile Sink with Round-robin Cluster Selection – The sink is mobile and visits one cluster for every time slot. The next cluster to visit is selected in a round-robin fashion among the 9 clusters. After entering the cluster, the sink randomly selects a sensor to collect the data and moves to the vicinity of the sensor to collect the data.

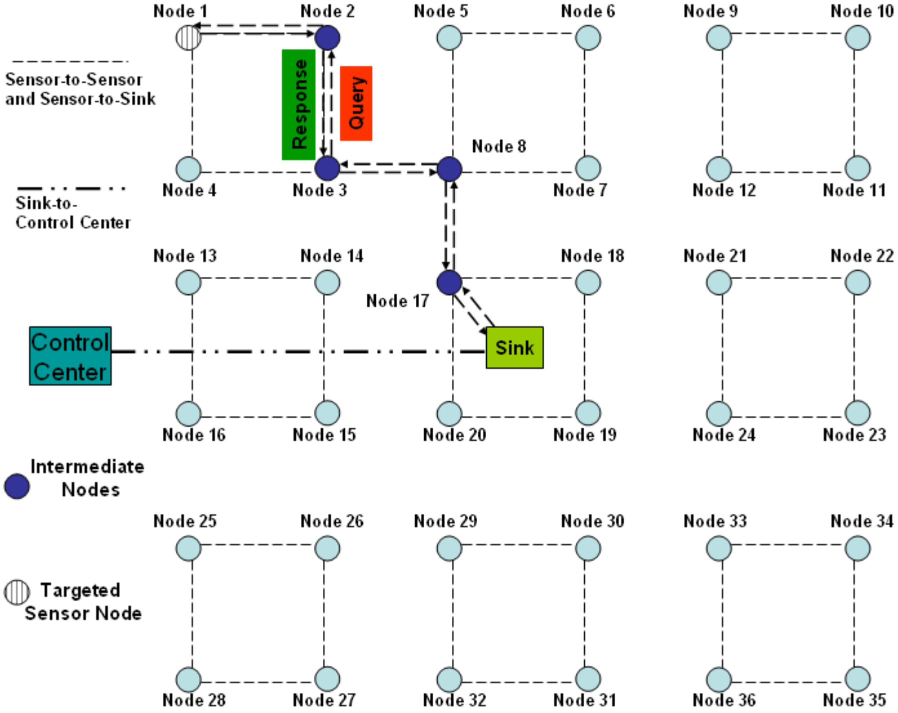

Figure 7: *Network Architecture with Static Sink and Multi-hop Query/ Response Propagation*

5.2 Scenario 1: Static Sink and Direct Querying

In this scenario, the sink is in the center of the whole network (refer Figure 6 for the network architecture). For every time slot, the sink randomly selects a sensor node to query for data. The sink sends the query packet with a transmission range equal to the distance to the selected sensor node. All the other sensor nodes that fall within this neighborhood drop the query after listening to its header. The targeted sensor node responds back with the data packet requested. The data packet is directly sent to the sink node using a transmission range equal to the distance to the sink node. This process is repeated for all the time slots.

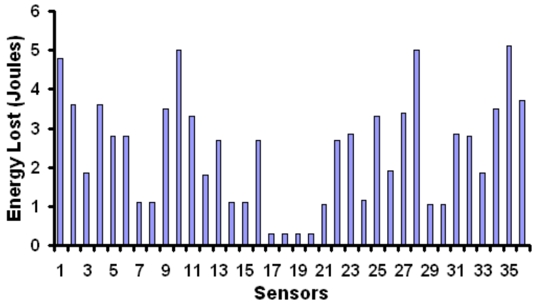

Figure 8: *Simulation Results for Static Sink and Direct Querying*

The energy lost at each sensor is plotted in Figure 8. The total energy lost at all the sensors is 86.52 Joules. The results indicate with static sink and direct querying, it is highly likely that the sensors far away from the sink lose lots of energy in disseminating data to the sink over a larger distance, while the sensors close to the sink lose less energy in disseminating the data to the sink.

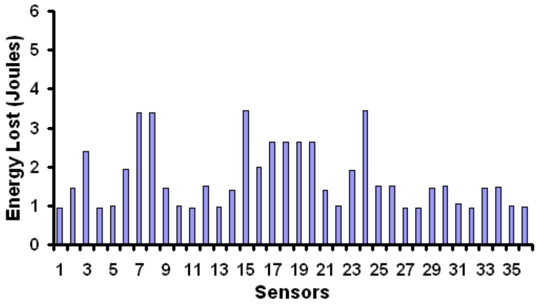

Figure 9: *Simulation Results for Multi-hop Query/ Response Propagation*

5.3 Scenario 2: Static Sink and Multi-hop Query/ Response Propagation

In this scenario, the sink is in the center of the network. For each time slot, the sink randomly selects a sensor node to query and gets the response. The sink is assumed to know this global topology. So, the sink runs the Dijkstra shortest path algorithm and determines the minimum hop path to reach the targeted sensor node. The sink sends the query to the sensor node by listing in the query header, the sequence of nodes forming the path from the sink to the targeted sensor node. An intermediate node receiving the query packet, forwards it further to the next hop if the node is listed in path information specified in the query header and that it has received the query for the first time in the particular time slot. If an intermediate node receives the query packet, but is not listed in the path information in the query header, the node drops the query packet. The targeted sensor node upon receiving the query packet will respond back with a data response packet on the reverse path traveled by the query. Figure 7 illustrates the network architecture and the propagation of the query and data response packets.

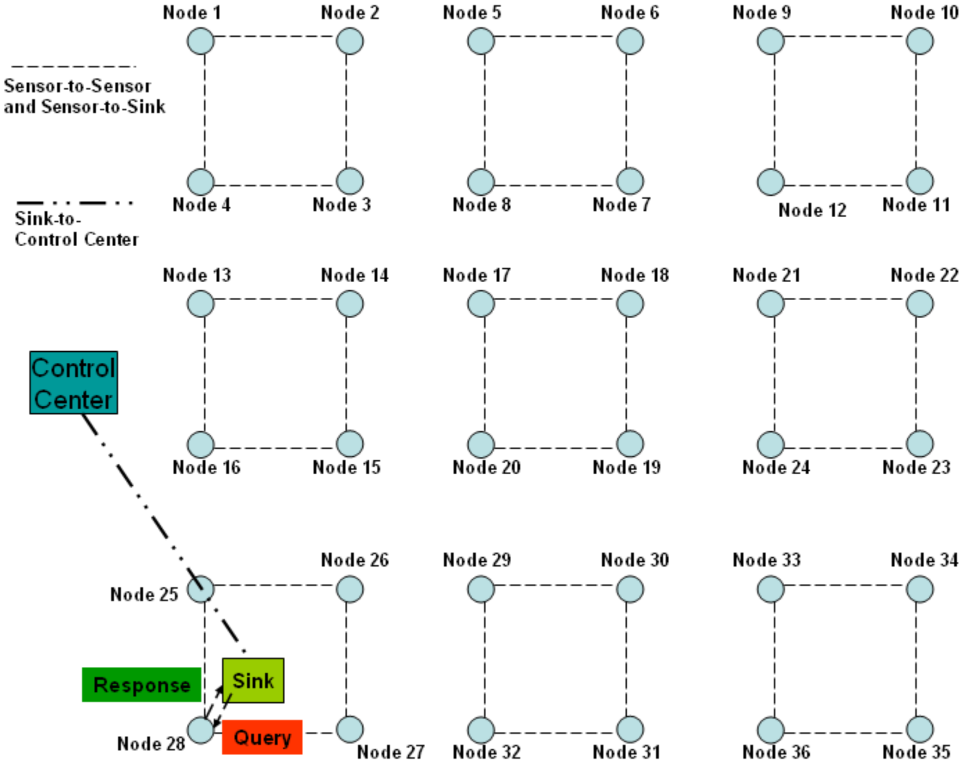

Figure 10: *Network Architecture with the Mobile Sink Selecting the Cluster in Random and Round-Robin Fashion*

The energy lost at each sensor is plotted in Figure 9. The total energy lost at all the sensors is 61.04 Joules. The results indicate with static sink and multi-hop query/ response propagation, it is highly likely that the sensors close to the sink lose lots of energy in forwarding (receiving and transmitting) data for sensors away from the sink.

All communications are limited in transmission range because of multi-hop propagation. Compared with Scenario 1 in Section 5.2 (refer Figure 8), we obtain an energy savings of 1–(61.04/86.52) = 29%.

5.4 Scenario 3: Mobile Sink with Random Cluster Selection

In this scenario, the sink is mobile. For each time slot, the sink randomly selects a cluster to visit and then after entering the selected cluster, randomly selects a sensor to collect the data. The sink goes to the vicinity of the selected sensor, within a distance of 20m, queries and collects the data response from the sensor. Figure 10 shows the network architecture used for this scenario and scenario 4 (discussed in Section 5.5). The energy lost at each sensor in the network at the end of 36000 time slots is shown in Figure 11. The total energy lost at all the sensors is 2.63 Joules. Comparing this with Scenario 1, we obtain an energy savings of 1 – (2.63/86.52) = 97%. Comparing the performance with Scenario 2, we obtain an energy savings of 1 – (2.63/ 61.04) = 96%. Note that there would be some delay associated in the sink moving from one cluster to another cluster. These results indicate the effectiveness of using mobile sinks to collect and disseminate data from the sensors.

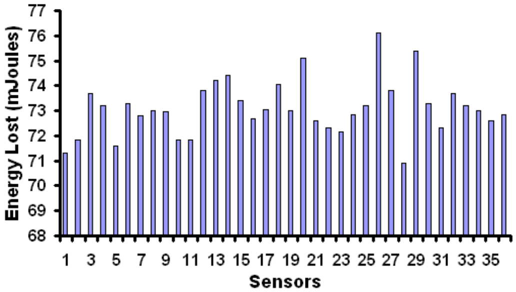

Figure 11: *Simulation Results for Mobile Sinks with Random Cluster Selection*

5.5 Scenario 4: Mobile Sink with Round-Robin Cluster Selection

In this scenario, the sink is mobile and visits the clusters in a round-robin fashion. The sink visits one cluster per time slot. After entering the selected cluster, the sink randomly selects a sensor to collect the data. The sink goes to the vicinity of the selected sensor, within a distance of 20m, queries and collects the data response from the sensor. The energy lost at each sensor in the network at the end of 36000 time slots is shown in Figure 12. The total energy lost at all the sensors is 2.63 Joules, similar to Section 5.4. Hence, the energy savings obtained with this scenario is same as that obtained with scenario 3. The next cluster visited would be the neighboring cluster that was visited 9 slots ago. Note that the delay associated in moving from one cluster to another cluster in a round-robin fashion is most likely to be less than the delay associated in moving between randomly selected clusters.

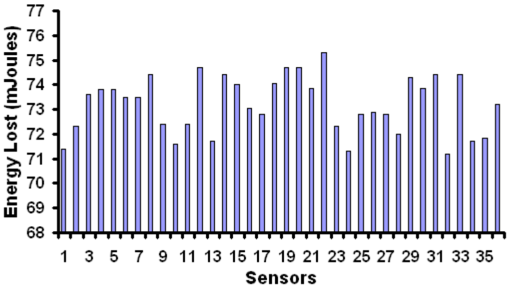

Figure 12: *Simulation Results for Mobile Sinks with Round-Robin Cluster Selection*

6. CONCLUSIONS

In this paper, we illustrate the effectiveness of using mobile sinks to collect and disseminate data in wireless sensor networks. We show that significant energy savings can be obtained at the sensors when sinks move to the vicinity of a sensor to collect the data and then transfer the data to the control center either by direct transmission or through multi-hop sink-to-sink data propagation. We run simulations in wireless sensor networks with one mobile sink and in wireless sensor networks with 9 mobile sinks. Under both these scenarios we show that significant energy savings can be obtained at the sensors by transferring the data dissemination overhead to the sinks.

For wireless sensor networks with 9 sinks, we implemented the MSSSN architecture proposed earlier [4]. The architecture logically comprises a mobile ad hoc network of sinks at the top layer and a static network of sensor nodes at the bottom layer. The MSSSN architecture connects isolated regions of sensor nodes using multiple mobile sink nodes, each collecting data from a certain region and transferring the data to the control center either directly or through multi-hop sink-to-sink propagation. The MSSSN architecture could be realized with existing IEEE 802.11 devices that use only a single half-duplex transceiver.

The MSSSN architecture opens up lots of interesting research problems like developing sink mobility models, determining multicast trees connecting the mobile sinks with static sensors, tracking a hotspot through collaboration between multiple mobile sinks and etc. In the near future, we would be working on developing data-driven mobility models.

REFRENCES:

[1] I. F. Akylidiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "A Survey on Sensor Networks," *IEEE Communication Magazine*, pp. 102-114, Aug 2002.

[2] D. Culler, D. Estrin and M. Srivastava, "Overview of Sensor Networks," *IEEE Computer Magazine*, pp. 41-49, Aug 2004.

[3] I. Chatzigiannakis, A. Kinalis and S. Nikoletseas, "Sink Mobility Protocols for Data Collection in Wireless Sensor Networks," *Proceedings of 4th ACM International Workshop on Mobility Management and Wireless Access*, pp. 52-59, Oct 2006.

[4] N. Meghanathan and G. W. Skelton, "A Two Layer Architecture of Mobile Sinks and Static Sensors," *Proceedings of the 15th International Conference on Advanced Computing and Communication*, pp. 249 – 254, Dec 2007.

[5] C. Intanagonwiwat, R. Govindan and D. Estrin, "Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks," *Proceedings of the 6th ACM International Conference on Mobile Computing and Networking*, pp. 56 – 67, Aug 2000.

[6] D. Coffin, D. V. Hook, S. McGarry and S. Kolek, "Declarative Ad Hoc Sensor Networking," *Proceedings of SPIE Integrated Command Environments*, pp. 109 – 120, Nov 2000.

[7] F. Ye, S. Lu and L. Zhang, "GRAdient Broadcast: A Robust, Long Lived Large Sensor Network," http:///irl.cs.ucla.edu/papers/grab-tech-report.ps, 2000.

[8] H. Luo, F.-Y. J. Cheng, S. Lu and L. Zhang, "TTDD: Two-Tier Data Dissemination in Large Scale Wireless Sensor Networks," *Wireless Networks*, Vol. 11, No. 1-2, pp. 161-175, Jan 2005.

[9] Z. Zhou, X. Xiang and X. Wang, "An Energy Efficient Data Dissemination Protocol in Wireless Sensor Networks," *Proceedings of the International Symposium on a World of Wireless, Mobile and Multimedia Networks*, Jun 2006.

[10] H. S. Kim, T. F. Abdelzaher and W. H. Kwon, "Minimum Energy Asynchronous Dissemination to Mobile Sinks in Wireless Sensor Networks," *Proceedings of the 1st ACM International Conference on Embedded Networked Sensor Systems*, pp. 192-204, Nov 2003.

[11] C.-C. Shen, C. Srisathapornphat and C. Jaikaeo, "Sensor Information Networking Architecture and Applications," *IEEE Personal Communications*, pp. 52-59, Aug 2001.

[12] IEEE 802.11 Working Group, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," 1997.

[13] Kaplan ED (ed.), *Understanding the GPS: Principles and Applications*, Artech House: Boston, MA; 1996.

[14] J. Deng and Z. Haas, "Dual Busy Tone Multiple Access (DBTMA): A New Medium Access Control for Packet Radio Networks," *Proceedings of IEEE International Conference on Universal Personal Communication*, pp. 973 – 977, Oct 1998.

[15] Z. Tang and J. J. Garcia-Luna-Aceves, "Hop Reservation Multiple Access (HRMA) for Ad Hoc Networks," *Proceedings of 18th IEEE International Conference on Computer Communications*, pp. 194 – 201, Mar 1999.

[16] A. Tzamaloukas and J. J. Garcia-Luna-Aceves, "A Receiver Initiated Collision Avoidance Protocol for Multi Channel Networks," *Proceedings of 20th IEEE International Conference on Computer Communications*, pp. 189 – 198, Apr 2001.

[17] S.-L. Wu, C.-Y. Lin, Y.-C. Tseng and J.-P. Sheu, "A New Multi Channel MAC Protocol with On Demand Channel Assignment for Multi Hop Mobile Ad Hoc Networks," *Proceedings of International Symposium on Parallel Architectures, Algorithms and Networks (I-SPAN)*, 2000.

[18] J. So and N. Vaidya, "Multi-Channel MAC for Ad Hoc Networks: Handling Multi-Channel Hidden Terminals using A Single Transceiver," *Proceedings of the 5th ACM International Symposium on Mobile Ad hoc Networking and Computing*, pp. 222-233, May 2004.

[19] D. B. Johnson, D. A. Maltz and J. Broch, "DSR: The Dynamic Source Routing Protocol for Multi-hop Wireless Ad hoc Networks," *Ad hoc Networking*, edited by Charles E. Perkins, Chapter 5, pp.139–172, Addison Wesley, 2001.

[20] K. Fall and K. Varadhan, "ns notes and documentation," The VINT Project at LBL, Xerox PARC, UCB, and USC/ISI, http://www.isi.edu/nsnam/ns, August 2001.

[21] G. Zhou, C. Huang, T. Yan, T. He, J. A. Stankovic and T. F. Abdelzaher, "MMSN: Multi-Frequency Media Access Control for Wireless Sensor Networks," *Proceedings of the 25th IEEE International Conference on Computer Communications,* pp. 1 – 13, April 2006.

[22] G. Zhou, J. A. Stankovic and S. H. Son, "Crowded Spectrum in Wireless Sensor Networks," *Proceedings of the 3rd Workshop on Embedded Networked Sensors,* May 2006.

[23] Y. Zou, and K. Chakrabarty, "Energy-Aware Target Localization in Wireless Sensor Networks," *Proceedings of the 1st IEEE International Conference on Pervasive Computing and Communication,* pp. 60 – 67, March 2003.

[24] X. Hou, D. Tipper, D. Yupho, and J. Kabara, "GSP: Gossip-based Sleep Protocol for Energy Efficient Routing in Wireless Sensor Networks," *Proceedings of the 16th International Conference on Wireless Communications, Calgary, Canada,* 2004.

[25] S-J. Park, and R. Sivakumar, "Load-Sensitive Transmission Power Control in Wireless Ad Hoc Networks," *Proceedings of the 45th IEEE Global Communications Conference,* pp. 42 – 46, November 2002.

[26] N. Meghanathan, "Energy Consumption Analysis of the Stable Path and Minimum Hop Path Routing Strategies for Mobile Ad hoc Networks," *International Journal of Computer Science and Network Security,* Vol. 7, No.10, pp. 30-39, October 2007.