An Energy-Efficient Data Dissemination Using Cross Topology in Wireless Sensor Network

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Abstract: Sink mobility brings new challenges to sensor networking. It suggests that information about mobile sink position be continuously propagated through the sensor field to keep all sensor nodes updated for the future data reports. Unfortunately frequent location updates from sink can lead to both excessive drain of sensors' limited battery power supply and increased collisions in wireless transmissions. In this paper, we describe a *data forwarding* scheme based on simple cross *topology* for wireless *sensor network* with mobile sinks. The mobile sink constructs a virtual cross *topology* periodically around itself to propagate its position to all nodes. A data source also configures a virtual cross *topology* to seek the mobile sink and report data to the sink. Our simulation results showed that our scheme offers satisfactory performance in terms of energy efficiency and packet delay time in wireless *sensor network* with mobile sinks.

Key-Words: - Data Forwarding, topology, sink mobility, sensor network

1 Introduction

The advances in micro-sensors and low-power wireless communication technology will enable the deployment of densely distributed sensor networks for a wide area monitoring applications. By deploying a number of micro-sensors and organizing a network of them, one can monitor and obtain information of environments or objects for the purpose of the applications, such as target detection or object tracking, environment surveillance, and intrusion detection etc.

When a sink is carried by a person, vehicle or mobile robot such as robotic sensor agents (RSAs) [2, 3], then the sink may move around all over the sensing field. In this paper, we consider a network with such mobile sinks which changes their locations dynamically in the wireless sensing field where a lot of stationary sensor nodes are deployed. In this network, a sink collects sensory data from stationary sensors as it moves close to them.

Sink mobility brings new challenges to a sensor network routing. For example, if the sink has moved to other place after a source reported to the mobile sink, then the reported data may be dropped during forwarding process. At this time, the source node does not know where the sink is. We call this as missing problem caused by node mobility. When this problem occurs, the source node should try to find sink node position by broadcasting sensor field entirely or partially.

To prevent a missing problem, a mobile sink needs to continuously propagate its location information throughout the sensor field, so that all sensor nodes get updated with routing for future data reports. However, frequent updates of sink position information at each sensor node can lead to both increased collisions in wireless transmissions and rapid power consumption of the sensor's limited battery supply.

In TTDD [1], they suggested a forwarding scheme to exploit sink mobility. In the scheme, the data source proactively builds a grid structure and the sink sends a query to the source in hybrid manners, broadcasting within a grid and geographical forward using grid structure. However, the performance of this scheme is sensitive to the grid size. Small grid size results in a significant overhead on grid maintenance while large grid size produces a big broadcasting overhead.

In this paper, we suggest a data forwarding scheme using a virtual cross topology to exploit sink mobility. As a mobile sink moves here and there all over the network, it constructs a virtual cross topology periodically. When a source has a data to be sent to the sink, it also configures a cross topology around itself. After that, the source queries sink position through the cross structure and reports data to the sink. When the sink moves far away at some distance, it eliminates the current cross topology, and makes a new one to support continuous data reporting.

The rest of this paper is organized as follows. Section 2 summarizes the related works, especially TTDD. The details of the proposed scheme are presented in Section 3. In Section 4, we validate our scheme through computer simulations. Section 5 concludes the paper.

2 Related Works

As the first attempt to exploit sink mobility, Fan Ye proposed Two-Tier Data Dissemination model (TTDD). When the sink moves around, the source sensor nodes that ought to report data to the sink need to know the current position of the sink. As a naive solution, a sink can propagate its own current position to the whole network by flooding, but it is neither scalable nor efficient. In TTDD, instead of flooding location information of the sink to the entire network, TTDD takes a reverse view point that a source announces a new data delivery to the whole network as efficient grid cross points – dissemination points. If the sink wants to get the sensed data, it queries the given dissemination nodes by local flooding. If the data dissemination node gets the sink's query, it requests data download to the original source node by grid axes in the reverse path to the data announcement. To support routing to mobile sinks the data packets are routed in two-tier hierarchical manner. At the higher layer, packets are forwarded from the source to the immediate dissemination node along grid horizontal and vertical axes. At the lower layer, packets are forwarded by trajectory forwarding [4, 6].

During the grid construction process, each dissemination node stores the source information and then forwards the message to the next adjacent crossing points. This process continues until all of the sensors that are closest to the crossing locations to become the dissemination and stops at the border of the network. If a source divides the plane into grids with a size of α^2, TTDD uses a threshold with a distance of $\alpha/2$ for a node to become a dissemination node in order to stop the grid construction at the network border. Using the approach, each data source proactively builds a grid structure [5]. However, the performance of TTDD is sensitive to the grid size α. Small grid size increases grid maintenance overhead and large grid yields broadcasting overhead.

3 Data Forwarding Scheme

In this section, we suggest a new data forwarding scheme using a virtual cross topology, called CDGF (Cross Directed Geographical Forwarding) to exploit sink mobility. CDGF gets the sink position by two kinds of cross and forwards data using the conventional GF (Geographical Forwarding). In CDGF, a virtual cross topology is constructed, which consists of a primary cross and a secondary cross. The primary cross is constructed by the mobile sink to efficiently advertise information about the sink position to sensor nodes over the network field. It is maintained all the times during the network lifetime once it is made. On the other hand, the secondary cross is constructed temporarily by the source that has data to be reported to the sink.

Our routing scheme is designed based on the following assumptions:

- A sensing field is covered by a large number of homogeneous sensor nodes which communicate with each other through short-range radios. Long distance data delivery is accomplished by forwarding data across multiple hops.
- Each sensor node is fixed and aware of its own location, through GPS or through other techniques [6], [7], [8]. Mobile sink also knows its locations.
- Initially, sensor node does neighbor discovery to find out neighbor nodes within its radio transmission range.

Our scheme is composed of several phases; configuration of primary and secondary crosses, sink search, data query and report as shown in Figure 1. When a sink is placed into the sensing field, it first appoints a node to construct a primary cross (Figure 1(a)). The nodes on the primary cross will know where the sink is. When a node newly becomes a source node, it constructs a secondary cross (Figure 1(b)). After configuring the secondary cross, the source broadcasts a sink search message to get position of the sink (Figure 1(c)). Only the nodes on the secondary cross will rebroadcast the search message. When a node on the primary cross overhears the search message, it sends query message including sink position (Figure 1(d)). After the source is informed of the sink position, it reports data to the sink using GF (Figure 1(e)).

The node located at the center of cross is called core node and the others that are participated in the process for topology configuration are called dissemination nodes. The core node monitors its vicinity, called core area, to seek the mobile sink.

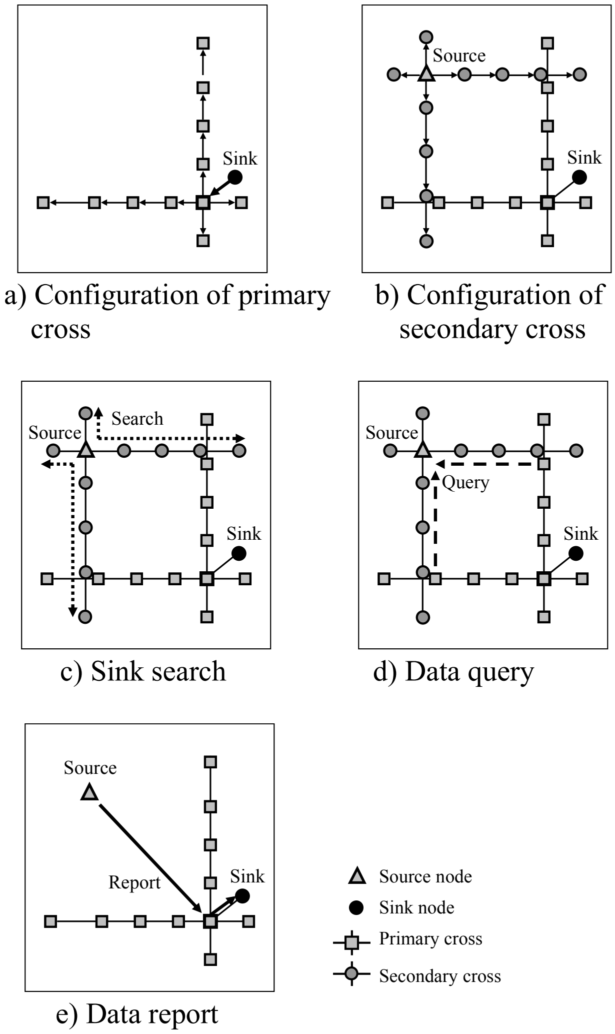


Figure 1. Concept of Cross Directed Geography Forwarding (CDGF)

The cross topology configuration is initiated by a core node which is selected by the sink and data source node. The core node configures a primary and a secondary cross independently. The procedures for construction of both crosses are basically the same.

Figure 2 shows that the core node selects four dissemination nodes. After selection of dissemination node, the core node sends a JOIN message to those four nodes to inform that they are selected as dissemination nodes. The JOIN message includes cross type (primary or secondary cross), position of the core node, dissemination direction, and topology expiration time. Each of the selected dissemination nodes again selects another dissemination node in the dissemination direction in the JOIN message to grow the cross topology. This dissemination node selection process is iteratively repeated until the sensing field border is reached. In this way, a virtual cross topology is expanded out to the sensing field.

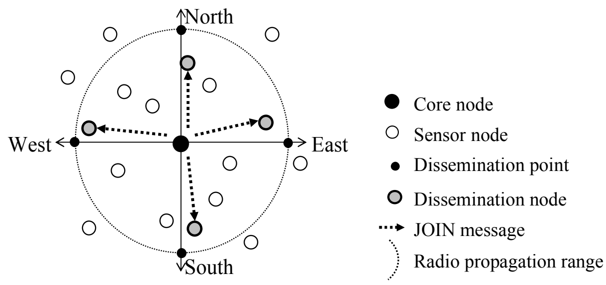


Figure 2. Selection of dissemination nodes

As previously described, when a sink is placed into the sensing field, it configures a primary cross with the messages. It first selects a core node from its one hop neighbors and sends a CORE message to the node to configure a primary cross. The CORE message includes sink identifier and topology expiration time. To maintain the cross topology constantly, the sink sends CORE message periodically until the topology expiration timer timeouts. When the core does not receive this message for some duration time, it stops its role as core. And, at the same time the primary cross dissemination node also stops its role.

After receiving the CORE message, the core selects four dissemination nodes and sends them a JOIN message to construct a primary cross. Each of the selected dissemination nodes again selects another dissemination node in the dissemination direction with a JOIN message to grow the cross topology. As the JOIN message includes core position, all the nodes on the primary cross will know the position of core node.

When a node newly becomes a source node, it checks whether it has information about where the sink is. If it does not have the information, it becomes a core node by itself and constructs a secondary cross with a JOIN messages as shown in Figure 3 (dashed box B). Otherwise, it reports data to the sink directly. After configuration of the secondary cross, the source broadcasts a SEARCH message to get position of the sink. At this time, only dissemination nodes on the secondary cross will rebroadcast the SEARCH message.

When a dissemination node on the primary cross overhears a SEARCH message, it responds to the source with a QUERY message. The QUERY message includes identifier of sink and position primary cross core. After the source is informed of the primary cross core, it reports data with a REPORT message to the core using GF, and finally the core forwards the data to the sink.

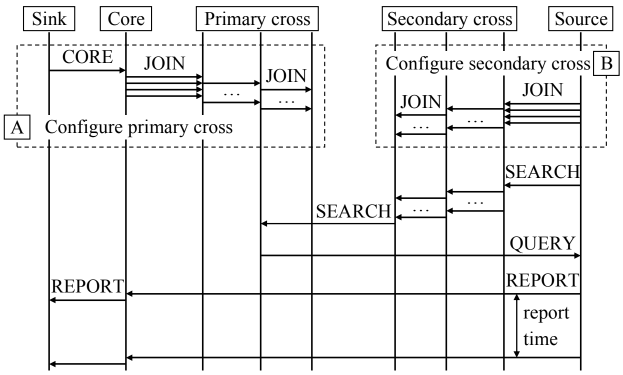


Figure 3. Timing diagram for message exchange in CDGF

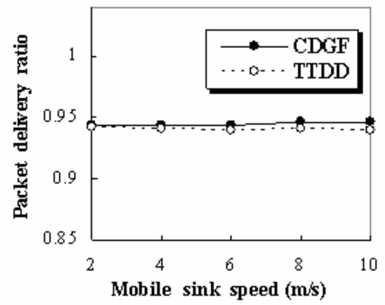
When the distance from the sink to the core is greater than some threshold value, it selects a new core to support seamless data reporting. After the sink moves away, it checks whether it is still inside the core area or not. If not, it constructs a new primary cross by selecting a new core node. At this time, the current primary cross will be removed when the topology maintenance timer expires.

The sink may send query to source node to adjust report interval. During the data reporting process, if a core is changed, the sink sends a QUERY message to the source to inform the position of the newly selected core. Now, the source continues data report to the sink through the newly selected core.

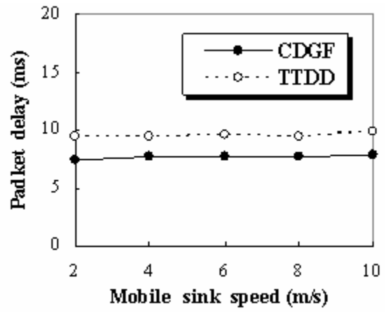
4 Performance Analyses

To validate our scheme, we perform simulation study with ns-2 simulator. For simulation, we use a CSMA MAC protocol for data transmission. We assume that radio propagation radius R is 20 meters. We distribute 100 nodes over a square field with a size of 100 x 100 m2 in a uniformly random fashion.

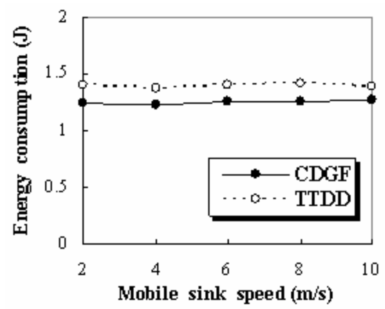
We use a Gauss-Markov mobility model [9] to simulate mobility characteristics of the sink node. Initially, the sink is located at the center of the network area, and the direction of the mobile sink is set to 60 degrees. It is assumed that the sink moves according to the mobility model with an average speed between 2 and 10m/s. When the sink node reaches the boundary of the map, it is assumed to be bounced back. The mobile sink node is scheduled to send a topology setup message every 5 seconds to propagate its position. We assume that an event arises at a random position of the network area and the node closest to the event detects it and sends data to the sink per 0.5 second. The number of events is limited between 1 and 4 and one event makes only one data reporting.



(b) Packet delay



(a) Packet delivery ratio



(c) Energy consumption

Figure 4. Performance of CDGF and TTDD as the sink speed is varied

We evaluate performance of CDGF and TTDD. The threshold (r) for selecting primary cross core in CDGF is set to 0.5R and the grid cell size (α) in TTDD is set to radio propagation radius R. We use three metrics to evaluate the performance; energy consumption, packet delivery ratio, and packet delay. The energy consumption is defined as the communication energy for transmitting and receiving whereas the idle energy is not considered. The packet delivery ratio means the ratio of the number of successfully received reports at the sink to the total number of reports generated by a source. The packet delay is defined as the average time difference between the moment a source transmits a packet and the moment the sink receives the packet.

Figure 4 shows the performance when the average speed of sink is 2, 4, 6 or 8m/s. Figure 4(a) shows that the packet delivery ratio. We can see that CDGF shows a constant delivery ratio (about 0.95) but the delivery ratio of TTDD is slightly decreasing as the sink move faster. This figure indicates that two schemes offer almost the same performance in terms of packet delivery ratio. Figure 4(b) shows the packet delay. The packet delay of CDGF is much shorter than TTDD as the sink moves faster. Figure 4(c) shows that our scheme can reduce energy consumption about 15% compared with TTDD.

Figure 4 tells us that both CDGF and TTDD work good in sensor network with mobile sinks regardless of moving speed of the sink but CDGF can offer a better performance than TTDD in terms of packet delay and energy consumption.

The simulation results indicate that our scheme offers a shorter packet delay and a less energy consumption than TTDD. The packet delay depends on the length of packet routing path, where our scheme has a shorter routing path than TTDD. The energy consumption of our scheme is mainly due to cross maintenance cost and data reporting cost while the energy consumption of TTDD is mainly involved in grid maintenance cost and data reporting cost.

4 Conclusion

In this paper, we have proposed a data forwarding scheme using a simple cross topology to exploit sink mobility. In our scheme, the sink proactively constructs a primary cross and the source makes a secondary cross.

Data forwarding can be done efficiently with aid of the two-cross topology. A core is located at the intersected area of the primary cross and it propagates information about the sink position through the cross. A data source does sink search through a secondary cross and gets sink position from the primary cross. And the source reports data to the sink through the core. To support seamless data report from source, the mobile sink can configure a new primary cross timely to prevent failure of data forwarding path.

Simulation result showed that our scheme could offer better energy efficiency and a shorter packet delay time than the conventional work such as TTDD. The simulation also showed out scheme can work well even if the sink moves fast. We are currently trying to improve our scheme by efficient scheduling with clustering and power saving.

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