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Energy-efficient mobile targets detection in the presence of mobile sinks

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ABSTRACT

Tracking moving targets has become an increasingly important application for sensor networks. Sensor nodes may sense moving targets far away from the Source, and hence a large amount of energy may be wasted by them to send sensory data to the Source. Designing efficient algorithms and protocols for data dissemination to mobile sinks is an interesting research and engineering issue, especially for large-scale wireless sensor networks (WSNs). Sink mobility brings new challenges to the design of data dissemination. The location updates for each mobile sink need to be continuously propagated through the field to all sensor nodes, so that future data reports can be correctly delivered to the sink. As energy and resources of a sensor node are limited, these algorithms and protocols should meet a high energy efficiency and a high delivery ratio. To deal with this issue, we propose a framework, called Tree Overlay Grid (TOG), for data collection and dissemination. To route queries and deliver data efficiently in our framework, a geometric routing *GFB* (Greedy Forwarding within Bound) is proposed to create a TTDD-like grid network, and a tree protocol is used to construct local trees around sinks. In addition, two mechanisms are introduced to prolong the network lifetime. The first mechanism tries to save energy by reducing the traffic load; the second one tries to slow down energy consumption by balancing the traffic load. The simulation results show that TOG outperforms the best known data collection solution and some current data collection solutions for WSNs with multiple mobile sinks.

1. Introduction

A wireless sensor network (WSN) consists of a large number of homogeneous battery-operated sensor nodes interconnected together to form a network autonomously. Those sensor nodes will assist in sensing ambient conditions in an interested area. They then will store and process sensory information and send and forward gathered data to sinks or base stations for post-analysis. Sinks are resource rich devices.

The following delay sensitive applications can be realized by WSNs: healthcare monitoring, environmental monitoring, habitat monitoring, traffic monitoring, manufacturing monitoring, disaster management, inventory tracking, forest fire detection, target tracking, intrusion detection (e.g., enemy detection or tracking), battle-field surveillance, and so on.

Among them, we are interested in applications, which are classified as an event-driven type. They include intrusion detection (e.g., enemy detection or tracking), target tracking, battle-field surveillance, habitat monitoring, and forest fire detection. Sensor nodes, in an event-driven application, monitor a sensitive area and are programmed to periodically sense some specific events, such as an intrusion. They gather event reports which are then forwarded towards sinks for post-analysis. For instance, in Fig. 1, we see that an enemy tank enters the field monitored by a WSN. Surrounding sensor nodes are programmed to detect enemy tanks in the monitored area. The detected event reports will be sent to the collector, the Source, which then sends collected sensory information to respond to the soldiers' requests. This procedure is called data dissemination.

The flooding method to send report events to static sinks seems to be a good mechanism for data dissemination protocols, because it does not involve costly network topology management and complex routing algorithms. However, it results in a hotspot problem which sensor nodes closer to static sinks drain their energy faster than other sensor nodes farther away from sinks.

Mobile-sink-based routing protocol is used to reduce or avoid the effects of the hotspot problem caused by static-sink strategies. In addition, it can prolong the network lifetime to some extent and optimize energy. Energy is one of the major concerns in designing protocols for WSNs. Various data dissemination schemes [1–4] have been proposed over the years to reduce energy consumption among sensor nodes. Virtual grid-based data dissemination schemes [5–7] are preferred for event-driven type applications, because they require less energy in grid-based routing algorithms.

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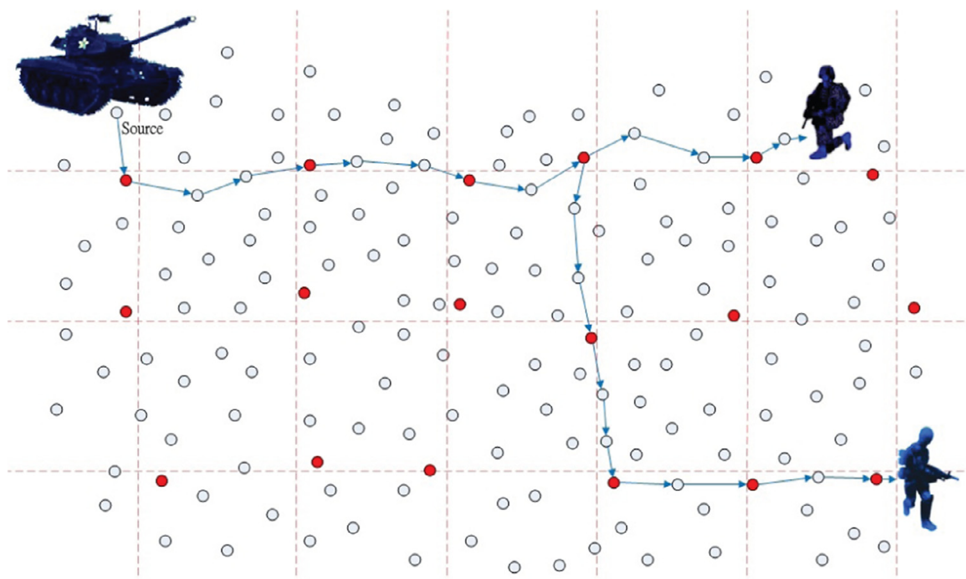

Fig. 1. The WSN is used in battlefield surveillance.

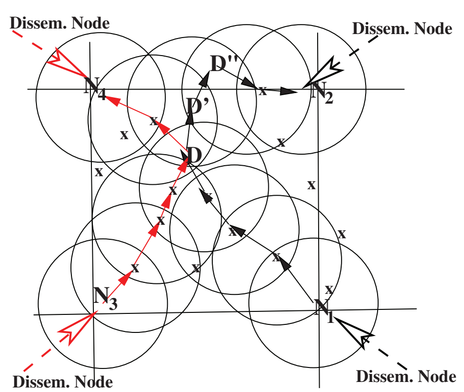

Fig. 2. The path between two dissemination nodes created by TTDD.

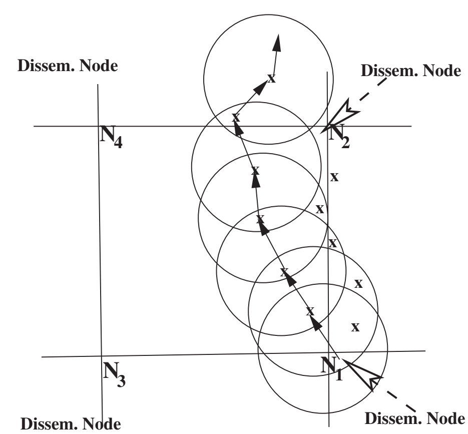

Fig. 3. The path between two dissemination nodes created by compass routing.

Authors of TTDD (Two-Tier Data Dissemination) [7], one of many studies on data dissemination in the presence of mobile sinks [8–12], employed a virtual grid structure to lessen energy consumption. However, there are a number of drawbacks due to the network itself and the routing algorithm used. In addition to the well-known dead-end issue [13], a routing path between two dissemination nodes may skew away from the line segment connecting the two dissemination nodes as shown in Fig. 2 when TTDD greedy geographical forwarding algorithm is employed. We also tried Compass Routing; Fig. 3 shows that Compass Routing fails to construct a path between two dissemination nodes. Namely, the resulting network may not only be disconnected but also non-grid-like. We wonder if there exists a sensor network and a routing algorithm such that routing paths constructed by the algorithm form a grid-like sensor network.

The major contributions of this study are as follows. First, unlike TTDD, the routing algorithm *GFB* in our framework guarantees that grid paths created by *GFB* do not intersect within a grid cell. Second, our framework introduces a new role of a sensor node, called a reporter, to handle multiple mobile stimuli/targets. Third, unlike TTDD, our framework uses only one network to handle multiple mobile targets. Fourth, we provide formal proofs for statements used in the study and algorithms.

The rest of the paper is organized as follows. In Section 2, we review related work. The network model and the detail of the design of TOG is described in Section 3. The simulation results and analysis are presented in Section 4. Section 5 concludes this paper. The facts used in Section 3 are presented as lemmas, theorems, propositions, or corollaries. With their proofs, they are collected in Appendices.

2. Related work

As mentioned in the previous section, many data dissemination protocols have been invented in the presence of mobile sinks. The primary objective of mobility schemes is to either deliver data in disconnected sensor networks or improve the network lifetime. Basagni et al. [14] classifies sink mobility schemes into three categories: random mobility, predictable mobility, and controlled mobility. In a random mobility scheme, no network information is required as the movement of the sink is random. The random mobility scheme is the most widely adopted scheme in WSN. TTDD and TOG protocols belong to such a scheme. In a predictable mobility scheme, a mobile sink injects its trajectory information into the network then sources use such information to determine the sink's future location. PMDD (Predictable Mobility-based Data Dissemination) [15] is an example of such a scheme. In a controlled mobility scheme, sink movement is controlled by certain network parameters such as residual energy, stimulus location, etc. A sink takes movement decisions to increase the network's lifetime. One such example is GMRE (Greedy Maximum Residual Energy) mechanism proposed by Basagni et al.