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A block-aware hybrid data dissemination with hotspot elimination in wireless sensor network

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ABSTRACT

As a significant milestone in the data dissemination of wireless sensor networks (WSNs), the *comb–needle* (CN) model was developed to dynamically balance the sensor data *pushing* and *pulling* during hybrid data dissemination. Unfortunately, the hybrid push–pull data dissemination strategy may overload some sensor nodes and form the *hotspots* that consume energy significantly. This usually leads to the collapse of the network at a very early stage. In the past decade, although many energy-aware dynamic data dissemination methods have been proposed to alleviate the hotspots issue, the block characteristic of sensor nodes has been overlooked and how to offload traffic from hot blocks with low energy through long-distance hybrid dissemination remains an open problem. In this paper, we developed a block-aware data dissemination model to balance the inter-block energy and eliminate the spreading of intra-block hotspots. Through the clustering mechanism based on *geography* and *energy*, "similar" large-scale sensor nodes can be efficiently grouped into specific blocks to form the *global block information* (GBI). Based on GBI, the long-distance block-cross hybrid algorithms are further developed by effectively aggregating inter-block and intra-block data disseminations. Extensive experimental results demonstrate the capability and the efficiency of the proposed approach.

1. Introduction

The development of micro-electro-mechanical systems technology, wireless communications, radio frequency circuits, and chips on systems has prompted the emergence of tiny, low-cost and intelligent sensor nodes. A large number of autonomous sensors can further compose a wireless sensor network (WSN) that is attractive for distributed fashion information discovery in a large scale data rich environment (Akyildiz et al., 2002). These features of WSNs are particularly attractive for mission-critical operations such as battlefield surveillance (Huang and Tseng, 2005), military reconnaissance and emergency response (Arora et al., 2004). In the areas, WSNs are commonly used in unattended environments where they are intended to work without a main control center such as a sink. Applications which are deployed in the unattended environment require sensors to collect, process and store data or information. Therefore, *information discovery* has become an important function of WSNs.

As sensor nodes are highly restricted to the limited battery power supply, one of the limitations of WSNs is their inherent energy resource limitations. One of the recent research objectives for information discovery is to reduce the overhead and thereby decrease energy consumption.

Strategies in *information discovering* can be proactive or reactive (Can and Demirbas, 2012). Sensors that gather information or detect an event can *push* this information out to every sensor in the network, or wait for a sensor to *pull* this information through a query. However, the efficiency of the *push* or *pull* strategies varies upon the differing demands for information: when a large number of sensors request the same information, the *push* strategy is more efficient; when the demand for information is low, the *pull* strategy is better.

Hence, the hybrid *push–pull* strategy has been typically adopted to balance *pushing* and *pulling* in large-scale WSNs. For example, in the *comb–needle* (CN) (Liu et al., 2007) model, each sensor node pushes its data to $\mathcal{L}$ (the needle length) neighbors and the query is

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disseminated only to those nodes at the fixed-space horizontal lines of the network. This gives an imaginable view this query is combing for needles in the sand.

As a significant milestone in the data dissemination of WSNs, the *push–pull* strategy of CN is still adopted in different contexts, such as balancing data broadcasting and information hovering of wireless networks (Alnuweiri et al., 2012; Liaskos et al., 2012), or data dissemination in vehicular ad hoc networks (Ye et al., 2012).

Typically in the *comb–needle* model, a sensor node that generates a large number of events always replicates its data along the same routing path. Sensor nodes on this path carry much more traffic overhead compared with distant sensor nodes. Since sensor nodes in WSNs are powered by batteries, and in general have no opportunity to replenish their power sources, such unbalanced energy consumption results in quick power depletion on the part of the network. These become the so-called "*hotspots*", and they can quickly exhaust the energy and bring down the entire WSN.

Let us consider one example scenario.

1.1. An example scenario

An imagined scenario with a mobile gas station needing protection from enemy attack requires efficient data gathering and dissemination from the gas supply and transport units to the *sink*, namely the central military unit.

The mobile gas station cannot be fixed at the location and the transportation path needs to be frequently changed. In such a dynamic and vulnerable environment, WSNs are an inexpensive but effective technology for enhancing the army's battlefield situation awareness (He et al., 2004).

As shown in Fig. 1, sensor nodes are deployed around three facilities in the imagined battlefield: the mobile gas station, the gas repository and the underground gas factory.

For effective information discovery, the *push–pull* strategy is adopted; when a sensor detects suspicious events, it will periodically *push* the information throughout the network (see the curve along the solid arrows) in anticipation of the enemy's activity. The central military unit will then collect the event information using a *pull*-based information query.

In most situations, neighboring sensor nodes in the above example collectively *push* a specific event or receive queries. When the mobile gas station is under attack, all surrounding nodes will broadcast this event, and the central military unit will inquire about the attack through its own surrounding nodes. In this way, sensor nodes in the interested areas may be roughly clustered into three blocks *A*, *B*, and *C* respectively, as shown in (1).

Suppose nodes in block *B* has relatively low residual energy than nodes in blocks *A* and *C*. If the nodes in block *B* still heuristically disseminate data across *B* in a hop-by-hop way, while ignoring the block energy characteristic ($Energy_B = low$, $Energy_A = high$, $Energy_C = high$), then a *hotspot* will eventually form and nodes in block *B* will exhaust quickly.

This example implies, it is necessary to offload the traffic from blocks with low energy, and utilize the long-distance hybrid dissemination to balance the load of different blocks. The heuristic only on the node's energy is inadequate for the balanced dissemination with global hotspot elimination (see the curve along the dotted arrows).

1.2. Research issues

Existing *hotspot elimination* techniques can be mainly categorized into two ways: (i) to utilize dynamic data dissemination to avoid exhausting the static routing path (Cheng et al., 2009) and (ii) to adopt energy-based heuristics to bring traffic off nodes with less-energy (Doss et al., 2009).

However, as we can see from the above example scenario, data dissemination for events originating in a specific block will mostly fall in this block. The exploitation of the status of immediate neighboring nodes' can be misleading and has a high chance of bringing the hotspot into the specific block. Considering the fact that neighboring sensor nodes usually have similar characteristics (e.g., *residual energy*), this *block characteristic* is essential and should not be overlooked in *information discovery*.

Blocks of neighboring sensor nodes have their own residual energy levels and these levels can be represented by the block energy centroid, namely the average energy for nodes in this block. This kind of block information can be maintained in the *sink* which is not constrained in terms of energy and computation resources. The utilization of block information can provide a global energy overview of the WSN for constructing an effective information dissemination path. If a block's residual energy level is significantly lower than other blocks, events originating in this block should be promptly disseminated and migrated to blocks with higher residual energy levels. This will balance the overall energy consumption and prevent hotspots forming in a specific block.

In this paper, both attributes of *geography* and *energy* are utilized to characterize the blocks, and the block-based hybrid data dissemination mechanism is further proposed. The aim of this

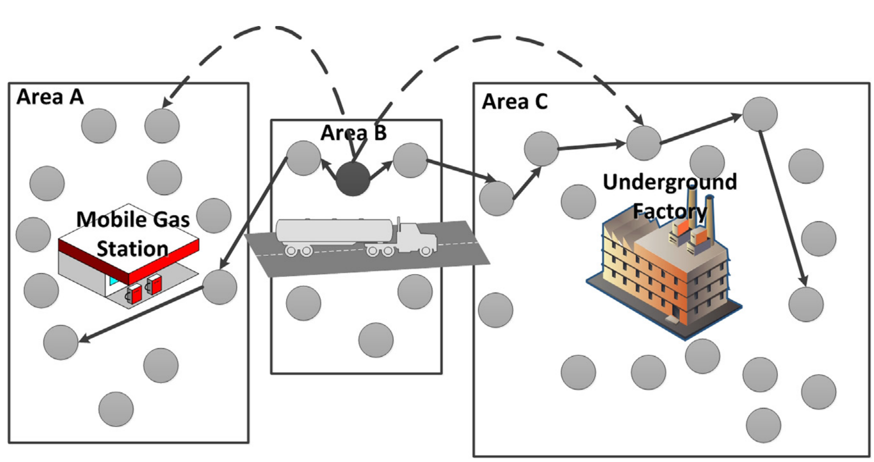

Fig. 1. A WSN example of a push–pull information discovery in military gas transportation.