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A Survey about Routing Protocols with Mobile Sink for Wireless Sensor Network

Jin Wang[1], Xiaoqin Yang[2], Zhongqi Zhang[2], Bin Li[1] and Jeong-Uk Kim[3]

[1] *College of Information Engineering, Yangzhou University, Yangzhou 225009, China*

[2] *School of Computer and Software, Nanjing University of Information Science & Technology, Nanjing 210044, China*

[3] *Department of Energy Grid, Sangmyung University, Seoul 110-743, Korea*

Abstract

Mobile sink node properly used in routing protocols can improve network performance. Thus we investigate the state-of-the-art mobile sink based query-based and location-based routing protocols. The latter strategy can be further classified into backbone-based and rendezvous-based routing protocols. In this paper, we first describe the main principles of the most representative routing strategies with sink mobility support, and highlight their advantages and disadvantages. Descriptions and comparisons of several typical routing protocols are given to deepen the understanding.

Keywords: *wireless sensor networks; mobile sink; query-based; location-based*

1. Introduction

Based on local collaboration, sensor nodes, which can integrate data acquisition, processing and communication functions in their tiny volumes, are able to self-organize themselves to form wireless sensor networks (WSNs). The advantages of WSNs like rapid deployment, fault tolerance, high precise monitoring and timely response, make them widely deployed in unfriendly or even harsh environments, such as military and disaster surveillance, industrial product line monitoring, agricultural and wildlife observation, healthcare, and smart homes *etc.*, [1].

However, sensor nodes are usually powered with limited batteries and replacing or recharging batteries on a large scale is not realistic. Once exhausted, communication on the corresponding link is easy to interrupt, which may cause the separation of network. Network lifetime is obviously subject to those nodes near sink nodes since they take more data forwarding task for other nodes.

Up to now, many energy efficient routing algorithms or protocols have been proposed with techniques like clustering, data fusion, multi-path, location tracking and sink mobility. Using sink mobility technologies can avoid excessive transmission overhead at sensor nodes since those sensors can forward their traffic only when sink node is nearby. Energy consumption can also get balanced since the hotspot nodes will rotate as sink nodes move around throughout the sensor network, and this will cause prolonged network lifetime. Besides, sink mobility technologies can ensure good network connectivity under sparse or disconnected sensor networks [2-3].

The main contributions we make in this paper are as follows. First, we investigate several sink mobility mobile patterns. Second, we present an overview of the representative location-based routing approaches supporting sink mobility. Location-based routing approaches can be further classified into backbone-based and rendezvous-based approaches according to their network structures. Thus, we not only describe the main principles of most representative routing strategies with sink mobility support, but also highlight their advantages and disadvantages. Appropriate routing

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strategy can be chosen to meet different requirements of sensor network applications by comparing different routing mechanisms

The rest of the paper is organized as follows. Section 2 discusses different sink mobility patterns. Section 3 presents an overview of most of the representative query-based routing approaches for WSNs with mobile sink support. Section 4 gives an overview of some famous location-based routing approaches for WSNs with detailed mechanism of each routing approach. Section 5 discusses some open research issues concerning sink mobility for WSNs, and Section 6 concludes this paper.

2. Routing Strategies with Sink Mobility Support

Compared with the adoption of normal mobile sensor nodes and relay nodes, the use of mobile sink node is relative easy to implement and management. Thus based on predefined moving schemes, sink node can move throughout the whole sensor network, and sojourn at some special positions to collect network information. Sink mobility technology can alleviate energy hole problem to some extent by rotating its nearby nodes with heavy traffic load as sink moves around. Based on movement trajectories, sink mobility schemes can be classified into three categories, namely random mobility, predictable mobility and controlled mobility [2-5]. Different mobile mode has its own characteristics, and we need to choose the proper mobile mode according to the specific situation. Moreover, existing routing protocols can be divided into different categories according to different standards. Here we mainly discuss the query-based and location-based routing protocols.

2.1. Query-based Routing Protocols

In query-based routing protocols, source nodes wait for query messages from destination nodes and then transmit their monitored data to destination nodes passively. Query messages contribute to establish data transmission path. In this sub-section, we mainly describe several query-based routing protocols supporting sink mobility.

Meeting position aware routing (MPAR) protocol [6] is query-based and self-adaptive in the time domain. Based on the prediction of data-sink meeting position, MPAR changes the original route only when the route correction is needed for data transmission. Sink node sends out a query message which contains the type of data, geographic information, and other parameters. Before forwarding data reports, estimated propagation time (EPT) will be computed by source node and then sent to the next relay nodes. Each relay node uses the EPT to calculate the estimated meeting position (EMP), and then check the time domain whether mobile sink node has passed the EMP or not. Position of mobile sink node can be predicted and queried data can be sent to the predicted position.

The multicast-query-based data dissemination (MQDD) protocol [7] is a localized approach which uses multicast for event query messages and unicast data communication with either beacon-based or beacon-less based geographic routing algorithm. Source node sends event announcement message to horizontal sensors to choose some dissemination nodes. Event information and upstream node location information is usually stored in these dissemination nodes. To reduce energy consumption, multicast routing algorithm is adopted for sink node querying the sensor network. Once the query message is received, sensor node which is responsible for continual forwarding task will perform multicast routing phase.

In Table 1, a comparison of the above protocols is given in the aspects of characteristics and advantages. MPRP protocol is designed for query-based sensor networks with random sink mobility. It can provide less end-to-end latency and reduced energy consumption. MQDD protocol adopts multicast and unicast mechanisms for query messages and data transmission. Compared with other protocols, it performs well in terms of data delivery ratio, and average delay.

Table 1. Comparison of Three Query-based Routing Protocols

Protocols	Characteristics	Advantages
MPRP	1. Dense node deployment; 2. Random sink mobility and multi-hop communication; 3. Position prediction technology;	1. Self-adaptive in time domain; 2. To avoid frequent route changes; 3. To keep the least destination reselection; 4. To perform well in energy efficiency and data latency;
MQDD	1. A localized protocol; 2. To use multicast and unicast; 3. Simple line structure to inform the event;	1. No need global topology information; 2. To perform well in energy efficiency, average delay and data delivery ratio;

2.2. Location-based Routing Protocols

Geographic location information is an important auxiliary tool to make routing protocols more effective. Via the aid of global positioning system (GPS), infrastructure based localization methods or other virtual coordinate systems [4], each node is location-aware. Based on virtual network infrastructure, location-based routing protocols can be further classified into backbone-based and rendezvous-based routing protocols [2, 4]. The basic idea of backbone-based routing protocols is to use self-organization schemes to build a virtual structure over physical network to promote data transmission. And the basic idea of rendezvous-based routing protocols is to use rendezvous points located in the vicinity of movement paths to store data. Thus we introduce several protocols to deepen the understanding of the above two kinds of location-based routing protocols.

(1) Backbone-based Routing Protocols

Dynamic directed backbone (DDB) protocol [8] is built on top of the low energy self-organization scheme. Initiate message of sink nodes can be sent through the non-directed backbone, which is built by localized self-organization scheme. Only a set of sensors will be chosen to send neighboring information, and will be defined as leader nodes interconnected by gateways. Leader nodes and gateways form the self-organized backbone. When a node joins, it will decide whether to be a leader node or not. A directed dissemination structure can be constructed by sending a sink request message through the self-organized backbone. Query message will be injected into the network once a sink node arrives, and will be translated by sensors which capture it. DDB can effectively reduce data traffic during data dissemination phase and save energy.

To obtain the location information on demand, a hybrid protocol called HMRP [9] is proposed, which combines benefits of both geographical routing and on-demand distance vector routing. Data reports are encapsulated with a new header which includes both source and destination location information together with adopted forwarding mode. The default forwarding mode is greedy forwarding, and the alternative mode is on demand shortest-path first forwarding mode used to recover from greedy dead-ends. Neighboring sensors periodically exchange hello messages, and a controlled broadcast mechanism is adopted to obtain location and the shortest route information. To minimize broadcasting overhead, underlying algorithm is used to calculate the minimum connected dominating set. HMRP can reduce the demand for flooding and automatically adapt to the minimum connected dominating set.

To effectively improve the network lifetime, sink mobility technology and clustering technology are combined to construct sensor networks. A mobile routing algorithm with registering (MRAR) in cluster-based architecture [10] is proposed to minimize the energy consumption while maintain certain network lifetime. Each sensor needs to establish a neighbor information table in order to hold the information about geographical address and the status of energy supply. Nodes with higher energy will be chosen as cluster heads, and then broadcasts the message to neighbor nodes. Neighbor nodes stop the wait time and join into the newly formed cluster. After completing the formation of clusters, sink node will move around according to those calculated random waypoints, and send out messages containing address information. Cluster heads compare the address information and then make the corresponding reflection to set up data transmission path based on the remaining energy capacity.

An overview and comparison of the above protocols with mobile sink support is summarized in Table 2, where some principle characteristics and limitations are provided. We can find that more research work is needed in terms of comparison of data dissemination, delay, load sharing and balancing, as well as residual energy comparison under different backbone scenarios with mobile sink support.

Table 2. Comparison of Four Backbone-based Routing Protocols

Protocols	Structure	Characteristics	Limitations
DDB	Backbone	1. Self-organization scheme; 2. Directed dissemination structure; 3. To reduce data traffic; 4. To be extended to mobile sink and multi-sink scenarios;	1. Lack of comparison of data dissemination using different backbone strategies; 2. To provide low energy transmission in data dissemination;
HMRP	Dominating Sets	1. Exchange geographical locations with neighbors; 2. No global topology or central management; 3. Location information is requested on demand; 4. Low packet loss rate and latency;	1. Security issues; 2. Load sharing between routing nodes;
MRAR	Clusters	1. To eliminate complicated computation upon operation; 2. To reduce energy consumption while prolonging network lifetime; 3. To decrease relay frequency of sensor nodes nearby sink ;	1. The delay of data disseminations; 2. Only consider the situation existing one mobile sink node;

(2) Rendezvous-based Routing Protocols

In order to offer robust persistence, a geographic hash table (GHT) system is described for data-centric storage in [11]. GHT protocol can be easily adopted in sensor networks using mobile sink nodes, even though it is not specially designed for mobile sensor networks. In GHT, hashing of a key into geographic coordinates is the critical step. The selection of an appropriate sensor node or home node storing the key-value pair is central to building GHT. Stored data will be replicated locally to ensure persistence when a sensor node fails. However if there is a clustered failure, localized replication is of little use. GHT can offer robust persistence and high data availability even when sensor nodes fail. However, all data reports and queries for the same storing node will cause high burden to storing node. Hot spot problem may occur which will lead to reduced network lifetime and degraded network scalability.

To provide network scalable and efficient data delivery, two-tier data dissemination protocol (TTDD) [12] using multiple sink nodes is proposed which adopts a grid infrastructure. Only the sensors located in the grid points need to acquire forwarding information. Each source node will proactively construct a grid structure, and chooses itself as the start crossing point of the gird. Data notification is sent to the four adjacent crossing points until reaching the next sensor closest to the crossing point by greedy geographical forwarding. Queries from sink nodes can be propagated along the grid until reaching the source node. Query message can successively traverse from low tier to the high tier. The former is within local grid square of current location of sink node, and the latter is made by dissemination nodes on grid. Thus data reports can be transmitted to sink node directly. In TTDD, only dissemination nodes need to participate in data transmission, and others can be relieved from maintain states. Thus, TTDD can provide scalable and efficient data delivery. Besides, query message from mobile sink nodes are confined within their current location, which can effectively avoid excessive energy consumption and network overload from global flooding. However, each source node needs to construct a grid structure to avoid frequent constructions. Thus, grid structure reuse needs to be further studied.

A line-based data dissemination (LBDD) protocol [13] supporting unpredictable mobile sink nodes is proposed to offer good network scalability. In LBDD, the whole sensor network is divided into two equal parts by a vertical line, as is illustrated in Figure 4. Sensor nodes within the boundaries of this vertical line are defined as inline-nodes. The core part of this protocol is the concept of a rendezvous region which decouples data dissemination operation. Therein, the vertical line acts as the rendezvous region, and it is located at the center of the sensing field. When an ordinary sensor node generates a data report, it will transmit the report to the virtual line. And the report will then be kept in an inline-node which is closest to the source node. Then sink node sends a query message which will be propagated along the line until reaching the storing node. Finally, new data reports can be transmitted to mobile sink node directly. LBDD can effectively address the hot spot problem with good network scalability. However, LBDD has poor performance in sparse networks and the data persistence problem against node failure and malicious nodes inside the virtual infrastructure needs should be further studied.

Table 3. Comparison of Three Rendezvous-based Routing Protocols

Protocols	Structure	Characteristics	Limitations
GHT	Hashed location	1. Data-centric storage; Hashing keys; 2. Keys are uniformly hashed; 3. To offer robust persistence and high data availability;	1. Non-uniform distribution of senor nodes; 2. Geographic boundaries; 3. To use only approximate geographic information; 4. High node burden;
TTDD	Grid-based	1. Scalable,and location-aware; 2. Efficient data delivery; 3. To reduce energy consumption and network overload;	1. Each source node needs to construct a grid structure; 2. Reuse of grid structure;
LBDD	Line/strip	1. To address hot spot problem, and be suitable for event-driven and query-based scenarios; 3. To provide good trade-off;	1. Sparse network; 2. Data persistence against node failure; 3. Malicious nodes inside the virtual infrastructure;

An overview and comparison of the above protocols with mobile sink support is summarized in Table 3. In addition to the above routing protocols supporting sink mobility, there have been many other research works on mobile sink node moving strategies in recent years. These research works is still undergoing with aim to achieve improved network performance under different applications. Detailed comparisons like structure, mobility model, and delivery model of the above mentioned routing protocols are provided in Table 4.

Table 4. Comparison of the Above Routing Protocols

Protocols			Structure	Mobility model	Delivery model	Multiple sinks	Location	Energy
Query-based		MPRP	Clusters	Predictable	Query		√	
		MQDD	Flat	Random	Continuous	√	√	√
Location-based	Backbone	DDB	Backbone	-	Query	√	√	√
		HMRP	Dominating sets	Controlled	Query		√	
		MARA	Clusters	Predictable	Continuous		√	√
	Rendezvous	GHT	Hashed location		Query		√	
		TTDD	Grid-based	Random	Event	√	√	√
		LBDD	Line/strip	Unpredictable	Continuous	√	√	√

3. Discussion

The study of node deployment strategies has been a hot research issue in recent years since it can improve network performance. Rather than carefully designing dozens of sensor or relay nodes, the adoption of a few mobile sink nodes is more practical, and contributes to network performance. First, it can help reduce energy consumption, and prolong network lifetime consequently. Second, it can alleviate hotspot problem when sink nodes move around. Third, it can help reducing average hop number or delay with proper sink mobility design. Finally, it is relatively easy to implement mobile sink nodes deployment. For example, sink nodes can be installed on some public vehicles with periodical and routine paths.

However, high data latency may occur due to the influence of mobile devices speed, especially in delay-sensitive applications. This will cause increased data transmission latency, and buffer overflow of sensors especially those sensors which act as rendezvous points or close to the final destination node. Again, the proper design of sink mobility pattern is a key research issue.

4. Conclusions

As an effective method, mobile sink nodes are applied to wireless sensor network to balance energy consumption. Sink node can move in different ways, such as moving randomly or moving controlled. In this paper, we mainly present an overview and comparison of query-based and location-based routing protocols with mobile sink node. Moreover, the location-based routing protocols can be further classified into backbone-based and rendezvous-based protocols depend on different virtual infrastructure. The analysis of different protocols can deepen the understanding of the above kinds of routing protocols supporting mobile sink nodes. Mobile sink node properly used in routing protocols can provide better network performance.

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Authors

Jin Wang, Dr. Jin Wang received the B.S. and M.S. degree from Nanjing University of Posts and Telecommunications, China in 2002 and 2005, respectively. He received Ph.D. degree from Kyung Hee University Korea in 2010. Now, he is a professor in the College of Information Engineering, Yangzhou University. His research interests mainly include routing protocol and algorithm design, performance evaluation and optimization for wireless ad hoc and sensor networks. He is a member of the IEEE and ACM.

Xiaoqin Yang, she obtained her B.S. degree in Binjiang College from Nanjing University Nanjing University of Information Science and technology, China in 2011. Now, she is working toward the M.S. degree in the Computer and Software Institute in her Alma Master. Her current research interests are in performance evaluation for wireless sensor networks, and energy efficient routing protocol and algorithm design.

Zhongqi Zhang, he obtained his B.S. degree in the Eletronic and Information Engineering from Nanjing University of Information Science and technology, China in 2012. Now, he is working toward the M.S. degree in the Computer and Software Institute. His current research interests are in performance evaluation for wireless sensor networks, and healthcare with wireless body area networks. He is a student member of ACM and CCF.

Jeong-Uk Kim, Dr. Jeong-Uk Kim received his B.S. degree in Control and Instrumentation Engineering from Seoul National University in 1987, M.S. and Ph.D. degrees in Electrical Engineering from Korea Advanced Institute of Science and Technology in 1989, and 1993, respectively. He is a professor in SangMyung University in Seoul. His research interests include smart grid demand response, building automation system, and renewable energy.