A Routing Method for Cooperative Forwarding in Multiple Wireless Sensor Networks

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***Abstract*—In recent years, the number of applications of wireless sensor networks (WSNs) has been increasing. Multiple WSNs can be constructed within the same geographic area. We propose a routing method for cooperative forwarding in such multiple WSNs that will extend their lifetime. For multiple WSNs, each sink location will differ from the others, and some nodes around a sink in one WSN may be far from a sink in another WSN. We focus on this issue in the proposed method, with a node that is far from a sink in its own network and near to a sink in another network being able to forward packets from a node in another WSN to the corresponding sink.**

Keywords-*multiple sensor network; cooperative forwarding; load balancing.*

I. Introduction

Wireless sensor networks (WSNs) are composed of tiny battery-powered sensor nodes that have limited storage and radio capabilities [1], [2]. Therefore, for WSNs to remain operational for a long time, much attention has to be paid to energy consumption in the nodes.

In a typical WSN, sensor nodes acquire and send data to a processing center called the *sink*. Because all data are forwarded to a sink, nodes around the sink tend to transmit many more packets than the others [3]. In this case, the energy of such nodes will exhaust earlier than that of other nodes, causing an "energy hole" to appear around the sink. No more data can be delivered to the sink after the hole appears. Consequently, the energy remaining in the rest of the network is wasted, and the network lifetime is shorter than it could be [4].

In some applications, a WSN may comprise several thousand sensor nodes within an extended area (e.g., agriculture and environmental monitoring). In these cases, the diameter of the WSN may be some kilometers. To enable networks to be scalable, a WSN is typically subdivided into clusters and the data collected by cluster heads are sent to a sink. Clustering also supports data aggregation. This is a method by which data from multiple sensors are combined to eliminate redundant information and transmission, thereby reducing energy consumption [5].

From another point of view, WSNs can be classified into two types, namely homogeneous and heterogeneous sensor networks. In a homogeneous WSN, all nodes have the same capabilities. In recent years, however, heterogeneous WSNs have attracted much attention. These have a small number of "high-end" sensor nodes, with a wider range of radio communication capabilities and/or a larger battery compared with the "normal" nodes. A clustering method to achieve effective use of these high-end nodes has been proposed [6]. However, a clustering method alone is not sufficient to prolong the network lifetime for a heterogeneous WSN, and a clustering and multi-hop hybrid routing method has therefore been proposed [7].

In recent years, multiple WSNs have been constructed within the same geographic area [8], [9]. For such cases, researchers have been investigating cooperation between the WSNs. Some routing protocols for multiple WSNs have been proposed [10], [12], [11], [13].

In this paper, we propose a routing method for cooperative forwarding to prolong network lifetime by reducing the load on nodes around sinks in a multiple-WSN environment. By reducing the load around a sink, we aim to overcome the problem of some nodes becoming "bottlenecks". Our method decides how much other WSNs with different sink locations can help such "heavy-load" situations.

The remainder of the paper is organized as follows. We first introduce some related work in Section Ⅱ. In Section I Ⅱ, we propose a routing method for cooperative forwarding to reduce the load around a sink. In Section Ⅳ, we evaluate the performance of the proposed method. Finally, Section V concludes this paper and indicates directions for future work.

II. Related Work

In recent years, the number of applications of WSNs has been increasing, with multiple WSNs attracting much attention. For such environments, some protocols have been proposed, as follows.

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The *Virtual Sensor Network (VSN)* is an emerging concept for supporting multipurpose, collaborative and resource-efficient WSNs by enabling, for example, dynamic variations to the subsets of sensors and users [10]. A VSN is formed as a logical network of cooperative nodes. For cases where applications overlap geographically, transmitting data for applications among a variety of devices enables the nodes to reduce redundant paths. Nodes are classified into an appropriate VSN based on the phenomena they are tracking (e.g., container tracking or corrosion-rate monitoring). It is expected that VSNs will provide protocols for the construction methods, maintenance and usage of subsets of sensors, providing a way to communicate efficiently between intermediate nodes or other VSNs.

Poorter et al. [11] propose to construct an overlay network for different WSNs. However, this protocol has the problem that differences in operating policies and radio communications are not considered.

Steffan et al. [12] focus on a general concept for the creation and maintenance of network-wide node subsets and describe a flexible and modular architecture that meets the requirements of multipurpose WSNs. However, the creation of these subsets is not very scalable. Most applications specify their own purpose and construct independent WSNs, but it is not necessary to offer acceptable cost performance and coverage.

Instead of many-to-one routing, many-to-many routing is proposed in [13]. This merges paths with simultaneous traffic, thereby minimizing the number of nodes involved in many-to-many routing and balancing their forwarding load. However, this proposal has the problem that the nodes along the merged paths have a heavier load and consume more energy.

Elhawary et al. [14] model a cooperative transmission link in wireless networks in terms of a transmitter cluster and a receiver cluster. They propose a cooperative communication protocol for the establishment of these clusters and for the cooperative transmission of data. The nodes calculate the link cost between these paths and select the most efficient path. This enables the nodes to reduce their energy consumption, but the nodes in a cluster need to be synchronized and each node has the increased overhead of forming many paths.

Taking another point of view, we propose to achieve load balancing by cooperative forwarding in multiple WSNs.

III. Proposed Method

A. Concept

It is assumed that there are n WSNs in the same area. These WSNs have different applications. In addition, their start and finish times may differ, depending on each network's requirements.

As shown in Figure 1, the locations of the sinks in multiple WSNs are separated. Some nodes around a sink in one WSN may therefore be far from a sink in another WSN. We focus on this fact in the proposed method, whereby a node that is far from a sink in its own network, but near a sink in another network, can forward a packet from a node in another WSN to the corresponding sink. In this paper, we call the former network the *home network* and the latter network the *visitor network*. The method achieves load balancing between a heavy-load node in a home network and a light-load node in a visitor network. As a result, the lifetime of both networks can be extended.

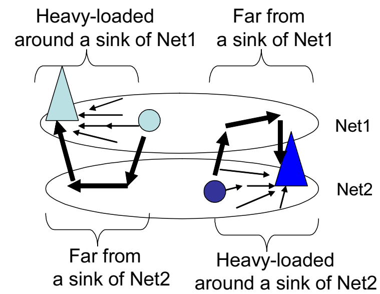

Figure 1. Heavy-load node around a sink

Specifically, each network constructs a path along which a node can't forward a packet from a node in another WSN in advance. It is based on the well-known Ad hoc On-Demand Distance Vector (AODV) protocol [15]), making it easy to implement. In addition, some nodes construct routes to the sinks of visitor networks.

B. Node Function

As described above, the proposed method enables a node that is far from a sink in its home network, but near a sink in a visitor network, and can forward a packet from a node in the visitor network.

Each node has a routing table that includes not only an entry for a sink in its home network but also an entry for a sink in the visitor network. When a node overhears a data packet from its visitor network, it decides whether to receive and forward it or to ignore it. This procedure is explained later in more detail.

C. Routing Table Creation

This subsection explains how to create the routing table.

Initially, each node sends an AODV-based route request packet to create an entry in its routing table for a sink in its home network. After this creation process, each node broadcasts an additional route request packet named *B-REQ* to the sinks of all visitor networks. (Nodes on the path from the node to the sink will create an entry in their routing table to the sink.)

In addition, as a metric to decide the next hop, *minEnergy* is also notified. This refers to the minimum residual energy of nodes along the path to the sink.

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D. Cooperative Routing Method

In the proposed method, when a node sends its sensing data, it attaches the value of its residual energy in a header field of the packet. When a node relays a packet, it compares the residual energy of the node itself and that recorded in the packet, and the recorded value is replaced by smaller one. As a result, the minimum energy along the path from its source node is recorded. According to this procedure, a node can record a value of minimum energy along the paths every networks and select the path for the maximum value of this energy.

Figure 2 demonstrates how the proposed method works. After node P has the created path in its home network (Sink1), it broadcasts a B-REQ to the visitor networks Net2 and Net3. When node Q and node R receive this B-REQ, they write their network ID in the header of the B-REQ and transmit it to their sink. After this procedure, the routes from node P to the sink via Net2 and Net3 are created, as shown in Tables I and II, respectively.

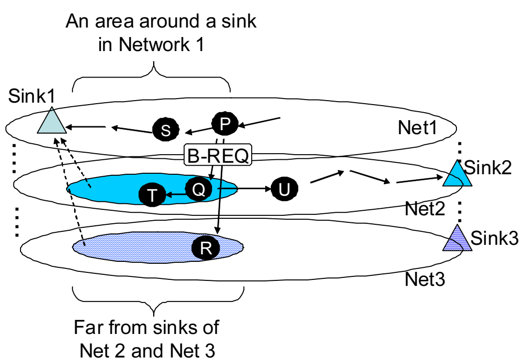

Figure 2. Multiple WSNs

Table I
NODE P'S ROUTING TABLE

Relay network	Destination	Next hop	minEnergy
1	Sink1	S	30
2	Sink1	Q	45
3	Sink1	R	65

Table II
NODE Q'S ROUTING TABLE

Relay network	Destination	Next hop	minEnergy
2	Sink2	U	55
2	Sink1	T	40

When node P receives a data packet for Sink1, it selects a suitable route from the entries in its routing table as shown in Table I. In this case, node P selects node R, which has the maximum value for minEnergy, as the next-hop node.

As we described below, the proposed method tries to extend the lifetime of each network by cooperative forwarding. However, it may result in a case where a network shortens its lifetime by the burden of forwarding for visitor networks. To avoid such a situation, in the proposed method, a node which has less residual energy does not relay packets from visitor networks.

Specifically, we define a value of *cooperation threshold* in each network as a metric to decide whether to forward packets from visitor networks or not. For this metric, each sink broadcasts the minimum value of residual energy among all the nodes in its home network to the nodes in its home network. When a node acquires the value, it compares with its own residual energy. If its own residual energy is smaller, it refuses to forward packets from visitor networks and applies itself to relay packets in its home network.

IV. PERFORMANCE EVALUATION

We evaluated the performance of the proposed method by simulation experiments using QualNet4.5.1 [16]. We simulated two WSNs (Network 1 and Network 2) as follows. Each WSN had 49 nodes based on a grid topology, as shown in Figure 3. The sensing field was a 60 m $\times$ 60 m square. The maximum range of radio transmission for each node was 15 m. One sink was located at the top left corner and another was at the bottom right corner. Each node sent data packets asynchronously, at intervals of 5 s.

For a comparison method, we simulated two WSNs coexisting in the same area, but with each WSN communicating independently (i.e., there was no cooperation and no sharing).

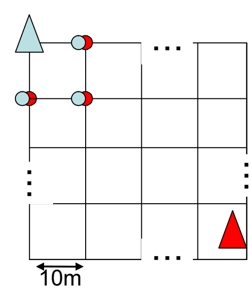

Figure 3. Simulation model

Figures 4 and 5 show the packet receiving rate of the sinks in Network 1 and Network 2, respectively. The receiving rate means the percentage of the packets which the sinks have successfully received for all sent packets by sensor nodes. It was observed every 400 seconds. The horizontal axis is elapsed time.

These figures show that the proposed method extends the lifetime of both Network 1 and Network 2. It indicates that the proposed method achieves good load balancing, with both networks benefitting.

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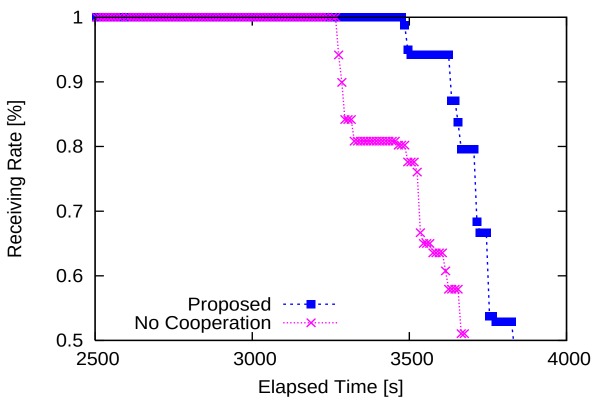

Figure 4. Receiving rate (Network 1)

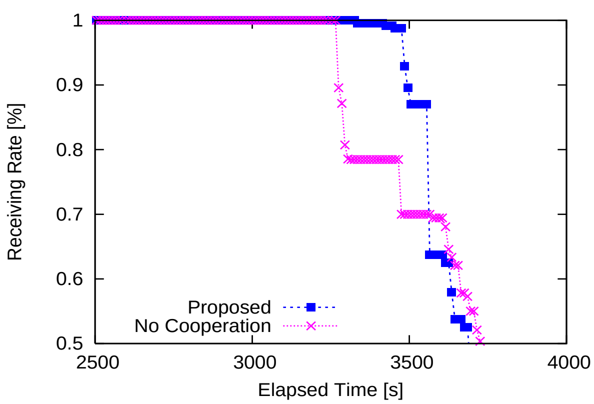

Figure 5. Receiving rate (Network 2)

V. CONCLUSION AND FUTURE WORK

In this paper, we focused on the situation where multiple WSNs operate simultaneously in the same area, and aimed to extend the lifetime of all WSNs by introducing cooperation between them.

To achieve this, we proposed a cooperative forwarding method. This enables a node near a sink in a visitor network to forward a packet from a node in the visitor network to achieve load balancing.

Simulation results showed that the proposed method can extend the lifetime of all WSNs working in the same area.

This study still has work in progress, and we recognize the following problems.

The method for choosing the next hop is too simple. We should at least take the number of hops to the sink into account. The simulation model is elementary, and we continue to evaluate the proposed method in a wider variety of situations.

REFERENCES

[1] I. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, “A survey on sensor networks,” IEEE Communications Magazine, Vol. 40, No. 8, pp. 102–114, Aug. 2002.

[2] J. Yick, B. Mukherjee and D. Ghosal, “Wireless sensor network survey,” Computer Networks 52, pp. 2292–2330, Apr. 2008.

[3] M. Perillo, Z. Cheng and W. Heinzelman, “On the problem of unbalanced load distribution in wireless sensor networks,” Proceedings of the IEEE GLOBECOM Workshops on Wireless Ad Hoc and Sensor Networks, pp. 74–79, Dec. 2004.

[4] X. Wu, G. Chen and S. Das, “Avoiding Energy Holes in Wireless Sensor Networks with Nonuniform Node Distribution,” IEEE Transactions on Parallel and Distributed Systems, Vol. 19, No. 5, pp. 710–720, May 2008.

[5] A. A. Abbasi and M. Younis, “A survey on clustering algorithms for wireless sensor networks,” Computer Communications, Vol. 30, No. 14–15, pp. 2826–2841, 2007.

[6] S. Priyankara, K. Kinoshita, H. Tode and K. Murakami, “A Clustering Method for Wireless Sensor Networks with Heterogeneous Node Types,” IEICE Transactions on Communications, Vol. E94-B, No. 8, pp. 2254–2264, Aug. 2011.

[7] S. Priyankara, K. Kinoshita, H. Tode and K. Murakami, “A Clustering/multi-hop Hybrid Routing Method for Wireless Sensor Networks with Heterogeneous Node Types,” Proceedings of the IEEE GLOBECOM Workshops on Heterogeneous Multi-hop Wireless and Mobile Networks, pp. 207–212, Dec. 2010.

[8] “e-Sense project”, http://www.ist-e-sense.org/ (Jan 2012, date last accessed).

[9] “U-City project”, http://ucta.or.kr/en/ucity/concept.php (Jan 2012, date last accessed).

[10] A. P. Jayasumana, Q. Han and T. H. Illangasekare, “Virtual sensor networks – a resource efficient approach for concurrent applications,” Proceedings of the International Conference on Information Technology (ITNG’07), pp. 111–115, 2007.

[11] E. Poorter, B. Latre, I. Moerman and P. Demeester, “Symbiotic Networks: Towards a New Level of Cooperation Between Wireless Networks,” International Journal of Wireless Personal Communications, pp. 479–495, Jun. 2008.

[12] J. Steffan, L. Fiege, M. Cilia and A. Buchmann, “Towards Multi-Purpose Wireless Sensor Networks,” Proceedings of the International Conference on Sensor Networks (IEEE SENET’05), 2005.

[13] L. Mottola and G. P. Picco, “MUSTER: Adaptive Energy-Aware Multi-Sink Routing in Wireless Sensor Networks,” IEEE Transactions on Mobile Computing, Vol. 10, pp. 1694–1709, 2010.

[14] M. Elhawary and Z. J. Haas, “Energy-Efficient Protocol for Cooperative Networks,” IEEE/ACM Transactions on Networking, Vol. 19, No. 2, Apr. 2011.

[15] C. E. Perkins, E. M. Royer and S. R. Das, “Ad Hoc On Demand Distance Vector (AODV) Routing,” http://www.ietf.org/internet-drafts/draft-ietf-manet-aodv-07.txt, Nov. 2000.

[16] QualNet Simulator version 4.5.1, Scalable Network Technologies, http://www.scalable-networks.com (Jan 2012, date last accessed).