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Queue State-Based Parent Selection Algorithm for Large-Scale Wireless Sensor Networks

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In this paper, we present a queue-state-based parent selection (QSPS) algorithm for large-scale wireless sensor networks (WSNs), which is designed to alleviate packet loss caused by traffic concentration. The process of QSPS consists of two major steps: 1) *packet loss alert*, and 2) *new parent selection*. In the former, sensor nodes check whether packet loss is imminent on the basis of the preconfigured queue threshold, and then identify the child nodes that must change their parent node. In the latter, the selected child nodes reselect a new parent node having the best queue state among the available parent candidates. To verify the effectiveness of QSPS, a simulation was conducted using the Cooja simulator in Contiki 2.7. The simulation showed that the QSPS significantly reduces the packet loss ratio and decreases the number of direct acyclic graph (DAG) information object (DIO) messages.

1. Introduction

Recently, wireless sensor networks (WSNs) have been used in various fields such as health care, environmental monitoring, manufacturing processes, and home automation. In most WSN applications, a single sink node and a huge number of sensor nodes constitute a large-scale network. The sensor nodes periodically probe for changes in the surrounding environment and then forward data to the sink node by multihop relaying. This example of a large-scale WSN is typically a low-power lossy network (LLN) in which the sensor nodes are constrained in terms of resources such as limited power, memory, and central processing unit (CPU). LLNs use various low-power communication technologies such as ZigBee, Bluetooth low energy (BLE), and power line communication (PLC).

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In an LLN, the sensor nodes may suffer from frequent packet loss owing to constrained resources and interference due to transmissions from neighboring nodes. To address this problem, the Internet engineering task force (IETF) routing over the LLN working group (ROLL WG) standardized the IPv6 routing protocol for LLN (RPL) in the RFC 6550.[1] The RPL is a simple distance vector routing protocol that is designed to minimize memory usage and routing signaling using a simple routing and forwarding mechanism. The RPL forms a tree-based routing topology, called a direct acyclic graph (DAG), that consists of one or more destination-oriented DAGs (DODAGs) depending on the number of boarder routers (i.e., sink node). For DODAG formation, the sensor nodes periodically broadcast a DAG information object (DIO) message. When the sensor nodes receive the DIO message from their neighbors, they select a preferred parent using the received DIO messages and an objective function (OF) that defines how to select and optimize the routes among the available sensor nodes.

Most cases of RPL implementations consider the use of OF0 as a default OF that uses the hop count (i.e., rank) and the expected transmission count (ETX) for parent selection. The ETX of the links refers to the inverse of the probability of successful packet delivery. With OF0, the sensor nodes select the parent node having the best link quality. However, an RPL with OF0 may cause frequent packet loss in a large-scale WSN since it does not consider the constrained resources of the sensor nodes. Specifically, the sensor nodes closer to a sink node may suffer from frequent packet loss because of low queue capacity and the high relay burden in a large-scale network.

Many studies have been conducted to identify ways to mitigate packet loss problems in a large-scale WSN. Liu *et al.* proposed a load-balanced RPL (LB-RPL) that allows a sensor node to select a parent node taking into account the queue state of the parent nodes.[2] The LB-RPL may cause a longer delay for the dissemination of the routing information, since the sensor nodes extend the DIO transmission interval in accordance with their own queue state. Kim *et al.* proposed a queue-utilization-based RPL (QU-RPL).[3] In the QU-RPL, each sensor node selects a parent node considering the queue-utilization of its neighbor nodes that refers to the number of packets in queue per total queue size. The QU-RPL can significantly reduce the packet loss ratio, but it may lead to unnecessary changes in the parent node and an increased number of DIO messages in the network, because the trickle timer to control the DIO transmission interval is frequently reset owing to the increased number of topology changes. Whenever the topology changes, the trickle timer resets its counter to 0 and selects its interval from the range of $[I/2, I)$, where I is a predetermined value of the initial interval size.

In this paper, we propose a queue-state-based parent selection (QSPS) algorithm designed to reduce the packet loss ratio caused by a limited queue capacity and to minimize the number of DIO messages in the network. The process of QSPS consists of two major steps: *packet loss alert* and *new parent selection*. In the former, the sensor node detects whether packet loss is imminent. If it is imminent, the sensor node decides which child nodes must change their parent node, and then broadcasts this information with the DIO. In the latter, the child node chooses a new parent node among the parent candidates considering the queue size of the parent candidates. A simulation was conducted in various environments using the Cooja simulator supported in Contiki 2.7. The simulation showed that the QSPS decreases packet loss ratio by 61.0% and the number of DIO messages by 10.5% on average compared with the existing routing protocols. In the following sections, we describe the design and performance of our algorithm in detail.

2. System Architecture of Large-Scale WSN

Figure 1 shows the system architecture for large-scale WSN. In the figure, the sensor nodes are connected to each other through a wireless link, and sensing data is forwarded to the boarder router via a multihop relay. The boarder router connects the WSN to the Internet via a wired link. In this paper, we assume that each sensor node operates with the same hardware resources and application. In other words, all nodes have the same queue size (k), service rate (μ), and sensing period (s). We further assume that the nth parent node has a set of average transmission intervals, $\boldsymbol{T_n}$, for the child nodes. When the number of child nodes is m, the $\boldsymbol{T_n}$ is given as

$$\boldsymbol{T_n} = \{t_{(n,1)}, t_{(n,2)}, ..., t_{(n,m)}\}, \tag{1}$$

where $t_{(n,m)}$ is the average transmission interval of the mth child node belonging to the nth parent node and can be calculated as

$$t_{(n,m)} = \frac{s}{1 + \text{Number of descendant nodes belonging to the } m\text{th child node}}. \tag{2}$$

Using Eqs. (1) and (2), the packet arrival rate of the nth parent node, λ_n, can be calculated as

$$\lambda_n = P_{size} \times s \times \left\{ \sum_{i=1}^{m} \left(\frac{s}{t_{(n,i)}} - 1 \right) \right\}^{-1}, \tag{3}$$

where P_{size} is the packet size of the sensor node.

3. QSPS

The process of QSPS includes *packet loss alert* and *the new parent selection* step. The first step consists of two operational substeps: queue-state monitoring and child selection. Figure 2 illustrates the process of packet loss detection. Prior to the beginning of the packet loss detection substep, each sensor node configures the loss alert value (LAV) for its queue. In queue-state monitoring, the sensor node monitors its own queue state and checks whether packet loss is

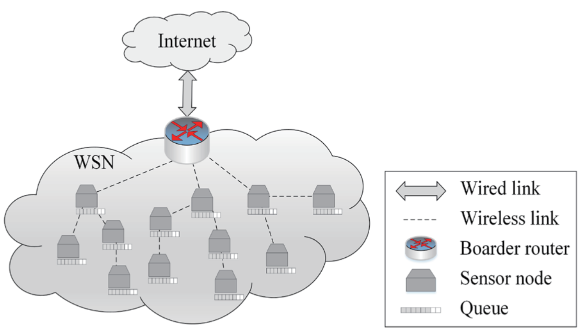

Fig. 1. (Color online) System architecture of large-scale WSN.

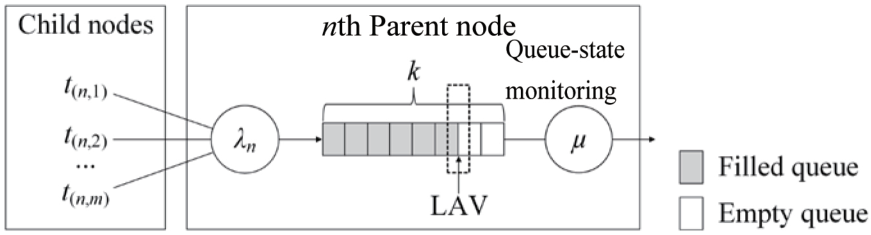

Fig. 2. Process for packet loss detection.

imminent using the LAV. When the queue state reaches the LAV, the child selection substep is started. If the LAV is not reached, each node selects its parent from among the neighbors on the basis of the ETX and the hop count. In the child selection substep, the parent node selects the child node having the shortest average transmission interval and eliminates it from the child list. After that, it calculates the new packet arrival rate (λ'_n) using the updated child list and compares λ'_n with μ. If λ'_n is bigger than μ, it repeats this procedure until λ'_n is smaller than μ. If λ'_n is smaller than μ, the parent node broadcasts the DIO message including the IDs of the child nodes that must change their parent node.

Upon receiving the DIO message, the sensor node compares its own ID with the child node IDs included in the DIO message. If one of the IDs matches its own ID, the sensor node eliminates the corresponding parent from the neighbor list. Then it selects a new parent node considering the smallest number of child nodes to be eliminated within the DIO message from among the parent candidates. If multiple parent candidates are selected, the child node compares their ETXs to choose a parent node having improved link quality.

4. Results of Simulation

Figure 3 shows an example of the topology setup in the Cooja simulator in Contiki 2.7. In the simulation, we deployed 24 sensor nodes with a single boarder router. The sensing period of each sensor node varied from 0.8 to 2 s. Considering the large-scale WSN (i.e., 1000 sensor nodes), the corresponding sensing period varied from 33.3 s to 1.4 min. The detailed simulation parameters are listed in Table 1.

Figures 4 and 5 show the packet loss ratio with varying sensing period. QSPS exhibits a lower packet loss ratio both in the worst case and the average case compared with the existing protocols (i.e., QU-RPL and RPL with OF0) because it bases parent node selection on the actual queue-state detection. Specifically, QSPS achieves 47.1 and 75.0% lower packet loss ratios compared with QU-RPL and RPL with OF0, respectively, in the average case.

Figure 6 shows the number of DIO messages generated by each sensor node. QSPS generates smaller DIO messages than QU-RPL because it changes the topology only when the queue state reaches the LAV. Compared with the RPL with OF0, QSPS generates more DIO messages because an RPL with OF0 does not consider packet loss because of its limited queue capacity. However, the increased number of DIO messages does not significantly impact the network performance compared with the packet loss caused by traffic concentration.

Table 1
Simulation parameters.

Parameter	Value	Parameter	Value
MAC/PHY	IEEE 802.15.4	Data rate	250 kbps
Packet size	100 bits	Number of sensor nodes	24
Queue size	10 packets	Sensing period	0.8–2 s
DIO minimum interval	12	DIO interval doublings	8
I_{min}	4 s	I_{max}	17.5 min

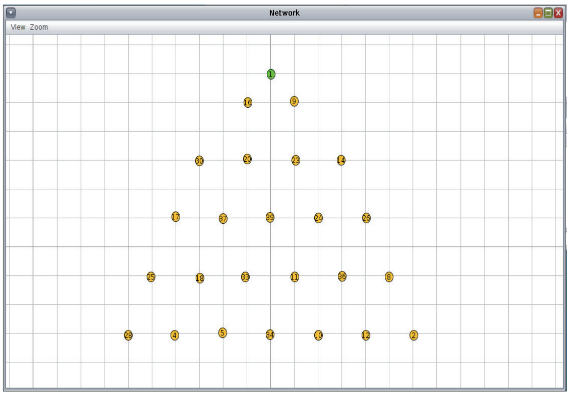

Fig. 3. (Color online) Topology setup in the Cooja simulator.

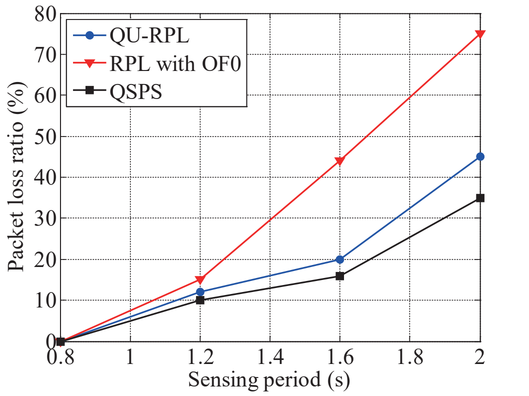

Fig. 4. (Color online) Packet loss ratio in the worst case.

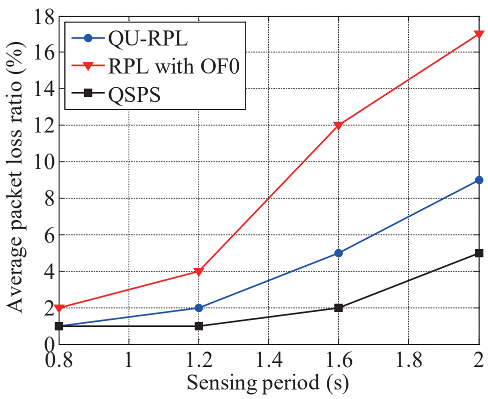

Fig. 5. (Color online) Average packet loss ratio.

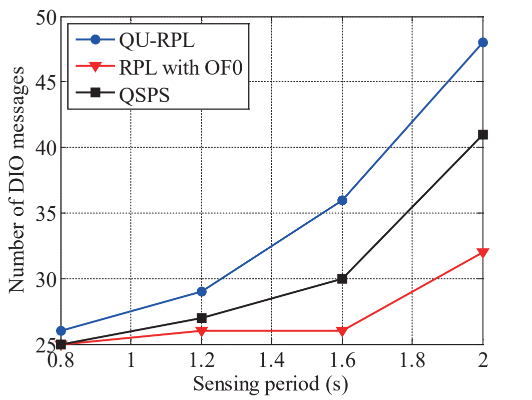

Fig. 6. (Color online) Number of DIO messages per sensor node.

5. Conclusions

We presented a QSPS for large-scale WSNs. It was designed to reduce packet loss caused by limited queue size. The process of QSPS consists of two steps: *packet loss alert* and *new parent selection*. In *packet loss alert*, the sensor nodes conduct queue-state monitoring based on the preconfigured LAV and child node selection based on the average transmission interval for the child nodes. In *new parent selection*, the child nodes select a new parent node that has the best queue state among the parent candidates. The simulation showed that QSPS significantly improves network performance in terms of packet loss ratio and the number of DIO messages compared with existing routing protocols.

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References

1 T. Winter, P. Thubert, A. Brandt, J. Hui, R. Kelsey, P. Levis, K. Pister, R. Struik, J. Vasseur, and R. Alexander: RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks: RFC 6550 (2012).
2 X. Liu, J. Guo, G. Bhatti, P. Orlik, and K. Parsons: Proc. Wireless Communications and Networking Conference (IEEE, Shanghai, 2013) p. 2238.
3 H. S. Kim, J. Paek, and S. Bahk: Proc. Int. Conf. Sensing, Communication, and Networking (IEEE, Seattle, 2015) p. 265.