Disruption Tolerant Wireless Sensor Network for Building Energy Management System

Manussanun Buranachokphaisan
The University of Tokyo
kaew@hongo.wide.ad.jp

Hideya Ochiai
The University of Tokyo
ochiai@vdec.u-tokyo.ac.jp

Hiroshi Esaki
The University of Tokyo
hiroshi@hongo.wide.ad.jp

Building Energy Management System (BEMS) is one of the emerging technologies in Smart Grid. Power consumption and environment information is collected by thousands of sensors in the building to analyze consumer behavior and load characteristic. Therefore, scalable and reliable network communication is required. Zigbee standard has been proposed to use in wireless sensor network in BEMS, however, Zigbee routing protocol has scalability and reliability issues. In this paper, we point out the shortcoming of Zigbee routing protocol and propose new idea applying DTN routing protocol to wireless sensor network in BEMS.

1. INTRODUCTION

Building Energy Management System (BEMS) is one of the technologies in Smart Grid [1] which integrates the electrical grid and communication infrastructure to form a sustainable, reliable and economical electric power system. BEMS monitors power consumption and environment as well as controls electrical appliances e.g. HVAC (heating, ventilating, and air condition) and lights in the building. Basically, the information, obtained by thousands of sensors deployed in the building, is used to analyze consumer behavior. Consumers can realize their electric consumption behavior and adopt their demand appropriately. Not only reflecting on consumer behavior, the provider can use this information to predict the forthcoming demand for scheduling the load to reduce the peak load and also the cost. The complete data set is required to get high precision analysis and prediction. As a result, scalable and reliable communication network is necessary for BEMS.

Recently, Wireless sensor network (WSN) has been proposed to monitor and control building's environment and power consumption instead of wired sensor network because of its easy deployment and low-cost maintenance. Zigbee is the standard that is getting popular for home automation and BEMS. Zigbee can operate perfectly in small network like home automation. However, it lacks of the scalability and reliability for BEMS. By cause of this problem, we would like to apply the routing mechanism used in Delay/Disruption Tolerant Network (DTN) to WSN in BEMS.

The rest of paper organizes as follows. Section 2 describes Zigbee standard and its shortcomings for BEMS. Section 3 explains DTN routing mechanism and consideration of applying this mechanism to BEMS. Section 4 presents the experiment and analysis. Section 5 concludes this work and explains future works.

2. ZIGBEE ISSUE

Zigbee standard [2] is a specification of network layer and application layer based on IEEE802.15.4 standard. IEEE802.15.4 specifies only physical and MAC layer for low-rate wireless personal area network (LR-WPAN). Zigbee provides two types of routing protocol i.e. cluster tree routing and ad-hoc on-demand distance vector routing (AODV).

2.1 Cluster tree routing

For cluster tree routing protocol, Zigbee establishes topology by assigning hierarchical distributed address to nodes in the network. Each node determines whether to forward message from the address of source contains in the message. The problem of this protocol is that the address can be exhausted, so some nodes probably cannot join network if network becomes larger. Moreover, Zigbee limits the number of hops only 10 hops for this protocol. That means cluster tree routing protocol has scalability issue.

2.2 AODV

AODV determines a route to destination only when node wants to send message to the destination. Routes are established through Route Request and Route Reply message and stored in the routing table of each node as long as they are needed by source. If the route between source and destination is not available, the Route Error message will be sent to source by intermediate node. Then, source need to find new route again. The scalability problem may occur with many-to-one communication which many nodes send message to a sink (data collector). Because all nodes have to store the routes from every source, the routing table of nodes located near sink may overflow due to memory limit. Furthermore, the links between nodes are likely lost due to signal attenuation in the building. Then, source need to find a new route. This causes network dynamic and overhead which increase congestion and rise probability of message collision respectively.

3. DTN

Delay/Disruption Tolerant Network (DTN) [3] describes the characteristics of the network which is high latency, low data rate, intermittent connectivity and high error rate. DTN has been researched for many applications namely outer-space communication, undersea communication, military, suburbs communication, wildlife tracking, mobile ad-hoc networks and vehicular ad-hoc networks. In such kind of network, DTN routing protocols use store-and-forward mechanism to promise high delivery rate. Source node floods messages to neighbor nodes. After receiving the message, neighbor nodes store the messages in their buffer and forward to the next available node. This mechanism occurs repeatedly until the messages reach the destination.

In the building, the signal can be attenuated by walls and WiFi interference. Hence, similarly to DTN, link can be lost and topology can change anytime. Due to high delivery rate feature, we would like to apply DTN routing protocol to use with WSN in BEMS in order to increase reliability. However, there are some considerations as follows.

- The existing DTN routing protocols use benefit of mobility to carry messages to the destination. On the contrary, all nodes in BEMS are statically deployed. Thus, the existing protocol cannot apply to this application.
- Most of DTN routing protocols rely on flooding which causes congestion in the large network. In the building that contains thousands of sensors, the delivery rate may decreases as a result.
- Since intermediate nodes have to store the messages in their buffers, nodes located near sink may face the memory overflow problem due to memory constraint.

4. EXPERIMENT

According to our idea proposed in last section, we set small experiment to study behavior of the network using DTN mechanism on IEEE802.15.4 standard. Network contains 5 nodes operating many-to-one communication (4 nodes send message to sink) with topology shown in figure 2 (Noted that topology may change during experiment). All nodes are developed on Arduino ATmega2560 and Xbee series 1. Buffer can store 32 messages. Nodes generate message every seconds and experiment time is 5 minutes.

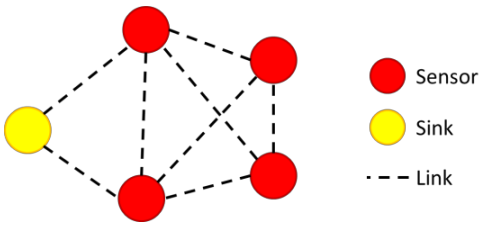

Figure 2. Topology used in this experiment.

Two protocols are developed in this experiment, flooding and gradient-based flooding [4]. For flooding, the node forwards message to all neighbor nodes. For gradient-based flooding, one of mechanism that can reduce congestion caused by flooding, nodes are assigned the gradient value. The higher gradient value, the farer nodes locate from the sink. The message is only forwarded to the lower gradient value node (toward sink). Both protocols use acknowledgement and node will retransmit message once if it does not receive acknowledge message.

In this experiment, we interest delivery rate and overhead ratio defined as follows.

$$\text{Delivery rate} = \frac{\#\text{ of unique delivered message at sink}}{\#\text{ of generated message}}$$

$$\text{Overhead} = \frac{\#\text{ of delivered message at sink}}{\#\text{ of generated message}}$$

According to the experiment's result in Table 1, gradient-based flooding gives higher delivery rate and lower overhead because of lower congestion in the network. Nevertheless, the overhead is still high whereas acknowledge message can be lost; therefore this cause nodes to send the replicated message. In addition, we notice that buffer of nodes located near sink are likely full, consequently, the efficient buffer management is required for the larger network.

Table 1. Experiment Results

Protocol	Delivery rate	Overhead
Flooding	91.33%	2.6093
Gradient-based flooding	92.10%	1.9814

5. CONCLUSION AND FUTURE WORKS

Scalable and reliable WSN in BEMS is essential for precise data analysis. Although Zigbee is mainly used in BEMS, Zigbee does not give satisfied QoS owing to its routing protocol issues. Applying DTN routing protocol to WSN in BEMS can increase reliability, however, the protocol needs to be adapted corresponding to BEMS condition.

For future works, we keep improving DTN routing protocol to increase delivery rate and reduce overhead as much as possible and also find appropriate buffer management for this application.

6. REFERENCES

[1] Farhangi, H., "The path of the smart grid," *Power and Energy Magazine, IEEE*, vol.8, no.1, pp.18,28, January-February 2010

[2] Prativa P.Saraswala, "A Survey on Routing Protocols in ZigBee Network", *International Journal of Engineering Science and Innovative Technology (IJESIT),* January 2013

[3] Voyiatzis, Artemios. "A Survey of Delay- and Disruption-Tolerant Networking Applications." *Journal of Internet Engineering 5*, no. 1, 2012.

[4] Khadar, Fadila, and Tahiry Razafindralambo. "Performance evaluation of gradient routing strategies for wireless sensor networks." In *NETWORKING 2009*, pp. 535-547. Springer Berlin Heidelberg, 2009.