EXPERIMENTS ON MOBILE SINK APPLICATION IN ZIGBEE NETWORKS

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ABSTRACT

Many sensor network applications have been developed for smart home, disaster management, and a wide range of other applications since the ZigBee standard was released. These applications, however, generally assume a static base station as well as static sensor nodes. For mobile sink applications, there are many challenges that need to be taken into consideration, such as the difficulty in detecting link failure, unstable network connectivity, and unreachable destinations, even though the new ZigBee standard (2007 version) supports device portability. In this paper, we analyze the problems of a mobile sink application, and propose a new application framework that supports seamless data communication when using a mobile sink in ZigBee networks. We evaluate the performance of the suggested application framework in terms of data reception rate and network connectivity of the mobile sink in experiments evaluating various rejoin conditions of the mobile sink.

Index Terms— ZigBee, Mobile Sink

1. INTRODUCTION

ZigBee is an emerging worldwide standard for wireless personal area network. Since ZigBee devices are designed for low cost and low data rates, it is used in many sensor network applications such as smart homes, building automation, and industrial automation. As well as these initial market application and products, ZigBee mobile phone systems are emerging as a new market since the new 2007 version of the ZigBee standard was released. ZigBee Alliance expects that ZigBee technology will produce many kinds of new services such as secure mobile payment, information delivery, and peer-to-peer data sharing by connecting telecom networks.

However, the ZigBee standard is not enough to support mobile sink application, even if the new standard defines the device portability function that supports the mobile node reestablishing network connectivity whenever it loses its link. In order to support a mobile sink application based on the ZigBee standard, many kinds of additional functions are required such as link failure detection, announcement of new network address of a mobile sink node, and data gathering algorithms. In this paper, we propose a mobile sink application framework to support seamless data communication and experiment the mobility effectiveness of a mobile sink node such as network connectivity and data reception rate.

This paper is organized as follows. Section 2 briefly introduces ZigBee routing algorithms and device portability function, and requirements of a mobile sink application will be discussed in Section 3. With the proposed application framework for the mobile sink node in Section 4, we then evaluate the performance of the proposed scheme through experimental results and conclude at Section 5 and 6, respectively.

2. ZIGBEE NETWORK SPECIFICATION

2.1. ZigBee Routing Algorithms

There are two kinds of routing algorithms in ZigBee networks. The first, ZigBee tree routing, uses network addresses that represent a tree hierarchy. While it can send data to the destination without a routing table and route discovery mechanism, it is inefficient because the packets follow the tree hierarchy even if the destination is located nearby. The second, table-driven routing, decides the routing path by using a route discovery procedure. It can calculate the optimal route to the destination, but, the route discovery operation is an additional overhead.

Both routing algorithms are not efficient to support a mobile sink node, because the routing cost of the tree routing is inefficient in order to transmit data to a mobile sink, which is an end device in a tree topology, and the route discovery of the table-driven routing is performed whenever the mobile sink rejoins the network. Therefore, we propose the sink-oriented routing to achieve both the optimal route path and no route discovery cost.

2.2. Device Portability Function

The ZDO (ZigBee Device Object) layer of the mobile device is notified of acknowledgement failures via the

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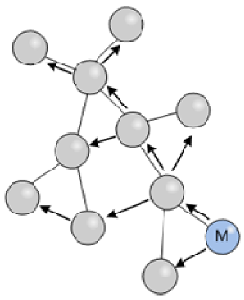


Fig.1. Announcement Period

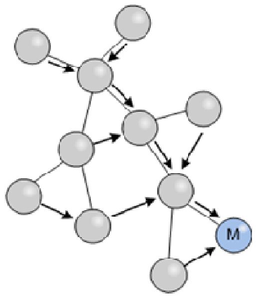


Fig.2. Data Gathering Period

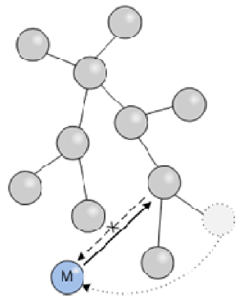


Fig.3. Link Check Period

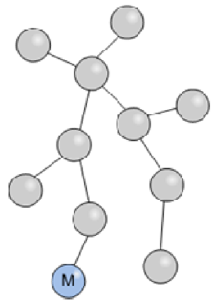


Fig.4. Rejoin Period

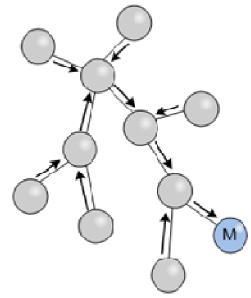


Fig.5. ZigBee Tree Routing

NLME-ROUTE-ERROR.indication primitive. Then, the network layer will rejoin the network through the MAC association procedure. Optionally, ZDO layer can notify its changed network address of the mobile device.

However, the NLME-ROUTE-ERROR primitive is invoked only when the device transmits data. If the mobile sink only receives data from other devices, it can't detect the link failure. Moreover, the link failure detection is handled in the ZDO layer, which is located in a higher layer than the network layer, so the response time for link failure detection and a network rejoin is higher than when they are handled by the MAC layer.

3. MOBILE SINK APPLICATION ANALAYSIS

The mobile sink application can be defined as a sensor network application with a mobile sink node. In other words, a mobile device, that is attached to a ZigBee communication module, such as a phone, PDA, or robot, collects data from other sensor nodes while moving around the sensor field, which can be a house, office, or other buildings. Due to the mobility of the sink node, the network rejoining procedure defined in the ZigBee specification is essential to maintain network connectivity. However, the mobile sink application still has some problems as follows.

•**Difficulty in detecting link failure**: The mobile sink node cannot detect unstable links or broken links if it only receives packets from other nodes in the current ZigBee stack. This may cause the mobile node to miss the period to rejoin the network and lose network connectivity permanently.

•**Unstable network connectivity**: When the mobile sink has a broken link or unstable link, before recovering through the rejoining procedure, it loses network connectivity. Therefore, packets sent to the mobile sink node before the rejoin may be lost.

•**Unreachable destination**: When the mobile sink rejoins the network, it may obtain a new network address. The other nodes in the network do not know it, and packets sent to the old network address of the mobile sink will not be delivered.

4. PROPOSED SINK APPLICATION FRAMEWORK

We propose the mobile sink application framework after considering the problems analyzed in the previous section. In our application framework, the mobile sink is charged with detecting link failure, rejoining a network, announcing a newly assigned network address, and accepting sensing data from sensor nodes. The Fig. 1-4 shows the proposed application framework, which is composed of four periods.

During the announcement period in Fig. 1, the mobile sink broadcasts its network address to sensor nodes to notify of its new network address. On receiving the broadcast packet, sensor nodes store the network address of the mobile sink (*DstAddr*) and source address of the broadcast packet (*AddrToForward*), and rebroadcast the packet to propagate it to the whole network.

Then, sensor nodes transmit its sensing data to the mobile sink node through *AddrToForward* node during the data gathering period as shown in Fig. 2. The proposed routing algorithm called sink-oriented routing uses the reverse path of the broadcast path during the announcement period, in order to avoid the 'unstable network connectivity' problem by optimizing the transmission delay, while not causing the overhead for route discovery. As we discussed in section 2, inefficient route path and route discovery cost are the critical problems when we apply ZigBee routing algorithms to the mobile sink applications. Our sink-oriented routing algorithms can achieve both optimal route path and no route discovery cost by employing the broadcast path during the announcement phase as shown in Fig. 1. The above Fig. 2 and Fig. 5 show our proposed sink-oriented routing and ZigBee tree routing. Whereas ZigBee tree routing needs a total of 33 hops from all sensor nodes to the mobile sink in Fig. 5, the proposed sink-oriented routing only needs a total of 25 hops in Fig. 2. The saved hops can reduce the transmission delay so as to reduce the probability of the 'unstable network connectivity' problem occurring.

The mobile node periodically checks its link with its parent node through the 'hello' message at the MAC layer as in Fig. 3. The interval of the link failure check is smaller than that of the data gathering interval in order to prevent missed packets from the ‘unstable network connectivity’ and ‘unreachable destination’ problems during the data gathering period. The unstable link or broken link can be detected through several missed acknowledgements for the ‘hello’ message in a certain interval or through the link quality indication. The network performance such as network connectivity and data reception rates can differ according to the link failure detection method used, and it will be discussed at the next section. If the mobile sink detects link failure, it joins a network through a new parent node which provides higher link quality as shown in Fig. 4.

In our proposed mobile sink application framework, the rejoin period and announcement period is performed only when it is necessary due to the link failure detection and the network address change of the mobile sink to simplify and optimize the performance of the application framework.

5. EXPERIMENTAL RESULT

Our ZigBee mobile sink application is developed on a 2.4 GHz IEEE 802.15.4 transceiver based hardware platform. It is small in size (3.5cm x 5.5) and equipped with various sensors such as temperature, humidity, light, CO, infrared, magnetic, and flame. The ZigBee stack, which we employ in our experiment, is the TI Z-Stack that is fully compatible with ZigBee Spec version 1.0.

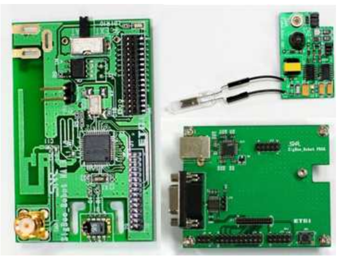
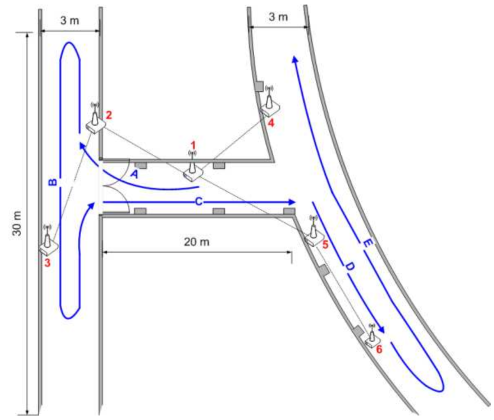


Fig. 6 Hardware Platform

In our experiments, six sensor nodes are deployed in the building like Fig. 7, and the average distance between sensor nodes is fifteen meters to provide reliable links between sensor nodes. The mobile sink is designed to collect periodical sensing data from other sensor nodes while moving around at about 2m/s velocity. Every cycle is ten seconds, and sensor nodes report indoor environmental condition as well as network address and application ID. The mobile sink moves from the path A to path E and every path has its own environment characteristics.

We tested the mobility effectiveness, such as network connectivity and data reception rate, with varying conditions for rejoining of the mobile sink. The rejoin conditions used in this experiments are NoAck1 (1 missed acknowledgement), NoAck2, NoAck3, and LQI<20 (LQI threshold less than 20 of the link with the parent node). For example, NoAck1 indicates that the mobile sink misses the acknowledgement packet for its ‘hello’ message at the link detection phase. The LQI threshold for potential parent node is set at 120 for reliable communications.



Route	Description
Path A	The mobile sink passes the iron doors and turns right along the wall. The parent candidates of the mobile sink is #1 and #2.
Path B	The mobile sink goes through without any obstacles. The parent candidates of the mobile sink is #2 and #3.
Path C	The mobile sink turns right and passes the iron door again. There are small numbers of sensor nodes and the parent candidates of the mobile sink is #3 and #1.
Path D	The mobile sink turns right along the wall. The shape of path is curve. The parent candidates of the mobile sink is #1, #5, and #6.
Path E	The mobile sink goes through and the shape of path is curve. The parent candidates of the mobile sink is #6, #5, and #4.

Fig. 7. Experimental Environment

The network connectivity in Fig. 8 is measured as the time that the mobile sink maintains the network link with its parent node. It is calculated by subtracting the rejoin duration from the total amount of time at each path. Since the larger no acknowledgement conditions tend to assume the link is stable, the rejoin conditions such as 1 missed acknowledgement (NoAck1) and LQI less than 20 show low network connectivity in almost all paths as shown in Fig. 8. However, it doesn’t mean that higher network connectivity guarantees higher data reception rate. The data reception rate of the mobile sink in Fig. 9 is highly related with the ‘unstable network connectivity’ and ‘unreachable destination’ problems.

In path A, the data reception rate for NoAck1 and LQI<20 is much lower than that of NoAck2 and NoAck3. This is because of the ‘unreachable destination’ problem. After detecting link failure, the mobile sink tries to find a new parent node; but, there are no parent candidates satisfying condition for potential parent node, that is, the LQI threshold higher than 120. According to Fig. 7, node #2 seems to be the parent node, but the link quality with the mobile sink node is not good enough to be a parent node due to the interference from the iron door. Therefore, the mobile sink cannot receive any data from the sensor nodes until it rejoins the network after moving away from the iron door's interference, while it maintains lower network connectivity as shown in Fig. 8.

The 'unstable network connectivity' effect can be found at NoAck3 conditions in the path B. Whereas the mobile sink using other conditions changes the parent node from node #2 to node #3 at the beginning of path B, the mobile sink using NoAck3 condition maintains the link with parent node #2 until it moves out of the transmission range of node #2. Because the mobile sink node keeps the unstable parent link although there are better links around, the data reception rate from NoAck3 in path B is smaller than other cases. This is the same reason that the network connectivity for NoAck3 condition is high, while that of NoAck1 and LQI<20 conditions is relatively small.

In path C, the 'unstable network connectivity' effect is detected for NoAck1, NoAck2 and NoAck3 conditions. In this experiment, the mobile sink at NoAck1, NoAck2, and NoAck3 conditions maintains the parent node #3 until the end of path C, whereas the mobile sink using LQI<20 changes the parent node from node #3 to node #1 at the begging of path C. Therefore, the data reception rate for these three conditions shows smaller value.

In paths D and E, the 'unreachable destination' problem affects the data reception rates in all cases. Even if there is no obstacle to interfere with the communications, the paths D and E are relatively longer than other paths, and only small numbers of sensor nodes are deployed in the paths. Therefore, the frequent network rejoins from the mobile sink is natural and it causes lower data reception rates. The reason why the data reception rate for NoAck2 and NoAck3 conditions in path E is higher than other conditions is because the mobile sink node keeps the parent node #6 and continues receiving data when it goes back, whereas it tries to find other parent nodes and misses receiving data in the NoAck1 and LQI<20 conditions.

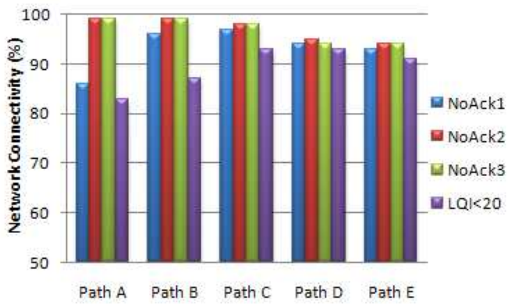


Fig. 8 Network Connectivity of Mobile Sink

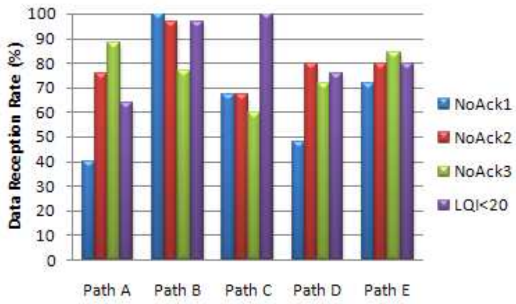


Fig. 9 Data Reception Rate of Mobile Sink

From the experimental result, the various rejoin conditions affect when the mobile sink rejoins the network and it can cause the 'unreachable destination' and 'unstable network connectivity' problems; however, it cannot estimate the best time to obtain high network performance.

6. CONCLUSION

We propose a mobile sink application framework for seamless data communication of the mobile sink by analyzing the problems and requirements in the deployment of a mobile sink. Experimental results show that the proposed application framework maintains relatively high data reception rate in spite of a number of network rejoins. In addition, they also show the mobility effectiveness depends on external environments such as physical environments, node deployment, and movement of the mobile sink as well as the rejoin conditions of the mobile sink. Therefore, the network performance in the mobile sink application can be enhanced through integration with environmental information and the movement schedule of the mobile sink node.

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