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Asset Localization in Wireless Sensor Networks*

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Abstract : Many hospitals have been considering new technology such as wireless sensor network (WSN). The technology can be used to track the location of medical devices needed for inspections or repairs, and it can also be used to detect of a theft of an asset. In an asset-tracking system using WSN, acquiring the location of moving sensor nodes inherently introduces uncertainty in location determination. In fact, the sensor nodes attached to an asset are prone to failure from lack of energy or from physical destruction. Therefore, even if the asset is located within the predetermined area, the asset-tracking application could "misunderstand" that an asset has escaped from the area. This paper classifies the causes of such unexpected situations into the following five cases: 1) an asset has actually escaped from a predetermined area; 2) a sensor node was broken; 3) the battery for the sensor node was totally discharged; 4) an asset went into a shadow area; 5) a sensor node was stolen. We implemented and installed our asset-tracking system in a hospital and continuously monitored the status of assets such as ventilators, syringe pumps, wheel chairs and IV poles. Based on this real experience, we suggest how to differentiate each case of location uncertainty and propose possible solutions to prevent them.

Key Words : Sensor Network, Location Uncertainty, Middleware, Asset Tracking.

1. Introduction

In many situations, finding an asset within a facility can be a cumbersome and time-consuming exercise. In order to overcome such inefficiencies, facilities have installed asset-tracking system. An asset tracking using WSN is concerned with geographical locations of sensor nodes. There are two kinds of sensor nodes to be used in tracking the asset. One is fixed node and the other is moving node. In case of fixed node, it can be supplied constant power by connecting wired line. However, moving node is typically battery-driven. The limited size of moving node makes them attractable for tracking service, at the same time their size causes power restrictions, limited computation capability, and storage restrictions. Currently, many researches were conducted to minimize the battery consumption of a sensor node because it is related with the life span of the sensor network.

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Because of its constrained capabilities, the WSN basically assumes the failure of sensor nodes. This causes a set of concerns in designing asset-tracking system based on WSN when the asset is removed along with the sensor node or the asset is taken away undetected by removing the sensor node and leaving it behind. Among such considerations, one of the most critical issues in asset tracking is location uncertainty regarding the sensor nodes because WSN basically assumes their failure.

In this paper, we classify the location uncertainty problem in asset tracking into the following cases. First, the sensor node isn't read at all because of sensor node failure, leading to misunderstanding that the asset is not present. Second, an incorrect location is read as a result of interference of RSSI, which provides an unreliable location of the asset.

This paper presents the overall architecture of our asset-tracking system using WSN and classifies the location uncertainty problems and solutions to prevent them. The paper proceeds as follows: Section 2 explains the architecture of our asset-tracking system and Section 3 describes our asset localization. Section 4 classifies the location uncertainty problem and the final section provides concluding remarks and offers suggestions for future research.

2. System Architecture

Our asset-tracking system manages the collection and processing of location data as well as the centralized management and configuration of the sensor network. The system was installed in the emergency room of a hospital to keep track of hospital assets such as ventilators, syringe pumps, wheel chairs, and IV poles.

The objective of the asset-tracking system is to allow personnel to spend less time looking for misplaced hospital equipments by helping the staff quickly locate the medical equipment so they can maintain, repair or replace it on schedule. The specific objectives of our asset-tracking system are as follows: 1) The system should report the real-time location of assets; 2) The system should monitor the status of assets such as the number of assets removed from the emergency room; 3) The system should report the exact time the asset was removed from the emergency room 4) The system should report the route of the asset in order to identify the place where the asset is most frequently used.

Our asset-tracking system is divided into following technologies: wireless sensor network, middleware, and application as shown in Fig. 1. The bottom layer of the system consists of the gateway and sensor network. The middle layer is a WSN middleware which provides an abstraction of heterogeneous

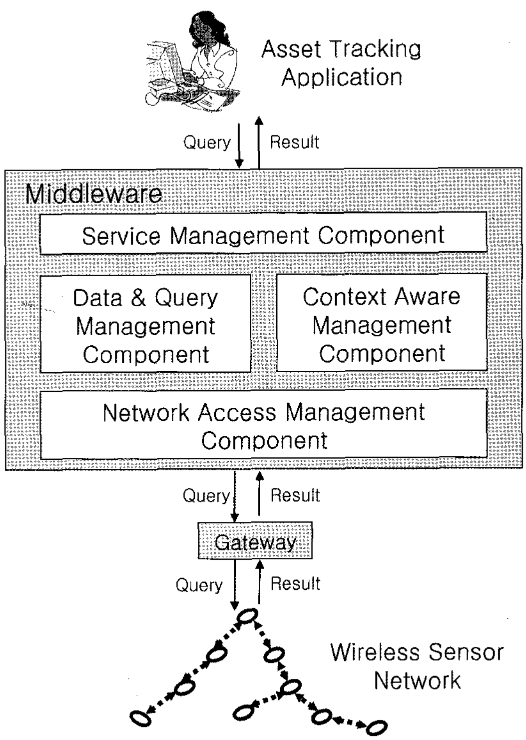

Fig. 1. Overall Architecture of an Asset-tracking System based on WSN.

sensor network. The top layer is the asset-tracking application used to control and monitor an asset. These technologies are closely linked for the functionality of the asset-tracking system.

The WSN is composed of two kinds of sensor nodes. One is fixed node and the other is moving node. A fixed node does not move and it is powered by electric wire. The node is configured with known locations and it provides anchor points for the system to determine the locations of the moving node. On the other hand, a moving node is powered by batteries and dispersed over an operational area. The location of moving node is calculated at the gateway. If the gateway receives RSSI data from one or more fixed nodes in the network, it estimates the moving node's location. Determining the location of moving node requires at least three fixed nodes' RSSI data.

The gateway serves a link between a sensor network and a middleware. It works as an interface to the sensor network and controls the sensor nodes attached to the assets. As the sensor network is formed, the PAN Coordinator informs the gateway of the sensor network's status. Then the gateway collects and maintains this information in its database. If a middleware sends a query to obtain current sensor network information, the gateway will provide it by dumping the contents of database. The database contains the following information: the number of current nodes in sensor network, the physical and logical address of each node, the capability of each node, current status of each node, the most recent sensing value of each node, the most recent location coordinates of each node.

The WSN middleware can be divided into several components, each of which has its own functionality. First, it can provide an abstraction for specifications and functions of sensor networks. An application may need to gather different types of data from several heterogeneous sensor networks. If it connects directly to every sensor network, it will need several accessing and gathering interfaces to achieve the same function according to the connection method of each sensor network. The middleware provides an abstraction function to the applications so that each application can connect to heterogeneous sensor networks without understanding their physical characteristics. In Fig. 1, the Network Access Management Component of a middleware is responsible for the task. In addition, the middleware provides filtering, storing, and managing data obtained from the sensor network and transmits sensing data acquired from the sensor network to the application. To fulfill this role, the middleware must support a seamless connection between the sensor network and the application by providing openness and interoperability in order to integrate and manage various services.

In our middleware, the interface between the gateway and middleware utilize XML over HTTP. The interface is exposed through an XML schema. Therefore, if an asset-tracking application sends a query through a middleware to obtain the location of sensor nodes, the location information is sent to the middleware in the form of XML by a gateway. The middleware in our system is responsible for the following tasks: manage connection to sensor network, configure the sensor network, maintain information about gateway and sensor nodes in the network, manage query to sensor network, monitor the sensor network, and provide interface for asset-tracking application.

3. Location Determination of Assets

Our asset-tracking system based on WSN is installed at hospital to track the location of hospital asset within emergency room. The fixed sensor nodes are installed on the wall of the emergency room and the moving sensor nodes are attached to the hospital assets.

If an asset-tracking application requests the location of assets by sending location query to middleware, the middleware transfers it to a gateway. Then, the gateway provides the coordinates after calculating it based on received signal strength indication (RSSI) of moving sensor nodes attached to assets. The RSSI readings are continuously collected by moving sensor nodes and they are sent to the gateway automatically.

Our asset-tracking system has the option to choose more desirable location algorithm between internal and external location algorithm. In case of internal location algorithm, it is equipped within gateway. Therefore, the gateway has the capability to calculate the location of moving sensor node with cumulated RSSI. On the other hand, external location algorithm can be equipped on middleware or application. In that case, a middleware or an application calculates the location information of moving sensor node by directly receiving RSSI readings from the gateway.

For this functionality, the gateway provides two kinds of interfaces. One interface is used to request current RSSI readings from all the nodes in a current sensor network, and the gateway collects the RSSI information from all nodes. The other interface is used to request the current RSSI readings from a single node in a current sensor network. Using these interfaces, middleware can choose whether to receive all nodes' RSSI readings or one specific node's RSSI reading.

Whenever an asset-tracking application requests the location of hospital assets, the middleware provides it to the application and stores it within the internal database. The cumulated location information can be used for various location services, such as tracking the specific asset or identifying the place where the asset is most frequently used.

4. Classification of Location Uncertainty in Asset Tracking

In an asset-tracking system using WSN, acquiring the location of moving sensor nodes inherently introduces uncertainty in location determination. Based on our real experience in a hospital, this paper classifies the location uncertainty problem in an asset-tracking system, as shown in Fig. 2.

One case of the location uncertainty is that sensor node isn't read at all, leading to misunderstanding that an asset is not present. In fact, the sensor nodes are prone to failure from lack of energy or from physical destruction. Therefore, even if the asset is existed within the predefined area, the asset-tracking application can "misunderstand" that an asset has removed from the predetermined area. The causes of such situations are classified into the following five cases: 1) an asset has actually escaped from a predetermined area; 2) a sensor node was broken; 3) the battery for the sensor node was totally discharged; 4) an asset went into a shadow area; 5) a sensor node was stolen.

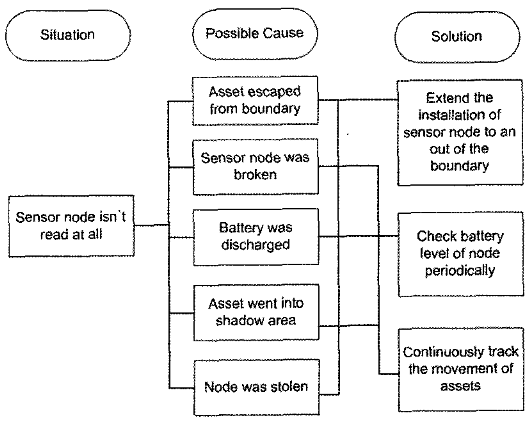

Fig. 2. Classification of the Causes of Location Uncertainty in Asset Tracking using WSN.

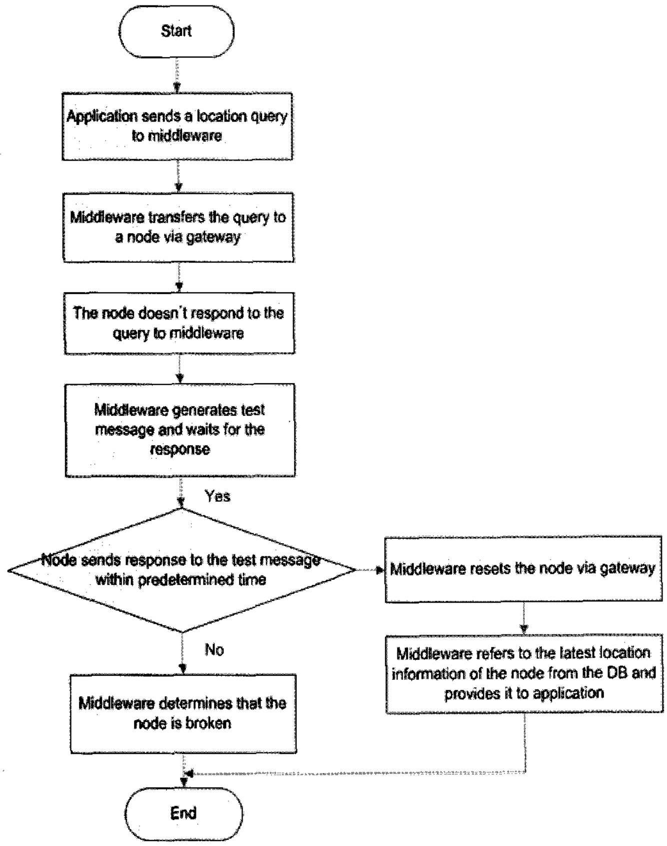

Fig. 3. Reducing the Location Uncertainty if the Location data is not received from the Node.

One of the methods by which to reduce the location uncertainty is shown in Fig. 3. If the location data is not received from the node, the middleware can use a test message to check whether the node is still "alive" or not. If the node sends a response to the message, the middleware can assume that the node is still alive and can be set back to the normal state by remote reset. On the other hand, if the node does not send any response to the message, the middleware can assume that the node is out of order or the battery is totally discharged and the problem can be managed manually.

In addition, the battery status of sensor nodes can also be valuable information to determine the exact cause of the location uncertainty. For example, the middleware could check the battery status of a sensor node periodically to determine its condition. Based on this knowledge, if the sensor node isn't read at all, the middleware predict the exact cause of the location uncertainty. For example, if the previous battery status was good, the node might have broken, so it would need manual repair. On the other hand, if the previous battery status was bad, the application can make a decision that the battery is totally discharged so the node can't operate any more. In any case, if the sensor node isn't read, even if the asset is located inside the predefined area, the application could not identify its location.

The other case of location uncertainty is that incorrect location is read due to interference of RSSI, providing unreliable asset location. Basically, all nodes in a sensor network are going to send signal to the gateway where they will be computed to obtain a meaningful location of sensor nodes. Such received signal strength indication itself is accurate. However, obstacles such as human body in the path, presence of walls, metal objects can all have a large effect on the path loss. This translates into uncertainty about the exact location of moving sensor nodes.

One of the methods to reduce the location uncertainty is to utilize latest location information which is collected from moving sensor nodes. In our system, the middleware keeps the location information database of all sensor nodes in current sensor network. Therefore, if a new location data of sensor node is received from the gateway, the middleware can determine whether the data is abnormal by comparing it with neighbour node's location. If the error exceeds a certain value, the middleware could determine that the received location information isn't reliable. In that case, instead of providing the received unreliable location data to the asset-tracking application, the middleware could provide more reliable location data utilizing neighbour node's location data.

5. Conclusions

The paper has presented the overall architecture of our asset-tracking system based on WSN. The system is designed using a layered architecture that includes WSN, gateway, middleware, and application. We implemented and installed our asset-tracking system in a hospital and continuously monitored the status of an asset. Based on the experience, we classify the location uncertainty problem and its cause, solution to prevent it and the method to reduce it.

Future work is expected to evaluate how to reduce location uncertainty in an asset-tracking system based on WSN and more concretely verify the cause of and how to prevent the problem.

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