LOCATION UNCERTAINTY IN ASSET TRACKING USING WIRELESS SENSOR NETWORKS

JungHee Jo, KwangSoo Kim, KiSung Lee, SunJoong Kim

Telematics-USN Research Division
Electronics and Telecommunications Research Institute
161, Gajeong-Dong, Yuseong-Gu, Daejeon 305-806, Korea
{dreamer, enoch, kslee, kimsj}@etri.re.kr

ABSTRACT. An asset tracking using wireless sensor network is concerned with geographical locations of sensor nodes. The limited size of sensor nodes makes them attractable for tracking service, at the same time their size causes power restrictions, limited computation power, and storage restrictions. Due to such constrained capabilities, the wireless sensor network basically assumes the failure of sensor nodes. This causes a set of concerns in designing asset tracking system on wireless sensor network and one of the most critical factors is location uncertainty of sensor nodes. In this paper, we classify the location uncertainty problem in asset tracking system into following cases. First, sensor node isn't read at all because of sensor node failure, leading to misunderstanding that asset is not present. Second, incorrect location is read due to interference of RSSI, providing unreliable location of asset. We implemented and installed our asset tracking system in a real environment and continuously monitored the status of asset and measured error rate of location of sensor nodes. We present experimental results that demonstrate the location uncertainty problem in asset tracking system using wireless sensor network.

KEY WORDS: Asset Tracking, Wireless Sensor Network, Location Uncertainty, WSN Middleware

1. INTRODUCTION

Wireless Sensor Network (WSN) is composed of several types of sensor nodes. Considering many possible applications for WSN, the size of wireless sensor nodes is one of the significant limitations. In order to unobtrusively deployed, the node should be as small as possible. Although their limited size makes them attractable for use in a number of services, at the same time their size affects resources such as the energy, computational power, and storage available.

First, the power restrictions of sensor nodes are occurred due to their small size and lack of wires. Since the absence of wires results in lack of a constant power supply, not many power options exist. Therefore, sensor nodes are typically battery-driven. Second, since there is a limited amount of power, computation is also constrained because it is strongly linked with the available amount of power. Third, the limited capacity for storage affects the space for the data of sensor nodes as well. Each sensor nodes may collect the Received Signal Strength Indication (RSSI) from neighbour nodes to estimate its location from another sensor node and store the calculated result in the nodes' storage space. However, the large number of sensor nodes requires a lot of memory, which may not be provided.

Due to such constrained capabilities, a set of concerns in designing asset tracking system using WSN arose such that "asset is removed along with the sensor", "asset maybe taken away by removing sensor node and leaving it behind", "base station maybe disconnected from the power source or the link between gateway and base station can be broken", "gateway can be disconnected". Among such considerations, one of the most critical issues in asset tracking is location uncertainty of sensor nodes because WSN basically assumes its failure. In this paper, we classify the location uncertainty problem in asset tracking into following cases. First, sensor node isn't read at all because of sensor node failure, leading to misunderstanding that asset is not present. Second, incorrect location is read due to interference of RSSI, providing unreliable location of asset.

The contributions of this paper are as follows: (1) we present the overall architecture of our asset tracking system using WSN (2) we show and analyze the experiment results which demonstrate the location uncertainty problem in asset tracking (3) we suggest the method to reduce the location uncertainty problem. The paper proceeds as follows: Section 2 explains the architecture of an asset tracking system using WSN and Section 3 describes the asset localization using our system based on WSN. Section 4 demonstrates the location uncertainty in asset tracking. The final section provides concluding remarks and offers suggestions for future research.

2. SYSTEM SPECIFICATION

2.1 System Objective

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. 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 hospital so it keeps track of the hospital asset such as ventilator, syringe pump, wheel chair, and IV pole.

The basic objective of an asset tracking system is not to spend much time looking for misplaced hospital equipments. It helps that the staffs of hospital can quickly locate the medical equipment so they can maintain, repair or replace them on schedule.

The following is the specific objective of our asset tracking system.

- The system should report the real time location of assets
- The system should monitor the status of asset such as the number of assets which removed from the emergency room
- The system should report the asset's exact removing time from the emergency room
- The system should report the route of asset to identify the place where the asset most frequently used

2.2 System Architecture

Our asset tracking system can be divided into following technologies: wireless sensor network, middleware, and application as shown in Figure 1. The bottom layer consists of the gateway and sensor network and middle layer is a middleware which provides an abstraction of heterogeneous sensor network. The top layer is the asset tracking application used to control and monitor an asset. These technologies are closely linked for the tracking of an asset.

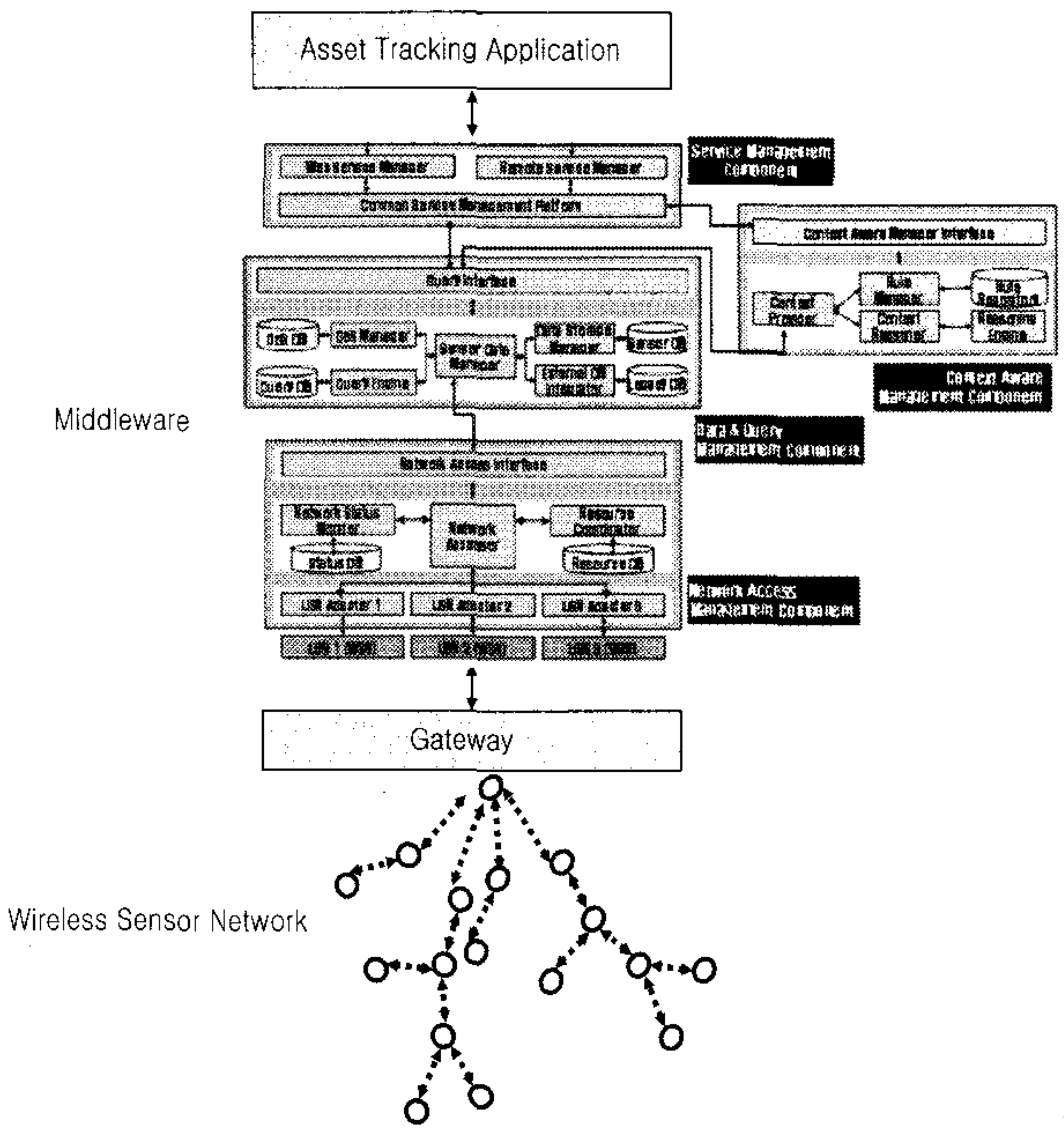

Figure 1. Overall Architecture of an Asset Tracking System based on WSN

The wireless sensor network 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 middleware provides filtering, storing, and managing data obtained from sensor network. 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 a 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 each gateway and sensor nodes in the network, manage query to sensor network, monitor the sensor network, and provide interface for asset tracking application.

3. ASSET LOCALIZATION THROUGH WSN

Many hospitals have been considering a new technology such as sensor network. 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.

Our asset tracking system which is 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 such as ventilator, syringe pump, wheel chair, and IV pole.

If an asset tracking application request the location of assets by sending location query to middleware, the middleware transfer 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 it is 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. In that case, the gateway collects the RSSI information from all nodes. The other interface is used to request current RSSI readings from a single node in a current sensor network. Therefore, using these interfaces, middleware can choose whether receiving all nodes' RSSI readings or one specific node's RSSI reading.

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

4. 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 and prediction. In this paper, we classify the location uncertainty problem in an asset tracking system into following cases.

First, sensor node isn't read at all because of sensor node failure, 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. In this case, even if the asset is existed within predefined space, the asset tracking application can assume that an asset is removed from the limited area.

Second, incorrect location is read due to interference of RSSI, providing unreliable location of asset. 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.

In our testbed environments, the emergency room of the hospital, there are 10 IV poles, 4 ventilators, 5 syringe pump, and 2 wheelchairs which equipped with moving sensor nodes.

Time	Asset Name	real x	real y	virtual x	virtual y
	IV Pole 1	139,5	105,6	138,0	102,0
11:20	IV Pole 2	125,8	100,9	126,7	101,6
	IV Pole 3	117,6	118,5	121,7	113,6
	IV Pole 4	122,2	112,3	118,6	109,9
11:00	IV Pole 5	131,7	109,5	135,8	107,8
11:05	IV Pole 6	109,4	100,6	104,7	104,9
	IV Pole 7	113,6	120,1	113,7	114,2
	IV Pole 8	101,8	100,4	103,7	104,9
	IV Pole 9	113,3	100,9	111,3	102,8
	IV Pole 10	101,8	100,4	106,8	105,4
	Ventilator 1	112,0	101,2	111,6	104,0
	Ventilator 2	101,8	100,6	103,6	105,6
11:15	Ventilator 3	at the ICU		108,9	103,9
	Ventilator 4	100,4	100,4	103,9	104,2
	Syringe Pump 1	100,2	113,4	104,7	107,6
	Syringe Pump 2	100,2	113,4	107,6	108,8
	Syringe Pump 3	100,2	113,4	105,5	108,7
	Syringe Pump 4	100,2	113,4	106,6	107,8
	Syringe Pump 5	100,2	113,4	105,6	106,0
	Wheelchair 1	124,8	103,7	122,4	106,8
	Wheelchair 2	on some other floor		107,4	107,2

Figure 2. Inspection of Location Information of Assets

Figure 2 shows the inspection results of the location information of assets. The virtual x and y means the coordinates which is received from the gateway calculated using internal location algorithm. On the other hand, real x and y means the coordinate which is manually measured coordinates in the emergency room. As shown in Figure 2, there is an error between real and virtual coordinates. Figure 3 shows the average error of assets and Figure 4 shows the average error by asset type. According to these experiment results, the average error of the location of asset in our system is 5.114m.

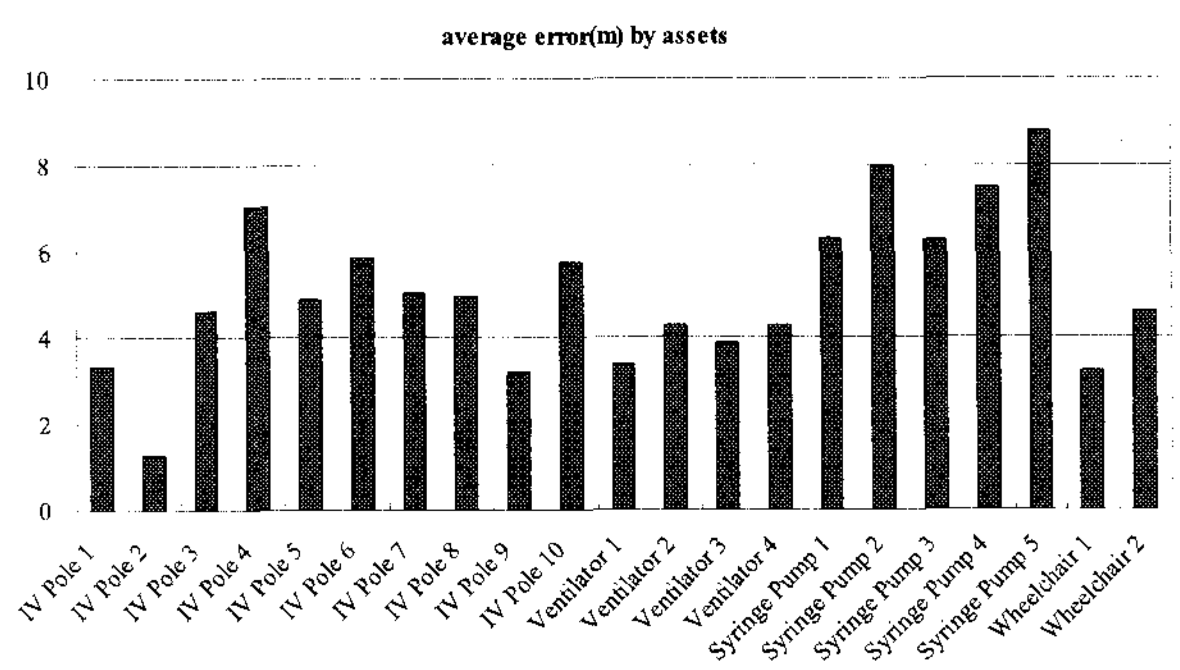

Figure 3. Average Error by Assets

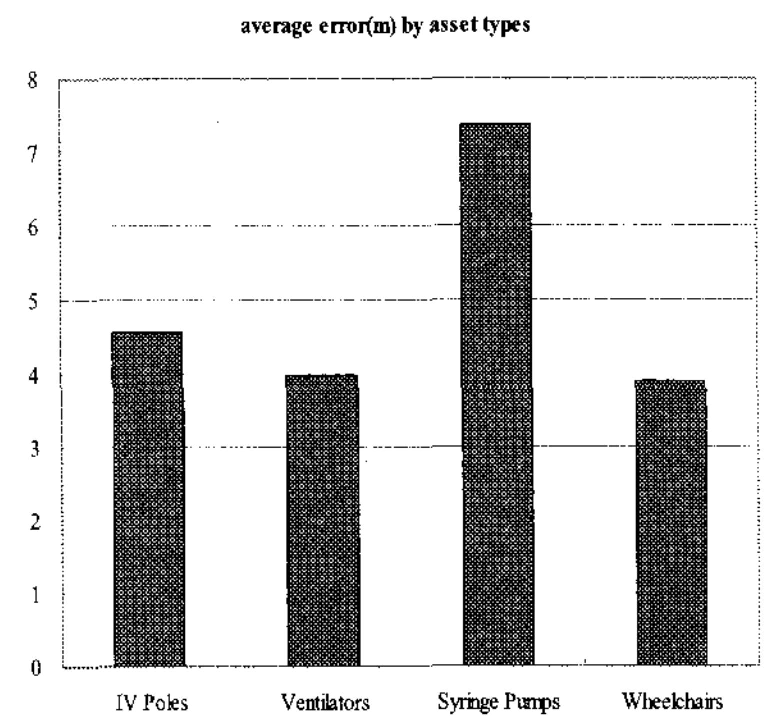

Figure 4. Average Error by Asset Types

One of the methods to reduce the location uncertainty in asset tracking using WSN 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 is over 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 based on neighbour node's location data such as the average location data of neighbour nodes.

In the same way, if the location data is not received from the node, middleware could predict the reason whether the battery is discharged or asset is removed from the emergency room. In this case, the middleware can check whether the node is still alive by sending test message. If the node sends response on the message, the middleware can assume that the node is still alive but the functionality of location acquisition is failed. In that case, the node can return to normal state by remote reset. On the other hand, if the node could not send any response to the test message, the middleware could assume that the node is out of order or battery is totally discharged. In that case, the problem could be managed manually.

5. CONCLUSIONS

In this paper, we implemented and installed our asset tracking system in a real environment and continuously monitored the status of asset and measured error rate of location of sensor nodes.

Sensor networks have emerged as an innovative tool for monitoring assets. They are distinguished from traditional sensors by strict limitations on system bandwidth and sensor energy resources. Due to such constraint, the location uncertainty problem is occurred in asset tracking system. We presented experimental results that demonstrated the location uncertainty problem in asset tracking system using WSN.

In the future, we plan to evaluate our method to reduce the location uncertainty problem concretely to provide more reliable location data of an asset by predicting the cause of location uncertainty.

Acknowledgements

This study was one of the results that the ETRI-Motorola cooperation project produced. The authors would like to thank Matt Perkins, Loren J. Little, Byung Y. Sung, and other Motorola members for their valuable reviews and comments.

REFERENCES

Rajendran N., Kamal P., Nayak D., Rabara S.A., WATS-SN: a wireless asset tracking system using sensor networks, ICPWC 2005, pp.237-243, 2005.

Parker T., Langendoen K., Refined statistic-based localisation for ad-hoc sensor networks, GlobeCom Workshops 2004, IEEE, pp.90-95, 2004.

Yang Yu, Bhaskar Krishnamachari, Prasanna, V.K., Issues in designing middleware for wireless sensor networks, Network, IEEE, Volume 18, Issue 1, Jan-Feb 2004 Page:15 - 21

Pavani, T., Costa, G., Mazzotti, M., Conti, A., Dardari, D., Experimental Results on Indoor Localization Techniques through Wireless Sensors Network, Vehicular Technology Conference, 2006, VTC 2006-Spring. IEEE 63rd, Volume 2, 2006 Page: 663 - 667

Bahl, P., Padmanabhan, V.N., RADAR: an in-building RF-based user location and tracking system, INFOCOM 2000, Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies, Proceedings. IEEE, Volume 2, 26-30 March 2000 Page: 775 - 784 vol.2

Chaczko Zenon, Klempous Ryszard, Nikodem Jan, Nikodem Michal, Methods of Sensors Localization in Wireless Sensor Networks, Engineering of Computer-Based Systems, 2007, ECBS '07. 14th Annual IEEE International Conference and Workshops on the 26-29 March 2007 Page(s):145 - 152

Tubaishat, M., Madria, S., Sensor networks: an overview, Potentials, IEEE, Volume 22, Issue 2, pp. 20 – 23, Apr-May 2003.

Eliana Stavrou, Wireless Sensor Networks, part 2: Limitations, http://webhosting.devshed.com/c/a/Web-Hosting-Articles/Wireless-Sensor-Networks-part-2-Limitations/1/

ARUBA, White Paper, Location & Tracking on the Mobile Edge

Hariharan Gowrisankar and Silvia Nittel, Reducing Uncertainty In Location Prediction Of Moving Objects In Road Networks, http://www.spatial.maine.edu/~nittel/publications/giscience02_hari.pdf