IEEE 802.15.4 MAC-based Location-ID Exchange Protocol for Realizing Micro-Cell Connectionless Location-Awareness Services

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We propose ID-exchange protocol for Connectionless Location-Awareness Service (CLAS) to locate mobile nodes in indoor sensor network. When adapting location-awareness service to sensor network, the target system must be designed in accordance with various metrics which reflect the system requirement. We especially consider sustainability of the existing service which has been provided for its original purpose, such as environmental monitoring. The detailed meaning of sustainability here is that, even if location-awareness service is newly added to the existing service, the system must be assured to retain a stable network condition, and to deal with newly caused traffic properly. The CLAS ID-exchange protocol is especially designed for fixture and mobile nodes communication to achieve these properties. The protocol operates on 802.15.4 MAC layer to make mobile node work independently of the procedure to build routing table of fixture node, so a stable routing condition can be achieved even if there are many mobile nodes. Moreover, the dedicated frequency channel is assigned only for this protocol, so that traffic caused by location-awareness service can be distributed to another channel. A real system adapting the protocol was implemented to monitor fire and authorities' positions. We verified the overhead and elapsed time for location-awareness. The result shows the proposed protocol has a high performance in detecting speed, traffic distribution, and stability of overall network.

Categories and Subject Description: Systems & Architecture [**Ubiquitous Computing**]

General Terms: Sensor Network, IEEE 802.15.4 MAC, ID-Exchange Protocol, Mobile and Fixture Node

Additiona Key words: Connectionless Location-Awareness Services, Dedicated Location-Awareness Service Channel, N-to-1 Acknowledgement Mechanism.

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1. INTRODUCTION

Location-awareness services provide people with specialized functions according to their physical positions. Basically, the service-user using mobile devices, like PDAs and cell-phones, communicates with a variety of positioning systems to locate their whereabouts. Advanced services, such as location tracking service, can be provided by exchanging data with the server bidirectionally. Especially, sensor network, which monitors environmental conditions in widely spread areas, is an emerging technology for location-awareness services. Each sensor node, called a fixture node, is installed at known position, and is connected to adjacent nodes to reach the remote server. This makes sensor network play an adequate role as an infrastructure to provide advanced location specific information as well as environmental data.

Generic communication stack for sensor network involves two core layers; Network-layer and MAC-layer. ZigBee, 6LoWPAN are widely used network-layer standards supporting mesh-network topology and multi-hop routing. These are the expansion of IEEE 802.15.4 MAC standards which defines single-hop wireless communication with low-power consumption. The simplest approach to adapt location-awareness service is to make mobile-fixture node communication use the same scheme with fixture-fixture node's one. Considering this scheme is defined in network-layer, routing path to the mobile node can be naturally achieved according to the routing procedure. This facilitates to deliver data to the remote server for bidirectional location-awareness service. In spite of assistances of the network-layer, the method has two drawbacks when it is adapted to location-awareness service. Firstly, mobile nodes, which move fast, try to update routing information of fixture nodes frequently. When the process, called the handover, fails to modify the information, routing paths can be duplicated or missing. Secondly, while initiating and closing sessions between mobile and fixture nodes, the procedure causes massive traffic which could interrupt the existing service. The existing service (basic service) means a service which has been provided for its original purpose, such as environmental monitoring. These situations lead to unstable network conditions, which make the system fail to provide basic services as well as location-awareness services conforming to end-user expectations. Therefore, another approach for fixture and mobile node communication is needed to assure a stable network condition.

Hence, we propose ID-exchange protocol for Connectionless Location-Awareness Services (CLAS). By placing this additional protocol on 802.15.4 MAC-layer, the session between fixture and mobile nodes is separated from the network-layer protocol. Adapting the separated layering strategy of location-awareness service, we can avoid the routing problems caused by mobile node's handover. Moreover, the strategy makes location-awareness service and basic service operate independently, so that traffic can be distributed into two distinctive frequency channels. We implemented a demo application to show high stability and high detecting speed of the proposed protocol.

This paper is organized as follows. Section 2 briefly surveys related work in consideration of location-awareness services of sensor network. Section 3 describes the CLAS network topology, and Section 4 explains ID-exchange protocol based on the topology. In Section 5, we explain the implementation and software design of the demo system. Experimental evaluation is discussed in Section 6. Section 7 summarizes the main contribution of the paper and suggests the future work.

2. RELATED WORK

GPS and RFID-based solutions are the best-known examples to locate mobile nodes in sensor network. Although GPS-based solutions measure devices' positions with a high accuracy in most places in the earth, they are difficult to locate callers inside buildings, in cars, under dense foliage or any other place without direct line-of-sight to GPS satellites [Poizer and Todd 1999; Wark et al. 2007]. RFID-based solution detects mobile nodes, to which RFID-tag is attached, in every place with high speed and high stability by communicating with RFID-reader. Even though the mobile device reduces its cost dramatically, it is difficult to provide two-way communication with fixture node. Moreover, both GPS and RFID-based solutions require the fixture node to change overly its hardware [Zhang and Wang 2006]. When GPS-transceiver and RFID-reader are combined with fixture node to communicate with the server, H/W and S/W interfacing between two distinctive systems is unavoidable which diminishes sustainability of the existing infrastructure. RF triangulation-based solutions, whereas, can be used inside building sharing physical and MAC-layer, so that it needs less changes to the existing system than other technologies. However, RF signal strengths have a tendency to be distorted by nearby obstacles making the system difficult to locate indoor-nodes with high precision [Arias et al. 2004; Amodt 2006; Bahl and Padmanabhan 2000].

Therefore, a simpler way is commonly used to locate mobile nodes for indoor sensor network system. Target environment is divided into a number of areas, and a geographical sense is entitled for each of them. Each area, called cell which is a basic unit of positioning, is where a fixture node provides location-awareness services to adjacent mobile nodes. For bidirectional services, it is essential for fixture node to use routing function to report mobile nodes' positions to the server, or to direct data, which is received from the server, to mobile nodes. ID-exchange procedure, in which fixture and mobile nodes identifies each other, is the basis to establish the routing table. The procedure defined on the network-layer, called JOIN, assists to build parent-child relationship, helping parent-side (fixture node) to maintain routing table which specifies the route to the child-side (mobile node). JOIN procedure is useful not only to locate mobile nodes in a cell, but also to set up a route from the server to the mobile node. Moreover, software developers can implement services on the top of the network-layer without detailed knowledge about underlying network topologies and routing algorithms. This method is called Cell-Based Connection-Oriented Location Awareness Services (COLAS) in this paper. Especially, the mobile node which operates on the network layer is called Network Layer Level Mobile Node (NL-Mobile Node).

However, COLAS brings routing-related problems. Sensor network takes advantage of ad-hoc routing algorithms which connect or disconnect sessions of two adjacent nodes dynamically [Akkaya and Younis 2005]. Yet, most algorithms are designed on the basis of the assumption that every node is stationary. When mobile nodes move around, routing tables of fixture nodes continuously have to be updated to retain the latest paths. If the information is not removed or added from previous and new connections as expected, paths can be duplicated or missing, which results in failure of both basic and location-awareness services [Sun et al. 2007]. Moreover, the concept of COLAS makes basic and location-awareness services tightly-coupled at the network layer by sharing the same frequency channel as well as routing tables. This channel usage makes both types of services use the low data rate supported by IEEE 802.15.4 MAC ineffectively. Such data rates are tolerable for basic services which send data periodically with a long interval. In contrast, location-awareness services treat event-driven data which is difficult to predict its traffic at a certain time. Consequently, the heavy traffic by the event-driven data may disrupt basic services instantly [Lee 2006].

In this paper, we consider Connectionless Location-Awareness Services (CLAS) to solve the problems of COLAS. CLAS places two types of services on different communication layers to make them loosely-coupled; the network-layer for basic services and the MAC-layer for location-awareness services. The mobile node of CLAS, called MAC Layer Level Mobile Node (ML-Mobile Node), interacts with a fixture node on the MAC layer, so that routing table of fixture nodes remains unchanged. In addition, the loosely-coupled service feature in CLAS makes it possible to separate the frequency channel used for location-awareness services from basic service's one. The separated channel, called Dedicated Location-Awareness Service Channel (DLAS), helps the system to spread traffic over two distinctive channels. In Section 3, we explain the network topology for CLAS.

3. NETWORK TOPOLOGY FOR CONNECTIONLESS LOCATION-AWARENESS SERVICE

When designing the network topology for CLAS, the sustainability of the existing

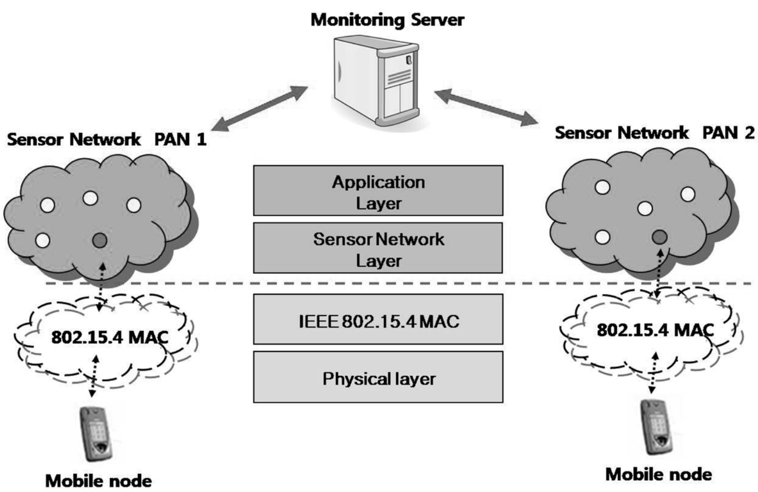

Figure 1. Network Topology for CLAS.

sensor network system must be considered primarily. We assume the existing system has been providing basic service, such as environmental monitoring. Even though location-awareness service is newly added to the existing system, basic service must operate with no degrade of its performance. Figure 1 shows the topology which uses two different communication layers for each service; network-layer for basic service and MAC-layer for location-awareness service. ML-mobile nodes interact with a fixture node in each cell only using MAC-layer. This is possible because we assume that any devices in a cell are in a single-hop RF range, which means the network-layer supporting multi-hop routing is unnecessary. Even so, the information of ML-mobile nodes has to be delivered to the server which is out of the single-hop range to provide advanced location-awareness services. In this case, the information can be forwarded by routing function used by basic service. In short, fixture node retrieves information of mobile nodes in a local cell using MAC-layer, and collected information is forwarded to the server using Network-layer.

The two steps of information processing may look like overhead. However, it is required for basic and location-awareness services to be loosely-coupled. This is very essential to assure sustainability for the basic service. Because most problems of COLAS stated in Section 2 were caused by operating two different types of services on the same network-layer. Thus, by loosely coupling two types of services over two different communication layers, dramatic advantages can be achieved. When communicating with NL-mobile node in COLAS, fixture node had to retain the information of the mobile nodes to maintain routing table. Retaining mobile nodes information may seem to be attractive, in that the route from the server to the mobile node is automatically established facilitating to provide bidirectional location-awareness service. However, considering limited storage of embedded system, the fixture node may not be able to hold information for many mobile nodes. The more serious problem is that routing table may have wrong information because of frequent handover of mobile nodes. In contrast to COLAS, fixture node of CLAS has no responsibility to retain information of mobile nodes for a long time since the information isn't involved to establish routing table. The information can be stored in fixture node for a short time, then forwarded to the server, and finally discarded from the storage of fixture node according to the application-layer demand. Since mobile node's information doesn't affect the existing routing table which has been used by basic service, both services can be provided together in a stable routing condition.

The loosely-coupled feature also gives the system flexibility of using the frequency channel. IEEE 802.15.4 MAC supports sixteen channels in 2.4 GHz frequency band, and each channel has 250 kbps data rates which are relatively much lower than other protocols, such as Bluetooth, or WLAN [Memsen 2004]. In COLAS, two types of services had to share a common frequency channel, called Sensor Network Backbone channel (SNB channel). This is because that as long as both mobile and fixture nodes operate on the same network-layer, they must agree on using the same static channel. That means, even if there is another unused one out of sixteen channels, both fixture and mobile nodes using COLAS have no choice to use it other than currently used channel. The limited channel usage of COLAS causes that two types of traffic,

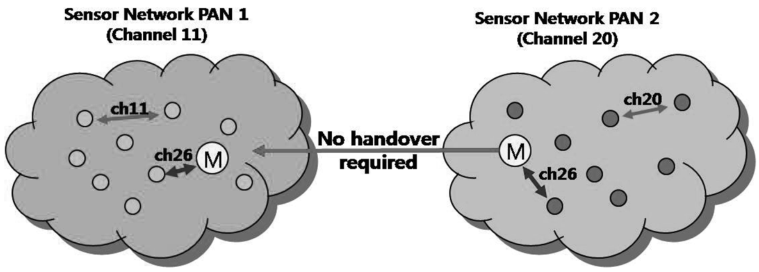

Figure 2. The channel usage for basic service and location-awareness service.

generated by basic and location-awareness service, are concentrated on a single frequency channel. At a certain time, a large traffic caused by location-awareness services may interrupt basic service which uses the same frequency channel, degrading the sustainability of the basic service. On the contrary, in CLAS, each service is allowed to use a physically independent frequency channel, since both services operate on different layers. Therefore, it is possible that the traffic caused by location-awareness service can be shifted to another channel (DLAS channel). Moreover, that makes ML-mobile node communicate with fixture node anywhere through the same frequency channel, so that no handover is required even if it moves other Personal Area Network (PAN) using different SNB channel. Figure 2 shows the channel usage adapted in CLAS. For example, even if PAN 2 uses channel 20 (SNB Channel) for basic service, location-awareness service is always provided through channel 26 (DLAS Channel). Moreover, when ML-mobile nodes move to another PAN which uses a different SNB Channel, it is unnecessary to change to the new channel [Jeong et al. 2006].

The proposed network topology of CLAS gives far more advantages than COLAS. However, it requires system to adapt another ID-exchange protocol on the MAC-layer for interacting between fixture and mobile nodes. The details of the protocol will be discussed in the following section.

4. ID-EXCHANGE PROTOCOL FOR CONNECTIONLESS LOCATION-AWARENESS SERVICE

4.1 Protocol Description

In Section 3, CLAS required two steps to send ML-mobile nodes' IDs, single-hop ID-exchange in a local cell and multi-hop routing to the remote server. The latter step is a typical procedure to deliver message to distant places in sensor network. Yet, the former step is newly added in CLAS under the constraint of which ID-exchange happens on the MAC-layer. In this section, we explain ID-exchange protocol which was used in the first step.

CLAS ID-exchange protocol provides ML-mobile node and fixture node with different kind of information. ML-mobile node identifies its location by receiving ID of the neighboring fixture node. Fixture node recognizes the ML-mobile node inside the cell by obtaining its ID. Figure 3 describes the procedure of CLAS ID-exchange

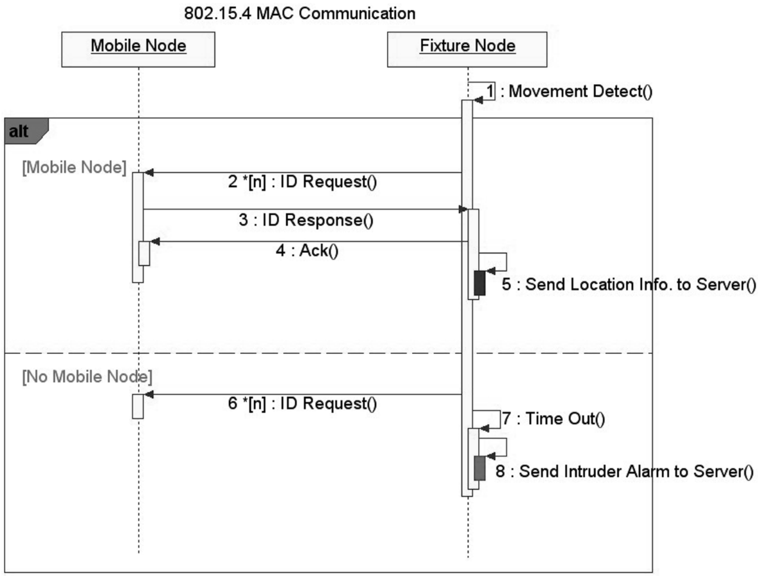

Figure 3. ID-Exchange Protocol based on CLAS.

protocol. The beginning of the protocol is to broadcast ID-request packet from either ML-mobile or fixture node, since both sides have no information of their counterparts. In this protocol, fixture node firstly sends its ID to ML-mobile nodes (1, 2). ID-request can be broadcasted only one time. Yet, when a large number of ML-mobile nodes exist in a cell, they reply back with ID-response packets at the same time causing extensive traffic instantaneously. A portion of packets can be missing lowering recognition rate of ML-mobile nodes. The higher recognition rate can be achieved by broadcasting ID-request more than one time. Followed by ID-request, ML-mobile nodes acknowledge with ID-response packet containing their IDs (3). The destination of ID-response must be the fixture node's address which initiated the procedure so that only the right fixture node receives the responses. Finally, the fixture node which received ID-response sends ACK packet to ML-mobile nodes indicating that ID-exchange has finished successfully (4). This ACK procedure will be discussed in detail in the following subsection. The fixture node which collected IDs of ML-mobile nodes forwards them to the server through multi-hop routing (5). Back to the first step, even if a fixture node broadcast its ID (6), if there is no mobile node listening to it, the procedure ends with an exception which can be handled by higher level

Table I. Information received after ID-Exchange Protocol.

	Mobile Node	Fixture Node	Server
Info.	Fixture Node ID	Mobile Node IDs	Fixture Node ID, Mobile Node IDs
Protocol Used	802.15.4 MAC	802.15.4 MAC, Network	Network, Internet

applications (7, 8).

Table I summarizes acquired information and used communication layers of each system components.

We found that when a number of mobile nodes replied with ID-response packet to fixture node, fixture node failed to send ACK packet to every mobile node because of the limited data rate. In following subsection, we suggest a novel ACK mechanism to support the proposed ID-exchange protocol.

4.2 Delayed Acknowledgement Mechanism for N-to-1 ACK Procedure

Under the low data rate of sensor network, the fixture node broadcast ID-request packets more than one time to detect multiple mobile nodes at a single cycle of ID-exchange protocol. That means, if many mobile nodes respond with ID-response to the first ID-request, some portion of mobile nodes may fail to transmit the response successfully, because the simultaneous access of mobile nodes to the medium cause large traffic. Considering these mobile nodes, multiple ID-requests in a single cycle of ID-exchange protocol make it possible to achieve higher recognition rate. The fixture node sends ACK packet back to the mobile nodes not only to assure the successful arrival of ID-response, but also make mobile nodes send only one response for the multiple ID-requests, so that unnecessary responses can be reduced.

In general, every packet needs to receive ACK packet from its destination to check its arrival. This is called N-to-N ACK mechanism in this paper. Although N-to-N ACK mechanism is the simplest way to assure the reliability of communication protocols, it is difficult to adapt in CLAS ID-exchange protocol. If many mobile nodes exist in a cell, the fixture node has to send multiple ACKs in response to the every ID-response packet in a short time. In our experiment, the loss rate of ACK packets was considerable when N-to-N ACK mechanism was used under the limited data rate (250 kbps). The loss results in, even if most ID-response packets were successfully delivered to the fixture node, a portion of mobile nodes which couldn't get ACK guesses that the ID-exchange was failed. This situation leads these mobile nodes to respond to the subsequent ID-request with the same ID-response packet occupying the limited bandwidth unnecessarily.

We adapt the Delayed Acknowledgement (DA) mechanism of Transmission Control Protocol (TCP) to solve this problem [Allman 1999]. DA of TCP delays ACK for a short time when receiving a packet. After the waiting timeout, TCP checks another data which is to be directed to the same destination where the previous ACK has to be sent, and delivers the data with ACK packet to the destination together. The DA proposed in this paper has the same concept with TCP's DA in that both use the communication medium efficiently. Yet, there is a difference in that DA in this paper is adapted to implement the N-to-1 ACK mechanism. In N-to-1 ACK mechanism, when the fixture node receives ID-response from mobile nodes, ACK procedure is delayed for a short time. Afterwards, only a single ACK packet is broadcasted to the nearby mobile nodes, rather than sending multiple ACK packets for each ID-response. The ACK packet contains a couple of source addresses of mobile nodes extracted from the received ID-response packets, so that each mobile node confirms that the ACK packet is directed to it. By reducing

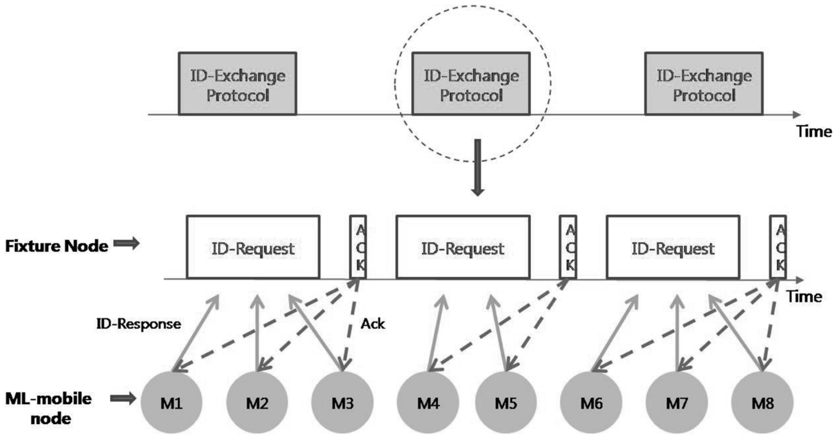

Figure 4. Delayed ACK in CLAS ID-Exchange Protocol.

the number of ACK packets, the N-to-1 ACK mechanism uses the limited communication bandwidth effectively. Figure 4 shows the N-to-1 ACK mechanism using DA. We assume a single ID-exchange protocol repeats ID-request three times. In the first ID-request, three of eight mobile nodes successfully send ID-response to the fixture node. Then, the fixture node waits for a moment, and sends a single ACK packet to the three mobile nodes (M1, M2, M3). The remaining mobile nodes (M4-M8) retry ID-response for the following ID-request with the same mechanism. When compared to N-To-N ACK mechanism which sends eight ACKs (or more in case of collision) to the eight mobile nodes, N-To-1 ACK sends only three ACK packets preventing unnecessary retransmission of ID-response. As a result, this mechanism reduces the loss rate of ACK using the low data rate efficiently.

A demo system adapting the ID-exchange protocol and N-to-1 ACK mechanism will be introduced with its software design in the next section.

5. SOFTWARE DESIGN AND IMPLEMENTATION

5.1 Software Design

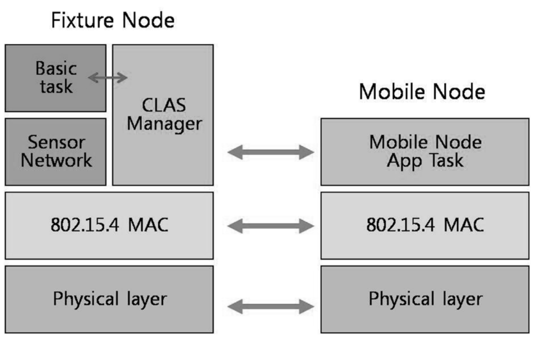

Figure 5. Communication stack between fixture and mobile nodes.

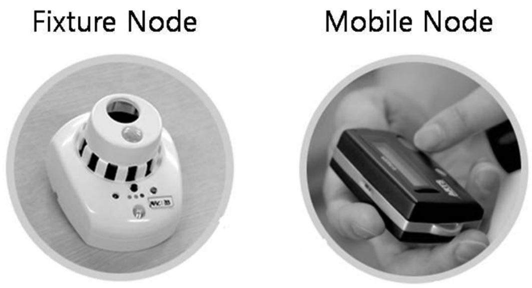

Figure 6. Fixture node and mobile node adapting CLAS ID-exchange protocol.

We applied CLAS ID-exchange protocol to the demo system which monitors fire and authorities' locations. Figure 5 shows the software stack for the fixture and ML-mobile nodes consisting of the system. The fixture node's stack is designed to use the network and MAC layer selectively. Two application tasks, Basic and CLAS manager tasks, are loaded on each layer. The basic task sends environmental data periodically to monitor fire. The CLAS manager task exchanges location information with ML-mobile nodes using ID-exchange protocol. Two tasks use distinctive frequency channels to spread the traffic, SNB and DLAS channel for each task. On the other hand, the ML-mobile node software has one application task on the MAC layer, Mobile Node App task. The task interacts with CLAS manager task of the fixture node's software on the same DLAS channel.

5.2 Implementation

The fixture node used in the demo system has smoke, flame, temperature sensors to detect fire. Movement detection was used to notice people or other moving objects. 8051-core based MCU works with CC2430 RF transceiver. For sensor network software, Z-Stack of TI [Texas Instruments 2006] is ported on the hardware to use ZigBee, which is the most popular sensor network protocol [Kinney 2003]. The

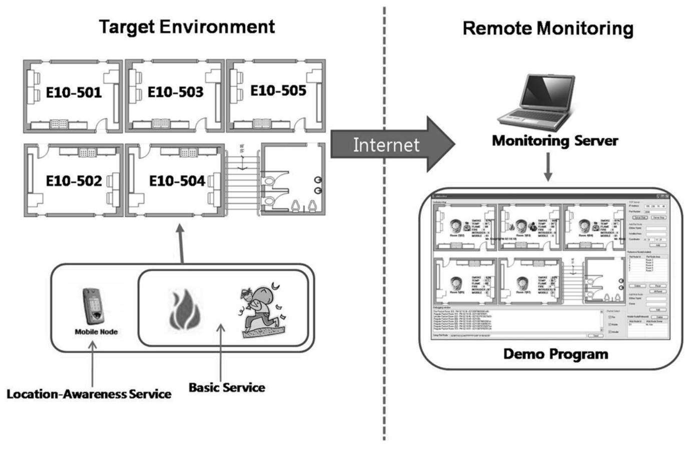

Figure 7. Experimental Setup.

mobile node employs the same hardware features with the fixture node, bringing together an accelerometer to sense movements, LCD and LED for user-interface. Figure 6 shows the fixture and mobile node.

Five fixture nodes were installed on the ceiling in each room of the building. Collected data are directed to the monitoring server through the gateway which connects the sensor network to the Internet. The monitoring server provides end-users with information of environmental conditions and authorities' current positions. The lefthand side of Figure 7 shows the demo environment, and the righthand shows GUI program to facilitate presenting information of each room.

6. EXPERIMENTAL EVALUATION

6.1 Experimental Analysis

We examined the system from three perspectives, ID correction time, recognition rate, and reporting time. The ID correction time is duration for completing a single-cycle of ID-exchange protocol. The recognition rate means the number of detected mobile nodes through a single-cycle of ID-exchange protocol. The reporting time is duration from the moment of detecting mobile nodes in a cell to the arrival of their IDs to the server, which is the sum of ID correcting time and multi-hop delivery jitter.

A fixture node broadcasts ID-requests to ML-mobile nodes more than one time to improve the recognition rate. Generally, an RF transceiver can use only one physical frequency channel at a time. When implementing the consecutive ID-requests, a router node should avoid taking the DLAS channel for a long time, because the routing function using the SNB channel can be interrupted. Therefore, a novel approach is necessary to occupy SNB and DLAS channels alternately. We inserted a time slice between the two successive requests to make the ID-request work like ISR (Interrupt Service Routines). As an example, Figure 8 shows a channel occupation for three sequential ID-requests. The graph was acquired from an oscilloscope screen by alternating LED on and off whenever DLAS and SNB channel are used. There are

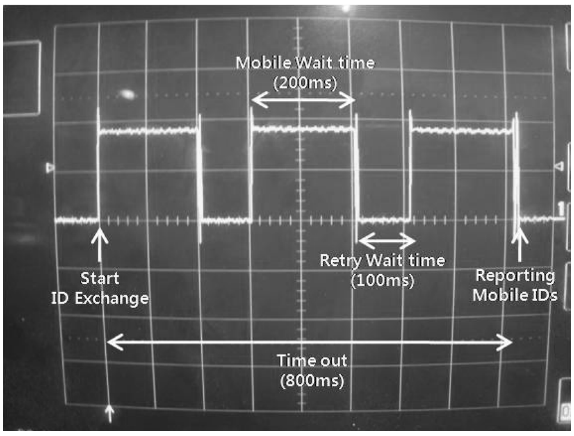

Figure 8. Channel occupation using CLAS ID-Exchange Protocol.

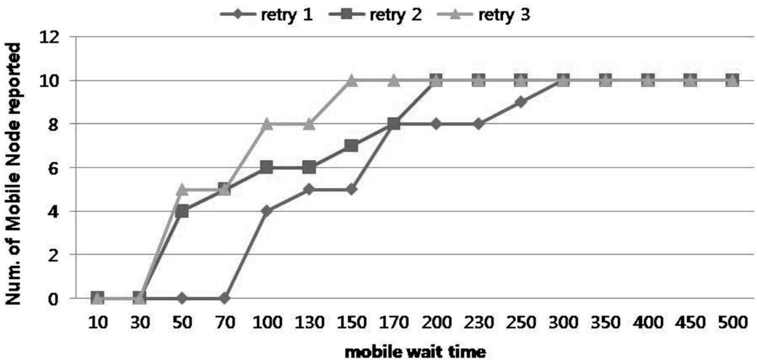

Figure 9. Performance of multiple mobile modes detection according to mobile wait time and max retry.

three parameters to determine the wave; *Mobile wait time* (200 ms), duration for waiting ID-responses, *Retry wait time* (100 ms), time slice between two consecutive ID-request, *Max retry* (3 times), the number of broadcasting ID-request. The ID correction time depends on these parameters. In this example, it takes 800 ms.

Figure 9 shows the recognition rate according to the various values of *mobile wait time* and *max retry.* Ten ML-mobile nodes which were placed in a cell interacted with a fixture node, and then collected data was forwarded to the server. As a result, higher recognition rate was achieved by setting a higher amount of *mobile wait* time and *max retry.* However, when the parameters become greater in amount, the ID collection time is also increased, which consequently delays the reporting time to the server. A trade-off is necessary between the recognition rate and the ID collection time.

We measured the reporting time of ten IDs of ML-mobile nodes to the server across multi-hop. In the previous experiment, *mobile wait time* was an important factor to determine the recognition rate. The reporting time was measured by varying *mobile wait time* and hop counts from the cell to the server. *Max retry* and *retry wait time* were fixed as 3 times and 100 ms respectively. Figure 10 shows the reporting time in which collected IDs in each cell (hop) arrives to the server. The minimum *mobile wait time* was 150 ms with 3 times of *max retry* to detect ten nodes at a time

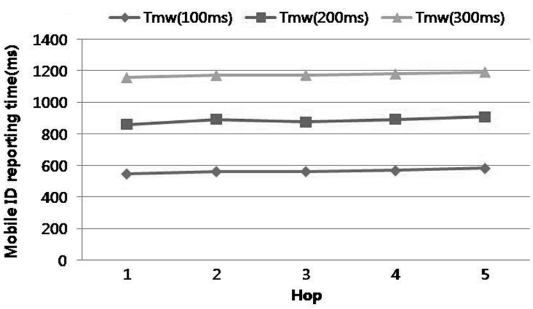

Figure 10. ID Reporting time according to mobile wait time.

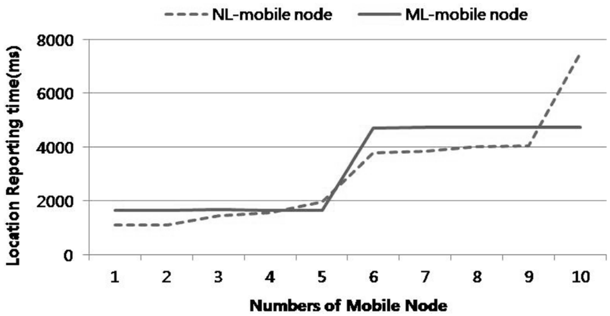

Figure 11. Performance comparison between NL and ML mobile nodes.

in Figure 9. Even if *mobile wait time* is set to 200 ms which is enough to detect the same amount of nodes, all IDs were reported to the server within a second.

The most distinctive feature of CLAS is to adapt ID-exchange protocol between fixture and mobile nodes which operates on MAC-layer. The CLAS ID-exchange protocol is alternative to the JOIN procedure of the network-layer to locate mobile nodes, so it is needed to compare the performance of both cases to report mobile nodes' location to the server. Figure 11 shows the comparison of performance of each case. It takes a constant time for ML-mobile nodes to report their IDs to the server unless the number of nodes exceeds the queue size, which is the maximum capacity of fixture node to hold mobile nodes' information. In case of NL-mobile node, it shows better performance than when ML-mobile node is used, when there are few nodes in a cell. As the number of mobile nodes increases, however, the performance of NL-mobile node is getting worse. This is because more numbers of packets are needed for JOIN procedure to exchange information between fixture and mobile node than CLAS ID-exchange protocol. Moreover, the number of packets to be forwarded to the server is increased in proportion to the number of NL-mobile nodes. In contrast, in ML-mobile node, the number of packets to be forwarded to the server can be reduced. It is Because a few number of mobile nodes' information can be compressed into a single packet during two processing steps of fixture node, as stated in Section 3. Therefore, when the number of mobile nodes is small, CLAS ID-Exchange protocol has a little bit lower performance because of its storing time. However, under a circumstance which has a large number of mobile nodes, the proposed protocol makes a significant improvement compared to the JOIN procedure of COLAS.

6.2 Evaluation and Discussion

During our experiments, we found that the fastest reporting time of ten ML-mobile nodes can be achieved when *mobile wait time* is 150 ms, *max retry count* is 3 from Figure 9. However, if the longer *mobile wait time* doesn't affect the reporting time too much, it is better to set the parameter to the higher value since the higher possibility to hold more mobile nodes at a single cycle of ID-exchange protocol (*recognition rate*) can be achieved. Referring to Figure 10, even though *mobile wait* *time* is doubled, all mobile nodes can be detected within 1.5 second. That means, as long as this performance is acceptable, setting *mobile wait time* to lower value than 300 ms may only bring the decrease in *recognition rate*. Therefore, it is important to find a trade-off between reporting time and recognition rate to maximize overall performance satisfying the system requirement.

Queue size of fixture node, which is to hold mobile nodes' information for a short time, also affects the overall reporting time. We assumed that the queue size used in experiment of Figures 9 and 10 was large enough to hold all information of mobile nodes in a cell, so all mobile nodes' IDs could be delivered to the server in a constant time. However, it is also possible that the queue size is smaller than the number of mobile nodes which wait for ID-exchange with fixture node. In Figure 11, we intentionally reduced the queue size to five, and ten ML-mobile nodes, which are larger than the queue size, were placed in a cell. As we expected, it takes two cycles of ID-exchange protocol, doubling the reporting time.

Mobile wait time, *max retry count*, and *queue size* of fixture node can be adjusted according to the system requirements. In the experiments above, we set the parameters to fairly lower values to show the visible effect of the parameters even if it was possible to set to larger values. Therefore, higher performance can be achieved in real system by setting proper parameter values. For example, queue size can be more than 100 to accommodate a number of mobile nodes if the storage of fixture node is enough.

7. CONCLUSION

We mainly focused to adapt bidirectional location-awareness services with high speed providing sustainability to the existing service. CLAS ID-exchange protocol, which operates on 802.15.4 MAC-layer, shares its physical-layer, so that no redundant hardware for communication with mobile nodes is required. Considering the stable routing condition is very crucial in wireless sensor network, the proposed protocol can be the right choice for location-awareness service since the direct cause of this problem is removed by placing interaction between fixture and mobile nodes on MAC-layer. Traffic distribution over two distinctive channel, SNB and DLAS channels, make the system use the limited data rate of sensor network effectively. Even though it may need some work to implement loosely-coupled services, it is worthwhile because higher performance to locate mobile nodes can be achieved compared to COLAS. Currently, the proposed protocol only defines communication between the fixture and mobile nodes in a cell. Future work includes the protocol extension to support message delivery service among mobile nodes across the sensor network, and middleware support for this extended protocol.

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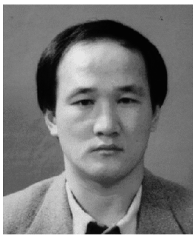

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