LITeTag: Design and Implementation of an RFID System for IT-based Port Logistics

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***Abstract*— Logistics has grown dramatically, especially where identifying, locating, or tracking objects in ports are important, because ports are gateways to extended markets. In this paper, we analyze the new requirements of port logistics after a brief introduction and present a system prototype. Then we describe the design and implementation of an RFID system for IT-based port logistics. Our solution named Logistics Information Technology electronic Tag (LITeTag) consists of three parts: a smart tag, a smart electronic container seal, and an RTLS system. These offer a complete range of port logistics services that cover the entire port environment. Also, our system design focuses on four parts: 1) the standard compliance with the ISO, 2) conservation of energy to extend the live of the tags for as long as possible, 3) a high identification rate in the presence of multiple tags, and 4) the fastest possible tag response time. A performance evaluation of the system is also included in the paper.**

***Index Terms*— Port logistics, Smart tag, Active RFID, Electronic container seal, RTLS**

I. Introduction

Ports have always been the gateway to extended markets and have in that sense always been an important part of the global logistics chain. As large hub ports can become heavily congested in the loading, unloading, and processing of containers into and out of ports currently they are bottleneck in the total supply chain. Consequently, the efficiency of port logistics must be enhanced. The traditional approach to enhancing the efficiency of ports has many problems, which can invoke large financial investments, in either new machines or hiring more labor.

In order to reduce the load and cost for managing ports, we can extend and apply an active RFID (radio frequency identification) system [1, 2], which has a great transmission range, for ubiquitous logistics environments to port environments. Active RFID tags are distributed throughout port environments. Automatic identification of and data capture from active RFID tags in ports can reduce the costs of managing port logistics and allow their logistics to be processed more efficiently and quickly. However, many problems must be overcome before RFID systems can be used in ports. First, the port contains a wide variety of materials and obstacles made of steel. These materials and objects are likely to cause problems like multipath, scattering, or reflected signals into an RFID system. Second, because containers are densely distributed throughout a port, efficient identification and data delivery are difficult. Most importantly, RFID tags for port logistics have been active which are powered by internal resources such as batteries. Finally, RFID tags should respond to commands from a reader as soon as possible. Thus, smart tags must be low-powered, light weight, and fault tolerant to meet these requirements. These issues have been addressed in terms of the whole system design, rather than as isolated sub-problems. Indeed, this whole system design yields pragmatic solutions that are simpler than what is generally found in the literature for individual sub-problems. We built and demonstrated an active RFID system which is composed of three parts: an RFID system, intended to address the need of automatic identification and data capture(AIDC), electronic container seals, which detect access by malicious users and alert a remote user, and real time locating system(RTLS), which is used to locate specific containers.

The RFID tags attached to containers at some ports can be read in other ports. For instance, an RFID tag attached to a container in the port of Gwangyang, Korea, can be read by the readers in the port of L.A., the U.S.A. In this new system, because each port can have a unique RFID reader system, RFID tags can not read at their destinations. In order for these heterogeneous systems to be compatible, conformance with international standards is important. ISO/IEC 18000-7[6] was enacted as an international standard for container identification in port environments. RFID systems should be designed and developed according to this standard.

In case research on container logistics fuses with active smart tag technology, studies are needed to cope with the next generation of active smart tags such as electronic container seals and RTLS[3] as well as technology mentioned in ISO/IEC 18000-7 standard document. As a result of extending the use of RFID tags to as many port applications as possible, information regarding a container's location and whether it has been opened could be used to reduce the cost of port logistics.

In this paper, our main contributions are:

- We employed whole-system analysis and utilized spatial and physical properties to design an efficient and simple mechanism. We believe this approach is useful a variety of applications in port environments.
- We provide information on the design and implementation of an active RFID, ECS, and RTLS for port logistics. We built and demonstrated the RFID system.
- We share practical advice for using the system in realistic port applications, including system design, and high level management service.
- Our systems comply with the international standard. The system can communicate with other devices which comply with the international standard.

The organization of the paper is as follows. We present the international standards and related works in the next section. Then, we describe the development of our systems operating at 433MHz in section 3. Before concluding this paper, we verify our systems and describe the performance evaluation of the systems in section, 4 and 5.

II. Related Work

In this section, we review the needs of active RFID systems, electronic container seal, and RTLS systems for containers in port environments, and discuss the international standards related with. Then, we focus on the air interface protocols for use with 433MHz systems.

A. Active RFID for port logistics

The standards for RFID systems are defined by ISO/IEC. 15961[4] addresses tag commands, 15962[5] depicts data syntax, and 19799 demonstrates API. In addition, 18000 is intended to address air interface. 18000 consists of the following parts: part 1, references the architecture and define the parameters to be standardized; part 2 is used with systems below 135kHz; part 3 is for systems up to 13.56MHz; part 4, for systems to 2.45GHz; part 6, for systems between 860~960MHz; and part 7, for systems up to 433MHz. As mentioned earlier, part 7 of ISO/IEC 18000 defines the air interface for active RFID systems in the 433 MHz band. The characteristics of the RF communication link between a reader and tags are as follows. The carrier frequency is 433.92MHz, and the accuracy is ±20ppm. The modulation type is FSK, and the frequency deviation is ±50kHz. The modulation rate is 27.7kHz. The wake up signal is transmitted by a reader for a minimum of 2.5 seconds to wake up all tags within its communication range. The wake up signal is a 30kHz sub-carrier tone for 2.5 to 2.7 seconds. Upon detection of the wake-up signal, all tags will enter ready state awaiting commands from the reader.

In the data link layer, a packet is comprised of a preamble, data bytes, and a final logic low period. The preamble is comprised of twenty pulses of 60us period, 30us low, followed by a final sync pulse which identifies the communication direction: 42us high 54us low is used to identify communication from tag to reader; and 54us high 54us low indicates communication from reader to tag. Data bytes are in Manchester code format, comprised of 8 data bits and 1 stop bit. A falling edge in the center of the bit-time indicates a 0 bit, a rising edge indicates a 1 bit. The stop bit is coded as a zero bit. The CRC is appended to the data as two bytes. Then, a final period of 36us of continuous logic low is transmitted for each packet after the CRC bytes[6].

B. Electronic container seal for port logistics

ISO/IEC 18185 international standard provides a system and a reference for the identification and presentation of information about freight container electronic seals. The identification system provides an unambiguous unique identification of the container seal, its status, and related information. The presentation of this information is provided through a radio-communications interface providing seal identification and a method to determine whether a freight container's seal has been opened. The physical layer of an electronic seal compliant with ISO/IEC 18185 standard should be in accordance with ISO/IEC 18000, Part 7. ISO/IEC18185-1[7] standard specifies the communication protocol for a freight container seal identification system with an associated system for verifying the accuracy of use, a seal status identification system, a battery status indicator, and a unique seal identifier including the identification of the manufacturer.

The advantages of the use of electronic container seal system are multi-fold. It enhances productivity by reducing the manpower needed to check the movement of containers and inspection of seals. It helps to enhance security since any tampering is easily detected.

C. RTLS system for port logistics

ISO/IEC 24730-3[8] defines RTLS systems operating at 433MHz radio frequency. Also, ANSI 371 dictates the terms for an RTLS system, where part 1[9] defines 2.4GHz, part 2[10] intends to address 433MHz, and part 3[11] demonstrates API. These standards define the air interface protocol for a location system that provides zone location information utilizing a device that generates a radio frequency transmission that can be received at a minimum of 100 meters of open-field separating the transmitter and receiver and is fully compliant with radio frequency regulatory requirements. The 433MHz systems utilizing the air interface protocol defined by ANSI 371-2 document will allow the user to manage assets within the infrastructure of the system on a real-time basis. The average location data provided by the system are within 10 meters of the actual location of the transmitting device. The RTLS system consists of servers, tags, and readers. The RTLS server aggregates data from the RTLS readers.

Host applications receive RTLS transmitter location and status information through the RTLS servers. RTLS transmitter is an active radio transmitter, battery powered, which is attached to an asset, item, container, or other targeted object. The RTLS transmitters transmit messages to RTLS readers and provide a unique ID for the asset as well as certain status information about the RTLS transmitter. The RTLS reader is a device that receives signals from an RTLS transmitter. A reader's physical location is preconfigured by the system. The RTLS system unifies and integrates a number of effective position location techniques, allowing an optimum match of performance to application requirements. Location ranging is performed by a time difference of arrival (TDOA)/RSSI on arrival (ROA) system.

III. SMART TAG FOR IT-BASED LOGISTICS

In this section, we design and implement a new system platform compliant with international standards for port logistics. Our system is composed of three parts: active RFID system called LITeTag, the electronic container seal called LITeSeal, and the RTLS system called LITeRTLS. Basically, our systems operate at 433MHz frequency radio and have a great communication range. LITeTags can be attached to containers and pallets, and comply with ISO/IEC18000-7 international standard. LITeSeal can guarantee the status and security of objects or container and complies with ISO/IEC 18185-1/7 international standard. And, the LITeRTLS system is included for an extended application.

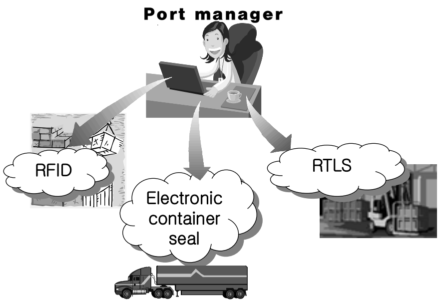


Fig. 1 Architecture of our system

A. Hardware implementation of LITeTag

LITeTag is an active RFID technology to identify containers or pallets in port logistics. In this section, we present the design and implementation of hardware for an active RFID, which complies with the part 7 of ISO/IEC 18000, operating at 433.92MHz.

The RFID platform is composed of two principal components: a tag, referred to as a transponder, and a reader, referred to as an interrogator. These two components are powered by 3V AA batteries attached to the bottom of the board.

Atmel's Atmega128L[12] was chosen as the processing unit of our platform. It is able to operate at a maximum frequency of 8MHz and provides reasonable processing power and memory to explore a wide variety of applications and experiments The on-chip memory includes 4KB of RAM, 4KB of EEPROM, and 128KB of flash memory. The MCU has 53 general purpose I/O pins and serial ports, such as RS-232 and SPI.

The communication subsystem of our LITeTag is based on the XEMICS's XE1203F radio [13], which is connected to the processor through an SPI interface and data bus. The XE1203F is 433, 868, 915MHz compliant single-chip RF transceiver, which is designed to provide a fully functional multi-channel FSK communication. It has an effective data rate of 153.2kbps, making it ideally suited for applications where high data rates are required. The processor can completely deactivate the radio or simply put it in sleep mode through the SPI interface, while the XE1203F can wake up the processor when an RF message has been successfully received. In addition, the radio chip provides a variety of four different output power levels that can be used for transmission. Output power can vary according to the needs of the application. The power consumption of the radio during transmission depends greatly on the output power level used.

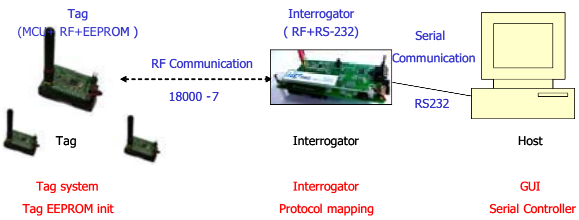
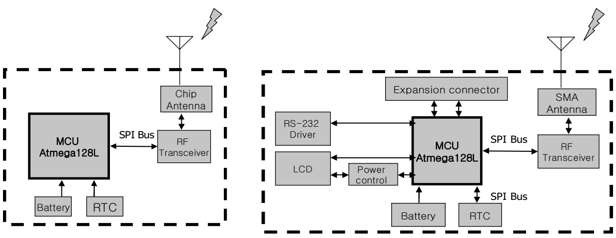


Fig. 2 Architecture of the active RFID system

Figure 2 depicts the operation of our active RFID system operating in 433.92MHz. The communication between the reader and the tag is of a master-slave type, where the reader always initiates communication and listens for a response from a tag. The host system controls the data flow between the reader and tags. It can be as simple as a personal computer connected to the reader by an RS-232 serial cable. The processor of the reader will process data received from the host and then transmits that data through the RF subsystem. As the RF subsystem transmits data by FSK modulation, and each bit is encoded with the Manchester code.



(a) LITeTag (b) LITeReader
Fig. 3 Block diagram of our active RFID

Figure 3 shows the block diagram of (a) the tag and (b) the reader. The tag consists of a processor, an RF transceiver, and an real time clock (RTC) [14]. The processor can completely control the radio through the SPI interface, and transmit/receive data using the processor's port D. for ease of changing operating modes an RF switch is accessible through port B. In addition, to visualize RF communication between the reader and the tag, three LEDs have been added. The reader basically contains a radio frequency module (transceiver), a microcontroller unit, an antenna and an RS-232 inter-face to the host system. To supply higher voltage to the LCD module, LT1302[15] that converts 3V to 5V DC supply is used. In addition, an expansion connector is added for interfacing with sensors.

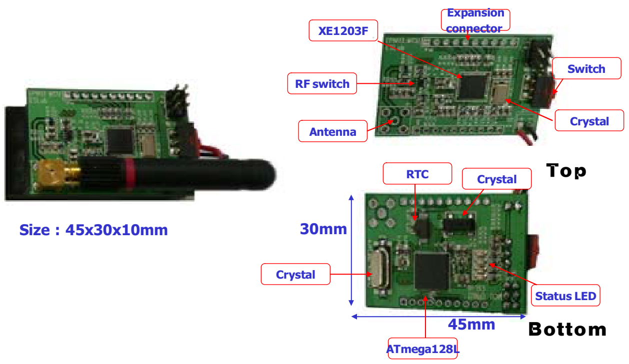


Fig. 4 Hardware components

Figure 4 shows the hardware components of the LITeTag and their module names. The hardware components are commercial off-the-shelf products.

B. Software implementation of LITeTag

To implement ISO 18000-7, we need to solve some basic problems. First, the standard requires Manchester encoding but XE1203F provide NRZ. This difficulty was solved by using an asynchronous mode in terms of software. This is completed in the transmitter. Second, there are timing difficulties in the receiver. A receiver can detect encoded data sent by a transmitter. The receiver needs to detect the exact time of data. For example, the preamble has 20 pulses. Each pulse is a 30us high and 30us low signal, but, checking the exact time of in the signal in the receiver is difficult because our system use the asynchronous technique. To solve the problem, we used the sampling mechanism shown in Figure 5. The receiver waits until the microcontroller detects a high signal demodulated by RFIC. The microcontroller samples at an interval of every 30us. If the preamble is detected, it will check sync bit. If a sync bit is identified successfully, the receiver will initiate the data format detection process. The detected data will be transferred to the upper layer. If the detection fails, a collision has occurred and the tag discards the packet.

Software for the active RFID system is separated into three types: a host program, a reader program, and a tag program. The host system controls the data flow between the reader and tags. It can be as simple as a personal computer connected to the reader by an RS-232 serial cable. More complex systems are possible where there are many readers in different locations and data is transferred to host servers through LANs or even over the Internet. We will deal with this problem in the near future. The host receives information from its user, analyzes the commands, generates packets, and then sends them to the reader system.

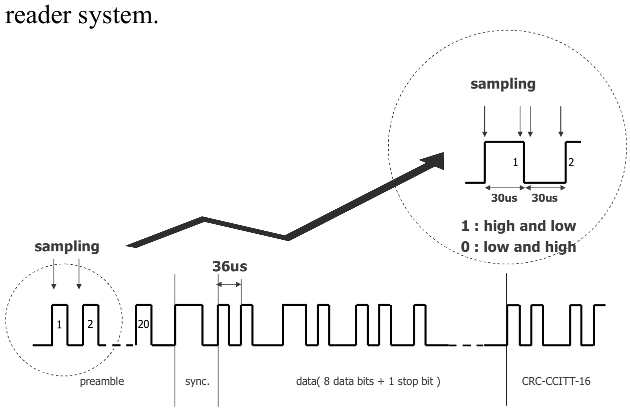


Fig. 5 Detection of ISO/IEC 18000-7 signal

The communication between the reader and the tag is of a master-slave type, where the reader always initiates communication and listens for a response from a tag. Figure 6 shows the operation of the reader. Upon receiving data from the host program, the reader classifies the data into commands and data, and then generates a new packet. Subsequently, CRC-CCITT[16] 2 bytes are appended to verify the data in the tags. The complete packet is sent through radio frequency after the wake-up signal is sent. As the RF subsystem transmits data by FSK modulation, we encode each bit with the Manchester code. The UART has to be initialized before any communication can take place. The initialization process normally consists of setting the baud rate, setting the frame format and enabling the Tx or Rx depending on the usage. Although it is possible to have a baud rate up to 250kbps using the double speed operating mode, the baud rate was limited to 9.6kbps. Then the reader waits for a response message from the tags. The received message will be transmitted to the host.

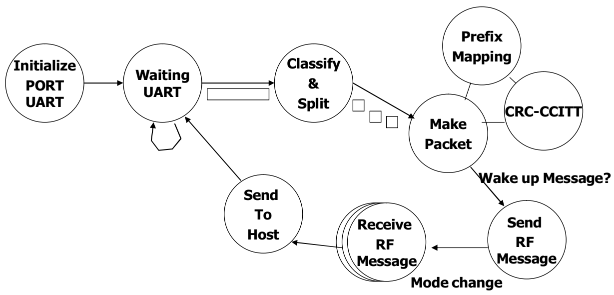


Fig. 6 State diagram for the reader system, LITeReader

Figure 7 depicts the operation of a tag. When the tags placed within the reader's RF communication range receive a wake-up signal that is broadcast from the reader, they will move into an active state. The selection is determined by a random number generator. On receiving a collection command, tags will check for an invalid CRC. If a tag receives a valid CRC, the tag will select their slot and respond with a message to the reader. In addition, in order to store a tag's unique ID, we use 4K bytes of data in the EEPROM memory. We also add a simple security mechanism to prevent access by malicious users.

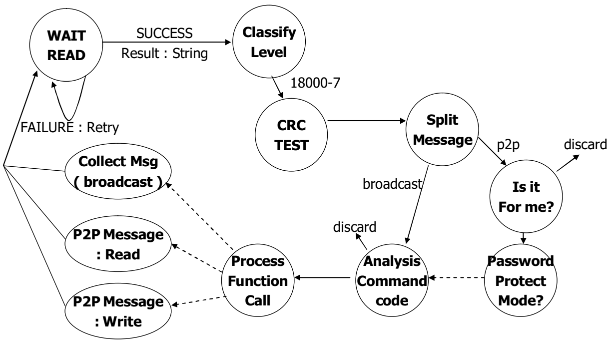


Fig. 7 State diagram for the tag system, LITeTag

Basically, there are two formats for the message types between a reader and a tag: a broadcast message and a point-to-point message. The P2P message format, which includes all commands except collection commands, requires a tag ID in order to access a particular tag. P2P message can be one of sleep, status, user ID length, user ID, owner ID, firmware revision, model number, read/write memory, set password, pass-word protect, and unlock commands. The broadcast commands are used to collect tag IDs, user IDs or short blocks of data from the selected group of tags using a batch collection algorithm. Broadcast commands are used for tag ID collection within reader's RF communication range.

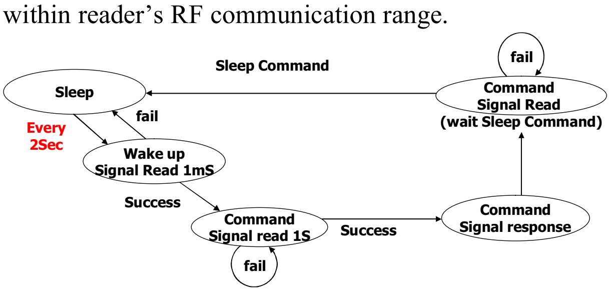


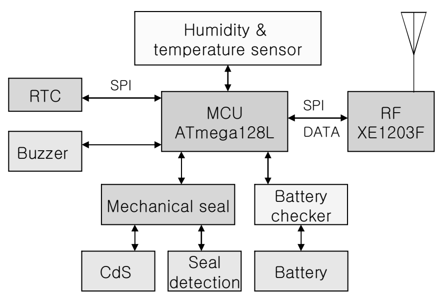
Fig. 8 State diagram of a power saving tag

There are a number of tags in an RFID field. If several tags try to transmit their signal at the same time, collisions can occur in the reader, and the reader can not complete its collection command. To solve the problem of collisions, we used a dynamic framed slotted ALOHA[17]. In the slotted ALOHA, the response is performed in a frame. In the frame, each tag randomly selects their time slot where data transmission is performed. The number of slots is usually predefined by administrator. However, this solution is inadequate when two or more heterogeneous systems co-exist. This problem was solved by allowing each node to compute their time slot for transmitting data. Each time slot is the time of preamble signal plus the amount of time need to transfer the. The preamble signal is twenty 30 high pulse and 30 low pulses, and 42 high and 54 low signals. The data type and total time are determined according to the reader's command. In each frame, if the data is successfully delivered to the reader, the reader sends a sleep command to the tags using a point-to-point command after each frame. Otherwise, if the data transmission failed, the reader rebroadcast its collection request without the wake-up signal in the next round. Thus, only tags that had their transmissions blocked by collision can respond to the reader. This action is performed until three consequent slots are empty. Because the active RFID tag is powered by an internal energy source, the lifetime of the battery is critical, so the tag requires an energy conservation mechanism. Figure 8 shows the state diagram of a power saving tag. The tags will enter the active state when the tags within the reader's RF communication range receive a wake-up signal. After data processing is completed the tag enters a sleep mode.

C. LITeSeal for IT-based Logistics

The physical layer of an electronic seal compliant with ISO/IEC 18185 standard should be in accordance with ISO/IEC 18000, Part 7. The LITeTag system is used for the LitTeSeal system. LITeSeal consists of three parts: a core board which includes an MCU and an RFM, a mechanical seal, and a sensor board. The core board is the same as the LITeTag, which consists of a microprocessor and an RF module. The mechanical seal is designed to detect the seal's condition. If the seal is broken, LITeSeal reports it as broken state. Also, cadmium sulfide cell (Cds) is attached at the end of the mechanical seal. If the seal is exposed light, LITeSeal detects it as a broken seal. The outward appearance and block diagram of LITeSeal are depicted in Figure 9. Furthermore, a humidity and temperature sensor, a Piezzo ceramic buzzer, and an expansion connector are added for extended applications. The buzzer will be activated if the seal is broken in addition to the real time RF report. LITeSeal maintains a history of the event using RTC, and several sensors once it is sealed.

(a) Outward of ECS



(b) Block diagram

Fig. 9 architecture of electronic container seal, LITeSeal

ISO/IEC18185-1 standard specifies a freight container seal identification system, with an associated system for verifying the accuracy of its use with a seal status identification system, a battery status indicator, and a unique seal identifier including the identification of the manufacturer. The basic data format of ISO/IEC 18185, implemented in software, is the same as 18000-7. The electronic seal's mandatory data includes the seal status, the seal tag ID and manufacturer ID, the data/time of being sealed and opened, seal status, low battery status, the protocol ID, the model ID, product version, and protocol version. The seal status is stored in EEPORM with the date and time information. There are three formats for the message types between the reader and the seal has three different formats: broadcast message, point-to-point message, and alert message. The P2P message can be sleep, product version, model ID, read RTC, read seal product parameter, standby, read event records, or status inquiring. The broadcast message can be collection, collect seal IDs with event record, or sleep. The LITeSeal system is always not master-slave communication. In order to alert the reader to the presence of a broken seal, the electronic container seal can initiate communication using an alert message.

D. LITeRTLS System for IT-based Logistics

RTLS can use both TDOA and ROA location methodologies. A ROA system is very simple so a very low-cost RTLS system will be able to provide locations with a range of resolutions within the covered space varying from 10 to 100 meters, depending on the location of the tag with respect to the readers. In many situations, a simple technique such as this can offer what most applications truly need without the complexity and cost of much more sophisticated techniques.

LITeRTLS is composed of a reader having a USB interface to connect with an RTLS server and a tag, called the RTLS transmitter. LITeTag is used for the RTLS tag without any modification. However, a problem exists in the RTLS reader. The XE1203F RFIC that we used only provides three bits of RSSI information to the receiver, which is not enough resolution to estimate the tag's location. To improve location accuracy, we used an external RSSI approach[18], using IAMP and QAMP. The algorithm is as follows.

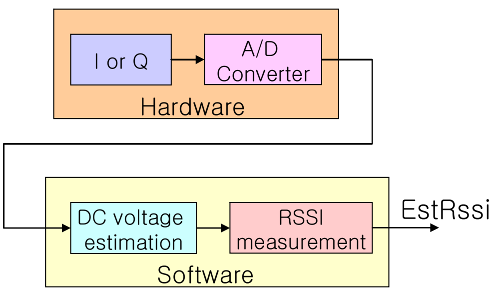


Fig. 10 algorithm for an external RSSI

EstRssi relates to the level of the signal at the antenna, so depending on the application the real power of the signal can be calculated by using the formula or experiments.

The basic data format implemented by software, is the same as 18000-7. RTLS broadcast blink messages using this data format periodically. Our system depends on the blink interval. If the blink interval is long, the life of the RTLS tag is prolonged. Otherwise, real time tracking of objects is possible. This is a trade-off. That is it depends on the application. A future study will evaluate the blink interval. This RTLS platform is shown in Figure 11, but the applications are not because they will be the topic of future work. Our RTLS system is basically composed of four readers. The readers receive signals from a transmitter and calculate the receive signal strength (RSS), and then send that data to the RTLS server. The server can estimate the location of the transmitter using RSS received from the RTLS readers. These basic RTLS systems do not have enough coverage to detect the many transmitters that are distributed throughout a large port. To extend this coverage in a port, many RTLS readers can be added to the reader network shown in figure 11, which are form a grid. Then, the higher the scalability of the reader, the further it is from the server. Also the number of readers that can be connected to the server is limited. In order to overcome of those limitations each reader can communicate with its neighbor using radio frequency and delivery its information to the server in a multi-hop manner. The intermediate readers collect and aggregate data from its neighbors, and then forward the compressed data to the RTLS server. Because simple broadcasts are used for communication between readers, sub-problems, such as slot allocation and time synchronization, remain to be resolved. These sub-problems will be considered when a realistic RTLS system will be implemented in our future work.

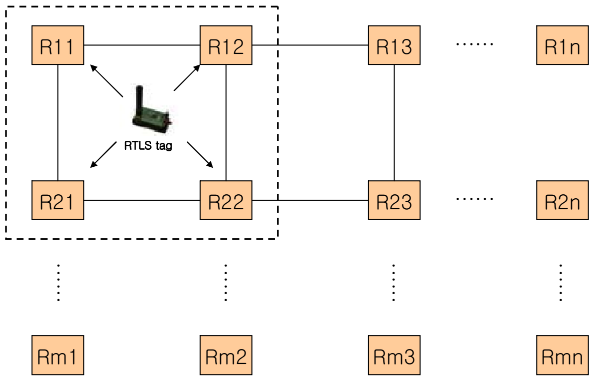
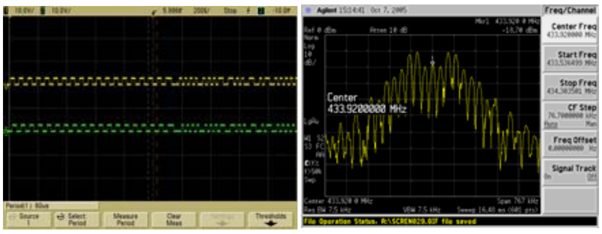


Fig. 11 Extensible RTLS system

IV. System Verification

Figure 12 shows the data format of ISO/IEC 18000-7, 18185-1/7, and 24730-3 or ANSI 371-2 and the evaluation of radio frequency. As can be seen in (a), a packet is comprised of a preamble, data bytes, and a final logic low period. The preamble is comprised of twenty pulses of 60us period, 30 us low followed by a final sync pulse which identifies the communication direction: 42us high 54us low indicates communication from tag to reader. Data bytes are in Manchester code format, comprised of eight data bits and one stop bit. The delay between pulse 1 and pulse 2 is measured in 14us. Figure 12 (b) shows the bandwidth resolution of our RFID system as measured with a spectrum analyzer. As result, the center frequency for the active RFID system is exactly 433.92MHz. Furthermore, our system is applicable to any system platform operating at 433MHz for wireless and non-contact information to manage items.



(a) ISO/IEC data format (b) Bandwidth resolution
Fig. 12 ISO/IEC data format and evaluation of radio frequency

V. Performance Evaluation

새 evaluate the performance of the system a testbed was made in a port in South Korea and an experiment was conducted during a realistic application of IT-based port logistics. The port we used has been enhanced as a hub for a supply chain in recent years. Annual processing capability of the port is increasing as shown in table 1. The survey shows that the number of containers processed in the port have increased dramatically. Thus, the port manger has to consider an efficient method for processing the containers.

TABLE I
ANNUAL CONTAINER PROCESSING CAPABILITY (TEU)

year	Total TEU	Transshipment TEU	total TEU / transshipment
1998	33,634	0	0.00%
1999	416,701	14,040	3.37%
2000	642,834	31,949	4.97%
2001	856,407	165,719	19.35%
2002	1,076,426	314,350	29.20%
2003	1,182,226	343,886	29.09%
2004	1,318,242	356,717	27.06%
2005	1,438,657	340,647	23.68%

Figure 13 shows containers stacked in the port where some tests were performed. In this section, we report on the results from a preliminary performance evaluation of our system, LITeTag. Our goals in conducting this evaluation study were two-fold. First, because tags can use up their limited supply of energy simply by performing computations and transmitting information in a wireless environment, energy conservation in communication and computation are essential. The other is a multi-tag collection. Collecting multiple co-located tags within a communication range is difficult and often unreliable because of collisions.

Fig. 13 The port where our evaluation is performed

A. Energy budget

The sleep mode enables the processors of unused modules, to be shut down thereby saving power. Table 2 shows the power consumptions by the operation mode.

TABLE II
POWER CONSUMPTION IN THE PROCESSOR

State	Condition	Typ.	Max.	Unit
Active	All		5.5	mA
Sleep	WDT	<15	25	uA

There are three possible states for RF: transmitter, receiver, or sleep mode. Additionally, an extra state, called the standby state has been added for state transitions and the initial state. Power consumption for each state are shown in table 3.

TABLE III
POWER CONSUMPTION IN THE RF SYSTEM

State	Condition	Typ.	Max.	Unit
Tx	5dBm	33	40	mA
Rx		14	17	mA
Standby	Osc. on	0.85	1.10	mA
Sleep		0.2	1	uA

Our system runs on a pair of AAA batteries, with a typical capacity of 2.5 amperes hour (Ah). We make a conservative estimate that the batteries will be able to supply 2.5Ah at 3V. Assuming the system will operate uniformly over the deployment period, each tag has 0.303876mA per day available for use. Two AAA (2500mAh) batteries can be used for one year.

B. Identifying multiple tags

Collecting multiple tags has been separated into two groups. One group will periodically identify only one tag. The other is to collect many tags at the same time. In order to periodically identify a tag, several assumptions have been made. First, the time interval is the period of time between when the previous message was completely sent and the start time of the next message. Second, the length of the message is 50 bytes except for the preamble message, and the number of messages is limited to be one thousand. For this experiment, the time intervals are 51.125usec, 101.125usec, 1msec, 10msec, and 30msec. The results of performance evaluation are shown in table 4. Table 4 shows that the successful transmission rate is sufficiently high (99% or more) for every time interval.

TABLE IV
IDENTIFYING ONE TAG

Time interval between messages	# of sent message	# of received message	miss	Pr. (%)
30.0msec	1000	1000	0	100
10.0msec	1000	1000	0	100
1.0msec	1000	998	2	99.8
101.125usec	1000	994	6	99.4
51.125usec	1000	997	3	99.7

In addition, the process for identifying multiple tags was evaluated. Figure 14 shows the tags deployed in an RFID field. To collect multiple tags, the reader broadcasts a collection command, which is read by the tags. Then, the collision arbitration sequence is performed for an efficient and orderly collection of the tags within the reader's communication range. Dynamic frame slotted ALOHA (DFSA) mechanism was used for collision arbitration.

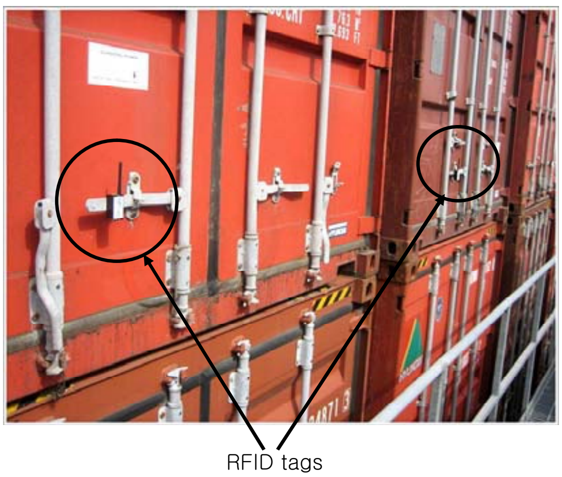


Fig. 14 RFID application attached to containers

The windows size is set to be 57.3ms. A collection round consisted of six slots. Each slot is long enough for the reader to receive a tag's response message. The actual duration of a slot is determined by the reader's collection command type and is a function of the tag's transmission time. All experiments were repeated 100 times. Each experiment was performed by using 1, 5, 10, and 20 tags as test models.

As mentioned earlier, the miss rate in identifying items is important because that is directly related with owner's property. Figure 15 illustrates the success rate for collecting all of the tags. As can be seen the response rates are 99.5% or more. This rate is sufficient to justify deploying the system in a realistic test of port logistics.

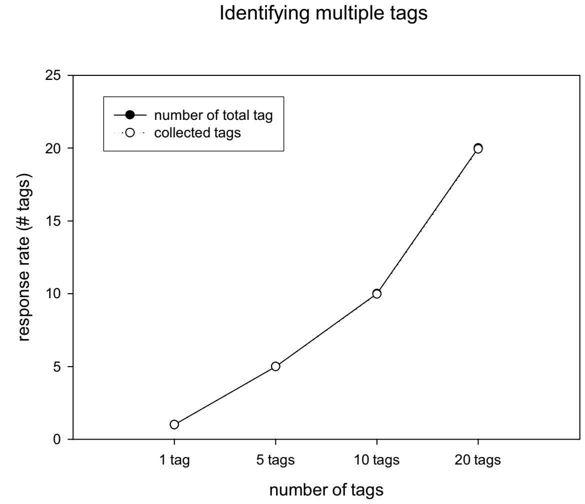


Fig. 15 Success rate all tags collect

Furthermore, we evaluated how much time was needed to collect all of the tags. Figures 16 and 17 illustrate the average time needed for collecting all of the tags. Figure 16 shows that the average time to collect 10 tags is around 600ms. When 10 tags are distributed, it takes about 1 second or less to collect them. The response time is composed of a response period and three empty rounds. One response period consists of several rounds to transmit the tag's information to the reader. DFSA uses the rounds to collect multiple tags.

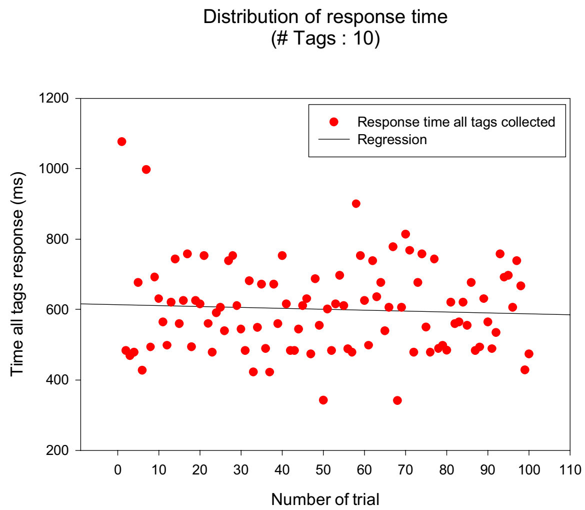


Fig. 16 Distribution of time for collecting 10 tags

We increased the number of tags up to 19 and evaluated how much time was required to collect all of the tags. Figure 17 shows that the time needed to collect all of the tags is around 1sec.

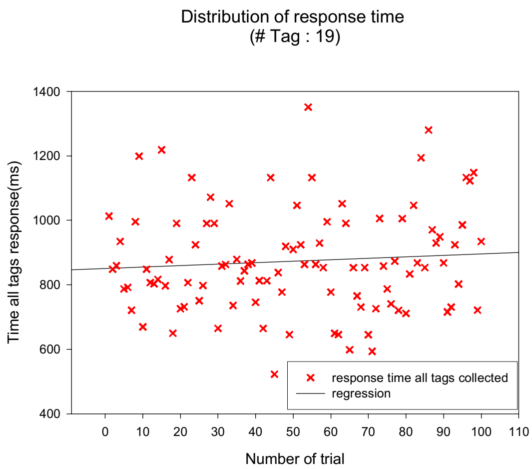


Fig. 17 Distribution of time for collecting 19 tags

Every tag selects their slot in the frame or round. The number of responding tags collected per round is shown in figure 18. When 10 tags were deployed in the RFID field, three or more tags were colleted in each round. When 20 tags were distributed, four or more tags were collected.

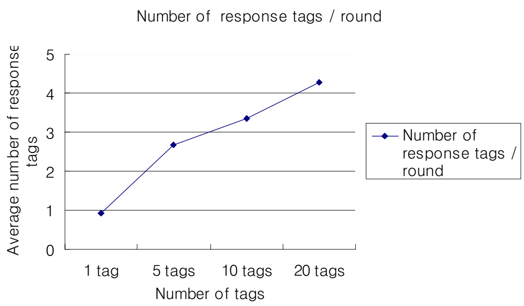


Fig. 18 The number of responding tags per round

Finally, the RSS of the RTLS system was evaluated. In order to measure the received signal strength, a large amount of information was received. Figure 19 shows that RSS values diminished by distance. This result can be useful for locating systems using 433MHz. Also, wireless communication environments can be effected by many external factors. Ensuring connectivity using RSS can provide a powerful communication link.

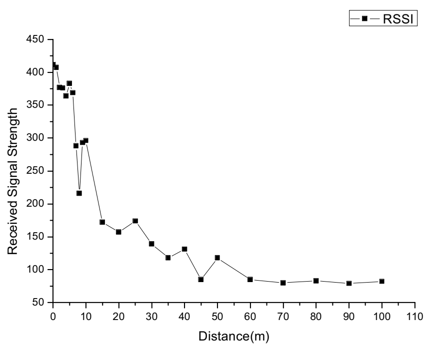


Fig. 19 the RSS distribution of our RTLS system

VI. Conclusion

In this paper, we presented LITeTag for an active RFID system, LITeSeal for an electronic container seal, and the LITeRTLS tag and reader for an RTLS system. Designing and implementing LITeTag enable us to establish relevant system design principles that are useful for other RFID systems. Our system features high identification rates of multiple tags, a reliable energy budget, and standard compliance with ISO/IEC or ANSI. LITeTag is useful for developing and evaluating prototype applications because of the flexibility of the design of both the hardware and software. So, our platform will be suitable for versatile port management applications.

In the near future, we will deploy a network that is larger than this is one by an order of magnitude to achieve many of the same goals as this work. We believe the same design philosophy should be followed in building future large systems. Future work includes the following: 1) reducing the cost of the platform, and 2) a sophisticated design to arbitrate collisions for multiple tags and interactions between different systems.

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