Feasibility Study of Surface Acoustic Wave RFID for Information Processing Asset Management

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Abstract— **Business-to-business (B2B) market of information processing devices such as printers, copier, fax, database servers, data storage arrays and laptops is growing seamlessly and rapidly, especially in developing country. Radio Frequency Identification (RFID) system can be the most promising system for information technology (IT) asset management because of its well-developed level of technology, worldwide standards and its lower price than other wireless protocol such as WiFi, WiMAX, Bluetooth and so forth. However, RFID system for IT asset management in B2B environment is limited by several constraints. So, Surface Acoustic Wave based RFID at 2.4GHz and UHF passive RFID at 900MHz are discussed as a candidate of it. By analyzing objective data, estimating their future performance, and measuring the readability of SAW RFID system in the standard office, we concluded that the most hopeful candidate for B2B information processing device asset management is Surface Acoustic Wave technology based RFID because of its batteryless passive RFID characteristic, relatively long readable range and its potential, and inherent sensor capability and its expandability as well.**

I. Introduction

CURRENT office environment is surrounded by information processing devices such as color laser printers, copy machine, fax machines, workstations, database servers, massive data storage arrays, desktops, laptops and so forth. Common characteristics of these devices are valuable in aspect of their physical price. However, more important common characteristic of these devices is that many of these devices are containing invaluable information and data which we never can buy it again or substitute for it.

Worldwide Business-to-Business (B2B) market of consumer electronics is $ 670 Billion in 2006, which is 55% of overall consumer electronics including information processing devices. Especially, B2B market of information processing devices is 76% of total information processing devices including Business-to-Customer (B2C) market. The annual average growth rate of information technology (IT) B2B market will be 17.5% until 2010 [1]. B2B market of information processing device is growing seamlessly and rapidly, especially in developing country. B2B market of these devices has been leaded only by a few major information technology electronics companies such as Hewlett Packard, Dell, IBM and Samsung.

In the meantime, many major multinational enterprises are locating their new R&D centers, marketing and procurement braches inside emerging markets such as Brazil, Russia, India and China (BRICs). Their technological, financial and operating assets for managing localized branches are totally put in their laptops, servers and data storages. Very valuable asset and information can be in danger of being lost or stolen. More serious things are that the stolen asset and information may flow into their competitor.

Information inside information processing device, sometimes, can be erased or damaged by itself, not by theft or hacker. Most of information processing devices are sensitive to environmental factor such as temperature and humidity. However, if we are able to detect environmental conditions around these devices remotely, severe damage by these must be prevented in advance. The most expected and important candidate is temperature sensing. Every computer device has its own cooling system inside. High-end workstation, server and data storage array have additional cooling system also. Most of internet service companies have special room for air-conditioned room for these devices.

II. RFID as a Solution of Asset Management

In recent years, Radio Frequency Identification (RFID) has been developed as having huge potential to improve the effectiveness of asset tracking in general [2], [3]. RFID systems have been used for many years in applications such as animal tagging [4] and road toll collection [5]. The optical readout systems have the advantage of low cost, widespread use, and established status; but they restricted line of sight

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and proper alignment. Even though they undoubtedly will persist, their shortcomings call for more flexible system. Various approaches for the replacement of bar code and the improvement of logistics management in target applications are being developed.

There are also research groups who are focusing on asset management, especially data centers, which are consisting of vertical racks where each rack may accommodate a variety of equipment. Tracking physical assets in a data center is an essential component of secure, reliable and efficient operations [6]. For example, if a computer server contains valuable and/or sensitive information, such as Social Security Numbers, an enterprise would like to know the whereabouts of that server at all times. Outsourcing companies need to quickly find and re-provision sluggish servers in order to meet service level agreements. Or, more urgently, locate a failed online sales application where each minute of down-time results in significant lost and unrecoverable revenue. However, this application is different from a general IT asset management because they can use 110V power from building wall.

So we are going to propose "new system" for general purpose of IT asset management. One solution of various RFID systems is a global surface acoustic wave (SAW) ID tag system operating in the 2.45 GHz ISM band [7]. Recently, one research group has been announcing their great achievement so that the one fabricated Single Phase Unidirectional Transducer (SPUDT) filters exhibit minimum insertion loss of 5.5-7.9dB together with 3dB passbands of 89-102 MHz [8].

In summary, there must be increasing need of securing, managing and preventing their information processing devices from uncertain or unexpected, and internal or external influences.

III. Office Environment Surrounded by Wireless Devices

In the past, office automation meant that peoples were using their personnel computers or terminals connected with mainframe computer. Peoples were trying to use fax machine to send document rather than internet or e-mail. Screens were black-and-white CRT. The office environment has been changed completely compared to the past.

Let's remind real office environment. We are surrounded by numerous digital information processing devices like laptops, cellular phones, GPSs, MP3 players and Bluetooth headset. All devices are wireless, therefore we can say that we are definitely surrounded by more or less strong and various electromagnetic waves.

Knowing and defining our office environment can let us know what the problem is and how it is going to be solved.

The standard office in Eng-IV building, UCLA is shown as Fig. 1, which is the view from the right main door. Overall area of the office is about 1438.44ft^2(=133.72m^2). Each cubicle is divided by separators. And lights with metal tube are placed on the ceiling.

Some people have more than 1 laptop (Fig. 2.). As we can see in Fig. 2., real office is surrounded by various wireless devices. These devices are transmitting different frequencies; WiFi is 2.4GHz, PCS is 800MHz, GPS is 1.6GHz and Bluetooth is 2.4GHz also. Especially, 2.4GHz band is very busy because Bluetooth, WiFi, Wireless mouse dongle, and

Fig. 1. The model office

SAW RFID are using this band as a ISM band.

The floor plan of this office is shown as Fig.3. The width is 47.98ft (= 14.83m) and the depth is 29.98ft (=9.14m). Total area is 1438.44ft^2 (=133.72m^2). There are two main doors (at the bottom of Fig3) and windows (at the top of Fig 3.) on the opposite side. In this office, there are totally 11 laptops, 4 workstations, 1 laser printer, 1 fax machine, 2 massive data storages and 1 server.

IV. Requirement of RFID System for B2B IT Asset Management

B2B environment is totally different from B2C. Customers of B2B are enterprises, not individual customers. Therefore, they can procure lots of information processing device at one time if these devices are useful, or if they can give much more profit than before.

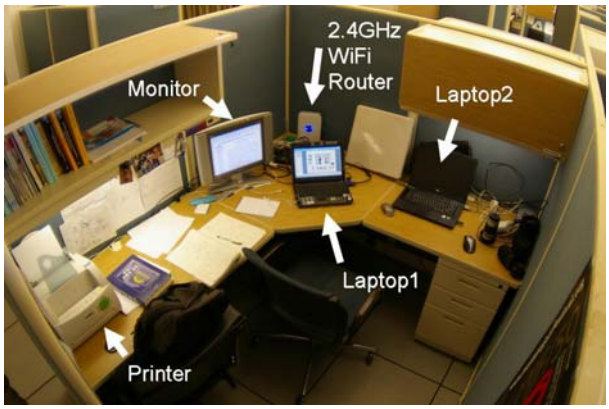

Fig. 2. Example of personnel cubicle

One of the biggest challenges to tracking assets prohibits

from the fact that equipment in the office is moved. The most obvious reason for moving equipment is when re-arranging the office layout. Some motivations for this are organizational such as an expansion of capacity, moving to new facilities, or even a change in the organization chart.

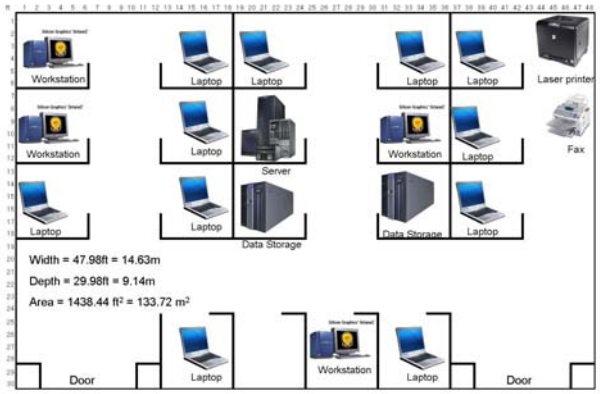

Fig. 3. Floor plan of office

Movable asset management is still not appropriately supported by existing IT systems. Items are not managed individually, information about location, status and usage is not accurate or lacking. This can cause delays in industrial operations, inefficient use or excess inventory of costly assets, and even lead to damages or accidents.

TABLE I
COMPARISON BETWEEN SAW RFID AND IC BASED UHF RFID

Items	SAW based Passive RFID	IC based Passive UHF RFID
Frequency	2.4GHz	900 MHz
Maximum range	19ft	18ft
Threshold voltage	No	Yes
Potential maximum range	Longer	Shorter
Interference	Better	Worse
Sensor	Temperature embedded	No
Semiconductor Process	Simple	Complex
Read/Write	No	Yes
Others	Ideal 2.4GHz is busy, sensitive to water	

So, our research will be restricted within narrow limit such as finding a suitable RFID system and testing feasibility of such a system for B2B IT asset management.

For B2B application, RFID system for IT asset management should be limited by several constraints.

1) Passive RFID: An active RFID needs maintenance inevitably. Some of new products can long last 1~2 years. Some prototype asset management system using long-life active RFID tags is based on 300MHz frequency band to avoid interference from WiFi [9]. The communication range was up to 20m in case of line-of-sight, and 10m in case of indoors.

However, there's no change of its basic characteristic of maintenance. For example, most of fire alarms in buildings are powered by DC battery. Their life is up to 1 year. However, sometimes, you might have heard beep noise from fire alarms in your home, office, subway or the other public places, which stands for running out battery.

More important thing is "antitheft". If RFID for security alert needs DC/AC power, thieves are going to pull out power cable from the laptop. Otherwise, if there needs DC battery for active RFID, they are going to eliminate the battery also. So, passive RFID is not a negotiable requirement.

2) Long transmission range: Maximum/effective transmission range of RFID system is key issue. One of the reasons is that the read range is deeply related to Total Cost of Ownership (TCO) of the company. The longer range can give us many benefits such as additional applicable functions such as Real Time Location System (RTLS). The ultimate final goal of asset management must be making a precise RTLS. Most of current commercial RTLS system use active RFID for each person and WiFi for laptop and other mobile devices.

There are couples of analysis about transmitting range of passive UHF RFID [10]. And fundamental read range limitations about two major types of passive (i.e. batteryless) RFID were calculated by Hartman for the first time [11]. The analysis showed 2.4GHz SAW based RFID potentially, not really, had a 30X read range superiority compared to passive IC based RFID operating 900MHz. However, these two major type of passive RFID show similar maximum range at present. But, theoretically, SAW RFID has a potential benefit of longer range accessibility than UHF passive RFID because SAW based RFID doesn't have threshold voltage. Table I shows pros and cons of SAW RFID and general passive UHF RFID.

3) Physical sensing functions: The information inside database server and data storage of company is invaluable. Some of information processing devices are sensitive to environment. However, if we are able to detect environmental conditions around these devices remotely, most of serious damage by these can be prevented in advance.

If we can get not only physical data such as pressure, velocity and acceleration, but chemical/biological data such as Volatile Organic Compound (VOC) and carbon dioxide (CO2) from sensor, we might get more chance beyond simple asset management of IT device.

The most expected candidate is temperature sensing. High temperature can shut down computer. Frequent shut-down let hard-disk-drive (HDD) fell into coma. To protect their

Central Processing Unit (CPU) from being overheated, every computer device has its own cooling system inside. High-end workstation, server and data storage array have additional cooling system also. Most of internet service companies have special room for air-conditioned room for these devices.

One another expected candidate is acceleration sensing. When we move expensive server or massive data storage array to the other place, or when it comes to be in earthquake, if these device has a function of detecting acceleration, Hard Disk Drive (HDD) can be automatically locked in order to prevent permanent data loss.

TABLE II
TAG SPECIFICATIONS

Items	Specifications
Type	Slot T-ID - slot antenna - function = ID + Temperature
Transmission range	6.5m (ID), 5.5m (Temperature) with 18dBi antenna
Temperature range	-55C to +400C
Resolution Temperature	0.01C to 0.2C
Accuracy of Temperature	+/- 2C

TABLE III
READER SPECIFICATIONS

Items	Specifications
Frequency band	2.4GHz-2.483GHz (ISM S-band)
Interface	RS 232
Max. reading speed	300ms
Max. output power	<+9dBm
Protection class	IP54

In recent years, a lot of application of SAW based sensor has been presented [12]. As shown in [13] and [14]-[18] by bending, stretching, and compressing the SAW substrate, sensors for torque, force, displacement, vibration, acceleration, etc. were made. Sensors for the Tire Pressure Measuring System (TPMS) have been developed to monitor the tire pressure [14] as well as the friction between the tire and the road surface [19].

There are two major candidates for passive RFID as we mentioned above, and they have pros and cons like Table I. Considering all of these requirements, SAW technology can be a strong candidate of this case to be sure. So, we take SAW RFID system for study of a B2B IT asset management.

V. SURFACE ACOUSTIC WAVE RFID

A. Surface Acoustic Wave Technology

Surface Acoustic Wave (SAW) Radio Frequency Identification (RFID) system has many unbeatable merits as a security system for it. SAW can detect ID as well as physical properties such like temperature, pressure, acceleration [20] and biomaterial [21].

SAW technology is commonly used in the electronic circuitry of everyday appliance, such as mobile phones and televisions, where the waves are used to filter frequencies [22]. SAW RFID uses its piezoelectric wave characteristic as transmitting the data inside tag as shown in Fig. 4. SAW tags use piezoelectric crystals with “reflectors” at pre-determined intervals to represent the tag’s data (which can be read by variations in amplitude, time, phase and/ or other variable). When the incoming radio energy is transduced to a soundwave propagating along the surface of the tag, each location reflects part of the signal back. The spacing of these reflections (or echos) indicates the location and relative position of each reflector. The position of each reflector can then be calculated and translated into a data representation.

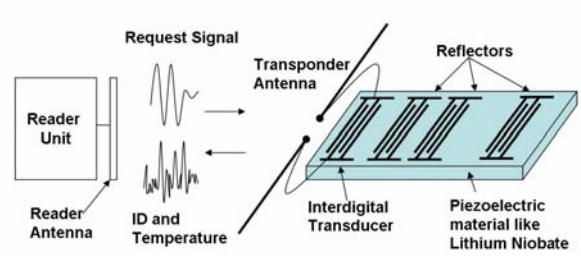

Fig. 4. Principle of SAW technology

In recent years, SAW sensors have gained increasing attraction for industrial measuring. When designed as a one port device which is connected to an electromagnetic antenna, it can easily be requested solely by a wireless radio link [23]. With such a SAW transponder typically having delay times in the order of some micro seconds (us), the data signals can easily be separated from the echoes due to multipath radio effects in the VHF/UHF range. Such sensors need neither wiring nor batteries.

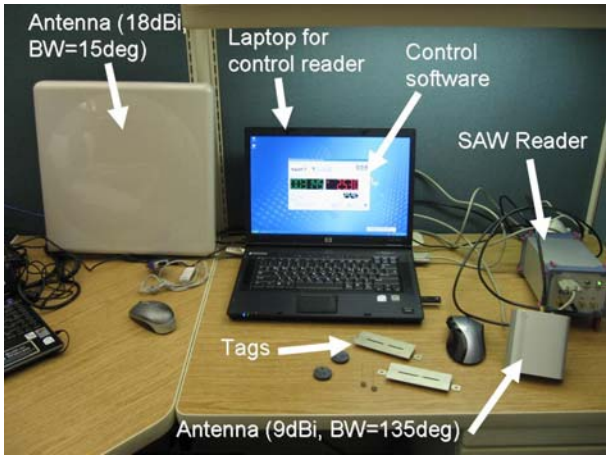

Fig. 5. Reader, Tags, Antennas and Operating software

In Europe, the ISM band at 433.92 MHz has a bandwidth of 1.74MHz. With 25mW EIRP and 10dB SNR we get transceiver-SAW transponder interdistances of up to 10m which is sufficient for interrogating purpose.

In [23], [24] it has been shown, that classical sensors with a varying impedance can be read-out wirelessly, when combined with SAW transponders. For this application, an IDT is used as a reflector, which is loaded by the external sensors. A variation of the load impedance changes the acoustic transmission and reflection properties of the IDT connected to the classical sensor [25].

In this business case study, SAW RFID system is only able to detect ID and temperature. However, if there is need of other physical/chemical sensing, original SAW system easily can be upgraded by simple modification of software and change of each tag, not the reader system. [22]

B. *SAW Reader and tags*

The CTR RF-IDT system consists of 1 reader, 2 different antennas for reader and several tags as shown in Fig. 5. The reader is controlled by the control software in laptop. Table III shows major specification of the reader. Frequency band is ISM S-band and maximum output power is 9dBm.

These SAW RFID system is SAW based wireless high frequency FM identification and sensing system. The transponder is totally passive SAW device consisting of ID, antenna and temperature sensing parts. This can measure temperature up to 400C. Table II shows the detail specifications of the tag.

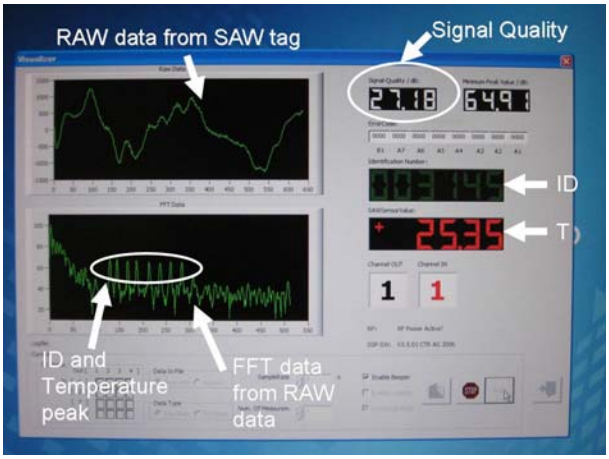

Fig. 6. Detecting ID and temperature

The reader unit sends a continuous frequency sweep signal in the ISM S-band. One total read cycle takes less than 500ms. Table III shows the detail specifications of the reader. A direct line-of-sight between the reader and transponder is not required.

In-house software is provided but this is not middleware but just control software for uploading and downloading the firmware for operating the reader. Not only ID and temperature but also frequency response at SAW reader by SAW tag can be displayed like Fig.6. Firstly, raw data, left top window in Fig. 6, from the tag is received. Then software transforms raw data to FFT data, left lower window in Fig. 6. Several peaks are the ID and the temperature of the specific SAW tag. If signal becomes weak, these peaks are going down and their sharpness is going to be blunt, which means their signal-to-noise (SN) ratio becomes bad. Finally there's no discrimination between peaks and dips. Temperature can be measured up to 400C.

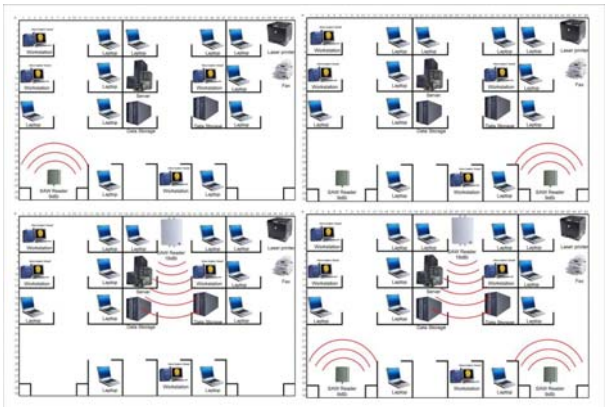
Fig. 7. Detecting ID and temperature

VI. Actual Office Environmental Test

A. *Conceptual Security System Architecture*

Office rooms usually have 2 or more doors, and there are windows at the other side (See Fig. 1 and Fig. 3). To evaluate suitability of SAW RFID system as the main system for asset management of B2B information processing devices, we located two SAW readers, with 9dBi antenna (beam width = 135deg), which have been placed on the top of each door (See Fig. 7).

These readers are for security check for antitheft and are going to send alert message to the "central security center" when outing any asset without pre-approval is checked. Candidate total security system flows are shown as Fig. 8. The central SAW reader is watching ID and temperature of several SAW tags. When it comes to missing ID, it calls the SAW readers at the doors. Then they keep watching door until finding ID. If there is no signal inside office or if there is crossing signal through the doors, RFID security system will send alert to "central security center". But, because middleware for this system has not been made, we couldn't test as this flow chart. We are going to develop security system using middleware as a future work.

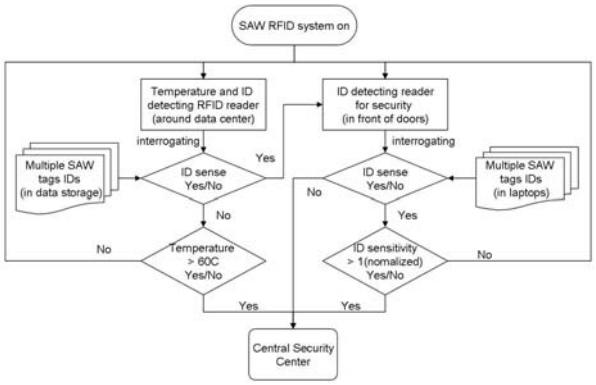

Fig. 8. System Flow

Instead of using 3 different readers for testing it simultaneously, we did experiment 3 times, practically. To measure Signal Quality, we moved experimental setup in every step like Fig. 9.

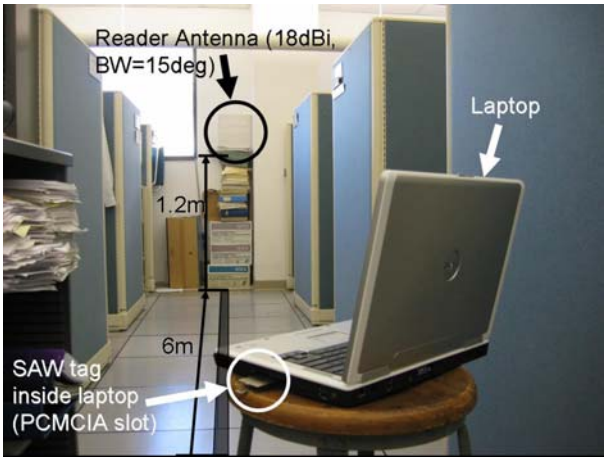

Fig. 9. Detecting ID and temperature

B. Power Calibration for Actual Implementation

The radiated power of SAW reader device is strictly restricted by firmware because each country has strong legal regulation of RF power. The maximum efficiency radiated RF power $P_{radiated}$ depends on adjustable value; P_{max}, damping losses in the connection cables and connectors ($Loss_{cable\text{-}length}$, $Loss_{cable\text{-}connector}$) and the antenna gain ($Gain_{antenna}$), $P_{radiated}$ can be derived according to the following equation (all values in dBm):

$$P_{radiated} = P_{max} - Attenuator_{value} - Loss_{cable\_length} - Loss_{cable\_connector} + Gain_{antenna}$$

The damping loss ($Loss_{cable\_length}$) of the specific antenna cable DT58 amount to about 0.5dBm/m. The connector losse ($Loss_{cable\_connector}$) is to be 1dBm.

For example, in case of 9dB antenna,
$P_{radiated}\ [dBm] = 3 - 2X0.5 - 1 + 9 = 10$

So,
$P_{radiated}\ [mW] = 10^{(10/10)} = 10$

In case of 18dB antenna,
$P_{radiated}\ [dBm] = -6 - 2X0.5 - 1 + 18 = 10$
So,
$P_{radiated}\ [mW] = 10^{(10/10)} = 10$

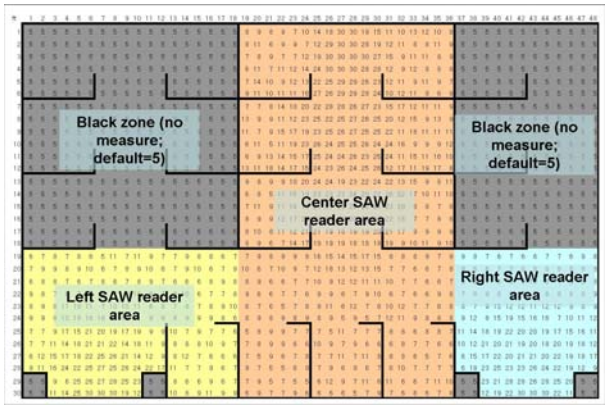

Fig. 10. Signal distribution of the office

C. Non-Line-Of-Sight(NLOS) Propagation

Non-line-of-sight (NLOS) is a radio transmission across a path that is partially obstructed, usually by a physical object in the Fresnel zone.

Many types of radio transmissions depend, to varying degrees, on line of sight between the transmitter and receiver. Obstacles that commonly cause NLOS conditions include concrete on walls, steel separators, human bodies, and high voltage electric power line. Some of these obstructions reflects certain radio frequencies, while some simply absorb or garble the signals; but in either case, they limit the use of many types of radio transmissions, including most of those used for Wi-Fi. As we can see in Fig. 10, general office environment is nothing but NLOS condition.

How to achieve effective NLOS performance has become one of the major questions of all RFID system. Currently, the most common method for dealing with NLOS conditions on wireless computer networks is simply to place relays at additional locations, sending the content of the radio transmission around obstruction. Therefore, SAW RFID system also should adopt this kind of methodology for acquiring good NLOS performance. This is also directly connected with TOC of overall system.

So we measured the signal strengths between each 3 readers and tags, at more than 1000 different points to investigate what happens and what can be existing problems and potential problem as well, when SAW RFID system was used in the office.

VII. RESULTS

In Fig. 6, the upper graph shows the measured raw data, while the lower graph gives the results of the Fast Fourier Transform (FFT) analysis. The value in the field Signal Quality is a measure for the quality of the HF signal. The value is a logarithmic scale and noted in dB. The higher the value, the better the signal quality. A good signal is in the range of 25dB and above; weak signal levels below 20dB can read to occasional blackouts of radio transmission.

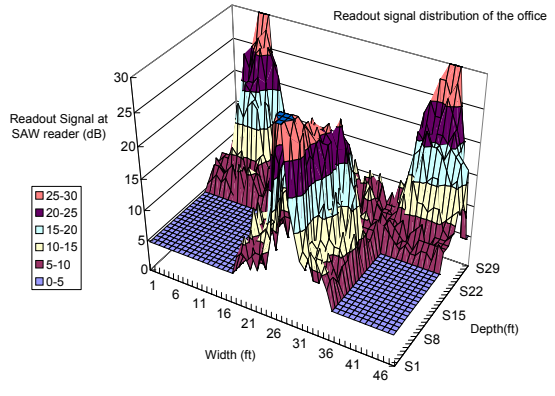

Fig. 11. Signal distribution of the office

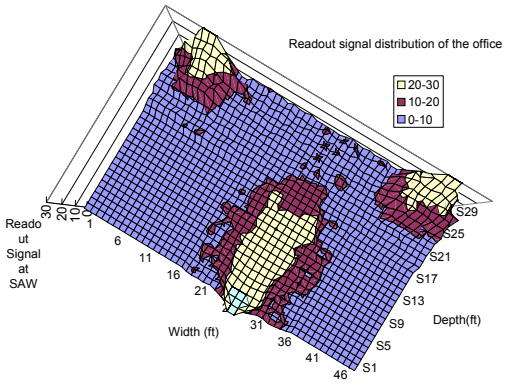

Fig. 12. Readout signal distribution of the office. ID and Temperature; >20, ID only; >10

So, we measured this Signal Quality as an index of readability of SAW RFID as shown in Fig. 10, over the whole office in the step of each foot. The Black Zones in Fig. 10 are not measured, because these zones are far from each SAW readers. Moreover, total points to measure are more than 1500 point because the whole office area is divided by each one foot. So we treat this Black Zone as ambient signal strength (=5dB).

The signal distribution of the office is shown in Fig. 11. Maximum readout signal is 30dB and ambient noise signal, which means the signal strength on the reader when there is no tag around the reader, is 5dB. The 25dB-30dB area is very strong and stable area able to detect ID as well as temperature.

Beam width of 18dBi antenna is only 15deg. Because of this highly directional antenna, the signal from the center SAW reader is very straightforward. There is diffraction phenomena of EM wave from the central SAW reader. In Fig. 12, some strong signal was detected little bit far from the center, which is at the corner of two separators at cubicle. Beam width of 9dBi antenna is relatively broad like 135deg. Because of it, the signal from the door is very broad, but weak.

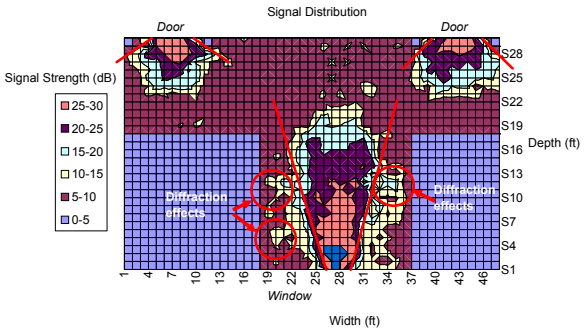

Fig. 13. Readout signal distribution of the office. Good signal is 25dB or over.

Bright area of Fig. 12 shows signal quality of 20-30dB. Good signal is 25dB or over. But, experimentally, we make sure that 20dB is suitable strength of signal to read ID clearly.

In Fig. 13, we can see signal fluctuations on far from the reader. This signal fluctuation may not be caused by real connection between the reader and the tag. When we were testing, all major strong WiFi routers was turned off. But several 2.4GHz devices like personnel Bluetooth device and wireless dongle were not turned off because this circumstance is much close to real situation. We guess these fluctuations have come from interference from these 2.4GHz. This is also demerit of 2.4GHz SAW RFID, same with what we already mentioned previous chapter.

In Fig. 14, the maximum effective readable range with line-of-sight condition of real office environment was 19 ft (=5.79m) at 18dB area which is minimum required signal strength in real experiment. The maximum effective readable range with non-line-of-sight (NLOS) condition of real office environment was 15 ft (=4.57m) at 18dB.

VIII. CONCLUSIONS

1) We derived that the best and the most hopeful candidate for B2B IT asset management is SAW RFID because of;

- Batteryless Passive RFID
- Relatively long readable range and its potential
- Inherent sensor capability and its expandability

2) The security system architecture is proposed with the actual experimental data using real SAW RFID system.

3) The distribution of the signal strength of all around the standard office has been acquired by testing more than 1000 point. We also acquired data in condition of NLOS. These

data can be helpful data whoever wants to build RFID system using SAW technology.

- Maximum readable ranges are up to 19ft (=5.79m) in LOS condition and 15ft (=4.57ft) in NLOS condition

- Diffraction of EM wave was observed at the backside of some of office dividers. This phenomenon inversely can use to enhance readable range.

- Signal fluctuation due to other 2.4GHz commercial

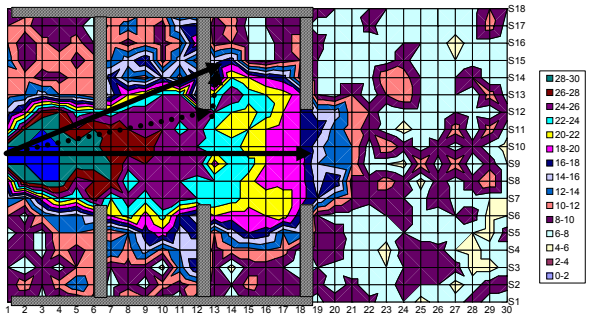

Fig. 14. Readout signal distribution of the SAW reader at the center

devices was observed around the office.

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