Analysis of signal characteristics of Zigbee for ubiquitous service

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***Abstract*—** This paper introduces Zigbee based ubiquitous service. Most of ubiquitous services require the position information. Positioning algorithms utilize the transmission characteristics of the signal. Zigbee based positioning researches have been conducted mainly for the spatial factors inside the building. This paper proposes the possibility to consider the temporal factors of Zigbee signal and analyzes empirically the signal characteristics influenced according to the temporal factors as well as the spatial factors for ubiquitous services based on Zigbee sensor network.

***Index Terms*—** LQI, RSSI, signal characteristics, Zigbee.

I. INTRODUCTION

As ubiquitous technologies are considered as base technologies of the future information communication industry, it is forecasted that various communication technologies, from PAN (Personal Area Network) to WAN (Wide Area Network), will be integrated and operated. Bluetooth and Zigbee have been raised as the representative PAN technologies. There is an opinion that the applications of Zigbee are overwhelmed those of Bluetooth in the near future since Zigbee has the merits of low cost and low power.

A. Ubiquitous services based on Zigbee

The Zigbee stack architecture includes a number of layered components including IEEE 802.15.4 2003 medium Access Control (MAC) layer and Physical (PHY) layer and well as the Zigbee network (NWK) layer [1]. Each of these provides applications with its own set of services and capabilities. The current version of Zigbee is ZigbeePRO in 2007 for home networking and industrial automation applications starting from Zigbee-2004.

Zigbee can support the various applications from the wireless networking of home and/or offices to the ubiquitous computing infrastructures. Zigbee targets the small size, low cost, low power and simple functional application markets. For example, the temperature sensors of the home network may transmit the information only a few times in an hour. This requirement needs a small and low cost device and wireless low power consuming device rather than a wired device.

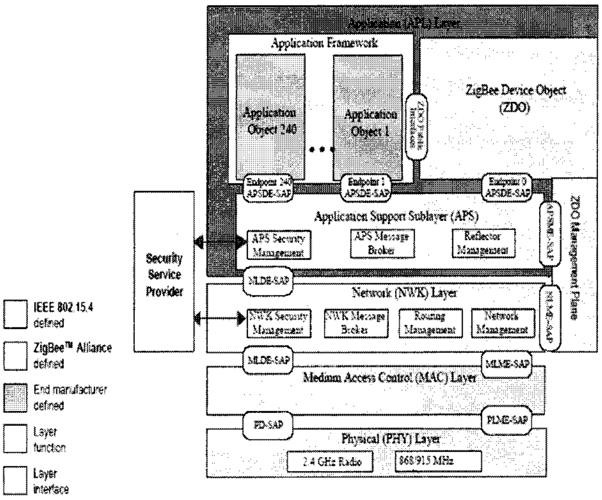

Fig. 1 Zigbee protocol stack

The early stage of Zigbee focused on the home automation and commercial building automation market. From then, understandings of finer merits and functions of Zigbee extend Zigbee applications to the diverse areas, like Advanced Metering Infrastructure (AMI) as new metering system, welfare for the aged, life assistance, medical instruments, communication, asset trace, entertainments, and so on. As well as Zigbee2007 (Zigbee PRO), Zigbee alliance finished the design of application profiles to define the kinds of devices and the communication languages which are supported in the communication networks. Starting from Home Automation (HA) profile, Smart Energy

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(SE) and Commercial building automation (CBA) are processing. In addition, IEEE 11073 related to Personal health and hospital care (PHHC) is going to be developed on Zigbee. IEEE 11073 is the standard which defines the safe transmission and data structure of medical data.

Most of aforementioned various ubiquitous services based on Zigbee require the relative or definitive position for both indoor and outdoor circumstances. Hence, the signal characteristics of Zigbee should be analyzed for indoor and/or outdoor environments. However, most legacy researches about Zigbee positioning focus on the indoor spatial conditions [5-10].

B. Motivation of Zigbee signal measurement

Our prior work was to develop the positioning algorithm based on fingerprint K-NN algorithm using Zigbee devices. To make the fingerprint map, we measured the signal strength several times. The measurements had been conducted from fall to winter and inside and outside of the building. And we found that the outside characteristics of the signal strength are different from inside characteristics.

We thought that this condition could be similar to eLoran System. In positioning applications, GPS is dominant technology for outdoors. eLoran is regarded as a GPS backup system. eLoran system compensates both the spatial error term and the temporal error term of received signal. These two error terms are defined as the Additional Secondary Factor (ASF) and caused by the ground conductivities and terrain. The ASF are generated in the surface wave transmission.

The influence of temporal variations about Zigbee signal has not been published before. Since Zigbee signal frequency is not a surface wave like eLoran signal and this kind of transmission error is not a common research topic in telecommunication.

Therefore, we introduce eLoran system briefly as the validation of our approach, present the possibility of temporal variations of Zigbee signal based on the empirical measurements and propose the early conceptual method to handle the temporal variations.

This paper consists of 4 chapters. Chapter 1 presents the overview of this research. Chapter 2 introduces eLoran system which motivates this paper's approach. In chapter 3, several measurements of RSSI and LQI are introduced and a conceptual proposal for more accurate positioning algorithm for ubiquitous service considering temporal noise factors is presented. Chapter 4 concludes this paper and introduces the future works.

II. eLoran

Enhanced Loran (eLoran) is an internationally standardized positioning, navigation, and timing (PNT) service for use by many modes of transport and in other applications. It is the latest in the longstanding and proven series of low-frequency, LOng-RAnge Navigation (LORAN) systems [2].

eLoran meets the accuracy, availability, integrity, and continuity performance requirements for aviation non-precision instrument approaches, maritime harbor entrance and approach maneuvers, land-mobile vehicle navigation, and location-based services, and is a precise source of time and frequency for applications such as telecommunications.

eLoran has the potential to back up GNSS, taking over seamlessly if the satellite signals are lost, thus allowing users to continue to operate and keeping communications and surveillance systems running.

A. eLoran System

eLoran system consists of transmitting stations, monitor stations, control centers, and user's equipments.

Transmitting stations are synchronized to an identifiable, publicly-certified, source of Coordinated Universal Time (UTC) by a method wholly independent of GNSS. This allows the eLoran Service Provider to operate on a time scale that is synchronized with but operates independently of GNSS time scales.

Control centers maintain the published very high levels of availability and continuity.

Monitor sites/Reference Stations are located in the eLoran coverage area, are used to provide integrity for the user community. The receivers used at these sites monitor the eLoran signals and provide real-time information to the control centers regarding signals in space. This is the concept of loran (differential Loran) like DGPS of GPS.

Temporal error terms are measured periodically at the monitor sites and broadcasted as a part of dLoran.

Users are notified immediately if any abnormalities are detected. Some of the monitor sites will be used as reference stations to generate the data channel messages. Selected sites will also have a t least one highly accurate clock for synchronization to UTC to provide time and frequency corrections for timing users.

An eLoran receiver is capable of receiving and decoding the data channel messages and applying this information based on the user specific application. This information, coupled with the published Signal Propagation Corrections (database related to spatial term in section B), provides the user with a highly accurate PNT solution.

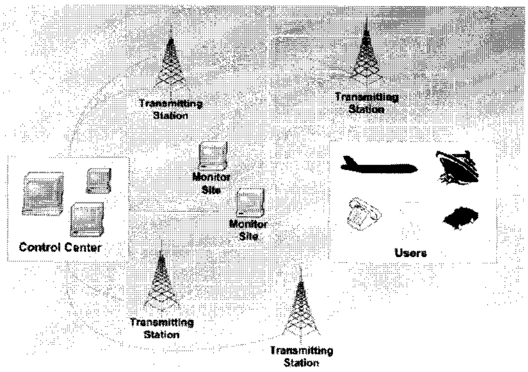


Fig. 2 eLoran system concepts

B eLoran signal characteristics

Location based applications mostly calculate their own position based on TOAs (Time Of Arrival) of several transmitters. Signals are influenced and delayed by some environmental noises during the propagation.

A significant factor limiting the accuracy of eLoran system is the spatial and temporal variation in the TOAs observed by the receiver. A significant portion of these variations are due to the signals propagating over paths of varying conductivity; these TOA modifications which compensate for propagating over non-seawater paths are called additional secondary phase factors(ASFs)[3].

Hence, a key component in evaluating the utility of eLoran as a GPS backup is a better understanding of ASFs and a key goal is to decide how to mitigate the effects of ASFs to achieve more accurate positions. In [4], the impact of the spatial variation of the ASF was considered and a single spatial ASF value didn't provide the desired accuracy for maritime users and the temporal adjustments applied by using a static reference site in a differential Loran scenario was adapted.

- spatial term : due to differences in the loran signal propagation path (i.e., topography, land versus sea, etc). Accounting for this term requires knowledge of a recent position which accesses a database of spatial variation for each visible Loran transmitter.
- temporal term: for short term TOA variability in a local area. Correcting for this term requires a nearby monitor site with broadcast communications capability.

The early research of Loran was focused on the spatial term. As a back up system for GPS, eLoran was required to meet the more accurate positioning level and began to study the temporal variations of eLoran signal. The recent researches are about the installation of monitor stations, measurements and broadcast mechanism of temporal noise term, etc.

III. ZIGBEE SIGNAL ANALYSIS

To calculate the accurate position of mobile devices, TOA (Time of Arrival) or TDoA (Time Difference of Arrival) can be used and in this case, the time synchronization among mobile devices and networks should be guaranteed. To reduce the cost of the time synchronization, the received signal strength of incoming radio signal can be used. That is, the characteristics of received signal strength from transmitters should be analyzed and according to the characteristics of received signal strength, the distances from the transmitters are estimated and the position of mobile device can be calculated. There are two indicators, RSSI (Receiver Signal Strength Indicator) and LQI (Link Quality Indicator) in Zigbee.

A. Prior work

1. RSSI

The idea behind Received Signal Strength is that the configured transmission power at the transmitting device (PTX) directly affects the receiving power at the receiving device (PRX). According to Friis' free space transmission equation [5], the detected signal strength decreases quadratically with the distance to the sender [6].

$$P_{RX} = P_{TX} \cdot G_{TX} \cdot G_{RX} \cdot \left(\frac{\lambda}{4\pi d} \right)^2 \qquad (1)$$

P_{TX} = Transmission power of sender
P_{RX} = Remaining power of wave at receiver
G_{TX} = Gain of transmitter
G_{RX} = Gain of receiver
λ = Wave length
π = Distance between sender and receiver

In embedded devices, the received signal strength is converted to a received signal strength indicator (RSSI) which is defined as ratio of the received power to the reference power (P_{Ref}). Typically, the reference power represents an absolute value of P_{ref}=1mW.

$$RSSI = 10 \cdot \log \frac{P_{RX}}{P_{Ref}} \qquad [RSSI] = dBm \qquad (2)$$

In practical scenarios, the ideal distribution of P_{RX} is not applicable, because the propagation of the radio signal is interfered with a lot of influencing effects e.g.

- reflection on metallic objects
- superposition of electromagnetic fields
- diffraction at edges
- refraction by media with different propagation velocity
- polarization of electromagnetic fields

Fig. 3 shows that the measured RSSIs rather differ from theoretical RSSIs defined in equation (2) [6]. they measured the RSSIs with Chipcon CC1010 Zigbee device.

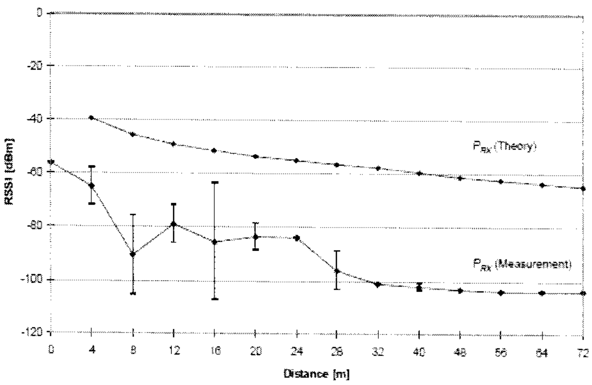


Fig. 3 Received Signal Strength of a Chipcon CC1010

We conducted the same indoor test with CC2420 Zigbee device within 40m ranges. Fig. 4 shows the comparison of measurements vs. theory. The dashed line represents the theoretical values and the others are the values for 8 times measurements, respectively. All of measurements differ from theoretical values.

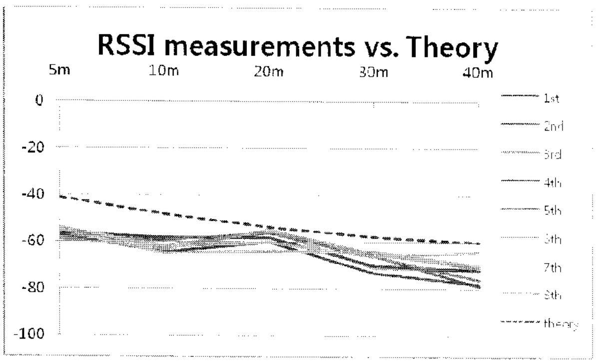


Fig. 4 Comparison of RSSI measurements of CC2420 vs. Theory

2. LQI

The propagation of radio packets reduces the quality of RSSI extremely. It makes positioning become imprecise. Another method to determine the distance from the transmitter is based on the Link Quality Indicator (LQI) of the transmission. It represents a number of required retransmissions to receive one radio packet correctly at the receiver.

In [6], the LQI of the Zigbee based devices (CC2420) was measured. Using two sensor nodes, one node serves as a reference device (beacon) and transmits packets continuously in a loop. The other one logs the LQI of the incoming radio packets and forwards the LQI to the connected PC.

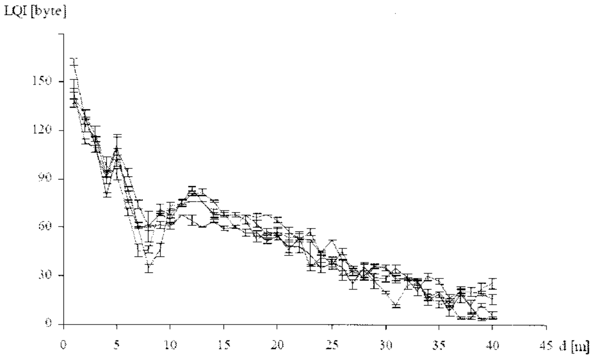


Fig. 5 LQI vs. distance between 2 Zigbee devices.

We conducted the same test with the same Zigbee based devices (CC2420) and present them in the next section.

B. Analysis of Measurements in this paper

CC2420 provides two useful measurements: RSSI and LQI. RSSI is the estimate of the signal power and is calculated over 8 symbol periods and stored in the RSSI VAL register. The minimum and maximum LQI values (0x00 and 0xff) should be associated with the lowest and highest quality. Scaling link quality to LQI is calculated per Software.

LQI = (RSSI register value + 38) * 4

So, measurements statistics of LQI and RSSI can show the similar conditions.

We conducted the measurements for both of two indicators, RSSI and LQI.

1. Temporal & Spatial Analysis of LQI measurement

Fig. 6 and Fig.7 show the LQI measurement results of winter weather. Fig. 6 shows the outside measurement and Fig. 7 shows the inside measurement. The lines represent the each measurement of 10 trials.

In Fig. 6, we can confirm that LQI measurements are influenced by the temperature, comparing to Fig. 7. Under the same weather, the outside measurement data tend to be more fluctuant than the inside data. We can guest that this is caused by the temporal factors like eLoran. Besides, during the outdoor measurements, the Zigbee CC2420 devices often were not operable.

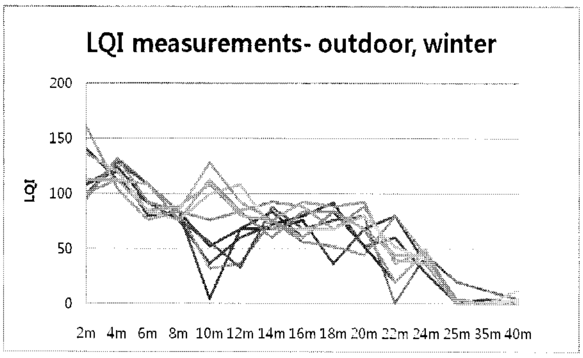
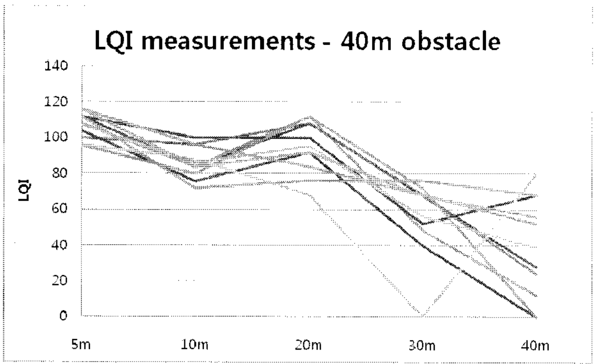
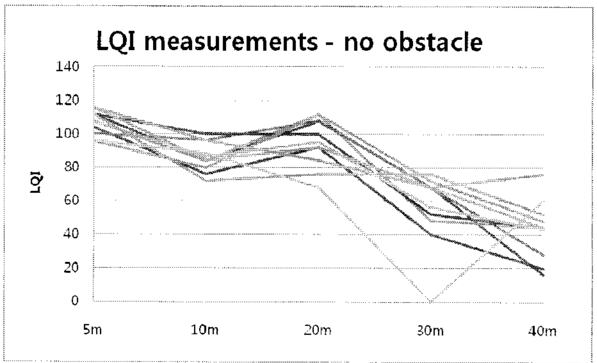


Fig. 6 LQI measurements in winter, outdoor condition

Fig. 7 shows the indoor LQI measurement analysis according to distances. The difference between (a) and (b) is the existence of an obstacle at 40m. There are more variations when an obstacle exists at 40m. The peculiar point about at 30m of (a) and (b) which has 0 LQI was the affection of the human obstacle. Through the simple experiments, we can see the influence of the multipath problem of obstacles in these figures.



(a) LQI measurements – 40m distance



(b) Obstacle at the 40m distance

Fig. 7 LQI measurements.

2. Temporal & Spatial Analysis of RSSI measurement

From Fig. 8 to Fig. 9 shows the characteristics of measurements of RSSI. Similar to LQI's measurements, the result of outdoor environment in cold temperature shows that RSSI may be influenced by the temporal factors like temperature.

RSSI values of the outdoor measurements are distributed from -40dB to -90dB, while RSSI values of the indoor measurements are distributed from -54dB to about -80dB except the peculiar value at 30m position.

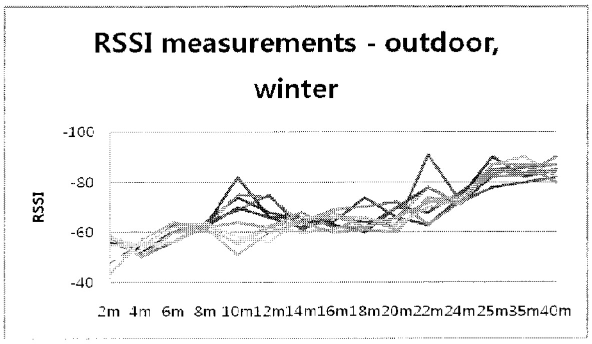
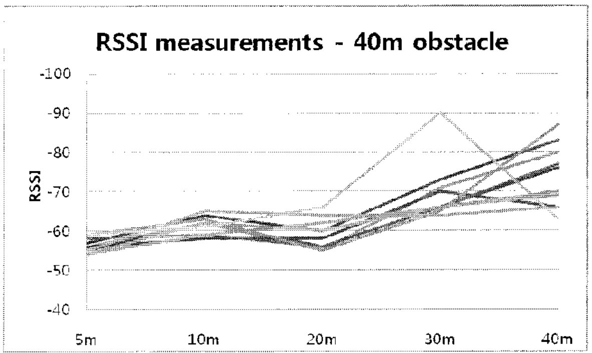
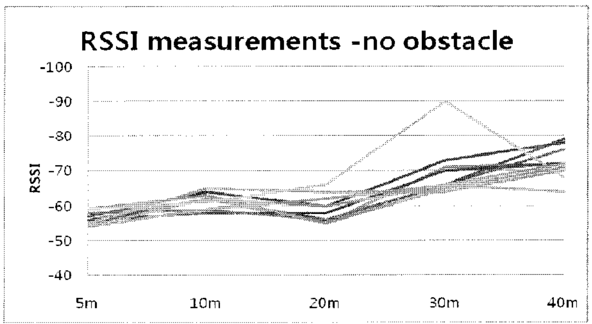


Fig. 8 RSSI measurements in winter, outdoor condition.



(a) RSSI measurement – 40m distance



(b) Obstacle at 40 m distance

Fig. 9 RSSI measurements

C. Conceptual proposal for temporal variation

Most of Zigbee based ubiquitous services assume that RSSI and/or LQI provide the rather stable statistics if no obstacles exist. That means that the only spatial factor needs to be considered to develop ubiquitous services. However, we identify additional temporal factors could exist when Zigbee based ubiquitous service is deployed in the outdoor environment and should provide the compensation method to mitigate the temporal noise term like eLoran signal.

There can be several approaches to solve the temporal variations. In case of positioning services using fingerprint K-NN algorithm, different fingerprint tables for RSSI and/or LQI can be provided, according to the temperatures. Then, users can select the proper fingerprint table. As another approach, temporal error term can be broadcasted like eLoran. To validate the method of handling and broadcasting the temporal variations, the continuous accumulative measurements should be conducted and then a proper modeling can be developed.

IV. CONCLUSIONS

This paper issues that the temporal factors can be considered to Zigbee based ubiquitous services by presenting the empirical measurements analysis. Since eLoran system has been researched with the similar concept, this paper introduces eLoran system briefly and proposes the method to mitigate the temporal error terms. The continuous measurements should be conducted to verify the temporal term's influence and characteristic for the future work.

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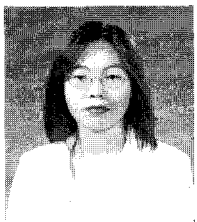

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