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Design and Implementation of a Bluetooth Signal Strength Based Location Sensing System

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***Abstract* — In a ubiquitous computing environment, location awareness is a basic necessity. There are various research projects, which discuss the problem of indoor location sensing. We have recognized *acceptability*, low power consumption, and cost as the key design factors for developing widely deployable location sensing systems. As a good candidate technology that could satisfy these needs, we proposed a location sensing system based on the widely available Bluetooth medium. Location evaluation is preformed by sensing Bluetooth signal strength with a reference model based approach. We discuss problems which arise when the Bluetooth RSSI (received signal strength indicator) is used as a signal strength indicator, and propose a novel access point that supports variable attenuators to overcome these problems. This access point allows the reading of a wider range of signal strengths using RSSI. We show that our approach to location sensing has reduced the error rate about threefold compared to systems which do not use variable attenuator supported access points.**

***Index Terms* — Bluetooth, Localization, Ubiquitous Computing.**

I. INTRODUCTION

With significant advancements in VLSI design and mass production, many ubiquitous computing services, which were once but a dream, have become technically feasible. In light of this, context-awareness has become a fundamental concern. Location data could be considered as the single most important piece of contextual data necessary for providing context-aware services.

Let us consider a simple ubiquitous computing scenario. Alice enters a room while communicating with a colleague by cellular phone. The colleague (Bob) is sitting in the lab in front of a fully equipped video conferencing system, using voice over IP to reach Alice's cellular phone. When Alice enters the room, she is faced with a network television system with greater communication abilities. The system thus automatically, in accordance with Alice's selected preferences, changes her communication session to the TV display system, and launches video conferencing. Among many other technologies, location sensing is one of the basic technologies needed to realize this scenario.

There are many location-sensing systems proposed within the past few years. MIT's Cricket[1], Microsoft Research's RADAR[2], AT&T and Cambridge's Active Bat[3] are just a few of the well known systems in this field, each of which have their own merits and drawbacks.

In the next section, we introduce our design goals in the field of indoor locating. Section 3 explains the challenges we faced dealing with Bluetooth as a location-sensing technology. Section 4 and 5 presents the design and implementation of a novel Bluetooth based location sensing system. Section 6 evaluation of the proposed system is given. Finally in section 7 conclusions are given.

II. DESIGN GOAL

Even though many indoor locating systems have been proposed, none of them have gained wide acceptance in real world deployment. A few have been industrialized and introduced into the market, but of these, most address special cases in location sensing such as high precision location sensing for industrial environments etc. It is thus our research goal to design a widely deployable location sensing system. We identify the following criteria as being necessary in designing such a system.

Acceptability: Ability to integrate smoothly with existing infrastructure. I.e. providing location sensing to user terminals should not require additional oversized hardware installation use of existing technologies to provide the service is preferable.

Low Power Consumption: Power consumption of the mobile terminal is a critical factor. A widely deployable location sensing technology should not consume much energy from the mobile terminal.

Cost: The infrastructure required to realize the location system should not be too expensive.

Among existing systems, CRICKET is one of the highly accurate, decentralized system which satisfies most of the criteria except acceptability; it needs an ultrasonic receiver to be installed on the user terminal. On the other hand, Active Bat is a centralized, high precise system. However, it needs expensive wiring and a grid of ultrasonic receivers to be installed in the ceiling of the indoor environment, which make it less acceptable and more expensive. RADAR satisfies almost all the criteria given above. However, it has relatively high power consumption because of the use of an 802.11b wireless link.

In future ubiquitous computing environments, the devices must be able to interact with one another so as to be continuously aware of available resources which other devices may provide. For this purpose, high bandwidth is not necessary; a low power consuming, always connected wireless link would be the best candidate for the job. Provide location-sensing abilities to the mobile terminal using such a low power wireless link would satisfy the above criteria. Bluetooth[4] and Zigbee[5] are technologies which are currently the closest technologies which could become such a low power wireless link in a future ubiquitous computing environment.

Bluetooth has already gained wide acceptance and many mobile devices have Bluetooth modules preinstalled. Zigbee is also a promising technology, but is yet to gain wide acceptance. Hence we focus on developing a Bluetooth signal strength based location sensing method as a possible solution for a widely deployable location sensing system.

III. Location Sensing with Bluetooth

We face 3 challenges with Bluetooth version 1.1 signal strength based location sensing systems. Firstly, in indoor environments, signal-strength is affected by many factors (multi-path effects, reflection effects, etc.). Hence, it is difficult to rely purely on signal strength as an indicator of distance to the terminal. Secondly, in our preliminary tests, we observed that Bluetooth RSSI (Received Signal Strength Indicator) varies according to signal strength as shown in figure 1. Here each Bluetooth tag was connected to an Agilent Bluetooth Tester (E1852A), and while changing RF level using the tester the RSSI of the tag was recorded. With wire loss subtracted, the variation of RSSI according to the signal strength is shown in the graph. As it can be seen, RSSI does not vary uniformly with signal strength. Thirdly, the Bluetooth takes longer to establish connections and get the RSSI value compared with wireless system such as 802.11b. From now on in our discussion we refer to version 1.1 when Bluetooth is mentioned.

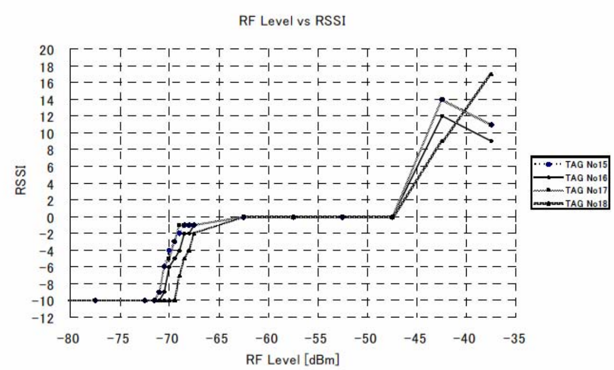

Fig 1: RSSI vs. RF level

IV. System Architecture

Most ubiquitous computing applications do not demand high precise location data. A Bluetooth signal strength based location evaluation system was the best candidate which satisfied our design goals and which could provide meter level accuracy. Thus we have proposed a novel location sensing system based on Bluetooth signal strength.

We have developed a multi-antenna Bluetooth access point (AP) for location estimation. The system is illustrated in figure 2. The AP can be used for evaluating the location of any Bluetooth supported device. In this system each antenna is connected to a Bluetooth access point. Every antenna connected to the AP has an attenuator. The strength of the attenuator can be controlled using the location data server. In this environment we assume that all the relevant devices support Bluetooth or have a Bluetooth tag attached to them. In case we are interested in locating non communication device like chairs and tables, we assume that Bluetooth tags are connected to all of these locatable objects.

When a Bluetooth based device is presented in the environment, the AP establishes a connection with the device using an antenna, then, for each value of the actuator, the signal strength is recorded. While preserving the connection, the AP changes antennas and record signal strength as mentioned earlier. The ability to preserve the connection is an important factor since it save the connection establishment time (3 seconds) , otherwise, the device has must connect to different AP's and it will take *n* times the connection establishment time to finish connecting to all the *n* APs.

We have developed a variable attenuator supported multi antenna Bluetooth access point (AP) for location estimation to overcome these problems as illustrated in figure 2. The AP supports switching antennae while preserving the connection established with the Bluetooth supported device. As a result, the connection establishment time to each antennae is reduced.

The problem of RSSI to Signal strength mapping is addressed by using the variable attenuator. We can represent the RSSI vs. RF level graph in an abstract way as in figure 3. As an example when there are 4 levels (-9, -6, -3, 0 [dB]) to the attenuator, figure 3 (from (a) to (d)) shows the RF level shift with the addition of attenuator value -9, -6, -3, 0 [dB]. By recording RSSI values at each attenuator value we can approximate the RF level. By using the attenuators in such a way, we have widened the readable RF range.

It is a well known that in indoor environments signal strength is affected by many factors (multi-path effects, reflection effects, etc.), hence, it is difficult to rely purely on signal strength as an indicator of distance that the signal has traveled. In indoor environment evaluating the position using triangulation almost impossible; hence we developed a RADAR[2] like reference model based approach for location evaluation.

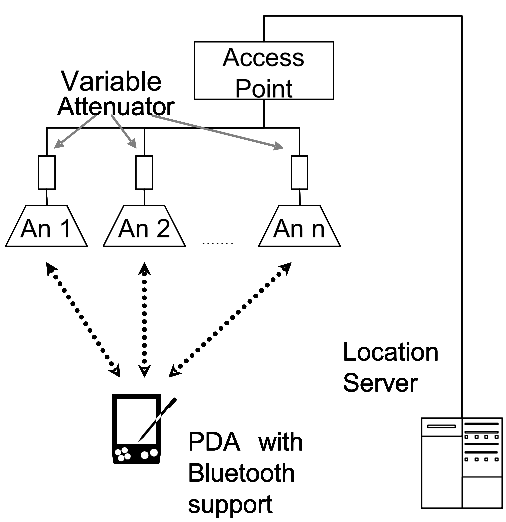

Fig 2: System Architecture

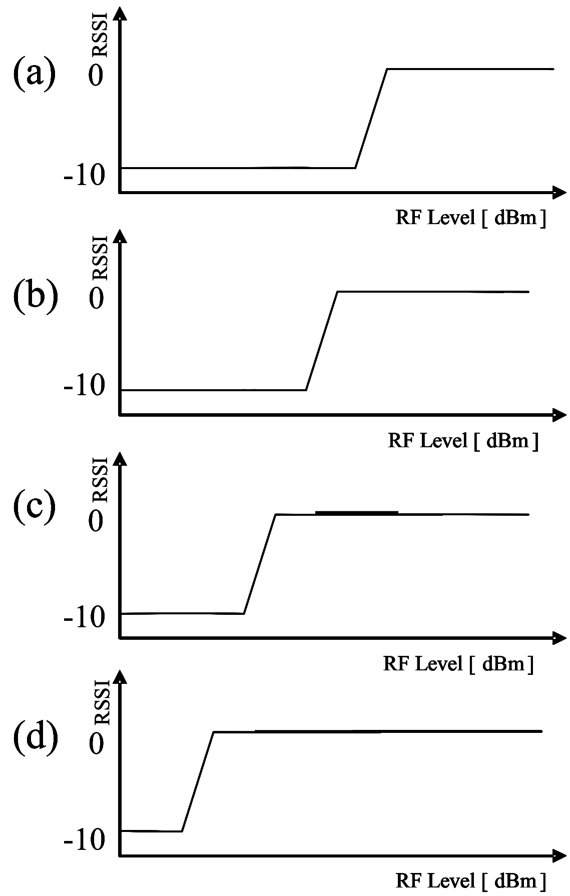

Fig 3: RSSI Shift

V. Implementation

We have implemented a system which incorporates the above system architecture in a 4.5m x 5.5m area called smart space as shown in figure 4. In this area walls are made of wood and many electronic appliances and furniture are placed in this indoor environment.

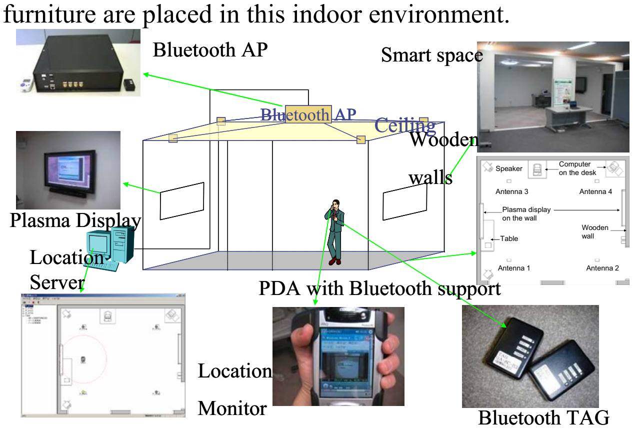

Fig 4: System Implementation

A Bluetooth access point with four antennae is placed in the ceiling as shown in figure 4. The antennae of the system placed in four corners of the ceiling. The four antennae placed in the ceiling and each actuator connected to them could be varied between 0dB, 3dB, 6dB and 9dB. The system contains the following component Bluetooth tags (Figure 4), a multi-antenna AP (Figure 4) and a location server.

VI. EVALUATION

The system setting can be shown as in Figure 5, with the four antennae are placed on the ceiling, two meters above the floor. The smart room is equipped with computers, speakers, and plasma displays. The boundary of the smart space is defined with wooden wall.

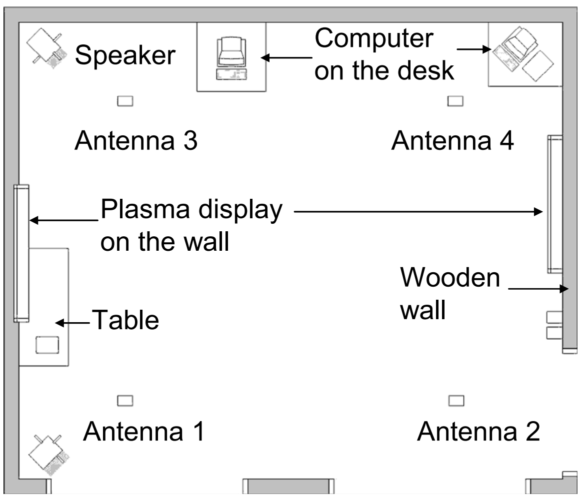

Fig 5: Smart Space Settings

A Bluetooth tag was placed in the Smart space and the location of the tag evaluated using the proposed system. As a comparison to our proposed method, we have also evaluated the location estimation ability with the attenuators locked into a certain value. In the experiment, the smart space was separated into nine areas (1.75m x 1.75m), and we evaluated the location sensing system's ability to find the correct area where the tag was placed. The data was sampled 11 times for each area. When we used the locating system as explained in section 3, we obtained 92% precision to within 2m accuracy. When the attenuators were set to a fixed value then the error rates within 2 m's were as follows:

Table 1: Precision Comparison

Att level [dB]	**Precision**
0	38%
3	39%
6	72%
9	22%
Proposed System	92%

As shown in table 1, the reliability of the date when the attenuator is fixed is not very high. The results show that the readable signal strength range has widened with our proposed methods. By the proposed method, the error rate becomes almost 1/3 compared to the best case with fixed valued attenuator.

In this implementation, our main focus was on making the readable RF level range wider with RSSI. It is possible to implement more complex learning (database) and attenuator switching algorithms in order to realize much better location evaluation with this system. We plan to implement advanced location sensing algorithms on the system in the future.

VII. CONCLUSION

Bluetooth has the following merits as a location sensing technology compared with 802.11b used in RADAR like systems:

1. Lower power consumption compared to 802.11b it is possible to use it as an always-on wireless connection.
2. High proliferation of Bluetooth technology.
3. Less interference when the number of device is high compared to 802.11b.

However, Bluetooth has its own problems as a location sensing medium. The RSSI does not vary linearly according to the signal which makes the readable range of signal strength narrow. We have proposed a Bluetooth Access Point that can overcome this problem. We have implemented a prototype system using these ideas. Functionality evaluation with the prototype system shows that the proposed system obtained better results.

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