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WLAN Positioning Technique Based on Measured Time Delay Distribution

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***Abstract*—Most approaches using time delay for user positioning in WLAN system have to modify the existing WLAN infrastructure. These modifications are on hardware up to the changes in protocol of WLAN. As a result, they are unattractive to use time delay for positioning system in comparing with using signal strength. This paper presents a new technique to locate the position of WLAN user by time delay measured on existing WLAN infrastructure. The advantage of proposed technique is no extra cost necessarily added in the system. The results confirm the validation of proposed technique.**

***Index Terms*—Time delay, Positioning system, WLAN, Measurement.**

I. INTRODUCTION

For outdoor environments, Global Positioning System (GPS) [1] have been promisingly used to deliver Location-Based Services (LBS) [2], [3]. Unfortunately, the level of localization accuracy needed for indoor applications cannot be achieved by the existing GPS methods. Furthermore, coverage of the GPS system in an indoor environment and dense urban area is limited [3]. In this light, a plethora of indoor positioning systems has been proposed employing various technologies such as proximity sensors, infrared, radio frequency and ultrasonic badges, Wireless Local Area Network (WLAN) radio signals, and visual sensors. Among those techniques, visual surveillance and tracking is the most widely studied and has been shown to provide highly accurate estimations [4]. However, this type of positioning techniques requires installation of infrastructure and calibration of cameras, which can lead to hardware and labor overheads in pervasive deployments. An even more profound concern is that of privacy in situations where users choose not to be visually monitored. With these concerns, several works have considered positioning based on WLANs owing to their wide availability and ubiquitous coverage in large environments.

From literatures, the positioning methods based on WLAN infrastructure can be classified into four methods depending on parameters utilized to estimate the location. The parameters are Time of Arrival (TOA) or Time Difference of Arrival (TDOA), Angle of Arrival (AOA), Received Signal Strength Indicator (RSSI) and cell-ID. Among those four parameters, TDOA or TOA are the best for indoor positioning systems. This is because the accuracy of positioning is affected least by multipath and distance between access point and user. In [5], the system employing TDOA is composed of special receiver, tags, and location server. The special receivers receive the positioning signal sent by a tag and then the received timing is sent to the server for calculating the tag's position. The drawback of this system is that the special tags must be used resulting in complexity. The same approach is also used in [6] but only minor changes have been made focusing on hardware. In [7], only two access points used for evaluating TOA are proposed instead of three access points. The tracking feature such a Kalman-based filter is necessary to be included in both access points. The approach using both TOA and TDOA is proposed in [8]. The experimental results confirm the superior performance of the methods using time delays over RSSI method.

Although the methods using TDOA or TOA for positioning system are widely successful in literatures, they still gain less attraction than the system using RSSI. This is due to the fact that RSSI measurements can be obtained relatively effortlessly and inexpensively without the need for additional hardware [9], unlike the system utilizing TDOA or TOA. Therefore, in this paper, the new approach to realize the location of user via measured time delay is presented. The proposed method can estimate the user location utilizing the measured delays without any extra modifications of either firmware or hardware on existing infrastructure. In additional, the proposed method has been verified by the measurement data of time delay distribution.

The remainder of this paper is organized as follows. In Section II, WLAN distributed coordinating function are presented and then the time delay distribution is described in Section III. In Section IV, the detail of time delay measurement is illustrated. The positioning technique and results are presented in Section V. Finally, the paper conclusion is given in Section V.

II. WLAN DISTRIBUTED COORDINATING FUNCTION

The IEEE 802.11 standard for wireless networks incorporates two medium access methods, the mandatory Distributed Coordination Function (DCF) method and the optional Point Coordination Function (PCF). The DCF is an asynchronous data transmission function, which well suits delay insensitive data such as email and ftp. It is available in ad-hoc or infrastructure network configurations and can be either used exclusively or combined with PCF in an infrastructure network. The PCF, on the other hand, well suits delay sensitive data transmissions such as real-time audio or video and is only available in infrastructure environments.

The Basic Service Set (BSS) is the basic building block of IEEE 802.11 WLANs. The coverage area of a BSS is referred as Basic Service Area (BSA). A station being a member of the BSS within the BSA may continue communicating with other members of the BSS. The IEEE 802.11 defines two types of network architecture, the ad-hoc network and the infrastructure network. An ad-hoc network deliberates on the grouping of stations into a BSS without the need for any infrastructure implementation. This type of IEEE 802.11 WLAN is often formed for only as long as the WLAN is needed. The infrastructure networks, in contrast to the ad-hoc networks, create a range extension and obtain some specific services from other wired or wireless LANs via infrastructure implementations.

The DCF is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. Under DCF, data frames are transferred via two methods. The essential method used in DCF is called basic access method. The 802.11 standard also provides an alternative way of transmitting data frames, namely the RTS/CTS method. In this paper, the authors focus only on basic access method.

Priority access to the wireless medium is controlled by the use of the Inter Frame Space (IFS) time period between the transmissions of frames. The IFS defines the minimal time that a station has to let pass after the end of a frame, before it may start transmitting a certain type of frame. In 802.11, three different IFS intervals have been specified to provide various priority levels for access to the wireless medium: Short IFS (SIFS), Point Coordination Function IFS (PIFS) and DCF-IFS (DIFS). The SIFS is the smallest followed by PIFS and DIFS. After SIFS interval, only acknowledgements, CTS and data frames may be sent. The use of the PIFS and the DIFS is used to separate the PCF and DCF modes, giving a higher priority to the former.

In order to minimize the probability of collisions, a random backoff mechanism is used to randomize moments at which stations are trying to access the wireless medium. The demonstration of backoff mechanism is shown in Fig. 1. This contention resolution technique is called Binary Exponential Backoff (BEB). In particular, the time following an idle DIFS is slotted and a station is allowed to transmit only at the beginning of each slot. A slot time is equal to the time needed by any station to detect the transmission of a frame from any other station. The backoff counter is decremented when the medium is idle and is frozen when the medium is sensed busy. After a busy period the backoff resumes only after the medium has been idle longer than DIFS. A station initiates a frame transmission when the backoff counter reaches zero.

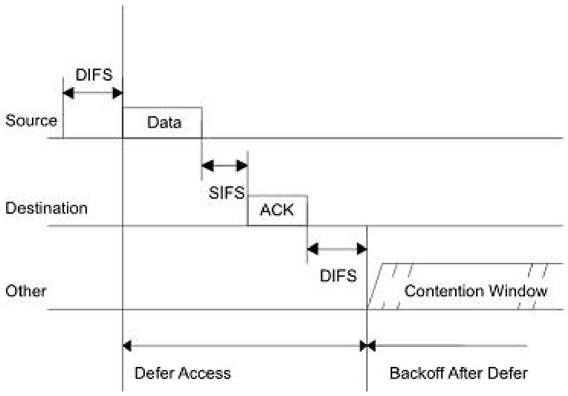

Figure 1. WLAN basic access mechanism.

The Contention Window (CW) is chosen in the interval (0,CW-1). The value of CW depends on the number of failed transmissions of a frame. At the first transmission attempt, CW is set equal to CW_{min}, which is called minimum contention window. A collision occurs when two or more stations start transmission simultaneously in the same slot. After each retransmission due a collision, CW is doubled up to a maximum value, $CW_{max} = 2^m CW_{min}$ where m is the number of different contention window sizes. Once the CW reaches CW_{max}, it will remain at the value of CW_{max} until it is reset.

The CW is reset to CW_{min} in the following cases: (a) after every successful transmission of a data frame (b) when number of retry reaches the Short Retry Limit, R, and (c) when number of retry reaches the Long Retry Limit. When either of these limits is reached, retry attempts shall cease and the frame shall be discarded.

After receiving correctly a frame in the destination station, an immediate positive acknowledgement (ACK) is sent to confirm the successful reception of the frame transmission after a time interval equal to SIFS. Since the SIFS interval is shorter than the DIFS interval, the station sending an ACK attempts transmission before stations attempting to send data and hence take priority. If the source station does not receive an ACK, the data frame is assumed to have been lost and a retransmission is scheduled.

III. TIME DELAY DISTRIBUTION

In this paper, time delay is defined as the time interval from the moment that data frame is queued in MAC layer until the ACK message for this frame is received. Following the formulas in [10], the probability P that a frame is successfully transmitted after a given time delay D is the summation of the probabilities for the time delay D at all backoff stage.

$$P(D) = \sum_{j=0}^{R} P_j(D) \quad \text{for} \quad 0 \le D \le \infty \qquad (1)$$

Where j is the stage number of backoff and $P_j(D)$ is the probability of successful transmission at jth backoff stage with time delay D. The time delay D of a successful transmission is computed as

$$D = T_c N_j + N_e \sigma + jT_c + T_s. \qquad (2)$$

Where N_e is the number of empty slots that a frame encounters before its successful transmission, σ is the duration of an empty slot, N_j is the number of transmissions from the rest of the stations that a frame encounters before its successful transmission, T_s and T_c is the time duration of channel that is sensed busy during a successful transmission and a collision, respectively.

The time duration of T_s and T_c depend on the channel access methods. For basic access method, the interval of T_s and T_c can be expressed as

$$T_s \approx T_c = DIFS + T_{frame} + SIFS + T_{ACK} + 2\delta. \qquad (3)$$

Where T_{frame} and T_{ACK} is the time interval of frame and ACK messages, respectively, δ is the propagation delay between the user station and access point.

Fig. 2 shows the time delay distribution in each backoff stage, $P_j(D)$. All parameters used for simulation is presented in Table II. These parameters are selected by estimating from practical information on measurement scenario. It can be observed that the total time delay distribution P, consists of multiple peaks due to the chance of successful transmission in each backoff stage. These simulations are based on the constant interval of T_s and T_c given in (3). In fact, the propagation delay, δ, is changed upon the location of users. Consequently, the interval of T_s and T_c is the function of user location and not deterministic. If the user is located in the nearer distance from access point, the interval of T_s and T_c has to be shorter. It implies that the propagation delay, δ, is now considered as TOA which is related to the positioning approach using TOA or TDOA in [5-8].

With the constraint of existing WLAN infrastructures, it is impossible to achieve TOA as same as δ without modifications of hardware and firmware [5-8]. However, as seen in (3), the information of δ can be indirectly realized via the time delay of a successful transmission T_s. In the light of this matter, the distance of user can be realized by T_s instead. Therefore, the new technique for positioning system is proposed by using the information of time delay distribution.

Although there is a definite relationship between T_s and distance of user station and access point, it is still difficult to mathematically formulate the function of T_s and distance. In this paper, the empirical concept using measured time delay distribution is adopted.

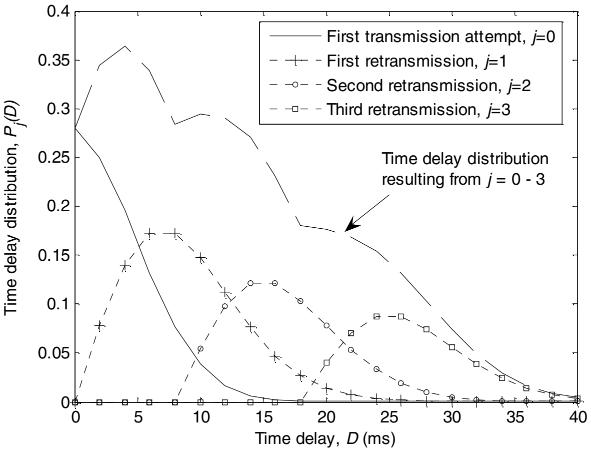

Figure 2. Time delay distribution calculated by parameters in Table II.

TABLE II
PARAMETERS USED FOR SIMULATING FIGURE 2.

Frame interval, T_{frame}	8.6 µs
DIFS	50 µs
SIFS	10 µs
Propagation Delay, δ	1 µs
ACK interval, T_{ACK}	0.3 µs
σ	20 µs
CW_{min}	32
m	5
R	6
Number of users	20

IV. TIME DELAY MEASUREMENT

The measurement is performed on the fourth floor of C-Building, Suranaree University of Technology. There are four access point covering WLAN services on this floor where the map of measurement area is shown in Fig. 3. The measured locations are marked by number 1 to 5 as presented in Fig. 3.

The method to collect the time delay of successful transmission is to use the ping command from any WLAN receiver such as notebook, PDA, or mobile station. At each location, 100 trial time delays are collected in order to compute the probability of time delays. It is clearly noticed that there is no modification needed at both access point and user hardware. As a result, it can be directly implemented to any existing WLAN system without extra costs.

After collecting all 100 values of time delays, one can calculate the time delay distribution. For example, the time delay distribution between location 5 and AP2 is shown in Fig. 4. It can be observed that the distribution is consisted of multiple peaks as explained by the same reasons as Fig. 2. The delays during the first peak are correspondent to the waiting interval of successful transmission occurred during the first transmission

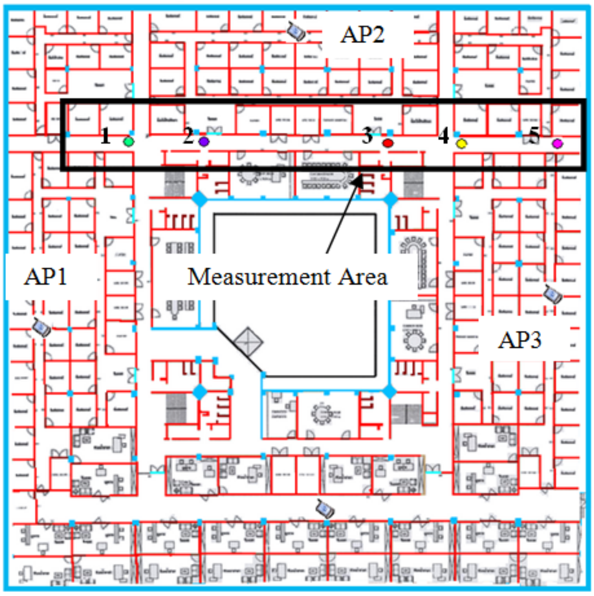

Figure 3. Map of measurement area.

attempt. The next peaks are related to a successful transmission occurred during the next retransmissions and so on.

As mentioned at the end of previous section, the distance between user and access point is directly realized by the information of time delay distribution. Hence, the aim of illustrating the distribution is to find the average value of time delay. As noticed in Fig. 2 and Fig. 4, the distribution is consisted of multiple peaks due to many stages of backoff times. However, each stage provides only one peak. Therefore, by considering only the first peak, it is enough to achieve the average time delay which has the direct relationship to the propagation delay, δ, as same as TOA. Although this average value represents the delay in case of successful transmission occurred only in the first transmission attempt. But it contains the sufficient information of propagation delay that can lead to the user location.

The average time delays calculated from measured data are presented in Fig. 5. Considering AP1, it can be observed that the average time delays increase in order from location 1 to location 5. In turn, the average time delays decrease in order from location 1 to location 5 while considering AP3. For AP2, the average time delays decrease from location 1 to location 3 and then increase from location 3 to location 5. By matching the results with measurement area in Fig. 3, it can be concluded that the average time delay is the function of location. The results provide the good fit with the concept of positioning system which is explained in the next section.

V. POSITIONING TECHNIQUE

The results in Fig. 5 enlighten the feasibility of positioning a user location by average time delay. In order to fulfill this aim, two tasks have to be carried out. The first task is to find the relation that can convert the average time delay into the distance. Then the second is to estimate the user position by triangle locating.

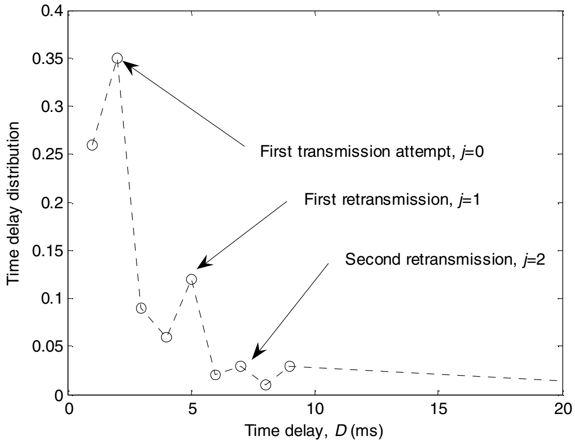

Figure 4. Example of measured time delay distribution.

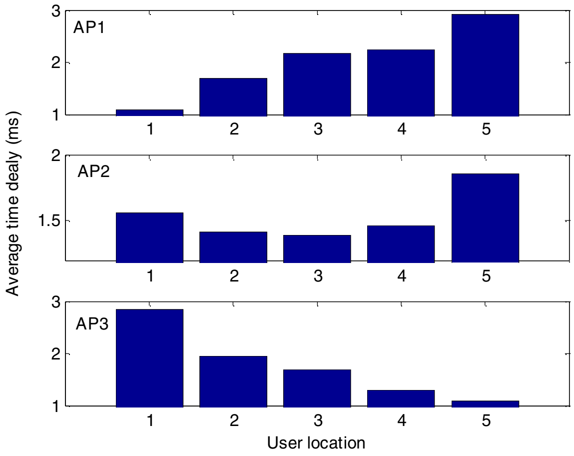

Figure 5. The average delay time versus user location.

A. Distance Approximation

As seen in Fig. 5, the average time delays of each location do not have the direct relation to each other. Hence, the approximate relation has to be applied. In this paper, the time difference, Δt, from minimum delay in each location has been used because it can indirectly calibrate the other factors in each location. For the information of distance, the authors directly measure from the map shown in Fig. 3. The distance difference, Δd, from minimum distance between user and access point is utilized as the same reason as time difference.

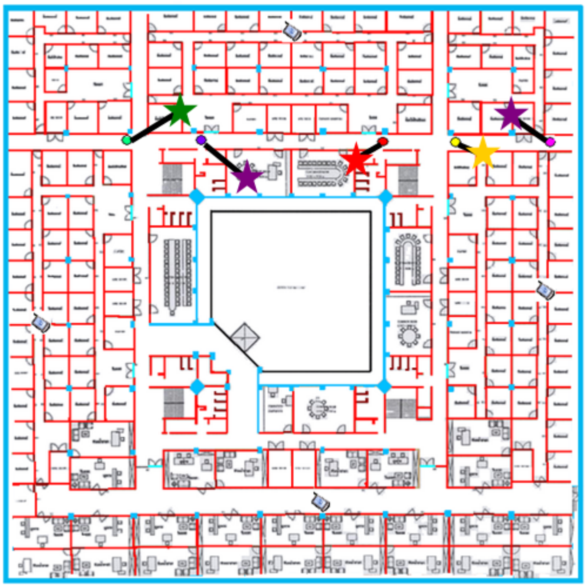

Figure 6. The estimated locations by the proposed positioning technique.

In this paper, the simple linear approximation is employed. The best fit for measured data is linearly esitmated. The formula presenting the relation between time delay and distance is approximated as

$$\Delta d = 28.57\Delta t. \tag{4}$$

Where Δd and Δt are in the unit of meter (m) and millisecond (ms), respectively.

B. *Triangle Locating*

After obtaining the relation between time delay and distance in (4), the next task is to estimate the user location. The concept of triangle locating is adopted to formulate the estimating problem. All coordinates of three access points are known thus it is obvious that to use three equations describing distance between user and three access points can solve the problem. Then all unknown parameters can be estimated.

C. *Results and discussions*

The estimated locations at each measured points are presented as shown with start symbol in Fig. 6. It is clearly seen that the estimated locations are close to the measured locations. The distance errors of location 1 to location 5 are 3.3, 5.7, 1.6, 2.8 and 6.4, respectively. The average error is 3.96 meter which is in the range of one office room only. The results confirm the success of proposed positioning technique on the existing WLAN infrastructure.

Although the errors are still high in comparing with the works presented in literatures, the proposed method is successful in stage of preliminary study with a novel technique. The improvement can be done by applying the fingerprint concept or developing the distance approximation in the future work.

VI. CONCLUSION

This paper has been demonstrated the new technique for WLAN positioning system. The information of time delay is collected to find the relation with distance between user and access point. The proposed technique provides the most convenient way to know the position of user without any extra cost of firmware and hardware compared with existing time delay approaches. The measurement results confirm the success of using proposed method.

ACKNOWLEDGMENT

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