Using time-of-flight for WLAN localization: feasibility study

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Abstract. Although signal strength based techniques are widely employed for WLAN localization, they generally suffer from providing highly accurate location information. In this paper, we first present the general shortcomings of the signal strength based approaches used for WLAN-based localization and then state reasons why time-of-flight could be an attractive alternative. We subsequently analyze the feasibility of using time-of-flight technique for WLAN localization by synchronizing the clock using Network Time Protocol (NTP) as well as measuring the time at *(i) network layer level*, *(ii) data link layer level*, and *(iii) firmware level*. We conclude that at present using TOF is not a feasible approach because of the limitation of current hardware and protocols.

1 Introduction

Location is an essential piece of information for many ubiquitous computing applications. Knowing location is useful for accomplishing emergency services, E911, follow me services, finding the nearest resources such as printers, etc. Although there are many preinstalled sensors such as IR and RF beacons that facilitate indoor localization, WLAN-based localization has proved to be a promising technique as it gives added value to the existing infrastructure. Some advantages of WLAN-based localization are:

- Ubiquitous coverage and scalability: The wireless network infrastructure already exists in many public places such as universities, corporations, airports, and shopping malls, providing an ubiquitous coverage.
- No additional hardware required: Localization can be done by a software-only method, thereby eliminating the need for additional hardware, hence there is no extra cost.
- Extended range: Compared with other radio technologies such as bluetooth or RFID, the range covered by WLAN is bigger, reaching approximately 50-100 m.
- No line of sight restrictions: Unlike the IR counterpart, WLAN is not restricted to line of sight.

2 Localization techniques

Localization techniques enable a mobile or a static node to answer the question 'Where am I?' either relative to a map, to another node, or to a global coordinate system. The existing location systems can be categorized based on the type of distance measurement technique employed as: range-based and range-free location systems [10]. An essential part of any range-based localization algorithm is a method to determine the distance between two wireless nodes [10]. In general, three methods have been considered.

One method is to use *connectivity* information (i.e. use information about the nodes within transmission range). This method is frequently used in dense networks such as wireless sensor networks [3].

Another method is to exploit the signal strength indications, in which the received signal strength indication (RSSI) of data packets transmitted is considered. This method is used in WLAN localization systems. However, signal propagation issues such as reflection, refraction, and multi-path cause the signal attenuation to poorly correlate with distance resulting in inaccurate and imprecise distance estimations. Due to the fact that signal strength sharply decreases in a non-linear and unpredicted fashion with distance, a mapping between RSSI values and pre-defined positions has to be created first. This phase is generally referred to as the labor intensive calibration phase. An example system using extensive calibration phase is the RADAR system [1], which has been one of the first approaches presenting an indoor positioning system based on WLAN. Another way of using signal strength measurements is without the calibration phase. Recently, there have been many initiatives in making the localization calibration free process [4, 5]. However, tradeoff between the accuracy and the amount of calibration used should not be ignored.

A third approach is to use the propagation time of radio signals. This method is usually referred to as Time-of-flight (TOF). TOF increases linearly with distance in free air. TOF is used both outdoors for GPS positioning [8] and indoors to find tagged objects and persons [9]. Although the TOF is also impacted by multi-path effect (similar to signal strength), it performs fairly better. The problem of the multi-path effect can be eliminated with a wider frequency band, e.g. ultra-wide band. However, TOF technique is not yet applied to WLAN-based localization. Location can be estimated accurately, when the propagation delay between the two devices are measured precisely. Hence, in this paper, we focus on analyzing the feasibility of using TOF technique for WLAN localization with the current hardware and protocol configuration.

2.1 Problems with signal strength based measurements

Signal strength is not a reliable parameter for localizing the wireless nodes particularly for indoor environment. Signal strength based measurements are impacted by both time-varying errors and environmental-dependent factors. Time varying errors mainly occur because of additive noise and interference and can be significantly reduced by averaging multiple measurements over time. Environmental factors are unpredictable and are considered as a random variable. In environments with many obstructions such as an indoor office space, measuring distance for estimating the location using signal attenuation is not accurate.

In a WLAN network coverage is provided by a number of distributed access points. One of the simplest algorithm using signal strength is the *Centroid technique* [6]. This simple technique uses the access points having strongest signal strength and their coordinates to obtain the user location. The device scans for the near-by access points. Among the heard access points the top three strongest are chosen and their coordinates are retrieved from the database. This information is used to position the user at the center of these access points. However, hearing the strongest access point does not necessarily mean that the user is closer to it.

Our *Enhanced centroid technique* [5] improves the performance of the simple *Centroid technique*. It reduces the time varying errors by incorporating a moving average filter in order to remove the fluctuations in the signal strength. Inspite of removing the time varying errors, we found out that there was a discrepancy in the results. This is mainly because of the arrangement of the access points used for triangulation and the collinearity problem associated with the triangulation in general. One alternative is to optimally place the access points such that they form a triangle, however, the placement of the access points is accomplished by the venue owners and their intention is to provide maximum coverage with minimal access points. Another solution to improve signal strength based algorithm is to develop a model-based algorithm [11], which uses the geometrical properties of the building and previous traces of the user.

3 Time-of-flight technique

As mentioned earlier, time-of-flight technique is a more promising approach for estimating the distance between two devices. Precise time measurement should give accurate location estimation compared to the location estimation only obtained from signal strength. The distance estimation obtained through timing can be used in place of the distance estimated from the signal strength in the localization computation. This would significantly improve the WLAN localization accuracy. However as indicated below, due to the limitation of current hardware and protocol configuration, there is no way of measuring and synchronizing time for WLAN and thus the time-of-flight does not currently work for WLAN localization:

1. **Clock synchronization using Network Time Protocol (NTP):**
   Network Time Protocol (NTP) is widely used for synchronizing the clocks of the computer over a network. We initially thought of using NTP as a means of synchronizing the timing between the access point and the client device. However, the synchronization accuracy in a typical wide area network environment is in the range of 10-100 ms [2], corresponding to a very huge error in the distance, thereby, making NTP not useful.

Another alternative, to achieve a better accuracy is to include a dedicated hardware that generates a PPS (Pulse Per Second) signal [2], which is in turn distributed to the clients. For instance, a GPS receiver can be used to generate PPS, which in turn distributes its RS232 output to the serial port of various clients. This gives an accuracy in the range of microsecond. Even obtaining a granularity in the range of microseconds, which corresponds to a distance error of approximately 300 m, still makes NTP unusable.

2. **Measuring time at the *network layer* level:**
   Ping determines if a destination on a TCP/IP network is reachable by sending ICMP echo request and measuring how long it takes to get a reply. Since ping is generated at the IP level, it not only returns the round trip time, but also the processing delay at the IP layer, data link and the radio layer, plus the delays encountered for scheduling by operating system. Hence it is quite obvious that measuring time at the network level results in imprecise distance measurements. However, we wanted to confirm how bad it is influencing the results. Hence we conducted experiments using Linux machine, as the resolution provided by the timers in Linux is much superior than that of Windows. The aim of this experiment is to connect the device to an access point whose location is known and the actual distance between the access point and the device is known. In our experiments, the link was pinged more than 100 times and then the minimum delay was chosen such that we minimized the unwanted queuing delay.
   Table 1 shows that there is a huge difference in the timing with regard to the actual distance. Also calculating the distance with the obtained timing is by no means straight forward.

Link	Round trip time(ms)	Actual distance (m)
1	0.6	6
2	2	3
3	0.7	12

Table 1. Results of the time measurement at the network layer

3. **Measuring time at the *data link layer* level:**
   The 802.11 standard defines various frame types that stations (NICs and access points) use for communications, as well as managing and controlling the wireless link. Among all the frames defined by the IEEE 802.11 standard, the beacon frame is of particular interest to us. The access point periodically sends a beacon frame to announce its presence and relay information, such as timestamp, SSID, and other parameters regarding the access point to radio NICs that are within range.
   Precise distance measurement could be possible by time stamping the received beacon frame sent by the access point locally at the client device.

This helps in estimating accurate distance between the access point and the client device, which enables accurate positioning. However, practically this is not possible because of the problem with the timer synchronization between the access point and the client device. Moreover, the timer on the access point is reset when it boots up, hence it cannot be used for any meaningful interpretation.

4. **Measuring time at the *firmware* level:**
The resolution of the current hardware time stamps, which are implemented in most current WLAN products, is 1 ms that corresponds to 300 m. In terms of the achievable accuracy this discrete time resolution is not yet precise enough. Recently, there is an initiative to time stamp the packets during serializing and deserializing [7]. An accuracy of 3 m was achieved on a custom made hardware with a back-to-back distribution. With hardware improvements and statistical techniques it should be possible to increase accuracy into the sub-meter range. This methodology needs changes in the protocol, and changes in the firmware such that the time stamping to be included in a standard 802.11 packet.

4 Conclusion

This paper presents the shortcomings of the signal strength based approach used for WLAN-based localization. Looking for an alternative, we focused on using time-of-flight. Consequently, we investigated the feasibility of using time-of-flight by synchronizing the clock using NTP as well as measuring the time at various stack layers, i.e., the network, the data link, and the firmware layers. However, due to the limitation of current hardware and protocols, we concluded that time-of-flight technique will not work for WLAN localization at present.

Future work includes exploiting other possibilities to enhance WLAN localization. Particularly we are interested in fusing location information reported from multiple sensors to enhance accuracy of the WLAN localization and to provide more meaningful location information.

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