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# A Novel Wireless Positioning System for Seamless Internet Connectivity based on the WLAN Infrastructure

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**Abstract** Nowadays, several positioning systems are available for outdoor localization, such as the global positioning system (GPS), assisted GPS (A-GPS), and other systems working on cellular networks, for example, time difference of arrival (TDOA), angle of arrival (AOA) and enhanced observed time difference of arrival (E-OTD). However, with the increasing use of mobile computing devices and an expansion of wireless local area networks (WLANs), there is a growing interest in indoor wireless positioning systems based on the WLAN infrastructure. Wireless positioning systems (WPS) based on this infrastructure can be used for indoor localization to determine the position of mobile users. In this paper, we present a novel wireless positioning system, based on the IEEE 802.11b standard, using a novel access point (AP) with two transceivers to improve the performance of WPS in terms of accuracy of the location estimation and to avoid service connectivity interruption. In our proposed system, the novel AP uses the second transceiver to find information from neighboring mobile stations (STAs) in the transmission range and then sends information in advance to associated APs, which estimate the location of the STA based on an internal database. We also use a TDOA technique to estimate the location of the STA when there is not enough information in the database (in this case, the STA moves into a new area where the system has not run the calibration phase). Using TDOA, the database can be generated and updated automatically. The initial results from our simulations show that the proposed system provides higher accuracy of location estimation than other related work and does not interrupt the Internet connection for end users in contrast with other proposed schemes.

**Keywords** Indoor location · Positioning · IEEE 802.11b · Wireless local area Network (WLAN) · Time difference of arrival (TDOA)

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## 1 Introduction

A relatively recent branch of mobile networking, location-based services (LBS) have expanded rapidly since mobile networks were enabled to determine the locations of mobile devices. LBS provide navigation, service information, targeted advertising, notification, and other services in which the awareness of user location is critical [1,2].

Some critical applications and services based on indoor localization—such as emergency rescue, fire brigade, or incident management—require an easily deployable location system that provides high positioning accuracy (i.e., about 1 m of error [3]) in medium and deep indoor environments. Since global (GPS) and wide-area (cellular networks) location systems remain inefficient indoors, alternative positioning technologies are required. Obtaining the location of a user without interrupting his or her Internet connection is another key issue related to the level of user satisfaction. Thus, it would be desirable, for example, if a user could have a voice over IP (VoIP) conversation with a friend while running an LBS application that guides him or her to a gathering place. The research challenge is the design and implementation of an indoor location system capable of providing accurate tracking and continuous Internet connection using the existing wireless local area network (WLAN) infrastructure (i.e., taking advantage of the wide deployment of IEEE 802.11b networks).

In this paper, we propose a novel wireless positioning system based on the WLAN infrastructure. The main motivation for our approach is twofold: to improve the accuracy of the location estimation and to avoid Internet connectivity interruption for end users. We introduce a novel access point module with two transceivers; the second transceiver is used to scan neighbor mobile stations (STAs) in the coverage area using a fast passive scan technique [4]. The information regarding the STA is sent to its associated AP, which analyzes and searches a database in order to estimate the location of the STA. In the novel wireless positioning system, we also use a time difference of arrival (TDOA) technique to estimate the location of the STA when there is not enough information in the database, as is the case when the STA moves into a new area where the system has not yet run the calibration phase. After the position of the STA has been estimated using the TDOA technique, all correlations between coordinate values of this position will be recorded in the database. By processing these two techniques simultaneously, the database can be generated and updated automatically. We show that our system outperforms other related work [5,6] in terms of accuracy without disrupting the Internet connection of end users. Using other related work, the STA must switch to another channel in order to measure the signal power from neighbor APs, thus disrupting the Internet connection. Our approach does not require customers to change or to upgrade their wireless LAN devices. However, users might need to update the firmware in their devices to support this novel wireless positioning system.

The rest of this paper is organized as follows. Section 2 describes other proposed and existing positioning technologies for outdoor and indoor environments. Section 3 discusses related work. Section 4 explains our proposed system. In Sect. 5, analysis and simulation results of the proposed system are shown. The conclusions of this work are presented in Sect. 6.

## 2 Positioning Technologies

Navigation and positioning technologies have entered the pluralistic age. Various positioning technologies have been proposed and are starting to be implemented in many countries. In this section, we summarize current positioning technologies for both outdoor and indoor environments.

## 2.1 Outdoor Positioning

The Global Positioning System (GPS) is a satellite-based navigation system consisting of 24 or more satellites worldwide. Each satellite is placed about 20,000 m above ground and transmits radio frequency (RF) signals to ground-based receivers. A GPS receiver calculates its position by measuring its distance from three or more GPS satellites. Measuring the time delay between transmission and reception of each GPS radio signal provides the distance to each satellite, since the signal travels at a known speed. The signals also carry information about the satellites' locations. By determining the position of (and distance to) at least three satellites, the receiver can compute its position using trilateration. The positioning accuracy of GPS after selective availability (SA) has been turned off typically ranges from 6 m to 12 m in 95% of cases [7]; however, GPS signals cannot be received close to high-elevation obstructions or in buildings.

A ground-based pseudo-satellite transmitter (GPS pseudolite) is a device that transmits GPS satellite-like signals. Using a GPS pseudolite, a GPS receiver can determine its location even in the vicinity of obstructions that block GPS signals from orbiting satellites, and can increase positioning accuracy [8].

Cellular phone carriers provide user location services using a number of systems, including assisted GPS (A-GPS), time difference of arrival (TDOA), angle of arrival (AOA), and enhanced observed time difference of arrival (E-OTD). A-GPS [9] is a technology that uses an assistance server to reduce the time needed to determine a location using GPS. A-GPS is assisted by base stations (BSs) that provide information to the GPS processing a cellular phone, which can search GPS signals quickly and can use the aiding information sensitively. The cellular phone sends the captured GPS signal to the base station, which then calculates the location of the cellular phone. TDOA, AOA/TDOA, and E-OTD are also used by a few cellular phone carriers such as Cingular and AT&T wireless [10]. In geometric approaches, the RF signal measurements are transformed into angle and distance estimates, from which the signal source location is deduced using basic geometry and triangulation.

While these techniques have been found to give good results outdoors, they are not so effective when deployed indoors due to multipath interference. The need for specialized hardware and fine-grain time synchronization leads to high costs for such solutions [11].

## 2.2 Indoor Positioning

For an indoor environment, a number of different systems using infrared, ultrasound, radio frequency identification (RFID), and radio frequency (RF) devices have been designed to determine the user location (see Table 1 for a comparison of these technologies).

The Active Badges system [12] is an infrared-based location system that typically provides room-size-location information. A base station is placed in each room, and users carry a badge that emits its ID over infrared. The base station senses the ID, and a central server collects the data from the base stations.

The Active Bat system [13] is an ultrasonic-based location system that determines the Bat tag position using time-of-flight measurement. In this system, users carry a Bat that acts as an ultrasonic generator. Receivers mounted on the ceiling measure the distance to the Bat, and a central controller determines the Bat location. This system provides accuracy within 9 cm of the true position in 95% of cases.

**Table 1** Comparison of indoor positioning technologies [7,14]

| Technology | Accuracy | Note |
|---|---|---|
| Infrared | 0.7–2.5 m | A clear view should be reserved between the IR transmitters and the IR receivers. |
| Ultrasound | 3–30 cm | Accuracy depends on the surrounding environment |
| Passive RFID | 10–30 cm | Accuracy is affected by RFID readout errors and simultaneous readout of multiple tags. |
| Active RFID | 5–7 m | Have their own internal power source and cover a larger area than passive RFID |
| RF-based Wireless LAN | 3–5 m | Accuracy depends on technologies and the surrounding environment |

RFID is an automatic identification method that relies on storing and remotely retrieving data using devices called RFID tags, which can also be used for location determination. In such systems, RFID tags are placed at key points, and the relation between tag ID and location is entered into a database. When the reader moves closer to a tag, it can report the tag's location to the user.

RF-based systems mainly use IEEE 802.11 wireless local area networks and attempt to deal with the noisy characteristics of wireless radio that mainly result from multipath fading. The radio detection and ranging system (RADAR) [15] is one of the first examples of a positioning system using an IEEE 802.11 network. This technique can provide location detection in urban areas and in buildings; 75% of errors are less than 5m. In this method, a client device measures the amount of power that it receives from several access points (APs) and uses this information to discover its own location $(x, y)$. The estimation process described in [15] is divided into an off-line phase (also called the calibration phase) and a real-time phase. During the off-line phase, the signal strength received from several APs is measured at fixed selected locations, forming a grid over the monitored area. This grid's positions and its respective received signal strength indicator (RSSI) values are recorded and stored in a database, resulting in a radio propagation map. During the real-time phase, the wireless client measures the RSSI values from all of the APs in range and tries to match them with some of the RSSI values in the propagation map in order to estimate the STA's location. The main problem with map-based techniques is the calibration effort in the off-line phase, addressed in [16]. The accuracy of such systems depends on this procedure, which consists of physically moving a wireless device over each radio map grid point and capturing RSSI values from APs. This kind of procedure is considered impractical and serves as a barrier to wider adoption.

## 3 Related Work

To improve the accuracy of the indoor positioning system, several techniques demonstrate the viability of this approach. Youssef et al. [5] show that the RADAR system can be improved using the perturbation technique (joint clustering technique) to handle the small-scale variations problem. This technique can improve the RADAR system and provide location accuracy up to 3 m.

The triangulation mapping interpolation system (CMU-TMI) [17] performs a location calculation on the current data, interpolates that data with the information in the database, and then returns a location estimate based on this interpolation. However, power consumption increases to measure the signal strength on the client side.

The Ekahau Positioning Engine 4.0 [18], released in October 2006, also uses an IEEE 802.11 network to provide location information. It achieves an average accuracy of 1m with at least three audible channels in each location. This system requires site calibration up to 1 h per 1,200 $m^2$. While calibration-based efforts present good accuracy results, there is still room for performance enhancements. Due to the very dynamic nature of the RF signal, the assumption that the radio map built in the calibration phase remains consistent to the measurements performed in the real-time phase does not hold in practice; thus, at times, there is a need to rebuild the radio map. It seems more reasonable to design a fully-automatic system capable of acknowledging RSSI characteristics and variations in both spatial and time domains.

Hitachi [19] released location technology based on TDOA in March 2005. This system uses two types of access points: a Master AP and a Slave AP. Slave APs synchronize their clocks with that of a Master AP and measure the arrival time from a mobile terminal; the Master AP determines the location of the mobile terminal using the TDOA between the signal reception times at multiple Slave APs. While this technique has been found to achieve good results in indoor environments, it requires specialized hardware and fine-grain time synchronization, which increases the cost of this type of solution.

Kanaan proposed a closest-neighbor with TOA grid algorithm (CN-TOAG) [6]. This geolocation algorithm presents a TDOA-based position detection technique to improve location accuracy in the indoor environment by estimating the location of the user as the grid point. This technique is similar to the previous one [9], as it needs specialized hardware and fine-grain time synchronization, which increase costs.

To date, there are various techniques to improve the accuracy of user location, but there are no positioning technologies that support seamless Internet connections to end users while providing high accuracy location. This is an important design issue, since end users do not need to stop their Internet connection before using the positioning service. In this paper, we present a new AP with two transceivers that improves the accuracy of user location without disrupting their network connection.

## 4 The Proposed System

In this section, we describe our proposed positioning system, which combines a positioning technique using received power information with a technique using TDOA information collected from neighbor APs. We explain the general architecture of our proposed system, which encompasses two position detection methods working in parallel to estimate user location; detail each position detection method, including the system synchronization and the location estimation for the TDOA-based technique; and then briefly discuss the advantages and disadvantages of our system.

### 4.1 System Architecture

The proposed technique is designed for two dimensions (2-D); at least three access points are needed to determine each position; for three dimensions, at least four access points are needed to determine the position, and the mathematical solution becomes more complicated. Most current positioning systems rely on mobile stations for processing. Mobile devices must constantly switch channels in order to measure the signal power from neighbor APs

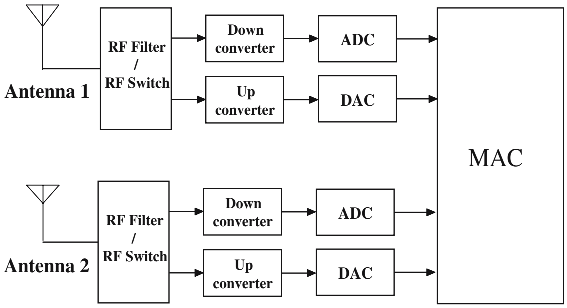



**Fig. 1** Block diagram of the new AP Module

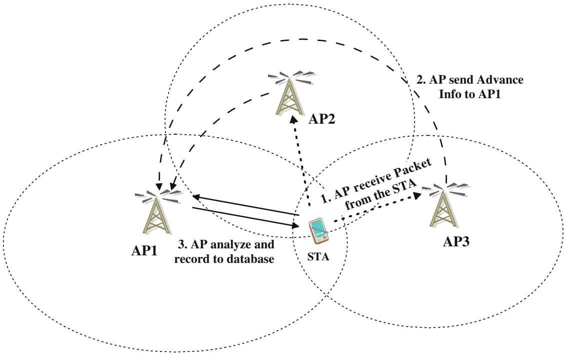
and estimate their own position, thus disrupting the Internet connection of end users. In order to provide both continuous Internet connection and location detection service, we propose the use of a novel AP with two transceivers (Fig. 1). In the novel AP, there are two IEEE 802.11-compliant transceivers. The first transceiver uses a normal IEEE 802.11 infrastructure communication transceiver (exchanging frames with associated STAs), while the second transceiver is used to scan and gather information on neighbor STAs that are located in its transmission range using fast passive scan [4].

In the proposed system, we use two position detection methods based on: (i) received power information, and (ii) signal arrival time difference. Both mechanisms work in parallel to estimate the location of the STA. The received power information method consists of two phases: data correction and estimation. In the data correction phase (Fig. 2), the AP uses the first transceiver to communicate with the associated STA and the second transceiver to gather information on nearby STAs in its transmission range. The STA associated with AP1 moves to an area where AP2 and AP3 can also receive a packet sent by the STA. When the STA sends the packet to AP1, then AP2 can receive the same packet using the second transceiver. The information about the packet transmitted from the STAs will be sent back to its associated AP (AP1) in the form of advanced information, including the received power and reception time. At the same time, AP3 receives the same packet from the STA using its second transceiver and sends back the advanced information regarding the packet to AP1. AP1 analyzes this information and records all correlations between the coordinate values of each known position and the received powers in a database. Note that because the second transceiver is used to continuously gather information on neighbor STAs, the database can automatically update each time that the position of the STA is estimated by the TDOA-based detection method. Since the position of the STA updates often, more historical data can be used to calculate the location, thus improving the accuracy.

In the estimation phase (Fig. 3), the correlation between the information from the produced database and the average received powers measured by the AP and neighbor APs are compared using a weighted least square method [20,21]. Coordinate values of the position with the highest correlation are chosen as the position coordinates. If the difference between the corresponding data is higher than a given threshold (e.g., 1 $m^2$ difference error), then the system will use the TDOA technique to estimate the location of the mobile station.

The position detection method using signal arrival time difference is used when there is not enough information in the database to estimate the STA's location, i.e. the difference between the corresponding data is higher than a given threshold. In this method, the AP first sends a request message through a wired infrastructure to neighbor APs, which can also receive packets transmitted from the STA in order to set their second transceivers to the same channel, and then sends a positioning request signal to the STA. When the STA receives the

Fig. 2 Proposed WPS using the novel AP



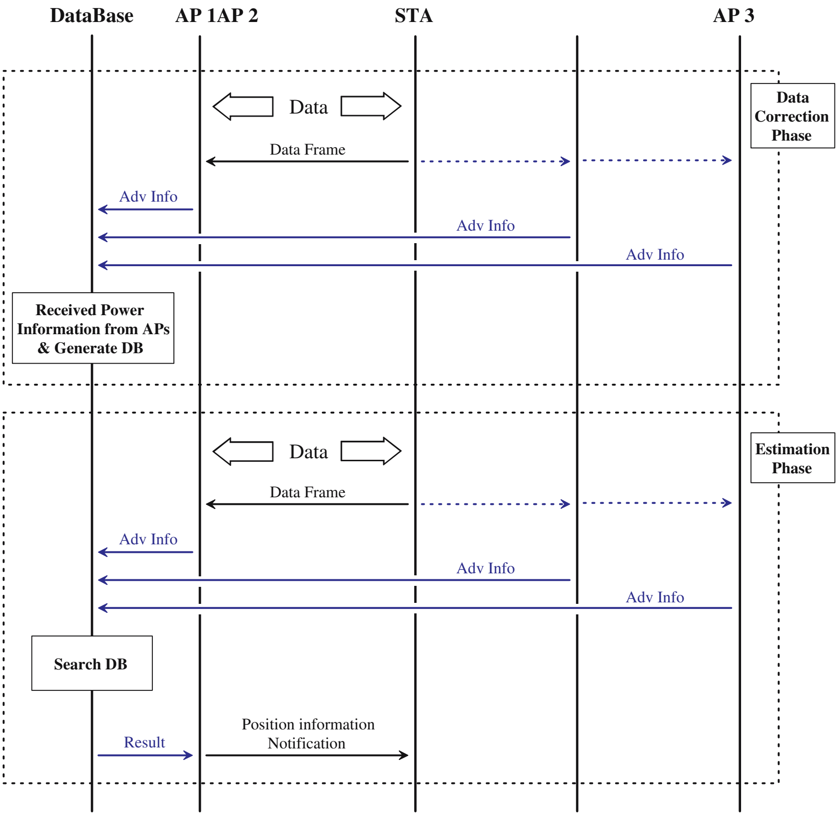




Fig. 3 Process flow of the proposed system

positioning request signal from the AP, it sends the position packet back to the AP. During this time, the neighbor APs can also receive and capture the position packet from the STA. The neighbor APs finish the capture mode and send back the advanced information to the associated AP, which calculates the TDOA values based on the position packets from the STA and estimates the location of the STA using the hyperbolic positioning algorithm (see Sect. 4.3). Finally, the AP informs the STA of its location information.

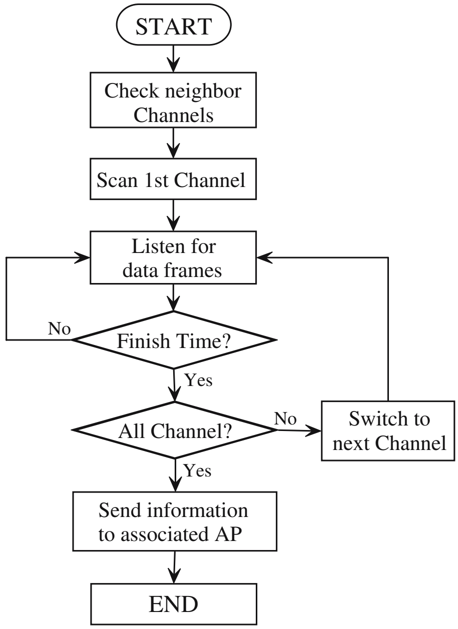



**Fig. 4** Fast passive scan phase

Figure 4 illustrates the fast passive scan that the second transceiver uses to obtain information on neighboring STAs. The AP checks the list of channels that neighbor APs are using and begins to scan the first channel. Note that the AP scans all external STAs in the transmission range every second. The AP uses the second transceiver to listen and wait for a data frame on the first channel; we propose a waiting time of 200 ms based on the assumption that the STA running real-time services has a packet interarrival time of 50 ms or less. After scanning the first channel, the AP switches the second transceiver to the second channel and then repeats the same procedure until all channels in the list are scanned. Based on the IEEE 802.11b standard, we use only three channels (Ch1, Ch6, and Ch11) that do not interference with each other; thus, the time period for this phase cannot exceed 600 ms. The AP finally sends back the advanced information to the associated AP of the STA to report the received signal strength and received time. Using the fast passive scan phase, we can reduce the time needed to gather information from neighboring STAs by scanning only two or three channels instead of all 13 channels.

## 4.2 Synchronization

Using signal arrival time difference, we can estimate the location of the STA from the location of the APs and the TDOA measurements received at the associated AP and neighbor APs. In this detection method, synchronization of the network access points is important to determine a precise location. Since our proposed system is based on a wireless LAN infrastructure in which all APs are interconnected via a gateway, we assume that the synchronization of all APs is provided by the gateway. Using the IEEE 1588 precision time protocol in combination with hardware-based timestamping can improve the synchronization time error to <2.5 ns [22], resulting in a positioning location error of 0.75 m, which is still acceptable.

### 4.3 TDOA Location Estimator

In general, the basic problem with TDOA-based techniques is how to accurately estimate the propagation delay of the radio signal arriving from the direct line-of-sight (DLOS) propagation path. Assuming that the STA moves at a low speed, the effect from the Doppler spread is negligible. Considering the system in terms of delay spread, which results from multipath signals, we can improve the performance of TDOA estimation using super-resolution techniques [23]. The use of super-resolution equalizers allows us to separate different propagation paths in an indoor scenario to accurately estimate the TDOA from all APs. In environments with many multipath signals, however, a training phase might be required for positioning calibration.

The position detection method using signal arrival time difference employs the hyperbolic positioning algorithm [24] to calculate the location of the STA from the location of its associated AP and neighbor APs as well as the TDOA measurements. In a 2-D hyperbolic positioning system (see Fig. 5), we consider an STA at an unknown location $(x, y)$ and three APs at known locations. The travel time (T) of pulses from the STA to each of the receiver locations is the distance from the STA to the APs divided by the pulse propagation speed (C = 299,792,458 m/s).

$$\begin{aligned} T_1 &= \frac{1}{C}\sqrt{(x-x_1)^2+(y-y_1)^2} \\ T_2 &= \frac{1}{C}\sqrt{(x-x_2)^2+(y-y_2)^2} \\ T_3 &= \frac{1}{C}\sqrt{(x-x_3)^2+(y-y_3)^2} \end{aligned} \tag{1}$$

Let AP1 be at the coordinate system origin.

$$T_1 = \frac{1}{C}\sqrt{x^2+y^2} \tag{2}$$

The time difference of arrival are calculated as:

$$\begin{aligned} T_2 - T_1 &= \frac{1}{C}\left(\sqrt{(x-x_2)^2+(y-y_2)^2} - \sqrt{x^2+y^2}\right) \\ T_3 - T_1 &= \frac{1}{C}\left(\sqrt{(x-x_3)^2+(y-y_3)^2} - \sqrt{x^2+y^2}\right) \end{aligned} \tag{3}$$

Knowing the time differences $(T_2 - T_1)$ and $(T_3 - T_1)$ from the information exchange among AP1, AP2, and AP3, we can solve the linear equations using Fang's Method [24] and thus estimate the location of the STA $(x, y)$.

### 4.4 Advantage

Both position detection methods are processed simultaneously. The result of the position detection determined earlier by the received power information method narrows the solution range of the time difference of arrival method, thus decreasing calculation time and improving accuracy.

Since the STA does not need to collect the received power information from several APs during the position detection process, few functions are required for the STA, and users can connect to the Internet without any interruption due to the position estimation process.

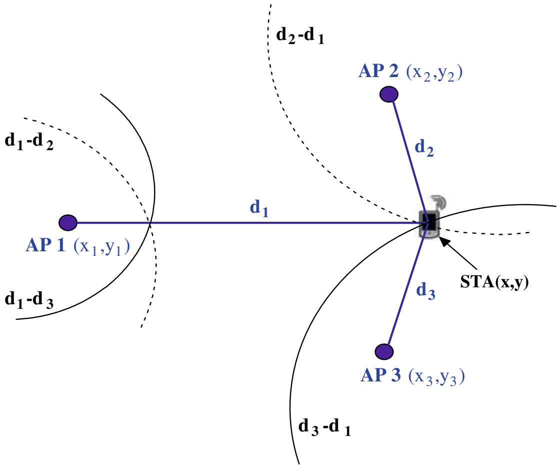



**Fig. 5** 2-D Hyperbolic positioning

Additionally, the database in which the value pairs (position of the STA and received power information) are stored obtains feedback from the position estimation using signal arrival time difference; thus, the database can be automatically generated and updated. As a result, the database does not need to be manually generated before the installation of the APs. Furthermore, even when the neighboring layouts change, the database is automatically updated.

### 4.5 Disadvantage

The disadvantage of the proposed system is that two radio interfaces are required for every AP in the system. However, this is not a large problem when compared to other proposals that require changes in current wireless LAN cards; it is always more viable to introduce changes on the network operator side. Users do not need to buy new wireless LAN cards but may be required to update the firmware in their devices in order to support this novel wireless position system.

## 5 Performance Evaluation

To evaluate the performance of the proposed system, we conduct simulations in OPNET [25] and compare the results with related works. In this paper, we consider a Rice channel with a strong finger component that allows us to estimate the TDOA accurately. For more severe multipath channel conditions, additional mechanisms, such as super-resolution equalizers or a training phase, may be required. Figure 6 shows the simulation environment of a wireless network with three APs and one STA; a typical 30 m × 40 m meeting room is considered the target area. The STA connects to AP1 and moves at a walking speed (5 km/h) to a specific area. Table 2 lists the parameter values used in the simulation.

We compare the proposed system with a joint clustering technique [5] and the CN-TOAG algorithm [6]. In the next section, we monitor the location estimation error and performance assessment of the proposed system with the other two mechanisms and compare the results.

**Fig. 6** Simulation environment

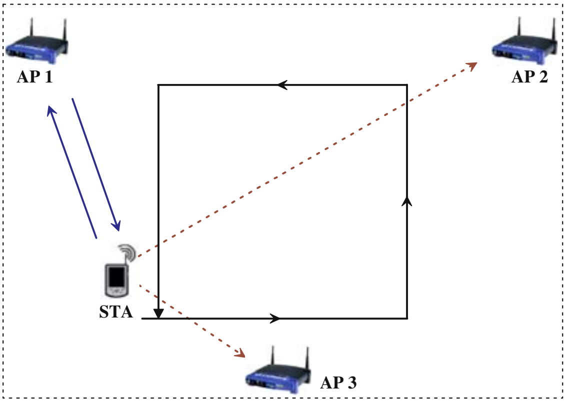



**Table 2** Parameters of simulation

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Area | 30 × 40 m | Number of APs | 3 |
| Data rate | 2 Mbps | Channels | 1, 6, 11 |
| Beacon interval | 100 ms | SIFS time | 10 μs |
| DIFS time | 50 μs | PIFS time | 30 μs |
| Slot time | 20 μs | Mac header | 240 bits |

### 5.1 Location Estimation Error

In the simulation, the moving STA communicates with AP1, while AP2 and AP3 continue to receive data frames from the STA and to send the advanced information to AP1 in order to estimate the location of the STA; this process repeats to continuously estimate the location of the STA. We simulate the STA using the joint clustering technique [5] and the CN-TOAG algorithm [6] to estimate the position of the STA every 2 s. The initial results from our simulation (Fig. 7) show that the proposed system can better estimate the location of the STA than these approaches. The proposed system runs the received power information method to continually estimate the location of the STA, while the time difference of arrival method simultaneously calculates the location of the STA using the hyperbolic positioning algorithm. As a result, the position detection time decreases, and the accuracy improves.

### 5.2 Performance Assessment

To evaluate the performance of the proposed system, VoIP traffic based on the G.711 codec standard [26] is used in the communication between the STA and AP1. A VoIP packet is generated every 20 ms with 160-byte data, a 12-byte RTP header, an 8-byte UDP header, and a 20-byte IP header. The VoIP packet size at the IEEE 802.11 MAC layer becomes 200 bytes per packet with a data rate of 80 kbps (excluding the MAC header). We simulate the system using our proposed technique and the joint clustering technique [5]. In this simulation, our proposed method continuously estimates the location of the STA, while the joint clustering approaches estimates the location of the STA only once. In our proposed system, the STA does not scan the received power from neighbor APs in different channels; instead, neighbor

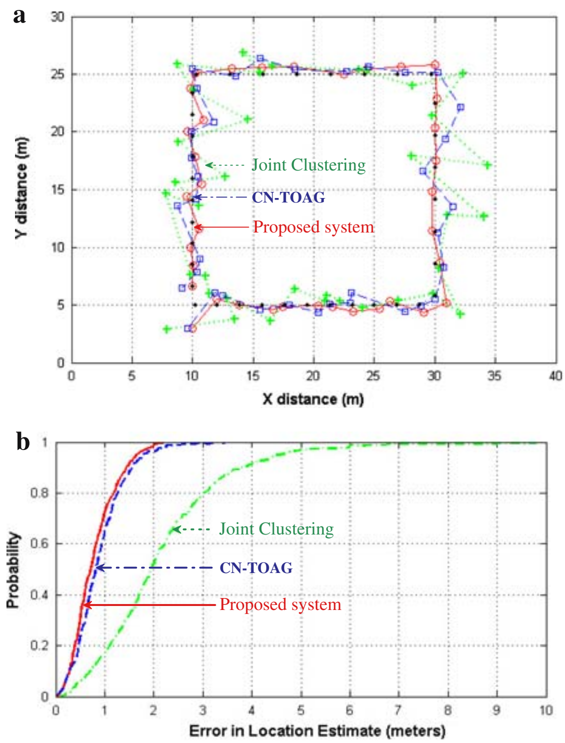



**Fig. 7** (**a**) Track of movement (**b**)CDF of the error in location estimation

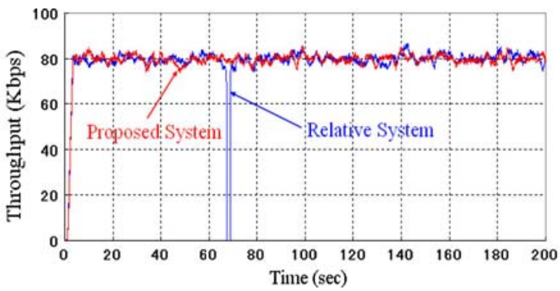



**Fig. 8** Throughput performance

APs use their second transceiver to continuously scan and gather information on neighboring STAs and then send the advanced information back to AP1.

Using the joint clustering technique, the Internet connection is disrupted when the positioning system is running, because the STA must switch its transceiver to each channel in order to scan and obtain the signal power information; this takes more than one second when using passive scan mode. The results from our simulation in Fig. 8 show that there is no interruption of the Internet connection using our proposed technique. This is a necessity for real-time applications such as VoIP that require a delay time of <50 ms.

## 6 Conclusion

Using an AP with two transceivers, the novel IEEE 802.11 WLAN-based wireless positioning system provides high location accuracy without disrupting the network connection. The second transceiver scans nearby STAs in the transmission range and sends advanced information to their associated APs, which analyze and search a database to estimate the location of the STA. The TDOA technique is processed simultaneously to improve the accuracy of the location estimation. Our initial results show that wireless networks are able to estimate the location of a STA without any interruption to the Internet connection; we also improve the accuracy of indoor wireless positioning systems. Although offering a number of advantages, the proposed system requires a novel AP with two transceivers, and users may need to update the firmware in their WLAN cards.

A high accuracy wireless positioning system that does not interrupt the Internet connection will be useful for future wireless LANs. Such systems are capable of supporting real-time services and can be enhanced to support higher data rates applications. Our future work will focus on using the location of the STA to improve wireless network performance in terms of both seamless mobility and traffic load balance among neighbor APs in order to support real-time applications.

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