A Research on Seamless Indoor and Outdoor Positioning

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Abstract—**Combining a variety of positioning technologies and making use of their respective advantages, this paper presents a strategy of seamless positioning. With this method, the positioning system can be used for both indoor and outdoor environments, and it can solve the problems which most LBS applications cannot locate in some circumstances. The paper also designs a new indoor positioning algorithm based on WiFi received signal strength (RSS) fingerprint. Then the "Indoor/Outdoor Positioning System" is designed and implemented on the Android platform according to the strategy and the algorithm above, and the performance of the system proves to be fine. It can meet the users' actual use properly.**

Index Terms—**Seamless Positioning, Global Positioning System (GPS), WiFi Positioning, Cellular Positioning, Received Signal Strength Indication (RSSI)**

I. Introduction

With the popularity of smart phones and the Internet of Things, more and more people start using LBS (Location Based Service). This business has gradually developed into an essential part of the mobile Internet. One of its key factors is that the access to the user's current location, which needs some kinds of positioning technology, should be considered first before a series of services based on location are carried out. When it comes to positioning technology, the most well-known is GPS (Global Positioning System), which is used as the main positioning method in most LBS applications such as Google Maps, Foursquare, etc. But due to the dependence of the satellite signal, it is almost impossible to use GPS in an indoor environment. Positioning based on network such as cellular positioning and WiFi positioning can be used both indoors [1] and outdoors [2]. But cellular positioning accuracy is too low, and generally used as the alternative of GPS. WiFi positioning performs well in the building where hotspots are deployed and signals of all reference points are collected beforehand. Microsoft RADAR system [3] is a successful application in this respect. But when users are far away from the building, they can't obtain a good performance again due to the weakness of the wireless network signal.

Currently, almost all LBS applications use GPS as the single positioning means. As it cannot be adjusted to the changes of the environment, it is impossible to obtain position information in many environments. That directly affects the overall functionality of the software. Therefore, it is necessary to propose a positioning strategy which can be adapted to the changes of the surrounding environment by combining different positioning technologies. There are some literatures which involve related researches. Most of them focus on the combination of GPS and WiFi positioning. Some people propose 4 positioning strategies combining GPS and indoor WiFi positioning [4]. And with experimental comparisons, they give an optimal strategy they consider. Other literatures propose some auxiliary means for positioning. One of them proposes several positioning algorithms with Kalman filtering aiming at the quantity changes of WiFi hotspots and GPS satellites [5]. The authors also discuss the border selection of indoor and outdoor positioning. Another one combines the results of several positioning programs using Kalman filtering and the computer visualization auxiliary [6]. Thus the authors obtain more accurate positioning results. Combining technologies such as Bluetooth, a group of people build a multi-layer architecture on the Nokia N95 platform to achieve positioning [7]. In fact, we must make use of the inaccurate cellular positioning in some cases such as when the platform is not configured with a GPS module or GPS and WiFi are all invalid. This paper gives a detailed positioning strategy combining three types of positioning technologies which can be used for indoor and outdoor seamless positioning. We also propose an indoor positioning algorithm based on WiFi signal strength fingerprint. It can balance positioning accuracy and position matching calculation, and further improve the performance of indoor positioning. Then we implement the "indoor and outdoor seamless positioning system" on the mobile terminal with Android system

This work was supported by China's Ministry of Science and Technology: Science and Technology based SME Technology Innovation Fund (Granted No. 10C26211200143).
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doi:10.4304/jcp.8.12.3047-3057

based on the strategy and the algorithm. In this way, the performance will be verified in all respects.

The rest of the paper is organized as follows: Section II compares several typical outdoor and indoor positioning programs. Section III, the highlight of the paper, proposes an indoor and outdoor seamless positioning strategy designed an algorithm based on signal strength fingerprint. Section IV presents a framework of the design and implementation of "indoor and outdoor seamless positioning system". Section V analyzes and compares the results of performance in experiments. Section VI, the last section, summarizes the paper and gives an outlook of the future.

II. Related Work

A. Outdoor Positioning

There have been some in-depth researches on the outdoor positioning. And some mature technologies appear, such as satellite-based positioning and network-based positioning.

As the most extensive use of satellite-based positioning, GPS was developed by the U.S. Department of Defense in 1978 and originally used in military equipment. It began to be used as a civilian traffic navigation technology from 2000 [8]. Via GPS, we can obtain precise longitude, latitude and height of the three-dimensional spatial positioning with the error approximately within meters. But when it comes to the severely sheltered indoor environments with non-line-of-sight noise interference, the positioning accuracy of GPS declines seriously, even becomes impossible to obtain location information. Assisted GPS [9] is proposed to solve this problem. By using some auxiliary data, mainly combining some information about the mobile terminal collected by the cellular network base station, it can improve the positioning effect when GPS satellite signal is weak. However, compared to GPS for outdoor positioning, the accuracy of AGPS declines seriously and simply can not function in the closed buildings.

Cellular positioning and WiFi positioning are two typical network-based positioning technologies. The former relies on the base stations of the cellular network such as GSM, CDMA, etc. It makes use of the known information of base station's position and time of the radio signal of arrival, signal strength and direction information from the base station measured by the mobile terminal to calculate the location of the mobile terminal. Overall, this positioning technology has a low precision, with the error in a range of about tens of meters to hundreds of meters. The latter i.e. WiFi positioning depends on the wireless LAN. It obtains location information by measuring the signal strength and deployment location of access points (AP) nearby.

Recently, Google Maps has established a huge database of positioning by means of collecting location information provided by end-users of Android mobile phones. Users upload the information about the current cellular network base station or the WiFi APs that can be searched and the signal strength in accordance with the requirements of the format. Google Maps contrasts the uploading information with the pairs of location and positioning information collected in the database. Then by a certain algorithm it selects the latitude and longitude coordinates of the most similar position as the

TABLE I.
A COMPARISON OF SEVERAL TYPICAL POSITIONING PROGRAMS

Program Name	Positioning Type	Technology and Method Used	Accuracy	Costs	Environment	Positioning Coordinates	Limitation
GPS	Satellite positioning	Wireless signal propagation (delay algorithm)	1~5m (95%~99%)	High (costs of receivers)	Outdoor	Geometric coordinates	Indoor positioning impossible
Microsoft RADAR	WiFi positioning	802.11 RF signals (scene analysis / triangulation algorithm)	3~4.3m (50%)	Low (wireless LAN deployment costs)	Indoor/ Outdoor	Geometric/ Symbol coordinates	The target object needs to configure wireless network adapters
Wireless Andrew	WiFi positioning	802.11 (nearest neighbor algorithm)	The grid size of 802.11	Low (wireless LAN deployment costs)	Indoor/ Outdoor	Geometric/ Symbol coordinates	The target object needs to configure wireless network adapters
GSM fingerprint	Cellular positioning	Cellular network (weighted kNN)	Within 10m (80%)	Ordinary (cellular network laying costs)	Indoor/ Outdoor	Geometric coordinates	The selection of fingerprint match channel is more complex

approximate location, and gives them back to the users. Because most of the location information is collected by GPS, when compared to the location calculated by a certain model with information of base stations or APs and signal strength, the accuracy will be enhanced greatly.

B. Indoor Positioning

The research on indoor positioning is still at an initial stage. Compared to the outdoor positioning showing location data with absolute coordinates based on geometric space, the indoor positioning more often use relative reference points based on symbol space to show the location data. Cellular network base stations can also be used for the indoor positioning as mentioned before. However, as the base station facilities are far from the user who is positioning, the positioning accuracy is so low that it is not generally used. Instead, we generally use infrared, Bluetooth, ultrasonic [11], RFID [12], WiFi and other short-range communication technologies for indoor positioning. Among them, WiFi positioning has a higher value due to the relatively low cost and the widely deployed infrastructural APs.

As mentioned in Section II.A, WiFi positioning locates with signal strength of APs and deployment location information. There are mainly two classes of methods. One is triangle measuring [3] and the other is fingerprinting based on the signal strength [13]. The former class of methods can measure distance directly by the received signal strength (RSS) [14]. That is, it converts the measured three signal strength to the distance to a measurement position. The location can be achieved by triangle measuring with a radio propagation model, such as Rayleigh fading model and Rice distribution model. It can also take advantage of the time of arrival (TOA) or time difference of arrival (TDOA) [15] measurement. Because the WiFi signal is susceptible to the interference of a variety of indoor environmental factors with the performance of the time-varying characteristics, this class of positioning methods is difficult to convert the signal strength into the exact position and positioning accuracy is low. The second class of methods includes two stages: data acquisition and online positioning. At the stage of data acquisition, we select a set of reference points, measure the received signal strength indication (RSSI) of each AP, and then establish a fingerprint database of position with the signal vector mappings. At the stage of online positioning, we search the closest reference point in the fingerprint database based on the real-time acquisition of signal strength vectors to estimate the target position. Before the measure, there is a certain amount of work which needs to be done to create a fingerprint database. The positioning accuracy depends on the number and location of the reference points that are selected [16].

The existing online positioning matching algorithm can be divided into deterministic algorithms and probabilistic algorithms. A typical representative of the former is Microsoft's RADAR system [3]. The method finds the closest K reference points in the fingerprint database, and takes their centroid as the estimated coordinates of the target. The algorithm is computationally efficient, but with less accuracy. The latter is mainly the use of Bayes' formula, locating by calculating the posterior probability distribution of the target position [17]. This algorithm has high positioning accuracy, but with a large amount of calculation.

C. A Comparison of Several Positioning Methods

Represented by GPS, a satellite-based positioning technology has a high positioning accuracy. However, the cost is also high, and it can not be used in the indoor environment. On the contrary, network-based positioning technology, such as cellular positioning and WiFi positioning, has a low cost and can be used in both indoor and outdoor environments, but the accuracy is much lower. Table I shows the comparison of several typical positioning programs [18].

III. Key Points of "Indoor and Outdoor Seamless Positioning System"

A. Indoor and Outdoor Seamless Positioning Strategies

For outdoor positioning, the positioning accuracy of GPS is much higher than that of cellular positioning, so GPS should be preferred in the outdoor environment. But when the mobile device is not configured GPS module but with a SIM card to access the cellular network, we could use the cellular positioning instead of GPS. Of course, on this way, there will be some errors with the result.

For indoor positioning, we can use an algorithm based on WiFi signal strength fingerprint (designed in Section III.B) in the building with a built WiFi signal fingerprint database. But in the indoor environment without collected signal fingerprint, we can only upload the signal information of the APs to the Google Maps server to complete the positioning as described in Section II.A. If the WiFi signal of the APs can even not be searched in some buildings, we can use cellular positioning when the mobile device is connected to the cellular network.

The switch of indoor and outdoor positioning is mainly aimed at the GPS and WiFi positioning. For switching smoothly, we generally choose to turn on the GPS and WiFi positioning at the same time (GPS accessing the positional information and WiFi searching APs' signal), rather than open one when the other fails to locate. According to experience, we generally make a decision every 5 seconds [4], and determine whether the respective positioning is a failure according to the updated information of two positioning methods in the last 5 seconds. Then we choose one appropriate positioning result as the output of the current positioning.

As GPS signal is weak in the indoor environment, we can determine its invalidation by not acquiring updated positioning information within 5 seconds, and affirm it is in the indoor environment. Then WiFi signal for positioning will be used. However, sometimes there is GPS satellites' signal still existing close to doors and windows in the indoor environment. GPS has a relatively low positioning accuracy at this time, and its positioning effect is poor compared with reference points for indoor

WiFi positioning. Also as we know, WiFi APs are generally deployed in the indoor environment. As the strength of wireless signal will decay along with the propagation distance, the farther we are from the building in the outdoor environment, the less APs and weaker signal we can search, and the less accuracy the positioning has. And we can't search the WiFi signal at a certain distance far. At this time, we can judge the failure of WiFi positioning also by not acquiring the updated WiFi signal within 5 seconds, and affirm it is in the outdoor environment. Then the positioning result of GPS will be used. However, in the outdoor environment near the buildings, we can still search WiFi signal which is overall weak, and the signal from some APs can't be searched anymore. Therefore, the indoor positioning algorithm based on signal strength fingerprint cannot be used effectively, with a poor positioning accuracy. Moreover, it is not easy to choose reference points to build the WiFi fingerprint map in the outdoor environment.

Through the analysis above, we know there is a problem of regional over-coverage, and the positioning accuracy of each positioning method is not high in the repeated coverage. Therefore, we need to propose a switching strategy selecting the proper positioning method at the edge of the indoor and outdoor environment with a more accurate positioning result. While WiFi signal covers a large area in the outdoor environment, the signal of GPS can only be searched in a few regions close to the doors and windows in the indoor environment. So we should prefer GPS, which can minimize the inaccurate positioning area. The following strategies are used in our positioning system: we always use GPS to position while we acquire continuously updated GPS positioning information; we determine the failure of GPS positioning when we cannot acquire the updated positioning information within 5 seconds, and thereby start to position with WiFi signal that can be searched; when we acquire the GPS positioning information in a succession of 5 seconds, we reuse the positioning result of GPS.

Sometimes, we need to use cellular positioning as the outdoor positioning strategy instead of GPS, so we also have to consider the problem of switching between cellular positioning and WiFi positioning. Since the cellular positioning can be used either in the indoor environment or in the outdoor environment (with a low positioning accuracy), and the cellular positioning in the outdoor environment, we need to switch to WiFi positioning timely when it's close to the building in the WiFi signal coverage area. The positioning algorithm based on signal strength fingerprint can be used in the building with a database of collecting fingerprints, but it's not easy to build a fingerprint map outside the building. Thus we generally take the indoor reference point nearest to the location where we want to position as the positioning result. There will be a greatly adverse influence on the positioning accuracy in this way, but we could only take such a switching strategy because the signal of cellular networks can be searched in the indoor environment, unlike GPS which can easily determine the boundary of the indoor and outdoor environment.

By the analysis of the two subsections above, the following positioning strategies will be adopted in the "Indoor and Outdoor Seamless Positioning System":

- **Outdoor Positioning**: We determine whether the mobile device has a GPS module, and if so, the GPS is preferred as the positioning method. We turn on the GPS module, and conduct an information update every second. If GPS is invalid in the mobile device, but the cellular network can be connected, then we use the cellular positioning instead of GPS.
- **Indoor Positioning**: If we acquire the signal of the deployed APs in the building collected in the fingerprint database, we use the signal strength fingerprint to position. Without the collected "fingerprint", when we acquire the signal of APs, we upload it to the Google Maps server to position. Like that, without APs' signal that can be searched, we generally upload the information of the cellular network base station for coarse positioning.
- **The Switch of Indoor and Outdoor Positioning**: For the case of GPS used as the outdoor positioning method, when we can't acquire GPS information for a succession of 5 seconds, it means we have entered a building, and we should switch to WiFi positioning; when we acquire updated GPS information, we switch back to GPS. For the case of the cellular positioning used as the outdoor positioning method, when we can acquire WiFi signal of APs for a succession of 5 seconds, it means we have entered the building or we are near the building, and we should switch to WiFi positioning; when we can't acquire the WiFi signal of APs for a succession of 5 seconds, we switch back to the cellular positioning.

The above positioning strategies can be described in the following flow chart (Figure 1).

B. Description of a WiFi Positioning Algorithm for Indoor Positioning

An algorithm based on signal strength fingerprinting is described below, and also divided into two stages: data acquisition and online positioning.

1) Data Acquisition

First, we collect the AP's information deployed in the buildings where indoor positioning is needed, and then we store the information in the database on the server. Generally at least three APs need to be deployed in the building in which we can locate with reference points. With less than three APs, it is unable to determine the exact position.

Then we can collect the position information at n different reference points with our mobile terminal device. We search the signal of all APs deployed in the building at each reference point, and obtain RSSI values to form a record as the fingerprint feature of the reference point. RSSI statistical characteristic is relatively stable, in that the value distribution is an approximation of the normal distribution. So we can take the average value of multiple acquisitions of the RSSI value for each AP as the feature of the AP, to avoid a single acquisition instability error. Generally, we can collect multiple sets of data, each after some interval of time, and then form a signal vector

$$\vec{S}_i = (s_{i1}, s_{i2}, ..., s_{im}) \;\; i = 1,2,...,n . \tag{1}$$

by averaging the results where n is the number of selected reference points, and m is the number of APs deployed in the buildings. Finally, we store these vectors as records in the fingerprint database.

2) Online Positioning

At the stage of online positioning, we can perform the following steps:

a) Upload the information of APs that are searched to the server; select the building which the most APs belong to as the current entering building in the database. Then we obtain the signal fingerprint information of APs at each reference point in the building, and form the signal fingerprint matrix

$$S = (s_{ij}) \;\; i = 1,2,...,n; \; j = 1,2,...,m . \tag{2}$$

. Each row of it is the fingerprint information of a reference point, and each column is signal values of an AP collected by each reference point.

b) Select a set of signal values which belong to the APs deployed in the current building among the APs searched as the signal vector of current positioning point

$$\vec{s}_{cur} = (sc_1, sc_2, ..., sc_m) . \tag{3}$$

, where m is the number of the APs deployed in the building. If the APs deployed in the building can not be searched currently, these signal values are 0.

c) Take the difference between each value of every row of the signal fingerprint matrix S (2) and each value of $\vec{s}_{cur}$ (3), and then we take the absolute values to form a signal difference matrix

$$D = (d_{ij}) \;\; i = 1,2,...,n; \; j = 1,2,...,m . \tag{4}$$

, where

$$d_{ij} = | sc_j - s_{ij} | . \tag{5}$$

is the difference of the signal value of the j-th AP between the current positioning point and the i-th reference point.

d) Take the maximum value of each column of the signal difference matrix D (4) to form a vector

$$\vec{d}_{\max} = (dm_1, dm_2, ..., dm_m) . \tag{6}$$

, where dm_j is the maximum difference of the j-th AP between the current positioning point and each reference point, i.e.

$$dm_j = \max_{i=1,2,...,n} d_{ij} . \tag{7}$$

e) According to the signal difference matrix D (4) and the maximum difference vector $\vec{d}_{\max}$ (6), the similarity of AP signal values between reference points and the current positioning point can be calculated to form a signal similarity matrix

$$P = (p_{ij}) \;\; i = 1,2,...,n; \; j = 1,2,...,m . \tag{8}$$

, where

$$p_{ij} = 1 - d_{ij} / dm_j . \tag{9}$$

f) Sum the values of each row of the signal similarity matrix P (8) to form a vector

$$\vec{p}_s = \begin{pmatrix} ps_1 \\ ps_2 \\ ... \\ ps_n \end{pmatrix} . \tag{10}$$

, where

$$ps_i = \sum_{j=1}^{m} p_{ij} \;\; i = 1,2,...,n . \tag{11}$$

That is to say we take the sum of the similarity values about each AP signal between the reference point and the current positioning point as the possibility weight in which the reference point is looked as the current positioning point.

g) If the targeting accuracy of positioning is not excessively demanded or the selected reference points are dense enough, we can select the reference point with the highest weight value

$$x = \arg\max_{i=1,2,...,n} ps_i . \tag{12}$$

as the positioning result of the current positioning point. But if further precise positioning is needed, we can select K reference points with the largest possibility weight based on the map of fingerprint formed by reference points, then we calculate the centroid and take it as the positioning result of the current positioning point.

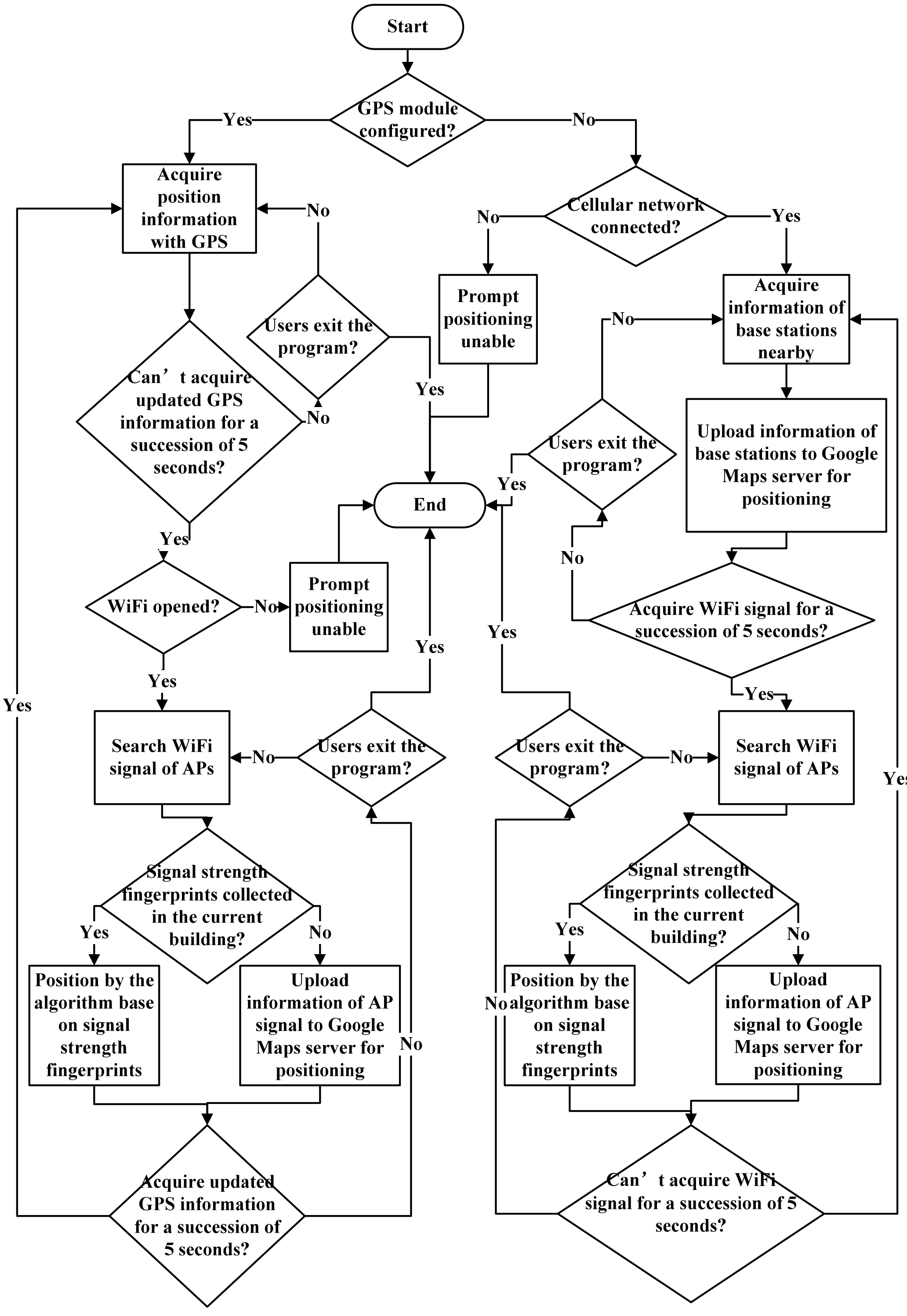

Figure 1. The flow chart of system positioning strategies.

IV. The Design and Implementation of "Indoor and Outdoor Seamless Positioning System"

A. The Design of Overall System Framework

The system is used to provide positioning and location based services (LBS) for mobile terminals, including recommending shops nearby in the outdoor environment and describing information about the current position in the indoor environment, etc. It is divided into two parts: the indoor positioning and the outdoor positioning, which are connected with each other by switching strategies.

The computing power, storage capacity and battery power consumption of embedded devices are all limited, so the work of the matching calculation of indoor positioning and searching for shops nearby should be put on the server. The client only needs to collect data and acquire position coordinates or signal. The server can be a physical server, and it is best divided into front-end web server, application server used for positioning business, and back-end database server, which is more conducive to the load balancing. The client can be connected to the Internet via WiFi or cellular network to access the server, and the two sides transfer information by standard HTTP. The overall network architecture is shown in Figure 2.

according to the "Indoor Positioning Strategies". Then we can acquire the current position and the algorithm mentioned above. Certainly, an alternative program is that uploading the descriptions of APs and signal strength to the Google Maps server to position, and the latitude and longitude coordinates to the application server to acquire the information of recommended shops within a certain range nearby, as adopted by the outdoor positioning.

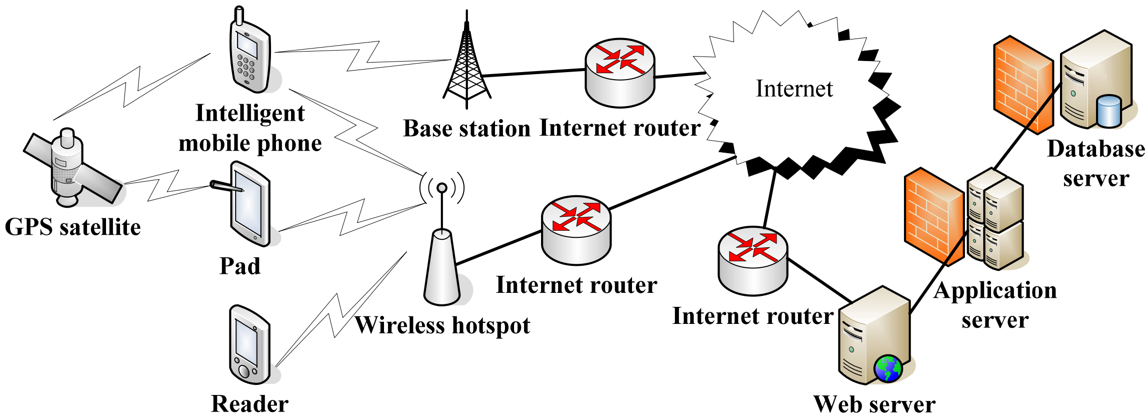

Figure 2. The network architecture of system.

B. The Implementation of Client Platform

A mobile terminal device, as a client, accesses the remote server to acquire indoor and outdoor positioning information and other location services. The client system can be divided into 3 modules, two data acquisition modules about shops' information and reference points' signal, and an online positioning module in which the "Indoor and Outdoor Seamless Positioning Strategies" is used to acquire position information and location services. Data acquisition can only be used by the specific staff of shops in actual use, while the positioning module can be only used by common users. The acquisition module of the shops' information acquisition module is used for uploading descriptions of shops and the precise location acquired by GPS as the shops' information for recommendation. The reference points' signal acquisition module is used for uploading descriptions of different rooms, booths, etc. as reference points and descriptions of signal strength searched at these positions as well. The information will be stored in the fingerprint database as the matching data by indoor WiFi positioning algorithm.

The online positioning module determines the current environment based on the "Indoor and Outdoor Seamless Positioning Strategies" mentioned above, and then choose indoor or outdoor positioning program accordingly. For the outdoor positioning, we can use GPS or upload the cellular positioning information to the Google Maps server according to the "Outdoor Positioning Strategies". Then we upload the latitude and longitude coordinates and a search range to the application server to acquire the information of recommended shops within a certain range nearby. For the indoor positioning, we need to search the signal of APs nearby, and then upload descriptions of the APs and signal strength to the application server

C. The Implementation of Server Platform

The server platform can be developed with the lightweight J2EE Servlet +Spring +Hibernate framework, deployed on Apache Tomcat server, and implemented as a three-tier architecture. The persistence layer and data access layer, the lowest two layers of the architecture, map entity classes and database tables by Hibernate technology. The database tables involve shops' information recommended after outdoor positioning, and indoor positioning information of buildings, reference points, APs and signal. Middle-tier business logic layer interacts with the upper and lower layers of the Spring framework, and mainly deals with 4 aspects of business including "collection of shops' information", "collection of APs and signal information", "query about nearby shops' information according to a user-specified range" and "query about current position description with the WiFi positioning algorithm". The top-level presentation layer provides the interface corresponding to the four aspects above implemented by Servlet technology, for receiving the client's request and data, and then returning the corresponding result.

D. The Implementation of Communication between Client and Server

The mobile terminals access the Internet through the cellular network or WiFi wireless hotspots, while the server accesses the Internet through wired LAN. We need to do port mapping on the router of the LAN where the server is, and then the client can access the server via a fixed IP address and port number. The two sides communicate with each other via HTTP. The client sends an HTTP POST or HTTP GET request to the server, and the server returns result data encapsulated in the JSON (JavaScript Object Notation) data interchange format, which is easy for the client to resolve and display to the user. The uploading of collected data is sent to the server by POST method, with data contents as parameters. The server then returns a JSON Object to the client to notify the processing results. As for the positioning process, the client sends a request by GET method, with the latitude and longitude coordinates of the current location or WiFi signal strength as the parameter. The server encapsulates the results into a JSON Array and returns it to the client. Figure 3 shows the architecture of the server and its interaction with mobile clients.

Since these positioning methods rely on the wireless transmission signal which is susceptible to environmental interference and affects the accuracy and the used time of positioning, we carry out 20 tests for each positioning method here and average the test results to reduce the error. Table II is a comparison of three positioning methods used for the indoor and outdoor environment.

As can be seen from Table II, GPS for positioning costs less time than the other two positioning methods obviously. That is because we set to update positioning information automatically at intervals and distances, and

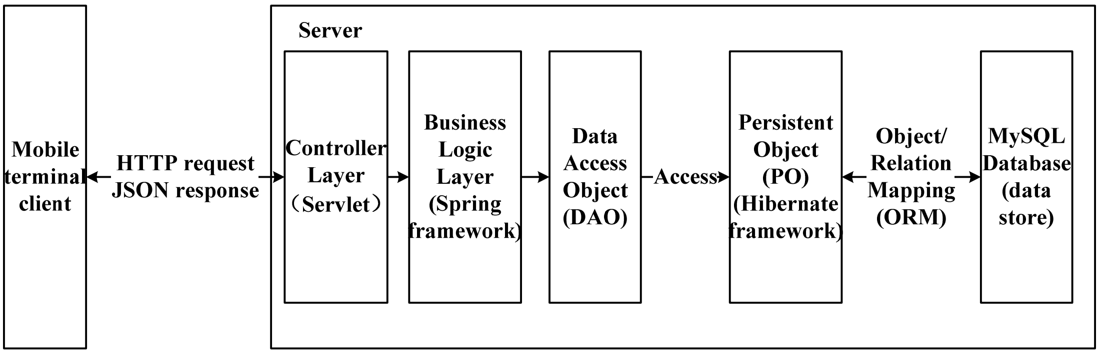

Figure 3. The architecture of the server and the interaction of system.

then we can acquire the latest updated positioning information directly when we need to position. The result of GPS for indoor positioning in the table is measured by assisted GPS (AGPS) which uses a similar mechanism as GPS for outdoor positioning, so the used time is also close to the latter. For the cellular positioning and WiFi positioning in the table, we all upload the feature of current position (base stations information or WiFi signal) to the Google Maps server to complete positioning. The data of the used time for these two methods includes two parts: "acquiring the feature of current position" and "interacting with the Google Maps server". Mobile terminal devices access the Internet through cellular network or wireless hotspots generally. It will cost a second or so to access the server for uploading information and acquiring positioning results through wireless network. Since the cellular signal may also be influenced by factors such as buildings shield, the signal acquired in the indoor environment is a little poorer than that in the outdoor environment, and it will cost longer to position in the indoor environment than in the outdoor environment.

V. System Performance Testing Experiments

In the "Indoor and Outdoor Seamless Positioning System", we combine several positioning methods by the "Seamless Positioning Strategies" for positioning in different circumstances. In the next, we test and compare the used time and accuracy of these positioning methods. All the tests are on a Samsung Galaxy Nexus (CPU 1228MHz, memory 1GB RAM) mobile platform configured with Android 4.0 OS.

A. Performance Comparison of Several Positioning Methods

In the system, we use the positioning algorithm based on signal strength fingerprint in the buildings in which the signal data have been collected. Besides, we also use general GPS and the method of uploading cellular or WiFi signal information to the Google Maps server to acquire the location. Here we compare the performance test results of the latter positioning methods first, while we focus on WiFi indoor positioning in the next subsection.

TABLE III.
A COMPARISON OF THREE POSITIONING METHODS USED FOR THE INDOOR AND OUTDOOR ENVIRONMENT (MS)

	The positioning of GPS	The cellular positioning	WiFi positioning
Indoor	1.85	1084.70	988.60
Outdoor	1.65	2685.75	1769.35

TABLE II.
A COMPARISON OF 3 POSITIONING METHODS' ACCURACY (M)

	The positioning of GPS	The cellular positioning	WiFi positioning
Indoor	/	118.68	80.57
Outdoor	2695.47	146.43	74.31

Table III above shows the accuracy comparison between 3 positioning methods. Since the positioning result of GPS is quite accurate in the outdoor environment, with the error within the range of a few meters, we take it as the standard position, and test the relative deviations of results of other positioning methods.

As can be seen from Table III, assisted GPS in the indoor environment has a very unsatisfactory result. It is difficult to use since the deviation of the distance is too large. The accuracy of cellular positioning and WiFi positioning in the outdoor environment is not much different from that in the indoor environment. Overall, the accuracy of WiFi positioning overtakes the cellular positioning both indoor and outdoor. The positioning result has a lot to do with the density of locations collected by Google Maps in different regions, so the positioning accuracy will be much different in different locations. However, the general deviation is within about 100m, in an acceptable range.

The results above can further demonstrate the correctness of the positioning strategies that we have taken. That is to say, we use GPS positioning in the outdoor environment as far as possible, and use cellular positioning instead in some special circumstances. We should collect the features of each location of the building in the indoor environment, so as to use the WiFi positioning based on signal strength fingerprint. But in the indoor environment without the certain condition, we resort to Google Maps for WiFi positioning or cellular positioning.

B. Performance Tests of the Algorithm Based on Signal Strength Fingerprintsn

As mentioned, the algorithm based on signal strength fingerprints can be divided into two stages: data acquisition and online positioning. We need to test the algorithm's performance on two stages respectively. The experiment is done on the fourth floor in a certain teaching building deployed with several WiFi APs. On the stage of data acquisition, we collect 10 times of WiFi signal fingerprints at each of the 20 reference points outside classrooms, and take the average of the 10 times of fingerprint values as the feature vector of each reference point. Then we upload all feature vectors to the server, and store them in the fingerprint database. The distance between two adjacent reference points is about 5~10m in Region A of the building, while it is about 15m in Region B. The specific location map is shown in Figure 4.

On the stage of online positioning, we choose A401, A407, A414, B403, C 5 points shown in the location map as test points, and do 30 groups of positioning test in each location. In order to improve real-time capability, and make the positioning delay within an acceptable range, we collect 3 times of signal data at intervals in each group and take the average as the feature vector of current test point. Then we upload the data to the server and contrast them with the fingerprint vector of each reference point in the fingerprint database. We take the most similar reference point about the feature vector as the positioning result. Table IV shows the positioning accuracy of the test points selected in 30 groups of test.

TABLE IV.
THE POSITIONING ACCURACY OF THE TEST POINTS SELECTED (%)

Test Point	A401	A407	A414	B303	C
Positioning Accuracy	90	76.67	93.33	86.67	0

Test point A401 and A414, are each on one side of the building and relatively far from their adjacent reference points (8~10m). In addition, in these two points, we can acquire the signal of some APs which cannot be acquired in other points. So the testing accuracy is relatively high due to the obvious signal characteristics. A407, nearly in the center on the south part of the floor, is comparatively close to the adjacent reference points (about 5m). The signal characteristics of the point are easily confused with that of the reference points nearby, so the testing accuracy of this point is relatively low. Point B403 is also in the center, which is on the north part of the floor. Since the reference points are relatively far from each other (about 15m) in Region B, and also far from the reference points in Region A (about 20m), the accuracy at Point B403 is much more better than that of Point A407. Point C in Figure 4 is not a reference point, so there is no feature collected at this point. Therefore, most of the test results at this point are Point A414 and Point B401, and a small amount of Point A413 and Point B402 also appear in the results. That means when users locate at Point C, the result of positioning is Point A414 or Point B401, but not Point C itself. In this case, the positioning result can be acquired by calculating the centroid of these reference points and labeled on the location map in actual use.

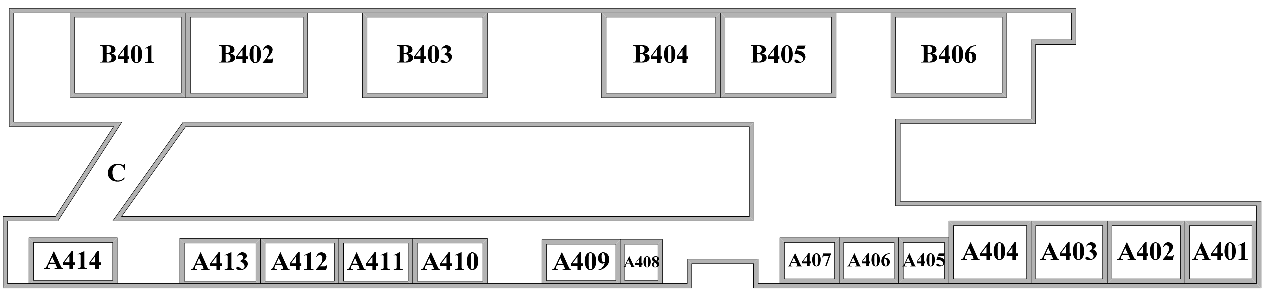

Figure 4. The location map of experimental environment.

According to the above test results, the accuracy of test points which have a distance of 8m or above from the adjacent reference points is above 90%. This is accurate enough. So the positioning algorithm's accuracy can be identified within 8m. The accuracy of test points which have a distance of 5m or so from the adjacent reference points is about 80%, which can be basically accepted. Therefore, the positioning accuracy of the algorithm can also be considered about 5m approximately.

TABLE V.
THE USED TIME OF TWO STAGES OF THE INDOOR POSITIONING ALGORITHM (MS)

	Data Acquisition	Online Positioning
Acquiring position's feature data	118894	1219
Interacting information with the server	1529	2477

The used time of the two stages--data acquisition and online positioning are shown in Table V.

The used time of acquiring position's feature data in the stage of data acquisition includes two parts: acquisition of WiFi signal 10 times and average calculation. The result shown in Table V is the average used time of data acquisition at 20 reference points. We make use of the Action mechanisms of the Android system to acquire WiFi signal at intervals. So it will cost 2 minutes to complete the data acquisition for 10 groups of signal in each location. The intervals between each acquisition and final averaging can avoid large errors to the feature vectors of reference points due to the instability of WiFi signal in a short period of time. The used time of acquiring position's feature data in the stage of online positioning includes two parts: acquisition of 3 groups of data and calculating the average as the current signal vector. The result shown in Table V is the average used time of testing 5 test points for 30 times. It costs about 1 second that can guarantee real-time of the indoor positioning basically.

It costs about 2 seconds in uploading the position feature information of reference points on the stage of data acquisition and acquiring positioning results from the server on the stage of online positioning. The latter one costs a little longer since the server needs to calculate the most likely reference points based on the algorithm designed above. Since the scale of the fingerprint database is relatively small, we take a PC—Lenovo Centre M5100t (CPU AMD Phenom II X4 2.59GHz, memory 3.0GB RAM) configured with Apache Tomcat 7.0.23 as the server to meet the performance requirements. We can deploy multiple servers with higher performance for location queries and calculations on a larger scale of fingerprint database in actual use.

VI. CONCLUSION

This paper proposes a series of seamless positioning strategies combining a variety of positioning technologies for indoor and outdoor environment, and designs a WiFi positioning algorithm based on signal strength fingerprints. We design and implement a positioning system which uses the strategies and the algorithm, and test the performance such as the used time and accuracy of common positioning methods and the algorithm. The performance of the system can meet the needs of users basically, but the performance still needs to be improved in some respects such as the positioning accuracy of the designed WiFi positioning algorithm that is proposed. In addition, the actually used positioning system can collect the feature data of intensive reference points on the stage of data acquisition. In order to improve the positioning accuracy, it also adopts the program in which the centroid of close K reference points on position feature is calculated and labeled on the fingerprint map. We will further improve the functionality and performance of the system in the future.

ACKNOWLEDGMENT

The authors wish to thank the members of the Embedded System and Information Security Lab, College of Information Technical Science, Nankai University for their support and help. This work is supported in part by a grant from China's Ministry of Science and Technology: Science and Technology based SME Technology Innovation Fund (Granted No. 10C26211200143).

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