Research and Development of Indoor Positioning

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Abstract: Indoor positioning systems have been sufficiently researched to provide location information of persons and devices. This paper is focused on the current research and further development of indoor positioning. The standard evolution and industry development are summarized. There are various positioning systems according to the scenarios, cost and accuracy. However, there is a basic positioning system framework including information extraction, measurement and calculation. In particular, the detailed positioning technologies mainly including cellular positioning and Local Area Network (LAN) positioning are listed and compared to provide a reference for practical applications. Finally, we summarize the challenges of indoor positioning and give a 3-phase evolution route.

Keywords: indoor positioning; LBS; cellular network; local area network

I. INTRODUCTION

Positioning is to determine the geographical location of an object in a certain coordinate system. Positioning applications in outdoor scenario include navigation and tracking, traffic management and travel services, etc. There are much more widespread availabilities in the indoor scenarios. According to the research of Strategy Analytics Corporation, people take 80%~90% time in indoor environment, and 70%~80% communication also occurs in indoor environment. For commercial demands, common use cases such as shopping in malls or supermarkets, warehouse management, game development and so on, is continuous improved. There are more new applications in 5G era. Internet of Vehicles (IoV), for example, needs the positioning information for smart parking, autopilot and navigation. Another typical application of positioning in the all interconnected era is the smart home, which needs the accurate positioning information of people to control the switch of the home appliances. More applications even can be found in Industry 4.0, Virtual Reality (VR) and so on. For commonweal needs, indoor positioning also plays an important role, such as care of the elderly and children, search and rescue of people in disaster.

The huge demands on the indoor positioning enable the technology innovation and enhancement to pursue the market interests. All of these in turn increase the expectations of user experiences. By now, there are various indoor positioning technologies. Cellular positioning [1] and Wireless Local Access Network (WLAN) positioning are common technologies.

The localization technologies based on the cellular network originated from the emergency call‘911’(E-911) proposed by Federal Communications Commission (FCC) early in 1990s, aiming to provide the accurate and reliable localization information [2]. Cellular positioning mainly uses the current cellular wireless networks to get the location of objective by using the signal measurements. Considering the wide coverage of cellular networks, bearing a variety of Internet services [3][4][5], and no needs updating of mobile terminal hardware, cellular positioning technology is more commonly used.

Owing to features of the high transmission rate, easy installation, free of charge in many places (office buildings, hotels, railway stations, homes, schools, supermarkets, etc.), and so forth, WLAN makes people quickly access the network anywhere anytime in their daily life and work. Therefore, WLAN positioning technology has become another popular way for people to get the location information. Indoor positioning could be implemented on the basis of multiple wireless communication systems, including WiFi [6], Bluetooth [7], RFID [8], UWB [9], ZigBee [10], etc.

Additionally, there are also some other positioning technologies besides cellular-based and LAN-based positioning, which exploit geomagnetic, barometer, LED, camera, shadow, etc. All the indoor positioning technologies have their own merits and demerits. To pursue further improvement of positioning performance, it is no doubt the hybrid of some positioning technologies is of importance, which can sufficiently make use of their advantages [11].

This paper aims to provide readers with a comprehensive review of the wireless positioning systems for indoor applications. The reminder of this paper is organized as following: In Section II, the current situation is presented. Then, the basic positioning architecture and principal are explained in Section III. Section IV gives the mainstream indoor positioning technologies. In Section V, the challenges of indoor positioning are summarized. And the future developments of indoor positioning in the 5G era are predicted in Section VI. At last, Section VII gives the conclusions.

II. CURRENT SITUATION OF INDOOR POSITIONING

2.1 Standard evolution

3GPP Service and System Aspects (SA) working group has focused on the Location Based Service (LBS) standardization for a long while, referring to wireless positioning methods, LBS service standards and the LBS architecture. The group mainly concentrates to provide the LBS applications and developments through cellular networks, which cover logistics management, navigation, traveling, hotspot search and commercial advertisement pushing, etc. 3GPP Radio Access Network (RAN) working group gave the standards of the network architecture, new network units for positioning, positioning process and positioning methods in cellular networks. The positioning technologies include Cell-ID, enhanced Cell-ID, Time Difference of Arrival (TDOA) [12], network associated GPS, etc.

The basic positioning method “Cell-ID (CID)” was proposed in Release 8 [13], which utilized the cellular network knowledge serving for users. In Release 9 [14], Observed Time Difference of Arrival (OTDOA), using the reference signal time difference measurements conducted on downlink Positioning Reference Signals (PRS) received from multiple base stations, was defined with the accuracy of 50-100m. Uplink TDOA (UTDOA), an alternative method to OTDOA, was standardized in Release 11 [15]. From Release 12 [16], the positioning accuracy was considered to satisfy the FCC demands (67% of accuracy is less than 50m, i.e. <50m@67%). The indoor positioning, which used WiFi, Bluetooth, barometer and Terrestrial Base Station (TBS), was proposed in Release 13 [17], and their positioning accuracy demand in altitude is less than 3m. In Release 14, enhanced positioning methods with higher accuracy (<3m@80%) and less time delay (initialization time is less than 10s and subsequent positioning response time is 10ms ~15ms) will be studied and discussed in 5G networks. The evolution of positioning technologies in 3GPP is shown in Fig. 1.

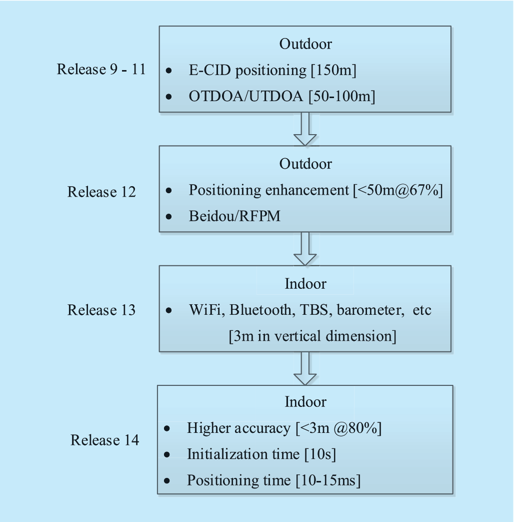

Fig.1 *The evolution of positioning technologies in 3GPP standards*

2.2 Industry development

Due to the high usage of smart terminals and the frequency of data connections, indoor positioning is considered to be the next market of ten billion dollars in the near future. Therefore, indoor positioning has become a critical opportunity that the companies seize in industry.

Baidu Map has opened a platform to developers, providing the capabilities of address information analysis, basic location description and surrounding Point of Interest (POI) search, with the aim that the developers can add the positioning services in their own products. To achieve the accuracy of 1~3m, the open platform uses the complementary platform including geomagnetic technology, enhanced WiFi fingerprint model, and so on. By now, there have been 30 billion positioning requirements received by the open positioning services provided by Baidu [18].

Google, another navigation giant, has provided the indoor navigation services since Google Maps for mobile 6.0, relying on the GPS, WiFi, and cellular networks. Recently, Google has launched a project named "Tango", which uses sensors and cameras to offer the 3D indoor positioning services.

iBeacon is an Apple's Bluetooth Low Energy (BLE) based positioning system, which allows Mobile Apps to listen for signals from beacons in the physical layer and react accordingly. In essence, iBeacon technology allows Mobile Apps to understand their positions. Compared with WiFi and UWB, iBeacon is lower cost, and easier to deploy. The iBeacon based positioning has been used in shopping malls, parking lots, and provided a set of indoor positioning solutions.

III. Framework and Principles of Indoor Positioning Systems

An indoor positioning system mainly consists

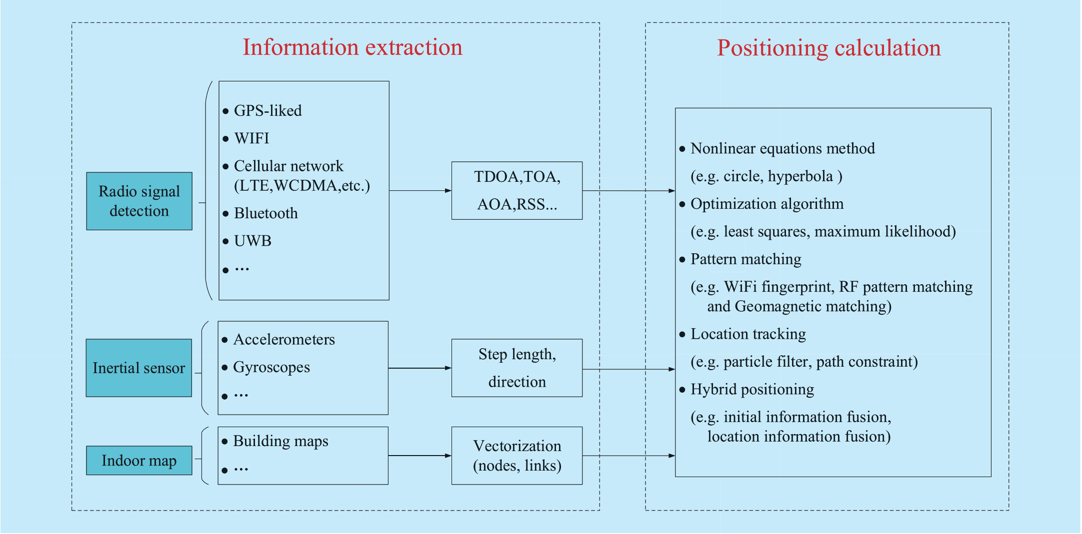

Fig.2 *Framework of indoor positioning systems*

of three parts as shown in Fig. 2. The first procedure is information extraction, which includes radio signal detection, inertial sensor information extraction and indoor map information acquisition. The radio signals, such as GPS-liked, WiFi, LTE, Bluetooth, UWB, etc., are transmitted from user terminals (detection of uplink signals) or radio access points (detection of downlink signals). The information extracted form signals includes power of received signals, signal transmission time, etc. The information can be converted to TOA, TDOA and Received Signal Strength (RSS). On the other hand, the common inertial sensors in mobile equipments are accelerometers and gyroscopes. The accelerometers can measure linear acceleration and the gyroscopes can measure angular velocity. These parameters can be converted into users' step length and direction. The building map is converted into the electronic version of indoor map. And the indoor map is modeled as a network of nodes and links. Finally, after the efficient information is collected, those parameters are calculated independently or in combination based on positioning algorithms to obtain the user's position.

3.1 Information extraction based on radio signal detection

In indoor positioning systems, the radio signal detection measurements include TOA, TDOA, AOA, RSS, etc.

TOA is one of the most popular methods in indoor positioning systems. The common methods to get TOA are the phase offset detection and direct time detection. The former method uses correlation calculation to obtain phase offset which is used to calculate TOA. In this method, the signal frequency must be synchronized. The latter method includes two strategies to get TOA: one-way TOA and two-way TOA. In one-way TOA, the time from transmission node to reception node is measured directly, and the time between those two nodes must be strictly synchronized with a common clock. In two-way TOA, the distance between two nodes is computed using the round-trip delay estimation without the need for a common time reference [19].

Instead of measuring the absolute distance, TDOA measures the time differences between transmission nodes and reception nodes. Calculate the difference between two TOA measurements to eliminate the unknown time of emission [20]. On the other hand, correlation calculations based on the correlation characteristic of certain radio signals are also frequently used to get TDOA.

AOA refers to the angle between the transmission direction of an incident wave and some reference direction, which is called as orientation. AOA represents the degrees in a clockwise direction from the North. When the orientation points to the due North, the AOA measurement is absolute, otherwise, relative. The common approach to obtain AOA measurements is to use an antenna array or the mechanical-agile directional antennas deployed at the receiving sensors.

In the RSS method, the propagation path loss from the transmission node to the reception node is modeled. Theoretical and empirical models are used to translate the difference between the transmitted signal strength and the received signal strength into a distance estimation. Besides, the RSS measurement can be used to construct the fingerprint database [21].

3.2 Information extraction based on inertial sensor detection

Inertial navigation is a self-contained navigation technology. The measurements provided by inertial sensors, including accelerometers and gyroscopes, can be used to estimate the location and orientation of the object relative to a known starting point. The typical inertial measure units (IMUs) consist of three orthogonal gyroscopes and three orthogonal accelerometers. The gyroscopes and accelerometers can measure the angular velocity and linear acceleration, respectively. These measurements can be converted into step length and direction, which make it possible to track the position and orientation of a mobile device [22].

After extracting the angular velocity and linear acceleration, some methods can be used to get the step length and direction. The common methods include constant estimation and step-detection-based estimation. Constant estimation assumes the step length is a constant and utilize integral function to calculate the change of angular and velocity. Then the move distance can be calculated. The value of the constant step length can be obtained from a table, which is produced by the empirical models. The principle of step-detection-based estimation is that the cyclic pattern of the total acceleration is used to detect the steps. There are many approaches including peak detection (Fang et al, 2005; Ladetto, 2000), autocorrelation (Weimann & Abwerzger, 2007), zero-crossing (Beauregard & Haas, 2006; Käppi, Syrjärinne & Saarinen, 2001), stance-phase detection (Cho &Park, 2006), and so on. The step detection can be used to determine the step frequency, which is needed for estimating the step length [23]. Then the step length can be used to calculate the use's moving distance.

3.3 Map-matching

A map database is used to control, to control, correct and update the position estimated by the navigation system. The comparison of geometric and topologic characteristics between the user's trajectory and certain elements in the map can be used to find a correct representation of the user's position. Based on different criteria, the estimated user's position can be associated with certain element of the map. This process of association is called Map-matching [24].

There are usually two methods to get an indoor map. If there is a Computer Aided Design (CAD) building map, the Integrated Development Environment (IDE) software tools are used to deal with it. Alternatively, the indoor map can be mapped directly by measuring the objects and characteristics of the building. Then the coordinate system should be established. We can choose a suitable point as the origin of the indoor coordinate system. Based on the requirements, the indoor coordinate system may need to be transformed into outdoor coordinate system. The latitude and longitude of special indoor points would be measured in order to match the outdoor coordinate system. For further positioning calculation, the map can be preprocessed, for example modeled as a network of nodes and links.

3.4 Indoor positioning algorithms

There are many different indoor positioning algorithms nowadays, including nonlinear equations, optimization algorithms, location tracking, pattern matching and hybrid

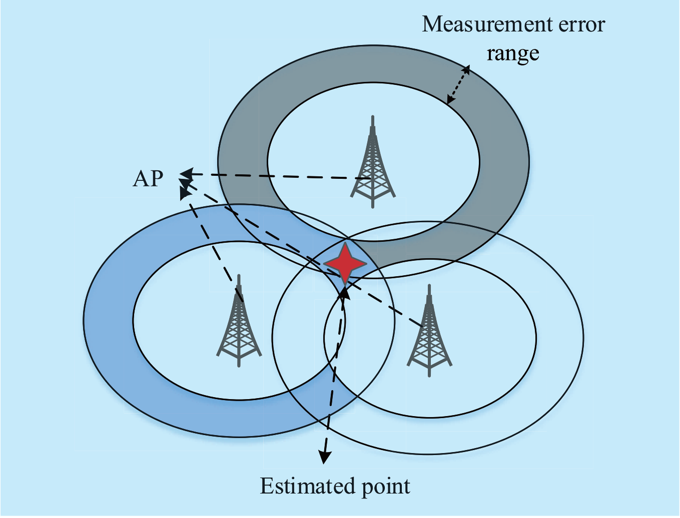

Fig.3 *The principle of TOA*

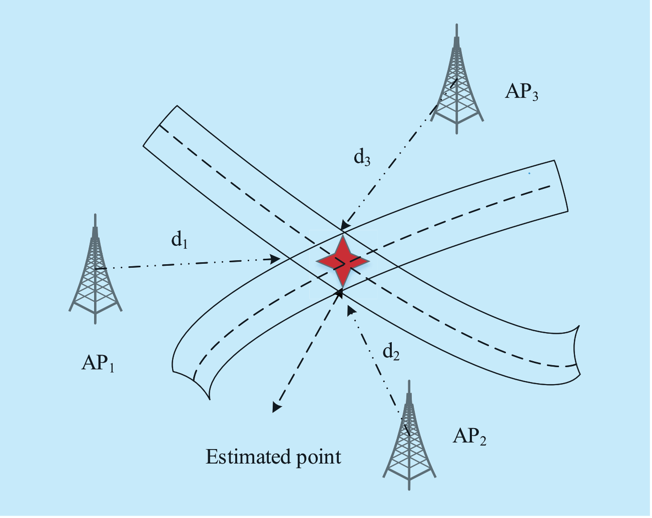

Fig.4 *The principle of TDOA*

positioning methods.

Nonlinear equations algorithm, also called geometric positioning algorithm, is a method that a set of equations based on the measurements, such as TOA, TDOA, are constructed. And the solution of nonlinear equations is the user's location. The TOA measurement is corresponding to the equations of circle. The basic principle is shown in Fig. 3. The intersection of circles is the location of estimated point. The principle of TDOA is similar with the TOA. The difference is that the TDOA measurement is corresponding to the equations of hyperbola. Its principle is shown in Fig. 4.

Usually, nonlinear equations are hard to find the analytic solution. So solving the nonlinear equations can be converted into nonlinear optimization. The common optimization algorithms include least square algorithm, Minimum Mean Square Error (MMSE) algorithm, maximum likelihood estimation, etc. In some situations, the computational complexity of non-iterative estimation algorithms is much large and the result is not well. So the iterative algorithms are proposed to improve the positioning accuracy.

Pattern matching is another method for positioning, including WiFi fingerprint, multi-path signal pattern matching and geomagnetic matching. Taken WiFi fingerprint as an example, fingerprint database is generated according to the different Received Signal Strength Indications (RSSIs) of WiFi Access Points (APs) , which is stored in the positioning server. In order to get a higher precision, much work must be done to fulfill the database.

In addition, location tracking is another important method to improve the positioning accuracy. It is mainly based on the users' history locations, electronic maps and some other information to track the UE's movement. Location tracking algorithms include particle filter, Kalman filtering, and so on. The filtering methods enable the UE's movement trajectory smoother, which can avoid the effect caused by a certain large positioning error.

In order to meet the requirements for higher accuracy, the above positioning technologies can be utilized in combination to obtain the user's position. In other words, the hybrid positioning algorithm is proposed. The hybrid positioning algorithm is divided into two types. One is initial information fusion, which is that the measurements of all the positioning methods can be combined before positioning calculations. The other one is post information fusion, which is that the positioning results of different technologies are merged after the single positioning calculating.

IV. Indoor Positioning Technologies based on Different Communication Systems

In this section, we focus on cellular-based positioning technology and LAN-based positioning technology. Then the other positioning technologies will also be introduced briefly.

4.1 Cellular-based positioning technology

This section is dedicated to introduce the positioning technology which rely on the mobile communication network. Fig. 5 shows the positioning architecture in LTE networks. There

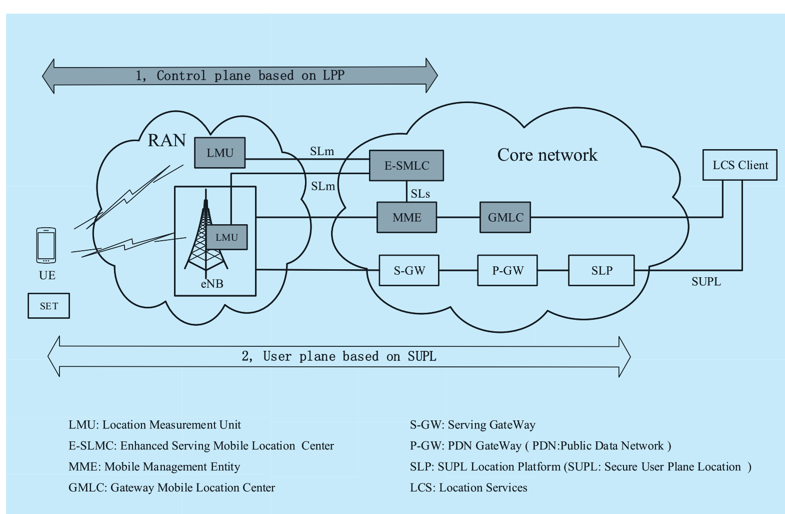

Fig.5 *Positioning Architecture in LTE networks*

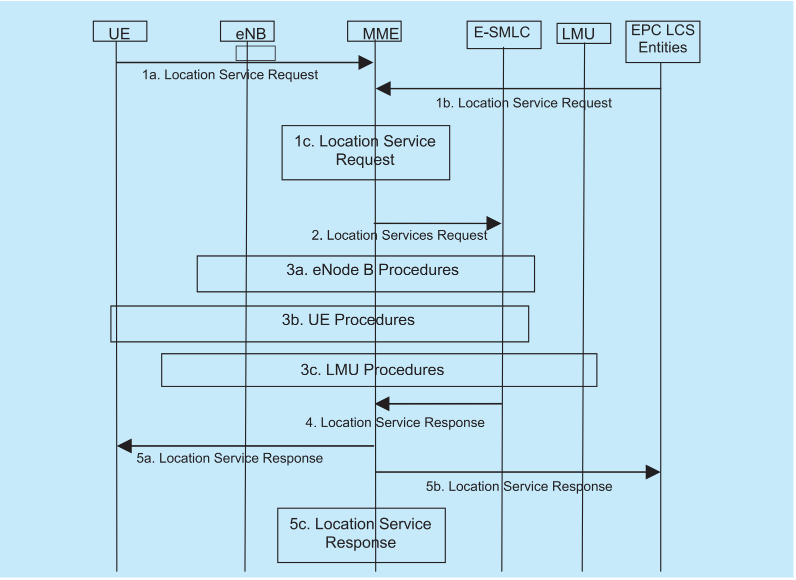

Fig.6 *Location service support by E-UTRAN in control plane*

are two positioning patterns in LTE networks. One is control plane positioning based on LTE Positioning Protocol (LPP) and LTE Positioning Protocol Annex (LPPa). And the other one is user plane positioning based Secure User Plane Location (SUPL). LPP supports positioning and location related services. It is terminated between the UE and the positioning server E-SMLC. LPPa is an eNB-terminated protocol which carries information between the eNode B and the E-SMLC. SUPL is carried over the user plane and supports the positioning for a SUPL Enabled Terminal (SET). In SUPL structure, SET is the target device and the SLP is the server. Besides, SUPL can support some 3GPP positioning protocols, including LPP. In summary, The entities related to control plane positioning include eNB, LMU, MME, E-SMLC, and GMLC. The entities related to user plane positioning include eNB, S-GW,P-GW, and SLP. Taken UE positioning operations in control plane as an example, the overall sequence of events applicable to the UE, E-UTRAN and E-SMLC for any location service is shown in Fig. 6 [17].

The general methods based on cellular network include Cell-ID, OTDOA, UTDOA, RFPM (Radio Frequency Pattern Matching), etc. Cell-ID positioning is a method that cell-ID of mobile cellular networks is used to estimate the location of the user. The accuracy depends on the size of cellular cells [25]. In OTDOA and UTDOA scheme, PRS (Positioning Reference Signal) and SRS (Sounding Reference Signal) are used for users' positioning respectively. The RFPM technology is proposed in 3GPP Release 12. The principle of RFPM is similar with WiFi fingerprint. It constructs a database which stores the RF measurements information. Positioning result is obtained by matching the actual measurements with stored measurements.

4.2 LAN-based positioning technology

The typical LAN-based positioning methods, which include WiFi, Bluetooth and UWB, are introduced in this section.

WiFi APs is usually deployed in the indoor environment and the coverage range of each AP is about tens of meters. Mobile terminals enabled WiFi function can connect to the Internet through WiFi APs. And it can receive signals from more than three APs simultaneously in most areas. Generally, the user receives the signals from different APs and analyzes the Media Access Control (MAC) addresses of APs to evaluate the user's position. The location database of APs should be stored in the server so that user terminals could get the positions of APs based on MAC addresses. In WiFi system, TOA, TDOA and RSS can also be used. Howerve, WiFi fingerprint is the most commonly used method.

The positioning system with Bluetooth is similar with WiFi. Because of its small coverage range, it is mainly used for small area positioning, such as a hall and storage. The advantage of using Bluetooth is that this technology is of high security, low cost, low power and small size. The highest specified power level of the Bluetooth standard has a maximum power output of 1mW (0 dBm) which enables communication ranges of 5m to 10m depending on the propagation condition. The typical Bluetooth low energy wireless positioning system is iBeacon of Apple company [26].

UWB, which uses narrow pulse within nanosecond to communication, is a short-range technology. It can detect TDOA or TOA from the reference nodes to calculate the user's position. Since the accuracy of TDOA or TOA measurement is directly correlated to the signal bandwidth, UWB is more suitable for high precise positioning than WiFi and Bluetooth. When the bandwidth is about several hundred MHz and appropriate time resolution is in the order of nanoseconds, the positioning accuracy can reach cm-level. Besides, UWB has a good performance in the situation of severe multipath because it can detect multiple time-delayed versions of a signal sequence. However, the reason that UWB is not applied widely is that it cannot be used in mobile phone directly. Dedicated transmitter-receiver infrastructure is required for UWB [21][26].

4.3 Other positioning technology

There are many other positioning technologies, such as radio frequency identification (RFID) technology, Infrared technology, sound technology, Earth's Magnetic Field Technology etc. For an intuitive understanding about these technologies, the values specified for accuracy and coverage are shown in Table I [26].

For the past few years, LBS has grown fast in the mobile devices industry. LBS can be applied for emergency positioning and commercial purposes, which include navigation, advertising, user positioning, etc. A single positioning technology may can not meet high accuracy demands in some scenarios. So the hybrid positioning technology is proposed and it would be the development trends of indoor positioning industry.

V. Challenges of Indoor Positioning

Although the positioning technologies are actually mature, there are some challenges to overcome. Here, some typically challenges are listed, and the corresponding possible solutions are discussed.

5.1 Multipath effect and NLOS propagation

Sight propagation is a necessary condition to obtain the accurate measurements of signal characteristics for positioning. When there is no direct path between the transceiver because of the complex building layout, furniture and equipments, the signals arrive at the receiving antenna only through the reflection or diffraction. The time of the first pulse arriving at the receiver is not the real LOS propagation time, and the TOA of the signals is not the real TOA of the direct path either. The NLOS propagation leads to the measurement error, and further leads to the positioning error. Even though there exists a LOS, the multipath effect in the indoor environment cannot be avoided, bringing a severe impact on the correct information extraction.

How to fully use the multipath effect and NLOS propagation is a particularly important issue for positioning. Here, fingerprint systems based on multipath signals are taken as an example to "overcome" the multipath effect. Theoretically, the smaller the dimensionality of the fingerprint, the harder it is for a system to reliably distinguish neighboring fingerprints and the worse the location performances. If the multipath characteristics such as Channel Impulse Responses (CIRs) are considered to be a fingerprint, and compared to a database of properties previously collected at a variety of

Table I *Comparison of IPS technologies*

Technology	Typical Accuracy	Typical Coverage(m)	Typical Measuring Principle	Typical Application
WiFi	m	20 - 50	Fingerprinting	Pedestrian navigation, LBS
RFID	dm – m	1 - 50	Proximity detection, fingerprinting	Pedestrian navigation
UWB	cm - m	1 - 50	Body reflection, time of arrival	Robotics, automation
Infrared	cm - m	1 - 5	Thermal imaging, active beacons	People detection, tracking
Sound	cm	2 - 10	Distance from time of arrival	Hospitals, tracking
magnetic systems	mm – cm	1 - 20	Fingerprinting and ranging	Hospitals, mines

locations (a radio map), multipath effect will become an advantage factors for positioning. At the same time, the signal bandwidth should be wide enough to reveal the multipath characteristics sufficiently.

5.2 Varying environment

The steady indoor environment is significant for positioning technologies such as fingerprint positioning, which has a database to match the measurements. However, the indoor layout is always changing in some scenarios, for example, the offices, supermarkets and shopping malls, etc. Therefore, the database needs to be updated frequently, making a huge hole in the workload. Moreover, the route optimization is also impacted, where the map information is essential.

To solve the above problems, the capability that system can renew the database is essential. The training sequence should be transmitted periodically. The system can recognize the changing of environment according to the large number of measurements and update the database automatically.

5.3 Full network coverage

Whatever kind of positioning technologies is used, the widely coverage of positioning signals is the basic condition for high-accuracy indoor positioning. GDOP [27] is an index to depict the network coverage condition, and there are some algorithms to array the antennas to optimize networking according to the GDOP. Considering the complicated and varying indoor environment, there are always some so-called "blind area" where no signal can reach. How to deploy sensors/antennas to improve the positioning accuracy, and how to finish deploying wireless positioning system in a short time, especially for emergency responder application is also worth considering.

Considering that indoor tracking is more common than static positioning, inertial navigation, which obtains the motion model via other sensor (such as gyroscope, magnetometer, and accelerometer), can effectively overcome the impact of the "blind area".

5.4 Real-time requirements

As a service that provides the location information to users, real-time is necessary for the overdue location is of no concern to users. There are many factors that influence the positioning delay, such as system architecture, positioning algorithm, etc. Then the tradeoff between the complexity and the performances should be considered.

5.5 Seamless switching between indoor and outdoor scenario

GPS, as the main methods for outdoor positioning, fails to provide a reasonable level of positioning accuracy and replaced by WiFi / Bluetooth positioning in indoor environment. Therefore, the switching of the positioning service when users get in or out the buildings is a great issue. How to integrate indoor and outdoor positioning system is another area of research. This integration may help in developing more efficient and robust detection systems for positioning of mobile nodes. In this case, a mobile node will be tracked indoor or outdoor using the same detection system.

Internetworking of different wireless positioning systems is a research and practical topic in order to extend the positioning range. The key technology is how to detect the process that people are walking in or out of the building. Dense deployment of the detectors such as cameras, infra-red detectors can increase the accuracy of the detection.

VI. Future Development of Indoor Positioning

There are three phases for the positioning evaluation as shown in Fig. 7, which includes:

1) Phase 1:Single network positioning, different solutions in various scenarios.

Given the different performances and costs for positioning technologies, the differentiated

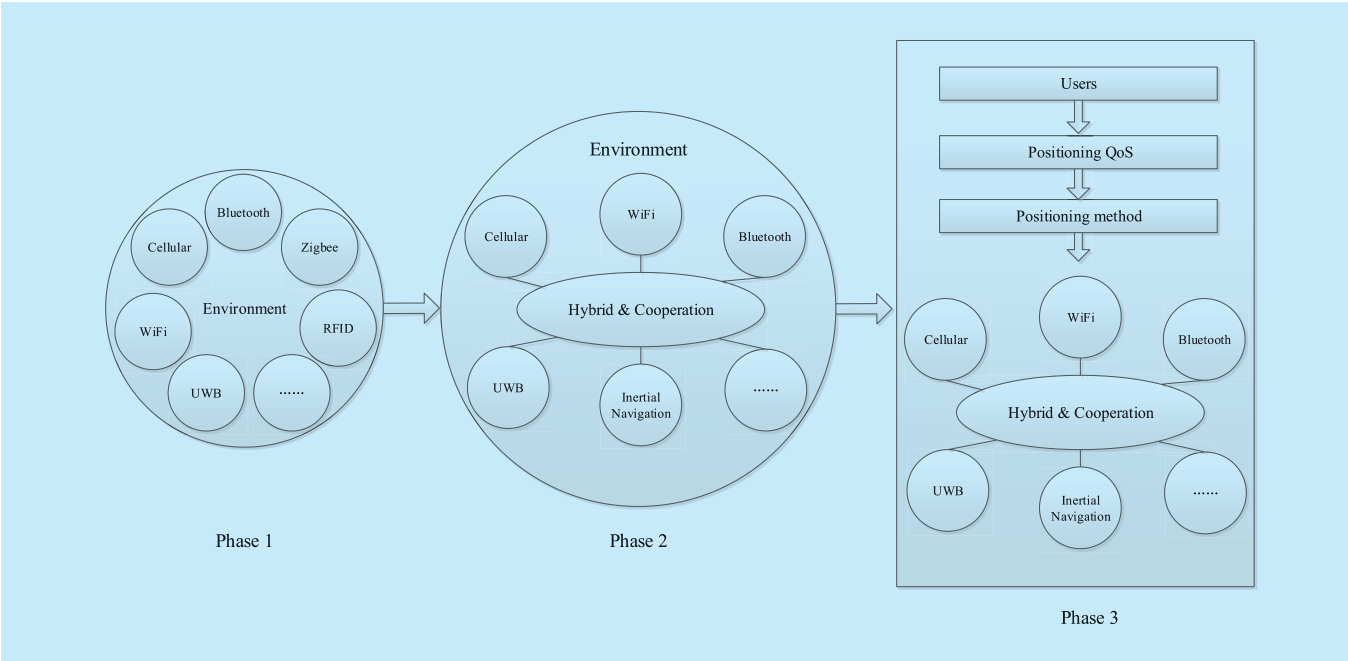

Fig.7 *The evolution route of indoor positioning*

solutions are essential to satisfy the positioning requirements in various scenarios. Firstly, the networking may be different in various scenarios. In the open areas with less multipath and NLOS, the cellular network is possible to achieve wide coverage, while in the closed areas with rich multipath, the WLAN network is more popular. Secondly, the accuracy may be also different. For example, the accuracy requirement may be 10 m for users to find the target store, while in the hospital, the accuracy may be 1~3 m to track drugs, devices and patients.

2) Phase 2:Hybrid positioning and cooperative positioning.

The complexity of indoor environments resulting from multipath propagation and frequent environment changes requires using more than one technique to improve localization accuracy. Data from Cellular, WiFi, UWB, Bluetooth, RFID, ZigBee, camera images and IMUs should be fused by multiple data fusion techniques to provide more precise and robust localization systems. The integration of multiple positioning functionalities seems inevitable and requires the convergence of positioning standards that ensure multi-stand and multi-vendor interoperability. These systems are evaluated based on location accuracy, cost, coverage range, and the data rate. Also the tradeoffs between these evaluation parameters should be considered.

In the future everything Internet era, everything can communicate with the each other, and all the data can be collected, analyzed, and reused. There are three scenarios that cooperative positioning can be used. (1) Terminals can communicate with each other to exchange the information (such as location, environment, and anchor information). The positioning result is obtained by analyze the information. (2) Terminals can measure each other, and calculate the positioning in terms of the measurements. (3) The terminals use the previous positioning information (such as inertial navigation) to help complete the current positioning.

3) Phase 3:Positioning network slicing for customizations.

Nowadays, the serving network determines which positioning method to employ for users. There is no right to chooses for users. Indoor localization with a significant degree of precision is extremely challenging. However, the high accuracy does not always obey users' demands, and the cost and response delay are also factors that users would take into consider. Then, a positioning network slicing, in which the positioning accuracy, cost and delay are designed by users comprehensively, is absolutely necessary in the further. Then, a proper positioning technology will be chosen according to users' demands.

In order to depict the users' demands, the positioning QoS should be parameterized in terms of response time, horizontal accuracy, optional vertical accuracy and associated confidence, etc. The user first determines that whether the positioning service is needed. Then the QoS model is set up by users according to the demands. The positioning flow is shown in Fig. 8.

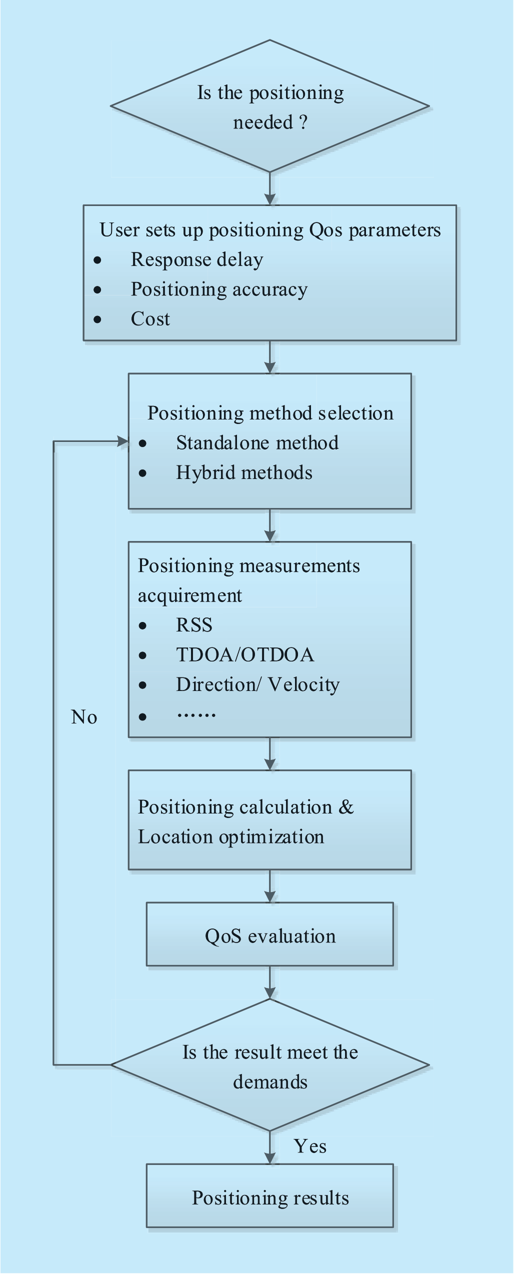

Fig.8 *The flow chart of the positioning slicing*

VII. CONCLUSION

In this paper, the significance of indoor positioning research was introduced, and the current situation of positioning standardization and industry development of indoor wireless positioning were introduced, including the roadmap of 3GPP and industry deployment of some well-known companies. Then, the indoor positioning system framework and principles were analyzed, and the corresponding positioning technologies were also introduced and compared. It was a certain that none of the technologies is perfect. A compromise is needed between accuracy requirements and cost. Instead of using a single method to estimate the locations of targets, combining some positioning technologies were proposed to improve the quality of positioning services. In the end, challenges and possible solutions were summarized, and the evolution route and future key technologies were predicted.

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