Wireless Positioning Technologies in CDMA System

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Abstract:
Location services not only provide address information, but also locate, monitor and track terminals on a real-time basis. To deliver fast and accurate location services, it is necessary to select an appropriate positioning method. Currently, 3 methods are available for CDMA wireless positioning: network based, Mobile Station (MS) based, and GpsOne positioning. As these methods are different in location time, accuracy, availability, privacy, and operation cost, they shall be selected according to the actual network conditions. Network structure, information bearer protocols, and transport mode make the basis of a wireless positioning system. They can be implemented in different ways, and some details shall be specified by the operators.

In 1996, Federal Communication Commission (FCC) of the United Sates required that mobile operators deliver emergency service (E-911) to users. The E-911 service was originally designed to offer the caller immediate rescue and became the beginning of the location service. After that, a variety of featured commercial location services were rolled out in countries like Japan, Germany, France and Finland. Nowadays location services are growing rapidly. With the location services, people can not only get prompt and accurate address information they need, but also locate, monitor, and track terminals. Therefore, location services have found widespread applications in the mobile communication field[1-3]. This article discusses positioning technologies adopted in the CDMA system.

1 Three Positioning Methods

1.1 Network Based Positioning

With the network based positioning, multiple Base Stations (BS) detect signals transmitted from a Mobile Station (MS). The BSes calculate the MS' position by processing stamp signals relative to the MS location and carried by all received signals. For this method, the positioning accuracy or even the positioning can not be guaranteed due to negative impacts caused by Non-Line-Of-Sight (NLOS), multi-path effect, various interference noises, and cell structure. Although all positioning technologies, such as Angle of Arrival (AOA) based and Time Difference of Arrival (TDOA) based positioning, can improve accuracy at a certain extent, it is necessary to invest significantly in the making of special alteration to software and hardware of the whole network.

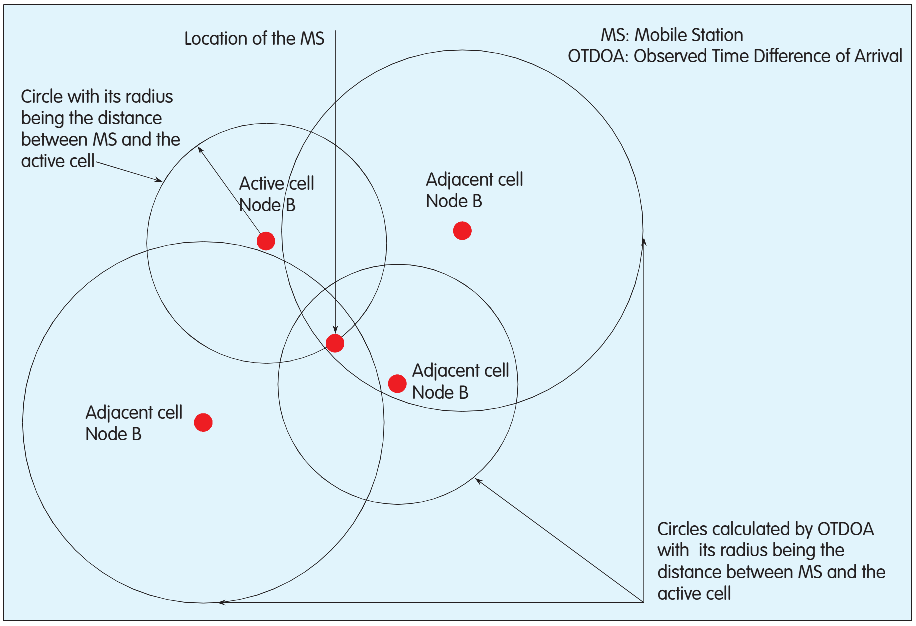
The network based method consists of two basic positioning technologies: Cell Identification (CELL-ID) and Time of Arrival/Time Difference of Arrival/ Observed Time Difference of Arrival (TOA/TDOA/OTDOA).

1.1.1 CELL-ID Positioning Technology

CELL-ID is the simplest positioning technology that is supported by the existing cellular networks without any alteration to the MS side and the network side. However, this technology provides low accuracy as it is only used to locate the MS covered by the active cell. When the cell radius is large and the MS is near the cell edges, there will be a considerable error in location measurement. However, for the cell with a small coverage radius, a certain level of positioning accuracy can be achieved, for example in an indoor distribution system covered by micro-cells.

1.1.2 TOA/TDOA/OTDOA Positioning Technologies

TOA is a positioning technology based on the reverse link. It determines an MS' position by measuring the time of arrival of its signals to multiple BSes. Only 3 BSes or above are needed to receive the MS' signals and calculate its location by using the trilateration algorithm. The TOA positioning accuracy relies on the geographical distribution of the BSes. We can get the highest accuracy when the spheres have an intersection angle of



▲Figure 1. OTDOA Positioning system.

90°. However, the TOA technology doesn't deal with errors at the receiver, therefore it still leads to a considerable error in the location measurement.

TDOA is anther positioning technology based on the reverse link. It determines an MS' position by detecting the time difference of arrival of its signals to two BSes. As the MS is located on the hyperbolic equation with its focal points being the two BSes, it is necessary to set up more than two hyperbolic equations to determine the MS' two-dimensional location coordinate. In other words, at least 3 BSes are needed to receive the MS' signals. The intersectant point of the two hyperbolic curves is the MS' two-dimensional location coordinate. Generally TDOA provides higher positioning accuracy than TOA because it does not need to know the specific time of signal transfer and can eliminate or reduce common errors generated by channels at all receivers. However, the power control causes low transmitting power of the MS close to the active BS and consequently the receiving power of the adjacent BSes is very low. Consequently, there will be a comparatively large measurement error resulted from too small Signal to Noise Ratio (SNR) of the adjacent BSes. Presently, some solutions are available to address this issue. For instance, in the event of emergency call, the largest instantaneous transmitting power of MS can be adjusted to improve positioning accuracy although it may have influence on capacity of the CDMA network.

OTDOA is a positioning technology based on the time difference of arrival of one MS' signal to 3 BSes. As shown in Figure 1, the OTDOA three-node location system is actually a three-dimensional positioning system. However, when it compared with the cell radius, the difference over the vertical direction is too small and that can be omitted. The MS sends the measured value System Frame Number to System Frame Number Observed Time Difference Of Arrival (SFN-SFN OTDOA) to the network. This value contains measured time difference of the active cells and the adjacent cells.

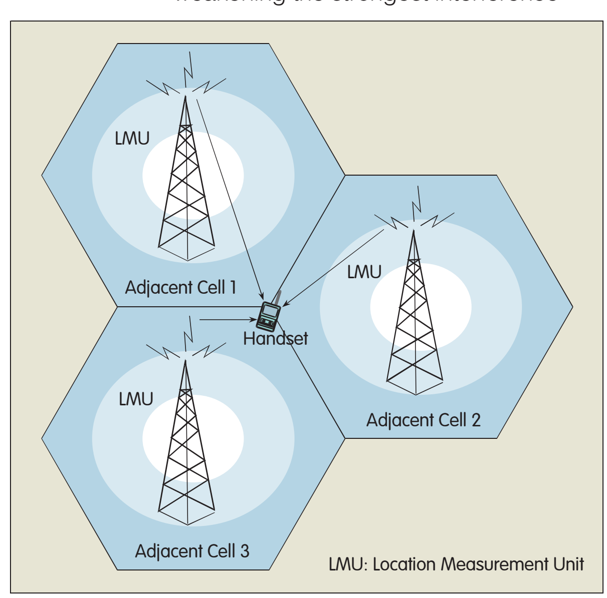
As the network has known the transfer delay from the active cell to the MS, the measured OTDOA value provided by the MS can be converted to OTOA, therefore, the distance between the BS and the MS can be estimated. The intersectant points of different circles in Figure 1 are the estimated location of the MS. Due to the measurement error these intersectant points are not concentrated on the same point.

1.2 MS Based Positioning

The MS based positioning method is derived from the Global Positioning System (GPS). The MS receives signals transmitted by several GPS satellites (usually 3 to 4 satellites). These stamp signals relative to the MS location, are used by the MS to determine its location relationship with each satellite and calculate its position. This solution still has some disadvantages. First, signals received from the satellites shall be guaranteed. Therefore, it is hardly applicable in indoor environments or urban areas with high buildings. Moreover, as the MS needs a relatively long time for cold start, the requirement for timeliness can not be satisfied. Finally the MS has large power consumption.

Idle Period on the Down Link/ Advanced Forward Link Trilateration (IPDL/AFLT) is the positioning technology adopted in the CDMA system. The IPDL/AFLT location system is shown in Figure 2.

IPDL can be an effective means to address the issue of audibility in the WCDMA system. In systems that use the IPDL technology, each BS stops transmitting for a preset short time to form a measurement period with low interference in its coverage. By weakening the strongest interference



▲Figure 2. IPDL/AFLT positioning system.

signals, IPDL improves Signal to Interference Ratio (SIR) of the active BS. In the CDMA cellular system, the MS measures time information it can receive from all neighboring BSes, and then takes one of them as the reference BS (such as the BS with the strongest signals). Finally it calculates the time difference between other BSes and the reference BS. In this way we can get the measured TDOA value and use it to calculate the MS' position. The Location Measurement Unit (LMU) can be used to estimate the time of arrival of the burst pulses and report it to the network, or the GPS can be used to synchronize these BSes, as the WCDMA network is required to be synchronous.

AFLT is a forward link based positioning technology used in the CDMA2000 system. In positioning operation, an MS can monitor pilot information of many BSes (at least 3 BSes) at the same time. It makes use of the chip delay to determine the distance between the MS and the nearby BSes, and finally calculates the MS' position by the trilateration algorithm. AFLT adopts a mechanism similar to that of IPDL. However, it uses GPS other than LMU to locate all BSes and needs additional entities to make use of the pilot information to calculate the MS' position. The additional entities contain the Position Determination Entity (PDE) and the Mobile Positioning Center (MPC). PDE obtains the pilot information in the following two ways.

(1) The pilot information is transferred, in accordance with the transfer mode defined in IS-801 protocols, to the Mobile Switching Center (MSC), and then to PDE. With this mode the MS is required to support IS-801 protocols.

(2) By using messages at the A interface, positioning based parameters are transferred to MSC, and then to PDE. With this mode, the MS needn't support IS-801 protocols, but the A interface is required to support the transfer of these parameters (the A interface has defined messages for transferring these parameters).

AFLT requires the MS to upgrade its software. Additionally, based on the way PDE obtains the pilot information, it determines whether the MS and the network side shall support IS-801 protocols. Its location algorithm can be performed either at the MS or at the network side. The accuracy of the AFLT based positioning technology is higher than that of the CELL-ID based technology, but lower than that of the GPS based technology. Generally AFLT provides an accuracy of 200 m-400 m, and reaches the highest accuracy of 100 m. BS density and geographical environment are major factors that have impact on positioning accuracy. In urban areas with dense BS coverage, the positioning accuracy is relatively high because of the higher BS density.

1.3 GpsOne Positioning

In the suburbs or villages with sparse BS coverage, an MS usually has connection with only one BS, therefore, it is impossible to implement the network based positioning. However, the GPS receiver there can receive signals from 4 or more than 4 satellites. In urban areas of dense buildings and indoor environments, although the GPS receiver usually receives no satellite signals, multiple BSes are available to detect the MS' signals. By leveraging advantages of the two positioning methods, the Wireless-assisted Global Positioning system (WAG) can operate smoothly in all environments while meeting the requirement for timeliness.

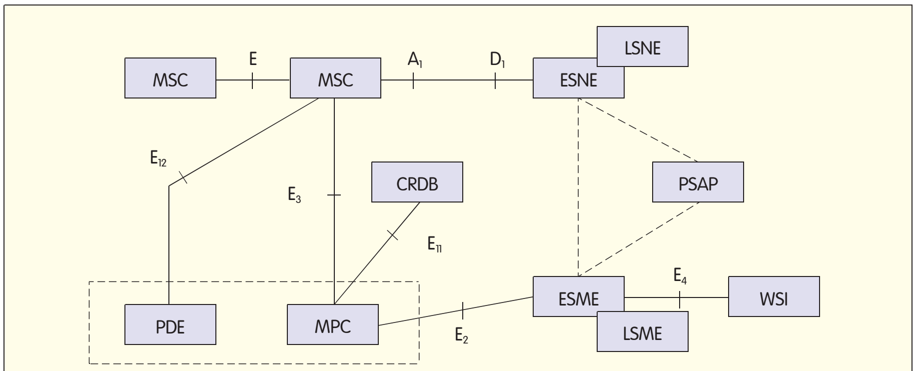
The GpsOne is a combined WAG and AFLT technology put forward by Qualcomm. It is developed based on the WAG. The AFLT technology only supported in the CDMA network can make use of the GPS time collection technique and CDMA system parameters, such as pilot phase offset (measurement value of AFLT), pilot strength, and to-and-back delay of the active BS. When using pilot phase offset parameter AFLT provides an accuracy of 15.26 m. The AFLT technology requires accurate BS parameters including the BS' latitude, longitude and height, pilot phase offset, and to-and-back delay calibration value.

Compared with WAG, the GpsOne technology provides higher accuracy and can be used for indoor positioning. The GpsOne positioning process is divided into two steps. First, use the AFLT technology to support the GPS and sensitivity-assisted data calculation. Second, combine favorably the MS based measurement data and PDE data to eliminate possible errors added in the positioning. The GPS and AFLT hybrid positioning technology takes advantages of the network based non-GPS technology and the GPS based network-assisted technology. In this way it becomes the current mainstream technology adopted in the CDMA system. With regard to the MS configured with a GPS receiver, the WAG technology can be adopted at first. In places (such as indoors) where the MS is unable to receive GPS satellite signals the AFLT technology can be employed. In this way, we can improve accuracy (outdoor accuracy reaches up to 5 m-50 m), enlarge positioning scope, and shorten positioning time.

2 Network Structure of Wireless Positioning System

Wireless positioning system is a combination of the original mobile communication system with a series of functional entities. It has two basic functional entities: PDE and MPC, which are generally called the positioning subsystems. As the core of the whole location service, the positioning subsystems provide users with accurate positioning information. Moreover, being scalable open systems, the positioning subsystems are separated from specific services and can be applied to wireless networks (such as CDMA and GSM). Furthermore, the positioning subsystems are allowed to have additional functional entities, such as the Coordinate Routing Data Base (CRDB), Emergency Service Network Entity (ESNE), Emergency Service Message Entity (ESME), Location Service Network Entity (LSNE), Location Service Message Entity (LSME), Public Safety Answering Point (PSAP), Wireless Subscriber Information (WSI), and more. The network structure of the wireless positioning system is shown in Figure 3.

PDE is the heart of the whole positioning system that produces positioning information through calculation. It can select an appropriate positioning method to meet the location requirement of the MS and calculate its location which is based on the measured



▲Figure 3. The network structure of wireless positioning system.

information and data. It supports IS-801 protocols and is connected to MPC and MSC via the SS7 link. Furthermore, it provides control functions such as multi-channel MS call management, real-time GPS reference data input, real-time location record, display, and more.

MPC is a network entity based on 2G and 3G GSM and CDMA standards, and able to obtain, transfer, store, and control location information. It receives location requests from application entities such as MPC, ESME and LSME, and sends them to PDE after processing. It also receives location result sent by PDE and transfers the result to MPC, ESME, LSME, and other application entities. Moreover, it completes user authentication and can control access to location information. It is connected to other functional entities via the SS7 link and serves as a software package to manage all relevant positioning technologies. As an open software development platform, MPC offers standard Application Programming Interface (API) to location service providers.

In addition, MPC serves as a positioning database to store time, latitude, longitude, and other data, and to help GPS and CDMA network to implement the AFLT positioning technology. It manages operator information as well as location data of positioning application service, and abstracts PDE from the content of positioning application service. As MPC effectively separates positioning technology from positioning application, it can flexibly adapt to the growth of new technologies and new services.

MPC contains location management units that are located on a scalable, safe, and reliable platform and allows the wireless operator to manage multiple PDEs. One MSC is only connected to one MPC while one MPC can simultaneously serve multiple MSCs. One PDE is only connected to one MSC while one MPC can be connected to multiple PDEs in its coverage area. LSME and LSNE are similar to ESME and ESNE. They all belong to positioning application entities. The difference is that ESME and ESNE are specially designed for emergency services. ESNE is responsible for voice connection while ESME for signaling flow and extraction of the alarm user's location information. WSI is used to provide wireless subscriber information for ESME and LSME. CRDB performs conversion of location coordinates, and converts the MS' latitude and longitude into a string of digits. Being the terminating point of an emergency service call, PSAP is responsible for answering the call.

3 Bearer Protocol of Positioning Information

Positioning information between MS and PDE is carried via IS-801 protocols. Based on the position determination service standards for dual-mode spread spectrum system specified by TIA/EIA, IS-801 protocols define a variety of location messages. According to the originated mode of IS-801 communication, the communication process is divided into Mobile station Originated (MO) mode originated by MS and Mobile station Terminated (MT) mode originated by PDE. Given below is an example of the GpsOne technical solution.

3.1 MO Mode

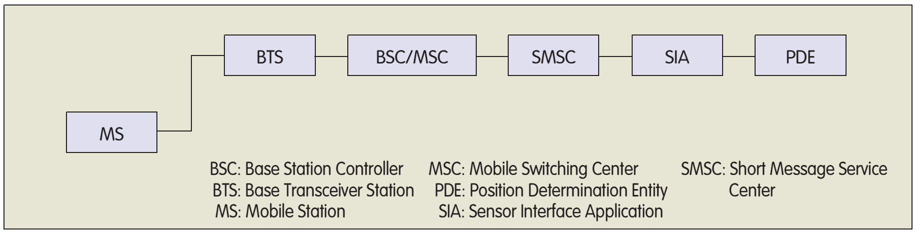
The communication process in the MO mode consists of 4 IS-801 messages.

(1) MS sends the first IS-801 message to PDE. The single IS-801 message contains two MS response elements and two MS request elements. In the two response elements one is used to provide MS information, which PDE can use to initiate the session and start the IS-801 processing. The other one is used to provide pilot phase measurement, which PDE can use to collect enhanced GPS signals and GPS sensitivity data, make initial positioning estimation, and provide particular value for temporary positioning when no GPS satellite is available for detection. In the two request elements one is used to request signal collection support from GPS and the other one is used to request sensitivity support from GPS.

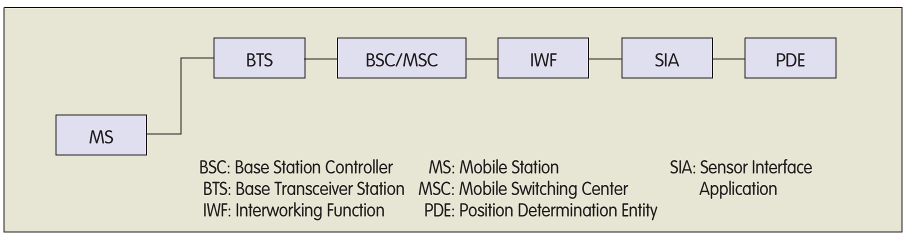
(2) PDE returns an IS-801 message, or the second IS-801 message to MS. This IS-801 message contains two PDE response elements and two PDE request elements. In the two response elements one is used to provide GPS information collection support and the other one provide GPS sensitivity support. In the two request elements one is used to request pseudo-range measurement and the other one request pilot phase measurement.

(3) MS sends again an IS-801 message, or the third IS-801 message to PDE. This IS-801 message contains two MS response elements and one MS request element. In the two response elements one is used to provide pseudo-range measurement that carries the WAG result of the GpsOne technology. The other one is used to provide pilot phase measurement that carries the AFLT result of the GpsOne technology. The request element is used to request positioning response so that MS can obtain the positioning result from PDE.

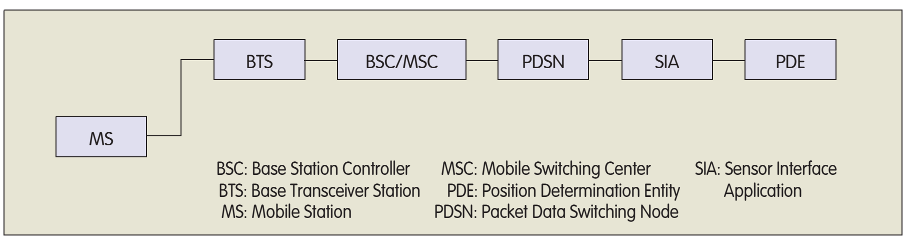
(4) PDE sends an IS-801 message,



▲Figure 4. SMS mode.



▲Figure 5. IMF TCP/IP mode.



▲Figure 6. CDMA2000 TCP/IP mode.

or the fourth IS-801 message to MS. This IS-801 message contains only one PDE response element. The response element provides positioning response used for PDE to return the positioning result, which is the positioning information the location-based API will send back to the browser.

3.2 MT Mode

The communication process in the MT mode has the same IS-801 messages as that in the MO mode, except that the first IS-801 message is originated by PDE. The whole communication process consists of 5 IS-801 messages and its details are not described in this article.

4 Transmission System of Positioning Information

The transmission system of positioning information is a path that transfers IS-801 protocols and messages between MS and PDE. Currently these messages are transferred in two modes: Short Message Service (SMS) and Transmission Control Protocol/Internet Protocol (TCP/IP).

The SMS mode is shown in Figure 4. It is only applied to the positioning service originated by MS and requires that MS should provide SMS positioning function, and that Session Interface Application (SIA) should support Short Message Service Center (SMSC) communication. In order to tell positioning information from SMS, SMSC specifies a higher priority for positioning information than ordinary SMS. We note, however, that single positioning information defined in IS-801 has a maximum length of 200 bytes, while the maximum length of SMS is 140 bytes that can be obtained directly through the maximum frame of the message transfer unit. In the case that the IS-801 message length is greater than the short message length, the operator can formulate the related standard as to whether to divide the IS-801 message into two short messages for transmission or to bond two short messages to carry the IS-801 message.

The TCP/IP mode falls into two specific modes: one is implemented through circuit domain network Interworking Function (IWF), where MS is connected to PDE via IWF and SIA after going through Base Transceiver Station (BTS), Base Station Controller (BSC) and MSC, as shown in Figure 5; the other is implemented through the packet domain device in the CDMA2000 network, where MS is connected to PDE via Packet Data Switching Node (PDSN) and SIA, as shown in Figure 6.

5 Conclusions

This article analyzes several wireless positioning technologies and algorithms, and discusses location-based signal selection, accuracy analysis, and other specific issues in the CDMA network. Although CDMA positioning systems provide high accuracy, we shall take into full consideration the economy, network evolution, and other factors when determining which positioning system will be adopted. The applications of CDMA wireless positioning technologies are at the beginning stage, so their vast market potentials need to be further exploited.

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