Network architecture and protocols for mobile positioning in cellular wireless systems

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Introduction

Wireless communications and wireless systems have experienced phenomenal growth over the past decade and have become part of the critical infrastructure of the country. The use of wireless devices such as cellphones, PDAs, and laptops (in general mobile stations – MSs) has become the enabler of viable *location based services* and applications that need position location information. The Federal Communications Commission (FCC) is also mandating the provision of enhanced-911 emergency services that need similar information.

The focus of this article is to provide a brief overview of the network architecture and protocols that are required to be in place in cellular wireless systems to provide location based services once the location sensing is completed. The complexity and large number of protocols, the different types of cellular networks, and the numerous standards that apply under different circumstances make it difficult to precisely document such information in a short article. Consequently, we present a simplified overview with a classification that closely follows how someone outside the field would perceive the network and its services. Readers should refer to the detailed standards produced by the third generation partnership project (3GPP) and its equivalents in the US for a complete understanding of the subject. We would also like to point out that the messaging considered in this article is primarily related to control (i.e., signaling required to enable the actual communication or transaction).

There are several techniques such as Cell ID, observed time difference of arrival, advanced forward link trilateration, etc. that are used to determine the position of the MS in cellular networks. In cellular wireless systems, the normal infrastructure for transporting voice and data traffic is leveraged in a *location services* (LCS) *architecture* for transporting the location sensing information and query management for location-based services. For simplicity, we break up the signaling and communication of location information into three parts: (a) *Over the air* transport that requires communication between the mobile station (MS) and the rest of the network. For example, the IS-801 standard handles this part of the communication for CDMA based cellular systems such as IS-95 and cdma2000. This is also called the access network; (b) *Signaling within the fixed part of the cellular system* that is necessary to enable position determination and account for mobility issues. For example, the JSTD-036 standards specified by the EIA/TIA for wireless emergency services and location services extend the ability of the signaling network to transport location and emergency related information in standardized formats. This is also called the core network; (c) *Application protocols that make use of the location services architecture*. We consider the *Mobile Location Protocol*, developed by the Open Mobile Alliance (OMA) that defines a set of constructs and services to enable location based services for applications.

This article summarizes the three types of communications required for location based services in cellular networks. The goal is not to cover all standards and architectures, but to provide an overview and summary of some of the standards and messaging that happens in cellular networks for location based services.

Cellular Network Architecture

Figure 1 shows a schematic of the architecture of a cellular system. While this schematic is not particular to a specific standard, it provides an idea of the different components in the network. The reader is referred to (Pahlavan & Krishnamurthy, 2002) for more details of architectures of specific systems. In the radio access subsystem, the mobile station (MS), sometimes called user equipment is the device whose position is to be determined. Base stations (BSs – also called Node Bs) are fixed transmitters that are points of access to the rest of the network. A MS communicates with a BS during idle periods (signaling), cellular phone calls (voice) or other data transmission. Base stations are controlled by radio network controllers (RNCs) that also manage the radio resources of each BS and MS (frequency channels, time slots, spread spectrum codes, transmit powers, and so on).

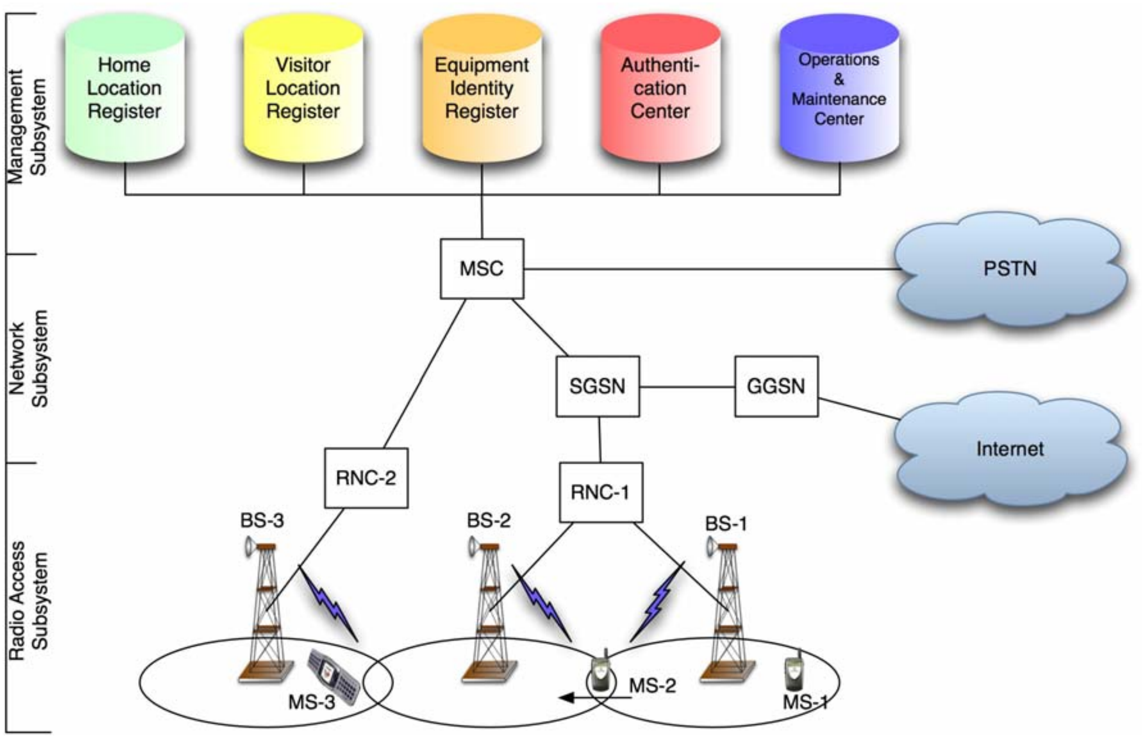

Figure 1: Generic cellular network architecture

The network subsystem carries voice and data traffic and also handles routing of calls and data packets. The mobile switching center (MSC) and the serving and gateway GPRS[1] support nodes (SGSN and GGSNs) are responsible for handling voice and data respectively. These network entities perform the task of mobility management, where they keep track of the cell or group of cells where a MS is located and handle routing of calls or packets when a MS performs a handoff, i.e., it moves from one cell to another

[1] GPRS stands for General Packet Radio Service

(see for example MS-2 in Figure 1). They connect to the public switched telephone network (PSTN) or the Internet. Several databases in the management subsystem are used for keeping track of the entities in the network that are currently serving the MS, security issues, accounting and other operations as shown in Figure 1.

The above architecture was designed to specifically handle voice and data communications and needs enhancements to enable support for location services. In particular, new entities are required to determine position location information, communicate this information appropriately to the concerned parties (public safety answering point – PSAP – for emergency services, location services clients, and so on). These changes are described next.

Location Services Architecture

As shown in Figure 2, additional network entities are required to support location services. The architecture shown in Figure 2 does not correspond to any particular standard, but tries to present some of the important network entities that are part of different standards such as the J-STD-036 and 3GPP TS 25.305. The goal here is to provide a general discussion of these entities rather than describe each standard individually. Also, some of these entities may be co-located although they are shown separately in Figure 2.

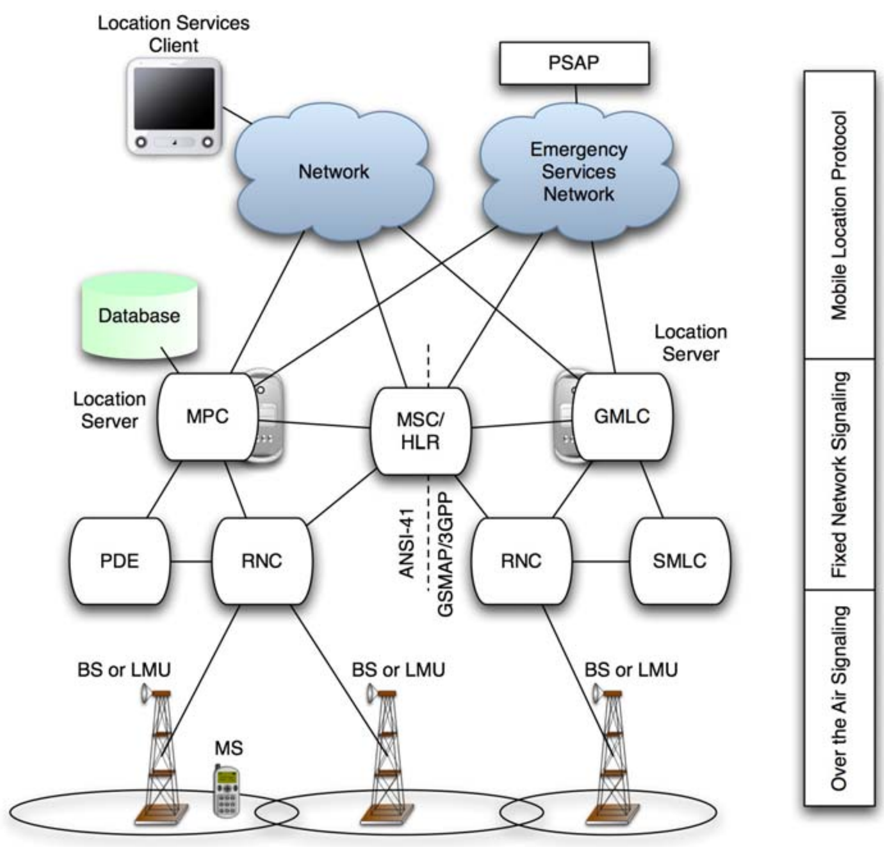

Figure 2: Architecture for location services in cellular networks

The location measurement unit (LMU) is a device that assists the MS in determining its position or uses signals from the MS to determine the position of the MS. It is used with assisted GPS to help the MS determine its position. With other positioning techniques such as uplink time difference of arrival, it makes measurements of radio signals and communicates this information to network entities such as the RNC. An LMU may be associated with a BS, in which case it communicates with the RNC over a wired link. Alternatively, it may be a stand alone LMU which uses the air interface to communicate with the RNC.

The Mobile Positioning Center (MPC) is the entity that handles position information in cellular networks that use ANSI-41 for signaling (TR-45, 2002). It uses a Position Determining Entity (PDE) to determine the MS's position using a variety of technologies such as assisted GPS or observed time difference of arrival. The PDE can determine a MS's position while the MS is in call or when it starts a call (using information from the MS or LMUs). There may be multiple PDEs that are used by one MPC. The MSC is associated with an MPC. The same MPC may be associated with multiple MSCs. The MPC and MSC communicate with the emergency services network as described later. The MPC also handles access restrictions to the position information.

In 3GPP based networks (3GPP TS 25.305, 2006) such as the Universal Mobile Telecommunications System (UMTS) or the Global System of Mobile Communications (GSM), the Gateway Mobile Location Center (GMLC) and the Serving Mobile Location Center (SMLC) take up the responsibilities for positioning similar to the MPC and PDE. The GMLC is the first point of contact when the position of a MS is required. The SMLC coordinates the resources necessary to determine the MS's position, sometimes calculating the position and accuracy itself (using information from the MS or LMU).

An emergency call is ultimately answered by a PSAP. The PSAP connects to the fixed infrastructure in the cellular system through the emergency services network (ESN), which interfaces with the MPC or GMLC and the MSC. Two types of calls are considered by the emergency services network – the first where the position information is pushed to the ESN along with the signaling that occurs with the emergency call and the second where the ESN has to pull the position information. In the former case (called Call Associated Signaling or CAS), an emergency services network entity (ESNE) communicates with the MSC serving the emergency call and obtains the position information. In the latter case (called Non-Call Associated Signaling or NCAS), an emergency services message entity (ESME) interfaces with the MPC or GMLC to pull the position information. The database shown attached to the MPC in Figure 2 translates the position of the MS into a number specifying the emergency service zone where the MS is located. It is the emergency service zone that is assigned to a PSAP and emergency services such as police, fire, or ambulance.

Finally at a higher layer we can consider location services clients and location servers (often co-located with the GMLC or MPC). These are often independent of the underlying network technology. The LCS client may be requesting position information either for emergency services or for some other purposes (e.g., concierge services). In any case, it has to communicate over some network (usually using the Internet protocol – IP) with the location server to obtain the MS's position.

Over the Air (Access Network) Communications for Location Services

Certain communications have to take place over the air interface in the process for locating a MS, which are specified by standards that are different for IS-95/cdma2000 and 3GPP systems. Although such signaling happens over the air, it is also important from the point of view of functionality – it enables querying MSs for measurements related to positioning such as signal strength, timing, round trip times, GPS information and so on.

The IS-801 standard (IS-801, 1999) defines the signaling messages between a MS and a BS to support position determination in IS-95 or cdma2000 networks. The standard specifies the formats of messages and procedures to be adopted by the MS and BS when messages are received. Most of the messages are in the form of requests and responses. Some of the request messages sent by the MS include those that ask for BS capabilities, GPS assistance, GPS almanac, and GPS ephemeris. Some of the response messages sent by the MS include MS information, pilot phase, time offset measurements, and pseudorange measurements. The BS makes requests for the response messages from the MS and provides responses to the MS requests.

In 3GPP (3GPP TS 25.305, 2006), the signaling messages to support position determination are carried by the radio resource control (RRC) messages (3GPP TS 25.331, 2006). The form of messaging is similar to the request-response scheme in IS-801. The serving RNC generates RRC measurement control messages that are sent to the MS through the BS. They include data about the SMLC, assistance data related to GPS, or instructions to the MS to perform measurements. In response, the MS sends an RRC measurement report that contains the position of the MS or other measurements that will help the SMLC determine the position. Several control and report messages may be necessary before success of failure of the position determination.

Signaling in the Fixed Infrastructure (Core Network) for Location Services

When a request for the position of the MS arrives, entities within the fixed infrastructure in Figure 2 have to communicate information between them to support the determination of the position and delivering this information to the appropriate destination. The signaling for this is specified in the JSTD-036 and 3GPP TS 25.305 V. 7.2.0 standards. These standards consider a variety of scenarios – such as CAS and NCAS calls, automatic detection of emergency calls, handling position determination and delivery in the case of calls that are in handoff, and so on. We provide a brief summary of some of the signaling in the fixed infrastructure.

When a MS initiates an emergency services call, the delivery of position information to the PSAP is called Emergency Location Information Delivery or ELID. The MSC serving the MS that makes the emergency call, contacts the MPC or GMLC for position information. A PDE or SMLC may have automatically detected the invocation of an emergency call and started procedures for computing the MS's position. Alternatively, the MPC or GMLC may contact the PDE or SMLC to start such procedures and obtain the information. Once the MPC or GMLC has the position information, it will send such information to the MSC. In the case of a CAS call, the MSC sends the position information to the ESNE. The information sent includes information such as the calling party number and the position of the MS. In the case of an NCAS call, the MSC serving the MS making the emergency call will send the Emergency Service Routing Digits (essentially information about the BS or cell sector serving the MS) to the ESNE. Then, the ESME associated with the ESNE autonomously requests the position information from the appropriate MPC or GMLC. Two or more MSCs may be involved in delivering position information if the MS is in handoff during the call.

Several standard formats are used for protocols between different networking entities involved in ELID. In ANSI-41 based systems (such as cdma2000 and IS-95), ANSI-41 is used for communication between MSCs, and also between MSCs and other entities. Two special protocols are also used in such systems. The *Location Services Protocol* (LSP) is used between the PDE and MPC or between the routing database and MPC. The *Emergency Services Protocol* (ESP) is employed between the MSC and the ESME. Protocols developed for integrated services digital network (ISDN) are used for communication between the MSC and ESNE. The GSM Mobile Applications Part (GSMAP) has been extended in 3GPP systems to enable similar communications.

The Mobile Location Protocol

The mobile location protocol (MLP) is an example of an application level mechanism used by a location services client to obtain position information about a MS from a location server (such as the MPC or GMLC). This protocol can also be used for emergency services. The MLP was initially developed by the location interoperability forum (LIF) (LIF TS 101, 2002). The goal of the MLP specification was to develop standard methods (using XML) for Internet applications to obtain position information from cellular network entities. The work of the LIF was later on rolled over into the activities of the Open Mobile Alliance (OMA) (Brenner et al, 2005), an industry form consisting of hundreds of telecommunications and related companies for generating market driven specifications for mobile services to ensure interoperability between these services.

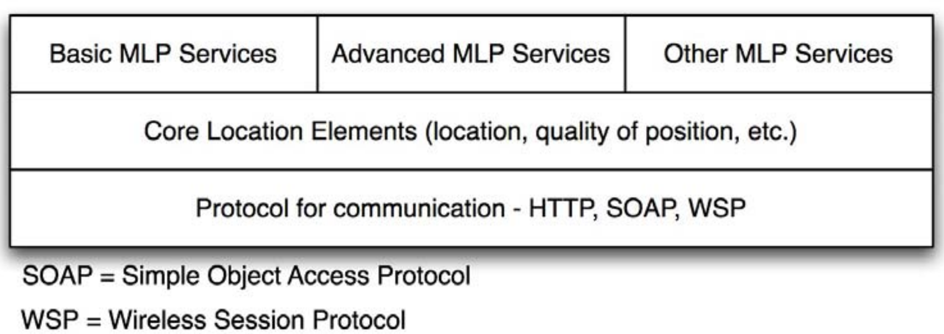

Figure 3: Part of the Mobile Location Protocol stack

Some protocol/service layers associated with the MLP are shown in Figure 3. At the top, three types of MLP services are defined. The Basic MLP service corresponds to emergency services and ELID as it is defined by 3GPP. Advanced and other services can be developed to follow the MLP specifications as required. Some services that have been already defined include standard and emergency location services (further classified into *immediate* for delay sensitive single location response and *reporting* for an LCS client requesting position information). A triggered location reporting service is specified for the instance when a MS's location needs to be reported when an event occurs or a certain time elapses. The core location elements are in the form of Document Type Definitions (DTDs) that form the building blocks for XML. The transport of these XML messages is specified in the lowest layer. Mapping to standard web/web services protocols like HTTP and SOAP are specified here, as well as mappings to the wireless session protocol, which is part of the wireless application protocol developed by the OMA.

The way the MLP operates is fairly simple. An LCS client requests position information from a location service using an MLP request, which may, for example, be transported using XML in HTTP and SSL. The location request is an XML document that could include the MS's identification in either the North American mobile identification number format or the GSM mobile subscriber identifier format, the age of the position information, the response time, and accuracy. The response from the location server is also delivered to the LCS client using MLP. The location response is also an XML document, which provides information such as the accuracy, response time, and so on.

Summary

Delivery of position information to location services clients or public safety answering points in cellular networks involves a complex set of protocols and messages between several network entities within and outside the cellular network, the mobile station and routing databases. The standards defining these protocols and entities are slightly different for ANSI-41 and 3GPP based cellular networks, but the functional operations are similar. At the application level, it is increasingly common to use XML in the mobile location protocol to support request and delivery of the position information.

Table of Acronyms

3GPP	Third Generation Partnership Project
BS	Base Station
CAS	Call Associated Signaling
CDMA	Code Division Multiple Access
DTD	Document Type Definition
ELID	Emergency Location Information Delivery
ESME	Emergency Services Message Entity
ESN	Emergency Services Network
ESNE	Emergency Services Network Entity
FCC	Federal Communications Commission
GMLC	Gateway Mobile Location Center
GPRS	General Packet Radio Service
GSM	Global System of Mobile Communications
GSN	GPRS Support Node
HTTP	Hypertext Transfer Protocol
LCS	Location Services
LIF	Location Interoperability Forum
LMU	Location Measurement Unit

MLP	Mobile Location Protocol
MPC	Mobile Positioning Center
MS	Mobile Station
MSC	Mobile Switching Center
NCAS	Non-call Associated Signaling
OMA	Open Mobile Alliance
PDE	Position Determining Entity
PSAP	Public Safety Answering Point
PSTN	Public Switched Telephone Network
RNC	Radio Network Controller
SMLC	Serving Mobile Location Center
SOAP	Simple Object Access Protocol
UMTS	Universal Mobile Telecommunications System
XML	Extensible Markup Language

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