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POSITIONING WITH LTE

MAXIMIZING PERFORMANCE THROUGH INTEGRATED SOLUTIONS

LTE supports improved positioning performance and provides more flexibility for applications that use positioning services. Consequently, it opens the door for new business opportunities based on accurate position information. Individual positioning technologies have their advantages and disadvantages in different environments, whereas integrated solutions can meet a wider range of requirements while using network and device resources efficiently.

GREATER ACCURACY EVERYWHERE

A decade ago wireless technology was dominated by mobile telephony. More recently, a 4G-capable mobile broadband platform is offered by LTE radio-access technology [1] developed by 3GPP. Today, there are around 5.8 billion mobile subscriptions. In the US market, for example, LTE networks cover more than 50 percent of the population and this figure is rapidly increasing. LTE enables an ever-widening range of services, enhanced QoS, efficient use of resources and flexible spectrum utilization. All of this in turn creates a wealth of new business opportunities, leading to tougher competition among service providers and application builders. Applications using highly accurate wireless-device positioning are constantly being developed and enhanced. This increases user expectations, which consequently creates demand for smarter services.

Positioning is the process of determining the geographical location of a device – such as a mobile phone, laptop or tablet computer, a personal digital assistant (PDA), or navigation or tracking equipment. Once the coordinates of a device have been established, they can be mapped to a location – such as a road, a building, a park or an object – and then delivered back to the requesting service. The mapping function and the delivery of location information are part of location services (LCS) – which, for example, emergency services depend on. Services that use location data are referred to as being location-aware, and customer services that offer added value by being location-aware are known as location-based services (LBSs). Services based on positioning benefit users, and LBSs can be used to optimize network performance and to enhance automated services such as network self-learning, self-optimization and services aimed at Minimization of Drive Tests (MDT).

The range of LBS applications is expanding rapidly. Some common examples include localized weather forecasts, targeted advertising and applications that can position the nearest bus stop, or find the location of an object – such as a subscriber's car keys.

INCREASING DEMANDS ON POSITIONING

Positioning in wireless networks is a challenge owing to the mobility of users and the dynamic nature of both the environment and radio signals. Positioning QoS is typically defined in terms of accuracy, confidence level and the time it takes to obtain a positioning result. The current trend shows that users, network operators, service providers and regulatory bodies are demanding:

- more accurate and reliable positioning for commercial and non-commercial services
- reduced latency from trigger time to the time when a result is available at the requesting node
- environment-agnostic accuracy implying comparable results for rural and urban, and indoor and outdoor environments
- more flexible QoS to support diversification of positioning services and enable user-adaptive and application-adaptive positioning services
- accurate positioning for emergency services and improved positioning performance in general. The objective is to meet the regulatory requirements of bodies such as the US Federal Communications Commission (FCC), which are becoming more stringent [2].

Users naturally presume that applications will work regardless of where they are and whether they are in a fixed location or on the move. They expect the same level of performance whether they are indoors at home or at work, outdoors in a rural or urban environment, or travelling.

From a commercial perspective, different applications require varying levels of accuracy. As the number and variety of applications and wireless devices grows, LTE, unlike previous radio-access standards, is well-positioned to support the higher level of application-adaptive requirements created by more advanced user needs and application development. To meet the requested positioning QoS, the best mix of positioning technologies should be selected for each case.

For network operators, it is important to provide a wide range

THE WIRELESS E911 LOCATION ACCURACY REQUIREMENTS [2]

For terminal-based and terminal-assisted positioning:

- 50m, 67% – within 50m for 67% of all calls measured at country level
- 150m, 95% – within 150m for 95% of all calls measured at county level

For network-based positioning:

- 100m, 67% – within 100m for 67% of all calls measured at county level
- 300m, 90% – within 300m for 90% of all calls measured at county level

Carriers must provide location, together with confidence and uncertainty data, for all emergency calls at the PSAPs.

of commercial services that meet user demands while efficiently managing network resources. To achieve this, operators need wide coverage and deploy cost-efficient solutions. Furthermore, operators are responsible for compliance with regulatory standards established to ensure reliable positioning in emergency situations (for example, E911 in North America and E112 in Europe).

The current Wireless E911 Location Accuracy Requirements [2] specify that carriers must over time, satisfy these standards at either a county level or at a Public Safety Answering Point (PSAP) geographical level, as well as being able to provide confidence and uncertainty data for all E911/E112 calls. The main challenge here is to achieve the required levels of accuracy for indoor locations. Recently, the FCC has indicated a shift towards accuracy requirements becoming technology-neutral, and all networks will be expected to fulfill the most stringent – terminal-based/assisted – requirements in the future.

The challenge is to provide a resource-efficient positioning service with the required levels of performance in all environments. However, as LTE is capable of implementing a wide range of positioning methods, this challenge presents a viable business opportunity. The approach adopted by LTE for positioning utilizes various aspects of terrestrial positioning. The benefits of this approach will continue to grow as global network coverage improves and denser networks, which include more and more base stations, are deployed.

WHY SATELLITES ARE NOT ENOUGH

Assisted-GPS (A-GPS) or GPS-capable devices could be a solution to rising user expectations and to meeting the more stringent requirements imposed by regulators and organizations. While many new mobile devices are likely to be equipped with GPS receivers, numerous devices that lack such receivers remain in use and offering GPS-capable handsets at no cost to subscribers does not solve the problem either, as no single positioning method, including GPS, works well in all environments. GPS, for example, fails to provide a reasonable level of positioning accuracy in indoor and urban canyon environments. In today's world, where more than 50 percent of mobile phone calls are made from indoor locations, there is a clear need for positioning methods that can provide the required level of accuracy in all environments.

Rural deployment of base stations is costly; as a result, the distances between sites in rural networks tend to be long, cells tend to be larger, and there are fewer detectable neighbor cells. Accurate positioning in rural areas is subsequently more difficult owing to the longer distances involved and larger coverage areas. Due to the maximum-power limitation of terminals, network-based positioning is both more coverage-limited and less efficient from a battery perspective than terminal-assisted positioning. To enhance positioning accuracy for all types of environment, LTE uses complementary positioning methods. The main location technologies used are Observed Time Difference of Arrival (OTDOA) and Assisted Global Navigation Satellite System (A-GNSS), due to the high level of accuracy these methods can achieve with no requirement for additional radio network equipment (where OTDOA is used for indoor locations and A-GNSS for outdoor environments). To further improve results, these methods can be complemented with additional technologies such as self-learning fingerprinting or proximity location. The use of a combination of technologies can enhance positioning performance, making hybrid positioning an important and powerful technique.

Individual positioning techniques do not perform at the same rates in all environments, so they should be used to complement each other rather than as standalone technologies. Integrated positioning solutions that effectively combine different positioning techniques can meet a wide range of accuracy and performance requirements, while allowing efficient use of network and device resources. Such solutions must operate well in synchronous and asynchronous networks, and with FDD and TDD.

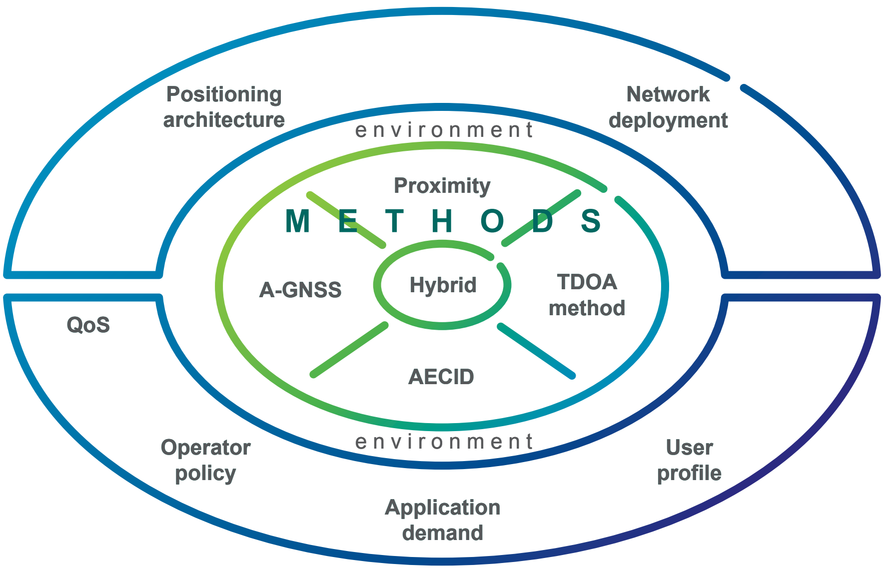

Figure 1: An integrated positioning solution and factors that influence the quality of the results

The approach used in integrated positioning solutions should also be applied to terminal-assisted, terminal-based and network-based positioning. Generally speaking, terminal-assisted positioning is technically superior to terminal-based positioning, as it can make use of terminal measurements together with the available knowledge about the radio environment accumulated in the network, while keeping UE-complexity low. Terminal-assisted positioning also has advantages over standalone network-based positioning, which relies on network measurements and network knowledge, is constrained by the maximum terminal power and cannot benefit from measurements at the actual user location.

Figure 1 illustrates an example set of positioning methods available in LTE. The set of methods operates as a unit, responding to network capability and architecture, meeting positioning QoS demands, and taking into account the radio propagation environment. The four methods shown have different typical accuracy ranges, and all of them may be used with the hybrid technique. Each method calculates positions using different measurements and signals from different sources. For example, satellite-based measurements enable the best performance for terminals with GNSS-capable receivers in suburban and rural areas. A method based on Time Difference of Arrival (TDOA), such as OTDOA, can be a better choice for indoor locations and urban canyon environments, while Adaptive Enhanced Cell Identity (AECID) is a good fit in all environments and is especially suitable for terminals that are not equipped with GNSS receivers.

SELF-LEARNING AND METHOD SELECTION

Positioning systems that are flexible and capable of learning about and adapting to the radio environment – while being responsive to service and user demand – can bring a significant improvement in performance. Network operators can save on tuning and populating positioning systems by using flexible and self-adaptive systems that:

- build up and manage databases automatically, accounting for radio environment knowledge
- employ adaptive positioning method selection, based on available environment knowledge
- use available information to enhance positioning performance.

Today, automatic build-up of databases and radio frequency (RF) maps is possible using methods such as AECID positioning. This can be further enhanced by MDT, for example, as well as other forms of automated RF-measurement collection.

The choice of which positioning method to use in a specific situation is typically controlled by operator-configurable sets of decision logic. Earlier cellular systems applied the different positioning methods sequentially. The decisions on which positioning methods to apply, and in what order to apply them, were determined based on parameters such as service class, UE capability, and target positioning QoS. These parameters were then compared to preconfigured method-specific parameters. Positioning performance could be greatly improved if method selection were instead based on statistics for method-performance in the relevant area and environment. The benefit of this approach on positioning performance is greatest when choosing which method to apply first; when the least amount of information is available for the UE and the user.

To ensure good performance, a positioning system should be self-learning and environment-adaptive, capable of building up information databases that store actual observations, and employ smart data-analysis mechanisms. By using more measurements, new ways of collecting them as well as more advanced algorithms, LTE has the capability to support flexible self-learning and network-adaptive positioning systems.

Table 1: Typical characteristics and expected QoS of LTE positioning methods

Positioning method	Environment Limitations	UE impact	Site impact	System impact	Positioning QoS		
					Response time (in RAN)	Horizontal uncertainty	Vertical uncertainty
CID Proximity location	No	No	No	Small	Very low	High	N/A
E-CID	No	Small	Small	Medium	Low	Medium	N/A
E-CID/AoA	Rich multipath	Small	Large	Medium	Low	Medium	N/A
RF fingerprinting	Rural (audibility)	Small	Small	Large	Low/medium	Low/ medium	Medium***
AECID	No	Small	Small	Medium	Low	Low/ medium	Medium***
UTDOA*	Suburban/ Rural (audibility)	Small	Large	Large	Medium	<100m**	Medium***
OTDOA	Rural (audibility)	Medium	Medium	Medium	Medium	<100m	Medium***
A-GNSS	Indoor (audibility)	Large	Small	Medium	Medium/high	<5m	<20m

*) being standardized for Release 11
) only for large bandwidth and only with special processing in the receiver *) optional support

Table 1 and Figure 3 summarize the properties and QoS of LTE positioning methods.

LTE POSITIONING ARCHITECTURE, PROTOCOLS AND METHODS

Decentralizing the radio-access network (RAN) architecture and minimizing the number of node levels are key characteristics of the design philosophy behind LTE. In addition to this, 3GPP decided that positioning architecture should be transparent to the underlying radio network. As a result, LTE positioning functionality is distributed across LTE radio nodes, eNodeBs, and the positioning node. The eNodeBs, for example, ensure proper configuration of positioning reference signals, provide information to the Enhanced Serving Mobile Location Center (E-SMLC), enable UE inter-frequency measurements if necessary, and provide network-based measurements on request from the E-SMLC.

The positioning node determines which positioning method to use, builds up and provides assistance data to facilitate calculating measurements, collects the necessary measurements, works out the position, and communicates the result to the requesting client.

Operators typically require support for positioning over both the control and user planes. In the control plane, a positioning request is always sent by the Mobility Management Entity (MME) to the E-SMLC, and the delivery of a response – including positioning data, user authorization and charging information – is controlled by the Gateway Mobile Location Center (GMLC). In the user plane, positioning information is exchanged over data channels using the Secure User Plane Location (SUPL) protocol in the application layer.

ARCHITECTURE AND PROTOCOLS

LTE positioning architecture contains three key network elements: the LCS client, LCS target and LCS server. The LCS server is a physical or logical entity that manages positioning for an LCS target device. It collects measurements and other location information, assists the UE in calculating measurements when necessary, and estimates the LCS target location. An LCS client is a software and/or hardware entity that interacts with an LCS server to obtain location information for LCS targets and may reside in the LCS target. An LCS client sends a request to the LCS server to obtain location information; the LCS server processes the request and sends the positioning result and, optionally, a velocity estimate back to the LCS client. A positioning request can originate from either the UE or the network.

LTE operates two positioning protocols via the radio network: LTE Positioning Protocol (LPP) and LPP Annex (LPPa). LPP is a point-to-point protocol for communication between an LCS server and an LCS target device, and is used to position the device. LPP can be used both in the user plane and control plane, and multiple LPP procedures are allowed in series and/or in parallel, reducing latency. LPPa is a communication protocol between an eNodeB and an LCS server for control-plane positioning – although it can assist user-plane positioning by querying eNodeBs for information and measurements. The SUPL protocol is used as a transport for LPP in the user plane.

Figure 2 illustrates LTE's high-level

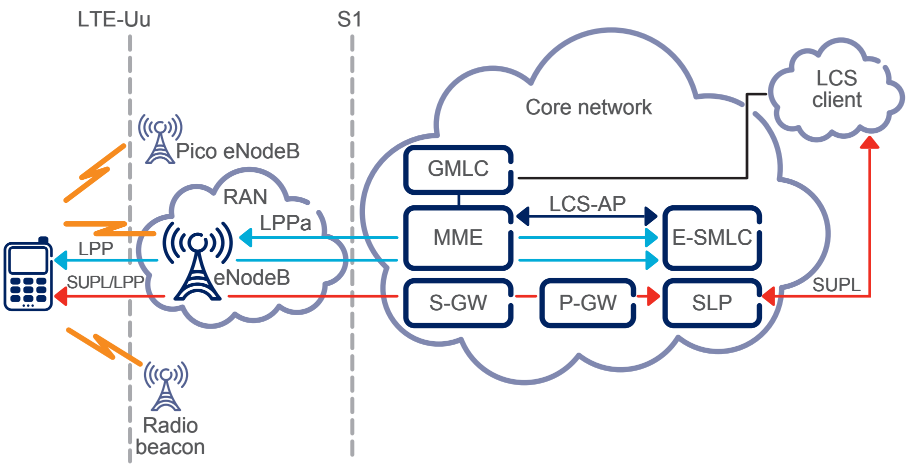

Figure 2: Positioning architecture in LTE Release 9/Release 10

positioning architecture, where the LCS target is a terminal, and the LCS server is an E-SMLC or an SLP. The control-plane positioning protocols with E-SMLC as the terminating point are shown in blue, and the user plane positioning protocol chain in red.

Deploying additional positioning architecture elements, such as radio beacons, can enhance the performance of individual positioning methods. Deploying extra radio beacons and, for example, using proximity location techniques is a cost-efficient solution that can significantly improve positioning performance both indoors and outdoors.

POSITIONING METHODS

To meet the demands created by LBS, LTE networks support a range of complementary positioning methods. The basic method – Cell ID (CID) – utilizes cellular system knowledge about the serving cell of a specific user; the user location area is thus associated with the serving CID. Support for this method has been mandatory since Release 8, and the following methods became available with Release 9:

- Enhanced Cell ID (E-CID) – UE-assisted and network-based methods that utilize CIDs, RF measurements from multiple cells, timing advance, and Angle of Arrival (AoA) measurements
- OTDOA – UE-assisted method based on reference signal time difference (RSTD) measurements conducted on downlink positioning reference signals received from multiple locations, where the user location is calculated by multilateration
- A-GNSS – UE-based and UE-assisted methods that use satellite signal measurements retrieved by systems such as Galileo (Europe) and GPS (US). LTE supports positioning with existing satellite systems and will develop as new satellite systems become available.

The following commonly known methods do not require additional standardization and are also included in LTE Release 9:

- RF fingerprinting, a method of finding a user position by mapping RF measurements obtained from the UE onto an RF map, where the map is typically based on detailed RF predictions or site surveying results
- AECID [3,5], a method that enhances the performance of RF fingerprinting by extending the number of radio properties that are used, where at least CIDs, timing advance, RSTD, and AoA may be used in addition to received signal strengths, and where the corresponding databases are automatically built up by collecting high-precision OTDOA and A-GNSS positions, tagged with measured radio properties
- hybrid positioning, a technique that combines measurements used by different positioning methods and/or results delivered by different methods.

Uplink TDOA (UTDOA), an uplink alternative method to OTDOA, is being standardized for Release 11. UTDOA utilizes uplink time of arrival (ToA) or TDOA measurements performed at multiple receiving points. Measurements will be based on Sounding Reference Signals (SRSs).

For some environments, positioning based on measurements of radio signals can be challenging. Alternative methods, such as enhanced proximity location, can be applied as complements to CID-based methods to improve positioning results. A proximity method may, for example, utilize knowledge about the set of detected networks or radio devices. As civic address information associated with a cell or network node is both comprehensible by a person and the native format for PSAPs, a proximity method may use this information instead of geographical coordinates.

CID is the fastest available measurement-free positioning method that relies on the cell ID of the serving cell – typically available information – and the location associated with that cell, but its accuracy depends on the size of the serving cell. A-GNSS, including A-GPS, is the most accurate positioning method in satellite-friendly environments. The most accurate terrestrial method is OTDOA, which is based on downlink measurements of positioning reference signals transmitted by radio nodes such as eNodeBs or beacon devices. OTDOA and A-GNSS provide highly accurate positioning in most parts of a cellular network and for most typical environments. UTDOA performance may approach that of OTDOA in some deployment scenarios that are not UL-coverage-limited, assuming the use of enhanced UL receivers. To improve positioning in challenging radio environments, these methods can be complemented, for example, with hybrid positioning, proximity location and new positioning methods in the middle accuracy range, including AoA, RF fingerprinting and AECID. Note that the AECID method utilizes a wider set of measurements than the RF fingerprinting method – including, for example, timing measurements – meaning that AECID is significantly less subject to environment limitations. In the future, as networks become denser, the role of proximity methods will become important.

POSITION-REPORTING FORMATS

Seven position-reporting formats, each associated with a Geographical Area Description (GAD) shape, are supported in 3GPP for LTE, UMTS and GSM. All seven formats can be used for positioning, although certain formats may be more typically associated with particular positioning methods. US emergency services apply an additional restriction for the permitted geometrical shapes used by cellular systems for position-reporting to emergency centers. Accordingly, shape conversion must be applied to positioning results delivered in a non-emergency-compliant format. This may result in an additional loss of accuracy in comparison with emergency centers that support all formats [4].

To interpret position reports correctly and benefit from collected statistics, it is essential that both position uncertainty and the associated confidence level are included in the position report together with the actual position. By including these qualifiers, position reports can be interpreted and processed correctly – taking any shape conversion, for example, into consideration. The resulting processed position information can be used with confidence for network services or for building up RF maps. Uncertainty and confidence level qualifiers should always be provided with all position reports and also in measurement reports that include position information such as measurement reports for MDT.

Civic address format is the native format for emergency centers. Positioning solutions using this format tend to be cost- and resource-efficient because, in the simplest case, a civic address may be directly associated with a radio network node, meaning that position calculation and positioning result conversion can be avoided if accuracy is sufficient – for example, when the coverage range of a node is small. This format is already supported, for example, for user-plane positioning with US National Emergency Number Association (NENA) i3 technical requirements [6] and IETF [7], although it is not yet supported by 3GPP.

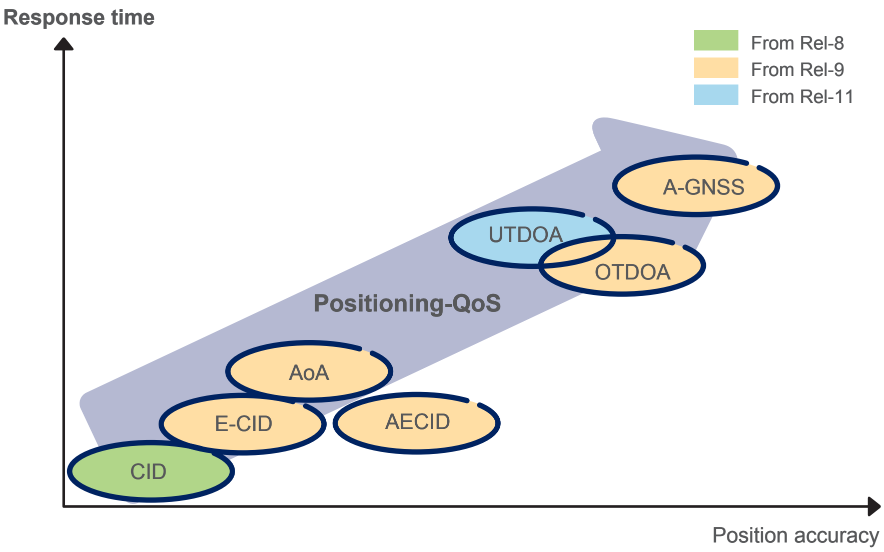

Figure 3: QoS for standalone positioning methods in LTE

FURTHER EVOLUTION AND TRENDS

A STRONG CASE FOR CONVERGENCE

Different radio-access technologies (RATs) have evolved over the years with different positioning architectures, functionalities and nodes. In addition, control-plane, user-plane and third-party solutions such as Google Maps positioning are widespread. This fast-growing variety of positioning standards may become a problem and, as a result, performance- and cost-efficient multi-RAT positioning solutions are likely to become available.

In today's cellular systems, the serving RAT determines which positioning method to use. To use and benefit from the positioning methods of another RAT, a terminal must hand over to that particular RAT. In a system capable of multi-RAT positioning, inter-RAT handover will migrate toward inter-RAT hybrid positioning.

Given the current trend toward harmonized standards – such as multi-standard radio (MSR) in 3GPP – the integration of multi-RAT positioning functionalities seems inevitable and requires the convergence of positioning standards that ensure multi-standard and multi-vendor interoperability. Multi-RAT network architectures enable seamless coverage and handover and so multi-RAT positioning solutions will need to facilitate smooth operation and ensure good performance in multi-RAT networks and in networks that include RAT islands.

As illustrated in Figure 4, a positioning node, in a multi-RAT positioning system, needs to interface with different RATs and should be able to select the most suitable positioning method from a set of methods, control- and/or user plane, which may be specific to individual RATs. The node must also be able to request the corresponding intra- and/or inter-RAT measurements from the terminal or other network nodes based on known capabilities and the requested positioning QoS.

Integration and standards harmonization will reduce the amount of positioning equipment needed and ensure maximum compatibility and reuse. This will enable cost-efficient positioning solutions, more flexible standards development, and smoother network deployment and network migration.

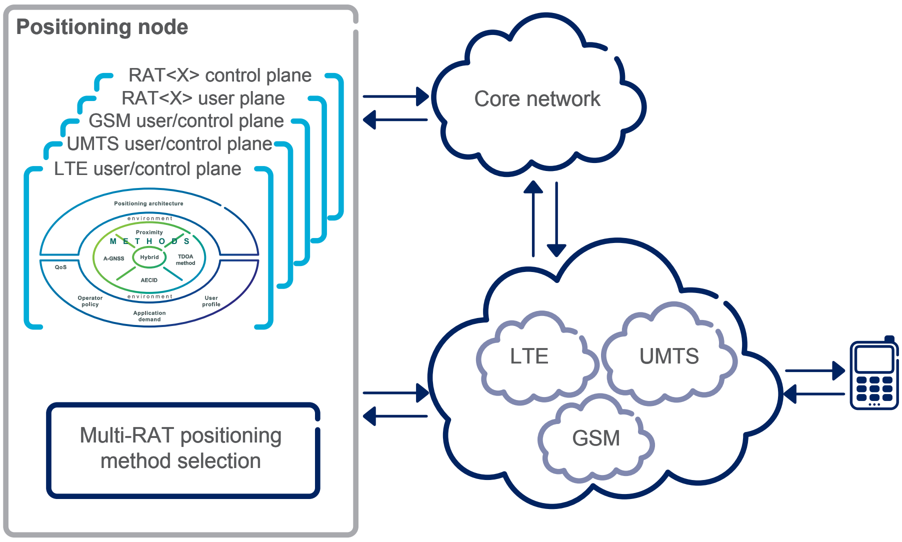

Figure 4: Multi-RAT positioning architecture – a high-level view

EVOLVED POSITIONING QoS

Positioning QoS in 3GPP is parameterized in terms of response time, horizontal accuracy, optional vertical accuracy and associated confidence levels. In UMTS, response time is encoded as low-delay or delay-tolerant, and accuracy is stated using one of 128 encoded uncertainty values. The radio-positioning protocol in LTE has been enhanced to better support positioning QoS, where response times are measured in seconds and confidence information is available in addition to uncertainty.

The requested positioning QoS parameters are input to the positioning-method selection logic, which also takes into consideration the capabilities of the positioning target as well as the QoS parameters associated with each positioning method. With this input, the server determines the sequence of positioning methods to be attempted for the positioning target. To determine whether another positioning attempt is necessary, the achieved positioning QoS should be evaluated after each trial.

In spite of the improved set of positioning QoS reports, the current LTE standard has inherited a simplified QoS model where the positioning method is selected based on a one-by-one check of the requested QoS parameters; response time is usually checked first, followed by horizontal accuracy and optionally vertical accuracy. Method selection procedures designed to maximize the use of self-learning and hybrid positioning methods are preferable to method selection based on the individual performance of each method in isolation. Futhermore, for method-selection algorithms to attain better positioning results they need to account for the fact that LTE allows positioning procedures to run in parallel.

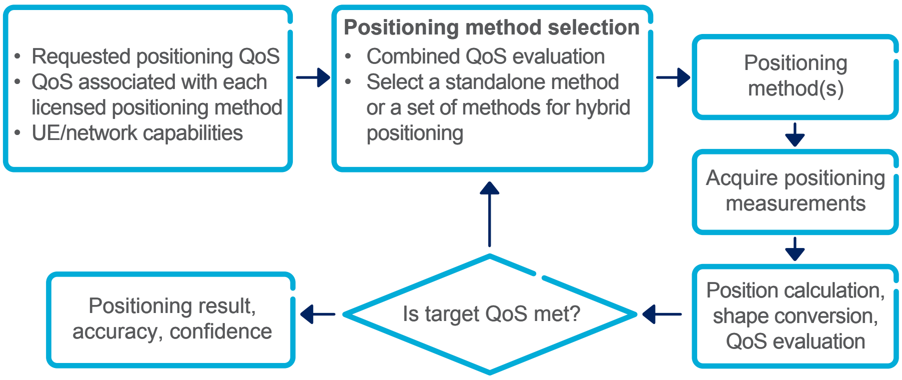

Figure 5: Improved positioning QoS mechanisms

As illustrated in Figure 5, advanced management of positioning QoS should allow for:

- combined QoS evaluation which simultaneously accounts for all QoS parameters
- the aggregate QoS of multiple positioning methods that are part of a hybrid method
- the selection of a set of positioning methods that may be executed in parallel.

CONCLUSION

LTE technology enhances positioning performance, provides flexibility for applications and creates new business opportunities for location-based applications and services. Because no single positioning method works well in all environments, new-generation positioning systems must have integrated solutions that combine a wide range of complementary positioning methods and techniques together with the ability to learn about and adapt to the radio environment. Indeed, the need for multi-standard positioning solutions is obvious in a world where such a large variety of radio access and positioning standards coexist. However, there remains a pressing need to align the position-reporting formats used by cellular networks and emergency systems if emergency services are to benefit from the degree of accuracy their line of work demands, while also remaining cost- and resource-efficient.

GLOSSARY

3GPP	3rd Generation Partnership Project
A-GNSS	Assisted GNSS
A-GPS	Assisted GPS
AECID	Adaptive Enhanced Cell Identity
AoA	Angle of Arrival
CID	Cell Identity
E-CID	Enhanced Cell Identity
E-SMLC	Enhanced SMLC
FCC	Federal Communications Commission
FDD	frequency division duplex
GAD	Geographical Area Description
GMLC	Gateway Mobile Location Center
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
LBS	location-based service
LCS	location services
LCS-AP	LCS application protocol
LPP	LTE Positioning Protocol
LPPa	LPP Annex
LTE	Long Term Evolution
MDT	Minimization of Drive Tests
MME	Mobility Management Entity
MSR	multi-standard radio
NENA	National Emergency Number Association (US)
OTDOA	Observed Time Difference of Arrival
PDA	personal digital assistant
PLMN	Public Land Mobile Network
PSAP	Public Safety Answering Point
QoS	quality of service
RAN	radio-access network
RAT	radio-access technology
RSTD	reference signal time difference
RF	radio frequency
SLP	SUPL Location Platform
SMLC	Serving Mobile Location Center
SRS	Sounding Reference Signal
SUPL	Secure User Plane Location
TDD	time division duplex
TDOA	time difference of arrival
ToA	time of arrival
UE	user equipment
UMTS	Universal Mobile Telecommunications System
UTDOA	Uplink Time Difference of Arrival

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