Unlocking the full potential of geolocation
State of the art and compelling use cases
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Introduction

Wireless geolocation is the ability to estimate with high accuracy the location of a device, object or subscriber (whether stationary or in motion) by using location algorithms and positioning methods.

Location techniques can be categorized by the technology (beacons, satellites or cellular network) or data source (handset or infrastructure) being used.

In this white paper we will highlight the different geolocation techniques available for mobile operators through their cellular infrastructure and generally based on radio signals transmitted and received between mobile phones and base stations. We will see that these location techniques are not applicable in every situation and area (dense vs rural, indoor vs outdoor) and that they depend on the data that is made available by the network, each presenting a different degree of accuracy and cost.

Mobile operators clearly understand the value of accurate and precise geodata which enables them to accelerate network roll-out, improve network optimization, enrich customer care analysis and create new value-added applications and services to monetize these data. After illustrating how operators can unlock the full potential of geolocation through concrete examples, we will describe Astellia’s awarded geolocation solution and how it responds to operators’ needs.
There exists a set of different methods to calculate the location of objects, subscribers or devices. In general, a wireless geolocation solution is composed of the following main elements:

1. **Data source**: provides the data to be used by the algorithm to calculate the position of the User Equipment (UE)

2. **Geolocation algorithm**: implements multiple geolocation techniques, which depend on the type of available data source

### Data source
- RF Measurements
- Time Measurements
- GPS Measurements
- Network topology

### Algorithms
- Cell ID
- Trilateration
- Triangulation
- Multilateration
- Fingerprinting

#### DATA SOURCES
The availability of certain measurements for geolocation is dependent on where they are taken. Likewise, a possible segmentation would be:

**Network-based measurements**
In this first case, measurements are taken and made available by the network elements. If measurements are defined as part of the technology protocol standardization, they can be obtained from signaling messages. If not, then the capability to obtain certain measurements is conditioned by the network element's measurement capabilities.

**Handset-based measurements**
The main difficulty is to extract and send the measurements from the UE to centralized servers. If measurements are reported as a part of the signaling messages exchanged between the UE and the network, then they can be decoded along with the rest of the signaling messages received by the network.

There are three main relevant classifications of data sources: Radio Frequency (RF), Time and Global Positioning System (GPS). These sources provide measurements that are usually available in signaling protocols for most of the radio access technologies (RAT).
1. RF MEASUREMENTS

RF measurements measure the properties of electromagnetic waves. For geolocation purposes, there are mainly two types of RF measurements to be considered:

- **Signal Strength (SS)** measures the power of the received signal either in uplink (network-based) or downlink (handset-based) radio channels. Propagation models characterize the signal strength as a function of frequency, distance, transmitter power and other variables. By combining received signal strength and propagation models it is possible to estimate the distance between the user and the base station. In 3GPP Release 13, for both WLAN and Bluetooth technologies, **Received Signal Strength Indicator (RSSI)** was introduced as part of the UE reported measurements in the signaling messages.

- **Angle of Arrival (AoA)** determines the incident angle of an arriving RF signal when having antenna arrays.

2. TIME MEASUREMENTS

As in the previous case, standardization conditions both the accuracy and availability of time measurements in the signaling protocols. In general, the following measurements can be obtained:

- **Time of Arrival (ToA)**. It measures the signal delay between the transmitter and the receiver. In 3GPP mobile networks there are multiple network-based time measurements available per RAT that are used for radio frame synchronization: Timing Advance (TA) in LTE and GSM, and Propagation Delay (PD) in UMTS.

- **Round-Trip Time (RTT)** is the travel time of a signal sent from a transmitter to a receiver plus the travel time back from the receiver to the original transmitter in the form of acknowledgement or corresponding aligned transmission, without considering processing and alignment times in the receiver.

- **Observed Time Difference of Arrival (OTDOA)** is a handset-based measurement where the UE calculates the observed time difference between pairs of network elements. The usage of this measurement in geolocation algorithms is conditioned by network synchronization.

- **Uplink Time Difference of Arrival (U-TDOA)** is a network-based time measurement where base stations provide accurate timestamping of uplink signal reception. The usage of this measurement in geolocation algorithms is conditioned by network synchronization.

Network synchronization is one of the most important factors impacting time measurements, however, not all existing RATs are synchronized today.
3. GPS MEASUREMENTS

GPS measurements provide a very accurate geolocation. However, the availability of GPS is conditioned by multiple factors. First of all, it depends on the availability of the required hardware in the handset. For instance, low cost IoT devices are brought to the market without an expensive GPS module. But, even if the device is GPS-capable, users sometimes wish to deactivate this feature because of high battery consumption. Finally, the system presents some deficiencies in indoor scenarios due to the lack of Line of Sight (LOS) with satellites.

In 3GPP mobile networks, there are three different types of GPS measurements that are reported as part of the signaling protocols, based on different network features.

- **Standalone GPS measurements.** The reporting of GPS measurements by UEs can be activated from the network. In the case of a 3GPP mobile network, this feature is supported in the signalling messages whereas in other networks, such as LoRaWAN, it can only be obtained via the User Plane contents.

- **Assisted GPS (A-GPS) measurements.** Whereas standalone GPS measurements depend exclusively on information from satellites, the A-GPS technology increases both the precision under poor satellite signal conditions and the satellite synchronization time by broadcasting the list of visible satellites from base stations. Contrary to standalone GPS measurements, this technology requires ad-hoc hardware to be deployed in the mobile network.

- **Minimization of Drive Test (MDT).** 3GPP introduced this feature in recent releases in order to support the reporting of GPS measurements from handsets in both dedicated and idle modes. The main advantage of this feature compared to the two previous ones is that it opens the door to new use cases such as coverage holes detection.

All in all, when a device reports a GPS measurement there is no need to implement further geolocation techniques for that specific device. However, this measurement can be used for geolocating other devices from which GPS measurements are not available, by making use of fingerprinting techniques, as explained later on in the algorithms’ section.

In addition to both UE and network measurements, the knowledge of the RAN network topology itself is a mandatory input for geolocation algorithms.

These different data-source options are not mutually exclusive. In general, multiple measurements are used simultaneously depending on the RAT. Note that the latest 3GPP releases state that all of the previous data sources are optional positioning measurements sent by mobile devices.
ALGORITHMS

The availability of the previous measurements, conditions the selection of the geolocation algorithm and therefore the accuracy of the solution. In this section, the most relevant algorithms used by geolocation solutions are analyzed in detail.

1. CELL ID

This methodology is based on correlating the measurement of the unique identifier of the radio transmitter (Cell Id, BSSID, etc.) with the known transmitter position based on network topology data.

As a geolocation method it is the simplest one. The accuracy is highly dependent on the coverage of the transmitter; the lower the range of the transmitter, the higher the accuracy. For instance in the case of WLAN, small cells or Bluetooth beacons, the accuracy can be a few meters because the maximum range of these technologies is very limited. However, with macro cells, the accuracy will be in the worst case a few kilometers, depending on the network density.

Cell ID geolocation algorithm is usually enhanced with additional data such as:

- **Cell sector:** If cells are sectorized there is an intrinsic accuracy gain by making use of simple antenna parameters such as the beam-width and azimuth. The former parameter defines the angular coverage of the antenna whereas the latter defines the direction of radiation of the main antenna lobe.

- **ToA measurements:** These measurements, such as Timing Advance or Propagation Delay, narrows the possible location area by measuring the time distance of the UE from the antenna. The accuracy of the ToA measurements defines an arc where the UE could be located.

2. TRILATERATION

The trilateration algorithm uses simultaneously UE measurements from different transmitters. The technique requires the estimated distance between the UE and the transmitter, which can be obtained either from signal or timing measurements.

- In case of using *signal measurements*, the estimated distance between the receiver and each transmitter can be calculated by using propagation models. The intersection of the resulting information provides a geolocation estimation.
• For a timing measurement the distance is directly calculated by using ToA or RTT measurements. Thus, the intersection of timing measurements provides another estimated geolocation point.

The accuracy of this technology depends on the number of simultaneous reported transmitters as well as on the receiver-transmitter distance. As a rule of thumb:

• The higher the number of reported transmitters the smaller the intersection area and the better the accuracy.
• The further the distance from the antenna the larger the intersection area and the worse the accuracy.

3. TRIANGULATION

Triangulation determines the location by forming triangles defined by the antennas’ location and the angle of arrival (AoA) measurements of the received UE RF signals. This technology requires sophisticated arrays of antennas and makes it therefore more costly for operators to deploy the solution in the network.

4. MULTILATERATION

Multilateration algorithms are based on the measurement of the difference in distance between the UE and multiple base stations. Unlike absolute timing measurements such as RTT or ToA, the usage of time difference measurements results in an infinite number of combinations that form a hyperbolic curve. When there are multiple transmitters, there are multiple hyperbolic curves which intersect in a finite number of points that determine the candidate location positions.

In synchronized networks, the usage of either OTDOA or U-TDOA measurements results in a method that identifies the intersection of multiple hyperbolas.

The accuracy of the multilateration methodology depends on many factors:

• A minimum number of 3 base stations is needed in order to intersect the resulting hyperbolas.
• The timestamp measurement accuracy depends not only on RAT requirements but also on the reference clock accuracy.
• Multipath propagation implies a default time measurement error when there is no LOS. This impacts the geolocation accuracy.
• The relative position of the UE and the base stations (a.k.a. Dilution of Precision, GDOP) greatly impacts the overall provided accuracy.
5. FINGERPRINTING

This method geolocates users/devices without GPS by taking advantage of other UEs’ GPS measurements.

Thus the fingerprinting algorithm is available for every network where it is possible to have some UEs regularly sending their GPS positions along with RF measurements. Those RF measurements constitute a fingerprint for that GPS position.

This fingerprinting-based positioning consists of two phases.

- Firstly, a **database of measurements is built up** by leveraging the GPS positions and RF measurements reported by a limited number of UEs. Measurement vectors corresponding to a concrete GPS position are stored in the database, which consists of as many samples – or fingerprints - as possible. The higher the number of samples in the database, the better the accuracy.

- In a second step, measurements from UEs with no GPS available are sent to a **central entity that estimates their location**. The estimated location is calculated using a database correlation method that finds the best possible match between the received measurements' vector and the stored database fingerprints.

The main constraints of GPS measurement data is that not all devices have GPS available and in some indoor scenarios there is no satellite coverage. This limits the accuracy of the final position.

Most of the existing geolocation solutions in the market include additional algorithms that, combined with the previous geolocation techniques, improve the overall result for both mobility and indoor scenarios.

Similarly, it is possible to combine any of the previously mentioned geolocation algorithms to improve the overall results. However, there are certain limitations that impact the usage of specific geolocation algorithms, either due to intrinsic technology constraints or network deployment costs. Next table shows the usual utilization of each of the geolocation techniques per RAT as observed nowadays by Astellia at operators worldwide.

<table>
<thead>
<tr>
<th></th>
<th>GSM</th>
<th>UMTS</th>
<th>LTE</th>
<th>NB-IoT</th>
<th>LoRaWAN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell ID</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Trilateration</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Triangulation</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Multilateration</strong></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes²</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Fingerprinting</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes³</td>
<td>Yes³</td>
</tr>
</tbody>
</table>

1 It requires specific and costly antennas which aren't deployed yet and therefore it is a technique that cannot be used in existing deployed networks.
2 It is expected that 3GPP introduces TDOA measurements in future releases thus enabling Multilateration support.
3 It could be possible if GPS data is made available by the device, whose info can be collected in the user plane.
ACCURACY

One of the common mistakes when talking about geolocation results is the confusion between accuracy and precision. While accuracy refers to the closeness of the estimated position to the real one, precision refers to the distance and the variability between each estimated position. Next exhibit depicts the difference between both terms.

There are multiple factors that impact the accuracy of geolocation solutions such as the measurement type, the network density or inter-site distance (ISD), the geolocation algorithm, the radio access technology, LOS, users' mobility, history of samples, etc. Due to the multiple sources of errors, geolocation solutions deliver an accuracy estimation for geolocated data.

The following table summarizes how main sources of errors affect the accuracy of the geolocation solution.

<table>
<thead>
<tr>
<th>Source of Error</th>
<th>Cell ID</th>
<th>Trilateration</th>
<th>Triangulation</th>
<th>Multilateration</th>
<th>Fingerprinting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-site distance</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Simultaneous reported cells</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Antenna positioning errors</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Line of Sight (LOS) / Multipath</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Speed of Mobility</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>History of samples</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Pathloss</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Antenna location</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Indoor scenarios</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Dilution of Precision</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

In summary,

- The most robust solution is fingerprinting but this requires the activation of optional features in the network.
- Any error which affects the delay in the radio-signal propagation time, such as multipath, has a strong impact on any TDOA-based algorithm.
- Incomplete or wrong network topology data such as antenna position affects those algorithms where the reference point of the antenna is being used.
Customer use cases: geolocation brought to action

Geolocation solutions are able to determine and provide, on a 24x7 basis, the location of each subscriber’s call by using the above-mentioned techniques. When aggregating all geolocated subscribers’ calls, a wide range of maps are available with multiple performance indicators such as traffic, failed calls, handovers, coverage, quality, etc. Additionally, there are different advanced filtering capabilities which allow operators to look for specific patterns based on services, handsets, roamers and so on. Both performance indicators and filtering capabilities are combined with geolocation intelligence algorithms that allow mobile network operators to use the solution in a large variety of applications like troubleshooting, analytics, marketing, optimization and planning. This not only creates more efficiency but also new revenue streams.

NETWORK ROLL-OUT

MANAGE TRAFFIC GROWTH IN HOTSPOTS

At the moment operators are looking for solutions to offload the traffic from macro to small cells both due to capacity and coverage issues. So, having periodic and nation-wide information on hotspots is very valuable when defining the right location to deploy new small cells. It enables operators to invest where it matters and improve the customer experience for problematic areas and thus increasing the Return on Investment (ROI) of small cells.
Unlocking the full potential of geolocation

ACCELERATE NEW TECHNOLOGY INTRODUCTION

Another relevant benefit of geolocation information is that it helps accelerate the introduction of new technologies and prioritize new service deployments. For instance, it can help by ensuring an optimal VoLTE experience, pinpointing areas with a high density of VoLTE capable devices and then prioritizing actions to guarantee optimal network performance. Once the new technology is deployed, operators benefit from reduction in the Mean Time To Resolution (MTTR) by using geolocation maps that identify problematic areas and allow drill-down capabilities for troubleshooting.

VALUE BASED NETWORK INVESTMENT

Geolocation maps are used during the network investment plan at both the planning and validation phase. During the planning phase, when new sites are deployed (i.e. for new carriers in the digital dividend), coverage maps are very useful to prioritize those areas where subscribers experience bad quality. Thus, operators focus the investment based on a customer-centric approach which directly implies an increase of revenues per site.

Once the sites are deployed, at the validation phase, geolocation maps ease the Single Site Verification (SSV) procedure by using real subscriber data and avoiding costly drive test procedures. It means that the usage of geolocation maps in the SSV procedure accelerates the “site-on-air” time with a consequent positive impact on revenues.
INCREASE NETWORK OPTIMIZATION EFFICIENCY

With geolocation, operators can have 24x7 massive performance maps for all the subscribers of their network. This allows network engineers to have a better view of network performance based on areas rather than cell indicators. Engineers can focus their analysis on those areas where subscribers experience bad performance and prepare ad-hoc optimization or troubleshooting activities. Subsequently, this will have a concrete and positive impact on subscribers’ experience and improve the efficiency of the optimization teams.

OPTIMIZE AREAS WITH DIVERSE TRAFFIC PROFILES

Operators face difficulties to optimize those areas where traffic profiles are diverse (i.e. static vs. mobility, indoor vs. outdoor, etc.) because existing OSS tools do not allow to split KPIs. By using geolocation maps with advanced filtering capabilities, operators can propose specific actions aimed at optimizing the scenarios based on the traffic mix. For instance, high mobility areas related to trains and roads can be monitored and analyzed with performance geolocation maps.

REDUCE DRIVE TESTS BY 80%

Drive tests are being used for many daily tasks. However, they have some real disadvantages:

- Drive tests are very costly because operators have to send teams into the field to launch measurements at each specific location.
- Data is not available instantaneously.
- It is difficult to reproduce the conditions of failed calls when customers complain.
- Most of the tests are only performed in specific locations and can only be executed outdoors. It is not adapted to indoor or pedestrians areas.
- Drive tests only provide quality of service snapshots at a certain moment in time.

Geolocation represents a very cost-efficient alternative to drive tests because it overcomes all the listed drawbacks. In addition, since it is possible to geolocate 100% of subscribers’ calls on a 24/7 basis, operators get a real view of the customer experience and can take proper actions where needed. Based on our experience with operators worldwide, drive test activities can be reduced by 80 percent when using geolocation solutions.
Each element that provides additional information on the customer, provides a better knowledge of that customer and hence insights to improve their experience. Valuable subscriber mobility information can be used to geolocate high revenue generating hot spots (roamers, VoLTE subscribers, fleets, etc.), determine the customer experience of these hot spots and avoid potential loss of revenues due to a bad functioning network in these areas.
DATA MONETIZATION

RESELL DATA TO VERTICALS

Marketing can exploit geolocation data to create additional revenues by, for instance, engaging with a customer that is accessing a predefined area (geofencing). Some examples of use cases are location-based advertising, analysis of population flows for road traffic information, helping shopping malls understand where their customers are coming from and the time they are spending at their premises, etc.

TRACK IOT DEVICES & MOBILITY

With the current internet of things (IoT) revolution, asset tracking and fleet monitoring are becoming revenue generating and value-added services, offered by operators to their enterprise customers. So being able to provide massive geolocation and mobility of low-cost IoT devices without costly GPS functionality is a clear competitive differentiator.
Astellia’s fully virtualised Nova Geo solution supports the most advanced geolocation techniques such as trilateration, fingerprinting and multilateration, hereby guaranteeing first class accuracy in locating devices across multi-technology networks (2G/3G/4G/LPWAN).

Overall, with Nova Geo, operators have access to richer data and can benefit from reduced OPEX, direct CAPEX savings and improved IT efficiency.

Nova Geo’s classification algorithms distinguish indoor/outdoor, static/mobility calls. Combined with advanced location aware algorithms, it precisely locates capacity hotspots, coverage holes, pilot pollution and VIP areas to target and prioritize network operations such as new site introduction, small cell planning and parameters tuning.
Fast and massive performance maps

Nova Geo features state of the art geolocation technology that leverages radio measurement data to produce **24x7 massive performance maps** (i.e. RF coverage, traffic, quality, etc.), from nation-wide coverage down to 50x50m. The advanced solution architecture provides the fastest solution in the market to calculate the maps and make them available through the user interface.

Geolocation goldmine capitalization

Nova Geo also offers the possibility to export geolocation data through a North Bound Interface (NBI) into operators’ big data lake to implement additional Use Cases on top of the existing ones proposed by the solution.

Advanced troubleshooting

In only one click, users can **drill down** from user-defined geographical areas to individual Call Detailed Records (CDR), hereby benefiting from improved troubleshooting efficiency.

Subscriber privacy respect

The solution embeds the most advanced security and privacy measures such as **IMSI ciphering**, **IMSI masking** and user profiles with different **access rights** in order to guarantee the privacy of each subscriber.

Powerful, future-proof solution

Nova’s **big data architecture** ensures proper scalability for dealing with future network and traffic growth, while reducing operators’ hardware expenses. Together with current research projects in **5G**, Astellia’s geolocation solution is your best choice for coming network evolutions.

Powerful geo-analytics

Multiple map filtering options provide users with capabilities to perform **in-depth analysis based on user-defined geographical areas**. By leveraging Astellia’s probing solution, geolocation maps can be enriched with very valuable User Plane information such as application usage and video quality.
A high speed train is a very complex environment due to the high speed in which customers are moving. Before, we were mainly using drive tests to optimize network conditions along the railway, but now, with Astellia, we adopt a new and very innovative approach which manages to filter out those people that are actually on the train. The optimization of high speed train routes is particularly important for business travelers that need to stay connected at any time. This allowed us to become the best service provider on high speed trains in Spain and created a real competitive differentiator for Orange!

Juan Serrano Sánchez
Quality Manager
Orange Spain

With Nova Geo, we have a solid solution at hand to improve overall customer experience and maximize return on investment of network infrastructure.

Vicente Abad
RAN Optimization Manager
Telefonica Spain

We have signed a global framework agreement with Astellia to deploy its geolocated-based RAN optimization platform. We will leverage Astellia’s best-in-class geolocation accuracy to optimize network deployment and increase RAN performance efficiency.

Juan Carlos García
RAN GCTO Director
Telefonica Group

We called upon Astellia for their flexible and feature-rich solution and their proactivity in solution evolution towards Big Data. We also highly value their expertise in radio optimization, geolocation and traffic analysis.

Thomas Vonlanthen
Head of Wireless Access Technologies
Swisscom Switzerland