

Unlocking the full potential of geolocation

State-of-the-art and compelling use cases

white
paper

EXFO

Unlocking the full potential of geolocation



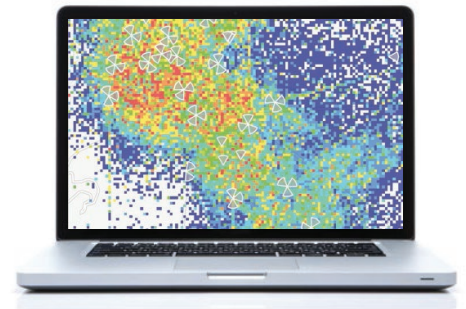
white paper



Mobile operators clearly understand the value of accurate and precise geodata that enables them to accelerate network rollout, improve network optimization, enrich customer care analysis and create new value-added applications and services to monetize these data.

Introduction

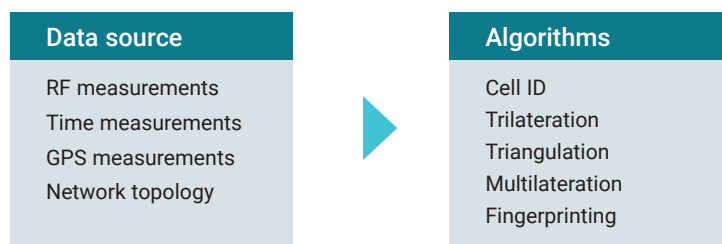
Wireless geolocation is the ability to estimate with high accuracy the location of a device, object or subscriber (whether stationary or in motion) by using location algorithms and positioning methods. Location techniques can be categorized by the technology (beacons, satellites or cellular network) 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 that enables them to accelerate network rollout, 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 this award-winning geolocation solution and how it responds to operators' needs.



Geolocation: data sources, algorithms and accuracy

Different methods are used 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 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 network elements. If measurements are defined as part of the technology protocol standardization, they can be obtained from signaling messages. If not, then the ability 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 part of the signaling messages exchanged between the UE and the network, they can be decoded as part of the signaling messages received by the network.

There are three main relevant data source classifications: radio frequency (RF), time, and global positioning system (GPS). These sources provide measurements that are usually available in signaling protocols for most 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 consider:

- **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 one of the UE reported measurements in the signaling messages.
- **Angle of arrival (AoA)** determines the incident angle of an incoming RF signal on 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)** 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. Use of this measurement in geolocation algorithms is conditioned by network synchronization.
- **Uplink time difference of arrival (U-TDOA)** is a networkbased time measurement where base stations provide accurate timestamping of uplink signal reception. Use 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.



GPS measurements provide very accurate geolocation. However, the availability of GPS is conditioned by multiple factors.

3 . GPS measurements

GPS measurements provide very accurate geolocation. However, the availability of GPS is conditioned by multiple factors. First, it depends on the availability of the required hardware in the handset. For instance, low cost IoT devices are brought to market without an expensive GPS module. And 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, A-GPS technology increases both precision under poor satellite signal conditions and 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 hole 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 to geolocate other devices from which GPS measurements are not available by making use of fingerprinting techniques, as explained later in the algorithm section.

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

These different data-source options are not mutually exclusive. In general, multiple measurements are used simultaneously depending on the RAT. Within the latest 3GPP releases, almost all 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 radio transmitter's unique identifier (Cell ID, BSSID, etc.) with the known transmitter position based on network topology data.

As a geolocation method it is the simplest one. 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 to within 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.

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

- **Cell sector:** If cells are sectorized, there is an intrinsic accuracy gain that comes with making use of simple antenna parameters such as the beamwidth 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:** Measurements such as timing advance or propagation delay, narrow down 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.



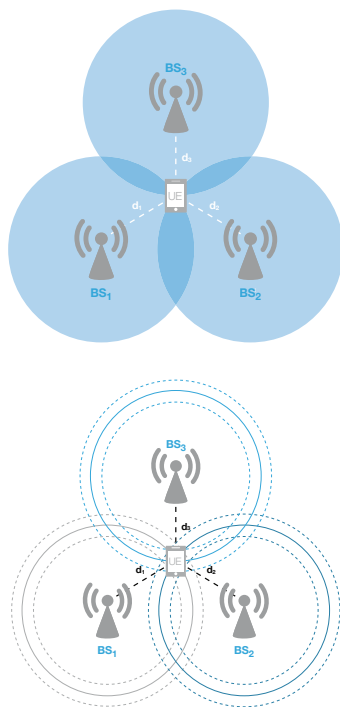
2. Trilateration

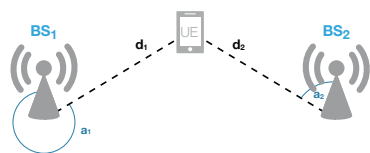
The trilateration algorithm uses UE measurements from different transmitters simultaneously. The technique requires the estimated distance between the UE and the transmitter, which can be obtained either from signal or timing measurements.

- When 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:

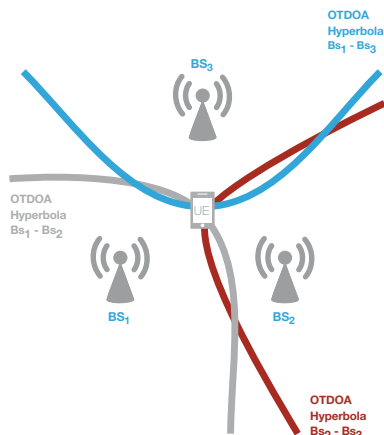
- The higher the number of reported transmitters, the smaller the intersection area and the better the accuracy.
- The further the distance from the antenna, the larger the intersection area and the worse the accuracy.





3. Triangulation

Triangulation determines location by forming triangles defined by the antennas' location and the angle of arrival (AoA) measurements of RF signals received from UEs. This technology requires sophisticated antenna arrays, which makes it more costly for operators to deploy 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, use 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 use 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 a variety of factors:

A minimum number of three base stations is needed in order to intersect the resulting hyperbolas.

- Timestamp measurement accuracy depends not only on RAT requirements but also on reference clock accuracy.
- Multipath propagation implies a default time measurement error when there is no LOS. This impacts geolocation accuracy.
- The relative position of the UE and the base stations (a.k.a. geometric dilution of precision, GDOP) greatly impacts the overall accuracy.

5. Fingerprinting

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

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.

Fingerprinting-based positioning consists of two phases:

First, 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.

Second, 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 are twofold: not all devices have GPS available available, and in some indoor scenarios, there is no satellite coverage. This limits the accuracy of the final position.

Most geolocation solutions on the market include additional algorithms that, when 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 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. The following table shows the current and typical use of each geolocation technique per RAT by operators worldwide.

	GSM	UMTS	LTE	NB-IoT	LoRaWAN
Cell ID	Yes	Yes	Yes	Yes	Yes
Trilateration	Yes	Yes	Yes	No	No
Triangulation ¹	No	No	No	No	No
Multilateration	No	No	Yes	Yes ²	Yes
Fingerprinting	Yes	Yes	Yes	Yes ³	Yes

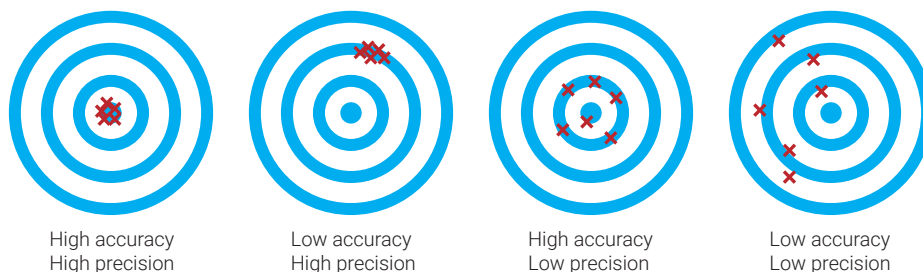
1. This requires specific and costly antennas which aren't deployed yet and therefore it is a technique that cannot be used in existing deployed networks.

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 to confuse the terms **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. The following diagram illustrates the difference between both terms:



There are multiple factors that impact the accuracy of geolocation solutions, including the measurement type, network density or inter-site distance (ISD), the geolocation algorithm, radio access technology, LOS, user mobility, history of samples, etc. Due to 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.**

	Cell ID	Trilateration	Triangulation	Multilateration	Fingerprinting
Inter-site distance	High	High	Medium	Medium	Low
Simultaneous reported cells	Low	High	High	High	Medium
Antenna positioning errors	High	High	High	High	Low
Line of sight (LOS) / Multipath	Low	Low	High	High	Low
Speed of mobility	High	High	Medium	Medium	Low
History of samples	Low	Medium	Low	Low	High
Pathloss	Low	High	Low	Low	Low
Antenna location	High	High	High	High	Low
Indoor scenarios	Low	Low	High	High	High
Dilution of precision	Low	Medium	High	High	Low

In summary:

- The most robust solution is fingerprinting, but it requires the activation of optional features in the network.
- Any error that affects the delay in 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 in action

Geolocation solutions can determine and provide, on a 24/7 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 that 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.



Geolocation solutions can determine and provide, on a 24/7 basis, the location of each subscriber's call

Network rollout



Manage traffic growth in hotspots

Operators today are looking for solutions to offload the traffic from macro to small cells due to both capacity and coverage issues. Having periodic and nationwide 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 in problem areas and thus increase the return on investment (ROI) of small cells.



Accelerate introduction of new technology

Another powerful 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 mean time to resolution (MTTR)** by using geolocation maps that identify problem areas and allow drill-down capabilities for troubleshooting.

"We called upon Astellia [now part of EXFO] 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



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 for prioritizing areas where subscribers experience bad quality. This helps operators **focus their investment based on a customer-centric approach** that directly implies an increase of revenues per site.

Once the sites are deployed, at the validation phase, geolocation maps facilitate the single site verification (SSV) procedure by using real subscriber data and avoiding costly drive test procedures. It means that the use of geolocation maps in the SSV procedure **accelerates the "site-on-air" time** with a consequent positive impact on revenues.

Network optimization



Increase network optimization efficiency

With geolocation, operators can have 24/7 massive performance maps for all their network subscribers. 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 areas where subscribers experience bad performance** and prepare ad-hoc optimization or troubleshooting activities. Subsequently, this will have a concrete and positive impact on subscriber experience and improve the efficiency of the optimization teams.

“A high-speed train is a very complex environment due to the high speed at which customers are moving. Before, we were mainly using drive tests to optimize network conditions along the railway, but now, with Astellia [now part of EXFO], we’ve adopted a new and very innovative approach that manages to filter out the people that are actually on the train. The optimization of high-speed train routes is particularly important for business travelers who need to stay connected at all times. 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



Increase network optimization efficiency

Operators face difficulties in optimizing areas where traffic profiles are diverse (i.e., static vs. mobile, indoor vs. outdoor, etc.) because existing OSS tools do not allow them to split KPIs. By using geolocation maps with advanced filtering capabilities, operators can propose specific actions aimed at optimizing 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. They are not adapted to indoor or pedestrians areas.
- Drive tests only provide quality of service snapshots at a certain moment in time.

Geolocation is 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 subscriber 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%** when using geolocation solutions.

Customer care and customer experience management



Enrich customer care analysis

By positioning subscribers' failed calls on a map when they call to complain, customer care agents can better understand subscribers' issues and propose a solution more quickly, not only for the customer with a complaint but also to all the subscribers in that area. Geolocation information increases customer care efficiency by **improving MTTR** and **reducing the costs for reproducing customer issues** with drive tests.



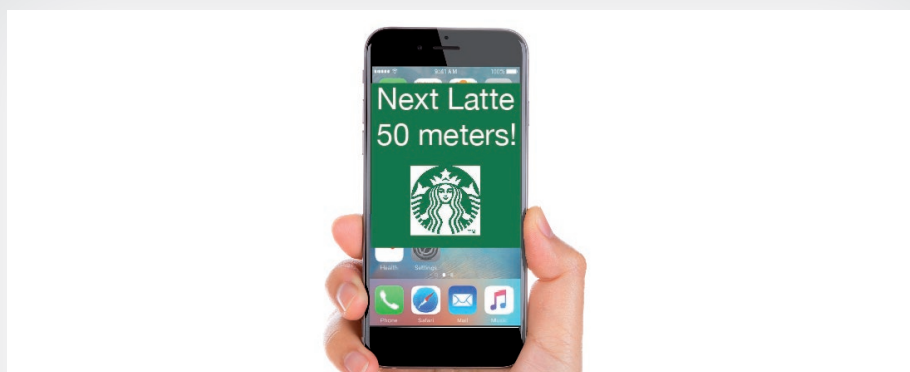
Increase revenues with geo analytics

Each element that provides additional information about the customer provides better knowledge of that customer and hence insights to improve their experience. Valuable subscriber mobility information can be used to **geolocate high-revenue-generating hotspots** (roamers, VoLTE subscribers, fleets, etc.), determine the customer experience at these hotspots and avoid potential loss of revenues due to a poorly functioning network in these areas.

"We have signed a global framework agreement with Astellia [now part of EXFO] to deploy its geolocation-based RAN optimization platform. We will leverage the platform's best-in-class geolocation accuracy to optimize network deployment and increase RAN performance efficiency."

Juan Carlos García
RAN GCTO Director
Telefonica Group

Data monetization



Resell data to verticals

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



Track IOT devices and 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. Being able to provide massive geolocation and mobility of low-cost IoT devices without costly GPS functionality is a clear competitive differentiator.

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

Vicente Abad
RAN Optimization Manager
Telefonica Spain

Nova Geo: The award-winning geolocation solution



The fully virtualized Nova Geo solution supports the most advanced geolocation techniques such as trilateration, fingerprinting and multilateration, thereby 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.



Machine learning algorithms

Nova Geo's classification algorithms distinguish indoor/outdoor, static/mobility calls. Combined with advanced location-aware algorithms, they precisely locate capacity hotspots, coverage holes, pilot pollution and VIP areas to target and **prioritize network operations** such as new site introduction, small cell planning and parameter tuning.



Powerful geo-analytics

Multiple map filtering options let users perform **in-depth analysis based on user-defined geographical areas**. By leveraging EXFO's probing solution, geolocation maps can be enriched with very valuable user plane information such as application usage and video quality.



Advanced troubleshooting

With a simple click, users can **drill down** from userdefined geographical areas to individual call detail records (CDR), thereby benefiting from improved troubleshooting efficiency.



Respect for subscriber privacy

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.



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.) on a 24/7 basis, with coverage ranging from entire countries down to areas of **50 m²**. Nova Geo's advanced solution architecture makes it the fastest available tool for generating maps and making them available through the user interface.



Geolocation goldmine capitalization

Nova Geo also offers the possibility of exporting geolocation data through a northbound interface (NBI) into operators' big data lake to implement additional use cases on top of the existing ones proposed by the solution.



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**, EXFO's geolocation solution is your best choice for future network evolutions.