Real-World Tests for GNSS Receivers
White Paper

Products:
- R&S®SMBV100A

Cities represent particularly difficult conditions for satellite-based navigation systems as a result of obscuration and multipath propagation. So how does one ensure that a receiver is up to the challenge? This white paper discusses the challenges of GNSS design for real-world conditions and the functionality to look for when selecting GNSS test simulators.

Real World Tests for GNSS Receivers

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April 2013 - Division 1GPP

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1 Real-world tests for GNSS receivers

Location-based services in smartphones and navigation devices can make our lives easier. Modifications to receiver modules for satellite-based navigation systems are making it possible for mobile devices to offer and utilize these services. The faster and more accurately a receiver module can determine its current position, the better the user experience for the customer.
Ideal reception conditions for these systems exist when they have a free line of sight (LOS) to satellites in the transmitting global navigation satellite system (GNSS). It is rare, however, that mobile devices are operated exclusively in open areas. Users rely on their devices to set up services consistently regardless of their location, including built-up areas or even in the urban canyons found in large cities.

Cities represent particularly difficult conditions for satellite-based navigation systems as a result of obscuration and multipath propagation. So how does one ensure that a receiver is up to the challenge? In the past, extensive and costly field tests in various cities were used to verify that a device functioned correctly under difficult conditions.

Increasingly, however, these series of tests are being replaced by record and playback systems. These systems reduce the number of drive tests that are required. Special GNSS simulators equipped with the appropriate functionality are used to test the various influences and to check if the implemented measures are effective.

1.1 What GNSS simulators should be capable of

Ideally, it should be possible to use a GNSS simulator to perform the various tests that crop up during the development process. Modern navigation systems support both the GPS and the Glonass standard. Therefore, a GNSS simulator solution should allow up to 24 satellites for hybrid constellations. This corresponds to the maximum number of satellites from both systems that are visible above the horizon at any given time. As a result, the simulator should provide the maximum number of satellites for a receive signal anywhere in the world.

For many standard tests, such as time to first fix (TTFF), location accuracy or stability under interference, the GNSS simulator must generate a signal that is equivalent to what would be received by the receiver at a specific location. A realtime simulator is very helpful in eliminating the need for continual manual changes to the configuration. The realtime simulator must independently adapt test signals so that they simulate the satellite constellation in orbit at the specified time. This mode represents ideal signals, without obscuration or other effects. An expansion makes it possible to simulate a moving receiver with data such as might be received by a GPS receiver in a moving automobile. And last but not least, the test scenario should also support tropospheric and ionospheric propagation effects to provide a complete simulation of real-world situations. The foremost models are the STANAG model for tropospheric effects and the Klobuchar model for effects in the ionosphere.

1.2 Real-world scenarios with lines of sight and obscuration

In urban areas, GNSS receivers seldom receive their signals directly. Signals typically undergo changes as a result of effects, such as obscuration or multipath propagation. A true simulation of the characteristics of a GNSS receiver in an urban enviroment requires that these effects be simulated as realistically as possible.

Obscuration can result from buildings, trees, vehicles or other objects. Simulation of complete obscuration without reflection is achieved by using an elevation and azimuth filter for all satellites across the entire GNSS signal. The characteristics of the filter are determined by the geometric characteristics of the environment being simulated. The simulation must determine the angle of arrival and positioning of every satellite in relation to the receiver separately and then adjust them to the objects around the receiver that are causing obscuration.

Because satellites are moving along their orbits, this adjustment must be carried out continuously. Greater update rates (including the calculation of obscuration) ensure more realistic generated signals for the receiver. An update rate of 1 Hz is usually sufficient to simulate this effect because the change in the angle of arrival for the satellites is significantly less than one degree per minute.

The obscuration filter for a static receiver can be calculated unambiguously by taking all effects around the simulated location into consideration. The simulator generates the objects in a circle around the receiver and overlays this filter with the angles of arrival for the satellites.

The situation becomes more complex when simulating a moving receiver. The objects and the resulting filters are continuously changing. Ideally, the process would be the same as for a static receiver, but since the receiver is moving, the filter must be continuously adapted. This process is often simplified by using only the objects to the right and to the left of the direction of movement when simulating obscuration for a moving receiver.

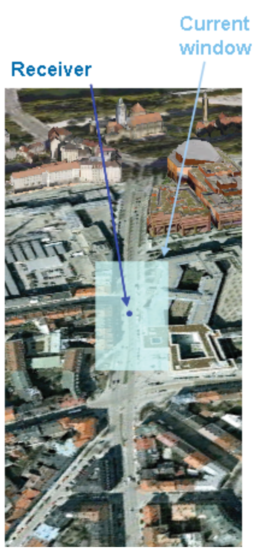

Figure 1: Residential street with overlaid filter

1.2 Real-world scenarios with lines of sight and obscuration (cont.)

The update rate in the GNSS simulator is an important factor in obtaining a realistic simulation of these effects. While an update rate of greater than 1 Hz is sufficient for a static receiver, in the case of a moving receiver, the variations in the speed at which the receiver is moving also have to be taken into consideration.

In order to simulate all effects during the simulation, the update rate of the simulator must be greater than the ratio of speed to object length. For example, assuming a maximum speed of 100 meters per second and an update rate of 100 Hz, the effect of an object of at least 1 meter in length can be simulated.

Obscuration is only one of the effects caused by buildings. Another consideration is the multipath propagation of individual satellite signals that results when the signals reflect off of various objects, such as glass or concrete building exteriors. The conditions for the individual signals vary greatly because each signal follows a different path. Four different scenarios are possible:

- Complete obscuration
- Direct signal (ideal signal) only
- Multipath propagation with a direct signal
- Multipath propagation without a direct signal

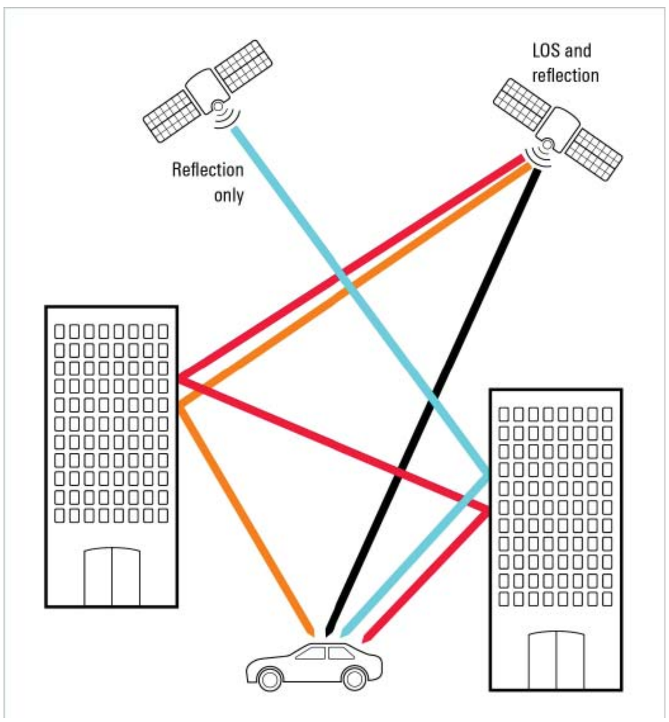

Figure 2: Multipath propagation with buildings

1.3 Many paths – one destination

Multipath propagation can differ significantly depending on the simulated environment. The type of reflective material determines the phase offset and the loss in level that are caused by the reflection. As a result, the simulation must take the different characteristics of concrete and glass building materials into consideration. Studies have shown that the number of paths to be considered depends on three criteria:

- The relative reception strength of a path at the receiver as compared to the direct (LOS) signal, or as compared to a path with an only slightly attenuated maximum strength. In this scenario, the signal must be considered because the resulting distortion is noticeable.

- If multiple signals, including the LOS signal, arrive from a satellite at the receiver with different strengths, the signals that were reflected multiple times will display the greater loss (typically more than 15 dB). These cause only a negligible distortion of the signal and therefore do not need to be simulated.

- When signals undergo multiple reflections, their delay as compared to the LOS signal can be significant enough that cross-correlation and tracking will cause the signals to be disregarded by the receiver. These can therefore also be ignored during the simulation.

The challenge for the receiver is to distinguish between a direct signal and any delayed reflections. Ground reflection can be ignored in this context because, assuming a height of about 1.5 meters and a path of 3 meters, the offset falls below the level of accuracy for a commercial GNSS receiver. When all three criteria are applied, of the large number of multipath signals that might reach the receiver, only a few are actually "seen" by it. Only those few need to be included in a simulation.

During the test, the multipath propagation effect must be simulated for both static and moving receivers. The multipath propagation can be simulated automatically in the GNSS simulator by defining objects for obscuration as well as the characteristics for any surfaces. All necessary data (satellite orbits from almanacs as well as ephemerids, location, time and object geometry) are stored in the simulator.

However, the signal quality is affected not only by the location of the signal transmit source, but also by the location of the receiver. Antennas provide a good example. The location of an antenna for the GNSS receiver can result in an additional effect to be considered. For example, if the receiver is in a smartphone or a mobile navigation device being used in a car, obscuration caused by the metallic body of the car must be taken into consideration. Because the result is an additional filter defining obscuration or a phase offset for signals from different angles, it is better known as an antenna pattern. These effects must also be included in the simulation.

1.4 Special Scenarios: Aerospace & Defense

A completely different special situation arises when using GNSS receivers in military applications. In the case of aerospace applications, the number of satellites being received is not reduced by obscuration, nor is there any need to include reflections from buildings or other objects in the calculation. However, because the receivers are operated at varying heights, ground reflection must be included in the study as long as the time delay for GPS is not greater than 2 chips. A variety of models for the specific ground conditions must considered. A distinction is made between water, dry ground and wet ground.

The way that the antenna is mounted also plays a role in the reception and simulation of GNSS receivers in military applications. If the antenna is mounted so that it sees in only one direction (at the top of an airplane, for example), the ground reflection effect is virtually eliminated. Depending on the position of the airplane during turn maneuvers, some obscuration can result because the airplane itself blocks individual segments of the sky. To simulate this effect, both the roll of the aircraft and the flight path must be defined so that the GNSS simulator can add the effect automatically to the antenna pattern filter.

This scenario can also be extended to missiles by modeling the effect of a continuously rolling missile in the simulation. Typically, the GNSS unit on a missile has multiple, evenly distributed antennas so that several satellites are visible at any given time. This ensures that the position can always be accurately determined. The missile spin can be defined through AM tracking. For a realistic simulation, the individual variations in reception strength must be simulated in the GNSS simulator for every satellite signal. This is because each satellite's angle of arrival at each antenna will change as the missile spins.

Summary

A GNSS simulator must offer significantly more functionality than simply simulating signals from multiple satellites. When testing whether a GNSS simulator will function correctly in real-world applications – beyond simple simulation of satellite signals – a wide variety of effects resulting from propagation effects in particular must be simulated for both static and moving receivers. This is made possible by precise calculation models and an extensive database.

GNSS simulator characteristics in the R&S®SMBV100A

- Multimode GNSS simulator, with support for GPS, Glonass and Galileo, including hybrid mode
- Support for military P code in GPS signal for up to 12 satellites
- Simulation of up to 24 satellites simultaneously
- Up to 24 channels used for satellites or multipaths
- Simulation of tropospheric and ionospheric effects
- Simulation of obscuration for static and moving receivers
- Automatic calculation of multipath propagation resulting from direct reflections based on the object definitions
- Simulation of antenna patterns
- Simulation of missile spinning
- Update rate of the signal in the GNSS simulator: 100 Hz, spinning effect is simulated at a significantly greater rate: >2 kHz
- Complete vector signal generator with support for all key digital standards, including LTE, Bluetooth® and WLAN, as well as radio standards such as HD Radio™

Figure 3: R&S®SMBV100A GNSS Simulator

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