Qualification of satellite-based localization systems for railway safety-related applications

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Abstract

GNSS plays a promising role for providing continuous as well as safety- and liability-critical localization of trains in safe train control systems. Therefore, an evaluation of the GNSS measurement quality becomes necessary for the safety acceptance of the localization function and further for the localization system. Currently, the railway environment is challenging for GNSS receivers because of the signal propagation route along the transmission path, such as multiple obstacles along and above the railway track etc. Those environments require a detailed examination to define the necessary characteristics of a train-borne localization unit. For this purpose, a tool chain has been developed to model the environment in an efficient way on the basis of satellite imagery. The developed methodology allows a receiver-independent evaluation of the environment.

Keywords: GNSS; HDOP; environment modeling; integrity; satellite imagery

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1. Introduction

For the realization of safety- and liability-critical applications in automated transport, the quality of GNSS receivers plays a major role for the applicability of localization technology. Especially for railway systems like ETCS (European Train Control System), a GNSS-based (Global Navigation Satellite System) on-board train localization system seems a promising technology for reducing cost, enhancing safety and raising efficiency. Therefore, a safety case and a hazard analysis are vital to approve GNSS technology as part of a safe unit for the train control system, requiring the certification of receiver quality. Currently, the insufficient knowledge about sophisticated railway environments impedes the development of saleable products. That is why the influence of those railway environments on receiver quality has to be investigated. For analysing GNSS receiver quality in the field of railway traffic, a simulation- and test-based three-step qualification approach has been developed. First of all, the most important GNSS performance indicators are identified and adapted to railway requirements. Secondly, to be able to evaluate those indicators, the impact of the railway environment has to be investigated by modelling its properties. The 3D models of significant environment scenarios are built on the basis of satellite imagery. The last step consists of performing MATLAB simulations and analysing the modelled environments with regard to different GNSS performance indicators, showing the feasibility of the proposed procedure. The procedure is presented by means of two scenarios in a typical railway environment.

2. Deployment of GNSS for safety-related rail applications

In the aviation domain, GNSS technology has been used for safety guidance in *en route* and *landing* manoeuvres for decades. This observation even holds true for safety-related operations (e.g. approach operations with vertical guidance). The reason for the frequent GNSS deployment in the aviation domain can be found in the characteristics of the environment, which is GNSS-friendly for a wide range of applications – especially if the object to be localized resides obviously above ground level. In this context, four main GNSS key performance indicators have been established to describe the quality of localization: accuracy, availability, continuity and integrity.

Accuracy is the most fundamental parameter, which is used to determine the general system performance. Being a static parameter (i.e. its influence on the system performance can be verified with certainty when making long-term observations), accuracy can be subdivided into the two characteristics *trueness* (conformance of the mean measurement value and the true value) and *precision* (scattering/variance). Apart from that, availability describes the percentage of time that a certain function is working with an asserted quality. Depending on the application, different definitions are commonly used (e.g. localization availability, integrity availability). Again, availability is a static parameter. Furthermore, there are certain applications that require *a minimum time span* of localization with specified quality. Therefore, the continuity parameter describes the probability that the specified localization quality will be delivered for a certain time span without interruption. Finally, the integrity function provides a means to evaluate and to assert the trustworthiness of the localization function. It is a diagnostic online tool that is able to find erroneous measurement values and to warn the user within a specified amount of time. Integrity is the parameter that is most difficult to understand, especially in comparison with accuracy. Whereas accuracy is a static system design parameter that may tolerate non-Gaussian outliers (see Spiegel et al. 2016), integrity provides an online monitoring that both complements and compensates for the insufficient accuracy-related assumptions (see Cosmen-Schortmann et al. 2008). Although the four key performance indicators are strongly interdependent (e.g. low accuracy cannot be compensated by a stronger integrity criterion, since availability characteristics would suffer), integrity is the parameter with the strongest link to safety (Lu 2014, pp. 102-104).

In the railway domain, dependability properties are described by RAMS parameters (Reliability, Availability, Maintainability and Safety), which can be translated to the GNSS performance indicators (see Lu 2014, p. 104). In this paper, only availability and safety are discussed, as the availability definition in both the GNSS and in the railway domain can be regarded as approximately comparable. In addition, the safety requirements can be fulfilled by the aforementioned integrity criterion. Although there are several approaches to accomplish the safety requirements (e.g. redundant system design with voting scheme, cf. Lu 2014, pp. 147-148; cf. Filip 2015), this paper acts on the assumption that classical RAIM (Receiver Autonomous Independent Monitoring) approaches are of interest. These have in common that integrity parameters are calculated autonomously by the receiver itself, namely based on a consistency check of redundant GNSS signal measurements. Therefore, the receiver needs at least five different GNSS signals at the same time (Conley et al. 2006, p. 347). If a more sophisticated integrity algorithm, e.g. FDE (Fault Detection and Exclusion) is to be deployed, at least six different GNSS signals are needed (ibid.).

In the case of FDE, redundancy is used to exclude at least one measured signal, which the algorithm considers the worst.

If new technology for safety-related localization is introduced to the railway domain, this technology has to fulfil the specified RAMS requirements. This is especially the case for a GNSS-based on-board train localization system that is designed to meet the specification of ETCS. Before being allowed to deploy safety-related signalling technology, a regulatory approval process has to be passed. This process comprises both a safety case and a hazard analysis, showing that the hazard rate (equal to the event that an unacceptably high GNSS measurement deviation is not detected by the integrity routine) is doubtlessly below the Tolerable Hazard Rate (THR). In preparation of that, the dedicated receiver should be developed and certified for its intended use in the railway environment in order to attenuate safety as well as liability risks. Therefore, one needs to know the vital GNSS properties of railway environments at first. The need for further environment characterisation is emphasised by the current funding of the research project STARS (Satellite Technology for Advanced Railway Signalling), whose main goal comprises the characterisation of railway environments (see Gurnik, P., Stamm, B.; Stamm, B., Gurnik, P.; STARS; STARS 2016). That is why this paper meets the demand for further research by means of the simulative investigation of GNSS quality in railway environments, developing the basis of GNSS environment characterization with the help of a simulation- and test-based three-step qualification approach. This task is especially challenging due to the fact that railway environments significantly differ from the well-known aviation environments, since local effects (e.g. multipath or non-line of sight reception (NLOS) due to obstacles such as foliage, walls, buildings etc.) cannot be neglected in sophisticated railway environments.

In this paper, safety-relevant GNSS train localization is related to railway signalling. At least for the European market, a newly developed GNSS-based train control system shall comply with ETCS. Most current train control systems make use of track-side signalling equipment (e.g. ETCS balises), which is expensive in both acquisition and maintenance. The advantage of GNSS deployment lies in the opportunity to migrate signalling equipment from track to train. As the results of the research project GaLoROI (Galileo Localisation for Railway Operation Innovation) show, in Western Europe up to 4,900 € per track kilometre and year could be saved in comparison to the approximate expenditure of 50.000 € for a train-borne localization unit. That cost structure makes a GNSS-based train control system financially attractive for low-density lines at first sight, but in the long run, even the modification of high-density lines becomes rewarding. The market analysis of GaLoROI shows that Australia, Northern America and Western Europe are the markets with highest interest in GNSS deployment for railway. Not only is it the financial aspect that makes train-borne localization attractive, but this kind of localization is also linked with higher traffic capacity (e.g. leading a facilitation of moving block control, to increased availability, to reduced travelling times and to reduced ticketing prices) and with higher safety (e.g. leading to less train collisions). Apart from that, there is one major challenge for rail transport companies that has to be overcome, consisting of the fact that some responsibilities (e.g. safety) shift form the infrastructure manager to the railway operator. Finally, it must be clarified that there already are several GNSS-based train control and operation systems, e.g. KLUB-U in Russia. But the deployment of those current systems seems much less sophisticated since none of them makes use of certifiable safe positioning data. (GaLoROI 2014; Manz et al. 2015).

3. Methodology of modelling the environment

The quality testing of GNSS receivers, which is required for the deployment of GNSS in safety-related railway applications, is a particular challenge. First of all, a suitable test strategy has to be found. In general, there are two methods of receiver testing. One method is to perform field tests by using real live-sky signals. This method has the advantage that it enables a receiver test under real test conditions. But this has a number of disadvantages. Since the evaluation of the pseudorange signals in GNSS receivers is based on stochastic behaviour, each new measurement or new test run delivers different results (Spiegel et al. 2016). In order to be able to produce meaningful results, a large number of test runs are therefore required, which would lead to an immense effort. One further challenge is that due to weather influences and different test times, constant test conditions cannot be guaranteed (Spirent pp. 24-50).

Another possibility of analysing the behaviour of GNSS receivers under certain conditions is the investigation by using GNSS simulators. Those GNSS simulators use the test time and the desired route trajectories as input data, generate the pseudorange signals in consideration of potential error influences and send them directly or via an antenna interface to the receiver under test. Such a test environment makes it possible to carry out a variety of measurements under the same test conditions. In this way, the potential sources of deviations such as satellite orbit errors, atmospheric impacts or interferences from external sources and others can be excluded explicitly. The actual aim is to investigate how individual receivers perform under certain location-specific conditions and thus,

creating a way of a receiver classification. This means specifically finding out how a receiver behaves under certain local conditions, such as reduced satellite availability or NLOS influences. Those local influences have their origin in the deflections or reflections of the radio waves emitted by the satellites. In order to model those influences, surrounding objects, which are suspected of influencing the view between a receiver and the satellite, must be identified. Subsequently, the elevation angle must be determined for the satellites in sight as well as the current receiver position. With this information, it is now possible to make a statement about the availability and possible influences by signal reflections at a certain position and a certain point of time. Jakob Jakobsen developed a tool called QualiSim to carry out this calculation. ''This simulator [developed with the MathWorks software environment MATLAB] can be used to perform simulations of GNSS signal reflections from buildings surrounding an antenna and their impacts in the position domain'' (Jakobsen et al. 2013, p. 8).

The results of the simulation can be evaluated in order to examine and understand the influences of specific environments on the performance of GNSS in traffic applications. In addition, the data can be used to support a simulation with GNSS test equipment and to create a most realistic test environment. In order to carry out the QualiSim simulation, an environmental model of the route has to be modeled at first. The 3D modeling, especially of urban as well as of rural areas, plays an important role in various applications. A very accurate but elaborate method was developed by the internet company Google Inc. in collaboration with the Stanford University in the project *City-Block*, which has later become known as *Google Street View*. The approach is to create position-dependent images with different camera and laser systems and merging all data to a 3D model. On the one hand, the image data generated offers the possibility of creating an accurate 3D model. On the other hand, this method leads to a very high effort regarding the software and the runs to record the images. (Anguelov et al. 2010).

Another method is based on the recording of 45 degree aerial photographs (Orford 2008; Wilson 2010). This technique is also used by Google to give the users of its platform *Google Maps* the opportunity to use *45° Imagery* of selected cities (ibid.). With this technique, many 3D models of especially urban regions have already been built (ibid.). Although this method has some flaws in detail, it still offers a good model of the recorded regions (ibid.). The models were also embedded into Google Earth and can be viewed from different perspectives. However, both platforms Google Maps and Google Earth do not provide the ability to export the 3D models as files, which is why the models are only suitable for determining the dimensions of surrounding route objects. The investigation of different environments in this work was primarily carried out with the software Google Earth. Especially in the evaluation of surrounding route objects, such as buildings in extensively urban sections, the regularly updated satellite images of Google Earth are of great value. In addition, Google Earth provides complete information about the given topography of an environment which allows a good analysis of the altitude differences as well as mountainous structures and provides a good basis for modeling the route environment later on. However, it is difficult to make out the accuracy of the topographical data. The same issue applies for all information about the used maps. Nonetheless, it can be assumed that it only varies between the typical GPS accuracies of a few meters.

After analyzing the environment of interest, a suitable 3D model has to be created. For that, the software SketchUp from Trimble was used. Initially, SketchUp is also a development of Google and contains a direct interface to Google Earth, offering the possibility of loading satellite imagery directly via the menu item *Add Geo-Location*. A great benefit of this is that distances between individual route positions and objects nearby can later be determined with high accuracy. For the modeling of buildings, SketchUp offers several standard geometries. It is also possible to import the topography of the loaded *Geo-Location* from Google Earth by using the option *Toggle Terrain* and to display the loaded map as a 3D environment. Various landmarks can later be used to precisely imitate and evaluate the topographical environmental conditions. The modelling of the environmental topography (height, terrain etc.) shall not be further considered herein. This kind of environment modelling and its influences to GNSS signals were evaluated in Dodinoiu (2017). The results showed that mountainous landscapes are not as critical as urban scenarios (ibid.), which is why this paper will focus more on the letter.

When creating models by using SketchUp, one particular advantage is the option to export the data as *.kmz-file. The unpacking of the *.kmz file creates a *.dae-file, which contains all information about the modeled objects and can be evaluated with regard to the modeled building geometries and positions. For the evaluation of the *.dae-files, the software MATLAB from MathWorks has been used. A written MATLAB script reads out the *.dae-files and searches for specific geometries, such as rectangles, cubes, circles, cylinders or lines marking mountain tops. Due to the simplicity of the *.dae-files and the given geometric structures, the comparative examples discussed above were limited to quite simple geometries. In the case of more complex building models, it is hardly possible to examine them for their position and building structure in detail. In addition, the position data of the examined objects cannot be taken directly from the *.dae-file, but must be transformed into a coordinate system with cartesian differences after the readout. The conversion was carried out by placing three reference points in SketchUp, with known positions of the x, y and z coordinates. By using the coordinates of the three known points, it is possible

to create the two matrices X_{sketch} (with the information about the internal SketchUp coordinates of the reference points) and X_{car} (including the information about the Cartesian coordinates of the reference points). Now, the transformation matrix M_T can be calculatet by solving the equation system $M_T \cdot X_{car} = X_{sketch}$. With help of the transformation matrix, it is now easily possible to convert all points of the coordinate system used in SketchUp into a coordinate system with Cartesian dimensions.

After reading out the *.dae-file, all buildings that have been found will be saved to a *.mat-file with the information about the building geometries and positions. Now, this *.mat is loadable by using QualiSim as a new environment and can be analysed. Like mentioned above, QualiSim provides the opportunity to make a calculation for the elevation angle between different receiver positions and the potential satellites in view, for different times. In this way, QualiSim calculates the satellite availability and the HDOP (horizontal dilution of precision) by evaluating the elevation masks. In addition, with the information about the availability it is possible to make a consideration regarding the feasibility of safeguarding trains using a RAIM approach at a single location.

As a next step, it would be possible to use that information to make a most realistic receiver simulation by using GNSS simulators. One example is the solution provided by the company Spirent. With the software package SimGen, it is possible to set up a virtual receiver test based on a motion file in that a user defines vehicle motions. In addition, there is now the opportunity to add user information about satellite shielding or influences from signal reflections to carry out a more realistic receiver test scenario. Table 1 gives an overview of the used software tools and how a receiver simulation for different locations can be carried out. As mentioned above, it is the first step to choose a railway location in which the environment shall be analysed. Therefore it is necessary to provide the position data of the receiver antenna motion. Now, it is possible to create a 3D model of the environment by adopting the method described above. Furthermore, to set up a QualiSim simulation, it is necessary at least to provide information about the clock time and the information about the satellite constellation. The second column gives an overview about the tools used to gather the aforementioned information. The next two columns show which tools are used to perform the actual simulations and which results can be obtained. In the last column, there is an outlook showing how the achieved results could be used for further research.

Table 1: Overview - process of simulation and outlook

simulation data	data source/ editing tool	data evaluation/ simulation	results	receiver test/ result studies
position data/ vehicle motion (e.g. NMEA file or KML file)	from measurement: using reference receiver, from digital map: Google Earth/Maps, Open Street Maps, etc.	MATLAB: getting buildings coordinates from 3D model, QualiSim simulation: analysing environmental influences	availability, HDOP	Spirent SimGen: generating the pseudorange signals using the results of QualiSim simulation integrity availability
environment model (3D model)	Google Earth: investigating the environment, Trimble SketchUp: building 3D models of the environment			
clock time, atmospheric information, satellite constellation, signal types (e.g. GPS L1)	NMEA file: includes vehicle position and time, RINEX file from IGS Network: includes satellite constellation, atm file default from SimGen: includes information about the atmospheric conditions			

4. Application of the methodology

As mentioned above, urban scenarios were discovered as the most critical scenarios. For this reason, the aim was to find environments with both typical railway-related challenges and urban surroundings. Two scenarios were chosen and thus two different cases for typical railway applications. The selection was made after evaluating potential environments by using satellite images from Google Earth. The first environment shows a train station scenario with urban surroundings (see figure 1 a). In this scenario, the train has to pass the partly sheltered platforms of the station, which should have a significant influence on the GPS signals. Furthermore, there are some high buildings in the surrounding of the track, the influences of which shall be investigated. The second scenario was chosen to evaluate the possible influences of overhead lines. Apart from that, a bridge under-crossing is investigated in this scenario (see figure 2 a). Since both scenarios are based on real environments, they build typical challenges for the railway sector in the area of Northern Germany. One deliberation was to pick a tunnel scenario as well, but very soon it became clear that such a scenario will not deliver meaningful results by implementing a

QualiSim simulation. Clearly, there will not be any signal after entering the tunnel and consequently no influences on objects near the track can be calculated any more. Henceforth the first scenario will be called *'station'* while the second scenario will be called *'bridge'*. After having decided about the scenarios, the satellite images were added to a new SketchUp model. By using the SketchUp modelling tools, all buildings around the railway have been modelled as applicable geometries like rectangles or cuboids to give the possibility of reading out the building coordinates as described in the previous paragraph (see figure 1 b and figure 2 b). Now, after having created the SketchUp models, the developed MATLAB script in this work can be run to find the modelled buildings and to calculate the building positions relative to the coordinate origin that was set in the 3D model. With the help of the SketchUp option *Geo-Location,* the latitude and longitude position of the SketchUp coordinate origin can be obtained. This information has to be added manually to the mentioned MATLAB script. After the MATLAB script was applied, all building information will be saved into a *.mat-file. Subsequently, the created environment is ready to be simulated in the simulation tool QualiSim. After having started QualiSim, a GUI for adding the simulation parameters will be opened. The first step is to add the information about latitude and longitude of the coordinate origin of the developed model. Next, the user has to choose the GNSS type (e.g. GPS) and to load the navigation file. The RINEX navigation file can be downloaded from *IGS Network*. This file includes the information of the satellite positions for a specific range of time. To add the created environment, the environment *.mat-file can be loaded by the field *Select environment.*

There are two ways to perform a QualiSim simulation, which are called simulation *Over time* and simulation *Along track*. The simulation *Over time* gives the user the possibility to perform the simulation for one single receiver antenna position about a user specified time range. Therefore, the user has to add the simulation start time, the stop time and the delta of the requested time step. As the simulated antenna position, QualiSim will use the origin of the selected environment.
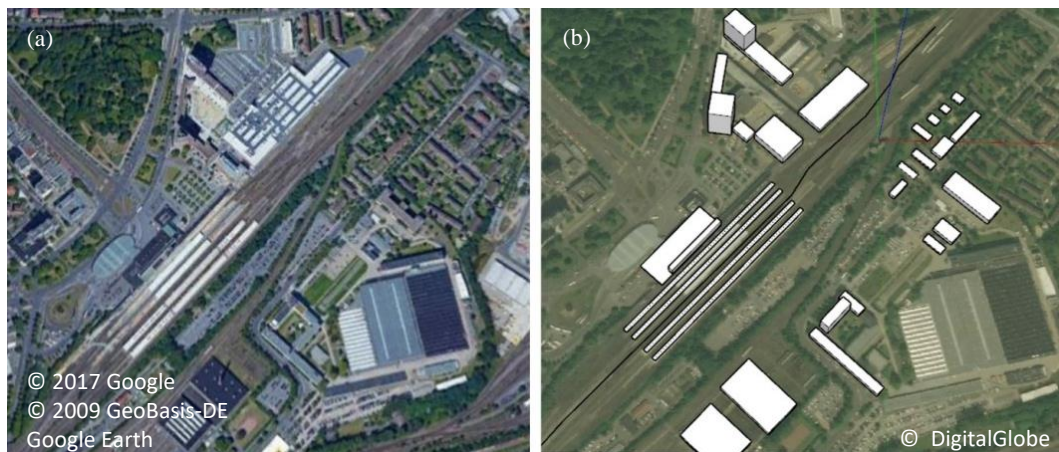

*Fig. 1 Google Earth satellite image (a) and SketchUp model (b) of scenario 'station'*
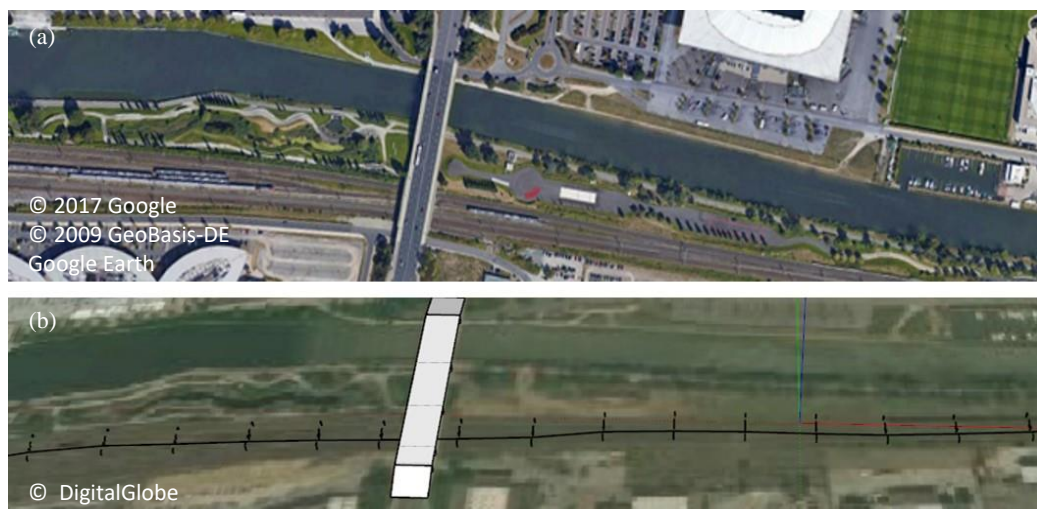
Fig. 2 Google Earth satellite image (a) and SketchUp model of the 'bridge' scenario (b)

The other way is to set up a simulation *Along track*. In this mode, QualiSim will run the simulation for different points on the track, at one defined point in time. The track can be defined by the user, creating a position table, which can be added to the simulation. In this table, the positions have to be defined as x, y and z coordinates, relative to the model origin. The coordinate origin represents the coordinate zero point. The antenna positions in the simulation are set to a height of five meters, taking into account that the antenna is assembled on the roof of a vehicle. Via the position table, the user specifies the number of antenna positions which should be simulated and the distances between them. For the simulations in this paper, the distance between two receiver positions was set to 0.5 m. To get more analysable results, it was decided to create a loop to run an *Over time* simulation for each single position (*Along track*) in the defined track table. The simulation start and stop time were set to achieve one sidereal day (23:56 h) to obtain results for as many constellations as possible. The time delta was set to 20 minutes because after this time, the measurement system kinematic has changed perceptibly (see ISO 17123-8:2015). It is useful to set the time delta as high as possible, because otherwise the simulation run-time becomes very high. The same applies to the position resolution. A small distance between the single position points leads to a more detailed analysis of the simulated environment, but leads to a higher simulation run-time as well. The chosen 0.5 m position resolution constitutes a good compromise. In this context, it needs to be emphasized that the vehicle velocity results from the position resolution. This means that in the case of analysing the environment for different vehicle velocities, the position resolution has to be changed and the velocity is defined by modifying the position resolution. If the velocity remains constant, it will be necessary to ensure that the position delta keeps constant as well. Furthermore, the position delta and the velocity should not be too large, ensuring a more accurate simulation result. Apart from that, another significant parameter is the elevation mask. It was decided to perform a number of simulations for different elevations and to compare the simulation results. The angle of the elevation mask was varied between 0 and 7.5° with an increment of 2.5°. Like discussed above, the principal objective is to analyse, how different environments influence the satellite signal. To restrict the results to the impacts of different surroundings, the impacts of the tropospheric and the ionospheric as well as the ephemerides inaccuracies are deliberately and completely excluded.

5. Results

The QualiSIM tool not only facilitates the simulation of the environment, but also allows a receiver-independent evaluation of the measurement conditions. For this purpose, three meaningful quantities are chosen: HDOP, number of LOS (line of sight) satellites and relative satellite availability.
The HDOP is a variant of the dilution of precision (DOP) and provides the information of the impact on the possible positioning quality in the horizontal direction caused by the satellite constellation. If the constellation is weak and so the satellite vehicles (SV) are near to each other, this circumstance causes a high HDOP value, indicating a poor positioning quality. If the satellites are far apart from each other, the constellation is strong and the HDOP value is low, below one. This enables theoretically a good positioning quality without the consideration of further interfering influences. (GPS NAVSTAR 2008).

The second chosen quantity is the number of LOS satellites. This number shows how many satellites can be used for the position calculation or for the integrity algorithms without any disturbances by shadowing effects. The results can be classified as a conservative estimation, since multipath is not considered in the simulation (the influence of multipath reception on both position and integrity calculation would be complicated).
To compare the number of used LOS satellites to the number of theoretically usable satellite signals, the relative satellite availability is chosen. This value provides, contrary to the key performance indicator availability (cf. chapter 2), the ratio between the number of LOS satellites to the number of theoretical satellites in view without any surroundings, thus making a first step towards the investigation of the safety-relevant GNSS performance indicators.

The receiver-independent results of the QualiSIM simulation are presented for the scenario 'bridge'. Fig. 3 shows the mean HDOP (a) and the maximum HDOP (b) of this scenario, dependent on different elevation masks. The elevation mask of 7.5° leads to averagely higher HDOP values than the elevation mask of 0° as the first leads to a weaker satellite constellation than the latter. The position of the power poles can be clearly seen in the HDOP peaks. Furthermore, these plots show that the impact of the bridge (approximately between measurement points 2,200 and 2,300) is not heavily greater than the impact of the power poles, due to the short spatial extension of the bridge.
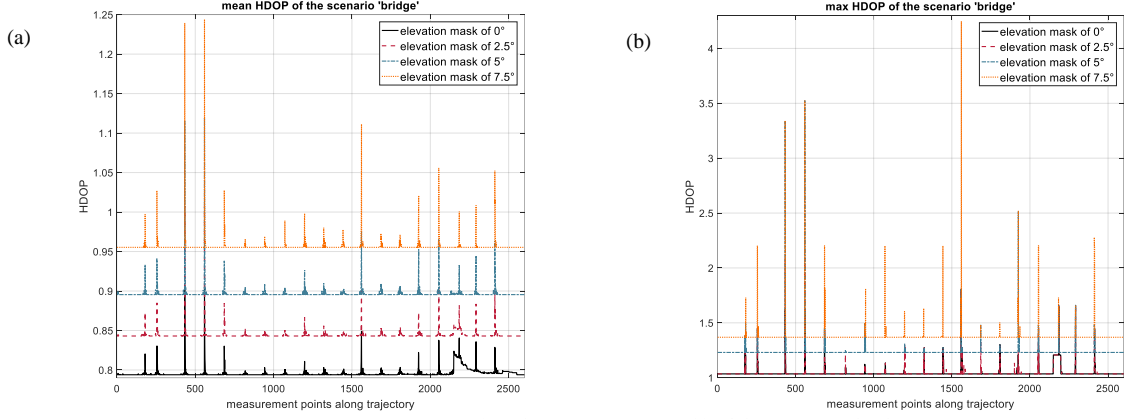
Fig. 3 mean HDOP (a) and maximum HDOP (b) of the scenario 'bridge'

The second Figure (Fig. 4) provides the information of the mean number of LOS satellites (a) and the minimum number of the satellites (b) of the simulation results of the scenario 'bridge'. Also in this visualization, the position of the power poles and the bridge can be clearly seen. Despite the small surface area and the resulting short shadowing by the power poles, the minimum receivable number of satellites is in some parts of the track too small – below six satellites in view – for complex integrity measurements such as FDE. If the short length of the evaluated trajectory is considered, it can be seen that the integrity measurement methods of the aviation domain can hardly be transferred to the rail domain.
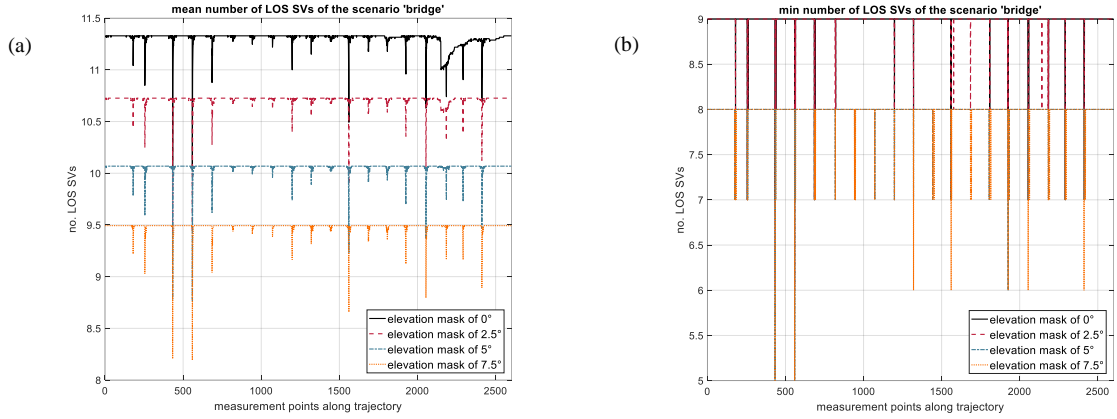
Fig. 4 mean number of LOS SVs (a) and min number of LOS SVs of the scenario 'bridge'

Fig. 5 shows the impact of the surroundings on the relative satellite availability of the scenario 'bridge'. These plots provide the information that the power poles and the bridge in the area of the direct shadowing above the simulated antenna position influence all evaluated scenarios in a similar way, approximately independent of elevation mask size. But there is one clear elevation mask-dependent impact: The bridge has the greatest impact only when simulated with 0° elevation mask.
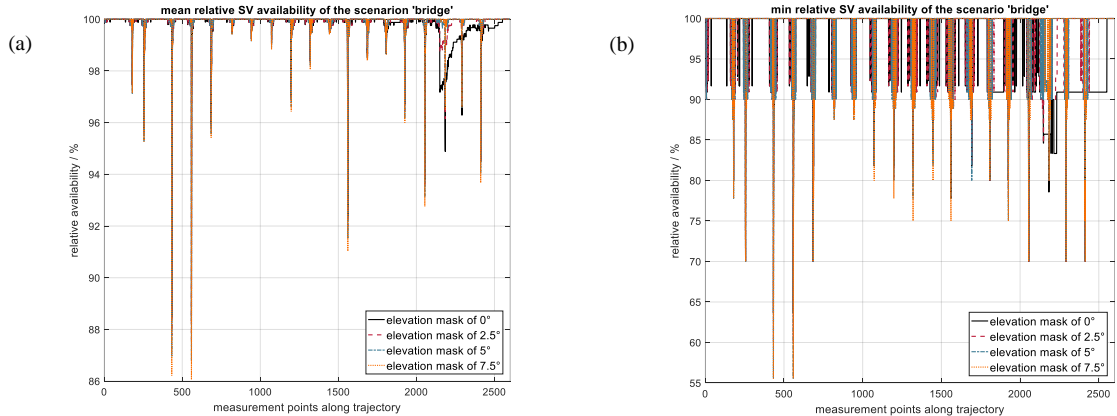

Fig. 5 mean relative SV availability (a) and minimum relative satellite availability of the scenario 'bridge'

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Fig. 6 - Fig. 8 show the simulation results of the scenario 'station'. The urban surroundings only have a small impact on the receivable signal availability, because of the distance to the trajectory and the relatively small height of the buildings (as in this case, the disturbing surroundings are seen with a small angle). The station itself has a higher impact. The track itself has no roofing, but is strongly shadowed by the roof of the departure platform. This impact can be seen between measurement points 1,200 and 1,400 (approx.).
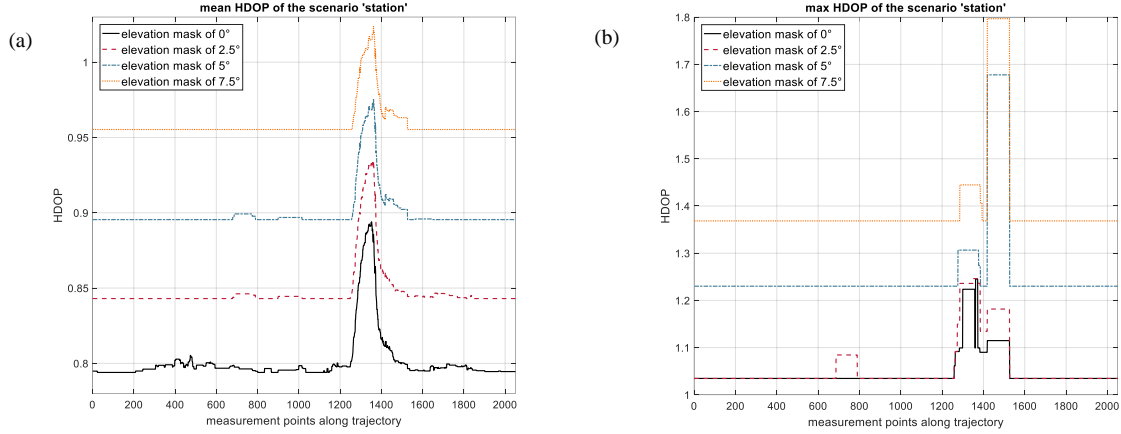
*Fig. 6 mean HDOP (a) and maximum HDOP (b) of the scenario 'station'*
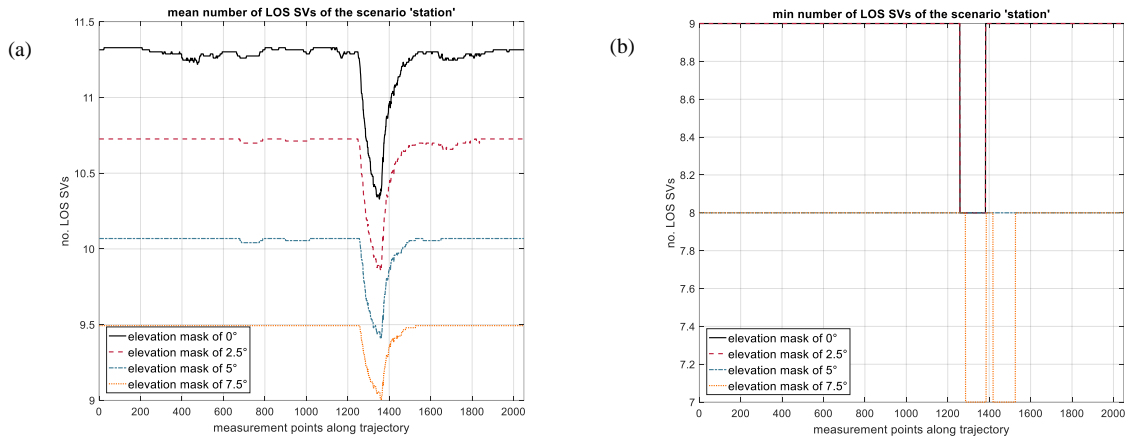
Fig. 7 mean number of LOS SVs (a) and minimum number of LOS SVs of the scenario 'station'
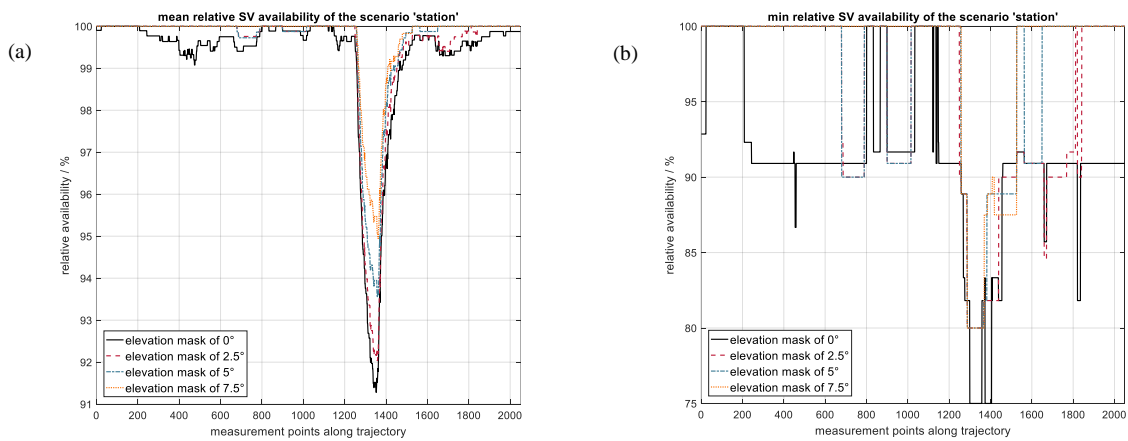

Fig. 8 mean relative SV availability (a) and minimum relative satellite availability of the scenario 'station'

6. Conclusion

The methodology chosen in this paper shows an efficient method to analyse and to characterise the surroundings along a selected trajectory. By simulating the surroundings it is possible to evaluate the impact on the expected receiver-independent position accuracy by analysing the computed HDOP and by multiplying it with the user

equivalent range error (UERE) of a receiver (see Conley, R. et al. 2005). Furthermore, it is possible to get first results of the impact (that the environment has on the GNSS availability) in the specific environment. The number of receivable satellites can be used to evaluate whether it is possible to calculate integrity measures like RAIM or FDE. If not enough satellites are receivable for these calculations (five SVs for RAIM, six for FDE), one solution could consist of deploying more sensors like inertial measurement units or odometry.

The analysis of these performance indicators is crucial for safety critical applications like a train-borne localization unit. Therefore, it is important to evaluate these parameters in an early stage in order to be able to identify the requirements of the localization unit in a railway environment. The simulation can provide this information and thus help to define interesting trajectories and environments which can then be analysed using real receivers in real-world or simulator tests.

In a next step, the information gained from the simulation can be used to perform hardware in the loop tests with a signal simulator. These tests can analyse the different behaviours of different positioning algorithms and other receiver-dependent characteristics like the signal reacquisition time, which will have an impact for instance on the scenario 'bridge' with the many but only short signal losses due to the power poles.

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