The CNI Open Source Satellite Simulator based on OMNeT++

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ABSTRACT

Satellite services (e.g. Internet-over-Satellite or GPS) are getting more and more important in our lives, whereby the operational area is still growing. To guarantee those services, reliable simulation tools are necessary to scale and validate actual and future satellite systems. Therefore, this paper gives an overview about development, functionalities and benefit of a satellite simulation framework which is already available for download, called the Open Source Satellite Simulator (OS^3). The use of OMNeT++ in combination with the INET framework allows the release under public license as well as a platform independent implementation. To provide an accurate and comfortable tool, OS^3 features a Graphical User Interface, live weather data integration, high resolution altitude data, accurate satellite movements, different visualization options, channel modeling and much more. In order to ensure the correctness of simulation results, numerous experimental and simulation tests were conducted.

A comparison between satellite position and movement predictions from OS^3 and the corresponding values provided by a DLR (German Aerospace Center) hosted website proves the accuracy of the satellite movement simulation. The experimental validation was done by comparing simulated channel characteristics with actual measurements. The result is not only a benchmark of the accuracy of the simulation, it also proves the capability of OS^3 to analyze existing or future satellite systems. Additionally, a simulation for VoIP transmission over a satellite link was implemented to show how OS^3 can be applied to specific use cases.

Categories and Subject Descriptors

I.6.5 [**Simulation and Modeling**]: Model Development; C.2.1 [**Network Architecture and Design**]: Wireless Communications

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Keywords

satellite simulation, satellite communication, OMNeT++, open source, voice over ip, simulation framework

1. INTRODUCTION

Thinking of modern satellite technologies like *GPS*, *Galileo*, *Location-based Services* or *Internet-over-Satellite*, it is an obvious fact that satellite systems are getting more and more important in our time, whereby the operational area is still growing.

But, beneath all advantages, satellite services have to face one common objective: the demand to assure a reliable radio link. High costs for prototyping, installation and in-orbit validation are clarifying the necessity of an simulation-based modeling and evaluation process for any given satellite system. This comes along with a reliable and adaptable tool chain for this kind of scientific challenge.

Hence, the focus of this contribution is the development of a platform independent, open source simulator for satellite systems, called the **Open Source Satellite Simulator (OS^3)**, enabling the evaluation of arbitrary system, constellations, applications and scenarios. The actual version of the OS^3 is already available for download[1]. Working with a modular framework also guarantees that the simulator is easily expandable and highly adaptive. To provide an accurate and comfortable tool, OS^3 features a Graphical User Interface (GUI), live weather data, high resolution altitude data, current satellite movement data (so-called *Two Line Elements*), different visualization options, channel modeling and much more allowing even further enhancements through the community later on.

To demonstrate the possible usage and benefit of OS^3, an exemplary use case scenario was implemented and analyzed. Using already performed experimental measurements of a digital voice communication via TETRA (IP-) over satellite [14], a quantitative comparison between real-world and OS^3 results clarifies the gained accuracy.

The rest of paper is organized as follows: Section 2 analyses actual satellite simulators and highlights the differences to the developed ones. Since OS^3 uses up-to-date satellite movements and atmospheric data, Section 3 quantifies possible deviations in using outdated data. Afterwards, Section 4 explains the simulation architecture before Section 5 clarifies qualitatively and quantitatively the gained performance.

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[1] at `http://www-os3.kn.e-technik.tu-dortmund.de/`

Section 6 shows an exemplary use-case implementation and underlines the benefit in using OS^3.

Additionally, the comparison to already known experimental results in Section 6 allows a further validation of the developed framework. At least, Section 7 wraps up the key points in a conclusion.

2. OS^3 COMPARED TO EXISTING SATELLITE SIMULATION FRAMEWORKS

Due to the large variety of proprietary satellite simulators the authors do not intend to enumerate them all. Nevertheless, all of them are limited to a specific scenario or mission type, due to their implementation and/or Closed-Source policy. For clarification, some selected examples will be quoted in the following.

The **Galileo System Simulation Facility (GSSF)** in the ownership of the European Space Agency mainly provides global coverage analysis for the future Galileo navigation system [17]. In contrast to OS^3, it is mainly useful for studies on the Galileo system and is missing flexibility for analyzing other satellite systems and cannot be extended with local considerations.

Other specialized simulators, like the **Multiscale Satellite Simulation Environment (MSSE)** developed in [10], or comparisons between statistical model and satellite simulators in [2] are both focused on the impact of different obstacles on satellite signals and clarifying that a detailed 3D model lead to comparable results to well known statistical channel models. In [5] the simulator is focused on a simulation of satellites flying in formation using GPS. It is optimized for a high relative position accuracy, comparable with the enhanced GNSS vehicle positioning, called **Position-Continuous Differential GNSS (PCD-GNSS)** in [9] and [8]. All of them could achieve a high accuracy, but are again limited to their kind of application.

Concerning comparable open source projects, however, to the best of our knowledge there is no simulator which works independently from the given scenario or from a specific mission type respectively. For example, **Satellite Navigation Radio Channel Signal Simulator (SNACS)** is primarily focusing on GNSS signal generation and signal acquisition [13] and cannot be adjusted for satellite communication aspects. The so-called **Open-Source extensible spacecraft simulation and modeling (Open-SESSAME)** aimed primarily at the simulation of spacecraft dynamics and control [16] and not on the integration of whole protocol stacks or additional functionalities.

Galileo, Iridium and DVB-S2 are just three examples of the large number of systems currently being installed using satellite. Thus, OS^3 is not limited to specific satellite systems but can be employed for arbitrary constellations, making it a powerful tool for any application and/or scenario. In addition, OS^3 is the only open source satellite simulator which uses the OMNeT++ framework, allowing the dynamic integration of already available code up to whole protocol stacks from a large community database.

3. WEB SERVICES FOR UP-TO-DATE ATMOSPHERIC AND SATELLITE DATA

The OS^3 faces, beneath other tasks, the integration of live weather, altitude (height above sea level) and current *TLE* data (set of parameters describing the position of a satellite as a function of time). This is imperative, because the performance of satellite connections highly depend on these characteristics [12].

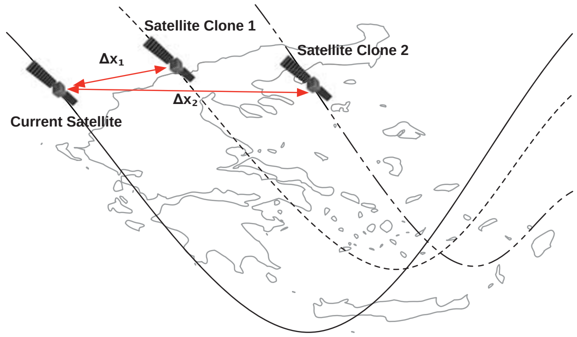


Figure 1: Evaluation-Scenario for analyzing the necessity of TLE actuality

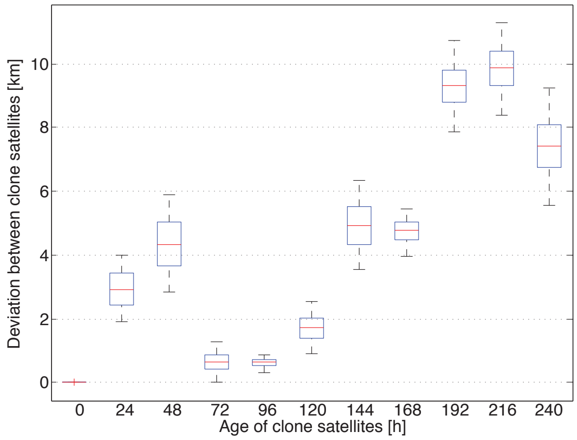


Figure 2: Mean TLE deviation over time for a LEO satellite (*SARSAT-7 (NOAA 15)*)

Just to give an example, Figure 1 visualizes a simulation scenario setup to clarify the importance of up-to-date TLE datasets.

The planar euclidean distance y between one *current satellite*, and different so-called *cloned* satellite Δx_i using older TLEs during the simulation for the same time interval is calculated periodically. Thereby, $y = r_s \cdot \frac{x}{r_e}$ describes the distance between the satellites on their orbit, taken from the subsatellites' distance x on earth surface, whereby r_e is the radius of the earth and r_s is the radius of the satellites' orbit). This results in a mean planar euclidean distance value which characterizes the accuracy of the clone satellites' position.

Figures 2 and 3 visualize the deviation between the satellite movements depending on the age of the TLE data sets for each satellite orbit.

In general, the deviation ($P_{deviation} = |P_{real} - P_{oldTLE}|$) is increasing with decreasing actuality of the TLE data set. The charts show the necessity to use up-to-date TLE data, indicating the positioning deviation described above has also

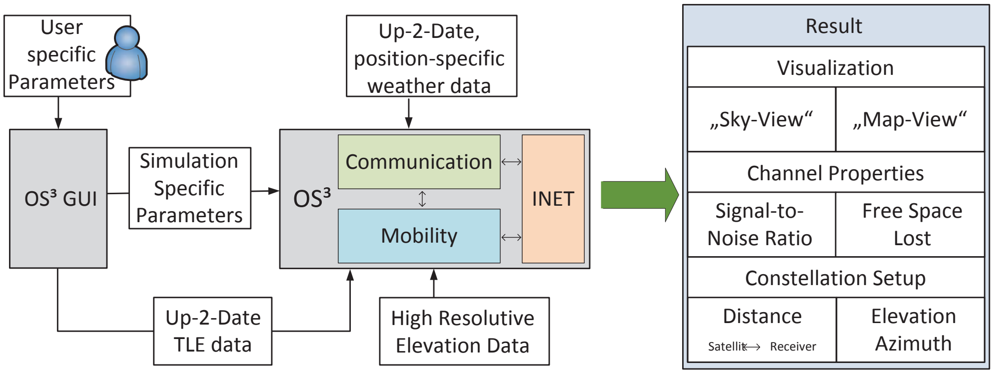


Figure 4: Visualization of the OS^3 simulation architecture

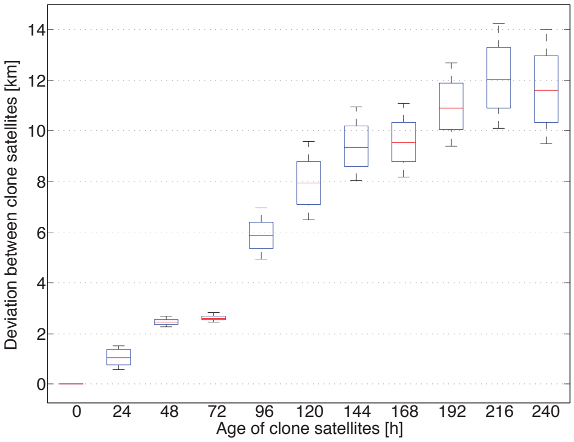


Figure 3: Mean TLE deviation over time for a GEO satellite (*ELEKTRO-L 1*)

individual characteristics which does not fit to any analytic description. This results in a **non predictable deviation** between the position of a current and a cloned satellite. There are multiple reasons for these deviations, e.g. satellite orbit modification by an administrative instance or atmospheric distortions. To solve the problem of keeping TLEs accurate, the simulator can update the TLE data set using web services during the simulations' start-ups.

The same procedure is used for altitude and weather information. The altitude relationships of the given scenario have a direct influence to possible shadowing effects. Hence, OS^3 accesses a global altitude database from the Astagdem project [3] with a resolution of $30m^2$.

In addition, the specific weather conditions within the signal path also affect the performance of satellite links. Formula 1 clarifies those impacts [11].

$$\begin{aligned} \gamma_r &= \alpha \cdot R^b \\ l_e &= \frac{d_R}{\sin(elevation)} \\ \alpha_{rain} &= \gamma_R \cdot l_e \end{aligned} \tag{1}$$

The atmospheric attenuation results from weather phenomena like rain, fog and snow. In general these losses are heavily frequency dependent and also differ with precipitation and shape of raindrops, both included as parameter in the used model. Hereby, γ_R is used as a parameter for the rain density dependent attenuation in $\frac{dB}{km}$, a and b are coefficients describing different raindrop distributions as a function of frequency and R is the precipitation in $\frac{mm}{m^2 \cdot h}$. To calculate the overall attenuation resulting from rain (α_{rain}), the length of the signal path through the rain (l_e) has to be determined, whereby d_R specifies the height of the rain area and clarify the necessity of include those phenomena position-specific.

4. OS^3 - APPROACH, STRUCTURE AND INTERFACE

OS^3 is developed as a modular satellite simulation framework, using adaptable and generally valid assumptions and link budget considerations, which will be explained in detail within this section. In addition, the structure of the simulation framework as well as the developed graphical user interface will be presented.

4.1 Structure of OS^3

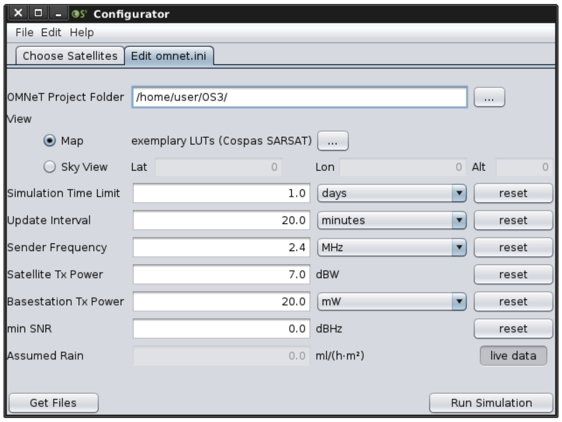
The main objective of OS^3 is to provide an adaptable and modular simulation framework for any simulative satellite signal evaluation process. Hence, structure and class hierarchy are designed respectively. Essential mechanisms are stored in outsourced modules or libraries to prevent inadvertently changes within the basic functionality. In addition, a graphical user interface based on Java is provided to assist the user in the simulation setup process. Figure 4 is visualizing the developed framework.

Concerning to the OS^3-GUI the user may select the satellites and parameters of interest for the whole simulation setup (e.g.: future Galileo constellation, ordinary dipole receiver and heavy rain) like explained in Section 4.2. Afterwards, the appropriate TLE-files are downloaded using the integrated webservice routines and all relevant OMNeT++ files are created automatically. Both data-sets are provided to OS^3, which uses the well-known *SDP4/SGP4* [4] algorithms in combination with the *INETMANET* framework to simulate the satellites movement realistically. The evaluation of the corresponding communication channel is also performed by the OS^3 in every simulation step, including specific connectivity considerations, which will be explained in detail in Section 4.3. The user himself may integrate any functionality within the existing OMNeT++ code he wants to and has full access to the satellites positions and the corresponding signal strength.

The simulated satellite movement, including the users specifications, functionalities and models can be visualized in two different pre-built methods of OS^3. The first one, called the *Sky-View* uses an azimuth/elevation presentation of the satellites movements based on the receivers position. The second visualization is a global *Map-View.* Deposited with a colored world map, every ground station can be included using a geo-referenced transformation into OMNeT++ pixel-coordinates. The satellites are represented according to their *Sub-Satellite-Point (SSP).* Both options providing realistic channel properties and multiple methods to the user, e.g.: calculation of the free-space-lost or the position and situation-specific SNR. Of course, the modular structure of OS^3 supports future extensions.

4.2 Easy Handling using the OS^3 Setup-GUI

To simplify the setup of the simulation a graphical user interface called *OS^3 Configurator* is provided, which assists the user in all configurations tasks. The GUI pursues two primary goals. The first one is to provide a comfortable access to actual TLE data for various satellite systems. Therefore, the GUI allows a selection of full constellations or specific satellites. To keep this efficient despite the high amount of available satellites, the selection is subdivided into three steps: Satellite's mission case (e.g.: *Positioning*, *Communication*, ...) , the respective constellation (e.g.: *GPS*, *Iridium*,..) and then the satellites themselves (e.g.: *GIOVE-A*). After the selection, the interface automatically downloads the corresponding TLE files using web-services.



OMNeT Project Folder /home/user/OS3/

● Map exemplary LUTs (Cospas SARSAT)

○ Sky View Lat 0 Lon 0 Alt 0

Simulation Time Limit 1.0 days

Update Interval 20.0 minutes

Sender Frequency 2.4 MHz

Satellite Tx Power 7.0 dBW

Basestation Tx Power 20.0 mW

min SNR 0.0 dBHz

Assumed Rain 0.0 ml/(h·m²)

Figure 5: Configuration options using the OS^3-GUI

The second goal of the developed GUI is to enable an intuitive handling of the multiple configuration options within OS^3. Figure 5 shows the multiple setting possibilities. The user is able to specify his home directory and the desired visualization (cmp. Section 4.1) with the appropriate setup option for center position of the *Sky-View* perspective. In addition, all physical parameters (like *frequency, transmit power,...*) may also be adjusted. The GUI even supports a manually editing of the *rain value* and an option, to use live weather data for the intersection area for every satellite-receivers connection with the troposphere using web-services.

Table 1: Tabular link budget calculation

	Transmit Power	P_T	dBW
+	Transmit Antenna Gain	G_T	dB
-	Free Space Loss	FSL	dB
-	Atmospheric Loss	L_M	dB
-	Boltzmann constant	k	$\frac{dBWs}{K}$
+	Figure of Merit	$\frac{G_R}{T_S}$	$\frac{dB}{K}$
=	Signal to noise ratio	$\frac{C}{N_0}$	$dBHz$

By using the OS^3 Configurator the *omnetpp.ini* file and the gathered TLE data-sets are created and stored in the denoted working directory. If the project was already built correctly, the simulation may also be started using an graphical option of the interface.

4.3 Satellite to Receiver Connectivity Considerations

Using link budgets to analyze and evaluate the signal quality of a received satellite signal is a well known method within the scientific world to characterize the channel properties of satellite links with the corresponding signal-to-noise ratio ($\frac{C}{N_0}$). To calculate a specific link budget certain aspects have to be taken into account [6]. An exemplary one is shown in Table 1:

Transmitter power and gain as well as receiver antenna characteristics are scenario specific and by that, have to be specified by the user for the given case. The *Free-Space-Lost (FSL)* can be calculated using the well-known Formula 2.

$$FSL = \left(\frac{4\pi d}{\lambda}\right)^2 \tag{2}$$

Using the atmospheric influences, already explained in Section 3, all losses for the given satellite-receiver constellation have been calculated. In addition, the performance of the used receiver equipment has to be considered. Therefore, the so-called *Figure of Merit*, which depends on the noise temperature of the system (T_s) is used. In general, the antenna noise temperature (T_A) is composed of cosmic microwave background, atmospheric and ground temperature. Each temperature is weighted with a certain coefficient depending on atmospheric attenuation and individual antenna characteristic. The antenna noise temperature can be calculated with Formula 3 using the Dissipation Theorem described in [7].

$$T_A = D_G \cdot T_0 + \frac{1}{L_M} \cdot T_B + \left(1 - \frac{1}{L_M}\right) \cdot T_M \tag{3}$$

Hereby, L_M describes the atmospheric attenuation corresponding to the a_{Rain} value transformed to logarithmic unit (dB). D_G equals the part of the antenna's radiation pattern pointing to earth surface (e.g. side lobes).

The system noise temperature can now be calculated by summing up T_A (antenna noise temperature) and T_R (user-specified receiver noise temperature).

5. PERFORMANCE EVALUATION OF OS^3

In order to validate and evaluate the satellite movements and the concerning simulation results, numerous experimental and simulation tests were conducted. First of all a comparison between real-world and simulativly derived satellite

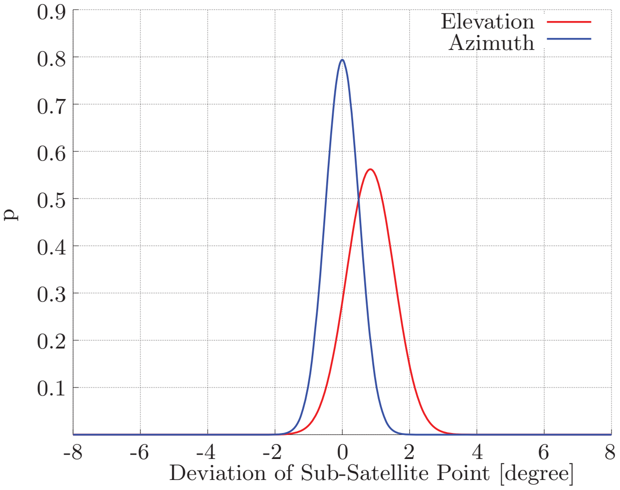


Figure 6: Deviations between OS^3 simulation and data from *Heavens Above*

positions and movement are performed. The corresponding values are provided by the DLR (German Aerospace Center) and used to prove the accuracy of the satellite movement simulation. In addition, an experimental validation was performed by comparing simulated channel characteristics with actual measurements using high-end GPS receiving equipment. The gained results will clarify the accuracy of OS^3 and also prove its capability to analyze existing or future satellite systems.

5.1 Simulative Accuracy Determination

In a first step, public available data from the *German Aerospace Center (DLR)* provided by the internet-service [2] is compared with the corresponding positions of the satellites within the OS^3. Therefore, a special validation target has been added to the simulation framework, which stores the first and last visible point of each satellite pass during the simulated interval with date, time, elevation and azimuth. However, due to unavoidable inaccuracies (at least rounding errors, possibly slightly different orbit data) a direct comparison, i.e., `==` operators, between data from the different sources does not work. The testing code therefore verifies that differences between simulated and downloaded data are within a given range. These tolerances are defined individually for each of the parameters, i.e., time, elevation and azimuth. Another restriction is that “Heavens Above” only provides a low resolution for the azimuth, given as an up to three letter orientation, e.g., “NNE” for North-Northeast. These orientations are transformed into 16 ranges. The simulation values are then compared to the ranges’ upper and lower limits.

Figure 6 shows the distribution of deviations in both azimuth and elevation from 2012-09-15 to 2012-09-21 as probability density function for the *International Space Station (ISS)*. It is obvious that both, elevation and azimuth, are simulated similar compared to used data source. Tests using other time frames have produced similar results, but are subject to the same restrictions. Hence, some further validation scenarios will be explained in the following.

Table 2: Used values for GPS receiver and transmitter modeling

Parameter	Symbol	Value
Transmitter Power	P_T	$13dBW$
Transmitter Gain	G_T	$14dB$
Receiver Gain	G_R	$0dB$
Radiation from Ground	d_G	0.5
Receiver Noise Temperature	T_R	$150K$
Wavelength	λ	$0.1905m$

5.2 Experimental Validation

Due to the existing restrictions of the used comparison data (cmp. Section 5.1), the following paragraph will provide an more detailed insight into the performance of OS^3. As mentioned in Section 4.3, the simulator enables calculations regarding signal attributes on the receiver side, e.g., the $\frac{C}{N_0}$ (Carrier to Interference Ratio) value.

So the approach is, to use GPS in order to collect experimental data for the researches presented. GPS is the most qualified system for the following studies since it provides suitable scenarios which can be modeled efficiently by OS^3.

5.2.1 *Simulation model*

In this study, OS^3 was used to model the actual GPS system within a simulation.Figure 7 left shows the so-called Sky-View representation of the satellites movements within the simulation scenario from the receiver’s point of view. The selected values for the accomplished simulation can be found in Table 2.

Typical antennas, especially for GPS receivers, have individual reception characteristics represented by antenna radiation patterns. Hence OS^3 is developed to simulate a comprehensive variety of satellite systems, radiation patterns have to be implemented by the user himself, but the basic functionalities are already included and documented. Due to the fact, that many GPS phenomena are highly time- and position-specific [9], all have to be included as described in [8]. To enable a validation anyway, the authors assumed an AWGN channel for this scenario setup as a simplification. As a consequence, the $\frac{C}{N_0}_i$ results are stationary for a given satellite/receiver constellation.

To validate the gained results, the range of all simulated $\frac{C}{N_0}_i$ values for the actual full GPS constellation are compared to real measured data using high-end GPS receiving equipment.

5.2.2 *Qualitative Validation of Satellite Orbit Calculation*

Figure 7 shows a qualitative comparison between two snapshots in time, the so-called *Sky-View* of OS^3 and the same visualization to the same point in time using the u-blox evaluation kit (*6T-EVK* [1]). All tracked GPS satellites are marked with red dashed circles in both figures.

Although this is a qualitative consideration, the congruence of both plots is clarifying the proper functioning of OS^3. In the following section, the authors will provide quantitative results to substantiate the mentioned statements.

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[2] at `http://www.heavens-above.com/`

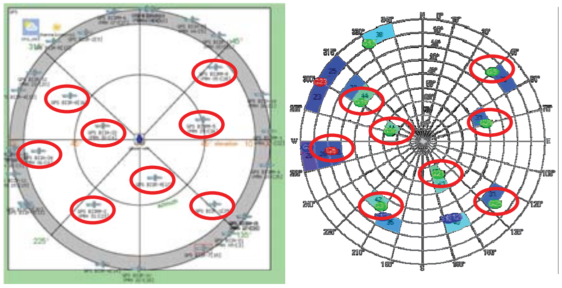


Figure 7: Sky-view of GPS constellation at 51.4923N, 7.4121E 2012-09-05 15:00, concerning OS^3 (left) and u-blox 6 (right)

Table 3: Class-Separation for used experimental comparison

Label	ϵ[deg]	Properties
Pure Line-of-Sight	>20	No buildings will intersect the LOS between receiver and satellite
Transition Range	$10 < x < 20$	Some minor multipath and shadowing effects with slight probability
High Multipath Effects	< 10	High probability for accuring multipath effects

5.2.3 Quantitative Validation of Signal-to-Noise-ratio

Beneath the qualitative comparison explained above, OS^3 also allows the determination of receiving power in $dBHz$ of any transmitted satellite signal to a specific time and at a specific position. Thus, a quantitative validation using measured GPS signal strengths and simulating them for the same circumstances becomes possible.

To measure $\frac{C}{N_0}$ values which can be compared with the calculations done by OS^3 the already mentioned u-blox evaluation kit (6T-EVK) [1] was used. The 6T-EVK includes a GPS antenna (Patch Antenna ANN-MS $25 \times 25mm$), a receiver and the corresponding software, which provides methods for evaluating received signal mixtures, e.g. the output of $\frac{C}{N_0}$ values for every satellite in range.

Nevertheless, measuring the signal strength of satellite signals comes along with some disadvantages. Like shown in [10], satellite signals are highly affected by the direct surrounding, e.g. multipath or shadowing effects, what might reduce the signal strength. Hence, we separate the measured signal strength values in three classes, depending on the **elevation angle** ϵ of the satellite (cmp. Table3).

The tracked $\frac{C}{N_0}$ values over time, separated in the mentioned classes, are depicted in Figure 8. Since OS^3 uses the AWGN channel model without additional position-specific losses, e.g., due to buildings or multipath fading, all simulatively determined $\frac{C}{N_0}$ values might be interpreted as LOS connections.

Using high elevation angles comes along with a low probability of multipath or fading effects, so those values shall be comparable with the actual considerations of OS^3. Any measured signal received under a high elevation angle ($\epsilon > 20°$) obviously fits to the corresponding simulated values of OS^3, visualized as black box at the top of Figure 8. This again substantiate the performance and accuracy of the developed framework.

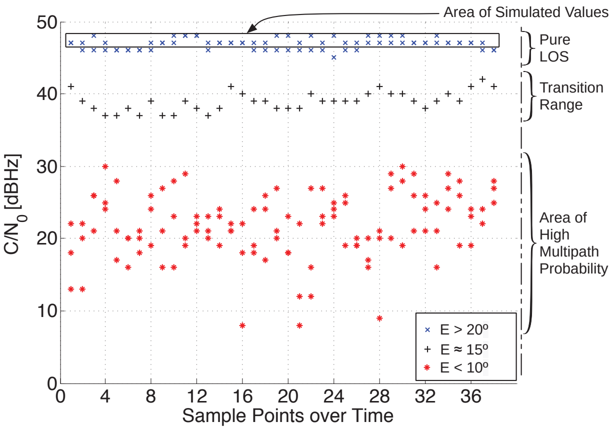


Figure 8: Comparison of simulative and experimental $\frac{C}{N_0}$ values for the actual GPS constellation

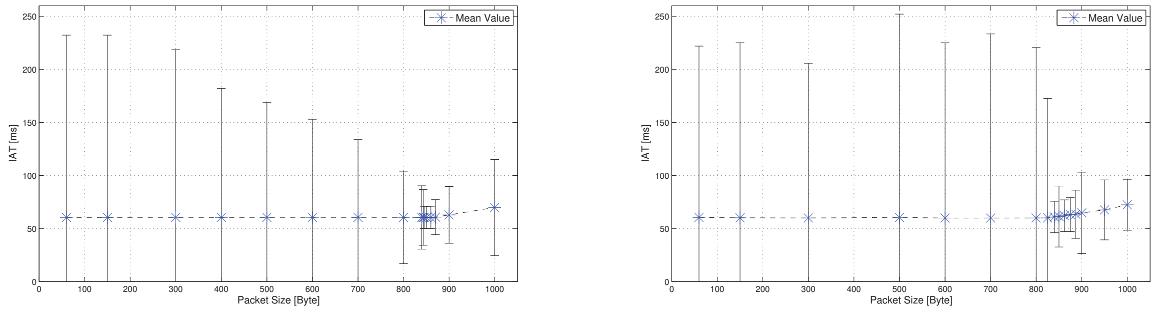
In addition, it is also obvious, that the two remaining elevation classes do not fit with the simulated values. But in those cases, the influence of multipath and shadowing effects is very likely and increasing with minor elevation angle ϵ and by that, the results are not comparable to the gained simulative ones. Nevertheless, they are clarifying the necessity of including position specific consideration within OS^3 using ray tracing for example as a next development step.

In conclusion, it is reasonable to assume that the OS^3 orbit prediction algorithms are implemented correctly and can be therefore used to gain scientific results.

6. USE CASE: VOICE OVER SATELLITE

To introduce an exemplary application using OS^3' features, a voice transmission is used to demonstrate flexibility, performance and benefit of the simulation environment. This use case implementation also offers an additional possibility to validate the results of OS^3 based on prior experimental measurements of the inter arrival time of a voice stream over satellite [14].

The scenario assumes that all terrestrial radio networks are either damaged or at least have no core-network connection, so it is mainly based on classical public safety and disaster relief operations [15]. In such a situation local professional mobile radio (PMR) terminals in the operational area need to be able to be linked with a core network for full communication capabilities. Additionally, specialized base stations could be applied within the scene to provide the full range of PMR services, but they need to be connected to a core network as well. To ensure the connectivity, a satellite link could be utilized. The challenge is, that voice transmissions employed on satellite links are faced with a variety of influences on the transmitted signal itself. Shadowing or diffraction influence the gained performance of the signal. This effect can be quantified using the variance in Inter-Arrival Time (IAT) and a bit error rate (BER). In addition, the internal resource management of the satellite link



(a) Simulated link

(b) Real satellite link

Figure 10: Jitter caused by satellite link [14]

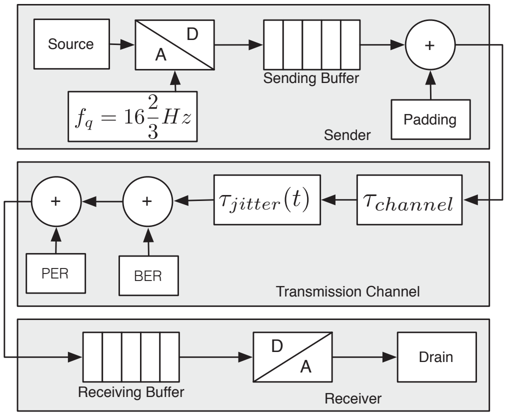


Figure 9: Communication model used in OMNeT++

also influences the transmission quality. Hence, the development of a PMR over satellite service using UDP packets can be seen as a kind of trade-off between QoS and resource management.

The generation and processing of voice packets is implemented within an independent OMNeT++ simulation as depicted in Figure 9 which is coupled with OS^3 to get an estimation of the current SNR. Based on the SNR, the PER is calculated, which can then be used as a key performance indicator for the usability of the satellite link in terms of voice communication. The jitter is assumed as a result of the internal buffering (sending buffer). The idea of the measurement was to increase the packet size to eliminate the negative influence of sending buffers.

The comparison of the simulated results and real world measurements is depicted in Figure 10 and Figure 11. It is obvious, that the simulation shows the same system behavior as the real satellite link. The differences in the deviation in Figure 10 are based on different weather conditions within the real measurement (which was taken in a period greater than one week). To sum it up, the implemented use case clarifies that the simulation's behavior is the same as a real-life system and by that, also the performance, accuracy and adabtablity of OS^3.

7. CONCLUSIONS

OS^3 provides an open source satellite simulator, supporting various existing, future and individual satellite constellations. With the modular structure and the integration within the OMNeT++-framework, the user may easily add own functionalities and/or modules and even has access to a huge bunch of network protocols and calculations using the OMNeT++ community. A developed and provided graphical user interface even supports the user within the simulation setup process. In addition, web services have been integrated to gather current and position specific altitude and weather data during a simulation, as well as up-to-date satellite emphasis at the beginning of the simulation run. Both, the simulator itself as well as the corresponding GUI is already available for download[3] to enable an integration in various scientific objectives within the community.

Beneath a detailed describtion of the OS^3 architecture and its functions, this contribution also proved its validity regarding the satellite movements using a comparison of simulated and measured positions. In addition, a hardware validation for the actual GPS system using an *u-blox* receiver confirmed the correctness and accuracy of both, satellite movement and signal strength calculations of the virtual space vehicles. To clarify the benefit of OS^3, a voice over satellite use case scenario has been implemented. Beneath the proven usability of the developed simulation framework, the gained results of this examplary scenario again validate the implemented features within OS^3, using a comporison to already published expermental measurements for the same setup.

For some use cases and for more adaptability the comprehension of more elaborate antenna patterns or an scenario-specific raytracing analysis for including also multipath effects might be necessary. Their inclusion and provision is one objective for further development.

8. ACKNOWLEDGMENTS

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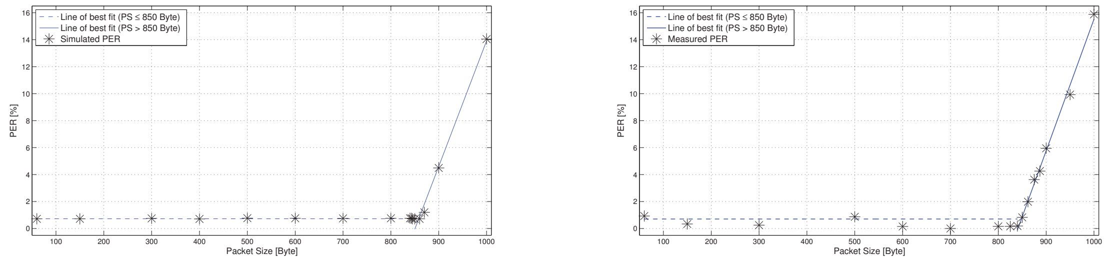
[3] at `http://www-os3.kn.e-technik.tu-dortmund.de/`



(a) Simulated link

(b) Real satellite link

Figure 11: BER on a satellite link [14]

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