Proposal of a Troposphere Model in Simulation for Automotive Applications

Angelo Arieta[1], Mauro Tropea[1] and Danilo Amendola[2]
[1]*Dimes Department, University of Calabria, via P. Bucci 39/c, 87036 Rende (CS), Italy*
[2]*University of Trieste, Piazzale Europa, 1, 34127, Trieste, FVG, Italy*

Keywords: Automotive, Troposphere Model, GNSS Simulator, GPS Receiver.

Abstract: The Global Navigation Satellite System (GNSS) is the standard generic term for satellite navigation systems that provide global coverage and it includes GPS, GLONASS, Galileo and other regional satellite navigational systems. The use of simulator for performing different kinds of test is a practice largely used that provides many advantages in different navigation systems thanks to the possibility of performing tests under controlled and repeatable conditions in a secure laboratory. The use of GPS simulation is largely used for testing GPS receivers. This paper presents a GNSS simulator for automotive applications, in particular the software used is *GPS-SDR-SIM*, an open source simulator written in C language and it proposes a simulator improvement providing the implementation of the Troposphere Collins model in order to improve the accuracy of the simulation experiments.

1 INTRODUCTION

The Global Navigation Satellite System (GNSS) is the standard generic term for satellite navigation systems that provide global coverage. This term includes GPS, GLONASS, Galileo, Beidou and other regional satellite navigational systems (Van Sickle and Dutton, 2014; Groves, 2015).

It is a geo-radiolocation for a terrestrial, marine or air navigation system, which uses a network of artificial satellites in orbit. Thanks to this global coverage, the receivers that are located anywhere on the Earth's surface or on the atmosphere, can determine their geographic coordinates by processing the RF signals transmitted by satellites.

The GNSS network is composed of several constellations. A satellite constellation is a group of satellites used in a coordinated way that they can offer global or partial coverage. Thanks to the trilateration operation, the receiver located on the earth's surface is able to obtain its position, as each satellite continuously sends information regarding the ephemeris (Tsui, 2005).

Ephemeris are information concerning the position of the satellites, the clock (timing) and health (Zhang and Ji, 2015). This information is sent through the navigation message that is transmitted by satellites and in the case of the Global Positioning System (GPS) constellation, it is transmitted in two frequencies which are 1575.42MHz and 1227.6MHz.

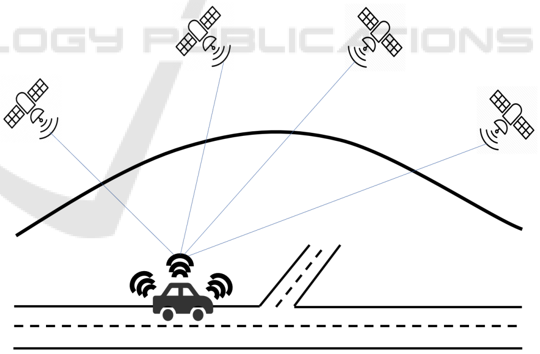


Figure 1: GNSS in a VANET scenario.

Today the GPS is considered an integrated part of the system that composes the Vehicular Ad-Hoc Network (VANET) (Ghori et al., 2018). The vehicles are equipped with GPS receivers and, in the next future, all vehicles will have a GNSS receiver on board (Hasan et al., 2018). The research in the joint use of GNSS and VANET shows a certain convergence toward a common objective: how to improve the GNSS systems exploiting VANETs by GNSS researchers and the use of GPS information to improve Quality of Service (QoS) and scalability by VANET ones. In Figure 1, a typical use case of global po-

Arieta, A., Tropea, M. and Amendola, D.
Proposal of a Troposphere Model in Simulation for Automotive Applications.
DOI: 10.5220/0009970901200127
In *Proceedings of the 10th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2020)*, pages 120-127
ISBN: 978-989-758-444-2

sition system in a VANET environment is shown. The vehicular network aims to improve road safety, traffic and energy efficiency giving also attention to the emission issues (Santamaria et al., 2019), (Fazio et al., 2017). Different works focuses their attention on mechanisms for advising dangerous or emergency situations by exploiting on-board sensors (Santamaria et al., 2018) also using predictive mechanism as in (De Rango et al., 2008), (Fazio et al., 2016), (Frnda et al., 2013). Moreover, very studied aspects for the ad-hoc network are routing issue as it is possible to view in (Zhou et al., 2006), (Fotino et al., 2007), (Socievole et al., 2011), and also for VANET is an important topic as it is possible to view in (De Rango et al., 2009), (Fazio et al., 2013).

Moreover, in the literature a lot of works exist that base their approach on the use of geo-localization data for routing purpose in order to improve the scalability of routing within vehicular networks (Devangavi and Gupta, 2017). Incoming automatic driving applications are going to require even tighter level of precision and security in order to guarantee the high required standard. The aviation sector, the first one to develop GNSS integrity solutions, analysed in a very detailed way many important aspects concerning the use of GNSS accuracy information.

In this paper, the proposal of a Troposphere model for GNSS simulator in automotive field has been presented. The simulator is *GPS-SDR-SIM*, an open source simulator written in *C* language. The proposed module implements the Troposphere Collins model in order to improve the accuracy of the simulation experiments.

The rest of this paper is organized as follows: Section 2 presents the related work on the considered research topic. In Section 3, a description of the GNSS applications in VANET scenario is given. In Section 4, we describe the used simulator considered for developing additional software module.The numerical results are presented in Section 5. Finally, Section 6 concludes the paper.

2 RELATED WORK

The scientific research of last decade has been characterized by a rapid evolution of GNSS software receivers. Since the first GPS Standard Positioning Service, different new systems are arisen able to provide global coverage and, they include GLONASS, Galileo and other regional satellite navigational systems. And, in order to perform different tests about navigation system in a secure and repeatable way, different software and hardware simulators are proposed in the scientific community. In the literature, several works were devoted to architectural and implementation aspects of GNSS simulators.

In (Deng and Wang, 2011) the authors propose a simulation design of digital IF signal based on the mathematical model of digital IF GPS signals. Their have designed a simulator and their experimental results show that the structure of simulated signals is closer to real signals.

The TUTGNSS Reference Receiver is a fully operational GPS I Galileo receiver, developed at Tampere University of Technology for educational purposes (Paakki et al., 2010). It provides a platform for testing and developing new algorithms for GNSS field without ”black boxes”, allowing developers to have full control over its further development.

The GNSS-SDR, an open source Global Navigation Satellite System software-defined receiver is proposed in (Fernandez-Prades et al., 2001). The paper describes the software architecture design and provides details about its implementation, targeting a multiband, multisystem GNSS receiver. The authors have built a testbed for GNSS signal processing able to allow any kind of customization, including interchangeability of signal sources, signal processing algorithms, interoperability with other systems, output formats, and the offering of interfaces to all the intermediate signals, parameters and variables.

An open source implementation of a GNSS software receiver that targets Galileo E1B and E1C signals is discussed in (Fernández-Prades et al., 2012), where the authors provide detailed descriptions of the main signal processing algorithms involved in acquisition and tracking of such navigation signals.

An open source GPS receiver software and laboratory hardware that is a straightforward modification of a COTS receiver to interface it to a PC bus are shown in (Kelley et al., 2002). In the paper, the authors describe the hardware and software architecture, the features added to allow debugging of the code and carrier tracking loops.

3 GNSS APPLICATION IN A VANET SCENARIO

The number of applications that use the Global Navigation Satellite System (GNSS) technology is constantly increasing. Many of these have increasingly stringent requirements so that in some cases it is necessary to integrate GNSS technology with other technologies in order to meet the requirements of a particular application.

To ensure that GNSS technology is forefront and reliable, the design of the various parts of the system, in particular GNSS receivers, must respect high standards and ensure reliable performance. To enable this, it is important that the product development process is based on appropriate tests from the concept to the production.

Traditionally, GNSS testing has been subdivided into following three distinct methods:

- Live sky testing
- Record and Replay methods
- Simulators

Nowadays, the best practices for testing GNSS receivers concern tests performed in a controlled and repeatable manner in a safe laboratory (Paakki and Nurmi, 2014).

This kind of approach allows to test all conditions, including tests performed to the limits of real and theoretical performance. This also allows the development of receivers for GNSS systems currently unavailable or able to operate also with a non-complete constellation.

The aim is to emulate the environment of a GNSS receiver on a dynamic platform by modeling the movement of the vehicle, the satellite, the characteristics of the signal, the atmospheric effects and other, making sure that the receiver actually navigates according to the parameters of the test scenario. Unlike road tests, simulator tests provide full control of simulated satellite signals and simulated environmental conditions. In this way, testers can easily generate and run many different test scenarios for different types of tests, with complete control over all simulation parameters such as date, time position, vehicle movement and environmental conditions.

The performance of a receiver varies on the basis of errors and effects applied to the RF signal. Figure 2 shows a representation of the signal flow through a GNSS simulator where additional effects are added, up to the output that represents the input signal of the trial receiver. The analysis of the simulation results can be done in real time or by post-test analysis of the recorded data. The access to simulation data (the data used to create the test signal) can be obtained in various ways: using streaming data or recording it in a file. This data can then be used to compare receiver performance with ”true” simulation data.

3.1 GPS-SDR-SIM: An Open Source Simulator to Test GPS Receivers

GPS-SDR-SIM (Hu, 2019) is an open source software written in *C* language that allows to generate baseband GPS data streams, which can be converted into RF signals using Software Defined Radio (SDR) platforms such as for example ADALM-Pluto (ada, 2019) and HackRF One (hac, 2019).

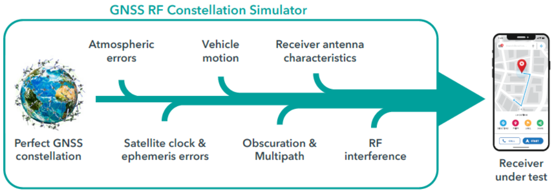


Figure 2: Representation of the signal flow through a GNSS simulator.

To generate a GPS signal, the GPS constellation to be used must be specified to the software. This can be done thanks to a file called GPS broadcast ephemeris file, which in the case of this study was downloaded from the site (eph, 2019) where it is possible to download the daily file containing information about the constellation at a given moment (in RINEX format (Gurtner and Estey, 2013)).

These files are then used to generate the simulated pseudorange and doppler frequency for the GPS satellites in sight. These simulated data are then used to generate digitized I/Q samples for the GPS signal (Rao and Falco, 2012).

The instant of simulation starting can be specified if the corresponding set of ephemerides is available, otherwise the first instant of ephemerides present in the RINEX file is selected. In addition to the RINEX file containing the satellite broadcast ephemeris, an National Marine Electronics Association (NMEA) file (a text file describing the coordinates of the receiver in the form of strings) for the vehicle coordinates to simulate has to be provided. These coordinates must have a frequency of 10Hz, which means that 10 NMEA strings correspond to one second of simulation. An NMEA GGA string specifies the position of the receiver; some of the most relevant parameters are: latitude, longitude, GPS signal quality, and so on.

4 PROPOSED SOLUTION

To improve and add novel functionality to the simulator, a model that takes into account the delay of the signal when it crosses the space portion of the troposphere has been implement. In order to realize this purpose, a valid model was selected to calculate the effects of the signal based on the parameters available in the simulator. In Figure 3, a scheme that summarizes the simulator functionality is shown. This scheme highlights the additional block implemented

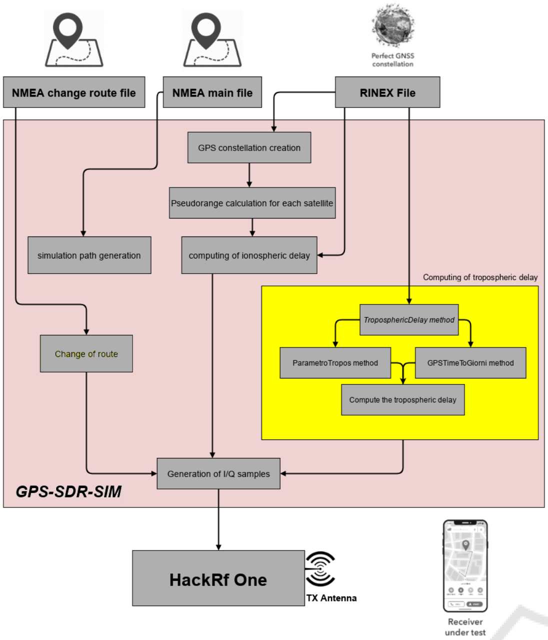


Figure 3: Simulator Block Diagram.

in the software.

In this work the Troposphere Collins model (Collins, 1999) has been used. This model is also used by Satellite-Based Augmentation System (SBAS) systems for maximum precision differential corrections, with the aim of increasing the accuracy and integrity of the GPS system data, such as the Wide Area Augmentation System (WAAS) and European Geostationary Navigation Overlay System (EGNOS), that are air navigation aids developed to augment the GPS, with the goal of improving its accuracy, integrity, and availability.

Delays due to the troposphere can be divided into two parts. One dues to the dry component of the atmosphere called $T_{z,dry}$, the other one dues to the wet component called $T_{z,wet}$.

$$T(E) = (T_{z,dry} + T_{z,wet})M(E) \tag{1}$$

$T(E)$ is the total delay dues to the two components, while $M(E)$ is defined as follows:

$$M(E) = \frac{1.001}{\sqrt{0.002001 + sin^2(E)}} \tag{2}$$

Where E represents the satellite elevation with respect to the receiver, in degrees. The most difficult part of the model regards the estimating the values of $T_{z,dry}$ and $T_{z,wet}$.

These two values depend on meteorological parameters such as:

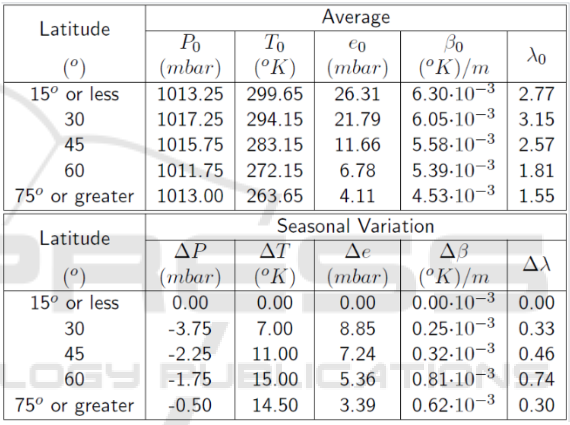
- Atmospheric pressure [P (mbar)].
- Temperature [T (K)].
- Water vapor pressure [e (mbar)].
- Lapse rate temperature [β (K/m)].
- Lapse rate of water vapor [λ (adimensional)]

Since these data are not available in the simulator, a formula was used to estimate them, based on various factors, such as: receiver latitude and day of the year:

$$\xi(\phi,D) = \xi_0(\phi) - \Delta\xi(\phi)cos\left[\frac{2\pi(D-D_{min})}{365,25}\right] \tag{3}$$

Where D_{min} assumes the value of 211 for the south latitudes and the value of 28 for the north latitudes.

Values of $\xi_0(\phi)$ and $\Delta\xi(\phi)$ represent the average seasonal variations at latitude (ϕ) and day of the year (D) of the receiver, which must be linearly interpolated from the table shown in Figure 4 (Collins, 1999).



Latitude (^{o})	Average				
	P_0 $(mbar)$	T_0 (^oK)	e_0 $(mbar)$	β_0 $(^oK)/m$	λ_0
15^o or less	1013.25	299.65	26.31	$6.30\cdot10^{-3}$	2.77
30	1017.25	294.15	21.79	$6.05\cdot10^{-3}$	3.15
45	1015.75	283.15	11.66	$5.58\cdot10^{-3}$	2.57
60	1011.75	272.15	6.78	$5.39\cdot10^{-3}$	1.81
75^o or greater	1013.00	263.65	4.11	$4.53\cdot10^{-3}$	1.55

Latitude (^{o})	Seasonal Variation				
	ΔP $(mbar)$	ΔT (^oK)	Δe $(mbar)$	$\Delta\beta$ $(^oK)/m$	$\Delta\lambda$
15^o or less	0.00	0.00	0.00	$0.00\cdot10^{-3}$	0.00
30	-3.75	7.00	8.85	$0.25\cdot10^{-3}$	0.33
45	-2.25	11.00	7.24	$0.32\cdot10^{-3}$	0.46
60	-1.75	15.00	5.36	$0.81\cdot10^{-3}$	0.74
75^o or greater	-0.50	14.50	3.39	$0.62\cdot10^{-3}$	0.30

Figure 4: Average environmental values.

The terms $T_{z,dry}$ and $T_{z,wet}$ at zero altitude are the following:

$$T_{z0,dry} = \frac{10^{-6}k_1R_dP}{g_m} \tag{4}$$

$$T_{z0,wet} = \frac{10^{-6}k_2R_dP}{(\lambda+1)g_m - \beta R_d}\frac{e}{T} \tag{5}$$

While, to calculate the delay taking into account also the height of the receiver, the following equations are used:

$$T_{z,dry} = \left[1 - \frac{\beta H}{T}\right]^{\frac{g}{R_d\beta}} \cdot T_{z0,dry} \tag{6}$$

$$T_{z,wet} = \left[1 - \frac{\beta H}{T}\right]^{\frac{(\lambda+1)g}{R_d\beta}-1} \cdot T_{z0,wet} \tag{7}$$

Where H is the height of the receiver above sea level (m), k_1=77.604 $(K/mbar)$, k_2=382000 $K^2/mbar$, R_d=287.054 $J/Kg/K$, g_m=9.784 m/s^2 e g=9.80665 m/s^2.

4.1 Implementation of The Model In The Simulator

In order to develop the model in the considered simulator, three functions have been created in *C* programming language able to calculate the signal delay, and then to add it in the pseudorange calculated for each satellite.

The main method has been called *troposphericDelay*, it takes as input the *g* variable of type *gpstime_t*, which is a struct that represents the GPS time in the week-seconds format; an array of three double elements called *llh* which contains the latitude, longitude and altitude of the GPS receiver and finally an array of two double elements called *azel*, which indicates azimuth and elevation of the satellite with respect to the receiver. The diagram is shown in Figure 5:

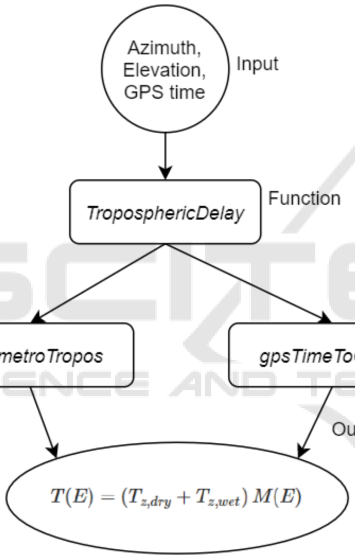


Figure 5: *troposphericDelay* function.

The other two functions are: *gpsTimeToGiorni* and *parametroTropos*.

The first has the aim of simply converting the GPS time from the week-seconds format, to the day of the year ranging from 1 to 365, the diagrams can be seen in Figure 6:

The *parametroTropos* function, see Figure 7, has the aim of taking the listed values and, on the basis of the involved parameter such as latitude, satellite elevation and day of the year, it calculates the correct value which will then be used in the main method.

The task of the *calcVal* function (see Figure 8) used in the *parametroTropos* function, is to interpolate the values taken from the table.

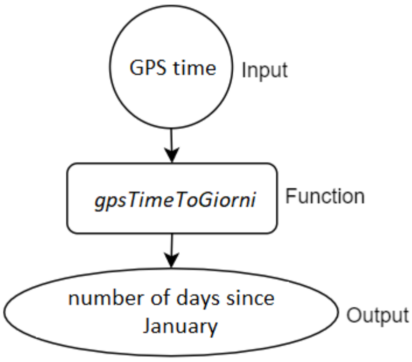


Figure 6: *gpsTimeToGiorni* function.

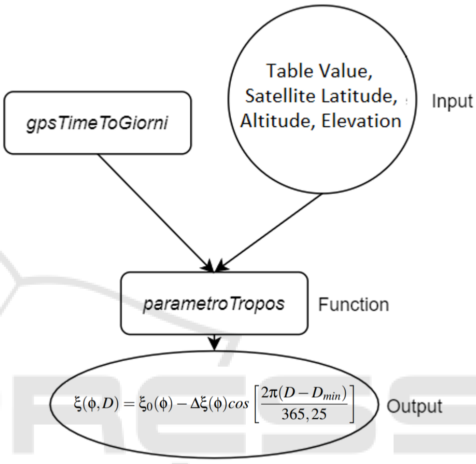


Figure 7: *parametroTropos* function.

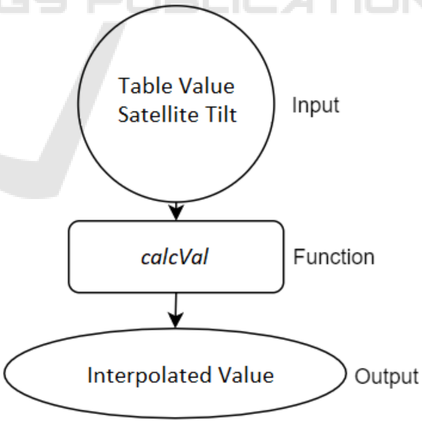


Figure 8: *calcVal* function.

5 PERFORMANCE EVALUATION

In this section the simulation environment is described and the experimental results are discussed in order to show the behavior of the software simulator with the adding of the proposed model based on the Tropospheric Collins algorithm.

5.1 Simulation Environment

In order to test the changes introduced into the simulator, an appropriate hardware needs to be used. The sending device uses the HackRf One card with the ANT500 antenna and the Nooelec Module Tiny TCXO 10Mhz module, a very precise oscillator with very low phase noise. It was chosen from the various options available for the HackRf One card in order to use GPS applications (see Figure 9).

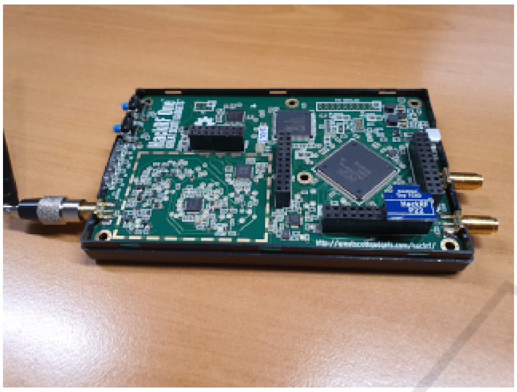
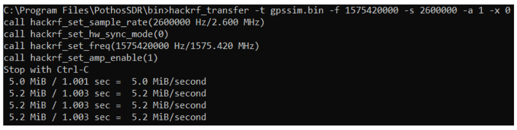


Figure 9: HackRf One with its ANT500 antenna and Tiny TCXO 10Mhz oscillator.

Thanks to Google Earth Pro software, a path was created consisting of eleven points on the map and then converted into NMEA format, to be simulated with the *GPS-SDR-SIM* software. Subsequently, the output file of the simulator was transferred in input to the HackRf One board through the Windows 10 command prompt shown in Figure 10.



```
C:\Program Files\PothosSDR\bin>hackrf_transfer -t gpssim.bin -f 1575420000 -s 2600000 -a 1 -x 0
call hackrf_set_sample_rate(2600000 Hz/2.600 MHz)
call hackrf_set_hw_sync_mode(0)
call hackrf_set_freq(1575420000 Hz/1575.420 MHz)
call hackrf_set_amp_enable(1)
Stop with Ctrl-C
 5.0 MiB / 1.001 sec =  5.0 MiB/second
 5.2 MiB / 1.003 sec =  5.2 MiB/second
 5.2 MiB / 1.003 sec =  5.2 MiB/second
 5.2 MiB / 1.003 sec =  5.2 MiB/second
```

Figure 10: Command used to transfer the binary file to the HackRf One card.

Once the HackRf One hardware is transmitting the GPS signal, the smartphone's GPS receiver is used to make some considerations. Two experiments were carried out: the first by deactivating the troposphere correction algorithm and the second one by activating the implemented algorithm.

5.2 Experimental Results

In the following section some graphics of experimental results are shown in order to discuss the goodness of the proposal module implemented in the software simulator. The line called ”true” path is related to the real coordinates given in input to the simulator.

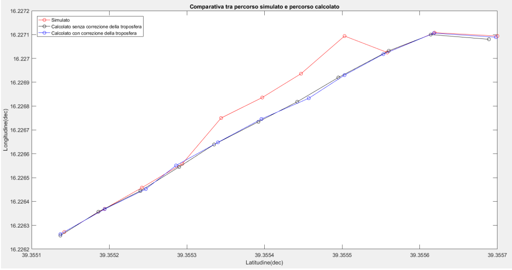


Figure 11: Comparison of the two simulated paths with the ’true’ path (intermediate latitude).

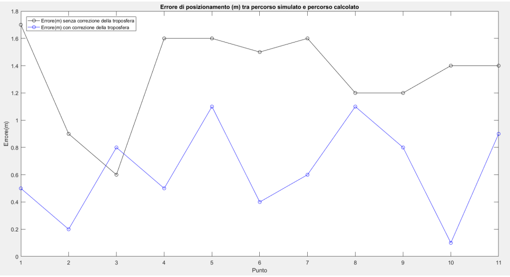


Figure 12: Difference in meters between simulated and ’true’ path (intermediate latitude).

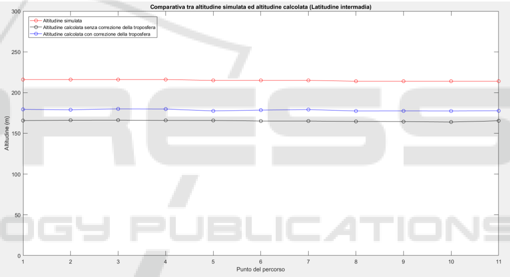


Figure 13: Altitude difference between the points of the simulated and ’true’ path (intermediate latitude).

In Figure 11, it is possible to observe a comparison between the ”true” path and the two simulated ones: in red the coordinates given in input at the simulator are highlighted. These coordinates represent the reference points from which a GPS receiver should not deviate too much in order to guarantee a correct GPS operation. The coordinates calculated by the GPS receiver are respectively shown in black, with correction algorithm disabled, and blue, with the correction algorithm is activated. A big deviation from red line means a big error by algorithm in calculating the correct position.

The graphic in Figure 12 shows the positioning error committed in meters, calculated with respect to the simulated path.

These two graphics show the results obtained starting from a path located at an intermediate latitude and an altitude of about 200 meters above sea level.

The graphic in Figure 13 shows the error committed in calculating the altitude above the sea level by the receiver.

As it is possible to observe in this Figure the error on latitude and longitude is on average lower in the case in which the tropospheric algorithm is activated, for each point of the considered path.

In order to verify the correct operation of the model in different situations, experiments were also carried out at extreme and equatorial latitudes. For that concern the considered path at extreme latitudes, a route in Norway was chosen by Google Earth Pro and the coordinates were given in input to the simulator.

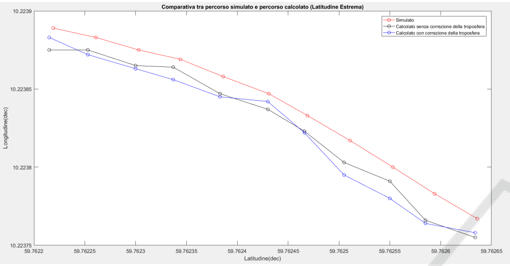


Figure 14: Comparison of the two simulated routes with the 'true' path (extreme latitude).

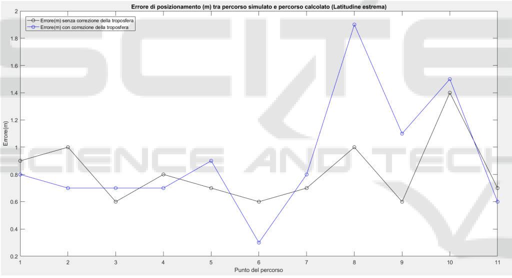


Figure 15: Difference in meters between simulated and 'true' path (extreme latitude).

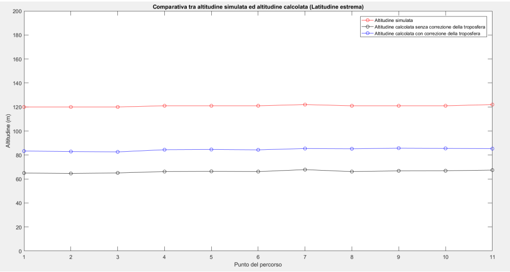


Figure 16: Altitude difference between the points of the simulated and 'true' path (extreme latitude).

Figure 14, 15, 16 show the same output parameters illustrated above (in the case of intermediate latitudes) considering the extreme latitude coordinates.

The same consideration made for the previous case is possible to done also for this new simulative campaign. It is possible to observe a better behavior of the system when the proposed module is activated in respect to the one with troposphere module disabled.

6 CONCLUSIONS

GNSS simulation is a widely used in practice for testing GPS receivers. In this paper, a particular GPS simulation software with the additional of a novel Troposperic Collins model has been considered. The improvement introduced regards the addition of the delay of the signal transmitted in the form of a pseudorange in order to simulate a very realistic scenario. The experiments made to test the troposphere model in the considered simulator were possible thanks to a special hardware: Hackrf One with its original ANT500 antenna and a very precise 10MHz nooelec oscillator. To better evaluate the applied model, three different tests were carried out at three different latitudes and, as it can be seen from the graphics, the main improvements in the application of the model are in the case of intermediate and equatorial latitudes. The results show how the implemented troposperic software module introduces an improvement in the system guaranteeing better performance in term of committed errors.

REFERENCES

(2019). Adalm-pluto - active learning module (plutosdr) - overview. https://wiki.analog.com/university/tools/pluto.

(2019). ephemeris data information. ftp://cddis.gsfc.nasa.gov/gnss/data/daily/.

(2019). Hackrf, open source hardware for software-defined radio. https://greatscottgadgets.com/hackrf/.

Collins, J. P. (1999). Assessment and development of a tropospheric delay model for aircraft users of the global positioning system.

De Rango, F., Fazio, P., and Marano, S. (2008). Utility-based predictive services for adaptive wireless networks with mobile hosts. *IEEE Transactions on Vehicular Technology*, 58(3):1415–1428.

De Rango, F., Veltri, F., Fazio, P., and Marano, S. (2009). Two-level trajectory-based routing protocol for vehicular ad hoc networks in freeway and manhattan environments. *Journal of Networks*, 4(9):866–880.

Deng, C. and Wang, D.-D. (2011). Study and simulation of digital if gps signals. In *2011 International Conference on Machine Learning and Cybernetics*, volume 2, pages 544–547. IEEE.

Devangavi, A. D. and Gupta, R. (2017). Routing protocols in vaneta survey. In *2017 International Conference* *on Smart Technologies for Smart Nation (SmartTechCon)*, pages 163–167. IEEE.

Fazio, P., Sottile, C., Santamaria, A. F., and Tropea, M. (2013). Vehicular networking enhancement and multi-channel routing optimization, based on multi-objective metric and minimum spanning tree. *Advances in Electrical and Electronic Engineering*, 11(5):349–356.

Fazio, P., Tropea, M., De Rango, F., and Voznak, M. (2016). Pattern prediction and passive bandwidth management for hand-over optimization in qos cellular networks with vehicular mobility. *IEEE Transactions on Mobile Computing*, 15(11):2809–2824.

Fazio, P., Tropea, M., and Marano, S. (2017). Node rerouting and congestion reduction scheme for wireless vehicular networks. *Wireless Personal Communications*, 96(4):5203–5219.

Fernandez-Prades, C., Arribas, J., Closas, P., Aviles, C., and Esteve, L. (2001). Gnss-sdr: An open source tool for researchers and developers. In *Proceedings of the 24th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2011)*, pages 780–0.

Fernández-Prades, C., Arribas, J., Esteve, L., Pubill, D., and Closas, P. (2012). An open source galileo e1 software receiver. In *2012 6th ESA Workshop on Satellite Navigation Technologies (Navitec 2012) & European Workshop on GNSS Signals and Signal Processing*, pages 1–8. IEEE.

Fotino, M., Gozzi, A., Cano, J.-C., Calafate, C., De Rango, F., Manzoni, P., and Marano, S. (2007). Evaluating energy consumption of proactive and reactive routing protocols in a manet. In *IFIP Conference on Wireless Sensor and Actor Networks*, pages 119–130. Springer.

Frnda, J., Voznak, M., Rozhon, J., and Mehic, M. (2013). Prediction model of qos for triple play services. In *2013 21st Telecommunications Forum Telfor (TELFOR)*, pages 733–736. IEEE.

Ghori, M. R., Zamli, K. Z., Quosthoni, N., Hisyam, M., and Montaser, M. (2018). Vehicular ad-hoc network (vanet): Review. In *2018 IEEE International Conference on Innovative Research and Development (ICIRD)*, pages 1–6.

Groves, P. D. (2015). Principles of gnss, inertial, and multisensor integrated navigation systems, [book review]. *IEEE Aerospace and Electronic Systems Magazine*, 30(2):26–27.

Gurtner, W. and Estey, U. (2013). The receiver independent exchange format.

Hasan, K. F., Feng, Y., and Tian, Y.-C. (2018). Gnss time synchronization in vehicular ad-hoc networks: benefits and feasibility. *IEEE Transactions on Intelligent Transportation Systems*, 19(12):3915–3924.

Hu, Y. (2019). Gnss sdr signal generator implementation based on usrp n210. In *Journal of Physics: Conference Series*, volume 1314, page 012016. IOP Publishing.

Kelley, C., Barnes, J., and Cheng, J. (2002). Opensource gps open source software for learning about gps. In *ION GPS*, volume 2002, pages 2524–2533.

Paakki, T. and Nurmi, J. (2014). Faster than real-time gnss receiver testing. In *International Conference on Localization and GNSS 2014 (ICL-GNSS 2014)*, pages 1–4. IEEE.

Paakki, T., Raasakka, J., Della Rosa, F., Hurskainen, H., and Nurmi, J. (2010). Tutgnss university based hardware/software gnss receiver for research purposes. In *2010 Ubiquitous Positioning Indoor Navigation and Location Based Service*, pages 1–6. IEEE.

Rao, M. and Falco, G. (2012). How can pseudorange measurements be generated from code tracking. *Inside GNSS Mag*, 7:26–33.

Santamaria, A. F., Fazio, P., Raimondo, P., Tropea, M., and De Rango, F. (2019). A new distributed predictive congestion aware re-routing algorithm for co 2 emissions reduction. *IEEE Transactions on Vehicular Technology*, 68(5):4419–4433.

Santamaria, A. F., Tropea, M., Fazio, P., and De Rango, F. (2018). Managing emergency situations in vanet through heterogeneous technologies cooperation. *Sensors*, 18(5):1461.

Socievole, A., De Rango, F., and Coscarella, C. (2011). Routing approaches and performance evaluation in delay tolerant networks. In *2011 Wireless Telecommunications Symposium (WTS)*, pages 1–6. IEEE.

Tsui, J. B.-Y. (2005). *Fundamentals of global positioning system receivers: a software approach*, volume 173. John Wiley & Sons.

Van Sickle, J. and Dutton, J. (2014). Geog 862: Gps and gnss for geospatial professionals. *Penn States Online Master of GIS*.

Zhang, S. and Ji, Z. (2015). A parallel gps satellite positioning algorithm based on broadcast ephemeris. In *2015 8th International Congress on Image and Signal Processing (CISP)*, pages 7–11. IEEE.

Zhou, B., Lee, Y.-Z., Gerla, M., and De Rango, F. (2006). Geo-lanmar: a scalable routing protocol for ad hoc networks with group motion. *Wireless Communications and Mobile Computing*, 6(7):989–1002.