XXXVII SIMPÓSIO BRASILEIRO DE TELECOMUNICAÇÕES E PROCESSAMENTO DE SINAIS – SBrT2019, 29/09/2019–02/10/2019, PETRÓPOLIS, RJ

# A New Module in Simulation Tool (SHARC) for Interference Studies between Vehicular Communication Systems and Satellites in 5.9 GHz

Marta P.C. Almeida, Carlos V. Rodriguez Ron, Jussif J. A. Arnez, Luiz da Silva Mello
Center for Telecommunications Studies
Pontifical Catholic University of Rio de Janeiro, RJ, Brazil
marta@cetuc.puc-rio.br; crodriguez@cetuc.puc-rio.br

***Abstract*—This paper presents the implementation of a module in the open source simulation tool SHARC for compatibility studies between vehicular communication systems and fixed satellite service (FSS). The SHARC tool was originally designed for compatibility studies between IMT systems (including 5G) and other radiocommunication systems (Radar, Earth Exploration Satellite Service EESS, etc). A new module dedicated to simulations with vehicular communications systems called SHARC-V2X is presented, which involves communication link between vehicle and a fixed infrastructure (V2I) and a communication link from vehicle to vehicle (V2V). The implementation was validated by the simulation results which reflect the operational range of a vehicular communication according to the 3GPP specification.**

***Keywords — Vehicular communication, V2I, V2V, fixed satellite service, simulation, sharing study, compatibility study.***

## I. INTRODUCTION

The Intelligent Transportation Systems (ITS) aim to support transportation of human and goods with information and communication technologies in order to use the transportation infrastructure and means of transportation, as cars, trucks, motorcycles or trains, in efficient and safe manner [1]. ITS have been studied in various standards development organizations. In international level, organizations of Radiocommunication Group of ITU (ITU-R), ISO Technical Committee 204 (ISO TC 204) and IEEE develop standards, recommendations and reports [1]. In Europe, the standardization entity European Telecommunications Standards Institute (ETSI) has groups ETSI TC ITS and CEN TC287 in work as a regional level. In Asia-Pacific Telecommunity, the Wireless Group (AWG) conduct the work as a regional level as ARIB (Japan), TTA (Korea), IMDA (Singapore) and others. The ITS deployments could be initially listed as electronic toll collection, automotive radar and vehicle information and communication. The evolution of ITS will involve many communications-related applications intended to increase travel safety, improve traffic management and maximize the benefits of transportation to both commercial users and the general public [2].

Regarding spectrum issues, ITS has many frequency arrangements worldwide. The 5.9 GHz band is more commonly used, but there are other bands already assigned for transportation systems, as in Japan with 5.8 GHz for DSRC and 760 MHz band for the ITS Connect [3]. ITU-R has been developing activities related to spectrum studies and harmonization to support decisions in countries. The World Radiocommunication Conference (WRC-19) will take major decisions related to Radio Regulations and the use of spectrum. ITS is covered in WRC-19 agenda item 1.12 (AI 1.12) which considers possible global or regional harmonized frequency bands for evolving ITS under existing mobile services allocations [4]. In this way, ITU-R is providing guidance on harmonized frequency bands for ITS, aiming cooperation between countries, to increase transportation operations and equipment manufacturing, resulting in economies of scale and equipment availability [5].

The frequency bands used by evolving ITS may also be used by other applications and services. In Brazil the 5.9 GHz has destination to fixed satellite service (FSS) and there are FSS earth stations distributed in the whole country, according to Brazilian database Sitarweb from Anatel. In this way, it is necessary to develop sharing studies between a vehicular system and the incumbent service FSS in Brazil, as the 5.9 GHz band is part of C-Band (satellite uplink operates in 5850 to 6425 MHz). Anatel developed a simulation tool for sharing and compatibility studies between IMT and other radiocommunication systems named SHARC based on Monte Carlo simulation [6]. This collaborative open source tool was designed to model 5G systems for coexistence studies with radiocommunication systems or services as the fixed satellite service and fixed point to multipoint links, among others [7].

The sharing studies between vehicular communication system and incumbent service in the 5.9 GHz band required the development of a module in SHARC dedicated to model the vehicle to vehicle communication (V2V) and the vehicle to infrastructure communication (V2I). This new module is named SHARC-V2X [8] and is based in the 3GPP technical specification regarding the radio transmission and reception interfaces of LTE for vehicular communications [9] [10]. The implementation of the module for V2X is presented in this work. This paper is organized as follows: Section II provides a description of a vehicular communication system and parameters for sharing studies with FSS service. Section III shows the implementation of SHARC V2X module, regarding to topology and propagation models. Section IV presents the simulation scenarios and the validation of the results.

## II. VEHICULAR COMMUNICATION MODELLING

The modeling of ITS systems for simulation purposes in the 5.9 GHz band (5850-5925 MHz) in this work employed the

3GPP specifications for LTE of the Release 14 concerning the operation scenarios for a communication system between vehicles (V2V) and between vehicle and a fixed infrastructure (V2I) [9] [10]. The V2V service operates in the ITS spectrum (Band 47 of the 3GPP) of 5.9 GHz provided by the PC5 interface. The V2I service is the communication link between a vehicle and a fixed infrastructure or the so called Roadside Unit (RSU), which also operates in 5.9 GHz.

## III. IMPLEMENTATION OF SHARC-V2X

The development of the module for vehicular communication systems employed the original structure of the SHARC simulation tool according Recommendation ITU-R M.2101-0 with a topology of one cluster with 19 sectors with 3 macrocells for each sector. This configuration results in 57 macrocells for the cluster. Inside each microcell, the hotspots (equipment with limited coverage around 100 meters) are randomly positioned at each snapshot of simulation. Each hotspot has a base station (BS) connected to some user equipment (U.E) in proximity. The simulation provides the calculation of coupling loss between BSs and UEs, resource scheduling and power control, in order to achieve the interference levels [7]. In SHARC-V2X the V2V and V2I communications were deployed separately to allow the calculation of each system configuration. New entities of vehicles and Roadside unit (RSUs) were created based on base stations and user terminals. Topologies for an urban grid scenario and highway scenario were implemented to represent the relative positioning of the new entities of vehicles and RSUs. The propagation models were implemented to provide calculation of short-range communications (V2V) and of micro urban and macro urban coverage (V2I) for 5.9 GHz. The details of these implementations are described below.

### A. *V2V communication*

The existing structure of hotspots with BS and UEs provided the basis for the V2V configuration. It is composed of a “reference vehicle” (a virtual BS) which sets the downlink and uplink paths with the surrounding vehicles (the equivalent to the UEs). The position of the “reference vehicle” varies randomly for each snapshot within the topology, as the relative position of the surrounding vehicles to the “reference vehicle”. As the vehicles communicate in broadcast mode, the final calculation will consider only the uplink direction when the FSS is the victim system, and only the downlink direction when the ITS is the victim system. In V2V configuration, a hotspot or BS is a “reference vehicle” and the number of surrounding vehicles can be chosen in the input file.

### B. *V2I communication*

The existing structure of BS and UEs also provided the basis for the V2I configuration. In this case, it is composed of a “RSU” (the BS equivalent) which sets the downlink and uplink paths with the surrounding vehicles (the equivalent UEs). The position of the “RSU” is fixed in the topology, and the relative position of the surrounding vehicles to the RSU varies randomly each snapshot. In V2I configuration, each hotspot has a “RSU” and the number of surrounding vehicles can be chosen as input in the configuration file.

### C. *Topology for urban scenario*

The topology of an urban grid was created and structured according to ETSI documentation where the urban scenario is set with a reference grid composed of 25 blocks (150 m wide each) resulting in a 5x5 matrix with double-lane roads (the reference grid is 750 m wide) [11]. This reference grid area is equivalent to the hotspot coverage area and can be replicated within the cluster. The position varies in each snapshot. This topology can be used with V2V or V2I configurations. Figure 1 shows four reference grids inside the macrocells (not in scale).

### D. *Topology for highway scenario*

The topology for a highway scenario was created also based on an ETSI reference [11], where the reference highway can have 6 lanes (3 in each direction) or 12 lanes (6 in each direction) with 6 km long. This reference highway is a hotspot which can be replicated within the macrocell. Figure 2 presents two reference highways inside the macrocells (not in scale). The position of the hotspots varies in each snapshot. This topology can be used with V2V or V2I configurations.

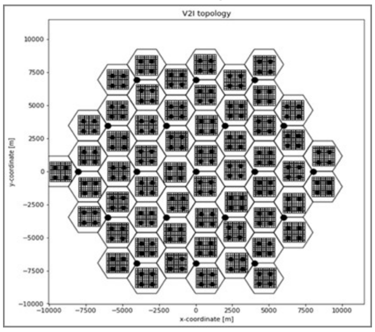


Fig. 1. Cluster with four reference grids in macrocells (not in scale)

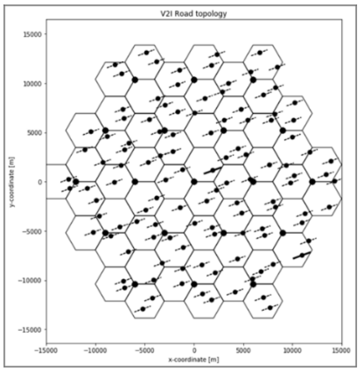


Fig. 2. Cluster with two reference highways in macrocells (not in scale)

The choice of vehicles randomly positioned within the topologies considered the statistical characteristic of the simulator, which provides the aggregated interference generated by many positions distributed in the macrocells. The input parameters for topology definition can be summarized in the Table I.

TABLE I. *CHARACTERISTICS OF TOPOLOGIES*

| Parameter type | Urban topology | Highway topology |
|---|---|---|
| Default | Reference grid: 25 blocks (5 x 5) | Reference highway: length = 170 m |
| Input | Street width (m); Number of reference grids | Lane width (m); Number of reference highways; Number of lanes (3 or 6); Inclination of highway inside the cluster (degrees); Number of reference highways in parallel |

Another group of parameters define the coverage in terms of distance and number of vehicles. The coverage for V2I configuration is 400 m and for V2V configuration is 100 m. The transmission station (RSU in V2I or the reference vehicle in V2V) allocates the resource blocks (RBs) between vehicles [7]. One RB is allocated for one vehicle [12], in a maximum of 50 RBs allowed for a 10 MHz channel [10]. The RSU and the reference vehicle transmit in maximum power and the vehicle transmission is subject to the uplink power control [7].

### *E. Number of vehicles in the scenario*

The vehicle density (number of vehicles per unit of area) in the area of simulation must be achieved. An approach can be an estimation based in the number of vehicles in municipalities given by an official database (ex. IBGE in Brazil) and the related geographical area. The total number can result very large, which can be computationally intensive. In this way, it is necessary to define a small number of vehicles and run a primary simulation, then scaling this result employing a multiplication factor as an approximation. This factor is achieved as the ratio of the total number of vehicles to the number used in the primary simulation [7].

### *F. Propagation models for V2V and V2I*

Two propagation models for V2V configuration were implemented: a short-range outdoor model from ITU-R P.1411-9 [13] and the Two-Ray Interference model [14].

The ITU-R P.1411-9 presents many propagation situations. In this work the best situation for V2V is given by the site-specific model for LoS situation for distances less than 1 km in urban scenarios, due to the proximity of vehicles, as follows.

$$L_{LoS,m} = L_{bp} + 6 + \begin{cases} 20\log_{10}\left(\dfrac{d}{R_{bp}}\right) & \text{for} \quad d \le R_{bp} \\ 40\log_{10}\left(\dfrac{d}{R_{bp}}\right) & \text{for} \quad d > R_{bp} \end{cases} \quad (1)$$

$$R_{bp} = 4\frac{(h_1 - h_s)(h_2 - h_s)}{\lambda} \quad (2)$$

$$L_{bp} = \left| 20\log_{10}\left(\frac{\lambda^2}{8\pi h_1 h_2}\right)\right| \quad (3)$$

Where $h_1$, $h_2$ are the terminals height and $h_s$ is the effective road height due to such objects as vehicles on the road and pedestrians near the roadway, given in [13].

The Two-Ray interference model propagation model composes the free space loss and the ground reflection, which is given by a term with the relative phase and magnitude of interference by the reflected ray [14]. It is useful for vehicular communication because increases the received signal accuracy in the simulation [14]. The expression for the loss is given as follows:

$$L_{tri}(d) = 20\log\left(4\pi\frac{d}{\lambda}\left|1 + \Gamma_{\perp}e^{i\varphi}\right|^{-1}\right) \quad (4)$$

Where the phase difference of interfering rays is given by:

$$\varphi = 2\pi\frac{d_{LoS} - d_{Ref}}{\lambda} \quad (5)$$

The length of direct signal is $d_{Los}$ and the length of indirect signal from ground reflection $d_{ref}$ are given in [14].

The propagation model for V2I configuration can be represented by a point-to-area model with a base station and a mobile terminal, respectively the RSU and the vehicle. The model implemented is presented in 3GPP TR 38901 for a micro urban (UMi) and macro urban (UMa) scenarios [16]. The expressions of pathloss depend mostly on the distance, frequency, height of base station and terminal antennas and a breakpoint distance. Also, the shadowing is considered in the LoS probability with standard deviation for each scenario.

### *G. Simulation procedure in SHARC-V2X*

The algorithm of interference calculation of SHARC was employed in the development of vehicular module V2X, where the systems considered in coexistence studies are ITS and the fixed satellite system FSS.

The structure of output results of SHARC could be completely used. The SHARC simulator analyses statistically the results of all snapshots to provide results of cumulative distributions functions of system parameters of the interfering and interfered systems. The parameters are the received power, transmitted power, signal-to-noise (SNR), signal-to-interference and noise ratio (SINR), coupling loss, antenna gains, and the most important, the interference-to-noise ratio (INR) in the reception of the victim system, generated by each snapshot.

## IV. VALIDATION TESTS OF THE IMPLEMENTATION

The testing methodology consisted in the simulation of a scenario with a vehicular system as interferer and the FSS as interfered system, employing system parameters of technical specifications of both systems. The results should show values of the SNR within the operational range of a vehicular system given by 3GPP references [9][10].

The FSS parameters are presented in the Table II and the ITS parameters employed in simulations for V2I urban, V2I highway, V2V urban and V2V highway scenarios are presented in Table III and Table IV.

TABLE II. *FSS parameters*

| Satellite parameters | Value |
|---|---|
| Type | GEO - 35780 km |
| Center frequency | 5860 MHz |
| Satellite bandwidth | 10 MHz |
| Antenna type<br>Peak antenna gain<br>3 dB beamwidth<br>Side lobe attenuation | ITU-R S.672<br>41.6 dBi<br>0.65 dB<br>20 dB |
| System noise temperature | 500 K |
| Interference criteria (INR) | -12.2 dB |

TABLE III. *DEPLOYMENT PARAMETERS*

| **[GENERAL]** | Version: September-2018 |
|---|---|
| System for compatibility study | FSS_SS; co-channel; Downlink; num_snapshots = 1000 |
| **[V2X]** | |
| Topologies | V2I Road / V2I urban<br>V2V Road / V2V urban |
| Cluster or macrocell | 1 cluster, 19 macrocells |
| ISD (km) | 238 |
| Vehicles per RSU | 8 |
| V2X suffers interference | False |
| V2X center frequency (MHz) / bandwidth (MHz) | 5860 / 10 |
| V2X resource block band (MHz) | 0.180 |
| V2X transmitted power (dBm) | 23 (RSU); 23 (vehicle) |
| Height (m) | 10 (RSU); 1.5 (vehicle) |

| | |
|---|---|
| Noise figure (dB) | 12 (RSU and vehicle) |
| Noise temperature (dB) | 290 (RSU and vehicle) |
| Ohmic loss (dB) | 0 (RSU and vehicle) |
| Uplink SINR (dB): min / max | -2 / 15 |
| Distribution type | ANGLE_AND_DISTANCE (Rayleigh for distance; Normal for azimuth) |
| Uplink power control | On |
| Power per RB (dBm) | -104.5 |
| Downlink SINR (dB): min /max | -2 / 15 |
| Channel model V2X | UMi |
| LOS probability / shadowing | III.95/ True |

TABLE IV. ANTENNA PARAMETERS

| | |
|---|---|
| **[V2X_ANTENNA]** | |
| Model | F1336 (RSU); F1336 (Vehicle) |
| Gain (dBi) | 12 (RSU); 0 (Vehicle) |
| Horizontal 3dB beamwidth (degrees) | 360 (RSU); 360 (vehicle) |
| Vertical 3dB beamwidth (degrees) | 60 (RSU); 60 (vehicle) |
| Mechanical downtilt (degrees) | 10 |
| **[V2IROAD]** | |
| Number of reference highways n_roads | 1 |
| Number of lanes (3 or 6): n_lines | 3 |
| Road inclination from the horizontal (degrees) (Road_inclination) | 30 |
| Number of reference roads per macrocell sector: (Num_roads_per_cell) | 1 |
| Lane width (m) (Line_w): | 4 |

The first simulation for testing purposes was performed for V2I and V2V configurations in a highway. The SNR of ITS system is achieved for downlink and uplink. In the downlink 25% of vehicles have SNR below the threshold of -2 dB, and in uplink, 6% of the RSUs have SNR below -2 dB, as shown in Figure 3. This dynamic behavior is normal due to the random positioning and the control power algorithm, giving a connection between RSUs and vehicles with good communication conditions. For the V2V case, in which only the UL direction is considered for analysis, 31% of vehicles have SNR below -2 dB.

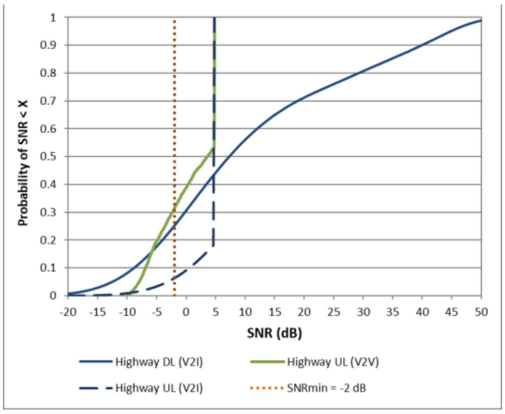


Fig. 3. SNR for downlink and uplink simulations

The antenna gains of ITS system achieved in the simulation with topology of highway and of urban grid are presented in Figure 4. The RSU antenna gain is 12 dBi at his maximum, and due to the relative position between vehicles to the RSU, values range from 9.7 to 12 dBi in the case of highway, and in urban grid the values range from 0 to 12 dBi. The antenna gain in vehicle is 0 dBi and also due to positioning, values found are from -3dBi to 0 dBi.

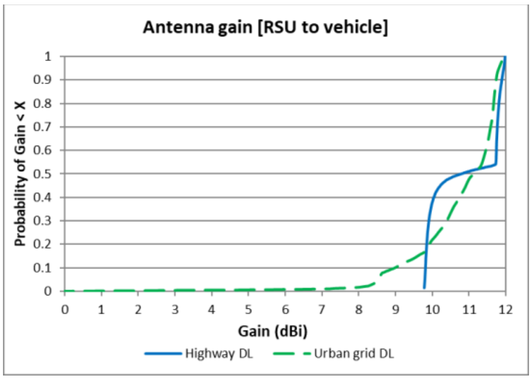


Fig. 4. RSU antenna gain in direction to the vehicle (V2I)

The coupling loss and path loss of ITS link budget from UMi model of TR38901 are shown in Figure 5. The pathloss range between 60 and 150 dB were according to theoretical calculation for ranges up to 400 meters.

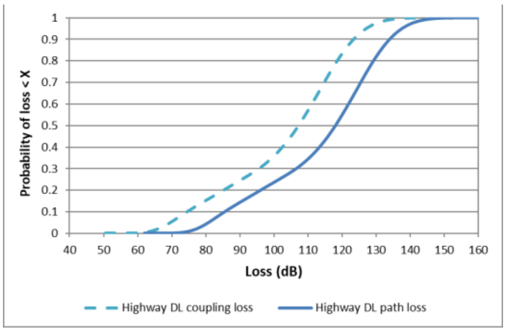


Fig. 5. Losses in downlink calculation (V2I)

Besides the ITS operational parameters, the simulation results present the RSU antenna gain and vehicle antenna gain in direction to the satellite, from simulation of V2I scenarios. The results from simulation in three Brazilian regions (North, Southeast and South regions) can be observed in Figure 6 and Figure 7. The results for urban and road simulations presented similar values in each region, as expected. Due to the extreme similarity the curves are visually overlapping. This similarity was expected due to the inclination angle to satellite, which is higher in the North region than in the Southeast and the South region. Considering the antenna diagram from ITU-R F.1336 with a directive vertical pattern, the difference in RSU antenna gain can be observed from one region to another.

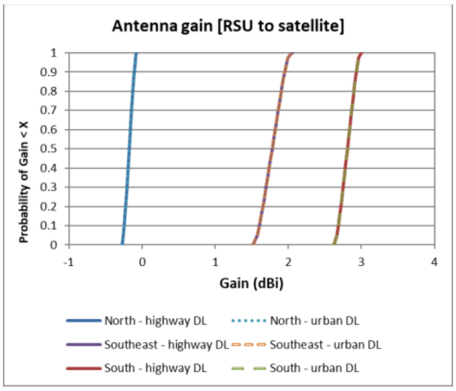


Fig. 6. RSU antenna gain in direction to satellite (V2I)

The antenna gains values from the vehicles to satellite achieved also variate from one Brazilian region to another, considering the different inclination angles. The positioning of vehicles during simulation vary along the scenario, providing more differentiation in gain values than the ones achieved in the results for the RSU. Also, there is some differentiation in the results for highway and urban scenario, due to the area for vehicles displacement, which is greater in the urban grid.

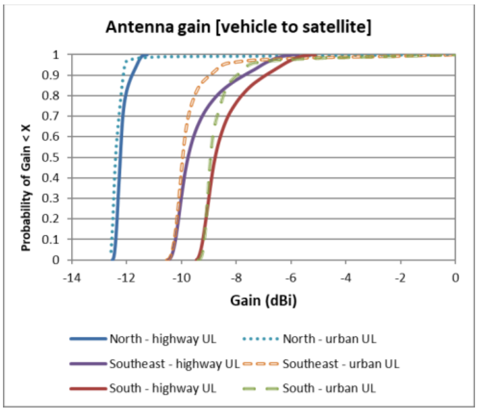


Fig. 7. Vehicle antenna gain in direction to satellite (V2I)

The most important result is the interference to noise ratio (INR) in the satellite receiver and the comparison with the protection criteria of the satellite receiver. The INR achieved from simulations for downlink and uplink (in V2I and V2V scenarios) for the Southeast region are presented in the Figure 8. This simulation was performed with less vehicles than the total for the region, as previously mentioned in order to reduce the simulation time. This simulation results in low values of INR, far below the threshold of -12.2 dB. One can observe the difference from uplink to downlink values which are due to the maximum gain in RSU (12 dBi) and the maximum gain in vehicle (0 dBi). This difference of e.i.r.p is reflected in the calculation of INR in the satellite receiver. The curves for urban DL (V2I) and highway DL (V2I) are overlapping because both refer to RSU transmission.

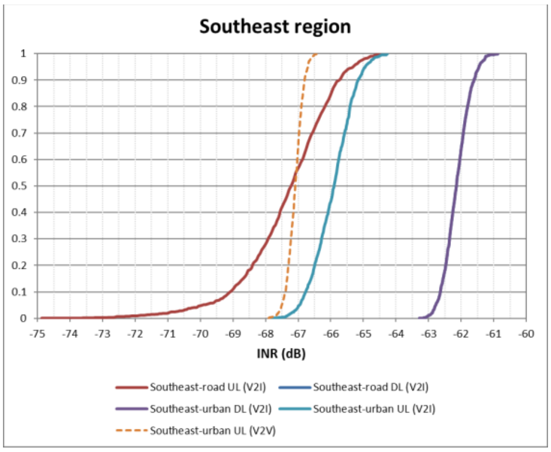


Fig. 8. Aggregate interference-to-noise ratio (INR) in satellite receiver from Southeast region, for each scenario

## V. Conclusions

This work presented the development of the open source module SHARC-V2X for simulation of vehicular communication systems with the aim of coexistence studies between ITS and FSS system. The construction of the module was based on the structure of clusters, hotspots, base stations and user terminal, allowing the creation of new entities of vehicles and roadside units (RSUs). The topologies of urban grid scenario and highways (roads) were inserted, in order to characterize the vehicles displacement. In terms of interference calculation, SHARC-V2X provides the interference from ITS in the victim system fixed satellite service (FSS), and from the FSS earth station. The validation tests consisted on the verification of results of SNR according to the operational range of ITS, of the behavior of antenna gains within the ITS system and in direction of the satellite, and the interference to noise calculation in the satellite receiver. The results for highways and urban scenario were achieved and the differences were achieved due to the available area for calculation.

## Acknowledgements

The authors would like to thank Anatel for the opportunity of joint work in SHARC in the development of SHARC-V2X for vehicular communication and thank Qualcomm for the support and sponsoring.

## References


[1] Preliminary Draft New Report ITU-R M.[ITS USAGE] "Intelligent transport systems (ITS) usage in ITU Member States", ITU-R Working Party 5A (WP5A), Document 5A/TEMP/347-E, 14 November 2018

[2] Automotive Intelligent Transport Systems (ITS). Available at https://www.etsi.org/technologies/automotive-intelligent-transport

[3] Preliminary Draft New Report ITU-R M.[ITS_ARR], "Examples of Arrangements for Intelligent Transport Systems deployments under the mobile service", ITU-R Working Party 5A (WP5A), Document 5A/TEMP/344-E, 15 November 2018

[4] ITU-R Resolution 237 (WRC-15), "Intelligent Transportation Systems applications". Available at https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000C0013PDFE.pdf

[5] Preliminary Draft New Report ITU-R M.[ITS_FRQ], "Harmonization of frequency bands for Intelligent Transport Systems in the mobile service", ITU-R Working Party 5A (WP5A), Document 5A/TEMP/343-E, 14 November 2018

[6] "SHARC Simulator," https://github.com/SIMULATOR-WG/SHARC

[7] Edgar Souza, Agostinho Linhares, Calil Queiroz, Leticia Valle, Ugo Dias; Andre Barreto, "An open source simulation tool for sharing and compatibility studies between 5G and other radiocommunication systems", 2017 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC), August 2017

[8] "SHARC-V2X", https://github.com/SIMULATOR-WG1/SHARC-V2X

[9] 3GPP TR36785 V14.0.0 (2016-10), "Vehicle to Vehicle (V2V) services based on LTE sidelink; User Equipment (UE) radio transmission and reception

[10] 3GPP TR36.786 V14.0.0 (2017-03) "V2X Services based on LTE; User Equipment (UE) radio transmission and reception (Release 14)

[11] ETSI TR 102 861 V1.1.1 (2012-01) "Intelligent Transport Systems (ITS); STDMA recommended parameters and settings for cooperative ITS; Access Layer Part"

[12] B. P. P. S. S. K. H. M. L.-a. Petri Luoto, "System Level Performance Evaluation of LTE-V2X Network," em European Wireless 2016; 22th European Wireless Conferece, Oulu, Finland, 2016

[13] Rec. ITU-R P.1411-9 (2017-06), "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz"

[14] Christoph Sommer, Stefan Joerer and Falko Dressler, "On the Applicability of Two-Ray Path Loss Models for Vehicular Network Simulation", IEEE Vehicular Networking Conference (VNC), 2012

[15] F. D. Christoph Sommer, "Using the Right Two-Ray Model? A Measurement-based Evaluation of PHY Models in VANETs," em 17th ACM International Conference on Mobile Computing and Networking (MobiCom 2011), Las Vegas, NV, 2011

[16] 3GPP TR 38.901 v14.3.0 (2017-12), "Study on channel model for frequencies from 0.5 to 100 GHz" R14," 2017