RSS improvement in VANETs by auxilliary transmission at 700 MHz

Adrian Abunei[1], Ciprian-Romeo Comsa[1,2], Ion Bogdan[1]
aabunei, ccomsa, bogdani @ etti.tuiasi.ro
[1] Telecommunications Dept., Technical University "Gheorghe Asachi" of Iasi, Romania
[2] Continental Automotive Romania SRL, Iasi, Romania

***Abstract*—Communication in Vehicular Ad-hoc Networks (VANETs) is standardized at frequencies around 5.9 GHz in Europe and USA. In this paper we demonstrate by simulation that using a supplementary lower frequency, e.g., around 700 MHz, the Received Signal Strength (RSS) is improved, enabling the communication in areas where obstacles obstruct the communication at 5.9 GHz.** [1]

I. INTRODUCTION

During the past few years, the inter-vehicular communications (IVC), through Vehicular Ad-hoc Networks (VANETs) gained increased interest as new applications have been and are proposed, [1, 2]. These applications can be divided into three categories: Safety, Information, and Entertainment. Applications related to safety demand reliable communication and extremely low transmission latency that cannot be achieved in existing communication networks, such as 3G or LTE ones. For instance, collision avoidance systems require transmission delays up to tens of milliseconds, much smaller than the ones guaranteed in advanced mobile networks. These low latency requirements can be achieved by IVC. However, the IVC reliability suffers due to phenomena typical to wireless communications. In particular, in urban and sub-urban environments, radio propagation effects can significantly reduce the range of radio transmissions. Moreover, of special interest is the case of signal loss due to shadowing caused by obstacles that often block the line of sight between communication nodes (vehicles or infrastructure nodes) [3, 4].

Currently, the Dedicated Short Range Communication (DSRC) standards encompass the IVC use the dedicated 5.9 GHz band, both in USA and Europe. In Japan the 700 MHz is used as it was available. Recently, in USA, there is interest, too, on exploring the white spaces within the 700 MHz spectrum, [5]. The 700 MHz frequency band offers a significant coverage advantage over current 5.9 GHz DSRC implementations. For an identical transmission power, a low-frequency signal has a greater range than a high-frequency one due to decreased free space attenuation and lower absorption by various building materials and obstructions. The range gain for the 700 MHz band over the 5.9 GHz one is about 8, when only free space propagation loss for the direct wave is considered [6]. Among the advantages of transmission at 5.9 GHz over the 700 MHz, we note the higher transmission rates capabilities, which however is not quite relevant for safety applications. In the same time, the 5.9 GHz band is less prone to inter-symbol interferences [5] and it has lower shadowing signal fluctuations [7]. However, the advantage of range gain for the 700 MHz band is expected to dominate. In order to prove the feasibility of our solution, VANETs were modeled and simulations were performed as presented in the following sections.

II. INTER-VEHICULAR COMMUNICATIONS

Specific frequency bands were allocated for the development of safety-related ITS (Intelligent Transportation Systems) applications. For example, the Federal Communication Commission (FCC) assigned 75 MHz of licensed spectrum at the 5.9 GHz band (from 5.850 to 5.925 GHz) for DSRC in the USA, divided in 7 channels, with one CCH (control channel) for safety messages. In Europe, the European Telecommunication Standard Institute (ETSI) adopted a spectrum allocation of 50 MHz (5.875-5.925 GHz) for DSRC ITS applications, divided in 5 channels, with one CCH. In addition to the 5.9 GHz DSRC band, Japan has recently allocated 10 MHz at the UHF - 700 MHz band (from 755 to 765 MHZ) for safety ITS applications. The 802.11p standard specifies a 10 MHz transmission bandwidth for OFDM signals. It uses 52 carriers and a subcarrier spacing of 156.25 kHz with guard intervals.

The Wireless Access for Vehicular Environment (WAVE) defines a complimentary architecture to the 802.11p one, which offers a standardized set of services that collectively enable secure V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) wireless communications. The IEEE 1609 WAVE consists of four standards. In Europe, ETSI TC ITS is paving the way towards ITS-G5 standard based on previously 802.11p one.

Beaconing has been identified as a communication strategy suitable for many challenging vehicular networking applications. It is standardized for the dissemination of safety critical information to be broadcast periodically at 1 to 25 Hz as cooperative awareness messages (CAMs) in Europe and as basic safety messages (BSMs) in USA. Every vehicle transmits CAMs to each other, providing information about its state such as speed, mobility, and location.

Typically, communication protocols are evaluated with network metrics such as goodput, latency, jitter, and, for wireless networks, channel load and collision rate.

---

[1] This work was funded in part by Continental Automotive Romania SRL, Interior Division Business Unit Body & Security, Iasi.

978-1-4673-7488-0/15/$31.00 ©2015 IEEE

III. SIMULATION FRAMEWORK

Simulation tools are widely used in research to verify ideas as an alternative to real testbeds. For VANETs, a simulation framework typically includes a Mobility simulator, a Network simulator and a Coupling simulator aiming at matching the first two. A comprehensive presentation of existing simulation frameworks is given in [8]. Among them, lately, the simulation framework formed by SUMO, OMNET++ and TraCi gained increased popularity [9]. SUMO (Simulation of Urban MObility) [10] is an open-source microscopic vehicular traffic simulator that models the behavior of every single vehicle in routes, as well as streets and intersections, interactions with other vehicles, junctions, multi-lane roads, traffic lights, etc.

In SUMO, road networks are XML files. These files can be generated by hand (by defining nodes and edges that connect them) or by importing data with different formats. With the data importing approach, typically Open Street Map (OSM) [7] is used because it provides free maps of almost all the world. SUMO includes several tools for map manipulation and for vehicular traffic generation.

OMNET++ is a discrete event simulation library and framework. Based on the OMNET++ simple or compound modules, different projects were developed aiming at building network simulators. Among them, MiXiM (MiXed siMulator) [11] is a modeling framework for OMNeT++ created to simulate mobile and fixed wireless networks. It offers detailed models of radio propagation, interference estimation and wireless MAC protocols. It defines several analogue models which add the influence of the channel on the transmitted signal, by adding an attenuation mapping (which defines the attenuation factors) to the signal. It also implements different physical and MAC layers models (CSMA, 802.11, etc.) and a special module whose aim is to decide if the incoming signal is correctly received. VEINS (Vehicle in Networks Simulation), [12] is a tool initially developed under INET Framework package for OMNeT++. Late versions are based on MiXiM, where wireless communications are modeled in a more detailed way. VEINS incorporates IEEE protocols approved for use in VANETs (namely IEEE 802.11p and IEEE 1609 WAVE) and models for obstacles that add the attenuation caused by buildings to the radio signal [13].

In order to couple the Mobility simulator – SUMO and the network simulator – OMNET++/MIXIM/VEINS, both of them are provided with dedicated interfaces. A generalized Traffic Control Interface (TraCI), which uses a command-response approach and a TCP connection are employed to ensure a bidirectional coupled simulation [14]. This way, the movement of the nodes in OMNET++ simulation is determined by the movement of vehicles in road traffic simulator SUMO. Nodes can then interact with the running road traffic simulation. OMNET++ provides build-in support for recording simulation data, via output vectors and output scalars.

The aim of this paper is to demonstrate the advantage of using supplementary lower frequency channels for transmission of safety critical messages in environments where the message exchange on 5.9 GHz channels is not feasible. Typically, this is the case of urban environments with many buildings acting as communication obstacles [4, 15]. Thus, the incorporated channel model and the obstacle models are of special interest. With the large scale effects in the vehicular wireless channel, the received signal strength (RSS) is given [7, 13, 16], by

$$P_r[dBm] = P_t[dBm] - L_{PL}[dB] - L_{Obs}[dB], \qquad (1)$$

where $P_t[dBm]$ is the transmitted signal power, $L_{PL}[dB]$ is the free path loss component, while the shadowing loss $L_{Obs}[dB]$ refers to loss of signal strength due to obstacles such as buildings in the surrounding area of the transmission. Small scale effects that refer to the Rayleigh or the Doppler effects are not considered. In VEINS, the propagation loss in free space of radio waves is [13]: $L_{PL}[dB] = 10\,\mathrm{lg}(16\pi^2 d^\alpha / G_t G_r \lambda^2)$, where G_t and G_r are the transmit and receive antenna gains respectively, and d is the distance between the transmitter and the receiver. One may observe the dependence of the path-loss on the carrier frequency f through its wavelength $\lambda = c/f$, c being the wave propagation speed. Also, one may note that the dependence on the distance is parameterized by the path-loss exponent α, that varies with the propagation environment [7]. In our simulations, carrier frequencies f of 5.9 GHz and 700 MHz are used, for which, in low density urban environments, $\alpha = 1.67$, and $\alpha = 1.54$, respectively, according to [7]. While typically the shadowing loss is expressed under the form of $L_{Obs}[dB] = 10\,\mathrm{lg}(X_\sigma)$, in VEINS a simple empirical formula is used: $L_{Obs}[dB] = \beta n + \gamma d_n$. This term is applied for the obstacles in the line of sight, and represents the additional attenuation that the signal suffers when it intersects n times the building's border and travels d_n meters inside it (see Figure 1.). The values of the two factors, $\beta[dB/wall]$ and $\gamma[dB/m]$ have been obtained by the authors of [13] which compared the results yielded by the above formula with measurement data for real vehicles equipped with IEEE 802.11p antennas. While their values differ for different types of buildings, for the vast majority of collected data, β is approximately $9\,dB/wall$ and γ is about 0.4 dB/m. Theses values are used in our simulations, regardless of the carrier frequency. By changing the carrier frequency from 5.9 GHz to 700 MHz, the path-loss term in (1), $L_{PL}[dB]$, is expected to give the highest impact on the improvement of the RSS, due to its quadratic dependence on the carrier frequency [7].

Figure 1. Screenshot from the VEINS simulator. Stars represent the intersection of the transmission line with the obstacles' walls.

IV. SIMULATION RESULTS

The simulation is run using the Iasi map, actually a specific area of the city of Iasi, Romania. The model of the terrain was directly imported into SUMO from *OpenStreetMap*. *OpenStreetMap* also collects data of other kinds like buildings, rivers, bus stops, etc. We use the *netconvert* tool to create road networks for SUMO. For extracting buildings from OSM data we use the *polyconvert* tool. In order to generate vehicular traces we use a tool included in the SUMO suite: a Python script called *randomTrips.py*. RandomTrips distributes evenly in time the generated trips between specified starting and ending moments. The script chooses randomly the origin and the destination edges in the map. This program then creates a trip XML file that can be used with DUAROUTER, another program of the SUMO suite that builds the route files (one of the simulator's input files) connecting those edges. The number of vehicles that will circulate in the map is determined by the above mentioned starting and ending moments and an extra parameter that specifies the time interval between two successive departures. For the chosen map, we created a route file with a series of 30 vehicles starting every 3 seconds, from “Palas” parking lot, going on “Sf. Lazar” Street, then on “Smardan” Street and ending in “Iulius Mall” parking. We placed an RSU (Road Side Unit) on the 15, “Sf. Lazar” Street. The simulation was successively run for the two frequency bands: 5.9 GHz and 700 MHz, respectively.

We assume that all the vehicles are equipped with 802.11p communication modules. Travel time is the approximate time that one vehicle needs to run a specific street segment and it is calculated as the street segment length divided by the maximum legal speed on that street.

We conducted 3 types of simulation:

1. All vehicles and RSU send and receive WSMs (Wave Short Messages) on the CCH channel frequency of 5.890 GHz. When an accident (or incident) happens, the implicated vehicle broadcasts a message containing the identifier for the type of message and its location. The vehicles which receive the *accident* signal are divided in three different categories based on the location of the accident and their location: a) vehicles that are not affected by the accident, b) vehicles affected by the accident, but cannot take any action, and c) vehicles affected by the accident, but are able to change their route.

The first category includes vehicles whose routes are not on the street with the accident and they ignore the messages. The second category includes vehicles on same street with the accident, but they are not able to change their route. The last category includes those vehicles that are not currently on the street with the accident, but that street is part of their route. This last category of vehicles can change their route in order to avoid the traffic jam. Figure 2. illustrates the case of an accident appeared on the “Smardan” street (car colored in red). One car of the second category (behind first one), unable to change their route, will enter a traffic jam. Four cars (colored in blue) of the last category avoid the street with the accident by changing their routes. All the other cars (colored in cyan) from the first category are not affected by the accident as they do not reach the street with the accident during the simulation time. This simulation demonstrates one benefit of V2V communication in solving traffic congestion.

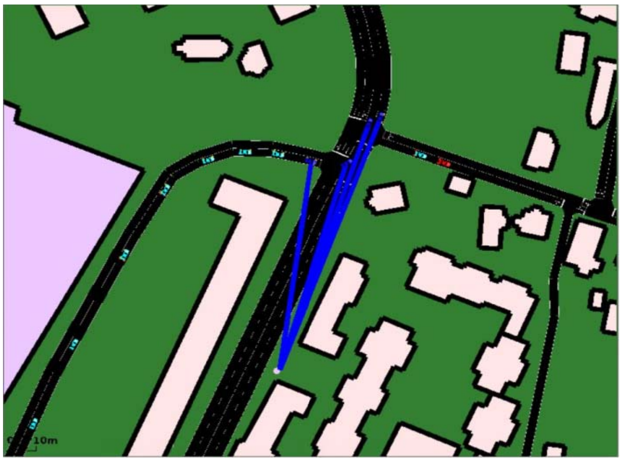
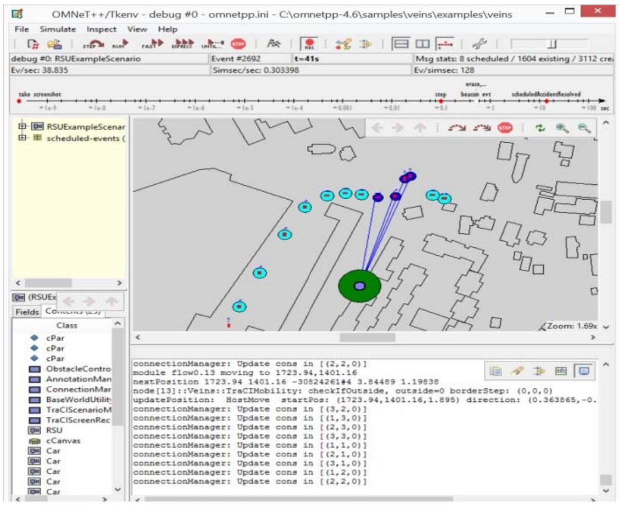


Figure 2. SUMO Map with cars that avoid congestion.



OMNeT++/Tkenv - debug #0 - omnetpp.ini - C:\omnetpp-4.6\samples\veins\examples\veins

debug #0: RSUExampleScenario | Event #2692 | t=41s | Msg stats: 8 scheduled / 1604 existing / 3112 cre

Ev/sec: 38.835 | Simsec/sec: 0.303398 | Ev/simsec: 128

```
connectionManager: Update cons in [(2,2,0)]
module flow0.13 moving to 1723.94,1401.16
nextPosition 1723.94 1401.16 -3082426104 3.84489 1.19838
node[13]::Veins::TraCIMobility: checkIfOutside, outside=0 borderStep: (0,0,0)
updatePosition:  HostMove  startPos: (1723.94,1401.16,1.895) direction: (0.363865,-0.
connectionManager: Update cons in [(3,2,0)]
connectionManager: Update cons in [(1,3,0)]
connectionManager: Update cons in [(2,3,0)]
connectionManager: Update cons in [(3,3,0)]
connectionManager: Update cons in [(1,1,0)]
connectionManager: Update cons in [(2,1,0)]
connectionManager: Update cons in [(3,1,0)]
connectionManager: Update cons in [(1,2,0)]
connectionManager: Update cons in [(2,2,0)]
```

Figure 3. Omnet++ canvas simulation for changing car routes.

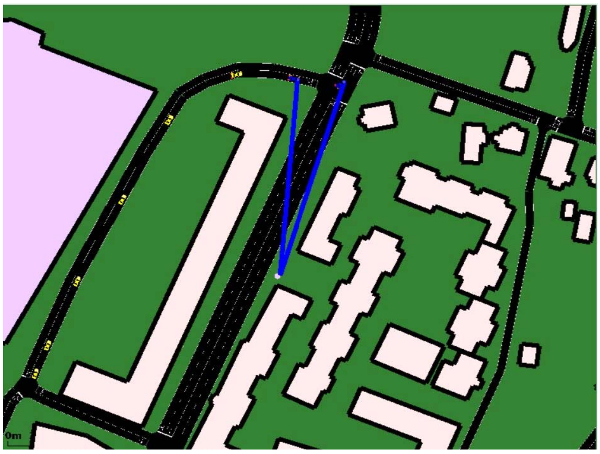
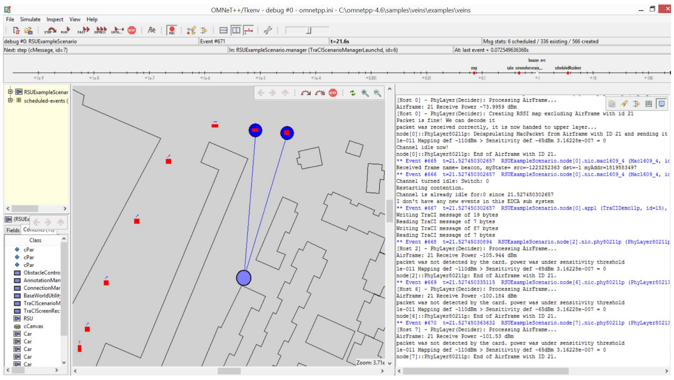


Figure 4. SUMO snapshot for 8 cars using 5.9 GHz frequency band.

2. Using obstacle model described in Section III, we employ simple beaconing, one-hop broadcasts, for exchanging safety critical information via DSRC 802.11p in 5.9 GHz.



```
[Host 0] - PhyLayer(Decider): Processing AirFrame...
AirFrame: 21 Receive Power -73.9959 dBm
[Host 0] - PhyLayer(Decider): Creating RSSI map excluding AirFrame with id 21
Packet is fine! We can decode it
packet was received correctly, it is now handed to upper layer...
node[0]::PhyLayer80211p: Decapsulating MacPacket from Airframe with ID 21 and sending it
1e-011 Mapping def -110dBm > Sensitivity def -65dBm 3.16228e-007 = 0
Channel idle now!
node[0]::PhyLayer80211p: End of Airframe with ID 21.
** Event #665  t=21.527450302657  RSUExampleScenario.node[0].nic.mac1609_4 (Mac1609_4, ic
Received frame name= beacon, myState= src=-1223252363 dst=-1 myAddr=1819583497
** Event #666  t=21.527450302657  RSUExampleScenario.node[0].nic.mac1609_4 (Mac1609_4, ic
Channel turned idle: Switch: 0
Restarting contention.
Channel is already idle for:0 since 21.527450302657
I don't have any new events in this EDCA sub system
** Event #667  t=21.527450302657  RSUExampleScenario.node[0].appl (TraCIDemo11p, id=15),
Writing TraCI message of 19 bytes
Reading TraCI message of 7 bytes
Writing TraCI message of 87 bytes
Reading TraCI message of 7 bytes
** Event #668  t=21.52745030894  RSUExampleScenario.node[2].nic.phy80211p (PhyLayer80211p
[Host 2] - PhyLayer(Decider): Processing AirFrame...
AirFrame: 21 Receive Power -105.944 dBm
packet was not detected by the card. power was under sensitivity threshold
1e-011 Mapping def -110dBm > Sensitivity def -65dBm 3.16228e-007 = 0
node[2]::PhyLayer80211p: End of Airframe with ID 21.
** Event #669  t=21.527450335115  RSUExampleScenario.node[6].nic.phy80211p (PhyLayer80211
[Host 6] - PhyLayer(Decider): Processing AirFrame...
AirFrame: 21 Receive Power -100.184 dBm
packet was not detected by the card. power was under sensitivity threshold
1e-011 Mapping def -110dBm > Sensitivity def -65dBm 3.16228e-007 = 0
node[6]::PhyLayer80211p: End of Airframe with ID 21.
** Event #670  t=21.527450363632  RSUExampleScenario.node[7].nic.phy80211p (PhyLayer80211
[Host 7] - PhyLayer(Decider): Processing AirFrame...
AirFrame: 21 Receive Power -101.53 dBm
packet was not detected by the card. power was under sensitivity threshold
1e-011 Mapping def -110dBm > Sensitivity def -65dBm 3.16228e-007 = 0
node[7]::PhyLayer80211p: End of Airframe with ID 21.
```

Figure 5. OMNET++ canvas for simulation of 5.9 GHz band.

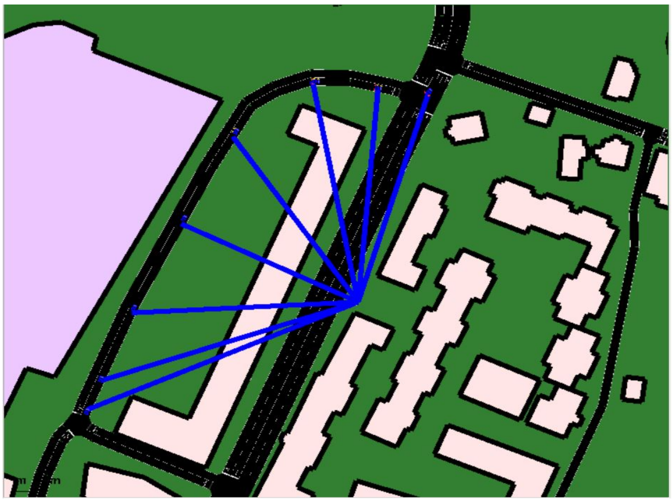
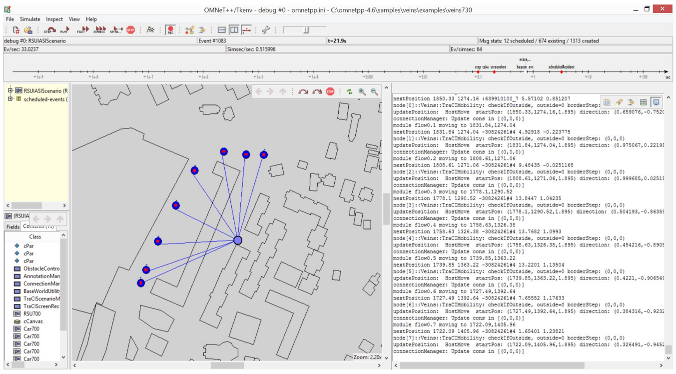


Figure 6. SUMO snapshot for 8 cars using 700 MHz frequency band.



```
nextPosition 1850.33 1274.16 :639910100_7 5.57102 0.851207
node[0]::Veins::TraCIMobility: checkIfOutside, outside=0 borderStep:
updatePosition:  HostMove  startPos: (1850.33,1274.16,1.895) direction: (0.659076,-0.752
connectionManager: Update cons in [(0,0,0)]
module flow0.1 moving to 1831.84,1274.04
nextPosition 1831.84 1274.04 -30824261#4 4.92918 -0.223775
node[1]::Veins::TraCIMobility: checkIfOutside, outside=0 borderStep: (0,0,0)
updatePosition:  HostMove  startPos: (1831.84,1274.04,1.895) direction: (0.975067,0.22191
connectionManager: Update cons in [(0,0,0)]
module flow0.2 moving to 1808.61,1271.06
nextPosition 1808.61 1271.06 -30824261#4 9.48435 -0.0251168
node[2]::Veins::TraCIMobility: checkIfOutside, outside=0 borderStep: (0,0,0)
updatePosition:  HostMove  startPos: (1808.61,1271.06,1.895) direction: (0.999685,0.02511
connectionManager: Update cons in [(0,0,0)]
module flow0.3 moving to 1778.1,1290.52
nextPosition 1778.1 1290.52 -30824261#4 13.8447 1.04235
node[3]::Veins::TraCIMobility: checkIfOutside, outside=0 borderStep: (0,0,0)
updatePosition:  HostMove  startPos: (1778.1,1290.52,1.895) direction: (0.504193,-0.8635
connectionManager: Update cons in [(0,0,0)]
module flow0.4 moving to 1758.63,1326.38
nextPosition 1758.63 1326.38 -30824261#4 13.7682 1.0993
node[4]::Veins::TraCIMobility: checkIfOutside, outside=0 borderStep: (0,0,0)
updatePosition:  HostMove  startPos: (1758.63,1326.38,1.895) direction: (0.454216,-0.890
connectionManager: Update cons in [(0,0,0)]
module flow0.5 moving to 1739.85,1363.22
nextPosition 1739.85 1363.22 -30824261#4 13.2201 1.13504
node[5]::Veins::TraCIMobility: checkIfOutside, outside=0 borderStep: (0,0,0)
updatePosition:  HostMove  startPos: (1739.85,1363.22,1.895) direction: (0.4221,-0.90654
connectionManager: Update cons in [(0,0,0)]
module flow0.6 moving to 1727.49,1392.64
nextPosition 1727.49 1392.64 -30824261#4 7.65552 1.17633
node[6]::Veins::TraCIMobility: checkIfOutside, outside=0 borderStep: (0,0,0)
updatePosition:  HostMove  startPos: (1727.49,1392.64,1.895) direction: (0.384316,-0.923
connectionManager: Update cons in [(0,0,0)]
module flow0.7 moving to 1722.09,1405.96
nextPosition 1722.09 1405.96 -30824261#4 1.65401 1.23821
node[7]::Veins::TraCIMobility: checkIfOutside, outside=0 borderStep: (0,0,0)
updatePosition:  HostMove  startPos: (1722.09,1405.96,1.895) direction: (0.326491,-0.945
connectionManager: Update cons in [(0,0,0)]
```

Figure 7. OMNET++ canvas for 8 cars using 700 MHz frequency band.

We transmit one beacon every second, only to/from RSU and we calculate RSSI for different location of cars. As seen in Figure 4. , only 2 cars (colored in blue) receive the beacon from RSU; all the others cannot receive the beacon due to obstacles (buildings). In Figure 5. on OMNET++ canvas, the two vehicles that received the beacon from the RSU are colored in blue, and lines are drawn indicating the correct reception of messages. The other cars did not receive messages from the RSU.

3. We use the same simulation framework, but we equipped cars with 700 MHz radio-communication transceivers, with same effective isotropic radiated power. As shown in Figure 6. and Figure 7. , when using 700 MHz frequency band, beacon messages were received correctly by all vehicles present in the simulation.

V. CONCLUSIONS

In this work, simulation results are shown to prove that using a supplementary frequency of 700 MHz has the potential to enable communication in areas where communication at 5.9 GHz is obstructed by obstacles. VANET simulations were carried out by implementing the necessary models for communication at 700 MHz in the VEINS framework (build on SUMO and OMNET++). The results provide strong arguments for continuing the work on adding the 700 MHz communication as a back-up for 5.9 GHz for the cases when the latter one fails.

REFERENCES

[1] T. Zhang and L. Delgrossi, *Vehicle safety communications: Protocols, security, and privacy* vol. 103: John Wiley & Sons, 2012.

[2] T. Kosch, C. Schroth, and M. Strassberger, and M. Bechler, *Automotive Internetworking* vol. 4: John Wiley & Sons, 2012.

[3] T. Abbas, K. Sjöberg, J. Karedal, and F. Tufvesson, "A measurement based shadow fading model for vehicle-to-vehicle network simulations," *arXiv preprint arXiv:1203.3370,* 2012.

[4] M. Boban, T. T. Vinhoza, M. Ferreira, J. Barros, and O. K. Tonguz, "Impact of vehicles as obstacles in vehicular ad hoc networks," *Selected Areas in Communications, IEEE Journal on,* vol. 29, pp. 15-28, 2011.

[5] R. Sevlian, C. Chun, I. Tan, A. Bahai, and K. Laberteaux, "Channel characterization for 700 MHz DSRC vehicular communication," *Journal of Electrical and Computer Engineering,* vol. 2010, p. 40, 2010.

[6] T. Tsuboi and T. Sekiguchi, "Optimization for Wireless Vehicular Network System in Urban Area," in *Communication Technologies for Vehicles*, ed: Springer, 2014, pp. 126-142.

[7] H. Fernandez, L. Rubio Arjona, V. Rodrigo, and J. Reig, "Path loss characterization for vehicular communications at 700 MHz and 5.9 GHz under LOS and NLOS conditions," in *IEEE Antennas and Wireless Propagation Letters, vol. 13, pp. 931-934,2014.*

[8] H. Noori, "Modeling and Simulation of Vehicle to Vehicle and Infrastructure Communication in Realistic Large Scale Urban Area," *Masters Thesis, Department of Electronic and Communication Engineering, Tampere University of Technology, Finland,* 2013.

[9] C. Sommer and F. Dressler, *Vehicular Networking*: Cambridge University Press, 2014.

[10] M. Segata, S. Joerer, B. Bloessl, C. Sommer, F. Dressler, and R. L. Cigno, "Plexe: A platooning extension for Veins," in *Vehicular Networking Conference (VNC), 2014 IEEE*, 2014, pp. 53-60.

[11] Köpke, Andreas, et al. "Simulating wireless and mobile networks in OMNeT++ the MiXiM vision." Proceedings of the 1st international conference on Simulation tools and techniques for communications, networks and systems & workshops. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2008.

[12] C. Sommer, R. German, and F. Dressler, "Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis," *Mobile Computing, IEEE Transactions on,* vol. 10, pp. 3-15, 2011.

[13] C. Sommer, D. Eckhoff, R. German, and F. Dressler, "A computationally inexpensive empirical model of IEEE 802.11 p radio shadowing in urban environments," in *Wireless On-Demand Network Systems and Services (WONS), 2011 Eighth International Conference on*, 2011, pp. 84-90.

[14] A. Wegener, M. Piórkowski, M. Raya, H. Hellbrück, S. Fischer, and J.-P. Hubaux, "TraCI: an interface for coupling road traffic and network simulators," in *Proceedings of the 11th communications and networking simulation symposium*, 2008, pp. 155-163.

[15] C. F. Mecklenbrauker, A. F. Molisch, J. Karedal, F. Tufvesson, A. Paier, L. Bernado, *et al.*, "Vehicular channel characterization and its implications for wireless system design and performance," *Proceedings of the IEEE,* vol. 99, pp. 1189-1212, 2011.

[16] S. M. Tornell, C. T. Calafate, J.-C. Cano, and P. Manzoni, "Accelerating vehicle network simulations in urban scenarios through caching," in *Performance Evaluation of Computer and Telecommunication Systems (SPECTS 2014), International Symposium on*, 2014, pp. 654-661.