Comparison between different technologies for vehicular communication

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***Abstract*—Millimeter Wave communication will be a key technology introduced by 5G cellular networks. Thanks to its high frequency, this kind of communication will enable networks with a datarate higher than the one offered by nowadays networks and a very low latency. Unfortunately, due to the high frequency, mmWaves suffer of high sensitivity to blockages and they require antennas with an extremely narrow beam with consequent difficulties in the alignment process. For this reason, other technologies will support mmWaves to ensure a good reliability also in case of harsh channel conditions at the cost of a lower datarate.**

In this work mmWaves are compared with LTE and IEEE 802.11p (DSRC) in order to show the pros and cons of each one, with a view to future applications in which these three technologies can cohexist.

***Index Terms*—mmWaves, Vehicular Networks, DSRC, LTE, ns3.**

I. Introduction

Vehicular communication will be a new promising technology that will be introduced with fifth generation cellular networks. In the near future, vehicles will communicate each other to share information regarding the surrounding environment or they will download information from Internet to allow services such as video streaming or navigation for autonomous cars. In this scenario each vehicle will send a lot of data over the network (in the order of terabytes per driving hour) and nowadays communication systems are not able to manage such a big amount of information [1].

For this reason several technologies (novel or well studied) have been proposed to replace or to support classic standards. Unfortunately each technology has pros and cons, mainly due to physical limitations, therefore the most recent researches try to make different technologies cohexist in order to exploit the efficiency of the network using the best technology in each moment [2].

This paper compares classical 4G communication (LTE), with millimeter waves (mmWaves) communication and Dedicated Short Range Communication (DSRC), two technologies that use a different spectrum and that offer a very different service, to find their key features and weaknesses while applied to a vehicular scenario. For mmWaves and LTE a Vehicle-to-Infrastructure (V2I) scenario is deployed in which a User Equipment (UE) communicates with its eNodeB while it is moving away from it. In the simulation, a dense urban scenario is considered. For DSRC, a V2I communication does not make sense since this type of technology is used mostly for direct communication, therefore a Vehicle-to-Vehicle (V2V) situation has been implemented. The results show how each technology can be used for specific applications depending on the amount of data shared and the required robustness of the communication.

In the next section the state-of-the-art of the multi-connectivity problem is briefly reported, then in Section III the structure of the simulator used is described, in Section IV the obtained results are showed and commented and finally in Section V conclusions are drawn.

II. Related Work

Vehicular networks have been studied for years to increase the safety in the streets, to make driving an easier task (with devices like navigators or obstacle sensors) or simply to increase the level of entertainment inside the vehicle. In the last few years, a lot of companies in the automotive industry tried to install communication modules in their cars to enhance the communication capability with the external environment, the technology that presented the most suitable features has been DSRC. Toyota in [3] presents some situation in which V2I and V2V communication would be desirable, their goal is mostly to increase the safety in the streets. In [4], the company introduces V2V communication in one of its products to share information with other equipped cars that can be used to alert drivers to upcoming potential hazards. In both these solutions, DSRC is used as enabling technology.

The next step in this field will be to exploit the potential of hybrid networking. The motivation for this approach is given by the availability of several communication modules inside the commercial vehicles. Each technology has different characteristics in terms of signal propagation, bandwidth and cost, the goal is to design a system that changes the kind of communication when needed.

Ylianttila et al. [5] propose an algorithm to switch between cellular and Wi-Fi networks. The vehicle's position is updated using GPS signal. Once the vehicle enters the coverage area of a Wi-Fi hotspot, radio signals from the access point are probed and handover towards Wi-Fi network is made only if the received signal's strenght is above a certain threshold.

Wang et al. [6] employ a decision tree to decide when is convenient make handoff towards Wireless Access in Vehicular Environments (WAVE) and Worldwide Interoperability for Microwave Access (WiMAX) from third generation cellular network. When a vehicle enters in a new access point coverage area, it feeds the decision tree with some predetermined metrics such as network statistics, type of service required or

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the speed of the vehicle to compute the probability to make handoff.

In [7] a novel approach to the problem is proposed, in which interface selection is controlled by a remote central server. The server provides vehicles with recommended interface selection strategies optimized based on statistical knowledge. The vehicles would normally follow server's directives, they can take some controlled decision whenever the actual channel conditions deviates from the statistics on the server.

In this paper we extend the previous work making a comparison between DSRC, mmWaves and 4G cellular networks in a vehicular scenario, searching for the strenghtness of each technology.

III. Simulation framework

To compare different communication technologies, the authors developed three independent scenarios using WAVE, LENA and mmwave module for *ns-3*. The latter is not in the official release but has been developed by University of Padua toghether with New York University (NYU) as an extension of lte module to allow realistic simulations also for higher frequency applications.

The simulation's scenario is slight different for DSRC and the other two technologies. In a realistic scenario, DSRC is used mostly in direct V2V communication, LTE is more suitable for a V2I communication and mmWaves can be used both in a V2V communication (assuming the vehicles are in line of sight and close to each other and assuming good enough environment conditions) and a V2I one. Nevertheless, in this paper mmWaves is considered only for V2I communication.

A. DSRC

To simulate the robustness and the feasibility of DSRC in our application, two vehicles have been positioned in Line-Of-Sight (LOS), they do not move during the simulation and their distance is increased from a minimum of 2 meters to a maximum of 200 meters. This scenario takes into account both the case in which the cars are actually stopped and when, instead, the cars are moving with the same velocity and the same direction.

A vehicle sends to the other 1000 bytes packets using UDP and 3 different inter-packet intervals: $8\mu s$, $80\mu s$ and $0.8s$, that correspond respectively to the datarates: $1Gb/s$, $100Mb/s$ and $10kb/s$.

The simulation has been made using the WAVE module of ns-3 that implements the core features of DSRC standards suite [8].

B. LTE

LTE is the most used technology in the 4^{th} generation cellular networks, therefore is used as backup technology in case DSRC or mmWaves are not usable due to environment conditions, the requirements of the application to use or any other reason.

The scenario implemented to simulate the behavior of LTE is a square area 500 meters wide in which 6 buildings and 4G LTE base stations (eNodeB) (i.e. the LTE base stations in 3GPP New Radio (NR) terminology) are randomly positioned. The number of eNodeBs positioned in the area increases from 3 to 40. This high density of base stations is irrealistic for LTE, since each eNodeB can give a coverage up to several km, but is used anyway to have data comparable with mmWaves' simulations. User moves from (100, 490) along x axis with a velocity of $30m/s$ for 10 seconds. During the simulation, it receives 1400 bytes packets from the closest eNodeB at a rate of $1.12Gb/s$. An example of a simulated scenario is shown in Fig. 1.

Handovers are made from an eNodeB to another if needed to receives in each moment the best signal possible. *LENA* module of ns-3 has been used for the simulation.

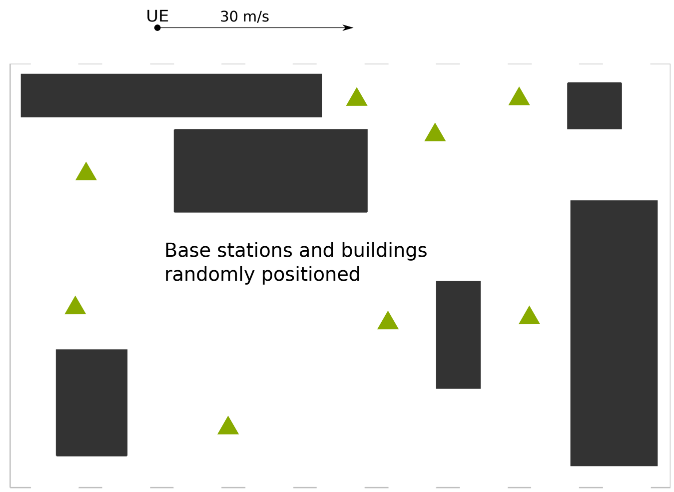

Fig. 1: Example of a simulation scenario, eNodeBs and buildings are generated randomly in the designated area.

C. mmWaves

The solution adopted to simulate mmWaves is the same used for LTE, this time 40 Next Generation Node Bases (gNB) (i.e. the mmWaves base stations in 3GPP NR terminology) in a square area 500 meters wide is a realistic scenario since each gNB has a very small coverage area due to the blockage problem of high frequency technologies.

For this part, an ns-3 module implemented by University of Padua and NYU has been used [9], that implements the PHY and MAC layer of mmWaves in a modular and higly customizable manner.

IV. Results

A. DSRC

In the scenario described in III-A, Montecarlo simulations have been performed, 15 runs for each distance and for each data rate have been simulated using each time a different random number generator's seed. The results have been elaborated to analyze mean throughput, mean latency, mean Signal-to-Noise Ratio (SNR) and Bit Error Rate (BER). The outcoming is plotted in Fig. 2, Fig. 3, Fig. 4 and Fig. 5.

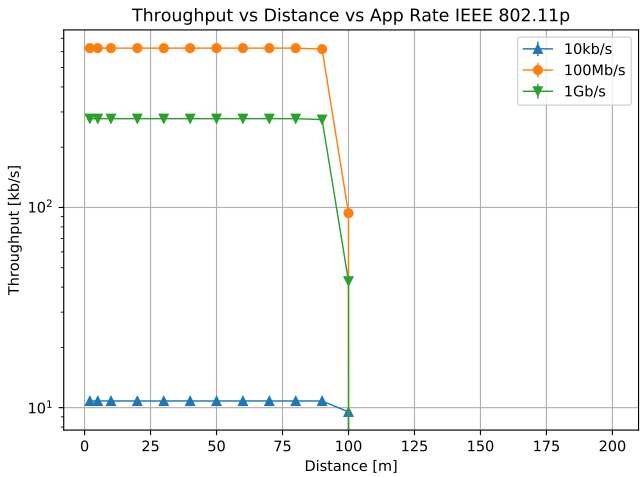

Fig. 2: Throughput comparison for 3 different application data rates

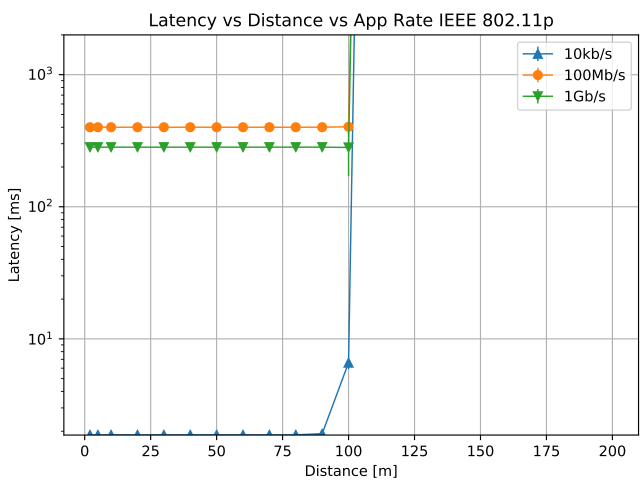

Fig. 3: Latency comparison for 3 different application data rates

Looking at the throughput, the only data rate well supported by this technology is the lower one, $10kb/s$, indeed the usual datarates available for DSRC are 6, 9, 12, 18, 24, and 27 Mbps with a 10 MHz bandwidth or 6, 9, 12, 18, 24, 36, 48, and 54 Mbps with 20 MHz bandwidth. In this simulation a 10 MHz channel has been used with a physical datarate of 6Mbps. In the case of the lower application datarate, the actual datarate of the communication is slight higher than $10kb/s$, for higher application datarates the physical datarate reached during the transmission is $200kb/s$ for the communication at $1Gb/s$ and $500kb/s$ for the other one, dramatically lower than the application datarate.

Comparing these results with the latency and the BER, can be seen as they are approximately 0 for the lower datarate, while for the higher ones, the latency is around 250ms and the BER is close to 1. The BER for the simulation at $100Mb/s$ is slight lower than the one measured at $1Gb/s$, this implies

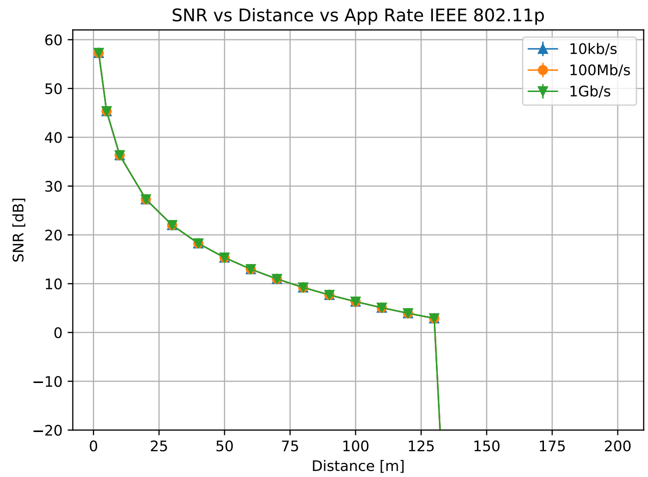

Fig. 4: SNR comparison for 3 different application data rates

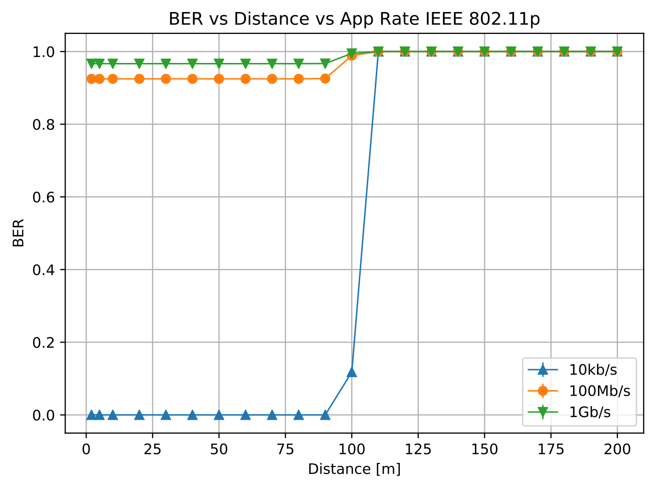

Fig. 5: BER comparison for 3 different application data rates

that the MAC layer of the transmitter has elaborated and sent successfully more packets at the cost of a very high latency. In the higher frequency case, less packets are sent successfully by the transmitter and so the latency measured at the receiver is a bit less.

This is only a matter of representation since the BER demonstrates as almost all the packets are lost.

With a distance higher than 100 meters, the SNR is too low and a communication is impossible, indeed the throughput after 100 meters is 0, the latency and the SNR are not defined and the BER is equal to 1.

B. LTE and mmWaves

Also in this part of the work, Montecarlo simulations has been used with 36 runs for each value of λ_{bs} (the base station's density in the simulation area) in the case of mmWaves and 18 runs in case of LTE.

The metrics here presented are mean throughput, mean latency, BER and Signal-to-Interference-plus-Noise Ratio (SINR), plotted respectively in Fig. 6, Fig. 7, Fig. 9 and Fig. 8.

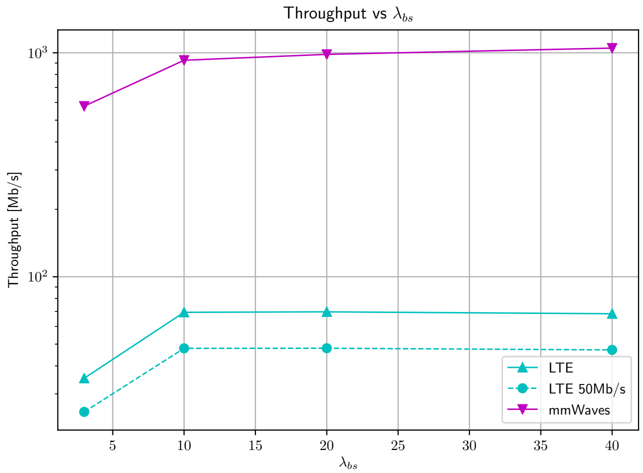

Fig. 6: Throughput comparison for LTE and mmWaves

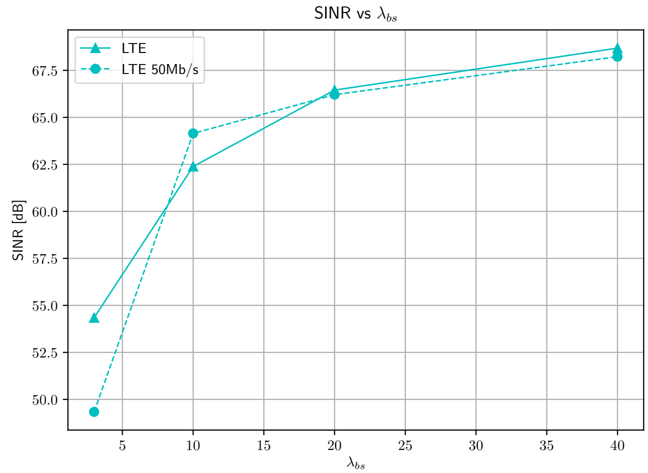

Fig. 8: SINR comparison for LTE and mmWaves

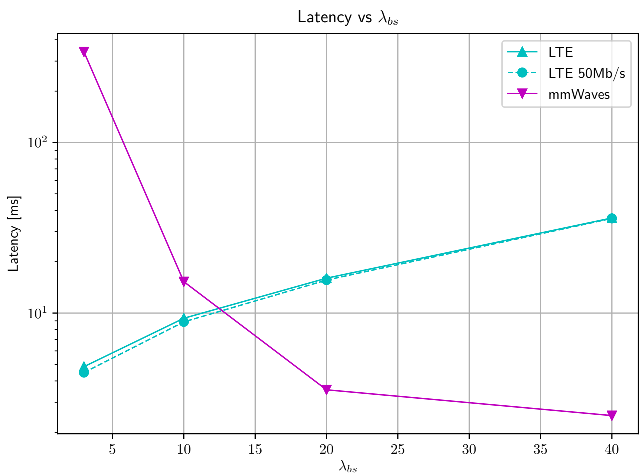

Fig. 7: Latency comparison for LTE and mmWaves

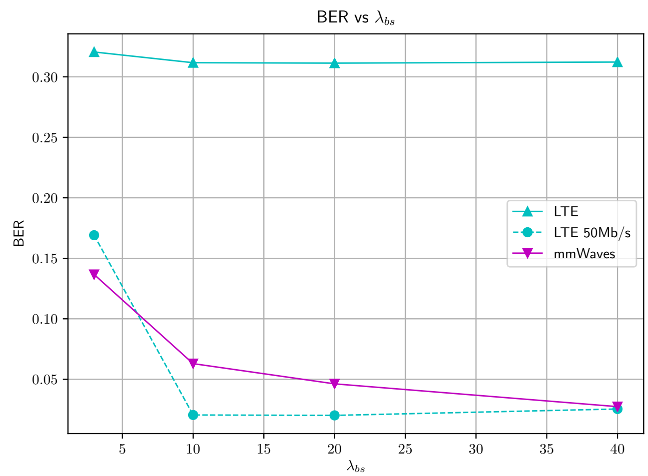

Fig. 9: BER comparison for LTE and mmWaves

In all the plots, the confidence intervals are not plotted since they are really big due to the fact that more simulations are needed to reduce the variance on data. Unfortunately, given the high density of base stations, the simulation time is long and does not allow a large amount of runs.

Even with a reduced number of simulations, can be seen as using mmWaves, the throughput is increasing with the number of gNBs per km^2, while the latency and the BER have the opposite behavior. LTE latency is increasing with the number of Base Station (BS) for any datarate used, this is probably due to the high interference suffered by this technology in presence of such an high number of BS in a small area. Looking at the throughput plot, can be seen as with a large amount of BS, LTE's throughput decreases. This is due to the interference between the BS. This does not happen using mmWaves since the transmission is directional and the interference is negligible.

In presence of few base stations (in this case 3 base stations is the minimum density simulated), the UE can be often in Non-Line-Of-Sight (NLOS) because of the distance from the closest base station or the presence of buildings between the UE and the BS. In these case, mmWave suffers of an high blockage phenomena and, in most cases, it is unable to enstablish a connection in NLOS, while LTE can still communicate given its lower frequency. As the density increases, UE can be often make handover towards a BS that ensures a more reliable communication, with a consequent decrease of the mean BER.

Looking at the BER plot, LTE has high values using 1Gb/s as application datarate, while is lower and decreasing for lower datarates. This shows how LTE can not afford such an high datarate.

In the following, an example of a single run for LTE and mmWaves is showed. A user is moving in the same scenario used before with 3 BS and 6 buildings. Fig. 10 and Fig. 11 show a mmWave run in which for the first 2.5 seconds the UE is in NLOS, from 2.5 to 4.5 seconds UE is in LOS and receives all the packets while for the remaining time it is in outage and no packets are received. In the LTE run, Fig. 12 and Fig. 13 show that the throughput and the latency are almost constant despite the buildings, since LTE uses a lower frequency. They have an abnormal behavior after 4 seconds since the UE is moving and it goes in NLOS. From 5 to 10 seconds no measures are taken, since the UE is in outage.

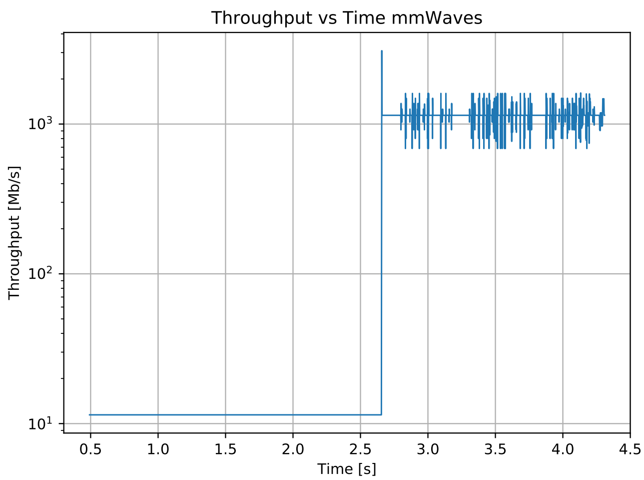

Fig. 10: Throughput registered in a single run using mmWaves

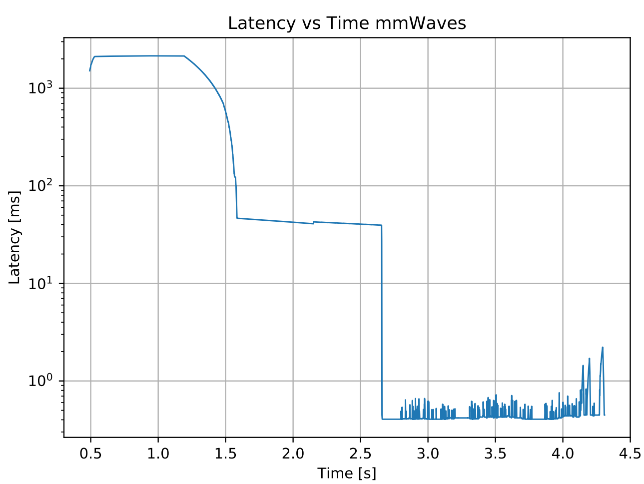

Fig. 11: Latency registered in a single run using mmWaves

V. Concluding Remarks

In this paper, a comparison between DSRC, LTE and mmWaves has been made, enhanching the pros and cons of each technology. The conclusions that can be drawn from this work are that each technology is suitable for a set of applications depending on the environment and the datarate. DSRC uses the classic IEEE 802.11 frequency band (5.9 GHz), therefore can be suitable for a dense urban environment, at the cost of a low datarate, since has been found that also data rates such as $100 Mb/s$ are too high for this kind of communication.

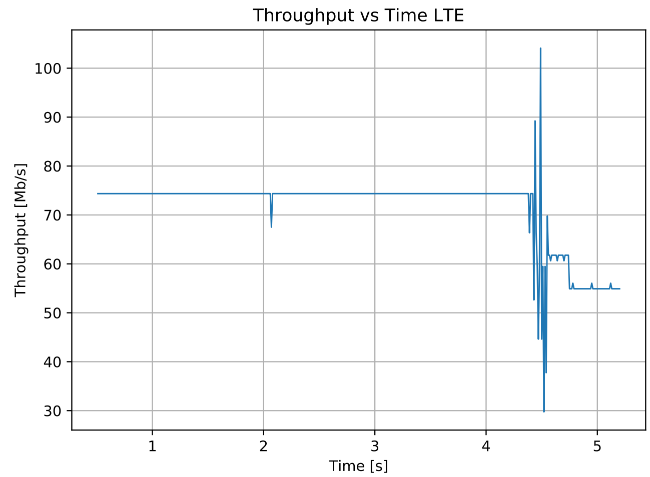

Fig. 12: Throughput registered in a single run using LTE

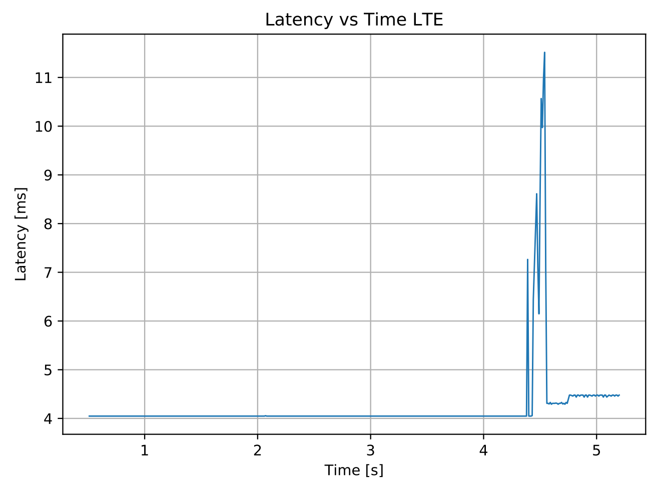

Fig. 13: Latency registered in a single run using LTE

Having a lower frequency allows also a larger antenna's beam, that makes this technology deployable in a V2V scenario.

mmWaves can afford very high data rates without losing packets, but it suffers of an high sensitivity to blockages like buildings or even vehicles or people. For this reason is less suitable than DSRC for a V2V scenario, but is a great choice in a V2I one with BS in LOS.

The last technology, LTE, is the trade off between DSRC and mmWaves, since it uses a low enough frequency (less than 10GHz) to be robust to blockages but it can not communicate at the data rates used by mmWaves. For this reason is a good backup solution where mmWaves BS are too far or in NLOS and a reliable communication is needed.

In the future, more simulations can be made to reduce the Confidence Intervals (CI) and have more statistically robust results. The next step on this field is to choose in which context can be used a technology instead of another and how to switch from mmWaves to LTE and DSRC without losing connection.

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