Prediction based framework for Vehicle Platooning using Vehicular Communications

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***Abstract*—One of the major advantages of V2V communication for development of vehicle platooning system is the low latency of message transfer between the vehicles as compared to the recognition by the sensor systems. The low latency allows the following vehicles to predict the trajectory of leading vehicle and plan the required control actions in a very short time. In addition, V2V communication can be effectively used in scenarios where the field of view of sensor systems is limited such as fast lane change or turn maneuver. In this paper, we focus on the development of such a vehicle platooning system based only on V2V communication between vehicles and evaluate the effect of communication latency and reliability on the performance of the system. Vehicle tests using prototype hardware for 5G-V2X and 802.11p communications show the effectiveness of the approach.**

Keywords: vehicle platooning; 5G-V2X; 802.11p; model predictive control (MPC); vehicular communication

I. Introduction and Related Work

The development of vehicle platooning system has recently been of wide interest since it offers to reduce traffic congestion by more efficient use of road network and minimizing the fuel consumptions by allowing vehicles to drive with smaller time gap between them. Systems based both on sensors and V2V communications have been investigated in literature. In [1] and [2] lateral control of vehicle platoon using forward looking sensor system i.e. camera, radar etc. has been achieved. The sensor systems were used to recognize the action of leading vehicle and plan the required control actions. In EU project SARTRE [3] forward looking sensor i.e. radar has been used in addition to V2V communication for the vehicle platooning system. Communication was based on 802.11p and the information between the vehicles was exchanged as UDP/IP packets. PATH [4] and Energy ITS [5] projects also focus on the development of vehicle platooning system based on both vehicle On-board sensors and V2V communication to achieve efficient traffic flow and minimum fuel consumption.

II. Motivation and Contribution of research work

Literature survey suggests that platooning based on V2V communication has the advantage that large latency due to recognition by sensor systems can be eliminated. Since information is directly transferred via V2V communication, the uncertainty involved in the recognition by sensor systems is also removed, thereby enabling faster and precise control of the vehicle. In this work we focus on the development of vehicle platooning system based only on V2V communication and differential GPS for vehicle localization. In addition, since V2V communication is associated with a certain latency and packet loss rate, effect of both the parameters has also been evaluated on the performance of vehicle platooning system. Prototypes based on 5G-V2X and 802.11p communications have been used to portray the effectiveness of V2V communication in this field and compare the two V2V technologies in terms of latency and reliability. The paper is structured as follows: section III presents the different V2X technologies relevant for this work, followed by system configuration and architecture. The section also presents the cooperative awareness message (CAM) and control algorithm used in this setup. In section V and VI the results of simulation and vehicle tests are presented, followed by conclusion and future work.

III. Overview of V2X Technologies

A. 5G-V2X

5G wireless standard needs to fulfill the future demands of connected autonomous vehicles. The autonomous vehicles are expected to communicate with other vehicles and cellular network without any human intervention and hence ultra high reliability and low latency communication (uRLLC) is essential for critical communication to ensure driver's and passenger's safety [6]. Thus the 3GPP RAN1 NR (New Radio) wireless standard for 5G needs to satisfy connected vehicle ecosystem which contains bandwidth demanding application on one side and uRLLC application on the other side. Reduction in nodes/protocol overhead is needed to deliver uRLLC data transmission on a short geo-location area and hence V2V communication over PC5 is the best solution for V2X application such as cooperative platooning. The release 15 SA1 technical report and specification on enhancement of 3GPP support for V2X services [7] were developed with focus on enhancements of V2X use case scenarios. Figure 1 shows the SA1 requirements on communication for different levels of vehicle automation, where the safety involved at each of the automation levels lay the stringent performance requirements for the communication delay and reliability.

Description		Payload (Bytes)	Tx rate (Message / Sec)	Max end-to-end latency (ms)	Reliability (%)	Data rate (Mbps)	Communication range (meters)
Among a group of UEs (or two UEs) supporting V2X application		50-1200	30	10			
		300-400	30	25	90		
Between UE supporting V2X application and RSU via another UE supporting V2X application		[50-1200]	2	500			
Between UEs supporting V2X application	Driver control	300-400		25	90		
	Fully automated driving	1200		10	99.99		80
Between UEs supporting V2X application	Conditionally automated driving	[6500]	50	[20]			[10] sec * (max. relative speed) [m/s]
	Highly/fully automated driving			[20]		[65]	[5] sec * (max. relative speed) [m/s]
Between UE supporting V2X application and RSU	Conditionally automated driving	[6000]	50	[20]			[10] sec * (max. relative speed) [m/s]
	Highly /Fully automated driving			[20]		[50]	[5] sec * (max. relative speed) [m/s]

Figure 1. Performance requirements for platooning [7]

B. ETSI ITS G5

ETSI ITS G5 [20] is the European profile for V2X communications based on the IEEE 802.11p standard, which specifies the physical layer in the 5.9 GHz bands. Several European Automotive OEM declared to introduce V2X communications based on ITS G5 in the near future [21]. Furthermore, since several projects founded by the European commission are dealing not only on research for future cooperative systems but also on the deployment on the European road network [22], this technology can be regarded market-ready. For this reason, a comparison of research prototypes for both 5G communications and for ITS G5 seems reasonable.

IV. System Architecture and Configuration

Figure 2 shows the configuration involving two vehicles. As seen in figure 2, the platoon leader obtains information regarding the vehicle states such as position, velocity, heading and yaw rate from high precision positioning system. This information is sent from leading to following vehicle over the communication module as a standard ETSI CAM message [8] with an additional container for vehicle platooning. The communication between the test vehicle has been realized using the 5G-V2X and 802.11p prototypes, while for the simulation purposes a mathematical model of the communication has been used. The vehicle data received by the following vehicle is used to predict and thus generate the trajectory of the platoon leader. The generated reference trajectory and vehicle state information available over vehicle CAN-bus is sent to Model Predictive Controller (MPC) for calculation of desired acceleration and steering angle to follow the vehicle in front. Acceleration and steering angle request is then sent to low-level vehicle controller that transforms it to a suitable command signal for actuators.

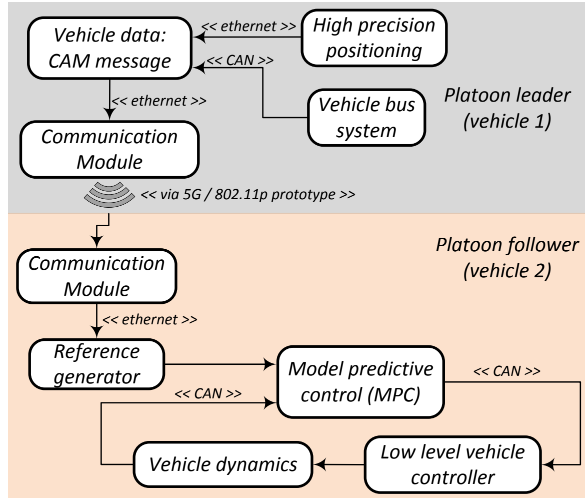

Figure 2. System configuration for vehicle platooning use case

A. V2V communications

As previously explained the information between vehicles is exchanged with a standard CAM message [8] with an additional container for vehicle platooning. The data fields in the container provide information to predict and thus closely follow the leading vehicle without the use of sensor data such as radar, laser scanner or camera. V2V communications has the advantage over the sensor systems that the vehicles can drive closely even in urban situations such as tight turns where the line of sight of sensors is limited or at distances larger than sensing capabilities of such systems. In this work the communication between the vehicles was unidirectional i.e. messages were sent only from platoon leader to follower. The CAM message used has been shown in table I and comprises of header, payload and platooning container. For realizing this use case, the CAM message was extended by the application-specific *platooning container*. Due to the ASN.1 structure (see below) backward-compatibility[1] to standard CAM messages is realized without additional effort.

The total size of CAM message is 70 bytes and an additional geo-networking header of 36 bytes was used for vehicle tests with 802.11p. The messages sent by leading vehicle were encoded as per the ASN.1 definition before being sent over to communication prototypes. The reader is referred to [19] for more information on ASN.1 definition. The messages received by following vehicle were decoded as per ASN.1 before being used for reference generation.

B. Control algorithm

The control algorithm used in this work is based on the concept of MPC [9]. Since the predictive nature and constraint handling capacity of MPC corresponds to way a real driver plans vehicle path, the concept of MPC can be effectively used for development of such autonomous systems. MPC is based

[1] A standard-compliant V2X receiver could easily decode all the CAM containers, except for the specific platooning container. Compared to other setups, a new application-specific message would not be accepted at all.

Name	Data Type	Size in Bits	Units
CAM Header			
MessageId	Integer	8	-
StationId	Integer	32	-
GenerationTime	Integer	16	-
Latitude	Integer	32	μ degree
Longitude	Integer	32	μ degree
Altitude	Integer	32	cm
CAM Payload			
LongitudinalAcceleration	Integer	16	m/s^2
VehicleSpeed	Integer	16	cm/s
VehicleLength	Integer	16	dm
VehicleWidth	Integer	8	dm
VehicleHeading	Integer	16	degree
VehicleYawRate	Integer	16	rad/s
CAM Platooning Container			
VehicleMass	Integer	32	dg
VehicleInertia	Integer	32	$dg.m^2$
VehicleLengthRear	Integer	16	cm
VehicleLengthFront	Integer	16	cm
$c_{\alpha F}$	Integer	32	-
$c_{\alpha R}$	Integer	32	-
AutomationEnabled	Bool	8	-
TargetVelocity	Integer	16	m/s
TargetAcceleration	Integer	16	m/s^2
BrakePedalPressure	Integer	8	bar
PositionRearAxleUTM$_X$	Integer	32	cm
PositionRearAxleUTM$_Y$	Integer	32	cm
VehicleSideSlipAngle	Integer	16	rad
DesiredAcceleration	Integer	16	m/s^2
CurrentSteeringAngle	Integer	16	rad

Table I
CAM MESSAGE COMMUNICATED BETWEEN VEHICLES

on the iterative, finite-horizon optimal control problem of model and comprises of a) dynamic model to predict behavior of the states and b) optimization problem consisting of set of constraints on inputs and states and cost function to be optimized (explained in next subsection) [9]:

1) System equations: In order to model internal dynamics of the MPC, a single track model for vehicle dynamics has been used, as shown in figure 3. The model comprises of following states namely: vehicle position x_s, y_s in UTM coordinates, velocity v_z, acceleration a_z, heading angle ψ_s, yaw rate $\dot{\psi}_z$ and side slip angle β, and the inputs are desired acceleration $a_{z,d}$ and steering angle of front wheels δ_{v_z}.

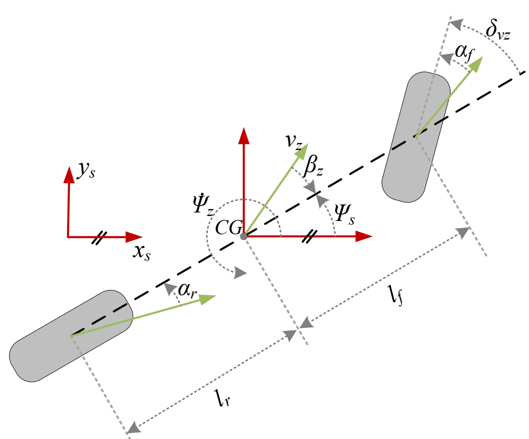

Figure 3. Single track vehicle model used for reference generation and optimization problem

The system equations are shown in eq. 1 and 2.

$$\dot{x}_s = v_z \cos(\beta_z)\cos(\psi_s) - v_z \sin(\beta_z)\sin(\psi_s) \tag{1a}$$
$$\dot{y}_s = v_z \cos(\beta_z)\sin(\psi_s) + v_z \sin(\beta_z)\sin(\psi_s) \tag{1b}$$
$$\dot{v}_z = a_z \tag{1c}$$
$$\dot{a}_z = -\tau_{a_z} a_z + \tau_{a_z} a_{z,d} \tag{1d}$$
$$\dot{\psi}_s = \dot{\psi}_z \tag{1e}$$
$$\ddot{\psi}_z = \left(\frac{-c_{\alpha v} {l_v}^2 - c_{\alpha h} {l_h}^2}{J_z v_z}\right)\dot{\psi}_z + \left(\frac{-c_{\alpha v} l_v + c_{\alpha h} l_h}{J_z}\right)\beta_z + \left(\frac{-c_{\alpha v} l_v}{J_z}\right)\delta_{v_z} \tag{1f}$$
$$\dot{\beta}_z = \left(\frac{-c_{\alpha v} l_v + c_{\alpha h} {l_h}^2}{m v_z^2} - 1\right)\dot{\psi}_z + \left(\frac{-c_{\alpha v} - c_{\alpha h}}{m v}\right)\beta_z + \left(\frac{c_{\alpha v}}{m v_z}\right)\delta_{v_z} \tag{1g}$$

$$\text{where: } x = \begin{bmatrix} x_s & y_s & v_z & a_z & \psi_s & \dot{\psi}_z & \beta_z \end{bmatrix}^T \tag{2a}$$
$$u = \begin{bmatrix} a_{z,d} & \delta_{v_z} \end{bmatrix}^T \tag{2b}$$
$$\dot{x} = f(x, u) \tag{2c}$$

Here the subscripts s and z denote the global and vehicle frame respectively. The optimization problem aims to minimize the objective function J subject to system dynamics and control constraints as described in eq. 3 and 4. Herein H_p is prediction horizon, $Q(i)$, $R(i)$ are state and control weighting matrices and $r_{k,t}$ refers to state-reference over a prediction horizon respectively. The state weighting matrices in J defines the relative importance of some states over the other and thus control the tracking performance of controller, while the control weighting matrices aims to minimize use of control action and thus smoothing the control inputs applied to the actuators. The output of the optimal control problem is $u^{\star}_{k,t}$, i.e. a vector of control inputs to be applied to vehicle to follow the trajectory of leading vehicle. The hard constraints on the optimization problem are shown in eq. 4 and model the safety and dynamic capabilities of vehicle. In receding horizon approach, first of these inputs is applied to the vehicle and the process is then iterated again to obtain a new optimal output.

$$u^{\star}_{k,t} = \min_{\tilde{u}_t} J(\tilde{x}_t, \tilde{u}_t) \tag{3a}$$
$$\text{where: } \tilde{x}_t = \begin{bmatrix} x_{i,t} & x_{i+1,t} & x_{i+2,t} & \dots & x_{i+H_p-1,t} \end{bmatrix} \tag{3b}$$
$$\tilde{u}_t = \begin{bmatrix} u_{i,t} & u_{i+1,t} & u_{i+2,t} & \dots & u_{i+H_p-1,t} \end{bmatrix} \tag{3c}$$
$$J = \sum_{k=i}^{i+H_p-1} \underbrace{||x_{k,t} - r_{k,t}||^2_{Q(i)}}_{\text{reference tracking}} + \underbrace{||u_{k,t}||^2_{R(i)}}_{\text{control minimization}} \tag{3d}$$

$$\text{subject to: } x_{k+1,t} = f(x_{k,t}, u_{k,t}) \tag{4a}$$
$$a_{z,d_{min}} \leq a_{z,d} \leq a_{z,d_{max}} \tag{4b}$$
$$\delta_{v_{z_{min}}} \leq \delta_{v_z} \leq \delta_{v_{z_{max}}} \tag{4c}$$
$$\beta_{z_{min}} \leq \beta_z \leq \beta_{z_{max}} \tag{4d}$$
$$\dot{\psi}_{z_{min}} \leq \dot{\psi}_z \leq \dot{\psi}_{z_{max}} \tag{4e}$$

In addition to the mathematical problem defined above, the parameter set and constraints used for MPC problem have been shown in table II.

Parameter Name	Setting	Parameter Name	Setting
H_p	2 s	control intervals N	50
integrator type	$RK4$	integrator steps	100
$a_{z,d_{min}}$	-0.7	$a_{z,d_{max}}$	0.7
$\delta_{v_{z_{min}}}$	-0.3	$\delta_{v_{z_{max}}}$	0.3
$\beta_{z_{min}}$	-0.08	$\beta_{z_{max}}$	0.08
$\dot{\psi}_{z_{min}}$	-0.6	$\dot{\psi}_{z_{max}}$	0.6

Table II
PARAMETER SET FOR THE MPC PROBLEM

One of the main challenges for implementation of such an optimization problem in test vehicle is its real-time feasibility. In order to deal with this issue of real-time feasibility, the optimization problem was implemented using the code generation features of ACADO toolkit. The reader is referred to [10] for more details on ACADO toolkit.

V. SIMULATION SETUP AND RESULTS

This section presents simulation results for vehicle platooning involving two vehicles. Since this work focuses to evaluate the performance of the vehicle platooning controller using V2V communications, two safety critical urban scenarios namely: fast lane change and turning maneuver have been considered. Since the latency and reliability of communication can have an impact on the performance of the vehicle platooning controller, this section also presents the effect of these parameters on vehicle platooning. The following two cases have been considered for simulation scenarios:

1) Case 1: $0ms$ additional latency and 100 % reliability
2) Case 2: $20ms$ additional latency and 90 % reliability

A. Simulation setup

For simulation purposes, the Dominion framework developed at DLR was used [18]. This framework provides code generation features coupled with a shared memory (Dominion Data Core), where all registered Dominion applications can access and interchange data. In addition the framework additionally provides GUI's for visualization (Figure 4) and test setup that were used for describing test cases and visualizing the behavior of the platooning controller using ACADO toolkit.

Figure 4. DLR Simulation viewer

For simulation purposes a simple mathematical model inducing the desired latency and reliability was used for communication while the vehicle platooning controller based on MPC problem has been implemented

B. Scenario 1: Lane change with two vehicles

Figure 5 shows lane change scenario involving two vehicles. Initially vehicles v_1 and v_2 drive in a straight line, where v_1 is guided by the simulation and v_2 by automation system i.e. platooning controller. Upon arrival near to the blocked lane, v_1 is guided by simulation to perform a lane change while v_2 performs lane change based on the information obtained from v_1.

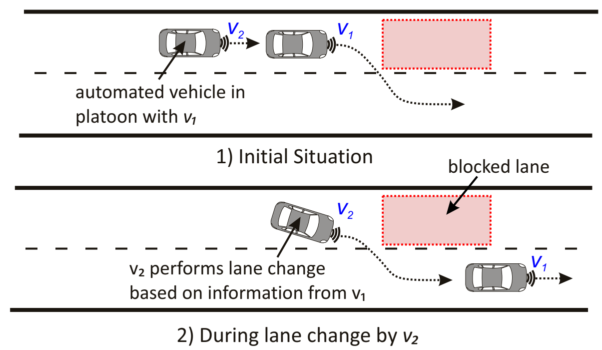

Figure 5. Lane change scenario in a vehicle platoon due to blocked lane

Figure 6 and 7 show position, velocity and heading angle of platoon leader can be closely followed in both the cases.

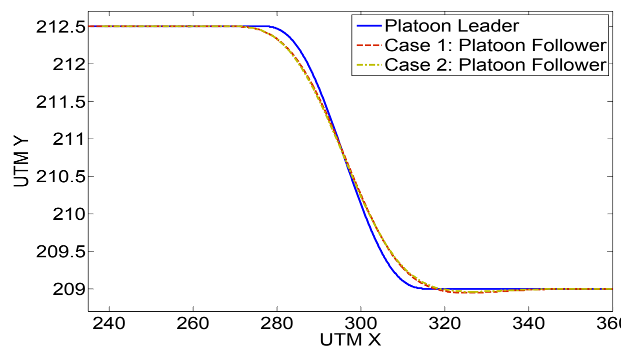

Figure 6. Position plot for lane change scenario at $13.33mps$

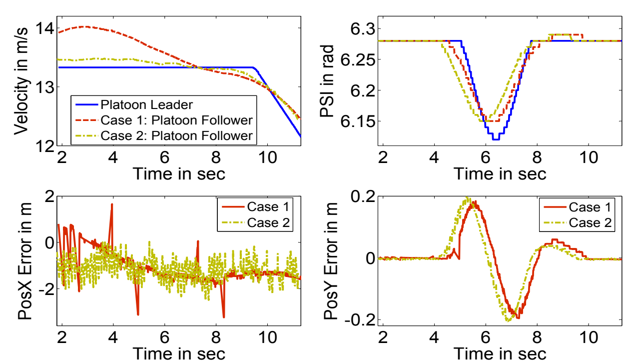

Figure 7. Velocity, heading and longitudinal and lateral error for lane change scenario at $13.33mps$ (meters per second)

The results depict that error in both the cases is of same order, a deviation between the velocities in cases is only seen because of differences in the initial velocity of the vehicles.

C. Scenario 2: Turn maneuver with two vehicles

Figure 8 shows the right turn maneuver involving two vehicles at $13.33mps$. As in previous section, v_1 is guided by simulation and v_2 by automation system. Initially the vehicles drive at a constant velocity of $13.33mps$, upon arriving near to the turn, v_1 slightly reduces its speed and turns right. Vehicle v_2 also performs the right turn maneuver based on the information obtained.

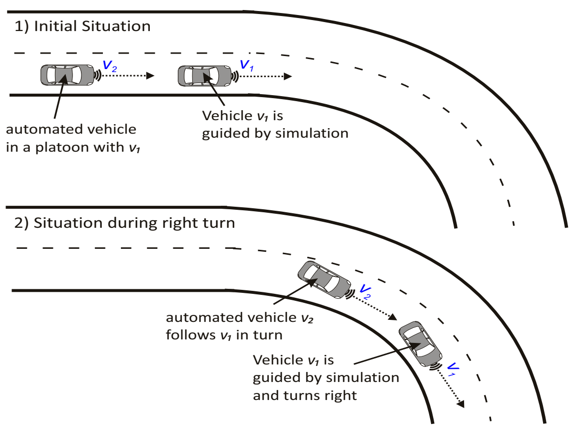

Figure 8. Right turn maneuver at $13.33mps$

Figures 9 and 10 show the position, velocity, heading and longitudinal/lateral error in both the cases. As in the previous case, results indicate that the following vehicle can closely follow the trajectory of vehicle in front for both the cases, but relatively smaller longitudinal error can be achieved in case 1, where there is no latency. Such a behavior is seen because in case 2, relatively old/delayed information of the vehicle in front is used to predict the vehicle position and speed and thus a bigger longitudinal error is seen.

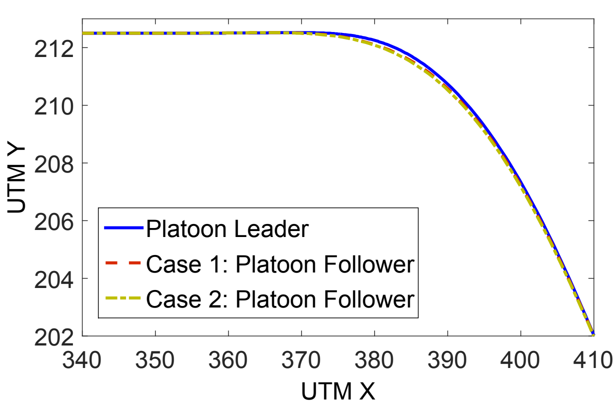

Figure 9. Position plot for right turn maneuver at $13.33mps$

Simulation results indicate effectiveness of the MPC based platooning controller using V2V communications. The results also indicate that latency and reliability of communication only

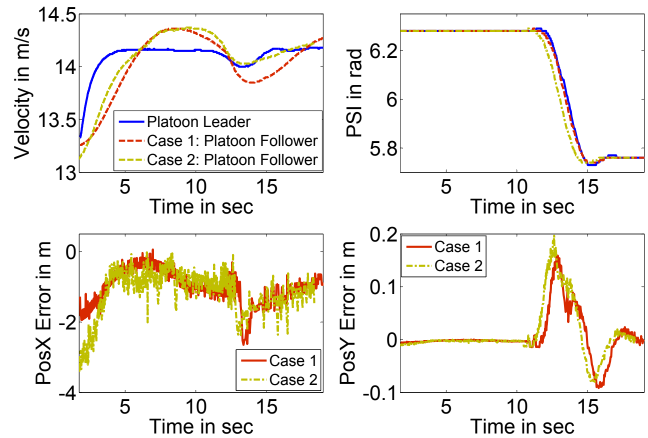

Figure 10. Velocity, heading and longitudinal and lateral error for right turn maneuver at $13.33mps$

play a minor role on the performance of the controller. Here it should be noted that results have been presented for a maximum latency and reliability of $20ms$ and 90% respectively, which are realistic values for the V2V communications as shall also be shown later during the vehicle tests.

VI. Test Vehicle setup and results

A. Automated cars platform

In order to test the effectiveness of the vehicle platooning controller in read driving situations, two DLR test vehicles were used. Each of the test vehicles are equipped with high precision differential-GPS with inertial measurement system for obtaining precise position, acceleration, heading angle and yaw rate of the vehicle. In addition each of the vehicles have access to its CAN-bus to obtain information about the current velocity, yaw rate, pedal position and steering wheel angle. Additionally, vehicles have the capability to be driven by the automation by sending command signals to the actuators [13]. The execution of automation processes including the platooning controller (every $30ms$), obtaining and filtering of GPS data and safety checks were performed on vehicle PCs. For communication using the 802.11p standards, each of the vehicle was equipped with a NEC LinkBird, development platform for vehicle communications. The communication hardwares used for the 5G-V2X and 802.11p are explained in next subsection.

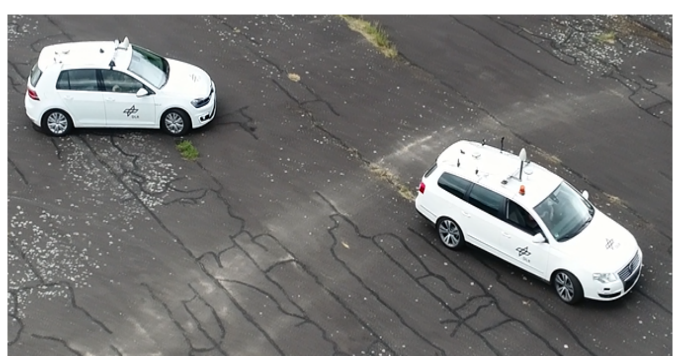

Figure 11. DLR test vehicles during the platooning use case

B. Communication Platform

The V2V communication was carried out using a 5G radio prototype based on the yet-to-be-standardized 5G-V2X interface optimized for vehicular communication [14]. The system is based on flexible and re-configurable software-defined radio and is optimized for low-latency and high-reliability [15]. The system parameters for the 5G-V2V prototype are shown in Table III. For the ITS G5 communications, we used a prototype hardware for V2X communications based on the Linkbird by NEC/Renesas. This prototype includes a software framework that realizes the geo-networking protocol specified by ETSI and allows for sending user-specific messages on the 5.9 GHz channel [16] [17].

Carrier Frequency	2.6 GHz
Bandwidth	10 MHz
MCS	QPSK, 1/3
TTI length	0.5ms
FFT size	256
CP length	64
Intercarrier Spacing	60 KHz
Number of symbols	17
Pilot spacing/Distribution	4 pilot symbols [1 6 12 17]
Waveform	P-OFDM
Transmit Power	8 dBm
Reception mode	Receive Diversity

Table III
5G COMMUNICATION PARAMETERS

C. Scenario 1: Acceleration and braking phase in straight line

In this scenario, the leading vehicle (manually driven in all scenarios) drives in a straight line and accelerates from 3-13.33mps and then brakes to standstill. Figure 12 show the position, velocity, longitudinal and lateral error for straight line driving. As seen in figure 12, platoon follower can closely follow the velocity profile of platoon leader during both acceleration and braking case. It should be noted that for safety purposes a time gap (1.6-2.0sec) was used and therefore a large longitudinal error is seen in the figure.

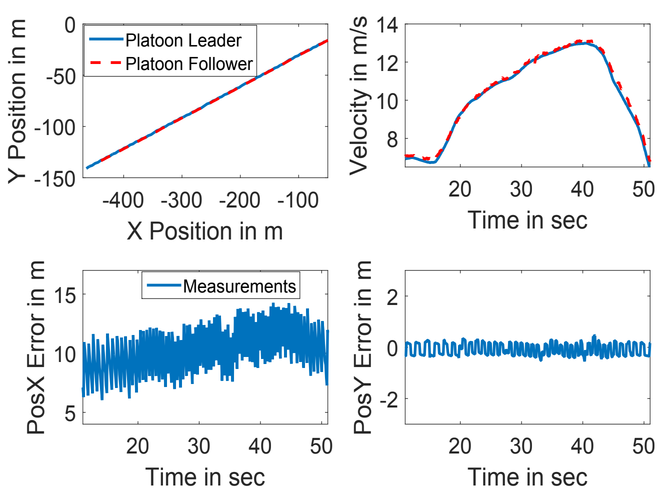

Figure 12. Position, velocity, longitudinal and lateral error for straight line driving using 5G-V2X

The desired acceleration and actual acceleration of the follower can be seen in figure 13. It can be seen that the acceleration and braking has been limited to 1 and 1.5$\frac{m}{s^2}$ respectively in order to remain within the acceleration allowed on DLR vehicles. Figure 13 also shows communication and total latency from sending of message from leader to processing this information for control action by follower. As can be seen, the communication latency has mean value of 1.6ms and total latency of 33ms, which is comparably smaller than that of sensor systems. Additionally standard deviation of 0.2ms has been seen for communication latency during the maneuver and a total of zero lost messages.

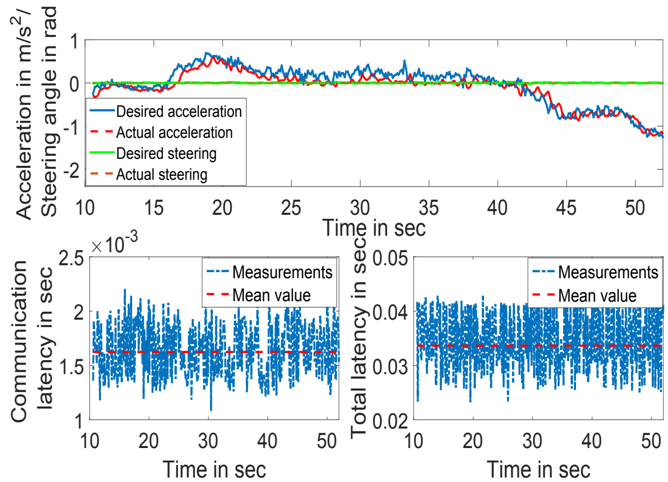

Figure 13. Longitudinal acceleration, steering angle and communication latency for straight line driving using 5G-V2X

D. Scenario 2: Sinus maneuver with two vehicles

In this scenario, the platoon leader drives in a sinus with a velocity of about 8.33mps. Figure 14 and 15 show the position, velocity, heading angle and position errors for this scenario. As can be seen in figures, platoon follower can closely follow the velocity and position of the vehicle in front. Figure 16 show acceleration, steering angle and communication latency during the maneuver. The results show that mean and standard deviation of communication latency during the maneuver are 2.5ms and 0.7ms, indicating that 5G-V2X technology is comparable or even more reliable than 802.11p.

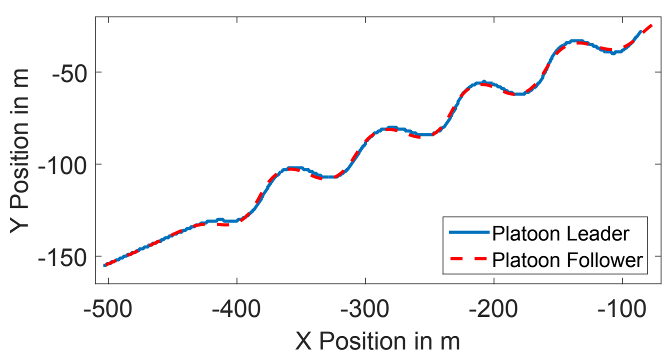

Figure 14. Position plot for maneuver using 802.11p

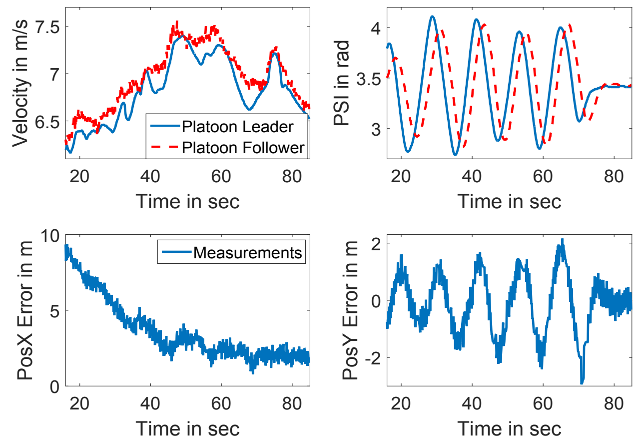

Figure 15. Velocity, heading and longitudinal and lateral error for sinus maneuver using 802.11p

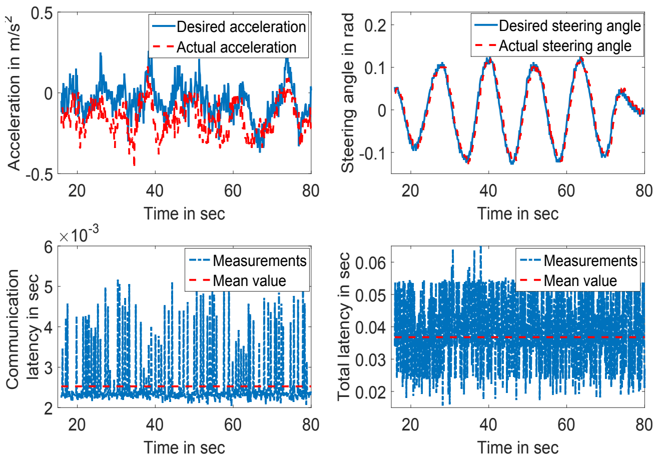

Figure 16. Acceleration, steering angle, communication and total latency for sinus maneuver using 802.11p

E. Scenario 3: Turn maneuver with two vehicles

In this scenario, platoon leader drives around on test track performing multiple turns to the right and follower closely follows platoon leader. Figure 17 and 18 show position, velocity, heading and longitudinal/lateral errors for the turn maneuver.

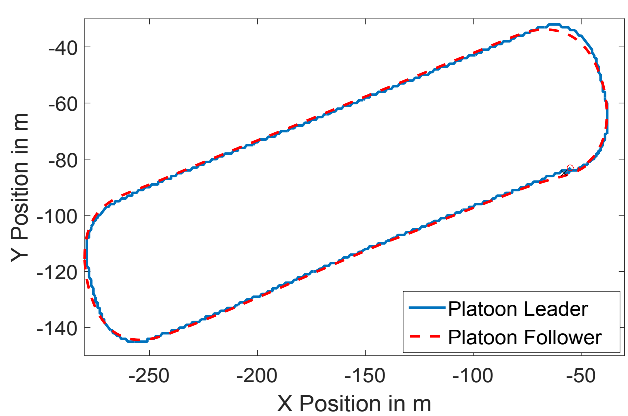

Figure 17. Position plot for right turn maneuver using 802.11p

As depicted from figures, platoon follower can closely follow the velocity and position of leading vehicle. The acceleration and steering angle have been shown in figure 19. As shown in figure 19, here also the communication and total latency (using 802.11p) has mean of $2.5ms$ and $34ms$ respectively.

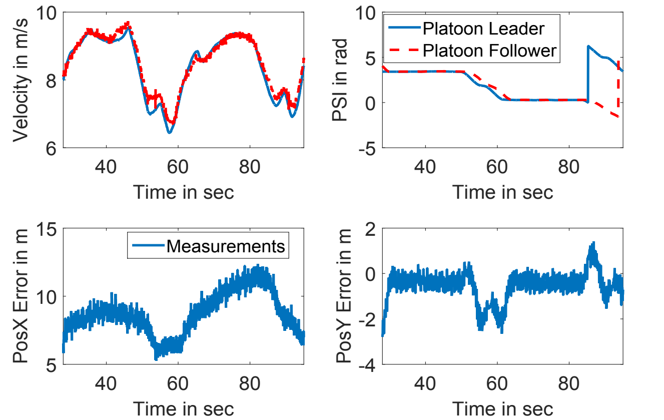

Figure 18. Velocity, heading, longitudinal and lateral error for right turn maneuver using 802.11p

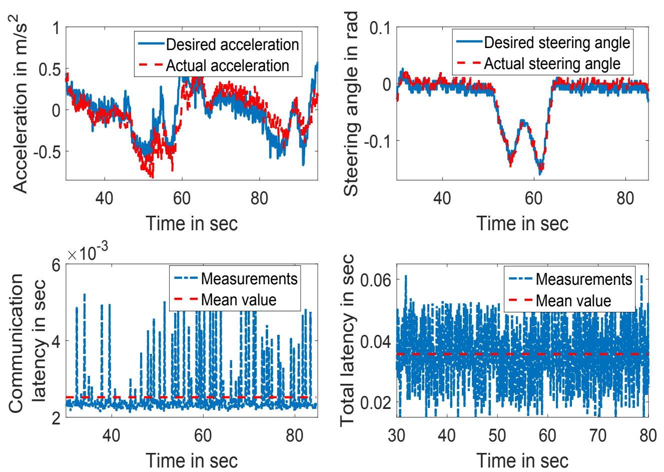

Figure 19. Acceleration, steering angle, communication and total latency for right turn maneuver using 802.11p

F. Performance evaluation of communication technologies

This subsection briefly gives an overview of the communication performance during different test runs. Table IV show results for 802.11p and 5G. The results here are based on all of the vehicle test performed i.e. approximately 500000 messages were evaluated for each of V2V prototype. As seen from table, the mean communication latency for 5G is 50 % smaller than that of 802.11p and a relatively large standard deviation for latency is seen in case of 802.11p. An additional comparison of the cumulative distribution function for 5G-V2X and 802.11p has been shown in figure 20.

VII. Conclusion and Future Work

In this work we presented vehicle platooning using the 802.11p and 5G-V2X vehicular communications. The simulation results indicated that vehicle platooning can be effectively

V2V Prototype	Mean	Standard deviation	Packet delivery rate (PDR)
802.11p	2.5ms	0.677ms	99.74 %
5G-V2X	1.6ms	0.437ms	99.53 %

Table IV
MEAN, STANDARD DEVIATION, AND MAXIMUM COMMUNICATION LATENCY FOR DIFFERENT V2V TECHNOLOGY

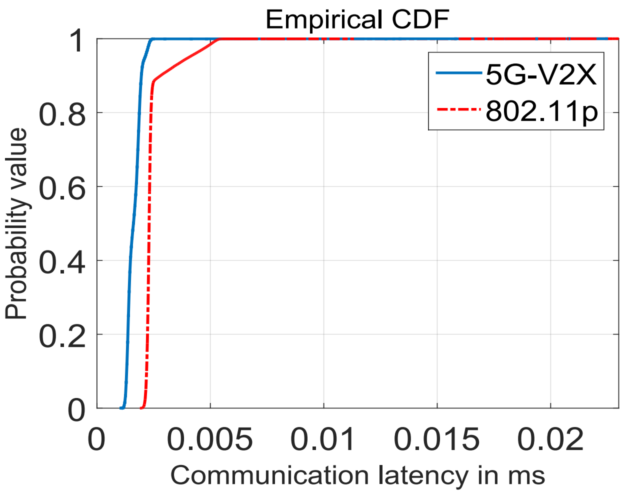

Figure 20. Cumulative distribution function for 5G-V2X and 802.11p

performed using vehicle communication for different real life scenarios. Results also indicate that latency and reliability in range of 0-20ms and 90-100% respectively, plays only a minor role on the performance of the controller, although higher latencies could potentially have a considerable effect on performance of the system. Vehicle tests performed using DLR vehicles also shows that vehicle platooning can be effectively performed using the following vehicular technologies namely 5G and 802.11p. Although 5G technology does not present any major advantages over 802.11p for use case presented here, analysis of vehicle test logs indicate a relatively reliable communication latency using 5G technology. The future work shall focus on exploiting the benefits of 5G such as larger data rate and communication range for the applications involving the communication between the vehicle and infrastructure in real life traffic situations such as crossing scenarios. The future work shall also focus on implementing bi-directional communication between the sender and receiver, for example in form of request and acknowledgment messages.

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