A Novel V2V Assisted Platooning System: Control Scheme and MAC Layer Designs

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Abstract*—Sensor based automated driving technologies, e.g., Adaptive Cruise Control (ACC), have been developed for many years in order to increase the traffic efficiency. Moreover, in the last decade, there has been a growing interest in further optimizing the traffic efficiency with the help from Vehicle-to-Vehicle (V2V) communications, e.g., Cooperative Adaptive Cruise Control (CACC). This paper investigates the utilization of V2V communication in platooning systems which is one fundamental application in future Intelligent Transport Systems (ITS). A novel V2V assisted platooning system is proposed in this paper, where a proposed prediction based control scheme is used to reduce the required intra-platoon gap under the stability constraint. Moreover, the impact of V2V communications range, delay and reliability on the performance of such platooning systems is discussed. Based on the distributed scheduling scheme in 3GPP Rel. 14 LTE-V2X sidelink (SL), a platoon based scheduling scheme is proposed to increase the intra-platoon V2V communication reliability.

I. INTRODUCTION

Many studies have shown the low efficiency of human driving system due to human distraction, delayed reaction, and inappropriate maneuver decision [1] [2] [3]. To eliminate human errors, many autonomous driving technologies have been developed [4]. Ultimately, fully autonomous driving system may replace human drivers, making and executing maneuver decisions automatically [5]. The concept of platooning systems has been brought up to increase the lane capacity, as one application in future Intelligent Transport Systems (ITS). In these platooning systems, fully automated vehicles in the same lane are able to form different platoons, in which vehicles are connected electronically and move together with a small inter-vehicle gap [6]. In general, on the one hand, with the same speed, a higher lane capacity can be reached with a smaller inter-vehicle gap, however, as a trade-off, the stability of traffic system decreases with the reduction of inter-vehicle gap. On the other hand, in order to avoid traffic jams and collisions, a minimum inter-vehicle gap is required to ensure the traffic system stability such that any oscillation is not amplified upstream the traffic flow [7].

Many control schemes are proposed to achieve small demanded inter-vehicle gap under the constraint of traffic flow stability. For instance, Adaptive Cruise Control (ACC) is a local sensor based control scheme, where via local sensors, one vehicle is able to detect the gap towards its preceding vehicle and the speed difference between them. The maneuver decision, i.e., acceleration in longitudinal cruise control, can be determined using the collected information, aiming at the desired speed and inter-vehicle gap [8]. Cooperative Adaptive Cruise Control (CACC) is developed on top of ACC. In CACC, vehicles not only collect information via local sensors but also from wireless communication. Specifically, in car-following scenarios, one vehicle can be aware of its preceding vehicle's acceleration via Vehicle-to-Vehicle (V2V) communication and use it as a reference value to determine its own acceleration [9] [10]. In addition, many studies have proved that CACC is able to maintain a smaller inter-vehicle gap than ACC under the same stability constraint [10] [11]. However, the performance of CACC suffers from communication delay since the received data is already out-dated when the maneuver decision is made. It is shown in [12] [13] [14] that with a high communication delay, CACC vehicles have to increase their inter-vehicle gap in order to keep the traffic system stable.

In terms of different V2V communication technologies, IEEE 802.11p is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism and has been standardized since 2010 [15]. LTE-V2X Sidelink (SL) was released in March 2017 as part of LTE 3GPP Rel. 14 to enable direct communication between User Equipements (UEs) and can be operated with or without the assistance of the eNodeB (eNB) [16]. When the vehicles (UEs) are in the coverage of eNB, eNB can perform resource scheduling of sidelink communication with global knowledge, which is known as centralized scheduling or mode 3 scheduling of LTE-V2X SL communication. Principally, the eNB can mitigate the interference problem by assigning UEs with diverse time and frequency resources. Alternatively, when the vehicles (UEs) are out of eNB coverage, distributed scheduling is applied. In such a distributed scheduling scheme, UEs access physical resources following a sensing-based Semi-Persistent Scheduling (SPS) scheme. According to this scheme, one UE keeps sensing the resource usage in one resource scheduling period all along. By decoding the received message or measuring the energy in every resource block, which is organized in different subframes and subbands in LTE-V2X SL, UE can be aware of the resource reservation condition and know which resources are free to use in the next scheduling period. Then, from the determined idle resources, the UE randomly selects the needed number of resources for transmission. According to SPS, once a UE selects the resources successfully, it tends to keep occupying them in the next few scheduling periods.

For safety reasons, cruise control V2V communication requires extremely high reliability [17]. [18] investigates the reliability performance of IEEE 802.11p and LTE-V2X SL with distributed scheduling. It is shown in [18] that when vehicles periodically broadcast their driving status using Cooperative Awareness Message (CAM), LTE-V2X SL with distributed scheduling reaches higher communication reliability than IEEE 802.11p.

The remainder of this paper is organized as follows. Section II introduces a prediction based control scheme along with the control law for maneuver decision making. Section III shows the platoon formation regarding the limitations given by the communication technology. In Section IV, the proposed platoon based scheduling scheme is introduced along with the simulation showing the obtained reliability improvement. Section V gives the conclusion.

II. A PREDICTION BASED CONTROL SCHEME FOR PLATOONING

A. *Time Synchronized Discrete Control Process*

The proposed scheme requires synchronous maneuver operation according to a common clock base, e.g., according to the Global Navigation Satellite System (GNSS) clock. During the time between two maneuver operations, which is defined as one adaptation period, the acceleration of a vehicle stays unchanged. Fig. 1 illustrates an example with two adaptation periods, where each adaptation period has a duration of T. At time point $(m-1)T$, vehicle having velocity $v[(m-1)T]$ and distance $S[(m-1)T]$ towards preceding vehicle adapts its acceleration to $a[(m-1)T]$. The vehicle keeps accelerating with $a[(m-1)T]$ for a time period T till the next adaptation at time mT when it changes its acceleration to $a[mT]$. Since the maneuver decision of cooperative driving can only be made after the vehicle receives all necessary messages from surrounding vehicles via V2V communication, adaptation period shall be large enough to accommodate V2V communication delay. It is noteworthy that mechanical delay is not considered in this paper.

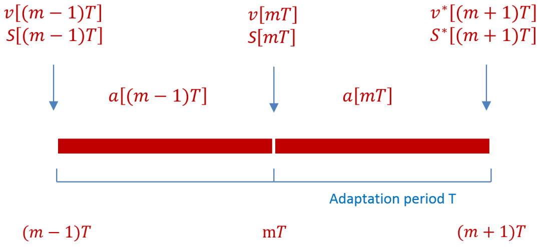

Fig. 1: Time synchronized discrete control

B. *Traffic Situation Prediction*

One reason for having such a synchronized discrete control scheme is that it is possible for vehicles to predict upcoming traffic situation and make their maneuver decisions based on predicted up-to-date information. For instance, at time $(m-1)T$ two adjacent vehicles, e.g., vehicle N and $N+1$ in Fig. 2, broadcast their driving status messages including distance $S[(m-1)T]$, speed $v[(m-1)T]$ and acceleration $a[(m-1)T]$. After certain V2V communication delay, vehicle N receives the message from vehicle $N+1$ and tries to determine the maneuver decision, i.e., $a_N[mT]$ (4), for next adaptation period. The traffic situation experienced by vehicle N at time mT is represented by its own speed $v_N[mT]$, the speed of its preceding vehicle $v_{N+1}[mT]$, the distance towards its preceding vehicle $S_N[mT]$ and the acceleration of its preceding vehicle $a_{N+1}[mT]$. $v_N[mT]$, $v_{N+1}[mT]$ and $S_N[mT]$ can be predicted from the sensed and received information valid at time $(m-1)T$ using (1)(2)(3). The prediction of $a_{N+1}[mT]$ is more complicated since it further requests predicting the traffic situation experienced by vehicle $N+1$ at time mT, i.e., $v_{N+1}[mT]$, $v_{N+2}[mT]$, $S_{N+1}[mT]$ and $a_{N+2}[mT]$. This issue will be discussed later in Section III.

$$v_N[mT] = v_N[(m-1)T] + a_N[(m-1)T] \cdot T \tag{1}$$

$$v_{N+1}[mT] = v_{N+1}[(m-1)T] + a_{N+1}[(m-1)T] \cdot T \tag{2}$$

$$\begin{aligned} S_N[mT] =& S_N[(m-1)T] \\ &+ (v_{N+1}[(m-1)T] - v_N[(m-1)T]) \cdot T \\ &+ 0.5 \cdot T^2 (a_{N+1}[(m-1)T] - a_N[(m-1)T]) \end{aligned} \tag{3}$$

$$\begin{aligned} a_N[mT] =& f_{control}(v_N[mT], S_N[mT], a_{N+1}[mT], \\ & v_{N+1}[mT], S_{min}, T_g, T) \end{aligned} \tag{4}$$

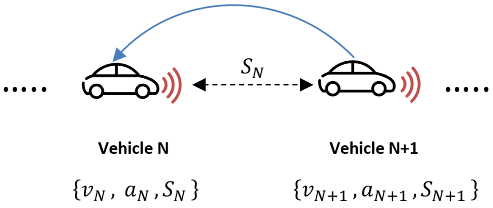

Fig. 2: Information flow between two adjacent vehicles

C. *Control Law*

Assuming the up-to-date traffic situation can be obtained through prediction, here we discuss the control law, i.e., the algorithm to determine the maneuver decision. Assuming a homogeneous traffic flow, where all vehicles follow the same control law, the maneuver of every vehicle is aiming at reaching the equilibrium as fast as possible, preferably within one adaptation period of T. As also shown in Fig. 1, if any perturbation to the traffic flow is introduced at time $(m-1)T$, then the acceleration/deceleration $a[mT]$ at each vehicle is determined such that after the adaptation at time mT, equilibrium, which is represented by desired speed

$v^*[(m+1)T]$ and desired inter-vehicle gap $S^*[(m+1)T]$, can be achieved at time $(m+1)T$, if no further perturbation is introduced.

On the one hand, one vehicle wants to reach the maximum speed v_{max} allowed by traffic regulation at time $(m+1)T$ as expressed in (5). On the other hand, it also wants to keep a desired gap towards its preceding vehicle where the desired inter-vehicle gap (6) at time $(m+1)T$ is the summation of the minimum inter-vehicle gap S_{min} and the production of speed $v[(m+1)T]$ and time gap T_g. The acceleration to reach the desired inter-vehicle gap at time $(m+1)T$ can be derived using predicted information at time mT as in (7). The acceleration $a[mT]$ (8), which is reached at time mT, is chosen to be the smallest among velocity oriented acceleration a_v, and inter-vehicle gap oriented acceleration a_s. It is also bounded by the vehicle's maximum acceleration a_{max} and deceleration b_{max} capability (8).

$$a_v[mT] = \frac{1}{T} \cdot (v_{max} - v[mT]) \tag{5}$$

$$S^*[(m+1)T] = v[(m+1)T] \cdot T_g + S_{min} \tag{6}$$

$$\begin{aligned} a_s[mT] =& k_a \cdot a_p[mT] + k_v \cdot (v_p[mT] - v[mT]) \\ &+ k_s \cdot (S[mT] - S^*[mT]) \end{aligned} \tag{7}$$

$$\boldsymbol{a}[mT] = bound(min(a_v, a_s), -b_{max}, a_{max}) \tag{8}$$

$$\begin{aligned} k_a =& \frac{0.5 \cdot T^2}{0.5 \cdot T^2 + T \cdot T_g}, k_v = \frac{T}{0.5 \cdot T^2 + T \cdot T_g}, \\ k_s =& \frac{1}{0.5 \cdot T^2 + T \cdot T_g} \end{aligned} \tag{9}$$

D. Stability Analysis

System stability is usually indicated by the transfer function in frequency domain. The system is stable if the magnitude of system transfer function is less or equal to one $|\Gamma(z)| \leq 1$ over the whole spectrum [12]. Since traffic system using proposed control scheme is a discrete system, a Z transform is performed here. Besides, in a car-following scenario, vehicles determine their maneuver mainly based on the acceleration/deceleration given as $a_s[mT]$ (7). Therefore, transfer function can be derived from (7) as follows.

$$\Gamma(z) = \frac{A(z)}{A_p(z)} = \frac{0.5 \cdot T \cdot z + 0.5 \cdot T}{(0.5 \cdot T + T_g) \cdot z + 0.5 \cdot T - T_g} \tag{10}$$

The magnitude of transfer function $|\Gamma(z)|$ is plotted in Fig. 3 with assumed adaptation period $T = 0.1$s, i.e., the maximum communication delay of 10Hz CAM messages [19], and different time gap values $T_g = 0.5$ s, 0.1 s, 0 s. Owing to the property of the transfer function, severe fluctuation can be observed in the plot. Although the curves are not smooth, some general tendencies can be observed. First, curves are always below 0 dB within the spectrum window, which indicates that the system is always stable regardless of the chosen time gap value. Besides, when the time gap becomes larger, a more stable system is implied by the reduction of the transfer function magnitude. Moreover, the system performance with zero time gap $T_g = 0$ s is worth mentioning. When time gap is zero, the transfer function is always equal to 1, i.e., 0 dB, within the whole spectrum. This leads to an interesting phenomenon that when there is no time gap between two neighboring vehicles controlled by the proposed scheme, the following vehicle would simply mimic the acceleration of its predecessor $a[mT] = a_p[mT]$ and all vehicles behave as one unit.

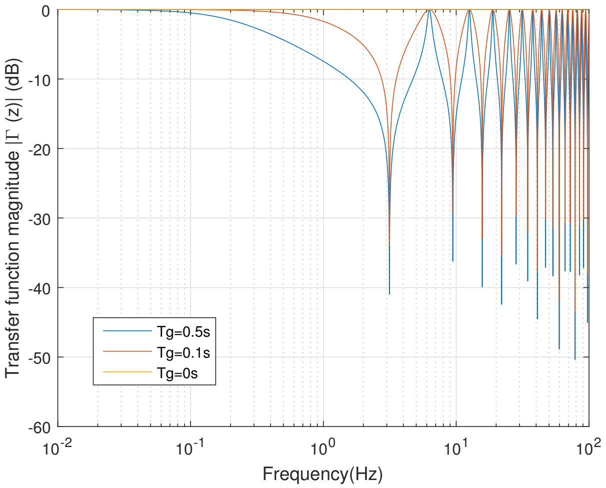

Fig. 3: Stability analysis of traffic system using proposed control scheme

In order to evaluate the system performance and demonstrate the theoretical stability analysis, a simulation is conducted with different time gap values of 0.5 s, 0.1 s and 0 s. At the beginning of the simulation, five vehicles controlled by the proposed scheme are moving at equilibrium with the same speed of 20 m/s and desired gap between them. At simulation time 2 second, a disturbance, i.e., a sudden brake event with deceleration of -3 m/s^2 is introduced at the leading vehicle, i.e., vehicle 5. Vehicle 5 keeps braking for one second and moves with the new speed of 17 m/s for the rest of simulation time. Fig. 4, 5 and 6 illustrate the speed and acceleration response of the following vehicles with different time gaps. It can be observed that, vehicles within the traffic system are able to adapt their acceleration properly and resolve the disturbance without overreaction. Moreover, the equilibrium, i.e., desired speed and inter-vehicle gap, can be re-reached using less time when the time gap is small. Fig. 6 shows the situation with zero time gap, where all curves are overlapped with each other. This proves that all vehicles behave in exactly the same way when the time gap is zero. This also shows the ideal case, where all vehicles move as one unit with same maneuver and keeps the inter-vehicle gap as small as zero, just like train carriages but without any physical connection. In other words, without any system errors, e.g., time synchronization error and sensing error, traffic system using proposed control scheme with zero time gap is capable of minimizing the demanded inter-vehicle gap and maximizing the lane capacity under stability constraint.

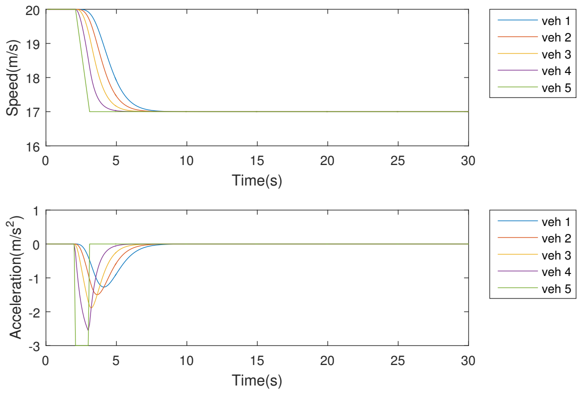

Fig. 4: Traffic system response with 0.5s time gap

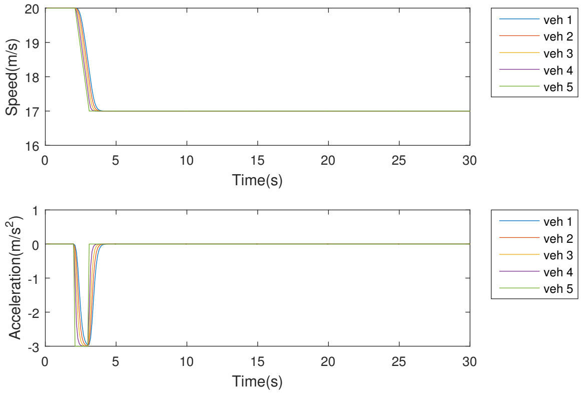

Fig. 5: Traffic system response with 0.1s time gap

III. PLATOON FORMATION

A. Limitations from communication system

In order to implement the control scheme in real platooning scenarios, practical issues such as communication range, delay and reliability limit the system performance.

As emphasized in Section II-B, prediction of the preceding vehicle's maneuver intention, i.e., acceleration in longitudinal cruise control, is crucial to determine the optimal local maneuver decision. Actually, predicting the acceleration at time mT of any vehicle requires the acceleration of its preceding vehicle at time mT being known or already predicted. This results in a prediction chain. The maneuver intention prediction, i.e., acceleration of the preceding vehicle, would follow the chain illustrated in Fig. 7 where it is done sequentially from the vehicle at very front. Ideally, with unlimited communication range, one vehicle can be aware of the global traffic situation and predict other vehicles' maneuver intentions precisely. However, with limited communication range, the perception range is also limited.

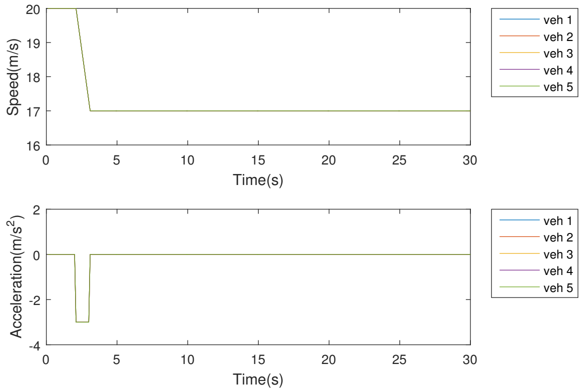

Fig. 6: Traffic system response with 0s time gap

$$\vdots$$

$$\downarrow$$

$$\boldsymbol{a_n}[\boldsymbol{mT}] = f_{\text{control}}\,(v_n[mT], S_n[mT], \boldsymbol{a_{n+1}}[\boldsymbol{mT}], v_{n+1}[mT], S_{min}, T_g, T)$$

$$\downarrow$$

$$\boldsymbol{a_{n-1}}[\boldsymbol{mT}] = f_{\text{control}}(v_{n-1}[mT], S_{n-1}[mT], \boldsymbol{a_n}[\boldsymbol{mT}], v_n[mT], S_{min}, T_g, T)$$

$$\downarrow$$

$$\vdots$$

$$\downarrow$$

$$\boldsymbol{a_1}[\boldsymbol{mT}] = f_{\text{control}}(v_1[mT], S_1[mT], \boldsymbol{a_2}[\boldsymbol{mT}], v_2[mT], S_{min}, T_g, T)$$

$$\downarrow$$

$$\boldsymbol{a_0}[\boldsymbol{mT}] = f_{\text{control}}(v_0[mT], S_0[mT], \boldsymbol{a_1}[\boldsymbol{mT}], v_1[mT], S_{min}, T_g, T)$$

Fig. 7: Maneuver intention prediction chain

In addition, although the inter-vehicle time gap can be reduced to zero as illustrated in Section II-D, it may be wise to have the inter-vehicle time gap T_g larger than adaptation period T to avoid collision caused by system errors. For instance, assuming one vehicle fails to receive the message from its preceding vehicle who starts to brake, the following vehicle would keep moving with the same speed in the next adaptation period. However, the following vehicle can be aware of the deceleration at front by sensing and also starts to brake after the next adaptation period. In this case, the following vehicle actually reacts to the deceleration of its preceding vehicle after a delayed time of one adaptation period T. Hence the collision can be avoided if the gap between two vehicles is larger than $v \cdot T$.

Moreover, control related V2V communication usually requires extremely high reliability for safety reasons. For instance, in future 5G Intelligent Transport Systems (ITS), a

99.999% reliability is demanded for some applications [17]. Such reliability requirement can be used to define a reliable communication range, where any V2V communication within this range has a reliability higher than the demanded threshold and can be regarded as a reliable link.

B. *A Novel Platooning System*

Based on the discussions so far, we propose a novel platooning system that enables a prediction based control within platoon. As shown in Fig. 8, vehicles moving on the road can be grouped into different platoons and the platoon length is limited by the reliable communication range. Vehicles in the same platoon are time synchronized and they adapt their maneuvers simultaneously every adaptation period of T. The adaptation period T is larger than the maximum allowed communication delay, e.g., 100 ms for 10 Hz CAM message. At the beginning of each adaptation period, each vehicle generates a driving status message and waits for transmission. During the adaptation period, each vehicle broadcasts its own driving status message and receives the messages from other vehicles in the same platoon. Note that, since vehicles in the same platoon are within each other's reliable communication range, they can receive each other's messages with a high success rate. After receiving the associated messages, each vehicle determines its local maneuver decision and adapts its maneuver at the end of the adaptation period.

Platoon members follow the proposed control law in Section II-C and determine their maneuver decisions by starting the prediction chain from the platoon leader, i.e., the first vehicle in the platoon. However, to make platoon leader's maneuver intention predictable, the platoon leader has to adapt its maneuver only based on what has been sensed and included in its driving status message. Actually, each platoon leader in this case can be equivalently seen as one ACC vehicle. Assuming the ACC control law in [8] and the demanded inter-platoon time gap is found to be 1 s by repeating the stability analysis as in Section II-D.

Therefore, in such platooning systems, vehicles in the same platoon can keep an intra-platoon time gap as small as the adaptation period T, e.g., 100 ms when 10 Hz CAM message is used. Meanwhile, the inter-platoon time gap has to be relatively large, e.g., 1 s, to keep the traffic system stable.

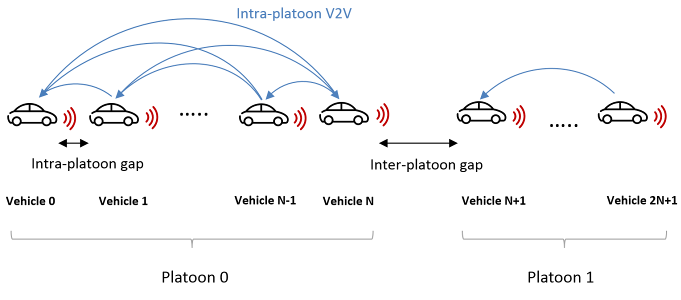

Fig. 8: Proposed V2V assisted platooning system

IV. PLATOON BASED SCHEDULING

A. *Scheduling Scheme Description*

In the proposed platooning system, V2V communication among vehicles in the same platoon, i.e., intra-platoon V2V communication, is crucial to broadcast and receive control related messages. Therefore, intra-platoon V2V communication requires high reliability. As proved in [18], using LTE-V2X SL with distributed scheduling achieves a higher V2V communication reliability than using IEEE 802.11p for CAM message transmission and reception. However, implementing LTE-V2X SL with distributed scheduling directly in the proposed platooning system may experience a reliability reduction due to intra-platoon blocking and interference. Assuming each vehicle is equipped with one transceiver, it cannot transmit and receive at the same time owing to its half-duplex nature. As a result, when two vehicles broadcast their CAM messages using the same subframe, they cannot receive each other's message even if they are using different subbands. Furthermore, when two vehicles broadcast using the same resource, i.e., same subframe and same subband, not only blocking problem will be triggered, they also cause severe interference problem at other receivers.

To further improve the intra-platoon communication reliability, we propose a platoon based scheduling scheme based on the existing distributed scheduling scheme. In platoon based scheduling scheme, instead of letting each vehicle perform spectrum sensing and resource selection individually, the platoon leader is in charge of scheduling for all vehicles in the same platoon. To be more specific, the platoon leader keeps sensing the channel, being aware of the idle resources and also monitoring its platoon members as well as their resource demand, i.e., required number of 1 subframe×1 subband resources. When the intra-platoon V2V communication is activated, the platoon leader assigns resources in different subframes to platoon members. It makes first full use of the idle resources and randomly select from busy ones when additional ones are needed. A resource reservation timer is also generated and reduced by one after each scheduling period. Then, all vehicles within the platoon will transmit messages using assigned resources of different subframes in the next few scheduling periods until the timer expires. Platoon leader will repeat the scheduling process again at that time as depicted in Fig. 9.

Fig. 10 gives an example of platoon based scheduling, where one platoon consisting of four vehicles is trying to access resources for intra-platoon communication in the next scheduling period. Assuming each of them needs two 1 subframe×1 subband resources for transmission, the platoon leader selects eight idle resources of different subframes in total and assign them to four vehicles.

The advantage of this platoon based scheduling scheme is that by assigning resources of different subframes to vehicles in the same platoon, the intra-platoon blocking and interference problems can be solved. Note that, although there may be other methods to achieve better communication reliability

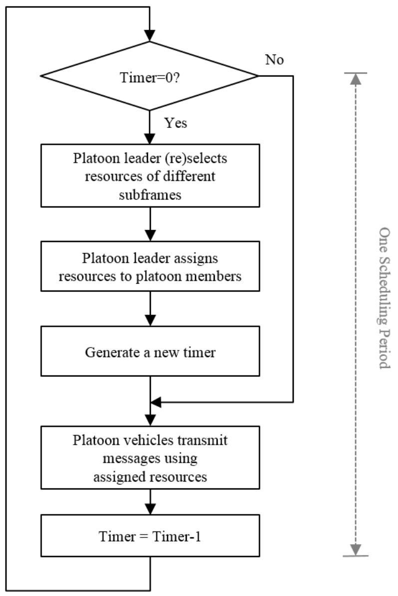

Fig. 9: Platoon based scheduling loop

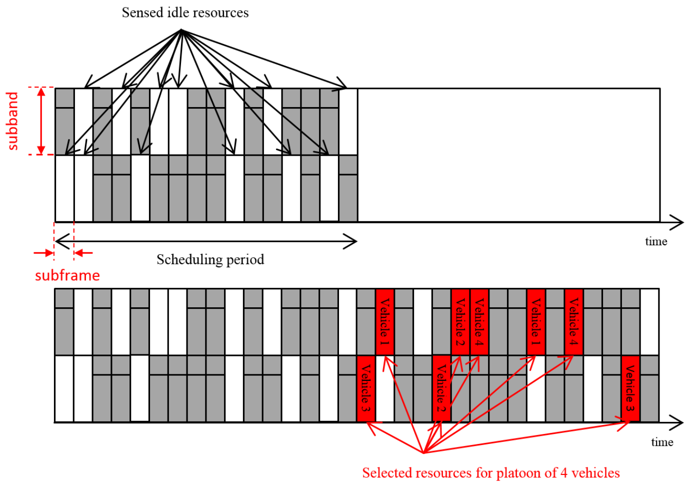

Fig. 10: Resource allocation in platoon based scheduling

in such a distributed system, letting platoon leader be a local scheduler could be the most practical way for implementation in a real scenario. This is because that in platooning use case, platoon leader is usually in charge of platoon management, keeps monitoring the status of the whole platoon and operates platoon merging or splitting [20]. Therefore, platoon leader has the best knowledge of the platoon's overall status and resource demand.

B. Simulation

1) Simulation Settings: A simulation is performed to demonstrate the communication reliability improvement. In the simulation study, we use the 10MHz channel and 100ms scheduling period that corresponds to 10Hz CAM message generation frequency, as already specified in standardization documents [19] [21] for V2X services. A one lane highway car-following scenario is created, where 500 vehicles controlled by the proposed scheme are moving in platoons with a certain velocity of 70km/h and platoon length. Since the transmission and reception of CAM messages is our focus here, we assume that vehicles are moving at equilibrium with desired speed and inter-vehicle gap, without disturbance. CAM messages are generated and broadcasted periodically during the simulation.

The communication system settings are according to the specification documents [16] [22] [23] and the channel model is based on the WINNER+B1 model with log-normal shadowing [24]. Details can be seen in Table I. In terms of the MAC layer scheduling schemes, both LTE-V2X SL with distributed scheduling (LTE-V2X-SL-D) and LTE-V2X SL with platoon based scheduling (LTE-V2X-SL-PB) are implemented in the simulator. The communication reliability performances of them are recorded and compared.

Mobility System	
Parameters	**Value**
Number of Vehicles	500
Vehicle Length	5m
Minimum Inter-Vehicle Gap	1m
Inter-Platoon Time Gap	1s
Intra-Platoon Time Gap	0.1s
Adaptation Period (T)	0.1s
Velocity	70km/h
Platoon Length	$[2:2:30]$ vehicles/platoon

Communication System	
Parameters	**Value**
Channel Bandwidth	10MHz
Carrier Frequency	5.9GHz
Number Subbands	2
Subband Bandwidth	5MHz
CAM Message Size	300bytes
CAM Generation Frequency	10Hz
Scheduling Period	100ms
Number of transmissions	2
Transmission Power	23dBm
Effective Antenna Height	0.5m
Transmitter Antenna Gain	3dBi
Receiver Antenna Gain	3dBi
Noise Figure	9dB
Shadowing Standard Deviation	3dB
Scheduling Scheme	[LTE-V2X-SL-D, LTE-V2X-SL-PB]

TABLE I: Parameters for communication reliability simulation

2) Simulation Results: The reliability performance is measured by the packet reception ratio (PRR) of intra-platoon V2V communication (11). In which, K is the total number of scheduling period simulated, M is the total number of vehicles. $Tx_{i,j}$ stands for the number of effective transmissions, which can be also regarded as the number of target receivers within the same platoon, of vehicle j in scheduling period i. $Rx_{i,j}$ is the number of successful receptions among those effective transmissions of vehicle j in scheduling period i.

$$PRR = \frac{\sum_{i=1}^{K}\sum_{j=1}^{M} Rx_{i,j}}{\sum_{i=1}^{K}\sum_{j=1}^{M} Tx_{i,j}} \tag{11}$$

The simulation result is shown in Fig. 11. It can be seen that the intra-platoon communication using platoon based scheduling scheme has a higher PRR than distributed scheduling scheme. When there are more vehicles in the platoon, the intra-platoon blocking and interference problems become more severe in distributed scheduling scheme. Therefore, the advantage of using platoon based scheduling scheme becomes more apparent when the platoon length increases. Moreover, with the same reliability requirement, using platoon based scheduling scheme can support more vehicles in the same platoon than distributed scheduling scheme, and the overall lane capacity may benefit from it.

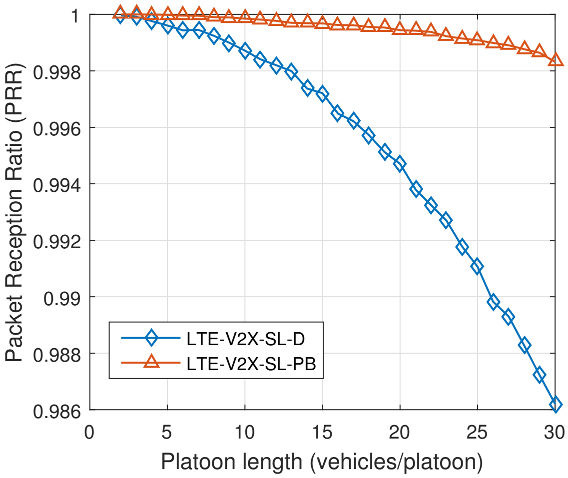

Fig. 11: PRR of intra-platoon V2V communication

V. CONCLUSION

A novel V2V assisted platooning system is proposed and simulated in this paper. Vehicles in the same platoon share their driving statuses via V2V communication. Taking the advantage of discrete and time-synchronized cruise control process in the same platoon, one vehicle is able to predict the traffic situation and determine its own maneuver decision based on estimated up-to-date information. It is theoretically proved that the proposed platooning system is capable of minimizing the demanded intra-platoon gap under the stability constraint. On the other hand, range, delay, and reliability performance of V2V communication system in reality limits the performance of such platooning system. This paper also investigates the way to improve intra-platoon V2V communication reliability by letting platoon leader be a local scheduler, i.e., platoon based scheduling. The simulation result shows the advantage of the platoon based scheduling scheme compared to the distributed scheduling scheme in LTE-V2X SL in terms of successful received transmissions.

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