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A Review on Cooperative Driving for Vehicle Platooning

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Abstract: In this era of automation, vehicle cooperative driving is one of innovations in the automotive industry that aim to improve the safety, traffic flow efficiency, mileage and time of travel of vehicles while decreasing pollution and reducing stress for drivers. Having interconnected vehicles on road can to some extent reduce the accidents caused basically due to lack of human intervention on time. In this paper we discuss how we can make interconnected vehicle platooning a reality with Cooperative driving technology.

Keywords: Cooperative Adaptive Cruise Control, Dedicated Short Range Communication, Vehicle to Vehicle Communication, Visible Light Communication, ZigBee, Platooning

I. INTRODUCTION

Platooning is the concept of driving several vehicles close to each other by considering them as one unit, the platoon. In order to do so safely, vehicles are communicating with each other. Doing this has several benefits as it can increase the road capacity, decrease fuel consumption and improve road safety.

Platooning includes using vehicles to communicate with other vehicles to link two or more vehicles in a convoy nearly together. The virtual link allows all the vehicles in the platoon to communicate with each other, allowing them to accelerate, brake together automatically and enable them to follow each other more closely than is typically possible with unlinked vehicles. They can also proactively respond separately and be manually regulated at any stage in time [4].

Platooning brings in lots of advantage for freight industry which includes, increased fuel efficiency, and reduced CO2 emissions. With allowing more predictive driving of the trucks on the road, platooning also improves safety for other road users. Truck platooning also optimizes transport by using roads more effectively, helping deliver goods faster. Reducing traffic jams by improving traffic flows and reducing tail backs thus enabling the supply chain and transport system to be optimized.

Reduced fuel consumption of vehicles in platooning, is due to vehicles travelling close to each other which results in lower air drag. Manually keeping short following distances at high speeds do however come with risks, as the human reaction time is limited. When driving too close to another vehicle, the driver may not be able to react in time to unexpected events, such as panic braking. In order to solve this safety issue, the vehicles following the lead vehicle should be automatically controlled based on the leading vehicle and its surroundings.

Addressing the fuel aspect of platoon, the claimed fuel savings vary [2] from 4.7-7.7% to 14% considering the distance between the vehicles and the highway cruise speeds. Shorter distance reduces the air drag as a result reducing fuel consumption.

Road safety is another important aspect that will be improved with interlinked vehicles. The response time of human perception, which is the time to first notice something occurring to apply force on the brake will be improved. This differs depending on the driver’s attention response time and also the braking capability of the truck. These problems are minimized by adding automated braking, although there are mechanical delays between sending the activation signal to the braking system to apply force and start slowing down the vehicle. This is further improved in a platoon with vehicles communicating, as a brake signal can be sent at the moment braking is desired as opposed to when the deceleration starts. This allows the vehicles to travel close enough to utilize the reduced air drag without putting the safety of the drivers and surrounding traffic at risk.

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Cooperative Driving

Cooperative Driving involves technologies that allow a group of vehicles to communicate with each other to coordinate their driving behaviour along with situational awareness which benefits themselves also other road users. This system is also one kind of vehicle-to-vehicle communication. It supports a number of aspects like information and warning exchanges between vehicles which will be gradually deployed in different phases in oncoming years over the market. In addition, along with mere sharing of status and sensor data, cooperative road users can also provide intention data, allowing them to interact intelligently and to coordinate their behaviour even in complex traffic situations. The prediction of which is an important requirement for the long-term goal of highly automated and autonomous driving. Platooning (Static or Dynamic), Cooperative Merging, Cooperative Lane Change and Cooperative Overtaking are the various applications of Cooperative driving.

Communication units are implemented in vehicles and traffic infrastructure for data exchange with each other forming a decentralized network. On-board units in the vehicles communicate data such as their position, speed, driving direction etc. Additionally, they send out messages about special incidents, such as an emergency brake or a vehicle defect. In this manner, cooperative systems support predictive driving, and keep the driver informed regarding the probable dangers on the road. Road Side Units (RSU), which will be part of the transport infrastructure, provides data on the stages of traffic lights, speed limits, road works and road barriers ahead thus enhancing traffic flow and driving comfort. Organizations like IEEE (Institute of Electrical and Electronics Engineers) and SAE (Society for Automotive Engineers) have standardized the formats of these information exchanges so that vehicles of different manufacturers and across borders are able to communicate with each other.

II. METHODS

This section details the existing methods available for cooperative driving and the existing communication protocols.

Adaptive Cruise Control (ACC)

Adaptive Cruise Control (ACC) is a smart form of cruise control that enables vehicles to automatically speed up and slow down to maintain up with the traffic before them. It is becoming an increasingly prevalent feature in vehicles today. Either a laser or radar system is mounted on the front of the car that scans the highway ahead for other vehicles and obstructions. Once the cruise speed has been set, user can also set the gap they wish to maintain from the vehicle ahead using the relevant buttons, which will either be given in seconds or meters, depending on the vehicle. If the vehicle in front slows down, ACC enabled vehicle will either slow down to maintain the gap set, or alert to apply the brakes which then deactivates the ACC system. If the vehicle ahead shoots ahead suddenly, the ACC enabled vehicle won't follow the car rather it will stick to the cruise speed previously set, unless it catches up to another vehicle in front. In both the cases, driver remains in full command of active control of the steering and the active monitoring of the driving environment.

USA mandates the minimum following gap in the case of heavy vehicles to be approximately 160m in highway speeds due to the time taken for humans to perceive and react to the incoming hazards also taking into consideration the brake lag and the brake capability difference of the adjacent vehicles as depicted on Fig1.

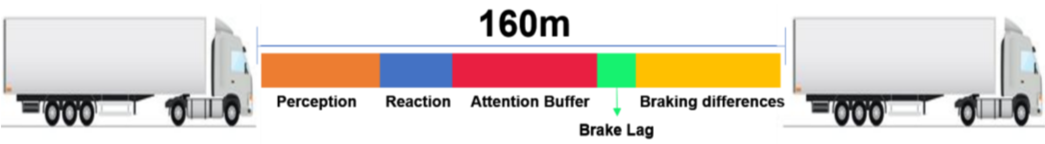

Fig 1: Factors hindering prompt response from a driver

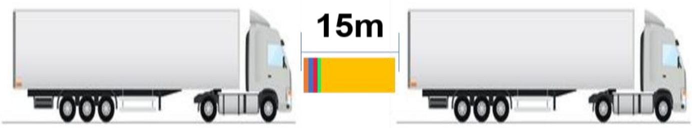

Fig 2: CACC reducing the factors hindering a prompt response

ACC comes with many advantages; one of the greatest benefits is that drivers can relax on the road, especially in case of those who drive for many hours. The system enables you drive on a constant speed without keeping the foot on the pedal. Driving the car on constant speed helps prevent fuel wastage, thus saving fuel expenses.

Since the system does much of the work, a driver may become disengaged from the road reducing the awareness of the surroundings. The driver is not in a position to react effectively in case of changing road conditions, making it

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dangerous. Technology failure can also be a matter of concern. In adverse weather conditions if the sensors are mudded or malfunctioning, then it can be almost impossible to apply brakes to the vehicle, even though it's uncommon, the fact still remains that they can occur.

Cooperative Adaptive Cruise Control (CACC)

Cooperative ACC (CACC) is a further development on ACC that adds vehicle-to-vehicle communication, taking the generic ACC implementation to a more reliable, safe and stable system. With Vehicle to Vehicle information sharing, the ACC controller will be able to better anticipate problems, enabling the platoon members to be much smoother and natural in response to dynamic road conditions such as sudden braking of the vehicle in front. With CACC the factors involved in hindering a prompt response from the driver can be minimized which can bring down the safe distance required (for heavy vehicles) from 160m to 10-15m as depicted in Fig 2. Although CACC is primarily designed for giving the driver more comfort and convenience, CACC has a tremendous effect on traffic safety and traffic efficiency.

Existing communication protocols for Cooperative Driving in Vehicle to Vehicle Communication

WiFi (IEEE802.11n)

There is a significant improvement in IEEE802.11n standard compared to previous standards in 802.11. The raw data rate of the wireless channel is up to 600 Mbps, more than tenfold improvement over 54 Mbps of IEEE802.11 a/g maximum data speed. At the Physical (PHY) layer of the standard is the multiple antennas at the receiver and transmitter, called MIMO (Multiple Input Multiple Output) together with signal processing and the usage of spatial division multiplexing (SDM). The main advantage is the capability to transmit and/or receive coincidentally from multiple antennas which offer spatial diversity improving the reliability of wireless connection through the space-time block coding (STBC). This coding method reduces the error rate in environments with the presence of high radio frequency interference and distortion. High data rate is obtained not only with multiple data stream through various (up to four) antennas but also with extended modulation and coding rate schemes.

At the sub-layer of the Data Link layer there is Medium Access Control (MAC) data communication protocol extensions like Frame Aggregation (FA) and Block Acknowledgement (BACK). FA is the way to reduce the MAC protocol overhead from 84% to 14% by transmitting multiple PHY frames. Frame aggregation or payload optimization is the method of bundling multiple frames together to reduce the preambles and inter-frame spacing thus increasing the throughput.

The major drawback of this protocol is that the time taken to establish connection between vehicles in a real traffic scenario would be unacceptably high. Also, interference considerably reduces connectivity in dense traffic conditions.

Visible Light Communication (VLC/LiFi)[1]

LED lights are commonly used in vehicles nowadays. Light-emitting diodes (LEDs) allow the vehicle's headlights and taillights to be designed flexibly while providing better lighting, lower energy consumption and longer lifetime. Additionally, LED lights generate distinct kinds of lighting to avoid other street users from glare and illuminate blind regions better. LED lighting specifications and design guidelines are now also included in the regulations for automotive lighting, enabling more companies to standardize the use of LEDs in their vehicles.

Modern vehicles also have image sensors like photodiodes (PD) and cameras. Currently, they are used in combination to detect ambient light and rain to activate headlights or wiper blades automatically, while cameras are used for driver aids such as pedestrian warning. It is therefore anticipated that the use of LED lights and image sensors in current cars will decrease the cost of applying the Visible Light Communication system (VLC) of the vehicle. Instead of signal phase information VLC systems uses intensity modulation changes. The mere reliance on signal intensity makes the VLC a suitable vehicle communication technology, as the human eye wouldn't able to notice the minor variation in the intensities of the light. In order to enhance traffic knowledge of neighbouring vehicle, V2V is currently only aiming to convey data on the speed and braking status of vehicles.

VLC based communication might be subjected interference issues from other ambient light sources. There are challenges to integrate VLC with WiFi systems (V2I systems). Other challenges are atmospheric absorption, shadowing, beam dispersion. The source and receiver should be in line-of-sight (LOS), hence non-LOS communication is difficult to be achieved.

Zigbee (IEEE 802.15.4)

In V2X communication Zigbee proves vital due to its long battery life, low cost for installation, ease in configuration & maintenance with mesh networking which effectively supports the wireless communication between many vehicles, routers and receivers. ZigBee system consists of two items: the ZigBee coordinator and the ZigBee router which operates at frequency 2.4Ghz. The ZigBee router is used to establish connection between vehicles in a mesh topology,

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the total number depending on the ZigBee system standard for number of devices within a mesh. Although the maximum data transfer rate for ZigBee device is 250Kbps, it has a very low packet overhead during transfer. The data transfer rate will maintain its consistency within 100-meter radius. Zigbee uses Direct Sequence Spread Spectrum (DSSS) technique. First, the transmitter feeds a signal of encoded data modulated into RF waves which is in turn fed into the antenna. The transmitter radiates the signal through the air where it is picked up by the antenna of the receiver.

Despite the advantages, the V2V communication will be difficult or interrupted if the vehicles moved apart more than 100m. Self-management, connectivity challenges, decentralized management, privacy and security are few other drawbacks of Zigbee communication.

III. CONCLUSION

DSRC (Dedicated Short-Range Communication) is the most recommended communication protocol for cooperative driving in vehicle to vehicle communication. Dedicated Short Range Communications (DSRC) is a wireless communication technology standard (SAE-J2735) intended to enable vehicles to interact with other automobiles or infrastructures. DSRC technology works on the radio frequency spectrum 5.9 GHz band and is efficient at brief to medium distances. DSRC is highly reliable due to the low latency involved in establishing communication between vehicles. It is secure and supports interoperability. Due to its short range, it is hardly disturbed even under extreme weather conditions. This makes it ideal for communication to and from fast moving vehicles.

DSRC technology can be used in either a vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) format, and communicates using transponders known as on-board units (OBUs) or roadside units (RSUs). In V2V, DSRC is used to allow vehicles to communicate with each other through OBUs. This communication is usually for safety purpose, such as to alert the driver of a car that the car in front of it is about to slow down. In V2I, an OBU in or on the vehicle communicates with surrounding infrastructure equipped with an RSU. This can also alert the driver about safety risks, such as that they are approaching a curve too quickly, or can be used to collect tolls and parking payments.

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