Chapter

Trends in Next Generation Intelligent Transportation Systems

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Abstract

The objective of Intelligent transportation system (ITS) and related National highway traffic safety administration (NHTSA) is to improve vehicle safety and reduce accidents, injuries, and deaths. Advanced driver assistance system (ADAS) is making a difference in vehicle safety. The objective of ADAS is to provide a continuous picture environment surrounding the vehicle. This vision around the vehicle is seen by the driver to take the decision. Vehicular communication is a part of Intelligent Transport System which provides an intelligent way of transport to avoid accidents. As the transportation moves towards environment of connected and autonomous vehicles, the role of communication and data transfer becomes important. Connected vehicles can be used for both infotainment and navigation for vehicle safety. Vehicle-to-vehicle (V2V) communication allows vehicles to talk to each other and exchange data about location, direction of travel, speed, brake, accelerator status, and other facts. This information is analyzed and used to avoid collision. C-V2X (Cellular-Vehicle-to-Everything) can provide better quality of service support, large coverage, and high data rate for moving vehicles. Device-to-device (D2D) communication in C-V2X provides high reliability and low latency. In 5G Rel.16 C-V2X will become an integral part of 5G cellular network providing higher capacity, coverage, etc. Today old aged/disabled person look for driving technology that is convenient and easy to use. V2X technology will offset some of the concerns about old aged/disabled driver's abilities to respond quickly to challenge by driving environment as they no longer be required to handle most of the decisions.

Keywords: ITS, ADAS, DSRC, C-V2X, LiDAR, Vehicle, Autonomous

1. Introduction

There are many accidents occurring on roads due to negligence and lack of proper Intelligent transport system (ITS). Around 1.25 million people worldwide die from traffic accidents each year and between 20 to 50 million suffer from non-fatal injuries (WHO, May 2013). Studies proved that 60% of accidents can be avoided if a warning message is sent to that vehicle at least half a second before accident. The primary objective of ITS and related National highway traffic safety administration (NHTSA) to improve vehicle safety and reduce accidents, injuries, and deaths. Advanced driver assistance system (ADAS) is making a difference in vehicle safety. Manufacturers are adding ADAS to achieve greater safety in vehicles. ADAS additional cost will become low when ADAS is made part of vehicle cost. ADAS includes backup camera, lane-keeping steering, blind-spots detection, automatic braking, parking assistance, pedestrian detection, traffic sign detection, night vision, etc. In ADAS, a cluster of sensors like video cameras, 77GHz millimeter (mm) wave radars like LiDAR (Light detection and ranging), and ultrasonic transducers feed their digital data via multiple serial interfaces to processors that store the data and process it. The vision processors prepare data for fusion processing, which combines the inputs from multiple sensors to produce feature recognition of nearby objects as well as their distance, motion, and status. They in turn make decisions and initiate the control of selected driving functions or provides driver notification by visual, audible signals. The objective of ADAS is to provide a continuous picture environment surrounding the vehicle. This vision around the vehicle is seen by driver to take decision. ADAS development involves massive software which includes special algorithms as well as Artificial intelligence (AI) technique such as machine vision and deep learning. It requires popular processors, interfaces, programing, and AI tools to speed up and simplify development.

As the transportation moves towards environment of connected and autonomous vehicles, the role of communication and data transfer becomes essential. Automakers are looking to offload critical, time-sensitive decisions-making from passengers to autonomous vehicles through a complex set of sensors and communication with everything around the vehicle. Connected vehicles can be used for infotainment and navigation to vehicle safety. There is large potential for connecting other road users such as heavy duty vehicles, pedestrians, cyclists, etc. The introduction of a communication interface into vehicles will also provide a pathway for state and local government that operate transportation system to communicate safety information from the Road side units (RSU) to vehicles. For the same the RSUs are connected to the Traffic management center (TMC). Given the volume of data to be transmitted, the RSU are connected to TMC through some short of backhaul. Wide spread audio/video (AV) technology deployment for infotainment will require robust communication system and communication infrastructure capable of moving the Megabit data generated in AV system. The integrated In-Vehicle Infotainment (IVI) helps to improve automobiles safety by providing the driver high quality information from audio, video, radar, and other sensors. It generates a seamless 360 degree view of vehicle surroundings from multiple independent HD video streams from front, rear, and side-mounted cameras. IVI also provides high quality audio, video entertainment. Imagine 10 to 20 cameras providing 360 degree view, all sending 4 k (3840X2160) resolution HD video streams with pixel depth increasing from 16 to 20 or even 24 bits. A single 4 k video camera with 24bits per pixel will produce around 200Mbit per frame at 10 to 30 frames per sec. This will range overall data rate around 6Gbps.

One forthcoming technology to be adopted is Vehicle-to-Everything (V2X) radio communication. V2X improves ADAS safety by providing radio communication between vehicles, and between vehicles and nearby roadside units that supply valuable information. V2X is a broaden term which includes V2V, V2I (Infrastructure), in addition to objects such as pedestrian crossing road (V2P), detecting bicycles, motor cycles on a car lane, detecting traffic light conflicts, and Internet based networks (V2N) which distribute software and firmware updates to vehicles including HD maps shown in **Figure 1** [1]. V2X technology has been mandated by NHTSA. Vehicle-to-vehicle (V2V) communication allows vehicles to talk to each other and exchange data about location, direction of travel, speed, brake, accelerator status, and other facts. This information is analyzed and used to avoid collision. The V2I will connect vehicles to Infrastructure that can inform about traffic congestion, road conditions, weather alerts, and construction going on to provide safety as well as convenience. The V2V communication is to avoid accidents by sending data about position and speed of vehicle in transit to another

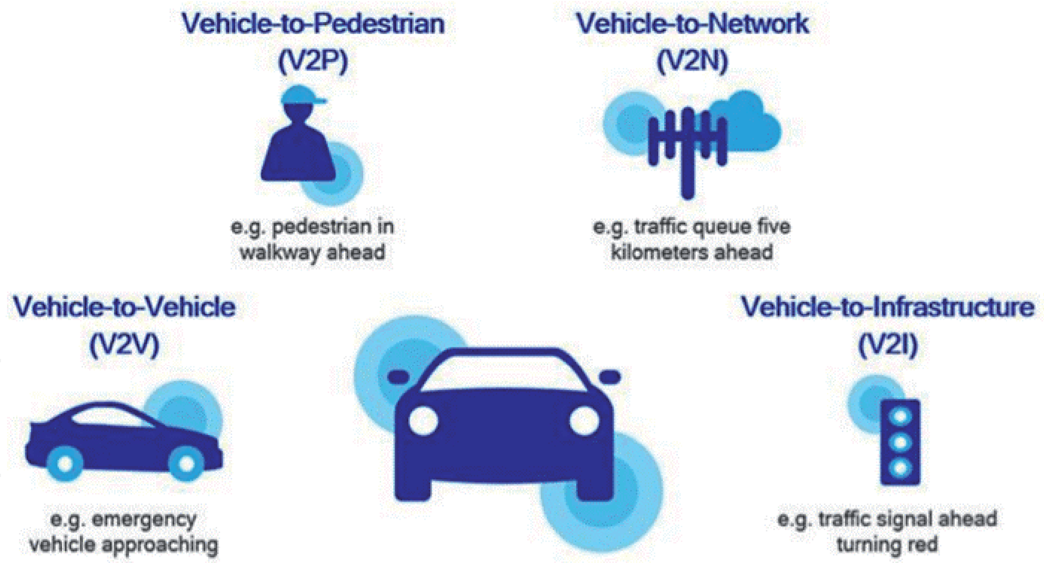

Figure 1.
V2X communication [1].

vehicle over an adhoc mesh network. It provides 360-degree awareness of surrounding threats. It supersedes techniques like blind spot detection, rear parking sonar, and backup camera. The main purpose of vehicle-to-vehicle communication is to provide an intelligent means of transport service. This is introduced in order to avoid accidents between vehicles by sending warning messages to each other. These warning messages consist of information regarding vehicles speed, emergency stopping, brake status, etc. V2V communication is like an additional step for warning the drivers. With the growth of mobile data, a cellular network has great potential to support various vehicular communication services for safety applications. Cellular system such as 4G-LTE can become the useful vehicle communication. Cellular V2X (C-V2X) can provide better quality of service (QoS) support, large coverage, and high data rate for moving vehicles. Device-to-device (D2D) communication in C-V2X provides high reliability and low latency, range, scalability, number of devices supported, security, and reduced cost of ownership. In 5G Rel. 16 C-V2X will be an integral part of 5G cellular network providing higher capacity, coverage. In this chapter Section 2 discusses V2X communication while Section 3 discusses Dedicated short range communication (DSRC). Section 4 discusses about Cellular vehicle-to-everything (C-V2X) while Section 5 discusses level of automation and Section 6 about self driving vehicles, and finally Section 7 conclude the chapter.

2. Internet of vehicles

Internet of vehicles (IoV) can be named as Internet of Things (IoT) on wheels. It will allow vehicles to communicate with their drivers, with other vehicles, with traffic signals, and city infrastructure.

2.1 Vehicle-to-vehicle communication

Inter-Vehicle communication uses multi-hop multicast/broadcast to communicate between each vehicle. Collision warning messages broadcast from V2V across multi-hops. This is suitable for short range, a vehicle communicates with another vehicle by using different protocols. In such cases receiver takes appropriate decision on the basis of emergency messages received and accordingly takes appropriate action. To avoid collision in V2V communication, location based multicast and broadcasting is used [2]. Multi-hop communication propagates the message in the absence of RSU infrastructure. However, in low density vehicular network V2V communication is not very good solution due to large range. V2V could eliminate 80% of crashes that do not involve alcohol or drugs.

2.2 Vehicle-to-infrastructure communication

Vehicle-to-Infrastructure (V2I) provides awareness of traffic light status, a road that is closed, to guide the vehicle around obstacles, traffic, road condition, weather, construction, etc. Vehicles connected to stationary infrastructure is known as Road side unit (RSU). Communication between vehicles and RSU are supported by V2R protocol. In V2R warning messages are sent first to RSU, and then RSU broadcast to all vehicles in the range. The Road side infrastructure involves additional installation costs. V2I provides large BW link between vehicles and RSU. The RSU can be deployed after every km to obtain high data rates required during heavy traffic. When a vehicle has mechanical failure or detects road hazards, vehicle generates an EWM (Emergency warning message) and keeps one copy with him for retransmission, if required. Vehicle broadcasts to neighboring vehicles and it transmits periodically to RSU also through transceivers with different frequency bands till it receives the message with the same ID from vehicle behind and RSU respectively. When RSU receives EWM from source vehicle, it replaces with own ID and forwards to all vehicles within the range [3].

2.3 Vehicle-to-network communication

Vehicles connected to Application server. It transforms connected transportation around the globe. It allows one way broadcast to multiple vehicles thereby facilitating V2N functions. The network based communication (V2N) operates over licensed spectrum to support telematics, connected infotainment, and growing variety of advanced informational safety use cases.

2.4 Vehicle-to-pedestrian communication

Vehicle is able to detect in advance pedestrians including cyclist, motor cycles in cross walks, blind spots, or other dangerous locations.

3. Dedicated short range communication

NHTSA proposed V2V technology called Dedicated short range communication (DSRC) for all new light vehicles. As a result IEEE approved an amendment to IEEE802.11 standard named as 802.11p for Wireless access in vehicle environment (WAVE). The 802.11p is enhancement of 802.11a Wireless local area network (WLAN) required supporting ITS applications [4]. This includes data exchange between high speed vehicles and between vehicles and Road side infrastructure (V2R) in ITS 5.9GHz band. The DSRC combines Wi-Fi and GPS positioning to get a 360-degree awareness of all vehicles around them. It helps to provide the driver with warning to avoid collision using on-board computer. The cars share their positions very rapidly even though two cars could be around a corner. DSRC allows Cooperative collision avoidance (CCA) in which cars warns each other about changing conditions to significantly improve safety. DSRC is a two way short-to-medium range wireless communication that permits very high data transmission in V2V communication. The main reason for using DSRC in V2V communication is to detect hazards in vehicle's path even though the driver in not in such a position to see. DSRC PHY (Physical) layer is targeted to operate in 5.9 GHz band (5.85–5.925GHz) with 75 MHz BW as opposed to IEEE 802.11a that allows only the unlicensed frequency band 5GHz. In MAC (Media access control) layer the DSRC band consists of seven channels each with 10 MHz BW and that include one control channel and 6 service channels. It can support a large family of vehicular safety and non-safety applications. Some requirements of MAC are low latency and high reliability. The PHY Layer provides better radio propagation with respect to multi-path reflection delay and Doppler effects occur due to high speed vehicles and road environment. The end-to-end delay is low (25 ms) and packet delivery ratio is high compared to 802.11a [5].

The 802.11p standard adds wireless access to vehicular networks and implements OSI layers stack. Upper layers of OSI follows IEEE1609 family standard as shown in **Figure 2**. Wireless Protocol works at licensed band of 5.9GHz with 300 m range, and data rate of 6 to 27Mbps. DSRC PHY layer adopts same OFDM and digital modulation types BPSK, QPSK, 16-QAM, 64-QAM as used in 802.11a.

The DSRC transmits Basic safety message (BSM) between vehicles. It includes information like exact vehicle location, direction of travel, speed, braking status, and some other data. The BSM is updated and transmitted 10 times per sec. DSRC is proven standard, mature technology, and cost effective but with little growth potential. Latency is around 25 ms which is not fast enough for collision avoidance action. Another application of DSRC is V2I but V2I depends on new development and deployment of infrastructure. This new infrastructure is a major investment.

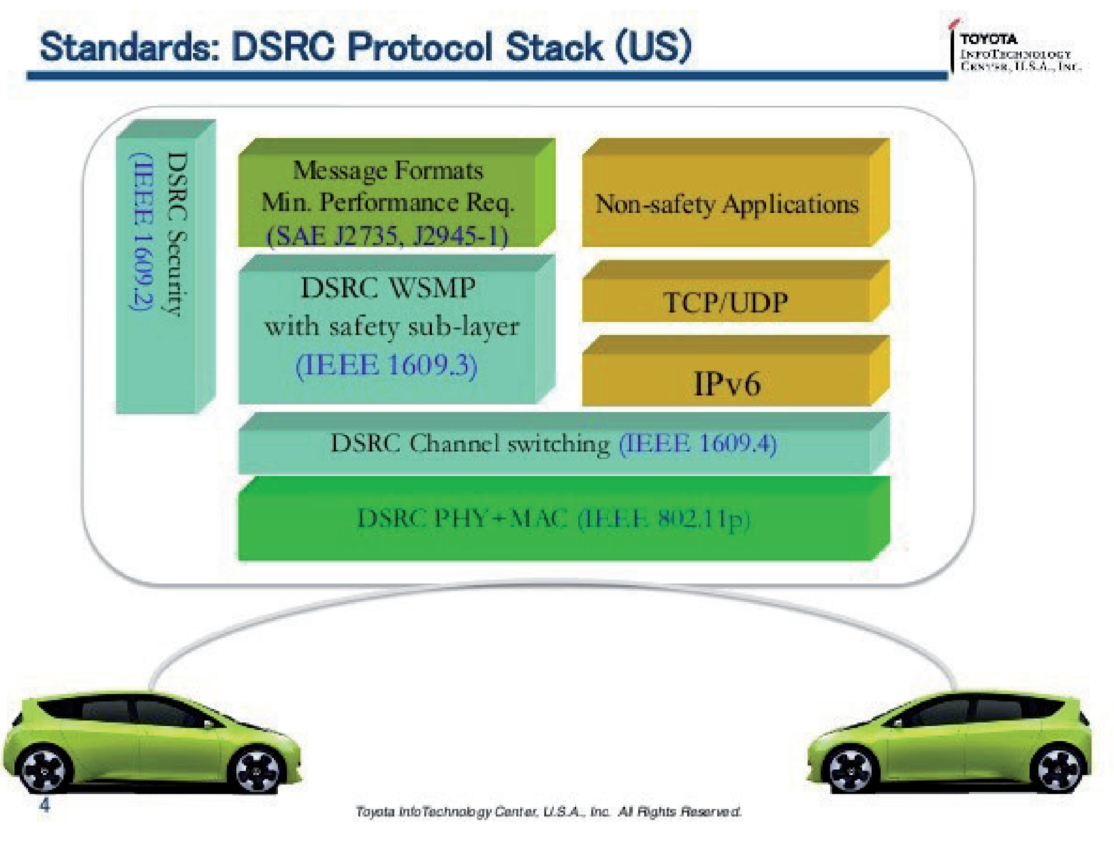

Figure 2.
DSRC protocol stack.

4. Cellular vehicle-to-everything (C-V2X) communication

The Automation industry was agreed upon DSRC but suddenly C-V2X popped up disrupting the DSRC plans. The DSRC will require new deployment of thousands of roadside units (RSU) and associated infrastructure network such as fiber backhaul along the roads. This is a challenge for rural areas considering vast distances involved. The progress of DSRC has been delayed because of new alternative radio technology based on cellular mobile communication called C-V2X. C-V2X utilizes cellular mobile technology to provide the link between the vehicles and rest of the world including other vehicles and traffic control system. C-V2X provide high performance for capacity, coverage, range, scalability, number of devices supported, and security. C-V2X can achieve longer range which can directly translates into earlier alert and better visibility of unexpected dangerous situation. It also allows vehicles to travel at higher speeds while still being able to stop in time to avoid hazardous conditions compared to DSRC. It was designed initially to use 4G-LTE cellular mobile standard defined in 3GPP Rel.14 [6]. The new version 5G (Rel. 15) includes device-to-device (D2D) communication (V2V, V2I, V2P) and device-to-network (V2N) which will transform connected transportation around the globe [7]. The 4G-LTE and 5G can provide RSU functions eliminating the need of additional RSUs in DSRC. The V2V and V2I will connect and interact with ADAS providing intelligence beyond the short range environment covered by ADAS sensors. V2V and V2I will make ADAS an attractive alternative to full automation. Finally security is a major factor, if automobiles are connected to the Internet where they may be exposed to hack.

C-V2X also uses 5.9GHz band but instead of OFDM, it uses Single carrier-Frequency division multiple access (SC-FDMA) to lower down the Peak to average power ratio (PAPR) to reduce power consumption. It uses Turbo coding and Hybrid automatic repeat request (HARQ) protocol to enhance reliability in data transfer at high vehicle speeds, and lower latency (< 5 ms). C-V2X is designed to be globally compatible with 5G. The 5G will provide very high throughput, high reliability, low latency, and accurate position determination. 5G can offer multi-gigabit speeds for infotainment, telematics, and teleoperation. C-V2X is designed to offer low latency communication to V2V, V2I, and V2P. C-V2X encompasses two transmission modes, direct communication (V2V), and network based communication (V2N). The network based communication utilizes 4G and emerging 5G cellular network for V2N, and operates over licensed spectrum to support telematics, connected infotainment, and growing variety of advanced informational safety use cases. C-V2X is the gateway to the connecting vehicles and in long run to the self-driving vehicles. Full automated driving will be in 5G environment and C-V2X will be the bridge towards 5G [8]. C-V2X will be able to take 5G network advantages namely enhanced mobile broadband (eMBB), ultra low-latency communication (uRLLC), and massive scale machine-to-machine (M2M) communication (mMTC). This will enable more V2X services by providing long range, higher density, very high throughput, reliability, high precision positioning, and ultra low latency (1 ms). LTE variant LTE-m (Machine) and Narrow band (NB)-IoT Low power WAN (LPWAN) are not fast enough. LTE-b (Broadcast) is another variant which allows one way broadcast to multiple vehicles thereby facilitating V2I and V2N functions. 5G Automation association (5GAA) has 50+ automobile manufacturers, and mobile network industry including Audi, BMW, Daimler, Ericsson, Huawei, Intel, Nokia, Qualcomm to collaborate between automotive and mobile communication industry. 5GAA has recommended C-V2X to NHTSA. After taking the decision, 2 years period would occur to accommodate manufacturers product development cycle, and full compliance would require additional 2 years.

4.1 LTE-m

Some potential candidates for V2V and V2I in 4G LTE cellular network are LTE-m and NB-IoT (Rel 13). LTE-m (Machine) is a versatile technology, supporting high data rates, mobility, and voice facility. It is a stripped version of LTE, uses 1.4 MHz instead of 20 MHz BW. Reduction in BW to 1.4 MHz will reduce size of FFT blocks results in cost reduction by 28%. Power consumption will also reduce as fewer number of subcarriers needs to be processed at RF level. This will further reduce the cost by 20 to 30% by means of RF transceiver design including low noise amplifier, mixer, and local oscillator. Overall average 39% cost saving and also modem complexity by 50% observed [9]. It effectively provides down link and uplink peek rates of 1Mbps covering 1.08 MHz bandwidth in half duplex mode. LTE-m supports full voice functionality via Voice over LTE (VoLTE) along with full mobility and in-vehicle hand-over. The major reason is that it can serve in automotive sector because of its extended range, deep penetration in buildings and basement, and low latency. The maximum uplink power transmitted by device is 23 dBm, and 46 dBm for downlink with 10–15 ms latency. It also supports power saving mode– sends an acknowledgement before going to sleep and then on waking up sends check along with data (if any) to the network.

4.2 NB-IoT

NB-IoT uses different technoloy (DSSS modulation in place of OFDM), but operates in LTE band [10]. With NB-IoT gatewys are not required, and thus sensor data is directly tranamitted to main server. NB-IoT has an advantage of low cost and lesser power requirements. The maximum tarnsmitted power is 20 dBm over 200 kHz bandwith (180 kHz one resource block). The complexity is reduced by 75% as compared to the LTE-m. Down link and uplink peek data rates supported by NB-IoT is around 250 kbps with 1.6 to 10sec latency. It works best for applications that requires moderate latency and throughput. It uses licensed band which eliminates interference and provides high security. It can provide 50 k to 100k vehicles connections per cell. It can operate by uploading a new software on LTE infrastructure. When transmitting 200 bytes in day on an average, one can achieve 10 years battery life time. NB-IoT Rel. 13 lacks mobile support and high power consumption while NB-IoT Rel. 14 support 160 kbps data rate and lower transmit power level.

4.3 Automotive Ethernet

Autonomous vehicles users will expect that their vehicle should provide seamless Internet connectivity to their laptop, mobile phone as provided in living room. It will be possible by using automotive Ethernet [11]. Ethernet is well known ubiquitous solution to traditional LAN (Local area network). The advantage of Ethernet is multipoint connections, higher BW, and low latency. IEEE introduced 802.3bw for automotive applications called 100Base-T1 supporting 100Mbps data on a single balanced twisted pair cable CAT5 or CAT6 of 15 m length [12]. To achieve 100Mbps it uses 3 bit per symbol (PAM3). It supports full duplex. Power over Ethernet (PoE) is being investigated and standardized using IEEE802.3bu with one pair power over data line group. The Gigabit ethernet (GbE) for 2.5/5/10GBase-T1 on single pair of wires standardized using IEEE802.3ch, is also being investigated for infotainment. Audi, BMW Mercedes have began implementation of Ethernet based connectivity.

5. Level of automation

There are five levels of automation defined by the Society of automation engineers (SAE) [13]. Level 0 has no automation, driver performs all the functions. In level 1 driver performs all the functions but ADAS system provides alerts and partial control. Level 2 defines partial automation. Driver must still monitor actions but automated system controls braking, steering, and acceleration. Level 3 called automated driving systems performs all driving activities. Driver must still be available to take control in special circumstances. Level 4 automated driving systems perform all driving activities. Driver may still control the vehicle if needed or desired. Finally in level 5 automation no driver is needed.

6. Self driving cars

Self driving cars also referred as Autonomous vehicles. It improves automotive safety and provides help to old age and handicapped citizen who may not be able to drive in difficult traffic conditions. Uber and Ola my also like to reduce the cost of personnel in driving activities. Currently automation level is 1 and 2. Testing is being carried out for level 4 and 5 but final product on road may take long time. Autonomous vehicles need ADAS with full sensor inputs from Radar, LiDAR, Video camera (360 degree field of view), and Ultrasound sensor unit. GNSS/GPS navigation mapping is also essential. Most modern vehicles use simultaneous location and mapping algorithm. It combines information from multiple sensors and an off-line map to calculate current vehicle location and generate more real-time map of the current environment. Real time HD mapping is critical ingredient for automated driving. HD maps play a critical role in path planning at cm level distance. All the data received from sensors are processed in real time so that steering, braking, and accelerator setting outputs are generated. This requires massive computing. Artificial intelligence (AI) has been responsible to implement because of improved performance of processors like GPU (Graphics processing unit). Some applications uses GPU cluster for training neural network. The challenge in neural networks is to determine weights, and number of nodes in each layer, and number of layers (or depth) of system. The weights are determined by training the network via set of inputs to recognize the object. Training uses feedback system when an input is matched with outputs and internal hidden layer weights are adjusted. Self driving cars do not sleep, do not drink, do not get phone calls, will certainly reduce car accidents caused by human error.

Auto Industries already ahead with manufacturers like Tesla, Audi, Mercedes, BMW produce level 2 automobile where driver not have to physically operate the vehicle, and can have his hands off the steering wheel and foot-off the accelerator/brake pedals at the same time. In level 3 human drivers fail to properly take over when necessary, or drivers of other cars are at fault. The Google automotive spin-off Waymo has recently started to test level 4 vehicle on public roads in Arizona, USA. According to GSMA 2013, 500 million cars will be connected by 2025, and 75% of cars on the road will be autonomous by 2035 as per Navigation Research 2013.

6.1 Autonomous motor bikes

A new self driving motor bikes developed by M/S AB Dynamics promises to allow ADAS and autonomous system to be tested under much challenging conditions. Motor bikes stability control utilizes advanced gyroscopes and accelerometers to detect parameters such as speed, lean angles, and braking force, and can quickly adjust electronic braking and throttle settings to help prevent crash. The system provides assistance by continuously monitoring a compressive set of key vehicle data including torque, lean angle, and acceleration to detect critical situations. This improves both riding stability and braking performance. According to Bosch Accident Research motor bike-to-car communication could prevent nearly 1/3 of the motor cycle accidents. The system uses DSRC IEEE802.11p. The motor bike will exchange information up to 10 times per sec. with other vehicles on the road within radius of several hundred meters. The information consists of vehicle type, speed, position, and directional travel. When a motor bike ends up in a car's blind spot or changes lanes to pass, this technology informs the car that motor bike is approaching. If system identifies a potential dangerous situation, it can warn the rider by sounding an alarm and flashing a warning notice on the dash board. The blind spot warning system works similar to those implemented in a car. A radar sensor serves as the blind spot recognition system's electronic eye, registering objects in hard-to-sea areas. The small radar sensor will help to detect vehicles approaching and offer a warning ideally by illuminating light in the appropriate side mirror. This system keeps a lookout in all directions to add motorcyclist change lanes safely. The system is active as soon as the vehicle starts and it supports the rider in all relevant speed ranges. If the system detects another vehicle is dangerously close and the rider does not react to the situation, it warn rider by way of an acoustic or optical signal.

The streets of China, Asia, and India are filled with millions of motor bikes, manufacturers feel that autonomous technology built in to motor bikes can be a good solution to manage the movements of vehicles. Kawasaki, BMW, Honda, Yamaha, and Ford are making a lot of headway to bring the concept to fruition much sooner.

7. Conclusions

V2X communication benefits the environment by reducing traffic jams that increases pollution. The coordination between V2I will reduce unnecessary braking further reduce fuel consumption and emission. C-V2X will save millions of lives but it will take time to equip into vehicles on road. The mobile network operators (MNO) need to offer C-V2X services by extending their networks to accommodate the C-V2X applications. For the same, service agreement would be required for each vehicle. Embedded SIM (eSIM) can be soldered in to cellular device of vehicles. GSMA has developed such eSIM profile specifications. ADAS and V2X form full autonomous vehicles. From level of automation it can be seen that level 5 automation may take long time to achieve with above, but level 4 can be achieved in shorter time. Although full automation is a goal but perhaps a better solution is simply let AI complement the driver rather than replace the driver. While some learning and adaptation will be required by the human, the powerful combination of human/AI should be able to provide the best safety improvement everyone needs. With C-V2X, 5G cellular network, and AI the intelligent connected vehicles will stay at the forefront of the automotive industry. Growing manufacturers have come to the conclusion that C-V2X is superior to DSRC IEEE802.11p technology. Global shifting is towards C-V2X as C-V2X is superior in a sense it enables not only V2V services, but in addition V2N services are also possible.

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