ADVANCES IN AUTONOMOUS DRIVING AND V2X TECHNOLOGIES

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INTRODUCTION

Automotive electronics has seen rapid evolution over the past several decades. Today's efforts are pushing toward what might be the ultimate safety and efficiency solution: autonomous driving. Many players across academia, government, and the private sector, have development underway. Significant work must be completed in a variety of areas. There is one key capability that is close to deployment into the market: Vehicle-to-Vehicle/Vehicle-to-Infrastructure (or V2X) technology. This paper provides a high-level look at the state of development of V2X and provides a perspective on this and other technologies required to make autonomous driving a reality.

A Brief History Of Key Enabling Automotive Electronics Technologies

Current automotive electronics technologies are built on a solid footing of gradual advances of elemental capabilities that have been released into production vehicles over the years. It is helpful to look at the history of various enabling automotive technologies to appreciate the current state and understand the pathway to reach full deployment of autonomous driving into the market place. A road map of a few key technologies that will likely be familiar as elements vital to autonomous driving is illustrated in Figure 1.

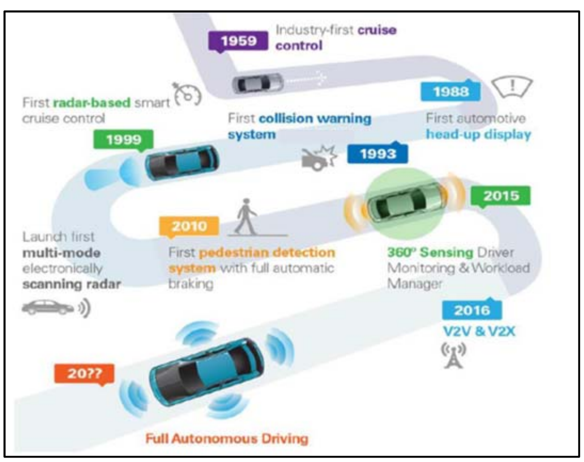

Figure 1: A Roadmap of Enabling Technologies

It is worth noting that this roadmap references back to the 1950s with the advent of cruise control. This 6-decade path illustrates that autonomous driving elements have had a solid history on the road. Examples are: collision detection/avoidance, pedestrian detection, sensors, all of which make possible advancements such as parking assist, and adaptive cruise, and lane management. In addition to these, basic cognitive capabilities permitting autonomous intervention now are advancing rapidly. The aggregation of these comprise many Advanced Driver Assistance Systems or ADAS capabilities. ADAS technologies are foundational to autonomous driving. More importantly, these are proven features in today's most advanced production vehicles.

Technologies Enabling ADAS and Automated Driving Vehicles

Many automated driver assistance features are well established in production vehicles. The majority of these comprise the foundation for autonomous driving. In fact, many experimental autonomous driving platforms incorporate production features. An example is Delphi Automotive Systems autonomous driving vehicle shown in Figure 2.

Figure 2: Autonomous Vehicle with Production Sensors

This platform incorporates many production features. Some examples are electronically scanning radar, Lidar, Ray-Cam Vision system, GPS, adaptive cruise, and parking aid. The subsystems feature content available in production vehicles today supports the point that most of the key capabilities are proven and ready for deployment. These are illustrated in Figure 3.

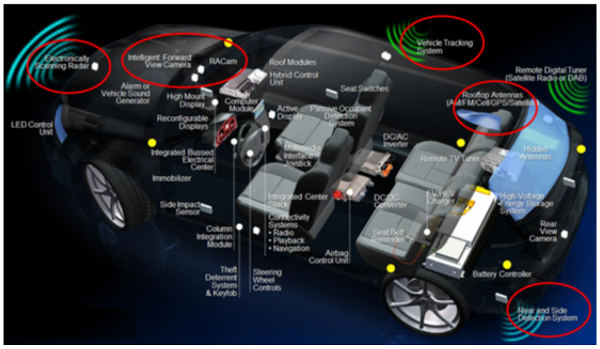

Figure 3: Production Sensors in an Automated Driving Vehicle

Cognitive Computing and Autonomous Driving

As sensor technologies have provided vehicles the "eyes", autonomous decision capability must complete the system by replicating and exceeding human thinking.

Software has its roots in the basic electro-mechanical rotary switch sequential state machines from the dawn of the computer age in the 1940s. Decision algorithms have been limited to predictable criteria. Vehicle operators face an overwhelming amount of continuously varying information. Rigid rule sets cannot confound the driver's ability to operate the vehicle safely and efficiently. The challenge is to make autonomous driving viable through adaptive algorithms. Human-like thinking is not an option, it is a must. This requires the application of cognitive computing into autonomous driving systems.

Cognitive computing is a departure from traditional sequential state logic. It has to realize a computing process that is fast, adaptive, and learning. This must perform to a level that mimics human thought processes. An example of cognitive computing is IBM's Watson [2] computer platform. Another challenge is that autonomous vehicles need to process huge amounts of data as illustrated in Figure 4 [1].

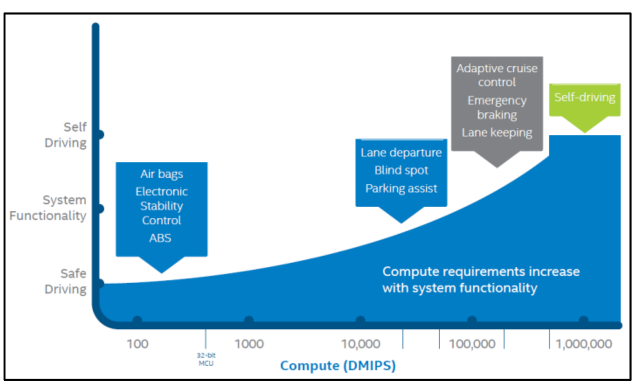

Figure 4: Adapted from: "Technology and Computing Requirements for Self-Driving Cars", 2014, Intel, Corp

To meet data volume and cognitive algorithm computing cycles, the autonomous vehicle platform discussed above utilizes a teraflop computing subsystem as the main autonomous driving decision engine. This subsystem concentrates and processes all information provided by the various sensors and information pipes: object detection subsystems, the vision subsystem, GPS, and vehicle-vehicle/vehicle-infrastructure data.

In practical implementation, autonomous driving cognitive decision processes must rely on heuristics and multi-policy [3] adaptive [4, 5, 6] reasoning that supports anticipation of outcomes and considers risk/reward scenarios relating to the host vehicle and other vehicles/agents operating within the range of concern. Learning must be built from a history of actions. Immediate decisions are based on a history of actions as predicted from similarities or differences in relation to historic actions. New decision outcomes increase the "experience" of the cognitive computer by virtue of the aforementioned heuristics.

The Objectives and Importance of V2X

Infrastructure (traffic controls, traffic data collection, traffic data communications) plays a vital role in the march toward autonomous driving. Vehicles and infrastructure require full-time state awareness to realize safer and efficient driving. V2I/V2V (V2X) subsystems and information are a critical part of autonomous driving real-time processes.

V2I technology has also evolved over many years. The first computer-controlled traffic systems were deployed in the early 1960s in Canada. Microprocessors sped advancements in the 1970s. The Intermodal Surface Transportation Efficiency Act sparked an earnest move toward interoperability in the 1990s. Since 1993, traffic signals have been managed by way of "adaptive control". Sensing technology has evolved to a wide range or solutions. These include: magnetometer, magnetic, microwave and laser radar, passive infrared, ultrasonic, acoustic, and video camera. Infrastructure has been "seeing" vehicles for quite some time. Vehicles must "see" each other thus automated vehicle-to-vehicle (V2V) awareness and communications is required.

V2V employs existing telematics technologies based on Digital Short Range Communications (DSRC). In the US, DSRC for V2V operates over FCC allocated 75 MHz of spectrum in the 5.9 GHz band for use by Intelligent Transportations Systems (ITS) vehicle safety and mobility applications. Channels and associated functions are assigned over this spectrum as shown in Figure 5 [7].

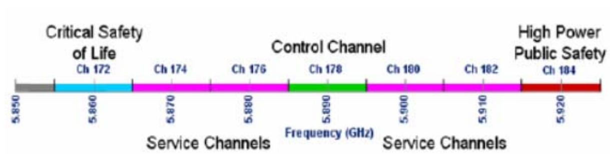

Figure 5: V2X Channel Assignments and Functions

Key information exchanged across V2X telematics links and a few key threat scenarios are presented in Figure 6, Figure 7, respectively, and the example list of data below.

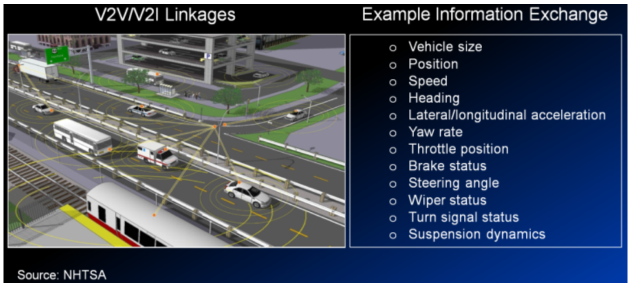

Figure 6: Vehicle-Vehicle/Vehicle-Infrastructure (V2X) Links and Example Data

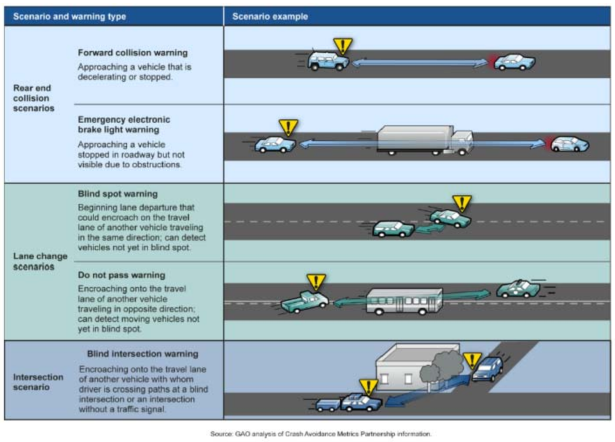

Figure 7: Example V2V Threat Scenarios

- The **S**tationary/**S**low **V**ehicle **A**head **(SVA)** feature Informs driver when a vehicle ahead has its hazard lights engaged.
- The **E**mergency **E**lectronic **B**rake Lamps **(EEBL)** feature shall warn the driver when a vehicle ahead is braking hard.
- **H**azard **L**ocation **W**arning (**HLW**) feature shall warn driver if a vehicle ahead detects a rough or slippery road surface.
- **I**ntersection **C**ollision **W**arning **(ICW)** feature shall be able to detect collision hazard and to warn the driver that there is a risk of collision with cross traffic at an intersection.
- The **E**mergency **V**ehicle **W**arning **(EVW)** feature should inform driver when there is an emergency vehicle approaching.
- The **T**raffic **J**am **A**head **(TJA)** system shall inform the driver when there is a stopped traffic ahead.
- The **R**oad **W**ork **W**arning **(RWW)** feature shall advice the driver of an impending roadwork area and informs about the remaining distance to the end roadwork.
- The **G**reen **L**ight **O**ptimization **S**peed **A**dvisory **(GLOSA)** feature shall inform the driver of the optimal driving speed to avoid stops at traffic lights.
- The **S**ignal **V**iolation **W**arning **(SVW)** feature informs the driver of potential traffic signal violation.
- The **I**n-**V**ehicle **S**ignage **(IVS)** feature shall advice the driver of the outside posted traffic signs. It can help to increase awareness of the traffic signage.

For vehicle integration, V2X electronics are designed into a module which is mounted in the vehicle cabin and interconnected to vehicle power, the vehicle communication bus, and DSRC/GPS antennae. In-vehicle components and functions are illustrated in Figure 8.

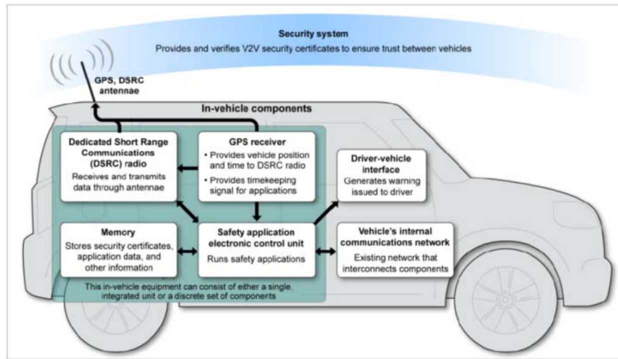

Figure 8: In-Vehicle Components of the V2V/V2I System

An example V2X (OBU) consists of the following major functional blocks and as illustrate in Figure 9.

- Microprocessor
- Memory
- DSRC RF transceiver
- 802.11P front-end and baseband communications
- Security/threat protection
- GPS (if not provided over the vehicle bus by another subsystem module)

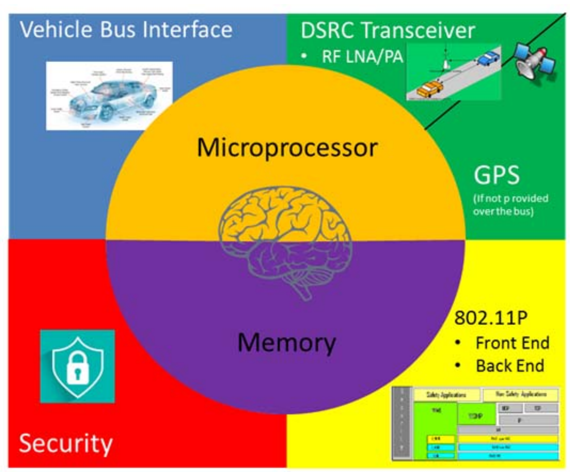

Figure 9: V2X Module Functional Blocks

V2X Communications Network Architecture

V2X Communications networks involve vehicles and roadside facilities (infrastructure) exchanging information. The architecture of V2X communications is defined by the ITS (Intellegent Transportation Systems) organization [8,9].

Participants include, the Vehicle Station, Roadside Stations, and Central Stations as shown in Figure 10.

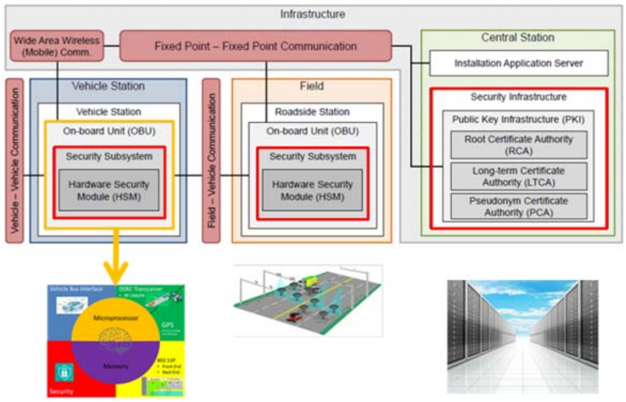

Figure 10: V2X Communications Network Architecture

Interoperability and Security
Vehicle Stations and Roadside Stations communicate using DSRC on a standardize network, complying with the IEEE 1609.4 standard, over a standardized wireless layer, IEEE802.11P. Message types include safety and certificate exchange. Safety messages include the examples shown in Figures 6 and 7 above. IEEE 802.11P allows sucruity and authentication to be provided by other standards (ex. IEEE1609. 2/ Wirless Access in Vehicular Environments (WAVE)). WAVE defines DSRC Security in terms of Anonymity, Authenticity and Confidentiality (Certificate type and class) across the network.

Indentity and Access Management of Devices and Access to Systems
For security in V2X, systems include:

- Entity Management – processes and technolotics managing credentials and users.
- Crentialing – Creation, revocation, reconciliation for credentials devices and users.
- Authentication: Verificationi and validation of devices and users.
- Authorization: Vaidation of device access rights to the network and services.
- Storage: Protection of information.

Implimentation of the security framework involves tremendous complexity across the V2X system. It is critical to protect all participants in the ITS. The key elements of the security framework are showin in Figure 11.

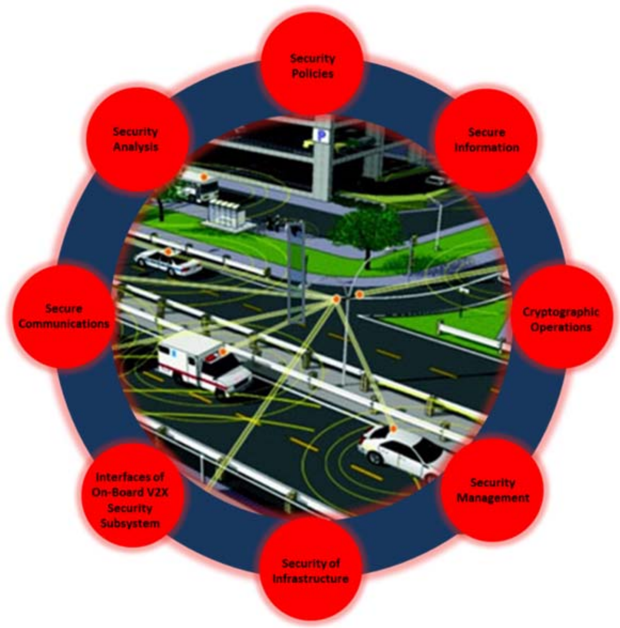

Figure 11: V2X Security Framework

V2X and Self-Driving Vehicles
V2X is a key enabler for autonomous driving vehicles. V2X provides vital connectivity with other vehicles and infrastructure. V2X information exchange passes critical real-time information far beyond the "eyes" (sensors) of automated driving vehicles. To achieve ultimate safety, traffic information, infrastructure systems operational states and potential threats in "blind spots" covered by V2X communications must be integrated into autonomous driving systems. A prime example may be seen in the case of today's technology deployments, namely ADAS. It is largely known that ADAS-equipped vehicles capable of automated steering are now on the road. These are not full autonomous driving capabilities. Drivers are required to react (take over) steering when alerted by the system. When a crash threat abruptly occurs, the reaction time of the driver to assume control is of utmost importance. Drivers are becoming increasingly at ease with automated steering and may not be able to react fast enough to avert collisions. V2X communications would provide advanced warning of the potential threat and allow both vehicles in such a case to warn drivers and possible allow on-board crash prevention systems to intervene and minimize or prevent a crash.

Autonomous Driving Systems Elements
Briefly touching on the essential elements of autonomous driving, a macro system view is shown in Figure 12. The entire system must function as the eyes, ears, and cognitive thought flow of human perception. Beyond human capacity are the 360-degree real-time detection capabilities of the sensor array. This actually far surpasses the real-time awareness state of vehicle operators.

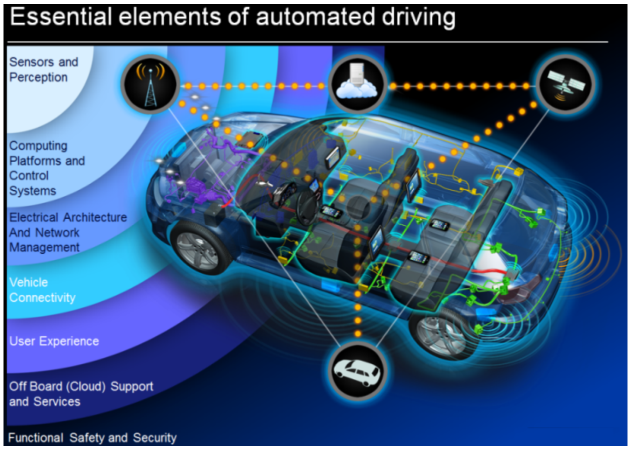

Figure 12: Automatic Driving Macro System

As mentioned earlier, today's automotive electronics comprise well established sensor systems many of which have been on the road for over a decade. Integration of these into autonomous driving development platforms is shown in Figure 13.

Figure 13: Production sensors in a Autonomous Vehicle Development Platform

SUMMARY AND CONCLUSIONS

Autonomous driving is progressing rapidly. Many OEMs have aggressive programs underway. The race to develop autonomous driving capability has expanded beyond traditional automotive producers. Academia, component suppliers, and government have played significant roles in the broader effort to bring autonomous driving into reality.

Significant accomplishments have been made. Millions of miles of autonomous driving have been logged on test courses and roadways. The vehicle highlighted above is credited with tremendous milestones. This platform was among the first to make an autonomous drive between major cities (San Francisco to Las Vegas for 2015 CES). It was reported as being the only vehicle that was allowed to operate on the city streets for demonstration during the 2015 CES. It was the first to make the historic autonomous drive across the United States. This highly reported experimental ride was conducted in the Spring of 2015 and ran from San Francisco to New York City. With the progress and practical testing, autonomous driving is breaking out of the laboratory and onto the streets.

Sensor technologies are showing great promise. In many cases these are based on, long established production solutions that have been available in the market. Critical refinements in radar and Lidar sensor technologies are progressing very well. Compact form factors, and total surround coverage have presented slight challenges to the integration of these elements into producible autonomous driving vehicles. The challenge of mounting the larger number of number of additional sensors must be overcome but OEMs that have used these sensor technologies in production vehicles are well positioned to solve these problems.

The area of greatest challenge remains to be human-like cognitive thinking. Development is revealing the limitations of current cognitive algorithms and adaptive learning. The most difficult areas tend to be where safety protocols drive decision behaviors that far below acceptance of normal driving under human operation. For example, at a construction zone, if caught in a restricted or closed lane, an autonomous vehicle may wait for all traffic to clear an adjacent open lane versus nudging into it.

Challenges in area of imaging are evident. Obscured or virtually obliterated lane markings may create difficulty in lane awareness and tracking. Improvements in imaging technology are helping but more reliance on GPS and V2X technologies will be vital.

V2X technology must progress quickly. OEM roadmaps have these capabilities rolling out on fairly short timelines. One OEM is expected to have the first production V2X capability in the MY2017 time frame. Reliance on V2X as a vital requirement autonomous driving necessitate ubiquitous deployment across many OEMs. Likewise, infrastructure must be in place for V2I to provide full capability. Infrastructure systems must also be common to work with all vehicle platforms.

Some predictions suggest autonomous driving will be rolling out by 2020. More conservative projections predict roll-out within the next decade. This is a wide range in outlook. Timelines can change in accordance to progress. As this technology evolves, unthinkable events, injuries or deaths, may slow development, but it will most certainly become reality. Heavier-than-air flight was not a certainty in its infancy but it became a reality despite countless setbacks. The same may play out for autonomous driving.

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