Exploring Vehicle-to-Vehicle Communications (V2V) in an Electrical Engineering Undergraduate Program

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Abstract

In this paper, V2V communication is discussed based on a wireless protocol called Dedicated Short Range Communications (DSRC). This protocol allows cars on the road to form a dynamic wireless networks that aid in driving with the overall goal of reducing car accidents and carbon footprint. The onboard car computer manages and controls all the communication systems as well as electrical systems or subsystems in the vehicle which involve many sophisticated sensors. These sensors, and the software, help cars to make automatic, or semi-automatic, decisions and provide warning information. V2V includes control technology that comes into play at the local (sensor-level) and higher layers of the communication architecture for this dynamic wireless network to work properly. Note that V2V is also being heavily promoted by the US government and car manufacturers should have all this technology ready for deployment in the near future. The authors stress that V2V is a very good example of systems engineering where different architectures (mechanical, electrical, computers and communications), including government policy, are integrated into a product. While this type of development is being disseminated through national media, which gives the public a better understanding as to why V2V communication is important, in-depth discussion of this technology is not typically found in an electrical engineering undergraduate curriculum. This paper is based on a report written in the context of an undergraduate Electrical Engineering computer and communications course at Penn State Harrisburg.

I. INTRODUCTION

V2V communication is an emergent technology that appears to be beneficial, growing fast and being recognized by the United States as a necessary to reduce car accidents[1-4.] Furthermore, many car companies are working together to develop the supporting networking technology that will be implemented in V2V communication [5]. Strangely, this technology is not required for self-driving cars, like the Google car [5]. It is also important to recognize that the US government wants to make this type of technology mandatory [1-5]. Hence, many institutions are researching this area. For example, researchers at University of Pennsylvania (UPenn) are implementing a crowd-sourced simulation software called GrooveNet [6]. This tool allows multiple roadside vehicles to be efficiently tracked. For instance, when a car is not on the right course by a fault of the driver, a warning will notify all vehicles in the car's vicinity to avoid it or take safety precautions by slowing or speeding up.

In this paper, V2V communications operation is discussed based on a wireless protocol, Dedicated Short Range Communications (DSRC)[7,8]. In V2V communications, every vehicle is also a router which allows for sending/receiving messages over multi-hop systems to/from other vehicles and/or roadside stations. The routing algorithm is based on the position of the vehicles and is able to handle fast changes of the network topology. Furthermore, control technology comes into play at local and higher layers of the communications architecture where uncertainties, delays, partial measurements, safety and performance objectives, and other aspects must be considered. The system must also be capable of making automatic or semi-automatic decisions, providing warnings information and potentially affecting driving actions. The vehicle architecture itself is another vital part of the system. In general, the onboard car computer system manages and controls all the electrical systems or subsystems in the vehicle which involve many sophisticated sensors. In fact, for V2V communication technology, sensors are the most important part of the system since sensors are used for object detection, lane tracking, intersection detection, and additional road uses.

Since this is rather a new technology, many of the discussions in academia are carried out in graduate courses. However, in-depth discussion of this technology is not typically found in communication and networking courses in an electrical engineering undergraduate curriculum. In this paper, the authors try to demystify the technology and present it at the undergraduate electrical/computer science program students as a good example of systems engineering. In fact a recent publication by the US Department of Transportation [9] highlights this fact where different architectures (mechanical, electrical, computers and communications), including government policy, are integrated into designing one product.

This paper is organized as follows. In section II theory and impact of this technology is discussed. V2V Implementation issues are presented in Section III. Conclusions are given in section IV. The authors stress that this paper is an extension of an Electrical Engineering undergraduate project presented in the context of a Communications and Networking class, and clearly shows the systems engineering approach.

II. THEORY and IMPACT of V2V

As indicated in the previous section, at the heart of V2V communications is the DSRC[7,8] wireless protocol. The DSRC is designed to create a short range cellular network that is based on a 3G and 4G cellular network. In this scheme, every vehicle is also a router and the complete system acts as a dynamic wireless network. The V2V's routing algorithm is based on the position of the vehicles and should handle fast changes in network topology since many cars are operating on the road. While V2V allows communication between cars, there is also an additional protocol Vehicle to Infrastructure (V2I) that is being tested, which allows communication with traffic centers[10]. Control technology comes into play at local and higher layers of the architecture. According to new research [11], uncertainties, delays, partial measurements, safety and performance objectives, and other aspects must be considered, and the system must be capable of making automatic or semiautomatic decisions, providing warning information and potentially affecting actions [11] taken by a car. The vehicle's architecture is another vital part of the system. The onboard controls involve many sophisticated sensors. In general the onboard system manages and controls all the communications, electrical systems or subsystems in the vehicle. According to[7], sensors, which can be long or short-rage radars as well as video stereo cameras, are the most important part of this technology and are used for sense object detection, lane tracking, intersection detection, and many road uses [7]. The objects can be determined by their position and velocity which can be sensed by radar/video sensors in the vehicle.

One of the first persons to be recognized for pursuing V2V technology is Mr. Anthony Foxx who is the Secretary of the U.S. Department of Transportation under the Obama administration. Mr. Foxx is trying to make V2V communication mandatory for cars by the year 2018 [12]. In a recent report Foxx stated, "Keeping drivers safe is the most important advantage of V2V, but it's just one of many" [1]. Gabe Nelson journalist from Automotive News stated that, "V2V can also help reduce congestion and save fuel. The potential of this technology is enormous"[1] since it can help reduce accidents that harm, and possibly kill, innocent citizens. Mr. Foxx believes that V2V technology can reduce 70-80 percent of crashes that involve unimpaired drivers[1]. This could be very beneficial and help keep people safe from drunk drivers or people who fall asleep when they drive. Another person who thinks this technology can reduce the amount of car crashes is David Friedman who was an acting administrator for the National Highway Safety Administration. Mr. Friedman believes that V2V technology is very innovative and can be proven to be very beneficial in highway safety[1].

Research is a key factor in making sure this technology becomes successful. The development for V2V technology started in 2002, when research was conducted by U.S. Department of Transportation Research and Innovative Technology Administration (RITA) office[13]. RITA explored issues that major auto companies have to deal with. Some of these issues include configuration design, attack on users, and attack on communications. When it deals with configuration design, some key factors are Public Key Infrastructure (PKI), vehicle hardware, and policy options. The main function of a PKI is designed to ensure users the ability to communicate with other vehicles having certain credentials[2]. An example of PKI is shown in Figure 1.

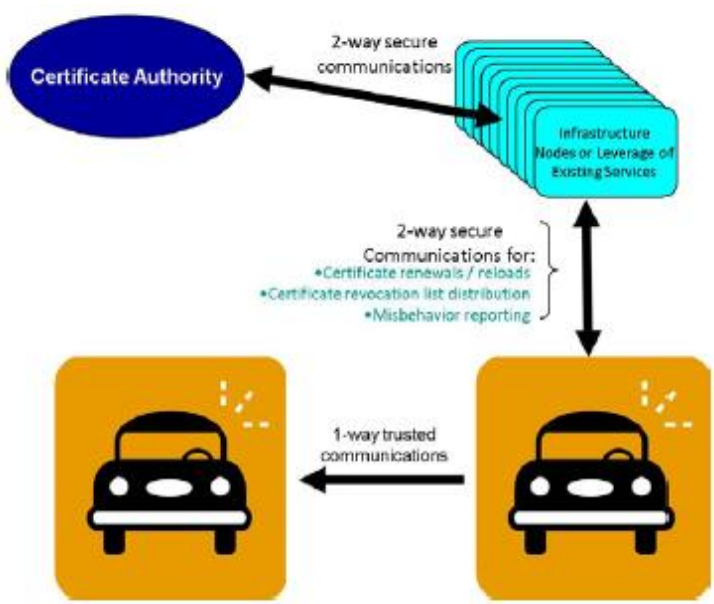

Figure 1 Public Key Infrastructure (PKI)[2].

With this technology, vehicles should be able to exchange information with nearby vehicles to prevent accidents. Other solution to be used, besides PKI, is a change of software that prevents any tampering of communication. An attack on users is a huge issue that plays a role in V2V communications. Some of these issues deal with user privacy, safety, and communications operations. According to[2] attacks on users have to deal with software manipulation when a user downloads malicious and harmful software that can affect another car's software[2]. It was also mentioned in[2] that interference of other car's sensors can affect messaging that warns another driver of nearby accidents[2]. These are some of the key security issues with V2V communication because it may allow hackers to harm the driver and/or the persons in a vehicle. The risk factors and their levels are displayed in Table 1, obtained from[1], below.

Table 1: List of Risk Levels[1]

Methods of Attack		Requires Physical Access	Level of Risk		
			A1	A2	A3
Key Extraction	Physically entering the vehicle and removing keys from the OBU	✓	Low	Medium	High
Software Manipulation	Use APIs[16] to extract keying material	✓	Low	Low	Medium
	Install software on device to create messages containing arbitrary information	✓	Low	Low	Medium
	Install software on device to alter information (i.e. system clock or sensor inputs)	✓	Low	Low	Medium
Sensor Manipulation	Interfere with input to CAN bus that directly report vehicle behavior (e.g. brakes)	✓	Low	Low	Medium
	Interfere with output from CAN bus to application processor	✓	Low	Medium	Medium
	Interfere with input from sensors that report external circumstances (e.g. GPS, lane marker detectors)		Low	Low	Medium
Denial of Service	Jamming the channel (denial of communication)		Low	Low	Low
	Send false messages that cause true messages to be ignored (denial of computation)		Low	Low	Low

III. IMPLEMENTATION

Major Companies such as General Motors, Toyota, and Volkswagen are working together to implement V2V communication in their vehicles and conducted research and testing for more than ten years on this technology[1]. Testing started in 2002 with automotive manufacturing companies researching on emergency brake light warning, forward collision warning, intersection movement assist, blind spots, and lane changing. Testing was also conducted with Dedicated Short-Range Communication (DSRC). In[1] Nelson stated: "Over 3,000 vehicles were equipped with DSRC devices in a test conducted August 2012." Even though DSRC has been implemented in many devices more tests have to be conducted. Gloria Bergquist, spokeswoman of the Alliance of Automobile Manufactures of Washington, believes that DSRC is very beneficial in the growth of V2V technology but tests still need to be conducted. Some issues need to be worked on such as security and privacy because it communicates on a cellular network. Nelson mentioned in[1], "We need to address security and privacy, along with consumer acceptance, affordability, achieving the critical mass to enable the network effect and establishment of the necessary legal and regulatory framework." Other big name companies are also a part of this development such as Cisco.

Andreas Mai of Cisco stated that, "Cisco is naming V2V "Internet Cars" and believes that if consumers switch to this type of technology they will be saving over $1,400" [14]. This is based on the reduction of CO_2 produced by vehicles, reduced car insurance rates, and traffic guidance produced by other vehicles. Mai mentioned that Cisco believes that the technology price range depends on the market where V2V is being sold[14]. Another factor that V2V faces is communication with cars from different manufacturers. For example, cars from BMW should be able to communicate with cars manufactured by Toyota. However, some auto makers are putting their patents on DSRC technology which can be used to create their own types of alarms for their cars[1], which can be a detriment of the wide-spreading of this technology.

Initial implementation of V2V communication software was conducted by utilizing the GrooveNet hybrid simulation tool[6], developed at UPenn Engineering department. See Figure 2 for a snapshot of its graphical interface. GrooveNet is crowdsourced Linux based software that allows a vehicle to track latitude, longitude, and heading, based on GPS, as well as vehicle transmission states such as the speed of the vehicle. The basic of the system involves path history and path prediction. Path history comprises the vehicle positions as it heads down straight and curved roads[15]. The path history would then be recorded and transmitted to nearby vehicles. Based on current GPS technologies, along with its path history, a car can predict its trajectory in both straight and curve roads[15]. GrooveNet also allows simulation of virtual against real vehicles in real time. Currently still under development, GrooveNet is a powerful application that offers engineers a platform to further develop V2V technology.

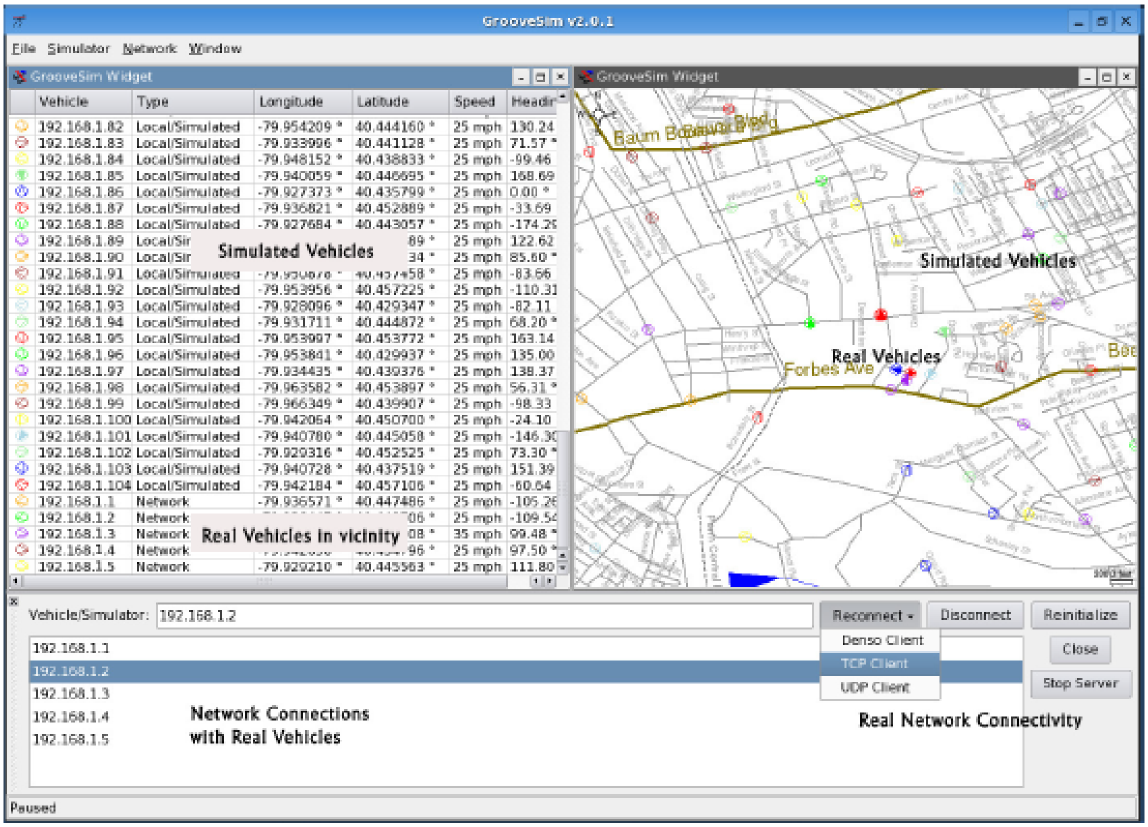

Figure 2: Snapshot of the GrooveNet Interface from UPenn[6].

The vehicle architecture allows onboard communications with other vehicles includes. This architecture involves an Electronic Control Unit (ECU) which deals with all data coming from a single vehicle (for example all data from Toyota or from BMW). One type of ECU can be classified as safety control seen in air bags, and brake assist systems. Other types are Power ECUs which can control the transmission and the power to the engine. Telematic ECU's are another type which can manage video, audio, and mobile communication systems. In V2V, the ECU processes the data coming from the sensors to maintain efficient driving performance. There are many complex tasks which require many control processes and accurate results may need multiple ECU's[7,16].

Radar, mounted on a car, is used to detect and track the movements of road users, such as animals and pedestrians. There are many types of radars which are used for different ranges. They can be classified as long-range radars and short-range radars. Long range radars have 15 to 20 degrees of field view or up to a 250 meter range. This radar is considered cheaper than the previous radar systems and can detect objects and other vehicles in smaller proximity up to 150 meters. There are also short range radars with a wider, and overlapping, field of views of up to a 60 meter range[17,18], and video stereo cameras to aid with the car's navigation (see Figure 3).

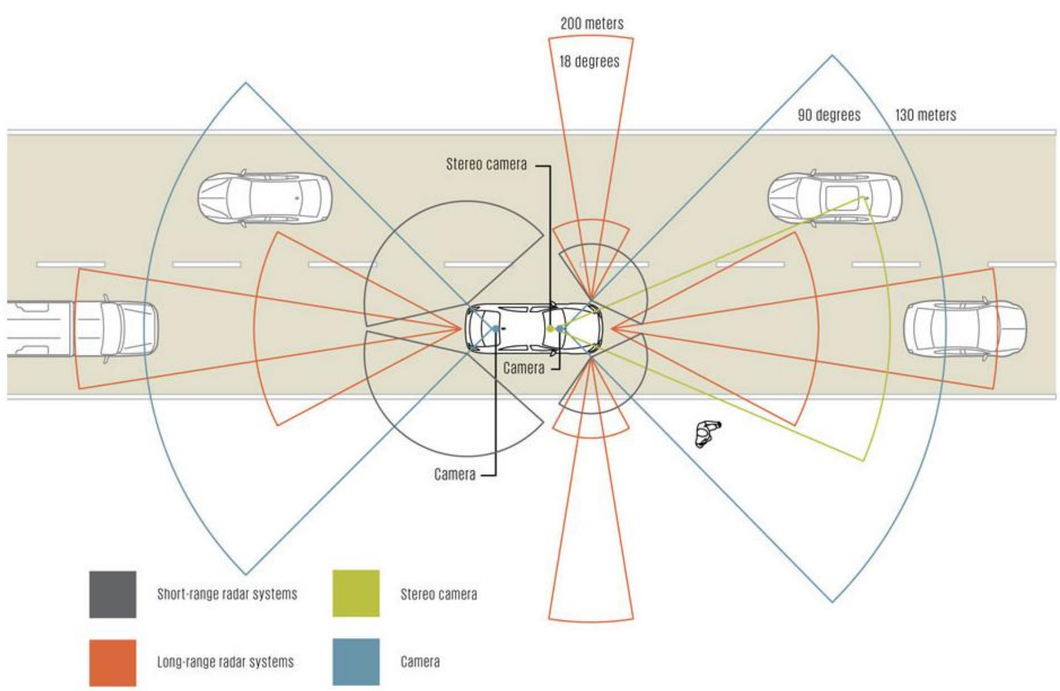

Illustration: John MacNeill

Sensors of different capabilities cover 360 degrees, with overlapping fields of view.

Figure 3: Diferent radar ranges and video stereo sensors in V2V[18].

The use of all of this technology is aimed to improve the driving experience while reducing car accidents and the carbon footprint of cars on the road.

IV. CONCLUSIONS

In this paper, DSRC has been introduced as one of the protocols of the V2V communication architecture. In this scheme, there are also a variety of onboard sensors that can be utilized to alert cars of problems on the road. One of the major goals of V2V is precisely accident avoidance. In order for V2V to work, major car companies have to come together. They will have to ensure their customers' safety and that their software can communicate with each other's vehicles. Car manufacturers also have to ensure that older car models have a device(s) to communicate with newer car models. Interesting, Google has developed an autonomous self-driving vehicle that possesses a driver's license, without the V2V technology. It was also discussed that behind this technology there is a big push from the government, through defined policy, in order to reduce car accidents. An additional protocol, Vehicle-to-Infrastructure (V2I) also needs to be investigated more deeply. Overall, V2V and V2I communication networks are active lines of research and new developments are coming every day. The authors stress that this paper is an extension of an Electrical Engineering undergraduate project presented in the context of a Communications and Networking class, and clearly shows the systems engineering approach where many areas of engineering (electrical, mechanical, communications, computers) come together as well government policy. The authors are also working in implementing software to check for spectrum usage in V2V communication.

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