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Autonomous Cars. History. State of Art. Research Problems

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Abstract. Vehicle-to-infrastructure communications is the wireless exchange of critical safety and operational data between vehicles and highway infrastructure. The following research questions have to be answered by the V2I Communications: What safety applications are effective and have validated benefits?; What minimum infrastructure is needed for maximum benefit?; Can signal phase and timing, and mapping information be transmitted over a car network via a universal architecture?; What degree of market penetration is required for effectiveness?; Are there unique applications for specialty vehicles (transit bus, commercial vehicles, light rail, etc.)?

In the paper we present the history of the autonomous cars and explore different issues relevant to V2V, analyzing the research conducted so far, the technological solutions available for addressing the safety problems. The used communication technology is highlighted. Research problems and corresponding approaches are shown.

Keywords: Autonomous cars · Vehicle-to-vehicle communications · Connected vehicle · Safety applications · Vehicle awareness device · Communication security · V2V technology · V2I technology

1 Autonomous Cars. Definitions

Autonomous cars, or cars that run without human control, have been developed over the past several decades, starting in 1977. Currently, we have autonomous cars still in experimental and development stage that have driven autonomously thousands of miles. According to World Health Organization, each year, approximately 1.2 million lives are lost due to traffic accidents worldwide, and around 50 million people suffer car accidents. Self-driving cars promise to reduce this number of deaths and injuries. Some autonomy systems are already being used in the cars such as: Cruise Control, Anti-Lock Brakes. Some systems are just starting to be used: Stability and Traction Control, Pre-Accident Systems, Traffic Jam Assist, Self-Parking Systems. In 2015, car manufacturers will introduce new feature — wireless broadcast of vehicle operational data. This will

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be used both for vehicle-to-vehicle communications (V2V) as well as for vehicle-to-infrastructure communications (V2I). The Society of Automotive Engineers (SAE) introduces J2735 standard, supports interoperability of vehicular applications by use of standardized messages. Autonomous cars use equipment such as: Radar sensors, Cameras, Image-processing software, GPS Units, Accelerometer, Ultrasound Sensor, Wheel Sensor, Laser range Finder. The car will become a "networked computer on wheels". GM has been testing the technology with two different platforms, one being a mobile transponder about the size of a GPS unit while the other is a smartphone application that is tied to the vehicle's display unit. Both platforms use Dedicated Short-Range Communication (DSRC) to transfer data between devices and have a communication range of about one-quarter of a mile.

An autonomous car, also known as a driverless car, self-driving car and robotic car, is an automated or autonomous vehicle capable of fulfilling the main transportation capabilities of a traditional car. As an autonomous vehicle, it is capable of sensing its environment and navigating without human input. Advanced control systems interpret sensory information to identify appropriate navigation paths, as well as obstacles and relevant signage. By fully autonomous cars, we mean that the vehicle is able to completely manage itself from point A to point B, without any human intervention whatsoever. Autonomous cars need to do basically two things to find their way and drive: (a) the complete map of its surrounding area, and (b) its relative position. An autonomous car uses equipment such as: radar sensors, cameras, image-processing software, GPS units, accelerometer, ultrasound sensor, wheel sensor, laser range finder.

The main benefits of autonomous cars are: reduced accidents, traffic reduction, higher safe speeds, reduce traffic police, car insurance premiums will decrease, time saving, reduced number of cars needed, improved transportation of goods, impacts on economy. In 2050, at a time when the manual driving will for so long be history and our manual driving of cars will seem like horse carriages today.

In the United States, the National Highway Traffic Safety Administration (NHTSA) has proposed a formal classification system:

- Level 0: The driver completely controls the vehicle at all times.
- Level 1: Individual vehicle controls are automated, such as electronic stability control or automatic braking.
- Level 2: At least two controls can be automated in unison, such as adaptive cruise control in combination with lane keeping.
- Level 3: The driver can fully cede control of all safety-critical functions in certain conditions. The car senses when conditions require the driver to retake control and provides a "sufficiently comfortable transition time" for the driver to do so.
- Level 4: The vehicle performs all safety-critical functions for the entire trip, with the driver not expected to control the vehicle at any time. As this vehicle would control all functions from start to stop, including all parking functions, it could include unoccupied cars.

2 Autonomous Cars. History

Some steps in developing autonomous cars are [10]:

Around **1478** Leonardo Da Vinci sketch a pre-programmed clockwork cart. This cart would have been powered by large coiled clockwork springs, propelling it over 130 feet. The clever control mechanism could have taken the vehicle through a predetermined course.

In **1964–71** the Stanford Artificial Intelligence Laboratory cart was build. It was based on techniques for navigating through an unfamiliar environment with artificial intelligence and machine vision. The cart wandered into a nearby road and survived unscathed.

In **1977** Tsukuba Mechanical Engineering Lab, Japan developed computerized driverless car. It achieved speeds of up to 20 miles per hour, by tracking white street markers with machine vision.

In **1980s** Ernst Dickmanns and his group at University Bundeswehr Munich build robot cars, using saccadic vision, probabilistic approaches such as Karman filters, and parallel computers.

In **1986** teams from the Robotics Institute at the School of Computer Science, Carnegie Mellon University developed Navlab 1, one of the first autonomous vehicle.

1996 ARGO team from Universities of Parma and Pavia, Italy drove their Lancia Thema test bed car 1200 miles around Italy. 94 % of the time was in autonomous mode.

In **2005**: DARPA's American "grand challenge" begins. The top car, with a max speed of 40 km per hour, to complete the 211 Km desert course was the Volkswagon of Stanford, which finished in 6 hours and 54 min.

Systems that are already in use are leading to autonomous cars are: Cruise Control, Anti-Lock Brakes. The systems that are just starting to be used now or in the near future are:

- Stability and Traction Control: These are the systems that use different sensors in order to determine the car parameters.
- Pre-Accident Systems: These are the systems that sense an imminent crash and prepare the car just before it.
- Traffic Jam Assist: which relieves drivers from the tiring work of stop and go traffic.
- Improved Cruise Control: In addition to the regular cruise control, using radar sensor placed in front of the car, the system can sense the car in front and will adjust the speed accordingly.
- Self-Parking Systems: is the self-parking ability.

Over the 6 years since Google started the project for autonomous cars, the been involved in 11 minor accidents (light damage, no injuries) during those 1.7 million miles of autonomous and manual driving with our safety drivers behind the wheel, and not once was the self-driving car the cause of the accident.

The history of V2V communications research began under the Vehicle Infrastructure Integration Initiative in 2003 [5]. It continue the Automated

Highway System (AHS) research of the 1990s. The mandate was issue by the Intermodal Surface Transportation Efficiency Act. The goal was to have a fully automated roadway or test track in operation by 1997. In 1997 twenty AHS-equipped vehicles demonstrating hands and feet off driving on I-15 in San Diego, California. U.S. Department of Transportation introduced the Intelligent Vehicle Initiative in 1997. It was authorized in the 1998 as Transportation Equity Act for 21st Century. In November 2003 it was announced allocating 75 MHz of spectrum at 5.9 GHz for research purposes to improve transportation mobility. The basic concept of operations was that V2V and vehicle-to- infrastructure (V2I) communication could support safety and mobility applications.

3 Autonomous Cars. Communication Systems

Today, most the Google car and the new Mercedes do not rely on V2V but only or mostly on their sensors. By the time a common V2V protocol is established, most driverless cars will be able to drive completely autonomously. V2V communication systems, are designed to prevent crashes in a number of scenarios such as:

- **Intersection assist**. When you approach an intersection, it alerts you if another vehicle is traveling at such a speed on a cross street that it could run a red light or stop sign and hit your car in the side.
- **Left-turn assist**. When in an intersection, it alerts you if there's not enough time to make a left-hand turn because of oncoming vehicles.
- **Do-not-pass warning**. When driving on a two-lane road, the system warns you when a vehicle coming in the opposite direction makes it unsafe to pass a slower-moving vehicle.
- **Advance warning of a vehicle braking ahead**. The system emits an alert when a vehicle that's two or more cars ahead in the same lane — and possibly out of sight — hits the brakes unexpectedly.
- **Forward-collision warning**. A warning will sound if the system detects that you're traveling at a speed that could cause you to hit a slower-moving vehicle in the rear.
- **Blind-spot/lane-change warning**. When traveling on a multi-lane road, this illuminates a warning light when a car is positioned in your blind spot.

Nearly every automaker — including Audi, Volkswagen, BMW, Ford, General Motors, Honda and Toyota — is developing some form of V2V technology. German automakers have launched a pilot program that combines V2V with V2I technology, allowing cars to communicate with each other and with traffic lights. GM is studying the possibility V2V systems also could recognize pedestrians by picking up their cellphone's wireless signal and alerting drivers to an impending collision.

Vehicular communication systems are a type of network in which vehicles and roadside units are the communicating nodes. There are several standards. The most popular are: **IEEE 1609**. It is a family of standards which deals with issues such as management and security of the network:

- 1609.1 -Resource Manager: This standard provides a resource manager for WAVE, allowing communication between remote applications and vehicles.
- 1609.2 -Security Services for Applications and Management Messages
- 1609.3 -Networking Services: This standard addresses network layer issues in WAVE.
- 1609.4 -Multi-channel Operation: This standard deals with communications through multiple channels.
- SAE J2735 SE which contains the Concept of Operations and the Software Requirements Specification for the J2735 SE standard, which covers the information exchange between applications in conjunction with wireless communications related to the next generation integrated transportation system, specifically, the interface to connected vehicles an infrastructure.

V2V communications includes a wireless network where cars send messages to each others on frequencies 5.9 GHz. The range is up to 300 m or 1000 feet or about 10 s at highway speeds. V2V communications include:

- Vehicle speed
- Vehicle position and heading (direction of travel)
- On or off the throttle (accelerating, driving, slowing)
- Brakes on, anti-lock braking
- Lane changes
- Stability control, traction control engaged
- Windshield wipers on, defroster on, headlamps on in daytime (raining, snowing)
- Brakes on, anti-lock braking
- Gear position (a car in reverse might be backing out of a parking stall)

In V2V network, every car, smart traffic signal could send, capture and retransmit signals. Five to ten hops on the network would gather traffic conditions a mile ahead. V2V warnings might come as different signals or cars brake and steer around hazards. Eight automakers: GM, Ford, Toyota, Hyundai/Kia, Honda, Volkswagen/Audi, Mercedes-Benz and Nissan/Infiniti, and 2500 vehicles been taking part in a University of Michigan V2V project along 73 lane-miles of roadway in Ann Arbor. GM suggests V2V will be effective when a quarter of cars on the road are equipped.

Some projects and research in the area are listed below.

AutoNet2030 (co-operative Systems in Support of Networked Automated Driving by 2030) is a European project connecting two domains of intensive research: cooperative systems for Intelligent Transportation Systems and Automated Driving. The research issues re as follows: how can all these vehicles with different capabilities most efficiently cooperate to increase safety and fluidity of the traffic system? What kind of information should be exchanged? Which organization (e.g. centralized or distributed) is the best? [2,4]

[7] proposed model which can describe the network-wide spatiotemporal propagation of information while factoring the constraints arising from traffic flow dynamics and V2V communications and with the integrated multi-layer

framework. The proposed model can describe the interdependencies among information flow, traffic flow and V2V communication events by simultaneously tracking the dynamics of information flow and traffic flow. The captures information flow propagation wave that can characterize how the density, speed, and locations of the vehicles lead to the dynamics of information flow. [3] addresses the design, sensing, decision making, and acting infrastructure and several experimental tests that have been carried out to evaluate both platforms and proposed algorithms. The communication and security aspects are also investigated.

In [1] multimedia-based ad-hoc networking (VANET) is tested to fulfill demands in a vehicular environment, and the need to evaluate the current standards. In [6] set of algorithms that determine the crossing order are fed with information about surrounding vehicles: actual and further GPS position, speed and an identification number. In [8] a novel distributed intrusion detection system designed for a vehicular ad hoc network by combining static and dynamic detection agents that can be mounted on central vehicles, and a control center where the alarms about possible attacks on the system are communicated. The proposed DIDS can be used in both urban and highway environments for real time anomaly detection with good accuracy and response time. In [9] a vision-based multi-object tracking system for checking the plausibility of V2V communication is presented. The system is addressing the challenge of fusing relative sensor observations as provided by a Mobil Eye vision-system with time-delayed absolute GNSS-based measurements from Cooperative Awareness Messages (CAMs) as provided by V2V.

[11] evaluate the effects of buildings on the vehicle-to-vehicle performance at urban intersections based on a profound simulation campaign. Due to the two dimensional nature of intersection topologies, we investigate the performance of V2V communication by analyzing packet delivery ratios and packet drop rates with respect to sender and receiver's position under varying node density and intersection layout. [12] provide an overview of ITS activities and status worldwide. It is divided into 4 main parts: standards/specifications applicable for ITS, spectrum allocation and channel plans, 802.11p PHY details, and test and measurement solutions to aid in design and verification of ITS devices and systems.

The purpose of [5] is to assess the readiness for application of V2V communications, a system designed to transmit basic safety information between vehicles to facilitate warnings to drivers concerning impending crashes. The United States Department of Transportation and NHTSA have been conducting research on this technology for more than a decade. A suggested V2V Security System Design for Deployment and Operations diagram in the report is giving in Fig. 1. The schema presents a full deployment model. This diagram shows also in dotted lines the initial deployment model where there is no Intermediate CA (certificate authority) and the Root CA talks to the MA (misbehavior authority), PCA (pseudonym certificate authority), and ECA (enrollment certificate authority). SCMS stands for Security Credentials Management System and CRL stands for certificate revocation list.

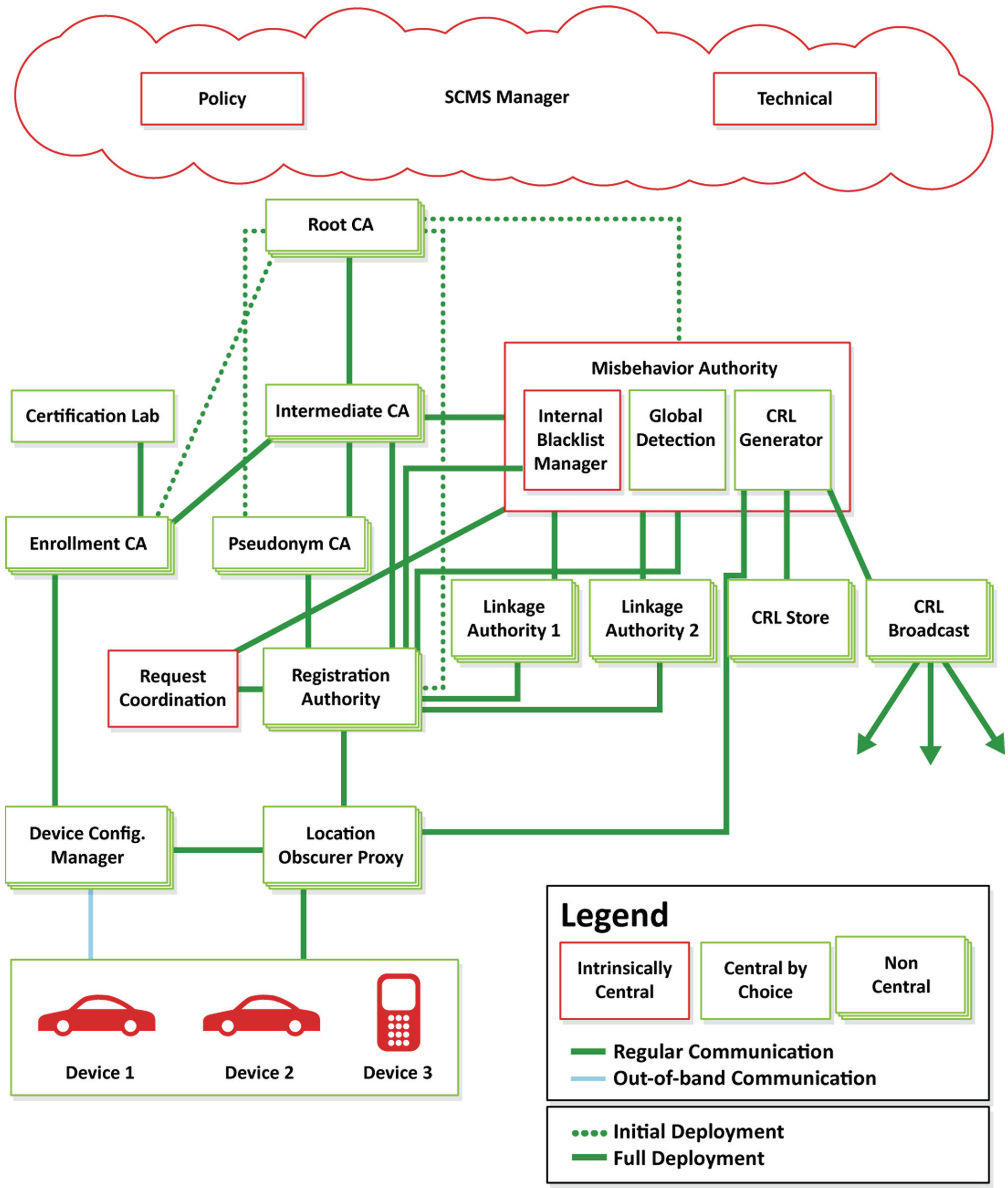

Fig. 1. V2V security system design for deployment and operations

Some issues for establishing V2V communications using [5] are:

- Additional protocols that enabled interoperability between devices have to be developed that would support a larger, widespread technology roll-out.
- More research would help the agency develop objective performance tests that would ensure consistent operation that is helpful to drivers.
- Based on preliminary information, NHTSA (National Highway Traffic Safety Administration) currently estimates that the V2V equipment would cost

approximately 341*to*350 per vehicle in 2020. The communications costs will range from 3*to*13 per vehicle.
- Based on preliminary estimates, the estimated total annual costs range from 0.3*to*2.1 billion in 2020.
- In terms of safety impacts, an annual basis potentially prevent 25,000 to 592,000 crashes, save 49 to 1,083 lives, avoid 11,000 to 270,000 MAIS 1–5 injuries, and reduce 31,000 to 728,000 property-damage-only crashes by the time V2V technology had spread through the entire fleet.
- Given that Wi-Fi use is growing exponentially, opening the 5.8–5.9 GHz part of the spectrum could result in many more devices transmitting and receiving information on the same or similar frequencies, which could potentially interfere with V2V communications.
- V2V device certification issues: This means that auto manufacturers (and V2V device manufacturers), attempting to comply with a potential V2V mandate, could have a significant testing obligation to guarantee interoperability among their own devices and devices produced by other manufacturers.
- V2V and safety application standards need to be objective and practicable, meaning that technical uncertainties are limited, that tests are repeatable, and so forth.
- In order to function safely, a V2V system needs security and communications infrastructure to enable and ensure the trustworthiness of communication between vehicles.
- Auto manufacturers repeatedly have expressed to the agency their concern that V2V technologies will increase their liability as compared with other safety technologies.
- Privacy: The system will not collect financial information, personal communications, or other information linked to individuals. The system will enroll V2V enabled vehicles automatically, without collecting any information that identifies specific vehicles or owners. The system will not provide a pipe into the vehicle for extracting data.
- One potential issue with consumer acceptance is maintenance. If the security system is designed to require consumers to take action to obtain new security certificates – depending on the mechanism needed to obtain the certificates – consumers may find the required action too onerous.

Further research to move toward deployment has been identified and will be conducted to address the following:

- The impact of spectrum sharing with U-NII devices;
- Development of performance requirements for DSRC devices;
- Development of performance requirements for safety applications;
- The potential establishment of device certification and compliance procedures;
- The ability to mitigate V2V communication congestion:
- Incorporation of GPS positioning advancements to improve V2V relative positioning;
- Remedies to address false positive warnings from V2V safety applications;

- Driver-vehicle interface performance to enhance crash avoidance warning effectiveness;
- An appraisal of consumer acceptance of the technology;
- Evaluation of V2V system privacy risks.
- An assessment of the security system to ensure a trusted and a safe V2V system.

4 Conclusions

Further tests and developments have to be conducted for the V2V applications and combined with the sensor-based systems. The current test procedures should be modified to reflect a greater range of speeds and a greater variety of road geometry configurations. Research in V2V safety has to identify the performance of V2V safety applications. Many questions have to be answered.

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