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Survey on Inter-Vehicle Communication Applications: Current Trends and Challenges

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Abstract: Inter-Vehicle Communication (IVC) has presented a promising role in vehicular technology to fulfill a variety of applications to improve safety and traffic flow. This article outlines IVC taxonomy, applications and challenges. Current trends of vehicular communication technologies are explained including classification, functions, applications, missions, requirements, advantages and disadvantages, respectively. Many IVC applications have been investigated from the literature to provide safe, comfortable and reliable vehicular operations. In this article, the recent research trends and development activities in inter-vehicle communications have been critically reviewed, emphasizing the areas where further work is needed. It is found that the continuous developing technology will certainly push the future market of high-quality IVC systems. However, the issues and challenges of the existing IVC system such as data aggregation, distribution, hardware/software compatibility, nodes density, security, mobility, market, etc. are highlighted to future system development. Thus, this study will lead the increasing need to develop new and improved IVC technology for many applications.

Key words: Inter-vehicle communication, application, challenges, vehicular information, vehicular control commands

INTRODUCTION

Road transport as the main mode of transportation is one the high priority research areas. Safety and economic concerns made this topic as the target of high technology inventions (Willke *et al*., 2009). The mission is to make the traveling time as safe, short and comfortable as possible. Inter-Vehicle Communication (IVC) systems among the latest concepts have this potential to fulfill safety concerns and also improve traffic flow (Popescu-Zeletin *et al*., 2010).

IVC consider on exchanging data between vehicles, therefore equipped vehicles have the advantage of receiving other vehicles' sensors data ahead of time. There is a vast types of applications based on IVC, while it may cover up a larger class, by using road-side infrastructures (Sichitiu and Kihl, 2008). In this article vehicular communication applications, requirement and challenges are explained with emphasizing on IVC systems. Vehicular communication applications have been classified based on their requirement and missions, into two main categories; vehicle information services and vehicle control commands.

The first category is about transferring information for the use of drivers and passengers. The second category considers commands which apply directly to the vehicle's actuators. The aim of these applications is to increase safety and information access of vehicle occupant and also make traveling time more pleasant and comfortable. Communication among vehicles can be realized by different methods based on equipment and application (Willke *et al*., 2009; Popescu-Zeletin *et al*., 2010). As it is shown in Fig. 1, vehicular communication systems have been categorized in three types of systems: Inter-Vehicle Communication (IVC), Land to Vehicle Communication (LVC) and Hybrid Vehicular Communication (HVC) (Sichitiu and Kihl, 2008).

Inter-Vehicle Communication (IVC) systems exchange data from one vehicle to another by using on-board transceiver systems, without any need to road-side infrastructure. Another type is Land to Vehicle

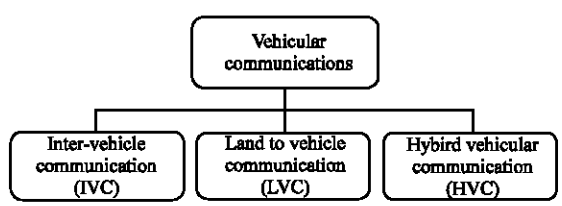

Fig. 1: Classification of vehicle communication systems

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Communication (LVC) which relies on road-side infrastructure to broadcast signals among vehicles (Palazzi *et al*., 2012). In comparison with IVC, LVC implementation is more expensive since it needs infrastructure in addition to on-board equipment. To extend the transmission range Hybrid Vehicular Communication (HVC) systems is proposed. In this type even out of range vehicles can communicate with specific road-side plant by using other nearer vehicles as routers. However sparse presence of vehicles may cause reduction in network connectivity (Sichitiu and Kihl, 2008). In this study we mainly focused on IVC applications, since they just rely on on-board equipment.

INTER-VEHICLE COMMUNICATION APPLICATIONS

The vast class of IVC applications can make driving safer and more comfortable for vehicle occupants (Popescu-Zeletin *et al*., 2010; Palazzi *et al*., 2012). IVC services can be achieved through different methods by exchanging data between vehicles and sometimes through land-based infrastructures. Figure. 2 shows classification of vehicular communication application. It helps us to focus on specific equipment to fulfill services and solve diverse problems (Reichardt *et al*., 2002; Yin *et al*., 2004).

Vehicle information services: Information services consider on broadcasting messages through the vehicular network or land-based plants for the use of drivers to make traveling safer and more efficient (Biswas *et al*., 2006; Lee and Gerla, 2010; Roccetti *et al*., 2011). Forwarded information will help the driver to get better decisions in dealing with hazardous situations or will assist them to experience an enhanced traveling. Traffic management centers can also use these collected data to monitor and optimize traffic flow on the roads (Reichardt *et al*., 2002).

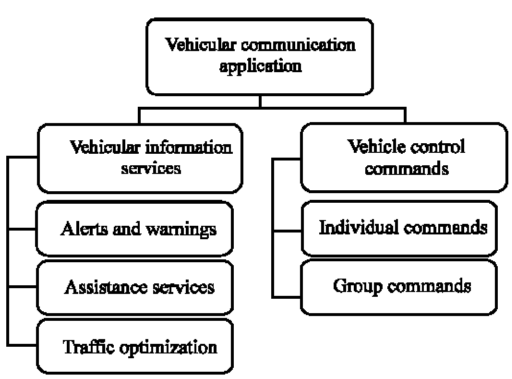

Fig. 2: Classification of vehicular communication applications

Alerts and warnings: Alerts and warnings are information about a dangerous or unpleasant event in the near future so drivers can try to avoid it based on their prior awareness (Willke *et al*., 2009; Hannan *et al*., 2006; Yin *et al*., 2004). There are several kinds of warnings such as collision, abnormal movement in neighborhood, accident on the road, sharp curve, and dangerous road surface (Caliskan *et al*., 2006). Distance between source and receiver will cause in latency which can raise a problem of late warning delivery. These applications can reduce significantly the number of injuries and fatalities on the road since many accidents can be avoided by giving knowledge of up-coming situation (Hannan *et al*., 2010a).

For example spreading emergency message via vehicular ad-hoc network (VANET) to other vehicles in the relevant area is based on analyzing motion state parameters of each vehicle to recognize some failures such as accidents and mechanical breakdown. Vehicles assumed to be equipped with Global Positioning System (GPS) and short-range communication systems. The CARTALK 2000 project also presented a similar method to distribute dangerous situation alerts among near vehicles. Latency in this kind of service should be as low as 40 ms and message repetition rate as high as 50 Hz (Reichardt *et al*., 2002).

Collision warning systems has this potential to prevent a quite large number of traffic accidents (Yin *et al*., 2004). Once an accident-like situation happened for a vehicle, such as deploying vehicle's airbag or dramatic change in vehicle's speed, it can broadcast this warning message to all other approaching vehicles. Intermediate relays could transmit the signal further than its transmission range (Domingo-Ferrer and Wu, 2009). Therefore the drivers will be informed about the up-coming situation and they can make better decision. Also vehicles coming through road junctions may end up in crashes. If vehicles involved in this situation be equipped with on-board communication system, it can prevent this kind of accidents as well. Also specific real-time constraints have considered for safety alerts (Zheng *et al*., 2004). Drivers should receive alerts in an appropriate time before they encounter the event so the information would be useful (Sichitiu and Kihl, 2008; Hannan *et al*., 2010b; Xu *et al*., 2003).

There are a number of technologies to realize danger warning applications. For short range wireless communication technologies, ZigBee (IEEE 802.15.4 standard) and UWB (Ultra-wideband) (IEEE 802.15.3a standard) are used to achieve sensor and advanced control network inside the car where UWB bit rate is extremely high about 1000 Mb sec^{-1} (Tsai *et al*., 2007;

Richardson *et al*., 2006). WAVE (Wireless Access in Vehicular Environments) (IEEE 1609 standard) is a medium range technology to cover up 1 km that has efficient broadcasting with low latency for local danger warnings (Campolo *et al*., 2011).

Assistance services: This class of applications considers more on information access and comfortable traveling for the vehicle occupants. It consists in data communication among vehicles and land-based infrastructures (Sugiura and Dermawan, 2005). These services require a low communication overhead and high information ratio. In this class IVC systems provide applications for exchanging data between vehicles in the area such as voice and instant messages or between police officers (Sichitiu and Kihl, 2008). Nowadays as many cars are equipped with GPS and on-board transceiver systems, useful collected data can be recorded in their databases. This information includes map update, available parking lots, nearest petroleum stations, hotels and even local advertisement and promotions (Domingo-Ferrer and Wu, 2009).

LVC can expand the assistance services to the larger class of applications and some cases as the initial feature of IVC systems. Internet is an essential need enables a variety of applications such as email, web browsing, digital maps, finding places and routs on the map, getting latest news, downloading music and video, etc can be realized through LVC (Popescu-Zeletin *et al*., 2010; Biswas *et al*., 2006; Namboodiri *et al*., 2004). Automatic parking and toll payment without time wasting also can be achieved in this class for easy driving (Bickel, 2006; Au *et al*., 2006). Vehicles can communicate with repair centers to diagnose and keep the record of maintenance (Sichitiu and Kihl, 2008). Complicated protocols can be applied since there is sufficient capacity of power supply and processing in vehicles.

Bluetooth and UWB are technologies used for vehicles occupants to exchange data among their devices (Tsai *et al*., 2007; Sugiura and Dermawan, 2005). WiMAX (Worldwide Interoperability for Microwave Access) (IEEE 802.16 standard) as a long range technology (5 km) provides internet access, email, etc (Chien *et al*., 2009). Cellular technologies such as 3G, LTE, UMTS, HSPA also can realize assistance services (Papadimitratos *et al*., 2009). WiMAX and cellular technologies got a bit rate up to 100 Mb sec^{-1} which is enough to fulfill purposes of this class.

Traffic optimization: Traffic congestion is an unpleasant experience in big cities due to the growing number of vehicles on the road (Nadeem *et al*., 2004). The main purpose of this class is to improve traffic flow and traveling time by giving drivers information of roads ahead to choose the most suitable one. It can primarily reduce congestion and fuel consumption (Domingo-Ferrer and Wu, 2009).

Motion status of each vehicle is a source of traffic condition that sent to the relevant vehicular network to inform approaching drivers. Transportation centers can also collect and analyze this data to help other drivers with the specific destination or emergency vehicles, to select the most appropriate routs (Roccetti *et al*., 2011). Under construction zones and accident spots can be broadcasted to the vehicular network to avoid traffic jam. Intelligent traffic lights set their timing based on the collected data to optimize the traffic flow. Authorities should evaluate this information to come up with new traffic plan for the future road maps.

Wi-Fi (IEEE 802.11n standard), DSRC (Dedicated Short-Range Communications) (IEEE 802.11p standard), WAVE (IEEE 1609 standard) are medium range technologies for communication between vehicle to vehicle and vehicle to land infrastructures. Traffic information can be exchanged through these networks with the range up to 1 km (Campolo *et al*., 2011; Harri *et al*., 2009; Hassan *et al*., 2011). Cellular technologies and WiMAX can be used to expand the range of network up to 15 km.

Vehicle control commands: In this kind of vehicular communication service, exchanging signals are used to control and regulate vehicles motion status by commanding to vehicles actuators directly. As explained in details, vehicle control commands gradually improve safety, traffic flow and consequently it reduces fuel consumption and traveling time (Rajamani and Shladover, 2001).

Individual commands: Individual commands include applications that regulate the speed, direction or state of the vehicle based on neighborhood receiving signals applied on actuators such as brake pedal and steering wheel. It avoids collisions or reduces the damage by taking action in early stages. The short interaction between vehicles requires this class to be strictly real-time (Hannan *et al*., 2008).

Aircrafts adopted the similar approach to detect and avoid crashes. Collected data from other aircrafts have been used to evaluate the situation and if the collision is inevitable, it prepares the aircraft for collision. PathProx is an example of this application which broadcast the information among in range aircrafts (Cassell, 2005). It calculates the time of collision based on path estimation, and then preprogrammed rules of the road that guide the pilot to resolve the conflict. Vehicles can adopt a similar system to prevent accidents or if it is unavoidable, it activates safety features to reduce the damage (Hannan *et al*., 2011; Hussain *et al*., 2006).

At intersection each vehicle can broadcast its location and motion status to the network and the reaching time is estimated. Therefore drivers would be aware of other vehicles presence and if it is needed, the actuators (e.g. brake pedal) would be employed to protect the driver. Rear-end collisions are also avoidable with the same method by informing and activating the approaching vehicles actuators in the case of sudden speed reduction of the leading car (Liu and Ozguner, 2003). IVC systems also provide navigation for autonomous vehicle based on interpreting collected neighborhood data and commanding the actuators to stabilize its movement (Javadi *et al*., 2012).

In this class of applications DSRC (802.11p standard) and WAVE (IEEE 1609 standard) are technologies to get neighborhood data and apply them to actuators. The advantage of WAVE is having efficient broadcasting with low latency which is essential in this class. DSRC also is useful however low penetration rate should be considered (Campolo *et al*., 2011; Hassan *et al*., 2011).

Group commands: Group commands applications plan for the group of vehicles with the same traveling path or destination to drive more efficiently. It regulates their motion parameters by establishing partnership to each other even for several hours (Rajamani and Shladover, 2001). This includes also speed management, improving traffic flow and coordinating at intersections. Low latency is an essential requirement to fulfill this type of vehicular service. Group commands are divided into three categories; individual regulation, leader-based regulation and virtual leader-based regulation.

Individual regulation optimize the traveling path for group of vehicles which are communicating together, they adjust their motion parameters in response to the surrounding neighborhood. It assists the driver to merge the highway or coordinate at intersections. Among different computed plans within the group, one would be selected to achieve minimum traveling time (Clark *et al*., 2003). It also improves the traffic flow and may reduce collision rate by pre-calculating the delays and resolving the deadlocks. Right-based intersection accidents can be prevented using this technology. Unlike the later class which prevents collisions just before happening, it manages a group of vehicles to coordinate with each other safely far before the meeting point.

In leader-based regulation, one vehicle provides motion control commands to other vehicles in the group. Each vehicle regulates its course of action based on receiving commands and sensor collected data (Seiler *et al*., 2004). Within the platoon vehicles stabilize the minimum distance from leading and preceding ones. This enhances the flow of vehicles on highways and also the fuel consumption. These motion commands should be real-time and synchronized to gain stability in the platoon. The leading vehicle should manage different scenarios including joining or leaving vehicles and platoon maneuvers (Halle *et al*., 2004). In order to achieve reliable performance transmission delivery ratio has to be high within the group (Li and Wang, 2006).

If the motion control commands are receiving from a virtual or distributed model as a leader vehicle then this type would be virtual leader-based regulation. As the approach used to control the behavior of robots and airplanes in group, the distributed architecture will cover up a large number of vehicles as a group (Moreau, 2003). DSRC (802.11p standard) and WAVE (IEEE 1609 standard) can be used for medium range communication and cellular technologies and WiMAX (IEEE 802.16 standard) for long range to realize group commands services. High bit rate and low latency are advantages of these technologies, especially LTE which is a new standard for wireless communication of high-speed data transferring (Chien *et al*., 2009; Papadimitratos *et al*., 2009; Hassan *et al*., 2011).

A summary of IVC applications, challenges and requirements is presented in Table 1.

CURRENT TRENDS AND CHALLENGES

Development in sensors, processing and electronic devices along with advanced codes and protocols opened new horizons upon car industry all over the globe. Transceiver equipments on vehicles with communication protocols got this potential to achieve a vast class of applications. A summary of applications for vehicular communication systems is presented in Table 2. However inter-vehicle communication brought strong promises in improving road travelling efficiency, it is still facing number of difficulties on its way. The most crucial challenges of vehicular communication applications are as follows.

Data filtering and aggregation: The main mission of IVC systems is exchanging data between vehicles which are equipped with on-board sensors and transceiver systems. Since each vehicle provides individual view of events, an event differentiation block is required to filter and aggregate the input data to reduce the amount of transmitted data.

Table 1: Summary of IVC applications, challenges and technical requirement

Class	Type	Advantage	Technical requirement	Challenges
Vehicle information services	Alerts and warnings	Providing warnings of collision, distance, abnormal movement in neighborhood, accident on the road sharp curve, dangerous road surface, etc.	Medium range of coverage (around 1 km), medium data rate (up to 27 Mb sec^{-1}), point to multipoint network, short latency	Data filtering and aggregation, nodes density, data security, distributing range, relative speed, challenging routing, deployment costs
	Assistance services	Providing voice and instant messages, internet access, map update, available parking lots, nearest petroleum stations or hotels, automatic parking and toll payment, remote diagnosis with repair centers, etc.	Long range coverage (more than 5 km), high data rate (more than 75 Mb sec^{-1}), full mobile network	
	Traffic optimization	Improving traffic flow, traveling time, Reducing congestions and fuel consumption, etc.	Long range (1 km), medium data rate (up to 27 Mb sec^{-1}), Point to point or point to multipoint	
Vehicle control commands	Individual commands	Regulating the speed and direction, Avoiding collisions, Navigation for autonomous vehicles, Preparing for inevitable accidents	network medium coverage (up to 1 km), extremely high data rate, very short latency	Fast and proper distribution, hardware/software compatibility, data security, relative speed
	Group commands	Group plauning, regulating motion parameters, speed management, improving traffic flow, coordinating at intersections, Managing different platoon maneuvers, etc.	Long coverage (up to 5 km), extremely high data rate, very short latency	

Table 2: Summary of applications for vehicular communication systems

Type	Application	Vehicular communication type	Communication technology	Real-time requirement	References
Alerts and warnings	Collision warning	IVC	ZigBee, UWB, WAVE	Yes	Willke *et al.* (2009) and Yin *et al.* (2004)
	Sharp curve warning	IVC-LVC		Yes	Caliskan *et al.* (2006)
	Dangerous road surface warning	IVC-LVC		Yes	Xu *et al.* (2003)
	Abnormal vehicle warning	IVC		Yes	Reichardt *et al.* (2002)
Assistance services	Toll and parking payment	LVC	Bluetooth, UWB, WiMAX,	-	Namboodiri *et al.* (2004)
	Internet access	LVC	Cellular Technologies	-	Popescu-Zeletin *et al.* (2010) and Sugiura and Dermawan (2005)
	Traveler information	IVC-LVC		-	Sichitiu and Kihl (2008) and Domingo-Ferrer and Wu (2009)
Traffic optimization	Traffic management	IVC-LVC	Wi-Fi, DSRC, WAVE, WiMAX, Cellular Technologies	-	Sichitiu and Kihl (2008), Roccetti *et al.* (2011), Domingo-Ferrer and Wu (2009) and Bickel (2006)
Individual-Group commands	Collision avoidance	IVC-LVC	DSRC, WAVE, WiMAX, Cellular Technologies	Yes	Chien *et al.* (2009), Papadimitratos *et al.* (2009) and Rajamani and Shladover (2001)
	Intersection collision avoidance	IVC-LVC	Yes		Rajamani and Shladover (2001)
	Platoon and group maneuvers	IVC	Yes		Hussain *et al.* (2006), Liu and Ozguner (2003) and Javadi *et al.* (2012)

Fast and proper distribution: Fast and secure distribution of event sensed data is an important factor to fulfill IV applications. In this stage it is necessary to identify neighbor cars to forward the information just to the interested ones. Existing internet transport protocols TCP and UDP showed poor performance in IVC systems (Sichitiu and Kihl, 2008). Vehicular Transport Protocol (VTP) and Mobile Control Transport Protocol (MCTP) are also proposed (Moreau, 2003). All these transport protocols need to be developed for IVC applications that require multicasting.

Hardware/software compatibility: Nowadays only few cars are equipped to IVC systems. The growing rate of equipped cars would be slow due to the long lifetime of existing cars. This will raise number of challenges; first of all the applications should be satisfying enough for consumers to buy this technology. Second hardware/software strategies need to be compatible with the network growth and also adaptive to future security, performing and safety considerations.

Nodes density: Even if all cars are equipped, the number of cars within a relevant area is another issue. Since

IVC systems are based on car to car communication, sparse and dense presence of cars will cause different penetration and data transfer rate, therefore IVC systems have to be flexible in these situations.

Data security: Safety of IVC systems is the highest priority since it deals with human life. Any malfunction in IVC system may cause a threat to involved people. Besides, to avoid any possible system manipulation, high security protocols for IVC systems should be considered as well. In addition privacy of users needs to be protected from any unauthorized access. An example is a proposed architecture for security in communication, called Communications Architecture for Reliable Adaptive Vehicular Ad Hoc Networks (CARAVAN). The goal is to develop protocols that protect network from possible threats (Bechler *et al*., 2005).

Distributing range: Fully distributed protocols as an essential issue in IVC systems highly have to be considered. Transferring data over a single hop from each vehicle to another in the vicinity is suggested to be every 300 msec sec in 10 sec travel time (Blum and Eskandarian, 2006). Therefore the broadcast range is between 10-300 m. In the case of emergency messages the range of broadcast has to be wider to cover up all the relevant area. Existing physical channel for prototype systems mostly based on IEEE 802.11b (2.4 GHz ISM band) (Raya and Hubaux, 2005) and IEEE 802.11a (5.8 GHz ISM band) (Hui and Mohapatra, 2005).

Relative speed: Due to the high relative speed of the nodes, the duration of communication connection between nodes might be less than a second. It implies data transferring time to be as short as possible. These network protocols should be compatible with all applications. It is shown that DSRC just delivers 50% of data packages in single hop experiments.

DISCUSSION

This paper investigated a detail survey on the inter-vehicle communication technologies, applications and the issues that are being facing problems. Different communication technologies with different specifications and applications are explained (Papadimitratos *et al*., 2009; Willke *et al*., 2009). Comprehensive inter-vehicle communication applications such as alerts and warnings, driver assistance, traffic optimization and control commands are discussed for safe, efficient and comfortable driving in realistic operating environments (Popescu-Zeletin *et al*., 2010). In comparison with other surveys, this study covers larger class of applications, along with its trends and challenges (Sichitiu and Kihl, 2008). Raya and Hubaux (2005) also did a survey on inter-vehicle communication systems, yet it is not focused on the required technologies to realize the applications (Raya and Hubaux, 2005). Zheng *et al*. (2004) also presented a review on inter-vehicle communication issues which explained warning systems without investigating on different types of applications and required technologies. This survey investigated and observed that the main issues and challenges of the existing inter-vehicle communication systems are data filtering and aggregation, distribution, hardware/software compatibility, nodes density, security, privacy, mobility, market, respectively. Hence, right technologies, efficient networks and suitable protocols are very important to achieve an effective inter-vehicle communication towards safety, comfort, capacity, reliability and convenience as well as lowering the traditional limitations. This study explained the existing inter-vehicle communication systems, their technologies, applications, challenges and problems in aiming to develop efficient low-cost and reliable future IVC systems. Thus, to achieve the aforesaid aims, this survey may lead as a starting point for increasing need to develop new and improved inter-vehicle communication systems.

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