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Investigation of Services and Application Scenarios for Inter-Vehicle Communication.

Master's Thesis in Computer Systems Engineering

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Description of cover page: Lane change scenarios where car A inform cars in the vicinity its intention to change the lane, it keeps sending the message until it get the confirmation that the lane change won’t cause collision.
Preface

I would like to thank my supervisor Annette Böhm for her patience, guidance and support throughout the duration of this thesis without her this work may not be completed at the time.

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Abstract

In recent years, the number of vehicles has increased dramatically in Europe, USA and Japan. This causes a high traffic density and makes new security features a crucial point in order to keep the traffic safe. Inter-vehicle communication offers solutions in this field, as cars can communicate with each other. To this date, there is no special technology standardized for inter-vehicle communication. This is the reason why car makers, researchers and academics have invested money and time in different research projects so that in future they may come up with a common solution. Some of the technologies like DSRC, CALM, IEEE 802.11 or Infrared are thought to be more reliable than others according to different authors [9][23].

The technologies described above will help to improve road safety and application scenarios like lane change, blind merge or pre and post crash situations can be addressed. The position of each car is known through a GPS; speed, heading and other dynamic data of a car are known to all cars in the same vicinity.

In this thesis, a thorough investigation of services and applications related to inter-vehicular communication technology (i.e. car-to-car and car-to-infrastructure or vice versa) will be carry out. The emphasis will be on requirements on the communication system, sensors and user interface in order to make the technology more useful for future vehicle alert system and to avoid as many of the mentioned scenarios as possible. A rear-end collision can be avoided if the driver is warned within 0 to 5 second of potential accident.
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6.1. CURVE SPEED WARNING
1. Introduction

Inter-vehicular communication can be defined as either car-to-car communication or car-to-infrastructure/infrastructure-to-car communication.

In the 21st century, the world has seen a spectacular change in car production as the per capita income increased. Many cars were sold and the number of accident increased, traffic jams became daily routine in big cities and human lives and economic loss are increasing day by day. The report of the World Health Organization in 2004, said that 600 people die in China every day and more than 450,000 are injured per year by car accident [1]. Around 50,000 people died in USA in 2005 and there were 6 million car accidents [2]. In the EU 38,739 people died in 2003 according to the Economic Commission for Europe Transport Division [3]. Beside the human loss there is a huge economic impact. In 2004, China lost between 12 and 21 billion US dollars, USA lost 230 billion US dollars. It is because of this, in many countries in Europe, Japan and USA, governments and car manufacturers started research in the field of inter-vehicle communication to improve road safety and minimize human loss.

Inter-vehicular communication is done in such a way that each car transmits and receives data of neighbouring cars; the data may contain its location, heading, speed etc. and the car is equipped with in-vehicle communication technology able to warn the driver if there is a potential collision. Through roadside infrastructure the driver can be informed of a traffic jam ahead.

In this thesis, a thorough investigation related to service and application in the field of inter-vehicular communication was carried out. Technologies used in inter-vehicular communication will be described like GSM, GPRS, UMTS, IEEE802.11, DSRC and different scenarios will be studied and related to these technologies. Some of the scenarios are left turn, blind merge, sign violation, cooperative forward collision warning, lane change warning, and emergency electronic brake light. The emphasis will be put on how communication techniques, sensors and user interface can improve traffic safety and reduce accidents (human loss, financial loss and environmental disaster caused by these accidents).

1.1. Problem Formulation

In recent years the number of vehicles has increased dramatically everywhere in the world. This causes a high traffic density and makes new security features a crucial point in order to keep traffic safe. Inter-vehicle communication offers solutions in this field, as the vehicles can communicate with each other, directly or via infrastructure. To achieve this complex operation a suitable wireless technology is needed. The complexity of inter-vehicle communication should be examined on the one hand and the vulnerability or weakness of wireless technology should be taken into account on the other hand.

The vehicle changes the speed, direction as well as the location; for example from a less congested area to the area where the communication is dense. During my investigation all these situations will be taken into consideration and be related to different technologies as none of the technology is able to handle all the situations.
1.2. Approach

The main goal of this project is to investigate service and application scenarios of IVC and highlight their communication requirements in order to make the technology more useful for future vehicle-to-vehicle communication as well as vehicle to infrastructure or infrastructure to vehicle.

To achieve this goal, I will adopt the following procedure:

1. Investigate different projects in the field of IVC in order to define a list of applications.
2. Define general communication requirements and characteristics for these applications.
3. Describe the application scenarios and highlight their communication requirements.
4. Investigate existing technologies and match them with specified scenarios.

The following technologies have been investigated: GSM (Global System for Mobile communication), GPRS (Global Packet Radio System), UMTS (Universal Mobile Telecommunication System), DSRC (Dedicated Short Range Communication) and IEEE 802.11. Due to time constraint, other technologies such as CALM, UTRA-TDD, IEEE 802.16 (WiMAX), infrared or millimeter wave were not investigated fully.

The sole reason to choose the above mentioned technologies is based on the fact that they are widely used in most of the ongoing or completed projects I was able to investigate. From their weakness and strength it will be easy to associate these technologies with the chosen scenarios.
2. Background

In this section a short description of ITS is given as well as an insight into how communication is done between vehicles or between vehicles and infrastructure.

2.1. Intelligent Transportation Systems (ITS)

The increase in number of vehicles causes constraints in existing communication infrastructure, which in turn generates accidents, environment degradation and loss of money and time. It is in this perspective Intelligent Transport System (ITS) have become a focus of attention as they can provide solutions to these problems. An ITS is a system that integrates information and communication technology; these include data storage and processing equipment, wire line and wireless communication systems, global positioning systems (GPS), sensors, etc [4].

The technologies mentioned above will be integrated into road infrastructure and in-vehicle communication systems to give ITS capability, i.e. to provide road safety, minimize traffic congestion, suggest alternative routes, monitor traffic and save lives, time and money [5][6]. ITS involves intelligent vehicles, intelligent infrastructure and their interaction with a human operator [7]. ITS communication requires two communication approaches, vehicle-to-infrastructure communication, where vehicles communicate through roadside units installed along the roadside and vehicle-to-vehicle or inter-vehicular communication, where there is direct contact between vehicles without involvement of a roadside unit.

ITS applications comprise the following parts [8]:
1. Automated Crash Notification Systems
2. Advanced Traveller Information Systems
3. Advanced Traffic Management Systems
4. Commercial Vehicle Information Systems
5. Incident Management Systems
6. Intersection Collision Avoidance Systems
7. Mayday Systems
8. Telemedicine Systems
9. Transit Signal Priority
10. Road Departure Collision Avoidance Systems

In my thesis the emphasis will be on safety applications which improve road safety, increase traffic flow efficiency (energy, comfort and time gains), avoid or minimize single or multiple collisions, environment pollution and human and financial loss. In my thesis safety applications such as lane change warning, pre-crash sensing collision warning, curve speed warning and related cases will be investigated.
2.2. Car-to-Car and Car-to-Infrastructure Communication

As described above in 2.1; the vehicle-to-infrastructure communication is done in such away that vehicles communicate through roadside units installed along the roadside and inter-vehicular communication is done directly between vehicles without involvement of a roadside unit or decentralized unit control [11].

In order to succeed in providing road safety, some information are stored in roadside so that the vehicle can collect them while in the communication range; these information are usually transmitted periodically; the stored information may include road condition (wet, curve, icy), traffic condition, weather, allowed speed; accident occurred in the last 24h, etc. The above information is gathered by the roadside unit; there is other information that can be gathered by the vehicle itself and be used in crash avoidance. In-vehicle sensors provide information about speed and acceleration, a vehicle equipped with an infrared system detects objects in a particular range and the vehicle or driver decide accordingly etc.

As inter vehicle is a chain of vehicles, some of the vehicle in the chain may not be able to interact with the roadside unit, even these capable of communicating with roadside may not be able to do so when they are not in the communication range, due to that some of the vehicle will work as bridge between the roadside unit and these out of the communication range.

It is assumed that some of the vehicles are equipped with a combination of DSRC antenna, a millimeter wave radar, an infrared sensor, embedded computer, a digital map, and a GPS, all these will facilitate data collection and the communication between vehicles as each one will have a particular function to perform. For example an embedded computer is capable of warning the driver if there is any sudden precaution to be taken, such as change in speed if the current speed is bigger than the allowed speed or if according to the received information there is traffic congestion it may suggest a new road to the driver.

2.3 Worst Case scenario

The worst case in inter-vehicle communication will occur when vehicles can not communicate properly due to the medium overhead caused by vehicles competing to send their message first. Let us assume a lane with vehicles within the communication range of 300m and these vehicles are spread out over the same interval of 300m, we can thus assume that some are separated by few meters (let say 50m) while others are far away.

In a communication range, when one of the vehicle send a warning signal, the neighbouring cars will exchange the message and take appropriate precaution; but what will happen if more than two vehicles send emergency signal at the same time? In this case the medium will service one vehicle and other warning signal from remaining vehicles will be in queue and will get access to the medium when it is free. As more vehicles are competing to send the message first, this will result in message collision, interference which will cause message loss or message distortion. Due to this, the allowable latency required in most of safety application may not be respected and this will lead in chaos as one crash may lead to multi crashes in the place where the traffic is dense.
Let us consider a busy hour in city where the traffic is dense, in this case the communication medium will be saturated due to repeated demands from more than one vehicles, due to this it won’t be possible for the medium to hold on as it can not serve the number of requested submitted. Based on this, the designed of a wireless medium should think how the medium will deal with such case and the in-vehicle communication should be able to access the situation and be able to provide an alternative solution.

There is also speed factor which make it hard for the medium as well as for the in-vehicle communication system to fulfil their duties by respecting the communication protocol; for example the routing is not easy in multi hop network as the vehicles changes often their position quickly and the update doesn’t not necessarily reflect the traffic situation, this may cause the medium/in vehicle communication system to keep the wrong information. This is added to short space between vehicles which may cause an accident for the reason mentioned above ( the medium can not service more than one request at once; the routing is complex due to the speed of the vehicles, update doesn’t reflect the current situation, and the space between vehicles make it hard to achieve the required response time). A solution is proposed in [10], where the vehicles in the same communication range are divided in group and the last in the group serve as bridge and each vehicles has the ability to know it position in the group as well as the last vehicles in the group.
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3. Related works - Research in vehicular safety systems

Due to accident increase and traffic jam caused by a huge number of cars on road, vehicular safety became a field of research interest for many car manufacturers, governments as well as universities.

3.1. Historic view on related research projects

The following is a historical review of Inter-Vehicle Communication (IVC). As reported in [12], the first research in Inter-vehicle communication was conducted in Japan in 1980 by the Japan Automobile Research Institute. In this research IVC was treated as traffic and driver information system incorporated in an ATMS/ATIS (Advanced Traffic Management System/ Advanced Traveler Information System).

From 1987-1994, PROMETHEUS (PROgraMme for a European Traffic with Highest Efficiency and Unprecedented Safety) was active. PROMETHEUS is a part of European Research Coordination Agency (EUREKA) which is supported by different industries and researchers. Its main goal was improved driver information, active driver support, and cooperative driving and traffic/fleet management. PROMETHEUS developed an IVC Communications system using 57GHz to achieve cooperative driving among multiple vehicles [13].

In 1997 the California Partners for Advanced Transit and Highways (California PATH) conducted the first automated driving with a speed of 96km/h with 6.3m between cars. The system uses inter-vehicle communication in a 900 MHz band using off the shelf wireless LAN. The same period a test of inter-vehicle communication was done with infrared where the back and the front of the two cars were used [12].

The following year, the Netherland Organization for Applied Scientific Research (TNO) used the same technology in inter-vehicle communication. The goal was to smooth the traffic flow and prevent congestion as the preceding vehicle is sending braking information to the proceeding vehicle so that a rear-end collision is avoided.

In 1998, the US Department of Transportation started the Intelligent Vehicle Initiative (IVI) project with the goal of improving safe driving. Intersection Decision Support (IDS) started in 3 states where the system can detect straight on coming vehicles from the ground but also combines GPS data with inter-vehicle and roadside unit communication data for on board display of other vehicles’ location.

In Japan, 1999 Intelligent Transport System (ITS) Forum is sponsored by four ministries and is under the Ministry of Internal affairs and Communications. The forum contributed to the use of IVC for Adaptive Cruise Control (ACC), cooperative driving, hazard warning, lane-change warning as well as other security issues [14].

CAMP (Crash Avoidance Metrics Partnership), a group of automobile manufacturers and the Department of Transportation and Standardization supported the Vehicle Safety Communication
Consortium (VSCC) from 2000-2004, which applies inter-vehicle and roadside communication systems for active safety.

In 2000, a system for incident warning was developed by Ohio state University using a 200MHz Very High Frequency (VHF) [12]. The same year a German consortium proposed a system useful when there is poor visibility to avoid an accident and smooth the traffic. The proposed system use 800MHz frequency and the host car alerts the cars in vicinity by hazard light as well as informing its neighbours about its location [11].

Car Talk 2000 is a three year project started in 2001 by the European Commission in its 5th framework and is coordinated by DaimlerChrysler AG, the Netherland Organization for Applied Scientific Research (TNO) formed by Centro Ricerche Fiat (CRF), Siemens ICN, Robert Bosch GmbH, Cologne and Stuttgart University. The main objective of the project was to develop driver assistance system which are based on inter-vehicle communication using self organizing ad-hoc radio network as a communication basis with the aim of preparing a future standard [15] [16].

3.2. Currently active projects

The developed countries, car makers and researchers have invested money and time in inter-vehicular communication in order to improve safety, comfort, efficiency, market penetration as well as economic benefit.

3.2.1. Cooperative Vehicle and Infrastructure System (CVIS)

Cooperative Vehicle-Infrastructure System is a 4-year project initiated and sponsored by the European Commission from 2006 to develop and test technology enabling car-to-car communication as well as car-to-roadside infrastructure. The information from Road Side Units (RSU) like traffic situation or road surface is transmitted wirelessly to the vehicle and is shown on a display. The driver decides which recommendations to follow.

The main goals of CVIS are [17]:

- Standards development for Inter-vehicle and Vehicle to Infrastructure
- Estimation of vehicle position and creation of map using satellite navigation more accurately.
- Development of new cooperating traffic and network monitoring system to detect the incident instantly while using in-vehicle system and road side infrastructure.
- Development of toolkits to address key deployment.
- A range of cooperative applications for traffic management, mobility services and driver assistance.

3.2.2. Network on Wheel (NOW)

Network on Wheel started in 2004 and is expected to finish in 2008. The project is co-funded by NEC Germany GmbH and the German government and the main goal is to address the following issues [18]:

-
Develop communication protocols and investigate security issues for car-to-car communication
Focus on active safety applications
Standardize it to a European level with the Car-to-Car Consortium.
Implement a reference system
Implement a radio system based on IEEE 802.11

3.2.3. SAFEPOST

SAFEPOST is co-funded by the European commission for Information Society Technology in its 6th framework program. The main goal is to prevent road accidents by developing a Safe Margin Assistant that detects in advance imminent dangerous situation and the driver’s awareness of the surrounding environment is extended in time and space [19].

The SAFEPOST is divided in 8 subprojects which are:

SAFEPROBE - In-vehicle sensing and platform
The main objective of this subproject is the development of an interoperable "vehicle probing" system, source of safety related information [19].

INFRASENS - Infrastructure sensing and platform
The subproject focuses on infrastructure improvement so that it may become an important source of information for road safety.

SINTECH – Innovative technologies
In this subproject, accurate and reliable localization will be developed. Existing and newly created technology will be analyzed, adapted and enhanced so that it can be integrated into vehicle and infrastructure platforms.

SCOVA - Cooperative systems applications vehicle based
This subproject will focus on safety applications based on a cooperative system implementing the active margin concept.

COSSIB - Cooperative safety systems infrastructure based
The aim of this sub-project is to specify and develop a set of co-operative safety systems appropriate for road scenarios in which there is an emphasis based on the contribution of roadside equipment [19].

BLADE - Business models, legal aspects, and deployment
The main objective of this subproject is to come up with concrete result from experiment and test made within the SAFEPOST IP to the real life. Other aim is to develop a deployment program for IP-results to reach the overall goal of the IP.

SCORE - SAFEPOST core architecture
Main objective of SAFESPOT Core Architecture (SCORE) is the definition of a System Core Architecture to be used as a reference across Europe for both the development of new ITS safety services and the development of applications increasing the ITS traffic efficiency [19].

HOLA – Horizontal activities
The aim of this sub-project is the overall coordination of the IP via the project management, undertaken by Centro Ricerche Fiat, and via the support of the core group activities [19].

3.2.4. Vehicle Alert System (VAS)

Vehicle Alert System project is conducted at Center for Research on Embedded System (CERES) at Halmstad University and is supported by Volvo Technology AB, SP Swedish National Testing and Research Institute and Free2Move AB.

The VAS project focuses on cooperative embedded system and vehicular ad-hoc network (VANETS). Three application scenarios are given more priority than others in this project. These are Emergency Vehicle Routing, Merge Assistance and Pedestrian Crossing Assistance.
4. Communication requirements

In this chapter the important communication requirements will be defined and later on these will be matched with the chosen scenarios. The following assumptions are made when defining the communication requirements:

- All vehicles in the communication range share the communication medium.
- Vehicles are in same/different lanes with same or different directions.
- Response time in congested area and in countryside is different.
- There are more sensors in traffic dense area.

In inter-vehicle communication like in other communication networks, a system should fulfil the minimum of the main communication requirement in order to provide a service to its clients. Among others, the system should have the following requirements: Reliability, high throughput, and short delay.

In [9] the following were defined as communication requirement for inter-vehicle requirements for DSRC application:

Type of communication:

- Source and destination of the transmission: vehicle-to-vehicle or vehicle-to-infrastructure or infrastructure-to-vehicle.
- The transmission method is unicast or broadcast where the message is just sent from one source to one receiver or from one source to many receivers without prior negotiation. There is also two-way communication where a negotiation between transmitter and receiver is established, the transmission is intended to one point or to multipoint (point-to-point or point-to-multipoint).
- Transmission mode which describes the way the message is sent; it can be either periodic where the message is repeatedly sent or sent only when an event occurs (event driven).
- The minimum frequency defines the rate the message should be repeated in order to fulfil the intended task.
- Transmitted/received data: This is the message content which describes the position, heading, speed, etc. of the sending or receiving vehicles.

Communication range: Distance defined by a technology to accomplish a certain application between two communicating nodes (vehicles or infrastructure); within this particular distance two communicating vehicles share information, beyond that a multi-hop communication is used to allow these vehicles to communicate if needed.

Allowable latency: It defines the maximum time allowed for sending and receiving a message; this includes all the delays of both sender and receiver.

In [20] the communication requirements have been described in detail and the most relevant ones to this thesis are described here and are matched with chosen scenarios later on.
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4.1. Reliability

A reliable communication system is defined as the one capable of functioning without error or failure during a specified period. In other words is the one that can provide the minimum service even when some of its component fails to function properly.

In term of inter-vehicle communication, the system i.e in-vehicle communication as well as the infrastructure should be reliable by eliminating error which may lead to message distortion/message loss and overcome the unreliable nature of wireless medium and high mobility of vehicles.

4.2. Latency

In communication, the amount of time for a packet to travel from the source to the destination is called latency. For a channel capacity, if the packet size is big, the latency increases. The data that is transmitted should have low latency at emergency situations. Most accidents can be avoided if the vehicle driver is warned at least half a second before the collision. The collision warning message should be delivered faster and with redundancy during an emergency event. Since the vehicles on the highway move with velocities between 70-110 km/h, the delay should be in microseconds [4]. The latency includes all delays in both the infrastructure unit and vehicle unit i.e. message initiation, message updating and re-routing delays. In this thesis the latency will be classified as follows: very low: 20ms; low: 50ms, medium: 100ms and long: when it is in second.

4.3. Bandwidth and Medium Access Control

In the wireless medium, bandwidth is limited and when the traffic density increases, the vehicles compete with each other to access the shared medium in order to transmit their information. When more than one packet of information is present in the same space at the same time, collision occurs in space and the packets are either detected at the receiver or lost. So a suitable medium access scheme must be present to oversee the usage of the available bandwidth in an efficient manner. Medium access control (MAC) protocols like pure-ALOHA, slotted-ALOHA, non-persistent CSMA, TDMA, DS/CDMA etc provide the means to access the shared wireless medium by defining rules that allow the nodes to communicate with each other and in efficient manner. Wireless systems have three resources which are space, frequency and time. In frequency division multiple access (FDMA), each communicator (node) is allocated a part of the spectrum all the time. In time division multiple access (TDMA), each pair of communicator is allocated all of the spectrum for a part of the time. In code division multiple access (CDMA), every communicator will be allocated the entire spectrum all of the time. CDMA uses codes to identify connections. Various communication protocols have been proposed based on the dynamic CDMA network. In this thesis, while matching the communication requirements with different scenarios, the bandwidth will be classified as either medium or high depending on the number of users accessing the channel.
4.5. Transmission mode

The transmission mode can be either event-driven or periodic. When vehicles are communicating with each other or vehicles with infrastructure, the transmission mode will depend on the circumstances. For example, when a vehicle transmits a sudden signal regarding his breaking, this transmission mode is event-driven and in the case of post crash signal, the transmission mode is periodic as the message will be repeated continuously.

4.6. Update frequency

Update frequency means the rate at which the transmission of messages should be repeated or updated (e.g. 1 Hz) [9], and it determines how fast (in one seconds) the information should be updated after the first transmission so that the message is kept alive for the new vehicles entering the communication range of the transmitter. It is should be noted that the update rate is related to the latency where it increases whenever the latency decreases; for example emergency warning messages must have high reliability or sufficient repetition so that every interested node gets a copy with enough probability. There are other situations where the update frequency need not be high; for example in post crash scenario where the idle vehicles repeat sending the message in a periodic way indicating his position and heading to the approaching vehicles.

4.7. Message content

The message content gives the necessary information about the transmitting vehicle; for example its position, heading, size, acceleration or deceleration, etc. The message size will depend to the situation or purpose of the message; for example the emergency message must be short in order to meet low latency. A short message is easy to update and easy to retransmit; in case the receiver has to re-transmit the message for example to avoid the multiple crash in a queue. With a long message, the bandwidth used is high and this will cause congestion in the communication medium which will result in medium degradation; in this case there is a risk of message collision /loss or error in the receiving end as the message can be modified while trying to compete for the medium.
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5. Technologies

In this chapter, different communication technologies for inter-vehicle communication are examined.

5.1. Cellular communication

The cellular technology combined with existing communication system will provide a safe and reliable inter-vehicular communication where two vehicles can not communicate directly cellular system may be used as bridge.

5.1.1. GSM

Global System for Mobile communication (GSM) is the second generation (2G) digital cell phone technology which is an improved version of 1st generation which used the analogue system. GSM uses a Time Division Multiple Access (TDMA) approach which allows more than one user to share the bandwidth, the data rate is up to 9.6 kbps and the privacy is provided through ciphering. GSM is useful in long range communication where a driver may request the information about traffic ahead from the main base and take a less congested road thus, save the time, the money and avoid any crash which may be caused by the jam ahead [26].

5.1.2. GPRS

General Packet Radio System (GPRS) served as bridge between the second generation (2G) and third generation (3G) i.e. between GSM and the W-CDMA/UMTS system [27]. W-CDMA is Wideband Code Division Multiple Access; also know as Universal Mobile Telecommunication System. GPRS improved GSM by the following; increase in data rate, 9 to 100 kbps, and use of message broadcasting, prevention of inefficient use of radio spectrum, priority scheduling and coverage in the range of 35 km. As GPRS use packet switched services and provide priority scheduling it is useful in emergency warning system [27].

5.1.3. UMTS

Third Generation (3G) or Universal Mobile Telecommunication System (UMTS) 3G compared to previous technologies has a high rate data transfer, multimedia, video to mobile user through a range of mobile terminals and can operate in both public and private environment [27]. 3G provides high rate data transfer and can be useful in vehicle communication as the message can be transmitted and received instantly thus improving traffic flow as well as avoiding any type of accident caused by information delay. The data rate for UMTS is 144 kbits/s compared to 50 kbits/s for GPRS.
5. 2. Wireless technologies for inter-vehicle communication

Wireless technology used in in-vehicle communication system as well in infrastructure communication systems will improve road safety, traffic flow and minimize disaster which the accident may cause.

5.2.1. IEEE 802.11

802.11 is a specification of IEEE accepted in 1997 which includes different versions, IEEE802.11a, IEEE802.11b, IEEE802.11g an IEEE802.11p also know as Wireless Access for Vehicular Environment (WAVE) designed to support Intelligent Transport System (ITS) application.

802.11p provides data exchange between high speed vehicle and road infrastructure in the ITS band of 5.9 GHz and because of this vehicle safety is greatly improved. The topology is thought to be a mesh topology where every vehicle serves as a repeater, due to this a real-time vehicle telemetric is possible. 802.11 may introduce a national wide ad-hoc/ mesh wireless network allowing real-time telemetric including real-time traffic reporting, vehicle positioning, etc. [28].

5.2.2. Dedicated Short Range Communication (DSRC)

The Dedicated Short Range Communications technology has the block of spectrum in the region of the 5.850 to 5.925 GHz band. The US Federal Communication Commission licensed this bandwidth for the purpose of enhancing the safety and the productivity of the transportation system [23]. It is a kind of short range communication system used specifically in the field of transportation [24] [26]. The capacity of the DSRC is limited by the distance between transmitter and receiver; it can transmit with accuracy and reliably a large volume of data within short distance. Usually 1 Mbps to 27 Mbps depending with data transmission scheme for example 1 Mbps for Amplitude shift keying (ASK), 4 Mbps for quadruple phase shift keying (QPSK) [25].

DSRC can be classified into two categories, namely:
Infrared communication: The wavelength used in this category is in the range of 850 - 950 nm.
Microwave communication: Based to the media of communication, this system uses the frequency band of 5.850 to 5.925 GHz.

Being a medium range communication system, DSRC is used to support both safety and licensed private operations over vehicle- to-infrastructure and vehicle-to-vehicle communications.
5.3. Comparison between technologies

Compared to other technologies, DSRC has the following unique capabilities [20][9][21]:
- A high data rate of 6 up to 27 Mbps and the communication range up to 1000 m.
- Provides broadcast messaging which gives it advantage over point-to-point wireless communications like cellular communication.
- Offers very low latency communication, where latency less than 100ms could be reached.
- Has the capability of providing high-availability communications. This allows two vehicles on of a prospective collision to be able to exchange important information until the last moments before the collision occurs.
- Can support vehicle-to-vehicle and vehicle-to-infrastructure communication.
- Can support one-way and two-way directionality.
- Support point-to-point and point-to-multi-point communication.
- DSRC is based on the IEEE802.11a OFDM technology. OFDM stands for Orthogonal Frequency Division Multiplexing where signal is divided into sub-signals that are then transmitted simultaneously at different frequency to receiver; the interference and crosstalk in signal transmission are reduced. Table 1 summarizes the overview given by [9] and [20] respectively, where more details have been given regarding other technologies which are not described in this thesis.

<table>
<thead>
<tr>
<th>Wireless Technology</th>
<th>DSRC</th>
<th>2G</th>
<th>2.5 G</th>
<th>3 G</th>
<th>IEEE 802.11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>1000m</td>
<td>4-6km</td>
<td>4-6km</td>
<td>4-6km</td>
<td>305-1000m</td>
</tr>
<tr>
<td>One way to vehicle</td>
<td>ok</td>
<td>ok</td>
<td>ok</td>
<td>ok</td>
<td>Ok (802.11b)</td>
</tr>
<tr>
<td>One way from vehicle</td>
<td>ok</td>
<td>ok</td>
<td>ok</td>
<td>ok</td>
<td>Ok (802.11b)</td>
</tr>
<tr>
<td>Two way</td>
<td>ok</td>
<td>ok</td>
<td>ok</td>
<td>ok</td>
<td>ok</td>
</tr>
<tr>
<td>Data rate</td>
<td>6-27Mbps</td>
<td>9.6-14.4kbps</td>
<td>40-320kbps</td>
<td>144-2Mbps</td>
<td>11M-54Mbps</td>
</tr>
<tr>
<td>Latency</td>
<td>100-200msec</td>
<td>1.5-3.5sec</td>
<td>1.5-3.5sec</td>
<td>1.5-3.5sec</td>
<td>3-5sec</td>
</tr>
<tr>
<td>Point-to-Point</td>
<td>ok</td>
<td>Ok</td>
<td>ok</td>
<td>ok</td>
<td>ok</td>
</tr>
<tr>
<td>Point-to-multipoint</td>
<td>ok</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table1: Summary of Carriers
Investigation of services and application scenarios for Inter-vehicle communication
6. Description of application scenarios

Inter-vehicle communication is pillar in road safety. There are many scenarios where inter-vehicle communication will be used in order to limit or minimize the disaster caused by road accidents. The Scenarios described hereafter seems to me more important compared to others especially for road safety which will avoid the death caused by accident.

6.1. Curve Speed Warning

Before the use of road beacons or other modern technique to inform the driver about the curve, the information was shown on posters on the beginning or in the middle of the road [9]. The driver cannot combine all factors alone to be able to take the precaution before the accident, that is why the vehicle as well infrastructure should contribute to road safety, i.e. the vehicle should be able to adapt to the road’s situation in advance (e.g. its speed should take into account the curve geometry or road surface parameters (icy road, etc.).

In the future, roadside beacons will be used to communicate all relevant information to the vehicle. The communication is done in such a way that the vehicle receives the information at time to decide which speed it should use. The message contains relevant and useful information related to the road (curve, lane width, max speed, surface condition) [9]. With advance in technology, the infrastructure combined with sensors, digital map or GPS position will provide accurate road information in a detailed way. In [9] and [30], the communication between vehicle and infrastructure is periodic, one way broadcast and is sent continuously 24h a day.

Whenever there is a change in road surface or in road geometry the message is updated and the in-vehicle system provides the response accordingly. In Fig1, each arrow carries an update message as shown below.

Figure 1 illustrates the Curve Speed Warning. The message transmission and reception is done as explained in the previous paragraph. The use of more sensors is needed to provide each and every road’s information and in-vehicle system should be enhanced so that the driver is warned at the right time without a false alarm.
The in-vehicle system processes the received message from infrastructure equipment. If the message is not relevant to its situation it is ignored otherwise it will compare the curve data to its own data, and decide to warn the driver to slow down the speed.

6.2. Pre-crash sensing for cooperative collision mitigation

The goal for pre-crash sensing system is to sense the threat as quickly as possible and alert the occupant’s protection system so that the injury is minimized. Pre-crash sensing doesn’t avoid the crash like crash warning systems, instead it is used when the crash looks inevitable, because of this the system should be robust and reliable [31] [29].
In [30] a system solution is proposed where sensors and actuators are integrated in vehicle to achieve pre-crash sensing. A sensor working with 24 GHz is used and is transmitting a wave signal continuously and as soon as it detect a threat the height of the vehicle is increased of 100 mm within 300 ms, so that if the crash occurs the door is not hit.

Pre-crash systems work in such a way that sensor/millimeter wave radar not only detect the imminent threat but cooperate automatically with the occupant protection to act as soon as the threat is detected. In this way they are two categories of measures called counter measures. There is reversible measure like non-pyrotechnic seat belt pre-tensioning, bumper extension or emergency brake assist. There is also a no-reversible counter measure which can not be reset after being activated, for example pyrotechnic seat-belt, pedestrian protection, etc.

As said above, sensors incorporated into vehicles are transmitting and receiving wave signal to and from other vehicle in communication range. The transmitted wave carries information about the vehicle (heading, position, velocity etc.) and by using this information; the vehicles in vicinity will act accordingly. What is needed is the ability of the vehicle to know how many cars are in the vicinity and at which distance and to achieve this, the system should have minimal latency. Figure 2 shows the chronological events before the crash, as said above if the crash is unavoidable the counter measures are use to minimize the injuries.
Description of application scenarios

**Road Traffic**

![Diagram showing No Collision Threat, Avoidable Collision, Unavoidable Collision, and No Collision Threat]

**Figure 2:** Chronological event before crash.

In Fig 2, the chronological events are as follows:

- **No collision threat:** in this case vehicles are far away from each other, the safety warning traffic light is not needed.
- **Avoidable Collision:** Here, vehicles are separated by few meters and the safety warning traffic light, stop sign violation, are used to warn the driver of the impending threat.
- **Unavoidable Collision:** Is in this case where the counter measure is used to minimize injuries as the chance of avoiding the collision is very low or zero.

![Diagram showing Side crash effect]

**Figure 3:** Side crash effect
Figure 3 shows a scenario where two or more cars are heading in different directions. We assume that some of the cars have the capability of detecting any threat in their view, not only that they are able to determine where and when the collision may occur. Here car A, based on its data and exchanged data from neighbouring cars detects a side collision with B, and warns the driver before the collision. Cars which are not equipped with a DSRC system may use GPS or other security facility provided by roadside unit.

6.3. Cooperative forward collision warning system

The CFCW (Cooperative forward collision warning system) is an application for vehicles moving forward in the same direction to avoid collision. To be able to avoid any crash between the host vehicle and its neighbours, it is assumed that each vehicle can act as sender and receiver, not only that each is equipped with a wireless device like DSRC, a sensor, a GPS receiver for position accuracy [31] because the distance separating two vehicles may be between 1 to 1.5m in lateral position. Low latency based on broadcast messages should be taken into account as each vehicle will broadcast a short message to indicate its current status (position, velocity, etc.). The delay should be minimized as the vehicle’s warning system must be fast enough to avoid a crash. Whenever the vehicle gets the message, it compares it to its current status if it is not relevant it is discarded, otherwise it is recorded for future statistical data gathering [22].

The other way of performing Cooperative Forward Collision Warning is to mount a forward looking sensor on the vehicles, so that they can communicate. This has the disadvantages of wave interference. In [9], data message set requirements are proposed; e.g. vehicle speed needs 16 bytes, vehicle position (longitude, latitude and elevation) 16 bytes each and vehicle size 48 bytes. If a DSRC device is used, the latency is less than 100 ms.

6.4. Lane change warning

The lane Change warning is mostly needed on a highway where the speed is high and the traffic is dense. In such situation any intention of lane change must be carefully studied. The warning is only given when the lane change will cause accidents. The vehicles exchange data through inter-vehicle communication systems and the exchanged data are used to predict if there would be a collision. The system design should be well organized in order to avoid false warning [9] [21]. Vehicle-to-vehicle communication systems create a table of a vehicle’s location, update it periodically and data of surrounding vehicles are stored and updated and based on that a warning is generated if a lane change will cause a collision.

In case of full market penetration this application can be solely accomplished by DSRC technology but knowing that a technology can not be accepted by all and it may have its own limitation, it will be wise to add to DSRC system, a DGPS (Differential GPS) to obtain the location of all vehicles around and a map database to determine if neighbour cars are in the same road and in which lane. It is possible to implement this application without using a DSRC system, by equipping the vehicle with radar on both sides. In this case, radars are in the position of providing the needed information and a warning if necessary.
6.5. **Emergency electronic brake light**

Emergency electronic brake is a typical car-to-car communication application. It helps to avoid accident by alerting cars in the same lane even in difficult situation (dust, big truck between two cars, snow etc.) by braking hard [9].

The DSRC system on the braking car plays an important role by sharing the host information with other cars and the receiving car should be able to decide if the message is relevant to it or not. This is possible through a GPS receiver mounted on both vehicles as well as an intelligence mechanism which allows the vehicle to assess the received message [9]. The GPS system will show where the message is coming from (right, left, rear and front) and the intelligence mechanism will decide if a warning is necessary.

In the example in figure 4, a 3-lane highway, a hard brake from car D in lane 1 moving in a right direction is not relevant to a car in lane 3 (car H) moving either in same or the opposite direction. But in case of cars in the same lane or neighbouring lanes, e.g. lane 2, the message can be relevant. For example, signals from car A can be relevant for H and D even if they are in different lanes. In every situation the in-vehicle unit receiving the message, examines it based on its own data and if it is relevant, it acts accordingly; otherwise the message is ignored.

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**Figure 4: Example scenario for use of Emergency Electronic Brake Light**
7. Scenarios vs. Communication requirements

The following section describes in short each scenario and gives its communication requirements, the given assumptions regarding the communication requirement may vary depending to the author, i.e. some may be based on simulation or reading different publications. It is in this perspective that the message size and the bandwidth estimation are based on [9], where the following have been given the size in bytes.

Vehicle’s size (48), position (96), heading (16), speed (16), acceleration (16), vehicle ID/Communication addresses (48).

7.1. Communication requirements

The communication requirements are a set of minimum requirements a system should fulfil in order to provide the service.

7.1.1. Curve speed warning

Communication requirements:
To be able to define the communication requirement for the curve speed warning, more assumptions are proposed for example curve shape, curve number, allowed speed, actual speed, the way the message is send, the way the received message is examined and how the receiver take action. It is clear here that curve speed warning is infrastructure to vehicle communication; even if vehicle may interchange the message between them for example a vehicle may communicate with another which is not yet in the communication range with the infrastructure.

The curve may have the following form:
  a. Sharp curve
  b. Very sharp curve
  c. Normal curve

The curve may have the following form:
  a. Sharp curve
  b. Very sharp curve
  c. Normal curve

By assuming a road of 1km; in the same road we may have more that one curve, lets say curve A, B, C, etc. we may also assign a particular allowed speed in each curve depending to its shape, for example 30km/h for a very sharp curve, 40km/h for a sharp curve and 50km/h for a normal curve.

With regular cars, i.e. cars without relevant sensors, is the driver’s duty to analyze each situation on the road. In the case of equipped cars, the in-vehicle sensor will compare the allowed speed communicated by roadside unit to its own speed and to signal the driver either to keep the current speed (green light or simply without any message), or simply a clear warning to slow down.

Messages from the infrastructure unit should be transmitted continuously and updated irrespective if a car is present or not. Based on the above assumptions, the system should have the following communication requirements:
Reliability:
Both systems i.e. infrastructure system as well as in-vehicle system should be able to communicate in all circumstances and produce the minimum services even in the harsh condition. For example the change in weather should not affect the ability of the infrastructure system to communicate or the change in road condition should not affect the in vehicle to react properly within a reasonable time.

Latency:
In this case, the latency includes all delays in both infrastructure unit and vehicle unit i.e. message initiation, message update, re-routing process in case the near by car forward its message to the following one. Here two scenarios may arise: The first one is that, the generated/sent message from infrastructure unit is send continuously to all cars in the vicinity, repeatedly for example 10 times a second. The second scenario is the one where the received message is forwarded by the receiving car to nearby car even those outside of the communication range of the infrastructure. Here the cars should have the capability to discard unnecessary or old messages and be able to update its own information. A latency of 1s is enough to handle all delays [9].

Frequency:
In curve warning speed, the frequency is an important parameter because it gives an idea of how the message should be repeated and updated. As stated above, the infrastructure sends the message continuously and updates it as soon as there is a change, thus a low frequency of the order of 1Hz [9] is sufficient for repetition as there is no competition between vehicles accessing/sharing the infrastructure. The vehicle should be able to react rapidly if there is any updated information.

Bandwidth:
In term of IVC or other communication system a big bandwidth is needed in order to allow everyone in the communication range to access the medium and use it. In curve speed warning, the bandwidth should be medium, because the communication is mainly point to multipoint where the infrastructure unit will continuously send update message to vehicles in the vicinity. A precise bandwidth assigned to an infrastructure can be calculated by considering different factors like number of cars passing the curve, message size, message update, etc. for example in congested area where there are a lot of cars the bandwidth should be big.

Message contents:
The message from the infrastructure unit to the approaching car will contain the curve information and the road condition. For the curve, the following information will be given: allowed speed, curve shape, curve length, next curve and traffic condition. Road condition such as wet, slippery or icy, as well as weather condition will be given. Message content should vary depending to the road or weather condition; for example in wet and slippery road, the data related to road conditions may be given preference compared to weather condition sand this may reduce the message size, in turn this will influence the bandwidth used.
7.1.2. Pre-crash sensing for cooperative collision mitigation

The following assumptions are set in order to be able to define the communication requirements for this scenario.
The distance between two vehicles is no too short ie not less than 1.5m
The sensor/millimetre wave and in vehicle (occupant’s protection) work properly all the time i.e. to breakdown of one of them is allowed.
The driver is always aware of the system function i.e. he is always the last person to take the final decision if something happen
All vehicles are equipped with sensors/millimetre wave and occupant’s protection
Vehicles without sensors may use infrastructure’s information to deal with the traffic situation as well as their safety.
The important communication requirement in pre-crash sensing cooperative collision mitigation is reliability because the system itself doesn’t avoid the crash but minimize its impact. The system should be reliable so that it coordinates the sensor and the occupant’s protection system.
Latency is very low as the reaction time should be short i.e. 20ms [9], as said above the in-vehicle should sense and warn the occupant’s protection in a very short time so that the injury is minimized at its lowest level. Here some scenarios may arise; both of the vehicles have a very high speed and the distance between them is very short; in this case the latency as said above should be very low to minimize the injuries. In the second case, one of the vehicles has a limited speed, let say 70km/h. In this case it is somehow easy to manage the impact as the car may decelerate again, and even the driver may intervene.
The occupied bandwidth by each vehicle is small because the messages to be sent in this situation are small but due to the number of vehicles on highway and their high speed the channel’s bandwidth should be high so that the channel doesn’t get congested which may cause delay and message loss which will lead to multi collision in this situation.
Due to the number of vehicles, their high speed and the need to repeat and update their information (position, speed,) in short time in order to achieve safe traffic; a high frequency is required. In [9], a frequency of 50 Hz is assumed; the communication range of 50 m is given as an idea distance between two vehicles in consideration of the high speed n high way as well as the traffic situation, in opposite case the sensor/millimetre wave may not be able to perform properly ie in less than 50m with a speed of 120 km/h, the occupant’s protection can not react in such short time; when the distance is more than 50 m, the driver himself may avoid crash simply by decelerating or hanging the lane or avoiding the approaching vehicle.
The message content is velocity, heading and position and its size of 128 bytes is small as it contains the necessary information needed by other vehicles in the vicinity.
7.1.3. Lane change warning

The following assumptions are taken into consideration while defining the communication requirements for lane change warning:

- All vehicles are in neighbouring lane
- All vehicles are equipped with technology able to detect and warn the neighbouring vehicles
- The speed is high and the traffic is dense.

Vehicles exchange information regarding their position, heading, and speed at regular intervals, this helps to warn the driver if the intended lane change is risky. As lane change is mostly risky in highway where the traffic is dense and the speed is high. The communication requirement should take into consideration these factors.

The reliability should be high so that the in-vehicle system of all vehicles that want to change the lane will be able to update and use the received information in all circumstances (with less or dense traffic, with very high or high speed and when the road and weather condition change suddenly).

The medium access has a high bandwidth to accommodate a high number of vehicles with high speed and changing position; due to that the message size should be small and this provides the following advantages:

- Short message is easy to send
- It is easy to update the short message
- It takes less bandwidth (to avoid congestion for a communication medium which will lead to delay, thus collision and multi-collision)

The latency should be low as the space between vehicles is small; the speed is high and their number is high, this is due to the fact that the response time must be short in order to notify the requesting vehicles that its intention may not be safe and as this notification took less time the requesting vehicles just keep sending the request until he get the permission.

The following is given in [9]: the latency is 100 ms, the frequency is 10 Hz, the communication mode is periodic, and the communication range is 150 m. The message size is only 96 bytes and is formed by vehicle speed (16 bytes), acceleration (16 bytes), heading (16 bytes) and vehicle size (48 bytes), in normal situation, where the traffic is not dense or the speed of vehicles is not high, the message content may vary and its size may increase; for example message may include GPS coordinates (96 bytes), GPS antenna (32 bytes) and time stamp, and the message size becomes 288 bytes.
7.1.4. Emergency electronic brake light

The reliability of the sending and receiving vehicle should be high so that the braking vehicle can easily send the signal even if its ability is deteriorating, the succeeding vehicles should be able to receive and re-route the same signal to all vehicles in the vicinity and on their side they should be able to conclude if the message is relevant to them. The update frequency as well as the bandwidth needed in this scenario are medium based to the fact that the received signal is retransmitted is up to the receiver to take necessary action; in case of multiple brakes at the same time, update frequency and the needed bandwidth should be high as the signals are repeated many times and the vehicles accessing the channel at the same time are many. It is always good to use short message indicating the necessary information in order to avoid delay caused by long message occupying high bandwidth. The latency is short because some time the distance between vehicles is short, due to this the time to examine and re-route the message should be small in order to avoid the multi-crash for the succeeding vehicles.

The communication requirements defined in 7.1.3 are applied to this scenario as the vehicles in these scenarios can be in the same situation.

7.1.5. Cooperative forward collision warning system

The CFCW is one of vehicular application for vehicle moving forward in the same direction to avoid collision. In this thesis, it assumed that:

- The vehicles are either in the same lane or neighbouring lane
- The distance between vehicles may be small 1m or more

In defining the communication requirement the above mention assumptions are taken into consideration. Reliability of the in vehicle communication should be high in order to avoid the collision even if the distance between vehicles is short, this is because if it fail to perform in all circumstances it may cause chaos in traffic with vehicles unable to cope with the new situation (when collision occurs and the next vehicles is unable to forward the information to its neighbours).

The bandwidth should be medium as each vehicle communicates with its neighbours and the message is re-transmitted to the next vehicles, in this way a channel with a medium bandwidth is enough to service all vehicles in its communication range.

The latency is very short-50millisecond as the distance between two communicating vehicles is less than 2meters because of this the response time should be short so that collision or multiple collisions are avoided.

The message content is vehicles position, heading, speed and size and its message size is 138 bytes as the message contains only the important vehicle’s information needed in collision warning and by taking into consideration of bandwidth as well update frequency which should be high as the message is transmitted periodically and it may be sent repeatedly many time in second depending to the situation.
### 7.2. Matching scenarios with available technologies

This thesis mostly investigated safety applications such as pre-crash, lane change, cooperative forward collision warning; these scenarios have in common the following communication requirements: low latency, high reliability, medium/high frequency, short message size and medium/high bandwidth. These communication requirements have been defined in details in chapter 4 and each one of them has been matched with each application scenario. The technologies investigated include cellular communication and wireless technology. Cellular technology is not suited for safety applications for the following reasons:

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>Type of communication</th>
<th>COMMUNICATION REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V2V, V2I, V2V, I2V</td>
<td>Reliability</td>
</tr>
<tr>
<td>Pre-Crash</td>
<td>High</td>
<td>Event-Driven</td>
</tr>
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<td></td>
<td></td>
<td>VLow 128</td>
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<tr>
<td></td>
<td></td>
<td>50Hz/ High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High 50m</td>
</tr>
<tr>
<td>Lane change</td>
<td>High</td>
<td>Periodic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low 96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10Hz/medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High 150m</td>
</tr>
<tr>
<td>Emergency E Light B</td>
<td>High</td>
<td>Event driven</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low 288</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10Hz/medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Med/ High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>300m</td>
</tr>
<tr>
<td>C.Forward C.Warning</td>
<td>High</td>
<td>Periodic / E driven</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low 138</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10Hz/medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium 300m</td>
</tr>
<tr>
<td>Curve Speed W</td>
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<td></td>
<td></td>
<td>Low 381</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1Hz/small</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium 200m</td>
</tr>
</tbody>
</table>

Table2: Scenarios and their communication requirements

Cellular communication does not match the short latency required in safety application. The latency in cellular system is in second (1.5-3sec) in case most of the safety applications need a latency of order of millisecond, for example lane change requires 100ms which can be provided by DSRC.
Cellular communication need to know the receiver address in order to communicate; this is not possible in inter-vehicle communication where there vehicles in a network keep changing, not only that in a situation where you need an urgent action you can not wait to know the address of the neighbouring vehicles.

In the future when comfort will be combined with safety; cellular communication is not the best choice as it can not be used to transfer or download a big file. Cellular communication is suitable where there is a centralized control communication where the information is provided on demand. For example when the driver need to know about the traffic information in general (traffic jam, weather,... etc); in Curve speed warning cellular communication may be useful if the vehicles is not equipped with an appropriate technology or if the driver want to know in advance the situation of the road, or if is not familiar with the road or place.

IEEE 802.11 being a combination of different specifications, some of them like 802.11a and b are typically designed for inter-vehicle communication. IEEE802.11a and b can be used where a high date rate and high speed are needed as more vehicles can be accommodated by a communication channel; beside that, IEEE802.11a is based on Orthogonal Frequency Division Multiplexing where interference and crosstalk are reduced thus making IEEE 802.11 a suitable candidate for inter-vehicle communication in congested area and vehicles equipped with IEEE 802.11b can upload and download data through a LAN while vehicles are in communication range and IEEE 802.11 support short range communication thus, suitable for safety application; for example in Cooperative Forward collision warning, lane change warning, etc. IEEE 802.11a is a basic standard for the 5.9 DSRC lower layers and the IEEE 802.11p modified version provide almost the same capabilities as DSRC. These include short latency, reliability in high way speeds.

Based on the shortcomings of cellular communication mentioned above and the communication requirements needed for safety applications, DSRC is the best candidate to suite these communication requirements based on its unique capabilities mentioned in [20][9][21], which are:

1. A high data rate of 6 up to 27 Mpbs, which means that it can accommodate many users at once; thus avoiding collision while users are sending the message simultaneously.

2. Provides broadcast messaging which is a must in inter-vehicle communication where the message is received by every vehicle in the vicinity and take appropriate action according to its position, speed, intention, etc.

3. Offers very low latency communication, where latency less than 100ms could be reached. Short latency is the communication requirement which is most crucial in safety application where the response time to a sudden situation must be very short in order to avoid crashes or multi crashes.

4. Has the capability of providing high-availability communications. This allows two vehicles on of a prospective collision to be able to exchange important information until the last moments before the collision occurs.
5. DSRC supports both vehicle-to-vehicle and vehicle-to-infrastructure communication, this is another point which make DSRC an ideal wireless technology for IVC.

6. DSRC supports one-way and two-way directionality as well as point-to-point and point-to-multi-point communication.

Four out of five scenarios investigated in my thesis are safety application these are Pre-crash sensing for cooperative collision mitigation, Lane change warning, Emergency electronic brake light, Cooperative forward collision warning system. In these entire scenarios, DSRC technology suite their communication requirements i.e. the response time in these scenarios should be in millisecond and DSRC is reliable when we consider factor like interference or crosstalk which are main hindrance in wireless technology.

IEEE 802.11 is suitable for cooperative forward collision warning as IEEE 802.11 exhibits the property of a mesh technology in which a vehicles is thought to be a node routing/re-routing the message from other vehicle. IEEE 802.11 provides a high data rate, thus its frequency update is high. This qualifies it for lane change warning where a message update play important role in crash avoidance.

The cellular technology is useful in centralized systems as the central unit has all the details. In curve speed warning the cellular technology is useful as the driver may get the information of the traffic a head. It is useful for vehicles that are not equipped with in-vehicles communication system capable of collecting the information itself.
8. Result and Discussion

In my investigation I have realized that IVC is a huge and new area where researchers, companies and countries are investing a lot money and time. Many new technologies have been invented, some are in the near future, and others are still in the development phase. During my investigation I have found that Dedication Short Range Communication is a promising technology for inter-vehicle communication as it provides more utilities compared to other technologies mentioned in this thesis.

In order to be able to match scenario, communication requirement and technology, the following solutions are proposed:

- In congested area like cities where there are a lot of vehicles and other human made obstacles that may cause communication degradation with either multi-path or wireless interferences; it is better to use more sensors and communication units for detection and re-routing of the received signal in order to overcome the above weakness.

- A combination of technologies is suited in order to make communication between vehicles and between vehicles and infrastructure faster and more effective. A GPS provides a location of a vehicle and a DSRC unit may enable the quick reaction time needed in some scenario; for example in pre-crash sensing for cooperative collision mitigation where a very short reaction time is required to minimized injury in case of a crash.

- Enhancement of in-vehicle as well as infrastructure communication system may reduce cost, accidents and make the communication easier. The ability of in-vehicle and infrastructure to examine independently any arising situation within a short time and in all circumstances will improve the inter-vehicle communication.
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9. Conclusion and future work

To be able to provide road safety, traffic flow efficiency, comfort and time gain, inter-vehicle communication is a major factor. This communication network differs from a normal network communication as its nodes/vehicles are dynamic and fast i.e. some enter the network or leave a network with a high speed based not only on the network changes depending on the place (highway or countryside) and time (morning, lunch time or evening). The vehicle communicates directly or indirectly periodically or the event may occur suddenly; this may cause crashes and traffic jams which lead to energy consumption, pollution and time wasting.

In this thesis, a thorough investigation has been curried out regarding services and application scenarios for inter vehicle communication in order to highlight the communication requirements, technologies used and matching them with selected scenarios. My investigation was concentrated on different projects done in European Union as well different scientific reviews of the projects done in Japan and USA.

Due to time constraints it was not possible to make a simulation or to investigate all technologies mentioned in different project. The future work should look into the following:

- Carry out a simulation to be able to determine a human reaction time.
- Simulate the same data and compare the result of different technologies and match them with different scenario.
- Include security issue in inter-vehicle communication as it is ignored (few authors focused on it) at moment.
- Investigate other technologies which are not mentioned in this thesis so that a broad knowledge of existing technology is shown.

There should be a common policy in different countries regarding inter vehicle communication (frequency band allocation and standardization, etc) as vehicles may cross the border from one country to another.

Security issues should be included in further research in this field as potential intruder may hijack the information and disturb the traffic.

More effort and resources should be added and it should be equally or proportionally distributed all over the world i.e. road safety should expand to the developing counties too as the number of accidents increases.
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10. References

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