Collaborating vehicles for increased traffic safety

Master’s Thesis in Electrical Engineering

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Abstract

Transportation has expanded the scope of human mobility, increasing the distances we cover on a regular basis. The large benefits of transportation have resulted in a huge recent increase in the number of vehicles. This, however, implies an increased number of traffic accidents that cause many fatalities and injuries every year. It also leads to problems like increased delay for commuters, and negative effects on the environment. Not to mention, the money spent in the wasted fuel, as well as the costs of fixing damaged equipment and property.

To help in mitigating these problems the vehicles and the road infrastructure should be equipped with intelligent devices that allow them to communicate and collaborate with each other and exchange safety information concerning accidents, road traffic conditions, and weather conditions as well as non-safety information. Recently, this topic termed telematics has gathered considerable interest constituting a lot of work and research all included under the title of Intelligent Transportation System (ITS).

The thesis work defines general communication requirements of future telematics applications and investigates various wireless carriers that are important to achieve communication in-between vehicles and between vehicles and nearby infrastructure. We analyse several future applications related to the ITS field and describe their communication requirements. Based on the communication requirements the applications are grouped into different profiles in order to determine the most suitable carrier for each profile.

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1. INTRODUCTION

1.1 Telematics

“Telematics” is a new word coined by the combination of telecommunications and informatics which usually refers to a two sided information service provided to vehicles through the use of multimedia-compatible computers. At the same time, the cars or vehicles should be equipped with a mobile telecommunications network terminal like a mobile phone or some other telecommunications module. Telematics include two main types of services. One is the automobile information specific services which are responsible for the communication between the vehicle and the station concerning the vehicle’s position and condition. The other one is the generalized information services which are responsible for convenience and amenity information and are usually provided over the internet through personal computers and mobile phones that are compatible with the internet protocol (IP) [1].

Consequently, telematics can be defined as the transfer of computerized data over a distance, and transport telematics means the ability to obtain information concerning the driver and the vehicle. Advanced transport telematics technologies are divided into three major categories:

1. Technologies with the ability to measure the current road traffic.
2. Technologies with the ability to change traffic signs according to the available traffic condition and thereby offer priorities.
3. Technologies with the ability to offer real-time congestion level evaluation and communicate with the vehicles.

Some benefits of telematics in the transport sector could be the enhancement of road safety by increasing the driver awareness, the road transport efficiency by using techniques like route guidance. These in addition to providing economic profit by reducing lost wages and wasted fuel that can occur due to congestion, and environmental protection [2].

There are already some existing applications in which telematics is used; these include, for example, navigation assistance, emergency services, and information services using cellular networks and Global Positioning Systems (GPS). Today, thanks to the ability of utilizing real-time data concerning vehicles such as their speed, position, acceleration, direction, etc implementing a lot of applications in many different areas became possible. This dynamic information could be exchanged between the vehicles and the infrastructure allowing the in-vehicle/infrastructure devices to make the appropriate decision for the driver [3].

Telematics is highly present and used in both types of vehicle communications namely vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Some typical applications of telematics requiring V2I communication could be safety applications such as dangerous road condition warning, crossing animals warning, obstacle around acute curves warning, traffic jam warning, curve speed warning and rollover warning. Some applications of telematics requiring
V2V communications could be blind spot warning, lane change warning, hard break event or vehicle breakdown warning [4].

### 1.2 Problem Formulation

The great enhancements of wireless communication technologies have led to their wide use in a number of applications relevant to Intelligent Transportation Systems (ITS). Most of these applications require a reliable wireless channel to realize the communication between vehicles and the infrastructure; this includes V2I, V2V, and infrastructure-to-infrastructure (I2I) communication. However, wireless channels are inherently unreliable and vulnerable to error. This poses a great challenge since the situation becomes worse the more complex the communication environment becomes, particularly with vehicles due to their high mobility. Therefore, additional efforts are needed to achieve the real-time communication requirements regarding timeliness, reliability, bandwidth, priority, and latency when using these channels.

A real problem today is that none of the existing wireless carriers is capable of supporting all or most of the transport telematics applications alone due to the varied and diversified nature of the requirements. Accordingly, a new methodology, technique or standard needs to be adopted.

### 1.3 The Approach

The main goal of this project is to evaluate the communication requirements of a number of ITS applications and suggest suitable carriers. To achieve this goal, the procedure will be to:

- Investigate a list of applications in different European projects in which Volvo Technology Corporation (VTEC) is involved.
- Clearly define general communication requirements and characteristics for these applications.
- Divide the applications into different profiles according to their different communication requirements and characteristics.
- Study some important existing short to medium range carriers with respect to the different communication requirements.
- Perform a detailed investigation on the carriers and the application profiles in order to match them together.
- Suggest appropriate carries for the most relevant application profiles, based on the detailed investigation.

A new list of communication requirements have been compiled containing the ones mentioned in earlier work, but with more requirements added. However, the list is still not exhaustive as, for example, the security requirements were not included. The carriers studied included the cellular networks, short and medium communication range standards, i.e. DSRC, Infrared (IR), and millimetre-wave (MM), as well as the new Continuous Air-interface Long and Medium range (CALM) standard. Other carriers like satellite communications are out of the scope of this thesis.
The choice of these specific carriers has been based on the point that they are widely used in the ITS field and seem to suit very much the considered applications.

1.4 Thesis Organization

The thesis is outlined as follows: Chapter 2 contains the field background covering the ITS, Inter-Vehicle Communication (IVC), and Road-to-Vehicle Communication (RVC). Chapter 3 discusses the communication requirements and profiling for several different applications. Chapter 4 describes the possible wireless carriers for the applications in chapter 3. The results are discussed and analyzed in chapter 5. Finally, Chapter 6 contains conclusions and suggestions for future work.
2. BACKGROUND

This chapter introduces to the reader the basic thesis literature, covering the definition and description of ITS, its applications together with the communication approaches involved.

2.1 Intelligent Transportation Systems

“Intelligent Transportation Systems (ITS) is the application of computer, electronics, and communications technologies and management strategies in an integrated manner to acquire and utilize information to increase the safety and efficiency of the surface transportation system” [5]. Nowadays, the rapid increase in the number of vehicles imposes constraints on the available road space which in turn results in environmental degradation. ITS therefore aims to maintain an environmental friendly transportation for the future [7]. ITS is also considered a very comprehensive info-communications system that deals with road traffic trying to integrate three entities together which are the vehicles, the roads, and the humans and allow them to interact with each other [6].

The most important ITS applications are divided into the following different categories [7]:

- Advanced Public Transportation Systems (APTS)
- Advanced Traffic Management Systems (ATMS)
- Advanced Traveller Information Systems (ATIS)
- Electronic Toll Collection and Traffic Management (ETTM)
- Commercial Vehicle Operation (CVO)

ITS requires different communication technologies such as data storage and processing equipment, wireline and wireless communication systems, sensors etc. These technologies can be classified into sensing and surveillance, information, communication, and traffic control technologies [7]. However, these technologies will be integrated into road infrastructure and in-vehicle devices to make use of the ITS benefits like enhancing safety, reducing traffic congestion, helping in the monitoring of traffic flow and hence providing alternative routes, improving productivity, and saving life, time and money [7] [8].

ITS requires communication networks for performing the collection and processing of real-time data needed for their performance. Two communication approaches are required, namely, Road-to-Vehicle Communication (RVC) and Vehicle-to-Vehicle Communication that is also called Inter-Vehicle Communication (IVC). In the RVC approach, the vehicles are communicating through the use of infrastructures that are installed along the roadside; while IVC comprises direct transmission of information between vehicles without the need of a fixed infrastructure [9].

2.2 Vehicle-to-Vehicle Systems

Inter-vehicle communication (IVC) has gained considerable attention and importance during the recent years because it is considered an important element of the ITS architecture and a solid
application of mobile ad hoc networks [11]. It has started to obtain increasing interest in many fields including the academic research community and automotive industry in countries like the US, Japan and the EC [10]. “An IVC network is considered an ad hoc network, which consists of a set of nodes (vehicles) that communicate through radio frequencies, without the use of a beforehand –deployed infrastructure and without the use of a centralized administration” [9]. The most important aspect of IVC is that it provides the driver with an extended horizon allowing him to communicate with vehicles that lay outside his line of sight range or even outside the radio range using multi-hop networks constructed between a number of vehicles. Doing so, IVC overcomes the limitations of the on-board devices (e.g. radar and sensors). Consequently, IVC could help in improving the road traffic in a very significant manner through information dissemination between drivers [10].

In the ITS system architecture in the US and Japan, IVC is considered one of the four main communication systems in addition to Dedicated Short Range Communication (DSRC), the wide area wireless communication and the wireline communication [11].

2.2.1 History of Research into Inter-Vehicle Communication

The earliest research on IVC started in Japan in the early 1980’s by JSK (Association of Electronics Technology for Automobile Traffic and Driving) now known as the Japan Automobile Research Institute. IVC was studied primarily in terms of driver and traffic information systems incorporated in ATMS/ATIS. From that time onwards, the perspective has changed into applying IVC to driver assistance and automated driving systems incorporated in Advanced Vehicle Control and Safety Systems (AVCSS). Later on, concrete results in automated platooning have been achieved by California Partners for Advanced Transit and Highways (PATH) and Chauffeur of EU. Demo 2000, an example of cooperative driving systems developed in Japan in the late 1990’s and 2000 also demonstrated a group of important applications for IVC. These systems made automated vehicle platooning a reality through allowing data, such as the acceleration of each vehicle to be transferred through IVC, which would have been otherwise difficult to be measured from other vehicles. Another important related subject in which the IVC is involved is the Adaptive Cruise Control (ACC) because before using it the traditional solution was to equip each individual vehicle with automatic control systems. Recently, systems that improve the automobile traffic safety using inter-vehicle or road-to-vehicle communication to transmit information regarding incidents’ warning, emergencies, etc. from a preceding vehicle to a succeeding one have been the focus of researchers in Europe, US and Japan. Examples of projects in this field trying to deploy such systems are the European project CarTalk2000 where issues like safety and comfortable driving depending on IVC are considered. Another project in this field is the fleetnet, which is working in cooperation with the CarTalk2000 for developing the IVC [10] [12].

2.2.2 Applications of Inter-Vehicle Communication

The applications of IVC are divided into three main groups:
1. Information and Warning functions:
Constitutes transmission of information regarding the road traffic condition, (this includes incidents such as vehicle breakdown, congestion, dangerous road surface etc) from the vehicle in the subjected site to other vehicles in the surrounding area.

2. Communication-based Longitudinal Control:
When a vehicle’s vision is blocked and it can’t see the other vehicle to adjust its reactions accordingly, the “look through” capability of IVC is used to help avoid potential accidents and improve the road capacity by platooning the vehicles.

3. Co-operative assistance systems:
Provide coordination between vehicles at sensitive points like blind crossing and when vehicles are entering a highway or at intersections to help avoid any misunderstanding between the drivers that could lead to an accident.

In addition to these there are the “added value” applications as well, like location based services and multiplayer games [10].

2.3 Road-to-Vehicle Systems
A Road-to-Vehicle system is an infrastructure network of ITS where a large number of roadside units are installed along the roads. This system is an important system in ITS since it offers a lot of information about traffic, travel, and safety to vehicles. Two considerations must be taken into account when constructing ITS communication systems in general and road-to-vehicle systems in particular. First, different services with different frequency bands must be supported by the same system taking into account that new services will appear in the future, so the network must be flexible in terms of supporting the available different services together with the ability to accommodate the new services without large modifications in the existing system. Second, since the amount of the exchanged information is changing with respect to the change in the transportation traffic, the network must be able to use the network resources (i.e. frequency band) in an effective manner [13].

The communication is performed between the roadside units and the on-board units mounted on the vehicles. There are several network configurations according to the service requirements. These are as follows [14]:

1. **Spot-type** where the service is available for dedicated short areas along the road. However, this configuration has two limitations, namely the passing period through the service is very short due to vehicles’ high speed and in some cases such as traffic jam some vehicles may not have access to the provided service because they may be in the spaces between the service areas for a long period of time. See fig 2.1.

2. **Seamless-type cellular zone** where several roadside units are installed in such a way that their zones are forming consecutive and overlapping zones providing continuous communication, see fig 2.2. An important issue which must be considered here is the ability to perform the handover mechanism in a fast way.
There are some existing applications of road-to-vehicle communication such as the Electronic Toll Collection (ETC), where a communication link is used between the vehicle and roadside unit to provide account information to toll facility. Other general applications could be at road points such as tunnels, bridges, sharp bends, short period road work, and monitoring of critical factors like ice, fog, and presence of queues and obstacles. In these applications, the infrastructure provides warning and other safety-related information to the approaching vehicles.

Infrastructure-based systems can overcome the limitations of vehicle-to-vehicle communication systems such as the lack of sufficient vehicle density and unreliability of in-vehicle systems. Moreover, it has the ability to support both equipped and non-equipped vehicles (i.e. by use of conventional signals), and it has the possibility to provide special solutions for road users other
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than vehicles like motorbikes and bicycles. Internet services and multimedia information can also be supported by infrastructure systems. However, the coverage area of this type is limited since it is too expensive to cover the whole road network [15].

2.3.1 Radio-on-Fibre Systems

Radio on Fibre system is a promising system of road-vehicle communication which could provide services like access to internet and download multimedia contents. This network is expected to support new services in the future and hence is considered to be one of the most appropriate networks in the ITS [13].

Radio on Fibre is a technology for transmitting radio signals long distances using optical fibres. The Radio-on-Fibre (ROF) based road-to-vehicle communication system has been developed to support higher data rates for multimedia transmission between vehicles and infrastructures. The system consists of a ROF network and a road-to-vehicle Radio Frequency (RF) communication network. The ROF network is used to transmit/receive RF signals to/from roadside base stations; while the road-to-vehicle RF communication network is used to allocate frequency band according to the communication traffic [13].

The basic idea in this system is that a control station (CS) is connected with several road base stations (RBS) via optical fibres. All the equipment for the modulation and demodulation are mounted on the CS, which receives the information from a Public Switched Telephone Network (PSTN), internet, and other CSs. The received information is converted to optical signal to be transmitted to the RBSs via optical fibres (down link). At the RBSs, the optical signal is detected by a photo diode (PD) and then converted to radio signal to be transmitted to the Mobile stations (MSs) or on-board units. On the other hand, the radio signal from the MSs is converted to optical signal to be transmitted to the CS (up link) [16] [14].

The advantages of using the ROF technologies are:

- The size of the RBS is reduced because all the equipment are mounted on the CS and only a device is needed at RBS to convert optical and radio signals.
- As the radio modulation units are at the CS, a large virtual zone can be constructed for the RBSs that are connected with the same CS using the same frequency; this reduces the number of handover needed [18].

2.4 Cooperative Approach

The new approach is the cooperation between the vehicle and infrastructure that makes it possible to obtain more information about the surrounding situations. This cooperation could allow both in-vehicle devices and infrastructure to provide more accurate recommended actions to the drivers. Moreover, instead of dealing with the application either totally in the vehicle or totally in the infrastructure system the cooperative approach will provide a cost-effective way for addressing some applications, such as intersection safety, in a more collaborative manner [19].

With this new approach, the applications could be vehicle-based or infrastructure-based. In vehicle based applications, the on-board device is more complex than the roadside device where
the information is collected by the vehicles with some support from infrastructure to allow the on-board device to make the decision. In infrastructure-based applications, it is the infrastructure that runs the application and then warns the vehicles about the critical situations along the road [15].

3. COMMUNICATION REQUIREMENTS & APPLICATIONS’ PROFILING

In this chapter, we define some communication requirements and highlight their importance and significance. We analyze these requirements from an ITS perspective in general, giving no special consideration for RVC or IVC. Each requirement is defined in terms of how well it satisfies the general needs of the applications in this field. A similar effort has been initiated in [20] and [21]. In [21] a group of selected safety and non-safety applications was studied and for each application an estimation for its general communication attributes was made; while [20] was an effort to standardize the communication method for inter-vehicle communication by making a reference model for IVC. This model consists of three parts, the applications, the requirements for the construction of an IVC system, and the requirements for the performance of this system. In this work we have included a wider range of applications, covering various areas such as safety, traffic management, tolling, and traveller information applications. A new list of communication requirements have been compiled containing the ones mentioned in [20] and [21], but with more requirements added. However, the list is still not exhaustive as, for example, security requirement was not included. The criterion on which we base our list is the fact that the list items represent the most general and important requirements to be defined in the first phase of developing the communication part of an application. Hence they could help in determining the most suitable wireless carrier for a specific application. Using the list, the communication requirements for a number of different applications in several projects have been deduced. Thereafter, we divide the different applications into different groups or profiles according to their communication requirements. The profiling of these applications has been based solely on the communication requirements ignoring other factors such as the type of application, cost, social acceptance, and commercial feasibility.

3.1 General Communication Requirements

Some of the general communication requirements related to different applications have been divided into three categories namely, communication requirements, traffic characteristics, and communication infrastructure. The communication requirements describe how the data should be handled and treated e.g. which message should be delivered first (priority) and how fast (latency). Traffic characteristics describe the data to be sent i.e. how much (message size), how often (how many times the message should be repeated) and when (after a certain interval of time). The communication infrastructure describes the different entities involved in the communication process e.g. vehicle and infrastructure and their specifications e.g. communication range for the corresponding application.
3.1.1 Communication Requirements

Some of the communication requirements could be defined as follows:

1. Directionality of information transmission
   This constitutes the following:
   - One-way communication for informative applications where the sender wants to inform the receiver/s about a certain situation or event.
   - Two-way communication for interactive applications where the communicating units need to establish a dialog [20].

   For both of them the communication could be point-to-point or point-to-multipoint. However, if we want to elaborate the difference between one-way and two-way communication, we could say that a one-way communication can comprise communication between both communicating units same as two-way communication but without the need for instantaneous negotiation.

2. Transmission scheme of information
   The transmission scheme of information defines the basic architecture of the transmission method of information being used and it varies according to the applications’ needs; while some applications require “Real-time transmission scheme”, others need “Storage transmission scheme”. In real-time transmission scheme, the information is transmitted directly whenever obtained by the in-vehicle or infrastructure systems; while in a storage transmission scheme the acquired information can be stored and transmitted when it is required e.g. in case of an infrastructure getting information about a road condition it can store this information as long as the condition exists and disseminate it when required [20].

   It is worth mentioning here that real-time transmission can constitute also some sort of information storage in some special cases and these are for example in the case of the lack of enough vehicle density, where the vehicle will have to store the information until it finds the next available vehicle or infrastructure.

3. Allowable latency
   It is defined as the maximum amount of time that should elapse between the generation of the message by the transmitter to its reception correctly by the receiver, or more precisely it is the time interval between the packet generation by the on-board device to the time it is received by the road station or vice versa. This includes the sensor (in-vehicle or infrastructure system) activation, hazard interpretation, message creation, and transmission. Allowable latency is especially important in safety applications where it must be very short (milliseconds); since a safety message is useful only for a short period of time and any large delay might not allow the vehicle to respond in time [21]. In order to allow a moving vehicle to establish a connection with other/s vehicles, a certain amount of time is needed and that is called connection set up time. This time is very critical in case of emergency messages since it will be deducted from the time available to send or receive the warning message i.e. reduce the allowable latency. Moreover, due to the fast changing topology of an ad hoc network, any prolongation in this set up time will make the vehicles’ positions update messages useless.
4. **Priority**
Some of the ITS applications are delay-sensitive and hence require some sort of priority mechanism which allows them to have access to the communication channel faster than the others. For example, emergency communications should be given a priority higher than commercial or private applications or offered a special channel or bandwidth reservation. Usually, the priorities of the messages decrease with the increasing transmission distance and the message age. Therefore, local communications messages are given a higher priority than non-local communications ones.

5. **Communication service**
The communication service can be “Connection oriented” where the connection should be set before the information transmission and maintained until its end, or “Connectionless” where each individual message sent from the source contains the destination’s address and reaches the recipient without the need for establishing a channel. However, in connectionless services there is no guarantee of message reception. Therefore, the connectionless communication service can be divided into acknowledged and unacknowledged services. In acknowledged services the transmitter must receive an acknowledgement from the receiver to ensure correct message delivery, where the message is retransmitted in case of a negative acknowledgement or when no acknowledgement is received within a certain time. However, in case of unacknowledged service, since there is no guarantee of message reception and the latency is very low, the message is always repeated to increase the reliability [23]. For safety messages that mostly have a broadcast nature acknowledgement is neither possible nor wanted; but for messages that use point-to-point communication acknowledgement together with re-transmissions can be used to reduce the packet loss rate.

6. **Reliability**
A reliable system necessitates that the network performance covers the predefined range and the data reaches its specified destination with sufficiently low error rate. Reliability becomes very important when dealing with time-critical safety warning messages where error is intolerable [24]. In general, the demand for reliability is higher in data communications than voice communications; if an error occurs in a voice communication it can still be understandable as long as the error is within a certain limit which is not the case with data communication. Since mostly ITS safety applications use wireless communications, they face some challenges that affect their reliability. These challenges are the interference from other sources i.e. natural and man-made, signal fading and multipath effects, and shadowing from tall buildings [17].

7. **Addressing**
This is an important issue especially for applications that require point-to-point communication. Initially, the roadside units must have an IP address to enable the vehicles to transmit their information to the nearest available unit, this information can then be transferred to traffic centres using mobile communication or Internet. For client/server applications like download of digital maps a vehicle needs its own IP address. The addressing requirement is going to be very important in the future implementation of Internet services in ITS applications allowing for example vehicle communication with back office applications through the internet. However, for applications using broadcast communication, there is no need for addressing mechanisms since it
is difficult for the transmitter to know the IP addresses of all the receivers due to the transiency in the relationship established between both [26]. Another kind of addressing is the geo-casting where the transmitted messages are location based addressed; this means the data is delivered to all the vehicles situated inside a particular area.

Addressing in vehicle-to-vehicle communication is influenced by some parameters that govern the behaviour of a node with respect to the whole mobile ad hoc network. These describe how a node starts, joins, separates from, and combines to the network.

### 3.1.2 Traffic Characteristics

In the following part we are going to define and discuss some of the traffic characteristics concerning communication in a vehicular environment. Originally these could also be defined as communication requirements but for the sake of further clarification we listed them under the traffic characteristics category because we think they fit here more. These are defined as follows:

1. **Information transmission control scheme**
   
   This defines the initiation process of the transmission (when the message should be transmitted). It could be an event driven scheme where the transmission is triggered by a certain event e.g. accident and hence the message is only transmitted when necessary; or time driven scheme where the information is sent at regular intervals i.e. periodic such as warning about a work zone in the road [20]. Otherwise it could also be a combination of both i.e. hybrid scheme which means that the information is usually sent in a periodic manner but as soon as a critical event takes place an event driven message is transmitted [21].

2. **Minimum frequency**
   
   This addresses the rate at which the transmission of messages should be repeated or updated (e.g. 1 Hz) [21], and it applies to both event and time driven schemes to determine how fast (in one second) the information should be updated after the first transmission. This repetition is important to keep the message alive for the new vehicles entering the communication range of the sender. It is observable that the update rate is related to the allowable 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.

3. **Transmission content**
   
   This defines the details of the messages to be sent or received needed for the communication such as the vehicle’s position, direction, and acceleration; according to it the message length (e.g. packet size) of the particular application is decided [21]. This message length or size determines the required bandwidth for the individual user (in-vehicle or roadside unit). Depending on this information and its accuracy, the in-vehicle/infrastructure system can help the driver to take the right decision. To meet the low latency requirement, safety messages must always be short.

4. **Bandwidth**
   
   The value of the bandwidth can affect certain parameters in the communication network; these are the number of cars that can use the same channel, the packet size, and the quantity of
information that can be sent. The required collective bandwidth for all users in a specific range can be approximately calculated based on the following parameters: the message update rate, packet size, reliability, distance allotted to a vehicle, communication range, and number of lanes. To get a more exact expression for the collective bandwidth, factors like message latency, the number of event driven applications as well as the number of connection oriented services must be considered. However, the bandwidth should be big enough in order to allow all the participants to communicate even in a high traffic density (traffic jams or queues) where a large number of vehicles can be constrained within the same communication range which will lead to interference when many vehicles attempt to communicate simultaneously.

An important concept to consider here is the data rate which defines the amount of digital data moved from one point to another in a certain time period (usually a second) and its relation to the bandwidth where the bigger the bandwidth, the higher the data rate.

3.1.3 Communication Infrastructure

For the communication infrastructure we followed the same procedure as with the traffic characteristics; where in some texts they refer to the communication infrastructure as a communication requirement, we classified them in a separate category named communication infrastructure. According to our definition for the communication requirements and traffic characteristics, the parameters noted below describe neither how the data should be handled nor the data to be sent (how much).

1. **Communication mode**
   This is divided into three types defining the source and destination of the communication:
   - Infrastructure-to-vehicle (I2V) communication
   - Vehicle-to- Infrastructure (V2I) communication
   - Vehicle-to-vehicle (V2V) communication [21].

   In both I2V and V2I modes, the communication is centralized where there is a central control or administration i.e. fixed infrastructure. This is not the case with the V2V mode, where the vehicles communicate in an *ad hoc* manner i.e. decentralized communication.

   Although sometimes the application may require both I2V and V2I, but when mentioning the communication mode for the applications below, we mention only the one that performs the most important part of the application, for example, in the case of an infrastructure warning approaching vehicles, the communication mode is I2V although V2I is also involved in sending the necessary information from the vehicle to the infrastructure.

   Vehicle-to-infrastructure communication is always point-to-point while infrastructure-to-vehicle can either be point-to-point or point-to-multipoint communication [23].

2. **Communication range**
   Communication range is the maximum distance defined between two communicating units [21]. This is an application requirement, and accordingly it should neither be too small, that some
vehicles will not have the sufficient time to obtain the required information, nor too large, that some vehicles will receive unnecessary information [24]. In general, the communication range should be small in case of traffic jam and large for low traffic density. The range is also related to the radio performance, since a big range allows a larger number of vehicles to communicate, this leads to channel congestion and hence to bad radio performance [24]. For less time-critical applications that have more flexible delay bounds, the communication range can be extended using a multi-hop transfer mechanism. It is also important to consider the type of antenna used, i.e. directional antenna for communication in a specific direction and omni-directional antenna for multiple direction communication.

3.2 Applications Profiles

In the sections below we divide some applications into different profiles with respect to their communication requirements. From this point onwards any mention of communication requirements refers to communication requirements, traffic characteristics, and communication infrastructure. The applications used here represent the list of suggested applications for the projects Cooperative Vehicle Infrastructure Systems (CVIS) and SAFESPOT, as well as some General Active Safety Systems applications, related to but not identical to the applications from the PReVENT project. These are discussed separately in individual sections. CVIS, SAFESPOT and PReVENT are Integrated Projects in the European Community’s Sixth Framework Programme. The European Commission DG Information Society and Media is co-funding these projects.

In order to analyse the applications we adopted a new method for quantifying some of the communication requirements defined above namely, latency, priority, reliability, bandwidth, and communication range. We assigned them values within a certain range i.e. high, medium, and low/short. The latency is divided into very short (up to 100 milliseconds), short (milliseconds to one second), medium (seconds to one minute), and long (minutes). The priority is considered high for hazard information that requires instantaneous response from the driver; and medium for information that requires special attention from the driver but does not pose a potential danger. Other commercial and entertainment information is considered to have low priority. Reliability is classified high for the safety applications that have short latency, medium for non-safety critical traffic information, and low for video and music download (entertainment). The bandwidth considered here is the bandwidth required by the individual user which depends on the message size. Small bandwidth is needed for short safety messages, medium for other traffic related information, and high for multimedia services. The communication range is divided into very short (up to 300 m), short (up to 500 m), medium (few km), and long (more than that).

3.3 General Active Safety Applications

First, we start by listing the applications with their corresponding scenarios and communication requirements. Note that the estimated latency levels and communication range levels are based on
information from the PReVENT project. The following descriptions have been taken from [20] and assumed to be similar to the PReVENT applications.

1. **Approaching Emergency Vehicle Warning**
   Here the emergency vehicle warns other vehicles to give it the right of the way. The emergency vehicle broadcasts its information and the other vehicles respond accordingly.
   
   Communication requirements:
   - Vehicle-to-vehicle communication
   - One-way communication
   - Real-time transmission
   - Point-to-multipoint communication
   - Event driven
   - Latency: low
   - Reliability: high
   - Priority: high
   - Bandwidth: small
   - Data content: position, lane information, speed, intended route
   - Communication range: very short

2. **Emergency Vehicle Signal Pre-emption**
   This application is similar to the previous one with the exception that the emergency vehicle requests the right of the way from the infrastructure unit (traffic light controller). The infrastructure ensures the authorization of the requestor through negotiation.
   
   Communication requirements:
   - Vehicle-to-infrastructure communication
   - Two-way communication
   - Real-time transmission
   - Point-to-point communication
   - Event driven
   - Latency: low
   - Reliability: high
   - Priority: high
   - Bandwidth: short
   - Data content: position, speed, direction, and intended route
   - Communication range: medium

3. **Cooperative Collision Warning**
   In this application the vehicles have got the ability to exchange information concerning their location, position, speed, etc. Each vehicle uses this information in accordance with its own to warn the drivers of a possible collision.
   
   Communication requirements:
   - Vehicle-to-vehicle communication
   - One-way communication
   - Real-time transmission
• Point-to-multipoint communication
• Periodic
• Latency: very low
• Reliability: high
• Priority: high
• Bandwidth: short
• Data content: velocity, acceleration, heading, and yaw rate
• Communication range: very short

4. **Highway/Rail Collision Warning**
This application prevents the collision between vehicles and trains on railway/highway intersections. It could be implemented in two ways either using vehicle-to-vehicle or infrastructure-to-vehicle communication. In case of vehicle-to-vehicle communication, the vehicles exchange the relevant information directly with the train; while in infrastructure-to-vehicle, the information is acquired from a roadside unit near the intersection.

Communication requirements:
• Vehicle-to-vehicle or infrastructure-to-vehicle communication
• One-way communication
• Real-time transmission
• Point-to-multipoint communication
• Event driven or periodic
• Latency: low
• Reliability: high
• Priority: high
• Bandwidth: short
• Data content: position, heading, and velocity
• Communication range: very short

5. **Vehicle-Based Road Condition Warning**
The vehicles detect the road condition using on-board systems and broadcast a warning message if needed, to other vehicles.

Communication requirements:
• Vehicle-to-vehicle communication
• One-way communication
• Real-time transmission
• Point-to-multipoint communication
• Event driven
• Latency: low
• Reliability: high
• Priority: high
• Bandwidth: short
• Data content: position, heading, road condition parameters
• Communication range: very short
6. **Post-Crash Warning**
In case of vehicle breakdown or damage due to an accident, the vehicle starts broadcasting information regarding its position, heading, and status to approaching vehicles. This application is of more benefit in case of poor visibility and bad weather conditions.

Communication requirements:
- Vehicle-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication
- Event driven
- Latency: low
- Reliability: high
- Priority: high
- Bandwidth: short
- Data content: position, heading, and vehicle status
- Communication range: very short

7. **Lane Change Assistance**
During their motion, 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.

Communication requirements:
- Vehicle-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication
- Periodic
- Latency: very low
- Reliability: high
- Priority: high
- Bandwidth: short
- Data content: heading, position, velocity, acceleration, and turn signal status
- Communication range: very short

8. **Blind-Spot Warning**
Through sharing the information periodically, the vehicles help each other to provide a warning to the driver if he intended to make a lane change during the presence of a car in his blind spot area.

Communication requirements:
- Vehicle-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication
- Periodic
- Latency: low
• Reliability: high
• Priority: high
• Bandwidth: short
• Data content: position, velocity, heading, acceleration, and turn signal status
• Communication range: very short

9. **Cooperative Glare-Reduction**
This application helps vehicles adjusting their light beam automatically according to the position of the vehicle in front. Vehicles exchange their information through broadcasting.

Communication requirements:
• Vehicle-to-vehicle communication
• One-way communication
• Real-time transmission
• Point-to-multipoint communication
• Periodic
• Latency: very low
• Reliability: high
• Priority: high
• Bandwidth: short
• Data content: position, heading, and velocity
• Communication range: short

10. **SOS Services**
This application is initiated instantly after an accident or other life-threatening situation. The affected vehicle sends an emergency message to an infrastructure unit which forwards it to the local authority to offer help.

Communication requirements:
• Vehicle-to-infrastructure communication
• One-way communication
• Real-time transmission
• Point-to-multipoint communication
• Event driven
• Latency: low
• Reliability: high
• Priority: high
• Bandwidth: short
• Data content: position, vehicle status and description, and time
• Communication range: very short

11. **Work Zone Warning**
Here the infrastructure broadcasts warning messages to vehicles approaching work zone areas.

Communication requirements:
• Infrastructure-to-vehicle communication
• One-way communication
• Real-time transmission
• Point-to-multipoint communication
• Periodic
• Latency: low
• Reliability: high
• Priority: high
• Bandwidth: short
• Data content: direction to work zone and reduced speed limit
• Communication range: very short

12. Pedestrian Crossing-Information
Whenever a pedestrian is present at a crossing area (walk button pressed), the infrastructure broadcasts a message to approaching vehicles informing them about the situation to help avoid collision.

Communication requirements:
• Infrastructure-to-vehicle communication
• One-way communication
• Real-time transmission
• Point-to-multipoint communication
• Event
• Latency: low
• Reliability: high
• Priority: high
• Bandwidth: short
• Data content: presence of a pedestrian
• Communication range: very short

13. Road Condition Warning
In this application the road condition warning is provided through the use of the infrastructure. The infrastructure unit will be fixed near the points that practice more road conditions change than others that is bridge, low point, etc.

Communication requirements:
• Infrastructure-to-vehicle communication
• One-way communication
• Real-time transmission
• Point-to-multipoint communication
• Event driven
• Latency: low
• Reliability: high
• Priority: high
• Bandwidth: short
• Data content: road condition warning message
14. **Intersection Collision Warning**

The roadside unit connected with a radar, sensor, and camera has the ability to detect all the vehicles approaching the intersection. Using the acquired information from the vehicles, the infrastructure can estimate the possibility of a collision and hence inform the in-vehicle system which in turn warns the driver.

Communication requirements:
- Infrastructure-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication
- Periodic
- Latency: very low
- Reliability: high
- Priority: high
- Bandwidth: short
- Data content: traffic signal status, timing, directionality, road shape, intersection information, vehicle position, velocity, and heading
- Communication range: very short

One can notice that different applications have different communication requirements. This is due to the fact that the information exchanged between the vehicles and roadside units has vastly different characteristics owing to its nature. Hence, each application has different communication requirements depending on the information needed to be exchanged, for example, the acceptable delay for the Road Condition Warning application is not like the one for Lane Change Assistance application.

For all the applications mentioned, the most common communication requirements are very low or low latency i.e. in the order of milliseconds, communication range (up to 1000m), real-time transmission, point-to-multipoint communication, one-way communication, high priority, high reliability, and short bandwidth.

Table 3.1 below summarizes all these applications associated with their communication requirements. The profiling of these applications is described in table 3.2 followed by their description in subsection 3.3.1.
### General Active Safety Systems applications

<table>
<thead>
<tr>
<th>Application</th>
<th>V2V/I2V</th>
<th>Directionality</th>
<th>Transmission Scheme</th>
<th>Event/Periodic</th>
<th>Latency (ms)</th>
<th>Reliability</th>
<th>Priority</th>
<th>Bandwidth</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approaching Emergency Vehicle Warning</td>
<td>V2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Event</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Emergency Vehicle Signal Pre-emption</td>
<td>V2I</td>
<td>Two-way real-time</td>
<td>Point-to-Point</td>
<td>Event</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Medium</td>
</tr>
<tr>
<td>Cooperative Collision Warning</td>
<td>V2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Periodic</td>
<td>Very low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Highway/Rail Collision Warning</td>
<td>V2V/12V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Event/Periodic</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Vehicle-Based Road Condition Warning</td>
<td>V2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Event</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Post-Crash Warning</td>
<td>V2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Event</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Lane Change Assistance</td>
<td>V2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Periodic</td>
<td>Very low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Blind-Spot Warning</td>
<td>V2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Periodic</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Cooperative Glare-Reduction</td>
<td>V2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Periodic</td>
<td>Very low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Short</td>
</tr>
<tr>
<td>SOS Services</td>
<td>V2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Event</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Work Zone Warning</td>
<td>I2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Periodic</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Pedestrian Crossing-Information</td>
<td>I2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Event</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Road Condition Warning</td>
<td>I2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Event</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
<tr>
<td>Intersection Collision Warning</td>
<td>I2V</td>
<td>One-way real-time</td>
<td>Point-to-multipoint</td>
<td>Periodic</td>
<td>Very low</td>
<td>High</td>
<td>High</td>
<td>Small</td>
<td>Very short</td>
</tr>
</tbody>
</table>

*Table 3.1. General Active Safety Systems Applications and their communication requirements*
### General Active Safety Systems applications’ profiling

<table>
<thead>
<tr>
<th>Profile</th>
<th>V2V/I2V</th>
<th>Directionality</th>
<th>Transmission scheme</th>
<th>P2P/ P2multipoint</th>
<th>Event/ Periodic</th>
<th>Latency (ms)</th>
<th>Reliability</th>
<th>Priority</th>
<th>Bandwidth</th>
<th>Range (m)</th>
<th>Applications</th>
</tr>
</thead>
</table>
| A       | V2V     | One-way        | Real time           | P2multipoint      | Event           | Low          | High        | High     | Small     | Very short | 1. Approaching emergency vehicle warning  
         |         |                |                     |                   |                 |              |            |          |           |           | 2. Highway/Rail collision warning  
         |         |                |                     |                   |                 |              |            |          |           |           | 3. Vehicle-based road condition warning  
         |         |                |                     |                   |                 |              |            |          |           |           | 4. Post-Crash warning |
| B       | V2V     | One-way        | Real time           | P2multipoint      | Periodic        | Very low     | High        | High     | Small     | Short     | 1. Cooperative collision warning  
         |         |                |                     |                   |                 |              |            |          |           |           | 2. Lane change assistance  
         |         |                |                     |                   |                 |              |            |          |           |           | 3. Blind-spot warning  
         |         |                |                     |                   |                 |              |            |          |           |           | 4. Cooperative glare warning |
| C       | I2V     | One-way        | Real time           | P2multipoint      | Periodic        | Low          | High        | High     | Small     | Very short | 1. Work zone warning  
         |         |                |                     |                   |                 |              |            |          |           |           | 2. Intersection collision warning |
| D       | V2I     | Two-way        | Real time           | Point-to-point    | Event           | Low          | High        | High     | Small     | Medium    | 1. Emergency vehicle signal pre-emption |
| E       | V2I     | One-way        | Real time           | P2multipoint      | Event           | Very low     | High        | High     | Small     | Short     | 1. SOS services |
| F       | I2V     | One-way        | Real time           | P2multipoint      | Event           | Low          | High        | High     | Small     | Very short | 1. Road condition warning  
         |         |                |                     |                   |                 |              |            |          |           |           | 2. Pedestrian crossing information |

*Table 3.2. General Active Safety Systems Applications profiles and their communication requirements*
3.3.1 Profiles Description

These profiles have been based on the main idea of the similarity in the communication requirements of the applications, i.e. the more the applications are similar in their communication requirements the more they fit together in one profile. The differences between the profiles are very slight which appear mainly in the communication mode (V2V, V2I, and I2V), directionality (one-way/two-way communication), and the information transmission control scheme (periodic/event driven). These differences can be verified through the following:

The main difference between profiles A and B is that A is event driven and B is periodic. If not for this difference they can be joined together in one profile. This applies also for C and E where they differ in the transmission control scheme. For D and F the main difference is in the directionality, where D is two-way communication and F is one-way communication.

Generally all these profiles describe applications that are safety or safety related which explains the observed similarity in their communication requirements. Therefore, they can all be contained in one big profile titled “safety applications profile”. Since all these profiles have been made with the aim of matching them to the suitable wireless carriers, it can be that only one carrier can satisfy all these profiles provided that it can support the slight differences in the communication requirements between them. This is to be investigated later in this study.

3.4 Cooperative Vehicle Infrastructure Systems (CVIS) Applications

This project will evaluate nine applications in three domains. These domains are: urban area, inter-urban area, freight and fleet and public transport managers. Cooperative here means that the systems can exchange real time messages in a decentralised manner to obtain the current traffic state and give the driver the appropriate advice to avoid accidents [28].

The next section discusses these applications together with their communication requirements. An important thing to mention is that extracting the communication requirements for the General Active Safety Systems was easier since the applications were more specific and well defined. However, this is not the case with the CVIS project because some applications define an area of services which can contain several applications inside and hence different values for some of the communication requirements e.g. short and medium. The communication requirements mentioned are a rough preliminary estimate obtained from the introductory project documents available at the moment.

3.4.1 Cooperative Urban Applications (CURB)

1. Cooperative network management
The control horizon is 5-60 minutes and the control area is a city or urban area. The aim is to optimize the vehicle traffic management using vehicle/driver destination information and other characteristics and also to individualise route guidance.
The steps needed to realize cooperative network management are described as follows. First the cooperative monitoring (COMO) information is sent to the central CURB service periodically to update an Origin/Destination data structure. Next, an external traffic model is used to estimate the traffic flows, which is then compared to the current traffic management strategy in order to obtain the best management scenario to be used. The selected scenario is transformed into sets of control rules for the lower layers in the network management system (sub areas, clusters of controllers, intersections) and also into sets of matching information rules for the communication with road users. According to the generated control and communication rules, messages could alternatively be broadcasted to the vehicles or sent specifically (narrowcast) to certain vehicles that have the same profile, such as specific location, destination, and type.

Communication requirements:
- Infrastructure-to-vehicle communication
- One-way communication
- Real-time and storage transmission
- Point-to-multipoint communication
- Periodic
- Latency: long (minutes)
- Reliability: medium
- Priority: medium
- Bandwidth: large (digital map for route guidance)
- Data content: vehicle’s destination, individualise route guidance
- Communication range: city or urban area (long)

When trying to analyse this application to deduce the communication requirements and specially the latency and the communication range there are two perspectives. One is to consider the whole application’s processes and hence the latency is denoted by the control horizon and the communication range by the control area. The other is to consider only the last process in the application which deals with communication between the infrastructure (controller) and the vehicles, where the latency is medium (seconds) and the communication range is short to medium. For the sake of completion we chose the first perspective.

2. **Cooperative area routing**

The control horizon is 1-5 minutes and the control area is a sub-area controlled by a limited number of roadside systems. Intersection traffic controllers receive information about their area and warn upstream controllers in case of capacity limitation. When the approaching vehicles send their characteristics and intended destination to the controller, the traffic controller calculates the new route advice (route via less affected part of the network) for them. Further characteristics are needed for appropriate routing of the vehicles to e.g. avoid routing a heavy vehicle to an unsuitable road. The intended destination is also needed for giving the vehicle the relevant route.

Communication requirements:
- Infrastructure-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication
3. **Cooperative local traffic control**

The control horizon is 0.1 second -1 minute and the control area is an area controlled by one roadside controller. The vehicles transmit their speed, characteristics, and destination to the intersection traffic controller; then the controller decides when to change the traffic lights depending on the information received from the vehicles. The controllers can also warn the vehicles of a high speed vehicle in the other direction that may not be able to stop in time. In addition, the controller can inform vehicles of expected services such as traffic light changing. Further, vehicles can also be informed about the optimum speed for their road and next road segment.

**Communication requirements:**
- Infrastructure-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication
- Event driven
- Latency: short (warning of high speed vehicle in the other direction) and medium
- Reliability: high and medium
- Priority: high and medium
- Bandwidth: small and medium
- Data content: vehicle characteristics, speed, acceleration, braking capacity, direction and priority, warning, traffic light status and optimum speed
- Communication range: an area controlled by one roadside unit (short)

4. **Cooperative Flexible Lane allocation**

The control horizon is 1 second to 1 minute and the control area is an area controlled by at least two roadside controllers. The idea is to increase the capacity of road infrastructure by making a dedicated bus lane available to licensed and CVIS equipped vehicles moving in the same direction. This will enable the vehicles to use the same bus lane after as long as they do not disturb the public transport and satisfy the requirements of speed, punctuality, and economy. This is done through vehicles interrogation by bus infrastructure. Using the cooperative system, the public transport vehicle forms a “clear space” ahead of it (virtual block). In case of no clear space request, licensed vehicles can use the lane; otherwise the CVIS equipped bus will broadcast periodic “leave bus lane” messages to them. On the other hand, when the Access Control Infrastructure obtains information about an approaching bus, it will inform vehicles using the bus lane to exit and others not to enter.
Collaborating vehicles for increased traffic safety

Communication requirements:
- Infrastructure-to-vehicle and vehicle-to-vehicle communication
- One/two-way communication (two-way for interrogating vehicles)
- Real-time transmission
- Point-to-multipoint communication
- Event driven
- Latency: medium (1 second to 1 minute)
- Reliability: high
- Priority: high
- Bandwidth: small
- Data content: traffic condition, prioritization, leave bus lane message
- Communication range: short

3.4.2 Cooperative Inter-Urban Applications

1. Enhanced driver awareness (EDA)
Most of the accidents today happen due to the fact that the drivers are not fully aware of the situation they are driving in. Therefore, it is important to inform the drivers about, for example, the road, weather, and traffic conditions as well as prevailing traffic regulations in their area. This will be done in a continuous manner either from road operators or other vehicles in vicinity. The driver will also be warned if he does not follow the traffic rules. One of the applications is SPEED ALERT, where the driver is informed when he exceeds the predefined speed limit. It is also possible to inform the driver about the parking regulations in certain places. In case Adaptive Driver Assistance (ADA) in-car systems are used, the system can also benefit from the information about the traffic regulations.

Communication requirements:
- Infrastructure-to-vehicle and vehicle-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication
- Event driven or periodic
- Latency: short and medium
- Reliability: high and medium
- Priority: high and medium
- Bandwidth: short and medium
- Data content: weather, road, traffic conditions, traffic regulations, and hazards
- Communication range: short

2. Cooperative Travellers’ Assistance (CTA)
The aim here is to supply the travellers with general information about the traffic state (congestion size, incidents, and travel times delays) on an individual basis, for example, to give strong wind conditions to campers and bridge weight limitations to big transports. Moreover, travel times maybe provided according to the driver and vehicle type. First, the vehicles
(travellers) send their data to the Traffic Control Centre which passes it to the Service Centre. The Service Centre has the current traffic state and gives the information to the drivers accordingly. The service centre will send the information to the vehicles using the CVIS communication technologies.

Communication requirements:
- Infrastructure (control centre or service centre)-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-point communication
- Event driven or periodic
- Latency: long
- Reliability: medium
- Priority: medium
- Bandwidth: medium
- Data content: vehicles data, speed, position, direction, destination etc,
- Communication range: long

3.4.3 Cooperative fleet and freight applications

The applications here are developed to increase security in the transport of dangerous goods and reduce the risk of vehicle breakdown inside sensitive areas.

1. Dangerous goods monitoring and dynamic route guidance
The objective of this application is to make dangerous goods transportation safe. Previous work in this field is the Swedish FARGO project. The system will work in a cooperative manner so that the navigation, monitoring, and control become more efficient, safer and more flexible than the stand-alone system. A specific scenario is when the goods move through different countries, and hence the responsibility is shifted from one local authority to another. The vehicles transmit their location and intended destination to the local traffic management centre. In case of receiving a location outside the area of the current monitoring centre, it will inform the vehicles about which monitoring centre to contact next. When an accident is reported from a vehicle, information about the last position and type of goods will be sent to the rescue personnel.

In route guidance, the vehicle sends a request about the recommended route to the navigation centre. Depending on the information received from the vehicle such as vehicle characteristics, height, width, length and others, the server calculates the best route. In case of an accident along the selected route, the server re-calculates the route and updates the vehicle with the new recommended route.

Communication requirements:
- Vehicle-to-infrastructure (local traffic management centre) in goods monitoring and infrastructure (navigation centre)-to-vehicle in route guidance
- One-way communication
- Real-time transmission
- Point-to-point communication
• Periodic or event driven
• Latency: long
• Reliability: medium
• Priority: high (in case of accident) and medium
• Bandwidth: medium
• Data content: vehicle characteristics, speed, acceleration, position and intended destination, last position, type of goods, height, width, length
• Communication range: long

2. **Dynamic booking and monitoring of loading bays and highway resting areas**
Assigning parking zones to trucks is different than to private cars due to the different physical facilities. CVIS considers two types of parking zones one for loading or unloading goods (loading bay) and the other for the driver’s resting period required by law (Highway resting areas). In advance planning booking and monitoring of loading bays is important to achieve a reliable and timely access to the road networks since they are often in urban areas where business premises are very close to the roads. For Highway resting areas, the law requires the driver to have a certain rest time; this is difficult in case of busy traffic which could consequently lead to illegal parking or overcrowded rest areas and hence affects road safety. Therefore, in advance planning of a trip including the rest areas would be important. The application aims to improve freight delivery and reduce congestion by allowing vehicles to make parking bookings in advance. The vehicles transmit their identity, freight type, estimated delivery time, and delivery location to the central booking system. The booking system replies with parking zone location and time slot, where access to the parking zone can be controlled by automatic gates. The monitoring of the vehicle can be continued until the vehicle leaves the parking zone.

Communication requirements:
• Infrastructure (central booking system)-to-vehicle communication
• One-way communication
• Real-time transmission
• Point-to-point communication
• Event driven
• Latency: long
• Reliability: medium
• Priority: medium
• Bandwidth: medium
• Data content: vehicle characteristics, identity, freight type, estimated delivery time, delivery location, parking location and available time slot
• Communication range: long

3. **Vehicle access control for sensitive zones**
Nowadays there is a need to define some sensitive zones such as school and hospital surroundings inside the city and road sensitive infrastructures like bridges and tunnels. These predefined sensitive areas can then be controlled for safety and traffic management purposes. The communication is initiated between the vehicles and the infrastructure as soon as the vehicles enter the monitored area around the sensitive areas. The vehicles send their data to be processed
by the control centre, which admits or denies access to the sensitive area. The control centre makes the decision depending on e.g., the vehicle diagnostics, driving style, and traffic condition inside the sensitive zone.

Communication requirements:
- Infrastructure-to-vehicle communication
- Two-way communication
- Real-time transmission
- Point-to-point communication
- Event driven
- Latency: medium
- Reliability: medium
- Priority: medium
- Bandwidth: medium
- Data content: vehicle’s diagnostic status, driver behaviour, and denial or admittance to sensitive zone
- Communication range: medium (since the vehicle/infrastructure needs to be informed before enough distance)

Table 3.3 next describes all the CVIS applications together with their communication requirements. It is followed by table 3.4 that contains the suggested profiles these applications. In both tables the letters L, M, H, and S define the values of latency, reliability, priority, and bandwidth where L stands for Long, M for Medium, H for high, and S for both Small (bandwidth) and Short (latency, range). Short latency is in the range of milliseconds to one second, medium (seconds to one minute), and long (minutes). Priority is high for hazard information that requires instantaneous response from the driver, medium for information that requires special attention from the driver but does not pose a potential danger, and low for other commercial and entertainment information. Reliability is classified high for the safety applications that have short latency, medium for non-safety critical traffic information, and low for video and music download (entertainment). Small bandwidth is needed for short safety messages, medium for other traffic related information, and high for multimedia services. The communication range is divided into short (up to 1000m), medium (few km), and long (more than that). Each profile is then described in details in subsection 3.4.5.
## CVIS applications

<table>
<thead>
<tr>
<th>Applications</th>
<th>V2V/I2V</th>
<th>Directionality</th>
<th>Transmission scheme</th>
<th>P2P/ P2multipoint</th>
<th>Event/ periodic</th>
<th>Latency</th>
<th>Reliability</th>
<th>Priority</th>
<th>Bandwidth</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative network management</td>
<td>I2V</td>
<td>One-way</td>
<td>Real-time/ storage</td>
<td>Point-to-multipoint</td>
<td>Periodic</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Cooperative area routing</td>
<td>I2V</td>
<td>One-way</td>
<td>Real-time</td>
<td>Point-to-multipoint</td>
<td>Event/ periodic</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Cooperative local traffic control</td>
<td>I2V</td>
<td>One-way</td>
<td>Real-time</td>
<td>Point-to-multipoint</td>
<td>Event</td>
<td>S/M</td>
<td>H/M</td>
<td>H/M</td>
<td>S/M</td>
<td>S</td>
</tr>
<tr>
<td>Enhanced driver awareness</td>
<td>I2V/ V2V</td>
<td>One-way</td>
<td>Real-time</td>
<td>Point-to-multipoint</td>
<td>Event/ periodic</td>
<td>S/M</td>
<td>H/M</td>
<td>H/M</td>
<td>S/M</td>
<td>S</td>
</tr>
<tr>
<td>Cooperative traveller’s assistance</td>
<td>I2V</td>
<td>One-way</td>
<td>Real-time</td>
<td>Point-to-point</td>
<td>Event/ Periodic</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Dangerous goods monitoring and dynamic route guidance</td>
<td>V2I/ I2V</td>
<td>One-way</td>
<td>Real-time</td>
<td>Point-to-point</td>
<td>Event/ Periodic</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Dynamic booking and monitoring of loading bays and highway</td>
<td>I2V</td>
<td>One-way</td>
<td>Real-time</td>
<td>Point-to-point</td>
<td>Event</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>resting areas</td>
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<tr>
<td>Vehicle access control for sensitive zones</td>
<td>I2V</td>
<td>Two-way</td>
<td>Real-time</td>
<td>Point-to-point</td>
<td>Event</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Cooperative Flexible Lane allocation</td>
<td>I2V/ V2V</td>
<td>One/two way</td>
<td>Real-time</td>
<td>Point-to-multipoint</td>
<td>Event</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>S</td>
<td>S</td>
</tr>
</tbody>
</table>

*Table 3.3. CVIS Applications and their communication requirements*
### CVIS Profiling

<table>
<thead>
<tr>
<th>Profile</th>
<th>A2V/I2V</th>
<th>Directionality</th>
<th>Transmission scheme</th>
<th>P2P/ P2multipoint</th>
<th>Event/ Periodic</th>
<th>Latency</th>
<th>Reliability</th>
<th>Priority</th>
<th>Bandwidth</th>
<th>Range (m)</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>I2V</td>
<td>One-way</td>
<td>Real time</td>
<td>P2multi point</td>
<td>Event/ periodic</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M/ L</td>
<td>1. Cooperative network management 2. Cooperative area routing</td>
</tr>
<tr>
<td>D</td>
<td>I2V</td>
<td>Two-way</td>
<td>Real time</td>
<td>P2P</td>
<td>Event</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>1. Vehicle access control for sensitive zones</td>
</tr>
</tbody>
</table>

*Table 3.4. CVIS Applications profiles and their communication requirements*
3.4.4 Profile Description

Again these profiles have been based on the same idea of similarity between the applications in their communication requirements which has been used before with the General Active Safety Systems applications. Unlike those applications, the applications in CVIS include a wide area of services covering safety, driver awareness, and traveller information. It can be noticed that in some profiles, some requirements have more than one value and this basically arises from the applications themselves. The other reason for this is that as long as the differences between the applications requirements are not very big, we have tried to fit them together in the same profile.

It should be pinpointed that although the applications in CVIS project are initially divided into three domains depending on the application’s area of service, when considered from the communication requirements point of view, applications from different domains fell in the same profile.

Profile A contains service applications that require a long communication range and communication with central office. The communication between the office and the vehicle is achieved in a point-to-point manner in order to support the vehicle with individualized information.

Profile B contains three applications – two of them involve communication with a local infrastructure which are the Cooperative Local Traffic Control and Cooperative Flexible Lanes allocation requiring short communication range. The third application, Enhanced Driver Awareness, does not need to communicate with a specific local infrastructure, it involves both vehicle-to-vehicle and infrastructure-to-vehicle communication all along the road. However, it has been included in this profile since it shares the rest of the requirements with the other two applications.

Profile C contains two applications that aim for traffic management. They require I2V communication with long latency, medium reliability and priority, and medium to long communication range.

Profile D contains one application that involves I2V communication with two-way communication needed to initiate a negotiation with the vehicle. It requires also point-to-point communication, medium reliability and priority, small and medium bandwidth, as well as short and medium latency and range.

3.5 SAFESPOT Applications

The new approach in the SAFESPOT project is the cooperation between the vehicle and the infrastructure in order to give the drivers an extended vision of their surrounding and hence having enough time to respond to emergency situations. The main idea is to define the “safety margin” which the vehicle always has to be inside. This is defined according to the information collected by the vehicles and the infrastructure. Both the vehicles and the infrastructure are
equipped with intelligence devices to exchange the information between vehicles (vehicle-to-vehicle), in-between the infrastructure (infrastructure-to-infrastructure), and between vehicles and infrastructures (vehicle-to-infrastructure). The applications could be vehicle based or infrastructure based. The two categories are described below [15].

In some applications the communication range has been estimated to have the same value as the corresponding one in the General Active Safety Systems section and that is due to the applications being similar.

3.5.1 Cooperative Safety Systems Infrastructure Based

In these applications warnings and other information regarding safety conditions will be provided by the roadside elements. This will be a significant first step towards a cooperative system since most of the vehicles are not equipped and it is important to include the other road users such as, pedestrian, bicycles, and motorbikes. Here is the main application focus.

1. Smart signalling for safety enhancement
In some cases, the driver needs some safety-related information for accident avoidance. This information includes weather conditions, traffic conditions, infrastructure elements such as bridges and tunnels, slopes and curves, and similar. Providing this information from infrastructure with cooperation with on-board units in vehicles will allow drivers to take the appropriate action in advance leading to a reduction of the number of accidents.

   Communication requirements:
   - Infrastructure-to-vehicle communication
   - One-way communication
   - Real-time transmission
   - Point-to-multipoint communication
   - Event driven or periodic
   - Latency: short
   - Reliability: high
   - Priority: high
   - Bandwidth: small
   - Data content: weather condition, traffic condition, and presence of tunnel, bridge etc
   - Communication range: short

2. Hazard and Incident Warning
This application is important in black spot areas, i.e. critical road areas such as dangerous bends (static black spot), accidents or road work (dynamic black spot). The information will be sent by the infrastructure with the help of in-vehicle units. The messages to be sent should contain all the needed information such as the type of the hazard, its location, and the recommended speed at that particular case. First, a vehicle detecting the hazard will send a message to the roadside unit and then the infrastructure will warn all vehicles approaching that area. The in-vehicle device will then process the message and inform the driver accordingly.
Collaborating vehicles for increased traffic safety

Communication requirements:
- Infrastructure-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication
- Event driven
- Latency: short
- Reliability: high
- Priority: high
- Bandwidth: small
- Data content: type of the hazard, its location, and recommended action to be taken
- Communication range: 300 m (short)

3. **Safe Urban intersection**
An intersection is considered one of the most dangerous places in urban areas. Therefore, special care should be given to it in order to reduce the number of accidents and mitigate the collisions. The infrastructure (road light controllers) will provide information to the drivers based on the collected data such as location, speed, and direction of the vehicles with the use of intersection topology. The drivers will be informed about dangerous situations where, for example, a vehicle in the other direction will not be able to stop due to its high speed, or if the driver does not follow the traffic rules. Moreover, information about recommended brake, acceleration, and speed could be sent with the possibility to inform non-equipped vehicles and other road users (walking people and cyclists). For the traffic controller to provide valuable information it is important to have local digital maps of the intersection with a map of all the vehicles.

Communication requirements:
- Infrastructure-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication
- Event driven
- Latency: short
- Reliability: high
- Priority: high
- Bandwidth: small
- Data content: vehicle speed, location, direction, and recommended action to be taken
- Communication range: 300 m (short)

4. **Speed alert and road departure prevention**
A large number of road fatalities are attributed to Road departure. The approach here is that the Infrastructure Information System (IIS) will update the digital road map segment according to dynamic information received from vehicles and infrastructures so that the vehicles in turn can update their map. In speed alert, the infrastructure calculates the maximum speed based on the current situation of the traffic and weather. Two systems could use this information, namely the informative system (display on a dash board or using audio warning) and the active system
(adaptive cruise control or automatic braking). This will lead to optimization of the speed for different vehicles in different situations and thereby reduction of congestion and fatalities. In road departure prevention, the static digital map onboard will be updated (from IIS) with dynamic information regarding weather and road conditions.

Communication requirements:
- Infrastructure-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication and point-to-point communication (digital map update)
- Event driven or periodic
- Latency: medium
- Reliability: medium
- Priority: medium
- Bandwidth: medium
- Data content: vehicle dynamic state, i.e., position, max speed, and digital map
- Communication range: 300 m (short)

5. Safety margin for assistance and emergency vehicles
Assistance vehicles (ambulance, fire brigade) and emergency vehicles (snow-removal, patrollers) have high priority and must get special care in order to protect both of them and other vehicles. These vehicles can send valuable information concerning their status, such as their position and if they are stationary or moving, to the infrastructure and other vehicles. Depending on the current situation, the infrastructure could provide dynamic support to vehicles in order to warn them or advice them with suitable recommendations.

In case of emergency vehicles, they can send information to the infrastructure about their route so that the infrastructure can warn other vehicles in the vicinity. This reduces the time for both collecting and broadcasting traffic data.

Communication requirements:
- Infrastructure-to-vehicle and vehicle-to-infrastructure communication
- One-way and two-way communication
- Real-time transmission
- Point-to-multipoint and point-to-point communication
- Event driven
- Latency: short
- Reliability: high
- Priority: high
- Bandwidth: small
- Data content: vehicle state (speed, position, moving or stationary and intended route), warning or recommended action to be taken
- Communication range: 1000 m (short)
3.5.2 Cooperative Systems Applications Vehicle Based

These applications are based on the vehicle in terms of being dependant on the onboard device to take the decision with some help from the infrastructure. The applications are developed in three main areas namely, Generic road, Critical road segment (tunnel, bridge), and Black spot (junction, sharp bend and road work). This is because these areas constitute some dangerous situations that may lead to accidents.

1. **Safe lane change manoeuvre**
   The conditions on generic roads are not always safe, especially in the Nordic countries where roads could be slippery. For this reason it is important to equip the vehicle with sensors that inform the driver about the road friction for safe lane changing.
   Communication requirements:
   - Vehicle-to-vehicle communication
   - One-way communication
   - Real-time transmission
   - Point-to-multipoint communication
   - Periodic
   - Latency: short
   - Reliability: high
   - Priority: high
   - Bandwidth: small
   - Data content: road condition (friction)
   - Communication range: 100 m (short)

2. **Frontal collision warning**
   In case of the risk of a frontal collision due to dynamic events, the vehicles will inform each other and the local infrastructure about their position and other obstacles along the road. This will help approaching vehicles to reduce their speed to avoid the collision.
   Communication requirements:
   - Vehicle-to-vehicle and Infrastructure-to-vehicle communication
   - One-way communication
   - Real-time transmission
   - Point-to-multipoint communication
   - Event driven
   - Latency: short
   - Reliability: high
   - Priority: high
   - Bandwidth: small
   - Data content: vehicles position, vehicles dynamics, presence of obstacles
   - Communication range: 300 m (short)
3. **Cooperative situation awareness**
Most of the accidents today happen because the drivers do not have enough information about their surrounding area. In this application, the information about critical events such as rear-end collision and vehicles in blind spots of a truck will be provided to the drivers in time so that the drivers can be aware of them and respond to them in the right way.

   Communication requirements:
   - Vehicle-to-vehicle communication
   - One-way communication
   - Real-time transmission
   - Point-to-multipoint communication
   - Event driven or periodic
   - Latency: short
   - Reliability: high
   - Priority: high
   - Bandwidth: small
   - Data content: vehicles position, vehicles dynamic state
   - Communication range: 300 m (short)

4. **Cooperative tunnel safety**
On entering the tunnel a truck is given specific safety-related information. The driver is also provided with a recommended speed to keep a safe distance with the surrounding traffic. This safety margin varies according to the state of the truck such as type and load. Other vehicles will also be updated about the truck status to adapt their speed accordingly.

   Communication requirements:
   - Vehicle-to-vehicle and infrastructure-to-vehicle communication
   - One-way communication
   - Real-time transmission
   - Point-to-multipoint communication
   - Event driven or periodic
   - Latency: short
   - Reliability: high
   - Priority: high
   - Bandwidth: small
   - Data content: truck position, truck load, truck speed, vehicles dynamic
   - Communication range: short

5. **Cooperative vulnerable road user detection**
The vehicles will cooperate to inform each other about vulnerable road user e.g. pedestrian in static black spot areas such as intersections. This will allow avoiding accidents related to vulnerable road users.

   Communication requirements:
   - Vehicle-to-vehicle communication
   - One-way communication
   - Real-time transmission
6. **Road condition status information**

Giving the drivers information about road conditions is also of considerable importance. This information will be collected by the equipped sensors and processed to warn the driver about the critical road conditions. The vehicles can also communicate with each other and with infrastructure to share this information.

Communication requirements:

- Vehicle-to-vehicle and vehicle-to-infrastructure communication
- One-way communication
- Real-time transmission
- Point-to-multipoint communication
- Periodic
- Latency: short
- Reliability: high
- Priority: high
- Bandwidth: small
- Data content: road conditions
- Communication range: 300 m (short)

7. **Cooperative anti-rollover**

This application is developed for dangerous bends where the vehicle must maintain its speed below the excessive speed limit to avoid rollover. The system is capable of predicting the rollover risk through calculations built on information about the road-geometry, obtained by the on-board navigation system or dynamics relative maps provided by V2V or V2I communication, and the load of the vehicle and hence to decide if the vehicle’s speed is exceeding the limit or not.

Communication requirements:

- Vehicle-to-vehicle or Infrastructure-to-vehicle communication
- One-way communication
- Real-time transmission
- Point-to-multipoint and point-to-point communication
- Event driven or periodic
- Latency: short
- Reliability: high
- Priority: high
- Bandwidth: medium
• Data content: road-geometry information, vehicle load and speed
• Communication range: 300 m (short)

8. **Road departure**

In case of black spots such as junctions and temporary road work, the in-vehicle devices will be used to warn the driver about the risk of road departure with respect to speed. Moreover, information about the speed limit and traffic condition will also be available.

Communication requirements:
• Vehicle-to-vehicle communication
• One-way communication
• Real-time transmission
• Point-to-multipoint communication
• Event driven
• Latency: short
• Reliability: high
• Priority: high
• Bandwidth: small
• Data content: road geometry, surface status, traffic condition
• Communication range: 300 m (short)

9. **Cooperative obstacle detection (in tunnel)**

The aim of this application is to increase the safety inside tunnels. Vehicles will cooperate to warn each other about dynamic events in the tunnel such as slow or stopped traffic.

Communication requirements:
• Vehicle-to-vehicle communication
• One-way communication
• Real-time transmission
• Point-to-multipoint communication
• Event driven
• Latency: short
• Reliability: high
• Priority: high
• Bandwidth: small
• Data content: dynamic events inside the tunnel, collision and accident
• Communication range: short

10. **Predictive speed reduction**

The vehicles inform each other in a cooperative manner about static obstacles and road work to obtain safety behaviours (speed and lane to take) in black spots. The active safety systems in the vehicle can maintain this information for future use in emergency cases.

Communication requirements:
• Vehicle-to-vehicle communication
• One-way communication
Collaborating vehicles for increased traffic safety

- Real-time transmission
- Point-to-multipoint communication
- Event driven
- Latency: short
- Reliability: high
- Priority: high
- Bandwidth: small
- Data content: present of static obstacle and road work, recommended action (speed and lane to be take)
- Communication range: short
# SAFESPOT Profile

<table>
<thead>
<tr>
<th>Profile</th>
<th>V2V/I2V</th>
<th>Directionality</th>
<th>Transmission scheme</th>
<th>P2P/ P2multipoint</th>
<th>Event/ Periodic</th>
<th>Latency</th>
<th>Priority</th>
<th>Bandwidth</th>
<th>Range (m)</th>
<th>Applications</th>
</tr>
</thead>
</table>
| A       | I2V     | One-way | Real time | P2multipoint | Event/ periodic | S       | H        | H         | S         | S 1. Smart signalling for safety enhancement  
2. Hazard and incident warning  
3. Safe urban intersection  
4. Speed alert and road departure prevention  
5. Safety margin for assistance and emergency vehicles |
| B       | V2V     | One-way | Real time | P2multipoint | Event/ periodic | S       | H        | H         | S         | S 1. Safe lane change manoeuvre  
2. Frontal collision warning  
3. Cooperative situation awareness  
4. Cooperative tunnel safety  
5. Cooperative vulnerable road user detection  
6. Road condition status information  
7. Cooperative anti-rollover  
8. Road departure  
9. Cooperative obstacle detection  
10. Predictive speed reduction |

*Table 3.5. SAFESPOT Applications profiles and their communication requirements*
3.5.3 Profile Description

All the applications listed here more or less have the same communication requirements for infrastructure-based and vehicle-based systems. The most common similarities are in one-way real-time and point-to-multipoint communication, short latency, high priority and reliability, small bandwidth, and short communication range. Therefore, the profiling will be founded on the base of the application that is if it is vehicle-based or infrastructure-based since the applications in this project are listed under these two categories. However, when abstracted into communication requirements and wireless carriers level, this is no longer a problem. Consequently all these applications can be grouped together in one profile.

Nonetheless, most of the applications here resemble to a great extent corresponding applications in the General Active Safety Systems section or are almost the same.
4. CARRIERS

This chapter describes some of the possible wireless carriers for vehicle communications and ITS applications. The selected carriers include the cellular networks, short and medium communication range standards, i.e. DSRC, Infrared (IR), and millimetre-wave (MM), as well as the new Continuous Air-interface Long and Medium range (CALM) standard. Other carriers like satellite communications are out of the scope of this thesis. The choice of these specific carriers has been based on the point that they are widely used in the ITS field and seem to suit very much the applications mentioned in Chapter 3. The features of each carrier are discussed individually in separate sections considering the different communication requirements.

4.1 Mobile Communications

This includes the Global System for Mobile communications second generation 2G, the General Packet Radio Service (GPRS) i.e. 2.5G, and the Universal Mobile Telecommunications System (UMTS) third generation 3G. These are briefly discussed in the following section.

4.1.1 Global System for Mobile Communications (GSM)

GSM is a digital system for mobile communications defined as the second generation (2G) of the public mobile telephone communications. It operates in the frequency band of 900 or 1800 MHz in a circuit-switched network where a connection channel is established between the two communicating units and keeps open until the end of the connection. Moreover, data transmission through the use of short message services is also available for transmitting short messages (SMS). The maximum transmission of data is up to 9.6 Kbps with a bandwidth of 200 KHz [29]. Nevertheless, the data rate can be increased to 14.4 kbps in some situations [30].

It can provide small data volume services such as parking, tolling and simple yellow page services but it is not suitable for medium or large data downloading [30].

4.1.2 General Packet Radio Service (2.5G)

GPRS is based on the GSM system and supports data transmission via packet-switched services. It is considered as a further step toward the third generation UMTS. With the use of packet-switched services, the capacity can be provided to the users on demand; this is known as “always on” where the users can send data at any time without the need to establish a connection channel since the data to be sent is divided into packets with each packet having its destination address [29]. This increases the infrastructure efficiency and improves the service delivery. Furthermore, it decreases the users’ costs since the communication channel is shared between them [31]. However, the delay could be increased, if the number of users is large with respect to the available capacity [29].
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The data rate that can be supported is up to 40 kbps for circuit switching and 320 kbps for packet switching network. Therefore, it can be used for limited data volume transactions with long range but not for large-volume data downloading [30].

4.1.3 Universal Mobile Telecommunications Systems (3G)

UMTS is the third generation of mobile telephone technology developed to allow data rates from 144 kbps up to 2 Mbps in case of low mobility and in-building environment; this feature makes it possible to transmit multimedia applications (i.e. simultaneous transmission of speed, data, text, image, and video). Besides the higher transmission rate, there are two more factors that allow the transmission of multimedia applications, namely the availability of large bandwidth (5 MHz) and the usage of the code division multiple access method (CDMA) [29].

The maximum data rate and the maximum speed of the user for different hierarchical layers are shown in the following table:

<table>
<thead>
<tr>
<th></th>
<th>Max data rate</th>
<th>Max speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro layer</td>
<td>144 Kbps</td>
<td>500 Kmph</td>
</tr>
<tr>
<td>Micro layer</td>
<td>384 Kbps</td>
<td>120 Kmph</td>
</tr>
<tr>
<td>Pico layer</td>
<td>2 Mbps</td>
<td>10 Kmph</td>
</tr>
</tbody>
</table>

*Table 4.1. Maximum data rate and speed of the user for different hierarchical layers of UMTS*

Where the macro layer is defined to have between 0.5 to 10 Km radius for global coverage, the micro layer between 50 to 500 m in cities, and the pico layer of 5 m inside the buildings [37]

The frequency band of the UMTS spectrum is defined between 1900 to 2025 MHz and from 2110 to 2200 MHz; a sub-band is also defined for satellite services as 1980 to 2010 MHz for uplink and 2170 to 2200 MHz for downlink.

Aside from the multimedia transmission, the third mobile generation can be used for other limited data volume transactions such as yellow services. However, it is still not capable for downloading very large-volume data at high speed (i.e. vehicles) [30]

In general mobile communications have several characteristics like large-scale usage and long range of communication. This is together with its ability to offer continuous access to reliable data and to implement security issues [29].

Nonetheless, the technology still has the under-mentioned disadvantages that prevent or restrict its use for traffic safety applications:

- Although the “always on” packet data ability will nearly eliminate the delay of data connection, the technology is still too slow for passing time-critical information, because of the large end-to-end delay (i.e. several seconds).
- Voice has higher priority than data packets which increases the latency in case of the capacity increase of voice traffic.
• In cellular technology, there is a need to obtain the destination number which is difficult in case of vehicles communications.
• The use of cellular technology requires operation fees.
• The technology is used by a large number of users which would affect the data latency since the probability of voice traffic increase becomes larger [29] [21] [32].

4.2 Wireless LAN

The increased demand in our everyday life for flexibility and mobility has led to the extension of wired LANS and hardwired computers to wireless LANs [33]. Today there are a number of WLAN international standards with varying levels of standardization and interoperability, like the American IEEE 802.11 and the European HyperLAN. These wireless network technologies use the license-free bands of frequency spectrums at 2.4 and 5.8GHz. As long as the broadcasting effect does not exceed 100mW, no license is required for using these spectrums. These technologies have one single characteristic that makes them suitable for bridging over short distances, which is their limited broadcasting capacity. They have a maximum communication range of hundreds of meters in obstruction-free surrounding; this is reduced to only few tens of meters inside buildings or in case of path blockage between sender and receiver [29]. WLANs have been originally specified for use in office environments that are characterized by low mobility. However, two of their important characteristics, high data rate (up to 54 Mbps) and the connectionless service have made them suitable candidates for mobile ad hoc networks where they allow message transfer between involved mobile entities.

A wireless LAN is based on a cellular architecture where the system is subdivided into cells. Each singular cell is called Basic Service Set (BSS) which is controlled by a Base Station (called Access Point or AP) [9]. It may consist of a single cell with a single Access point but usually several cells are used and the APs are joined together by a sort of backbone called Distribution System or DS, typically (Ethernet 802.3) and sometimes through wireless itself. The upper OSI networking layers consider the entire interconnected WLAN with all its entities, the different cells, the APs, and the DS as a single 801 network called the Extended Service Set (ESS).

802.11 wireless networks have two operation modes ad hoc or infrastructure mode. In the IEEE standard, the ad hoc mode is defined as Independent Basic Service Set (IBSS) and the infrastructure mode as Basic Service Set (BSS). In ad hoc mode, each client is able to communicate directly with other clients provided that they are within the same transmission range. Otherwise, if a client wants to perform an outer communication, he should use a member of the cell to act as a gateway and hence perform routing [34]. No administration is required; therefore, the networked nodes share their resources without a central server [33]. In infrastructure mode, the operation is centralized; therefore, each client forwards its communications to a central station or access point (AP). The access point here has the role of an Ethernet bridge sending the communication to the required network which could be either a wired network or another wireless network. An association should be established between the wireless clients and
the access points before any data communication could take place [34]. The access points hence allow the wireless nodes to share efficiently the network resources available [33].

4.2.1 IEEE 802.11

This standard was finished in June 1997. It designates an operating frequency of 2.4 GHz with data rates of 1 and 2 Mbps. The IEEE 802.11 specifies both the Medium Access Control (MAC) and the Physical Layers (PHY) [14]. The MAC layer for 802.11 defines two different services, namely Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The DCF protocol, which is the basic access method, uses the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism. The DCF defines the way in which the stations should share the medium. The PCF is an optional service used only in the infrastructure mode that uses a polling mechanism in order to make possible contention-free multiple access and is used only when data should be delivered within a time-bound [35].

There are three physical layers specified in the 802.11 that include two spread-spectrum techniques, namely Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS) together with a diffuse infrared specification which means that it uses a diffuse mode of propagation [36].

The IEEE 802.11 consists of a number of different protocols (a, b, e, f, g, h, and i) which are described below:

IEEE 802.11a: indicates working in the 5GHz band with data rates up to 54 Mbps using the Orthogonal Frequency Division Multiplexing (OFDM) modulation mode. It has vantage over IEEE 802.11b of higher capacity and less RF interference with other devices e.g. Bluetooth or any other user of the 2.4GHz. However, its main disadvantage is its incompatibility with the IEEE802.11b; therefore, require bridging products in-between [33].

IEEE 802.11b: uses the DSSS and works in the 2.4 GHz. Under this standard, the devices can have a data rate of 11Mbps, which drops gradually to 5.5 Mbps, 2 Mbps, until reaching 1 Mbps in the presence of interference or weak signal strength. 802.11b can support a short range of 305m in open areas and 76-122m in closed areas [24]. This standard is the most used nowadays when deploying wireless LANs. However, its main drawback is that the frequency band is very crowded and hence vulnerable to interference from other devices like microwave ovens, 2.4GHz cordless phones, and Bluetooth. Other limitations are its lack of interoperability with voice devices and inability to provide QoS for multimedia data. Using both 802.11a and b could allow vehicles to be included in wireless home LANs. These home systems are capable of offering large data downloads to garaged vehicles and allowing the download of non-time critical information from vehicles to Wider Area Networks (WANs). The wide use of 802.11b in different areas including home, office and public area LANs will allow vehicles equipped with 802.11b to upload and download data via these wireless LANs as long as the vehicles are within the coverage range of the hotspots [21].

IEEE802.11c: this standard deals with network interoperability and its main concern is the bridging in wireless bridges or access points. It is now included as part of IEEE802.11d [62].
IEEE 802.11d: this standard is similar to 802.11b with optional abilities to adjust frequency, power level, and signal bandwidth. It is used in countries where it is not allowed to use the other 802.11 standards [63].

IEEE 802.11e: since the 802.11 standard is not optimized for audio and video data transmission, the 802.11e will be used to provide better QoS for both audio and video applications by giving description for both error correction and bandwidth management that should be used in 802.11a and 802.11b [63].

IEEE 802.11f: The available 802.11 standard does not include communications between access points to allow users roaming from one point to the other. There is the lack of interoperability in roaming between the access points supplied from different vendors, and this is the basic problem. The IEEE802.11f will define an inter-access point protocol that gives the access points the information they need to exchange in order to be able to support the 802.11 distribution system functions (e.g. roaming).

IEEE 802.11g: An important feature of this standard is its ability to increase the data rates in the 2.4GHz band to rates higher than the ones of IEEE 802.11a and being compatible with the 802.11b. It uses two modulation modes, the Complementary Code Keying (CCK) mode and the OFDM mode and it has a maximum data rate of up to 54 Mbps [33].

IEEE 802.11h: The IEEE 802.11h is under development to be used only in Europe. It helps the 802.11a systems to avoid conflict with the other users of the 5GHz spectrum by defining processes that allow them to be in compliance with the ITU rules. These processes are two namely, Dynamic Frequency Selection (DFS) to allow uniform usage of channels and therefore avoid channel conflict and Transmit Power Control (TPC) to decrease the radio transmit power of Wi-Fi devices [63].

IEEE 802.11i: is specifying improvements to deal with issues related to wired equivalent privacy (WEP), to provide the wireless network with a security level equal to the wired network.

### 4.3 Dedicated Short Range Communication

Dedicated Short Range communication (DSRC) is a newly rising technology in the field of wireless communications that seems to be very promising and has a great potential. One of its main expected uses is in the field of ITS in the establishment of a reliable communication link [38]. DSRC is defined as a general purpose radio frequency (RF) communications link between the vehicle and the roadside. To be more specific, it could be defined as a short to medium range communications service that supports both public safety and private operations in roadside to vehicle and vehicle to vehicle communication environments [61].

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4.3.1 DSRC Standardization Process

The standardization of DSRC was first started by the Technical Committee TC278 of the Committee European Normalization (CEN) in 1992. Then DSRC was considered by the Technical Committee TC204 of the International Standards Organization (ISO), where there are two working groups namely, WG15 for DSRC and WG16 for medium to long range communications. The Japanese have developed their own set of DSRC standards as two generations, which are ARIB T55 and ARIB T75. The frequency band of 5.8-5.9 GHz has been accepted as a standard for DSRC in all standards [39]. In October 1999, the Federal Communications Commission (FCC) allotted the 5.9GHz band to the DSRC-based ITS applications and endorsed a number of basic technical rules for the operation of DSRC. In 2003, the ASTM-DSRC standard was approved for North America. It is based upon the IEEE802.11a physical layer and the IEEE 802.11 MAC layer and was called the ASTM E2213-03. This standard is currently being shifted to the IEEE 802.11 standard where it is being revised by the Wireless Access in the Vehicle Environment (WAVE) study group [40] to introduce the necessary changes. This group has been turned into a task group and the expected system after the changes shall be standardized as IEEE802.11p.

4.3.2 The 5.9GHz DSRC

The FCC has newly assigned a spectrum of 75 MHz width at the 5.9GHz to the DSRC. This new spectrum allows the available ITS systems to adopt a new generation of RF communication between vehicles and the roadside and vehicles themselves [41]. The 5.9 GHz DSRC link uses digital radio techniques for data transfer over short distances within the immediate vicinity of a vehicle [38] [21]. Through this link, a variety of different tasks including traffic flow enhancement, highway safety, in addition to other applications related to ITS environments called DSRC/WAVE (Wireless Access in a Vehicular Environment) are accomplished [38].

To be able to handle the strict requirements of public safety together with the ones for non-safety applications, the 5.9 GHz DSRC system has prerequisites of quick, robust, and localized transmissions from both vehicle-to-vehicle and vehicle-to-infrastructure [38]. Moreover, since safety applications are expected to be extremely important in cases of life threatening conditions, they are given priority over non-safety applications with the extra prerequisites of response time and reliability [40].

The system technology is based upon the IEEE 802.11 “Wi-Fi” standard which is already deployed widely in many areas [38]. In fact, it is supposed to be an outdoor high-speed vehicle technology extension for the IEEE 802.11a [40] with the exception of some changes necessitated by the need for latency minimization, authorization, prioritization, and anonymity while in the same time not affecting or influencing the messaging reliability and integrity, content, security, and robustness [38]. None of the available IEEE 802.11 standards is capable of meeting the vehicle-to-vehicle safety applications that include dealing in a limited time frame of milliseconds with highly mobile vehicles in addition to offering high levels of service quality associated with a number of overlapping communication zones. DSRC is meant to be a complement to cellular and satellite communications by providing very high data rates in circumstances where minimizing
latency in the communication link and isolating relatively small communication zones are important; with the difference that it does not offer “2-Way Voice/Broadcast” or “Tracking” device capabilities [38]. The systems physical layer (PHY) is an adaptation of the IEEE 802.11a PHY which uses the orthogonal frequency division multiplex (OFDM) technology. This is not the only similarity with the IEEE 802.11 but also the DSRC multiple access control (MAC) layer resembles to a great extent the IEEE 802.11 MAC which is based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol with a few modifications which are as follows [40]:

- Optional combination of 10 MHz channels to one 20 MHz channel
- Having special working rules for these channels
- Providing MAC layer queues to handle a number of channels with different priorities for each
- Providing a modified ad hoc mode to use for acquiring a link quickly
- Using random MAC address that uses an address space with local administration to ensure privacy
- Providing capabilities for transmit power control.
- Reducing the data rate to allow communications with higher reliability at high speeds
- Reducing or getting rid of the LAN-based handshaking needed to reduce the system latency from seconds to milliseconds [21].

The 5.9 GHz band constitutes seven 10 MHz channels which include one control channel and six service channels. The control channel contains the announcements of services and short data messages while the service channel is meant for extra data transfers and particular specific applications.

The system is composed of Roadside Units (RSUs) that are connected to the infrastructure and On-Board Units (OBUs). The basic idea behind the operation is based on “events and snapshots” in a read zone. As soon as an OBU is sensed within the range of a RSU, a message is sent to the OBU on the control channel. When the OBU receives the message, it responds back by sending either public data about the whole situation or private data concerning its own situation. In the case of vehicle-to-vehicle communication, the transmission is initiated by one of the OBUs which hereby borrows some of the attributes of the RSU [38]. Only for particular applications, the OBUs will use the service channels directly, otherwise they will automatically listen to the Control Channel and wait for an application to be announced.

4.3.3 Summary of the Exclusive Capabilities of DSRC

DSRC exhibits a number of unique capabilities that are summarized as follows [21]:

- Has a maximum range of 1000m, data rate of 6 up to 27 Mpbs with vehicle speed up 192Kmph [38].
- Allows broadcast messaging which gives it advantage over point-to-point wireless communications like cellular communications. This is very important when dealing with
vehicle safety applications, since it could be difficult to formerly know the phone numbers of other approaching vehicles.

- Offers very low latency communications, where latencies less than 100 ms could be reached.
- Has the capability of providing high-availability communications. This allows two vehicles on the verge of a prospective collision to be able to exchange important information until the last moments before the collision occurs.
- Can support both kinds of communication, vehicle-to-vehicle and vehicle-to-infrastructure.
- Can support one-way and two-way directionality.
- Support point-to-point and point-to-multi-point communications.
- Has low interference likelihood since it is supposed to work on a part of the spectrum prespecified for transport safety applications [24].
- Has high bandwidth, small error rate, and strong resistance to multipath since it is based on the IEEE802.11a OFDM technology which has an inherent capability to resist multipath. All this makes it a perfect candidate for intersection safety applications [24] [35].

### 4.4 Infrared (IR)

In intelligent transportation systems, infrared has been used in some projects such as Electronic Toll Collection in Malaysia and Korea, the German Truck Tolling Scheme, and Vehicle Information and Communication Systems (VICS) in Japan. Infrared has also been used for Electronic Vehicle Identification (EVI) applications [29]. Since April 2001 a new group inside Infrared Data Association (IrDA) has been established, under the name of Travel Mobility Special Interest Group (TM-SIG), with the aim of developing wireless low cost and high speed connectivity for ITS applications.

Two components are needed for the system to work. The first is an infrared roadside unit that can transmit and receive data to/from the passing vehicles. The second is an IR tag/in-vehicle unit with the ability to stay in the standby for a long time. The infrared tag is energized by an internal battery; while the in-vehicle unit draws power from the vehicle's battery [29].

An important feature of this media is its high beam directivity which is useful in applications where lane dependent messages have to be transmitted and also in vehicle-to-vehicle communication [14]. Directional communication can be used for many purposes such as sending position dependent messages, transferring high volume data traffic, and to achieve high transmission reliability and privateness [42]. The typical range of infrared is up to 100 m with a data rate range from 1 Mbps to 1 Gbps.

The most important features can be summarised as follows:

- No license is required for the use of infrared any where in the world and hence can work in any distance
• Not difficult to work with i.e. like working with light and shadow
• Can support higher data rates in a narrow cone of operation
• Can be used where radio operation has regulatory constraints
• Possibility to provide continuous communication through chained networks
• Ability of sending information in active manner without the need for an external antenna to provide it with power
• Can work and function properly with metallic windshields of modern cars
• Low power consumption which allows the use of solar power in roadside units
• Can adapt link budget with respect to the application and hence can manage to work with dirt, fog, and snow [29] [43]

There are many other general advantages to infrared that are interesting for ITS applications. It has very good beam-shaping features with no interference between cross-beams. There is no bandwidth allocation restriction with infrared and it can offer multiple transmission speeds (1, 2, 18, 16, 32, 64, 128 Mbps and more in future) that can be adjusted according to the signal/noise ratio. Moreover, it allows using economical multi-beam antennas to control its directivity and can support different types of communication such as point-to-point, point-to-multipoint, multiple point-to-multipoint, broadcast, multicast, and master-slave communication. Finally, infrared provides very short link-setup and connection re-establishment time after a disconnection (< 10ms) [42].

The main drawbacks are the need for line-of-sight communication and a source of power e.g. battery [29]. Previous drawbacks that have been solved are the strong background light from the sun (the signal to noise ratio) and high power consumption due to the standby mode of the in-vehicle device [43]. This has been achieved in the practical applications.

Examples of some expected uses of infrared are e-commerce, image transfer, navigation system update, and tourist information systems (video, games) [30].

### 4.5 Millimetre-Waves

Millimetre-wave band is defined as the frequencies between 60-64 GHz or 30- and 40 GHz [44]. Millimetre wave at 60 GHz can support direct communication between vehicles to form inter-vehicle communication without the use of a fixed infrastructure. Compared to the infrared system, the millimetre wave system at 60 GHz has three main advantages. First, it is less affected by weather conditions, second, it is less prone to interference from sunlight [45], and finally, it can provide communication links even in case of nonline-of-sight conditions by use of multipath propagation [44] [46]. Other advantages of millimetre wave can be summarized as follow:

• Availability of high capacity for high-speed broadband communications
• High spatial filtering which leads to high reuse efficiency of channels, because of its high degree of attenuation due to the high frequency and high rain and oxygen absorption [44] [46].
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- Possibility of lower number of interfering signals due to the high level of attenuation [44].
- It has a possibility of integration with radar systems where it shares circuit with the on-board radar system [45] [47].
- Ability to use small antenna sizes and radio-frequency circuits that can be easily integrated in the car and infrastructure [44] [48].

For all these advantages, millimetre wave has been considered as a potential medium for ITS IVC applications. However, due to the short wave length, the communication can be affected by the relative movement between the vehicles. In addition to that, strong signal fading can occur due to the interference between the direct and reflected waves [45]. Another disadvantage of millimetre wave is the difficulty to provide long distance transmission since the radio waves are attenuated in space but this has been considered as additional advantage due to the high reuse efficiency of frequency and security [49]. Consequently, millimetre wave can be used to service either short or medium range services. By enabling vehicle-to-vehicle communication, millimetre wave can support many applications such as collision avoidance, safe driving at intersection, and support for platooning. The data rate can be in the order of few megabits per second with the range from few meters to one kilometre [44].

4.5.1 Radio-on-Fibre

One of the prospective uses of millimetre-wave band frequency is in the radio-on-fibre based road-to-vehicle communication system that will be developed to support a higher data rate than that of DSRC. The system can then allow transmission of multimedia information at several Mpbs, i.e. 2-10 Mpbs beside voice and data transmission. For the multimedia information to be sent at higher data rates between the base station and the Mobile station (MS), two factors must be taken into account. One is to let the frequency band used for the radio carrier wave signal wide enough to allow a large number of users, so millimetre-wave band (36 or 60 GHz) is used. The other is to use a robust modulation scheme to accommodate for the signal distortion resulting from multipath fading and Doppler frequency shift. A multiple access scheme should also be used to allocate frequency and time resources to users [14]. However, the use of the millimetre wave leads to the occurring of two problems because of its short wavelength; these are the frequency fluctuation caused by Doppler shift and the high free space loss. The latter has led to a smaller size of the coverage area (several 10 m) and hence increasing the number of roadside units needed, and accordingly will increase the number of handovers. The problem of frequent handovers has been solved by constructing a large virtual zone for the base stations that are connected to the same control station, so that the handover is only performed between the large virtual zones and not between the small zones of the local base station. Further, interference occurs at the boundaries between the adjacent road base stations (RBS) zones because they use the same frequency band; a code division multiplexing (CDM) scheme has been used to minimize this interference [16].
4.6 Communication Air-interface Long and Medium

The working Group (WG16) in the ISO TC204, that is called Wide Area Communications, together with the IEEE is working on the communications for a longer range than DSRC applications. They are considering the use of data-exchange protocol (i.e. IP) in the ITS field. New requirements have been taken into account such as that the contact has to be over a longer distance for a longer connection period (continuous communication) than that for the DSRC. For these requirements, a new standard is being developed to support medium (defined as 20-100 m) to long (as > 100m) distance high data rates (above 1 Mbps) transactions and hence this standard is called Communication/Continuous Air-interface Long and Medium range (CALM) [50]. “The scope of the CALM is to provide a standardized set of air interface protocols and parameters for medium and long range, high speed ITS communication using one or more of several media, with multipoint and networking protocols and upper layer protocols to enable efficient communication services” [50]. So CALM will include some of the existing media together with modern internet protocols to provide continuous communication for ITS applications. Different media have been defined in CALM so that an international standard can be implemented to avoid the drawbacks of using single medium and support more number of applications. This combination of media is also because of different applications that have different requirements, where a single media can not be optimised for all the applications.
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There are differences in the national regulations for the frequencies used in ITS between the countries such as in the 5 GHz in Europe, USA, and Japan. This leads to the fact that different countries may not use the same wireless technology or frequency for a specific application, for example, although 5 GHz has been standardized for ETC, Germany has used a GPS/GSM system. It is, therefore, of no use to be waiting for a single wireless technology to support continuous communication in the future. CALM will provide continuous communication between vehicles or vehicles and infrastructure through the use of multiple wireless media with the ability to switch from one to another if needed. Due to the different choices of media in different countries, CALM includes different media in order to be able to operate in any place at any time. One can imagine CALM to be sitting in the middle between different applications or services and multiple available media and functioning as a manager for the continuous communication between them. The continuous communication could be between one or multiple applications and one or multiple media [51].

Five sub-working-groups are working inside the WG16 where each is responsible for a specific task about the CALM. These sub-working-groups are [52]:
SWG 16.0 for CALM Architecture.
SWG 16.1 for CALM Media.
SWG 16.2 for CALM Network.
SWG 16.3 for Probe Data.
SWG 16.4 for Application Manager.

CALM’s service includes different communication modes as Vehicle-Vehicle, Vehicle-Infrastructure, and Infrastructure-Infrastructure. The media used inside the CALM includes 2/2.5G Cellular systems and 3G systems UMTS (for long distance), Infrared and 60 GHz system millimetre-wave (for short and medium distances directed communication), 5 GHz microwave (for short and medium distances), and others may be added in the future. Using these media, different applications are expected to be supported by CALM in different communication modes. These applications can be divided into safety and commercial applications. Some of the safety applications are intersection collision warning (I2V), intelligent traffic light pre-emption for priority vehicles (V2I), and cooperative collision warning (V2V). On the other hand, some examples of commercial applications could be internet in-car and video download (I2V), and cross vehicle messaging (V2V) [51]. Other general applications could be “infotainment” which includes video and image transfer, update of roadside telemetry and messaging, collision avoidance, route guidance, car to car safety messaging, Radio LAN, and yellow page services [30] [50]. Also there will be many new applications that can be supported due to the long range and high data rate capabilities [52].

In the network layer Internet Protocol, version 6 (IPv6) is defined as the basic addressing scheme with the mobile IPV6 elements for handover. Accordingly, CALM is expected to be compatible with internet services without the addressing shortcomings of the IPv4 protocols [52]. The function of CALM networking protocols is to decide which medium to be used depending on the application requirements [53]. It must be able to support two levels of handover; the first is within the same technology and service provider, while the second is in the case where the technology or service provider changes [54].
Now the differences between the DSRC and the CALM become clear; while the communication zone is less than 20 m in DSRC, it can be more than that in CALM. High data rates for longer duration with handover mechanism can be provided by CALM. On the contrary, DSRC supports up to 259/500 kbps for short durations without implementing handover mechanisms. In both, the maximum vehicle speed is assumed to be 160 Kmph [30].

Although CALM will support multiple media simultaneously, there is no need for the equipment or the in-vehicle device to support all these media. The selection of which media to be supported will be made by the vehicle or equipment manufacturer. Furthermore, it will also depend on the available media in the particular country and the cost constraints, in summary “the choice is commercial not technical”. It is also important to understand that there will be a firewall between the CALM functions and the other in-vehicle control computers and data-buses; this is due to the fact that vehicles’ manufacturing companies must have a full control of the safety systems in the vehicle. The function of the CALM is just to provide an air interface to the available media [51].

4.6.1 CALM Media

As mentioned above, the CALM includes standards of media that will be supported in the future. Some of these standards have been completed such as CALM Infrared (IR) while work is still proceeding on the others. Other standards are CALM M5 for Microwaves, CALM MM for Millimetre-waves, and CALM 2G/3G for wide area communication using Cellular technologies. Although enough information about these standards is not available, a short description for each is given below.

4.6.1.1 CALM 5

This standard specifies the air interface by the use of microwave systems operating in the 5 – 6 GHz frequency range. It provides protocols and parameters for long range, medium speed wireless communications in ITS [55]. It is also defined as a new WLAN for mobile use which will be a promising general purpose communication media for safety applications. The main feature is its ability to communicate around the obstacles. Moreover, it will provide omni-directional communication between moving objects at a data rate of 6 Mbps and range of 300 m radius. It can be useful for both V2V and low-directive V2I communications [28], and it also supports point-to-point and point-to-multipoint communications [56].

In safety applications such as cooperative collision avoidance, the communication link must be of a high performance and reliability which is the aim of CALM 5. However, CALM 5 must be able to coexist with DSRC (5.8-5.9 GHZ). CALM 5 will provide continuous communication even if the physical link is not continuous, which requires the use of handover mechanisms where the application context is kept unchanged during the handover. It could be homogenous i.e. within the same medium, or heterogeneous i.e. between different media [55].

Many reasons have led to the use of the 5 GHz as a frequency band for this standard. First, it is in the same frequency band as the US DSRC standard, and has the ability to go through walls and bend around the corners. Moreover, it is based on 802.11 WLAN standards and hence it will have
many suppliers and many other advantages such as low cost, high reliability, and suitability for both V2V and V2I. Furthermore, there are many channels available for emergency and safety application (dedicated channels) and others for less critical applications. Considering all the above, CALM 5 is expected to be the next high-volume ITS communication medium [57].

4.6.1.2 CALM 2/2.5G and 3G

Cellular technology has been included in CALM media to provide wide area communication. It was the first media used in ITS for providing two way communications. However, the main limitations of the 2G system in supporting continuous communication are the high cost and the differences in the basic systems between countries. Moreover, it is unable to provide high data rates and data speeds needed for ITS applications. For 3G systems, the systems in different countries can co-operate by using common protocols but, at the current time, the system is not ubiquitously available [51]. One of the features of the 3G system is its ability to support IPv6 which will enable direct interface with the CALM in the future.

The CALM 2/2.5G and 3G standards will define the air interfaces using the cellular network generations i.e. 2/2.5G and 3G. The aim is to provide communication for long range with medium speed to support quasi-continuous, short communications between vehicles or vehicles and infrastructures. The CALM communication will be in a packet switched manner while non packet switched networks will be used for transmission of non time critical messages to predefined users. The connection/disconnection processes will be according to the particular cellular standard. When the connection is established, the CALM session will start and be maintained until the connection is terminated either by connection ending or signal loss. There will be two methods for initiation/termination of the CALM session, namely the default method and user controlled method. In the default method, the session starts from the time the vehicle is switched on and keeps open until the vehicle is switched off. In the case when the communication link is not available, the connection establishment request will be repeated periodically until the communication link is established. On the other hand, the initiation/termination will be controlled by the user in the user controlled method. However, it is the in-vehicle systems that will determine how the user controls the connection and disconnection of the session [58] [54].

4.6.1.3 CALM 60-70 GHz

This is defined as a millimetre wave band and has been included in the CALM media because of its high data rate and high directivity. It can also be integrated with the radar signal to operate at the same frequencies. The work in this standard is still in the progress phase.

4.6.1.4 CALM IR

Infrared has also been included in CALM media because of its several advantages mentioned earlier in the infrared section. CALM IR specifies the air interface by using infrared systems operating in the range of 820 to 1010 nanometres. The aim is to enable medium range, medium to high speed wireless communication for ITS applications. The link will support quasi-continuous,
relatively long or short communications between vehicles, vehicle and infrastructure, and fixed infrastructure and mobile devices. The standard supports data rates up to 128 Mbps and more with the communication range of 100 m to 1000 m. Moreover, it has very short latency (in order of millimetres) and can support a minimum vehicle speed of 200 km/h [59]. The work in this standard has been finished and the complete standard is provided now by the ISO. The first implementation of CALM-IR was used in the German Truck Tolling project. Other CALM IR applications could be curve warning, traffic information, and hazard warning [60].

4.7 Carriers’ Summary

This section provides a summary for the carriers mentioned above in a table form which depicts the carriers associated with some of the communication requirements. This means that the requirements mentioned here does not cover all the communication requirements defined in chapter three. Some of them like priority, addressing, transmission control scheme, minimum frequency, reliability, and transmission content are not included. This is due to the fact that some of them can be supported by any carrier (priority, transmission control scheme) and hence does not affect the choice of the carrier. In discussing some of the requirements it is notable that from a carrier perspective they are different than from the application perspective, for example the reliability requirement when viewed from an application’s point of view, defines the level of reliability required according to the type of the application (high, medium, and low) while here it describes how able the carrier is to support a reliable communication. Nevertheless, the reliability requirement here could be variable where for some applications the carrier can be considered of high reliability while for others it can be of low reliability; e.g. the reliability for data traffic is different from that for voice. Voice can tolerate a high bit error rate of nearly 1% while data traffic requires extremely reliable delivery. In fact, a value of $10^{-6}$ bit error rate for a carrier implies high reliability. The same applies for the transmission content and minimum frequency where both depend mostly on the type of the application. However, the data rate and the latency requirements discussed in the table can give an idea about the transmission content and the minimum frequency respectively; since a high data rate implies high bandwidth and hence large transmission content, while short latency implies a high message update rate (minimum frequency). The addressing requirement constitutes different aspects such as broadcast addressing, location based addressing or IP addressing; this makes it difficult to attribute a certain addressing type to a specific carrier. From a carrier viewpoint, the bandwidth considered should be the aggregated (collective) bandwidth and that is to cover all the communicating units in a specific coverage range. However, in the table the bandwidth has been replaced by the data rate because we think it gives a better idea about the possible data rate available for the users and hence could be more effective in determining the suitable carrier.

Since most of the V2V communications require short latency, the cellular technologies are not suitable for them because of their several seconds latency. This arises from the server processing needed in the mobile location registers and the forwarding of packets required for data delivery to/from dynamically changing cellular sites. However, there exist some suggestions for using
cellular technologies for V2V communication and hence we think in spite of the strict latency requirement it is possible but difficult.

The communication range of the WLAN mentioned refers to the 802.11b, which represents the highest among the three (a, b, and g).

Most of the communication requirements are not applicable (NA) for CALM MM, this is because it is still under development and no sufficient information about it is available. Other unfilled requirements spaces in the table are because it was not possible to find information about them in the text.

Despite the fact that specific values are assigned to these requirements, some of them could still be implementation dependent (especially for CALM media), for example the communication range can depend on the traffic scenario and power setting.
## Carriers’ Summary

<table>
<thead>
<tr>
<th>Carriers</th>
<th>V2I</th>
<th>V2I/2V</th>
<th>Directionality</th>
<th>P2P</th>
<th>P2multipoint</th>
<th>Latency</th>
<th>Data rate</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cellular Technologies</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>One/two-way</td>
<td>Yes</td>
<td>No</td>
<td>1.5-3.5 (sec)</td>
<td>9.6-14.4 Kbps (2G)</td>
<td>4-6 (km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40-320 Kbps (2.5G)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>144 kbps-2Mbps (3G)</td>
<td></td>
</tr>
<tr>
<td><strong>Wireless LAN 802.11 (a, b, g)</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>One/two-way</td>
<td>Yes</td>
<td>No</td>
<td>3-5 (sec)</td>
<td>802.11a: 54Mbps</td>
<td>305 (m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>802.11b: up to 11Mbps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>802.11g: up to 24Mbps</td>
<td></td>
</tr>
<tr>
<td><strong>DSRC</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>One/two-way</td>
<td>Yes</td>
<td>Yes</td>
<td>&lt;100 (ms)</td>
<td>6-27Mbps</td>
<td>1000(m)</td>
</tr>
<tr>
<td><strong>Infrared</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>One/two-way</td>
<td>Yes</td>
<td>Yes</td>
<td>Order of ms</td>
<td>Up to 1Gbps</td>
<td>100 (m)</td>
</tr>
<tr>
<td><strong>Millimetre-Wave</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>One/two-way</td>
<td>Yes</td>
<td>Near zero [64]</td>
<td>Few Mbps</td>
<td>Few meters to 1 km</td>
<td></td>
</tr>
<tr>
<td><strong>CALM M5</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>One/two-way</td>
<td>Yes</td>
<td>Yes</td>
<td>Order of ms</td>
<td>6-27 Mbps</td>
<td>300 (m)</td>
</tr>
<tr>
<td><strong>CALM 2G/3G</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>One/two-way</td>
<td>Yes</td>
<td>1.5-3.5 (sec)</td>
<td>Same as cellular technologies</td>
<td>4-6 (km)</td>
<td></td>
</tr>
<tr>
<td><strong>CALM IR</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>One/two-way</td>
<td>Yes</td>
<td>Yes</td>
<td>Order of ms</td>
<td>1-128Mbps</td>
<td>100 m</td>
</tr>
<tr>
<td><strong>CALM MM</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>One/two-way</td>
<td>Yes</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

*Table 4.2. Carriers’ Summary*
5. Analysis and Results

This chapter represents the conclusion of our work where we started out by studying different applications with their respective communication requirements as well as different relevant wireless carriers. Here we try to establish the relation between the carriers and the application profiles based on the communication requirements.

We carried out this process following the same order used in the applications profiling, i.e. starting with the General Active Safety Systems applications followed by the CVIS project and the SAFESPOT project. The carrier matching was based on the different profiles derived from the applications in Chapter 3.

In deciding the carriers’ suitability, only the communication requirements that could affect this decision have been considered implying that some, like the transmission scheme of information (real-time or storage), information transmission control scheme (periodic or event), and priority, have been ignored. This is because the former two can be supported by any carrier; while the latter (priority) is independent of the carrier since it can be achieved using some sort of priority mechanism in an upper layer.

5.1 General Active Safety Systems Profiles

All General Active Safety Systems profiles contain applications that can be called safety applications and they all have the common requirements of point-to-multipoint communication, short latency and range, high reliability and priority, and small bandwidth and differ in the communication mode and information transmission control scheme. As mentioned earlier we included them in one profile under the name “safety applications”. In determining the best carrier/s for this profile we considered these common requirements together with the communication mode. As noticeable from the carriers’ chapter, the DSRC and CALM 5 are the two best candidates for such safety applications since they satisfy the above mentioned requirements. CALM 5 is capable of providing both V2V and V2I/I2V with point-to-point and point-to-multipoint communications. An important feature of this carrier related to this profile is its high performance and reliable link which is a prerequisite for the high reliability and short latency requirements of safety applications. This is together with the availability of dedicated channels for emergency and safety applications that also aid in offering short latency. On the other hand DSRC can also support the same requirements since it can offer V2V and V2I with point-to-point and point-to-multipoint communications, short latency of less than 100ms, and high bandwidth which satisfy and even exceeds the needs of the short safety messages accommodated here. Further, it provides high availability communications which gives vehicles enough time to communicate in case of hazards since it allows quick connection set ups between vehicles. The DSRC low interference probability will allow it to perform better in its crowded frequency spectrum where the interference amount should be kept minimal between different similar applications. Moreover, it has small error rate and high resistance to multi-path which is especially important in intersection safety applications. However, the difference between DSRC
and CALM 5 is in the communication range where CALM 5 has a range of 300m radius while DSRC has a range of up to 1000m.

### 5.2 CVIS Profiles

Since the CVIS applications contain more than one communication part per application; in choosing the carrier for each part we focused on the communication range more than the other requirements because here it is an important requirement which if not satisfied, the carrier will no longer fit the application.

Profile A contains applications with long range and latency requirements, medium reliability, priority, and bandwidth. Since in these applications vehicles will communicate directly with a central office across a long distance (long range), CALM 2G/3G could be the most suitable carrier for this profile. This is due to its long range communication capability in a continuous manner. The main feature of this carrier over the 2G system is its ability to provide global communication (international standard) where in some applications such as monitoring and guidance of dangerous goods, the communication will be through different countries with different communication regulations and standards. The medium bandwidth requirement for this profile does not pose a problem for CALM cellular since it is based on the basic cellular standards (2/2.5G and 3G) that are able to support up to 200 KHz and 5 MHz for 2G and 3G respectively.

Profile B has some requirements similar to the safety applications profile in the General Active Safety Systems applications (short latency and range, high reliability and priority, and small bandwidth). Looking at these requirements, DSRC and CALM 5 are again the best candidates for the Cooperative Local Traffic Control and Enhanced Driver Awareness applications. Taking into account the other values for these requirements, it can be found out that these carriers are also capable of satisfying them e.g. medium latency, reliability and bandwidth. This is because both carriers have high reliability and short latency; hence medium reliability and latency can be fulfilled. They are also capable of offering the medium bandwidth required (DSRC has a spectrum of 75 MHz and data rate up to 27 Mbps). Also, for the Cooperative Flexible Lanes allocation application these same carriers can be used for the communication between the vehicles and lane bus infrastructure and the vehicles between each other, this is because of the short latency and range requirements.

Profile C contains two applications where the communication could be divided into two parts. For Cooperative network management, there is communication between road infrastructure and the central CURB. This requires long latency and communication range, medium reliability and priority, and medium bandwidth. For this part of the communication CALM 2G/3G is the best choice due to the long range requirement of the application. The second communication part covers communication between road infrastructure and vehicles which implies short range communication. Accordingly DSRC and CALM 5 can work here.

In Cooperative area routing, the first communication part is between different intersection traffic controllers which require medium reliability and communication range, and long latency. Here
the CALM cellular could be used. The second part is between the individual intersection controllers and the vehicles, where both CALM 5 and DSRC are suitable.

Profile D contains the application Vehicle access control for sensitive zones. For this application, we estimated the range to be medium (few km) between the control centre in the monitored area and the vehicles; this is to give the control centre enough time to allow or deny access. For the monitoring zone, the communication between the approaching vehicles and the infrastructure should be an “always-on” seamless communication where either the vehicle or the infrastructure becomes aware of the status change and a communication channel is established between them. Considering the always-on seamless communication requirement, medium range, latency, reliability and bandwidth the elected carrier is CALM 2G/3G. CALM 5, DSRC, CALM IR and IR are not suitable since they offer a range less than the required one.

5.3 SAFESPOT Profiles

In the profiling section of the SAFESPOT project, the applications have been grouped together in one profile due to similarity in most of the communication requirements. It has been found out that these requirements are safety applications requirements (similar to the General Safety System’s section). Thus the most recommendable carriers could again be CALM 5 and DSRC.

5.4 Discussion

For most of the applications in the CVIS project the recommended carrier was one of the CALM media. This is due to the fact that the CVIS is directly based on the CALM standards and is expected to offer an evaluation implementation platform for the standardisation of CALM since the results of the project will form a major input to validate and finalize its standards [28].

Between the two recommended carriers DSRC and CALM 5, the one that can currently be used is DSRC since the CALM 5 standard is still under development. However, in the future both standards are supposed to coexist.

For profile C in the CVIS project an alternative solution that is currently undergoing a fast research could be the ROF system since its structure is similar to the basic structure of the applications in this profile especially Cooperative network management application; where a central control office is connected to networked control stations which offer information to the road site units.

As mentioned before, most of the applications in the SAFESPOT project resemble to a great extent corresponding applications in the General Active Safety Systems section or are almost the same.
## Results’ Summary

<table>
<thead>
<tr>
<th>Profile</th>
<th>Project</th>
<th>Carrier/s</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>General Active Safety Systems</td>
<td>DSRC or CALM 5</td>
<td>Safety Applications with common requirements of short latency and range, high reliability and priority, and small bandwidth</td>
</tr>
<tr>
<td>B</td>
<td>CVIS</td>
<td>CALM 2G/3G</td>
<td>Applications with long range and latency, medium reliability, priority, and bandwidth</td>
</tr>
<tr>
<td>C</td>
<td>CVIS</td>
<td>DSRC or CALM</td>
<td>Similar to General Active Safety Systems Safety Profile</td>
</tr>
<tr>
<td>D</td>
<td>CVIS</td>
<td>CALM 2G/3G and CALM 5/DSRC</td>
<td>Applications need two different communication parts</td>
</tr>
<tr>
<td>E</td>
<td>CVIS</td>
<td>CALM 2G/3G</td>
<td>“Always-on” seamless communication</td>
</tr>
<tr>
<td>F</td>
<td>SAFESPOT</td>
<td>CALM 5 or DSRC</td>
<td>Safety applications with requirements similar to General Active Safety Systems</td>
</tr>
</tbody>
</table>

*Table 5.1. Results’ Summary*
6. Conclusion

The thesis defines a number of communication requirements and applies them in a comprehensive analysis of various telematics applications and several wireless carriers. Accordingly, the applications are grouped into different profiles with a recommended wireless carrier/s assigned to each profile. It was found out that some applications profiles could be merged together due to their equivalent communication requirements. For example, all safety applications profiles implying different warnings could be grouped into one single profile. Other applications needed two different carriers to accomplish their full function, e.g. the CVIS application Cooperative network management. Finally, for some applications profiles, more than one suitable carrier was recommended. The scientific contribution of this work is twofold; firstly, identifying and evaluating the different communication requirements, and secondly, classifying a wide range of diverse applications and wireless carriers based on these requirements.

To attain a realistic concrete plan for the implementation of the future transport telematics applications, a service viewpoint only is not enough. The communication point of view of the services should also be taken into consideration in order to formulate the complete picture. This is a major significance of this thesis work, since it provides VTEC with a sufficient background concerning the communication part of the selected applications and hence constitutes an overall look, covering some of their most important aspects. This could be very helpful in estimating the commercial feasibility of these applications in the future. It could also be a crucial step towards developing an independent standard that could later be adopted by Volvo Technology for evaluating the equipment involved in these applications from a communication viewpoint. In addition, it provides the company with adequate knowledge about several important wireless carriers that could be very useful when arguing with different specialized authorities involved in different projects that the selected applications are part of. In general, this work forms the basis for a wireless strategy for future telematics applications.

An important and required process in the future work of this project is a detailed simulation to verify the suitability of the recommended carriers to the applications profiles. Moreover, due to time limitation and the large number of available wireless carriers, we were not able to cover all the existing carriers, although some of them seemed promising. For example, UMTS Terrestrial Radio Access-Time Division Duplex UTRA-TDD which has been recommended by the CarTalk2000 project. Another promising carrier is IEEE 802.16 (WiMAX) which is a newly emerging wireless technology optimized for long-distance links (50 km range, 70 Mbps bandwidth). However, the investigation of these carriers as well as others together with checking their suitability to the applications profiles could also be left as a future task.

Finally, we think that the work in this area should be further nurtured, encouraged, enhanced and developed and we recommend the company to push more effort and support towards the establishment of firm bases for such work since this would be of great prospective benefit and importance.
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Collaborating vehicles for increased traffic safety


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