WIRELESS STERATEGIES FOR FUTURE AND EMERGING ITS APPLICATIONS

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ABSTRACT

Within the Intelligent Transportation Systems (ITS) field, many applications of a diverse nature are considered and thus their communication requirements differ significantly. This makes it difficult for one wireless carrier to support all or most of these applications. Therefore, we have complied a list of communication requirements for future ITS applications and used it to analyze different ITS applications as well as different wireless carriers. Accordingly, the applications can be grouped into different requirements profiles with recommended wireless carriers assigned to each profile. The concept of profiling can also be used to classify the applications according to their non-technical requirements and hence accelerate their future deployment by encouraging involved stakeholders to make the most common requirements available. It can also be useful when developing a roadmap for deployment of future ITS applications defining which application will most likely be implemented first.

INTRODUCTION

In a not too distant future, vehicles and road infrastructure are expected to be equipped with intelligent devices that allow them to communicate and collaborate with each other, exchanging both safety and non-safety information. Various applications within the Intelligent Transportation System (ITS) field are considered for safety, efficiency and environmental purposes. Recently, cooperative vehicular communications have gathered considerable interest through different European projects such as: CVIS (1), SAFESPOT (2), and COOPERS (3). Similar activities are also ongoing in the US and Japan.

In order to realize the communication in-between vehicles and between the vehicles and roadside stations, a reliable wireless channel is needed. However, wireless channels are inherently unreliable and vulnerable to transmission errors. This poses a great challenge especially noticeable in a vehicular environment due to its dynamic properties and high mobility. Therefore, additional efforts are needed to achieve the communication requirements regarding timeliness, reliability, bandwidth, priority, and latency when using wireless channels. Today, none of the existing wireless carriers is capable of supporting all of the emerging ITS applications alone due

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to the varied and diversified nature of the requirements. Accordingly, a new methodology, technique or standard needs to be adopted.

The main goal of this paper is to evaluate the communication requirements of a number of ITS applications and, based on these, suggest suitable wireless carriers. Our approach is mainly based on the concept of profiling. First, some general communication requirements for future ITS applications are defined. Next, a list of ITS applications extracted from different EU projects is compiled and assessed according to the communication requirements. The same communication requirements are then used to evaluate some important wireless carriers. Finally, appropriate carriers are assigned to the selected ITS applications.

COMMUNICATION REQUIREMENTS

A list of communication requirements for ITS applications has been compiled based on the work in e.g., (4-5). However, even though the list has been extended, it is still not exhaustive since, for example, security requirements were not included. The criterion on which we base our list is that the list items represent the most general and important requirements likely to be defined in the first phase of developing the communication part of an ITS application. The requirements have been divided into three different categories: data traffic characteristics, communication functionality requirements and communication quality requirements. Note that these requirements are found on different levels in the ISO OSI protocol layer stack. For example, the data traffic characteristics are typically derived from the application layer, the communication functionality requirements originates both from the application layer and from the network layer whereas most of the communication quality requirements are met at the data link and the physical layers.

The data traffic characteristics describe the characteristics of the data to be sent, and is defined as follows:

1. *Information transmission control*: this defines when a transmission of data is initiated which could be *event driven* or *time triggered*. It could also be *hybrid* scheme where information is usually sent in a periodic manner but as soon as a critical event occurs an event driven message is transmitted.
2. *Minimum frequency*: this addresses the rate at which the transmission of data messages is repeated or updated (e.g. 1 Hz). It can be applied to both event driven (once an event has occurred) and time triggered schemes. Note that this value is zero if a message is never to be repeated.
3. *Transmission content*: this defines the details of the contents of the data messages to be sent or received such as the vehicle's position, direction, and acceleration.

The communication functionality requirements describe how the data should be sent, and include:

1. *Communication mode*: this is divided into five different types defining the source and destination of the communication: *vehicle-to-vehicle communication* (V2V), *vehicle-to-roadside infrastructure communication* or roadside infrastructure-to-vehicle communication (V2R), *roadside infrastructure-to-roadside infrastructure* communication (R2R), *vehicle-to-traffic management center* communication or vice versa (V2C) and

finally *roadside infrastructure-to-traffic management center* communications or vice versa (R2C).

2. *Addressing*: this is important especially for applications that require *point-to-point* communication and for future implementation of the Internet. However, the addressing scheme may also need to support *point-to-multipoint*.
3. *Directionality of information transmission*: this includes *one-way* communication for informative applications; and *two-way* communication for interactive applications where the communicating units need to establish a dialog. For both of them the communication could be point-to-point or point-to-multipoint.
4. *Communication services*: this can be *connection oriented* where the connection should be set-up 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 connection.
5. *Transmission scheme of information*: this could be either *real-time transmission* where the information has to be transmitted directly when obtained; or *storage transmission* where information can be stored and transmitted when it is required.

The communication quality requirements describe what quality is needed for a particular message to support the overall application and include the following:

1. *Allowable latency*: this defines the time interval between the data packet generation by the transmitter to the time it is delivered to the receiver.
2. *Bandwidth*: the bandwidth defines the rate, i.e., the amount of data (in bits/second) that is needed by a particular data message at a particular time instant.
3. *Communication range*: this is the maximum distance between two communicating stations that can be supported.
4. *Reliability*: a reliable system necessitates that the network covers the predefined range and that the data reaches its specified destination with sufficiently low error rate. Reliability becomes very important when dealing with time-critical safety warning messages where errors are close to intolerable.
5. *Priority*: a priority mechanism defines which application, e.g., delay-sensitive, should have access to the communication channel faster than the others or which application that should have the highest bandwidth at a particular time instant.

APPLICATIONS PROFILES

The applications considered here are suggested applications for the projects CVIS (1) and SAFESPOT (2), as well as some general active safety applications, related but not identical to the applications from the PReVENT project (6). The applications in the CVIS project are developed mainly to increase road throughput and efficiency. Applications in three domains are considered namely, cooperative applications for urban areas (CURB), e.g., *area routing and control*, inter-urban areas (CINT), e.g., *enhanced driver awareness* and freight and fleet management (CFF), e.g., *dangerous goods monitoring*. The applications in SAFESPOT are focused on cooperative road safety, and are divided into vehicle-based (e.g., *lane change maneuver*) and infrastructure-based (e.g., *speed alert*) applications. The general active safety applications are mainly aimed at increasing road safety (e.g., *pedestrian crossing information*).

To quantify the communication quality requirements (i.e., latency, bandwidth, range, reliability and priority), we assign values within a certain range, i.e., high/long, medium, and low/short. For example, the latency is classified as *very short* (up to 100 milliseconds), *short* (milliseconds to one second), *medium* (seconds to one minute), and *long* (minutes). A *small* bandwidth is often enough 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). Reliability is classified *high* (safety-critical data traffic), *medium* (non-safety critical data traffic), and *low* (video, voice and music download). Priority is typically *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 e.g., commercial and entertainment information.

The CVIS applications can be described shortly as follows (1):

- Flexible Lane Allocation: in urban areas a dedicated bus lane can be made available to certain vehicles to increase vehicle traffic efficiency as long as public transport is not compromised.
- Network Management: individualized route guidance and traffic management in urban areas by using vehicle/driver destination and other characteristics.
- Area Routing and Control: local intersection controllers in urban areas give individual, destination-based route guidance and informs about disturbances in local traffic flow as well as suggesting appropriate rerouting advice.
- Local Traffic Control: enhanced local intersection controllers in urban areas supports and creates green waves through speed profile recommendations for the drivers and data exchange with neighboring intersections.
- Enhanced Driver Awareness: inform vehicle drivers (within 5 s) in inter-urban areas by communication from the roadside or from other vehicles, about relevant aspects of the dynamic traffic situation, current speed and other regulations, road and weather conditions downstream.
- Travelers Assistance: personalizes the route selection in inter-urban areas. Will provide information to the driver (within 15 s) about a major congestion incident and (15 s) later they receive a recommendation about an alternative route.
- Monitoring and Guidance of Dangerous Goods: tracking and route selection for vehicles carrying dangerous goods.
- Parking Zone Management: reservation of (commercial) parking space or loading place.
- Access Control to Sensitive Infrastructure: geo-fencing for e.g., preventing vehicles with dangerous goods from entering certain areas.

The SAFESPOT applications (2) typically include warnings being exchanged between vehicles, e.g., lane change, front collision, black spot warning and cooperative situation awareness, which also include information obtained from roadside infrastructure.

In Table 1 below the communication requirements of the different applications are shown. Note that all applications assume connection-less real-time communications.

Event driven / Time triggered	Communication mode	Addressing	Directionality	Latency	Bandwidth	Range	Reliability	Priority	Applications
Event	V2R R2R R2C	P2P	Two-way	M-L	M	M	M	M	CVIS CURB: Flexible Lane Allocation
Time	V2R R2R R2C	P2P	Two-way	M-L	M	M	M	M	CVIS CURB: Network Management
Event	V2R R2R	P2P	Two-way	M	M	S-M	M	M	CVIS CURB: Area Routing and Control
Event	V2R R2R	P2P	Two-way	S-M	M	S	M	M	CVIS CURB: Local Traffic Control
Event/ Time	V2V V2R R2R	P2multiP	One-way	M	M	S-M	M-H	M-H	CVIS CINT: Enhanced Driver Awareness
Event/ Time	V2R R2R R2C	P2P/ P2multiP	One-way/ Two-way	M	M	M-L	M	M	CVIS CINT: Travelers Assistance
Time	V2C	P2P	Two-way	L	M	L	M	M	CVIS CFF: Monitoring and Guidance of Dangerous Goods
Event	V2R/ R2C	P2P	Two-way	L	M	S/L	M	M	CVIS CFF: Parking Zone Management
Time/ Event	V2R/ R2C	P2P	Two-way	L	M	S/L	M	M	CVIS CFF: Access Control to Sensitive Infrastructures
Event	V2V /V2R	P2multiP	One-way	VS-S	S	S	H	H	SAFESPOT / General Active Safety Applications

Table 1: ITS applications and their communication requirements

WIRELESS CARRIERS

The evaluated carriers include cellular networks, Wireless LAN (IEEE 802.11), Dedicated Short Range Communication (DSRC), Infrared (IR), and millimetre-wave (MM), as well as the new Continuous Air-interface Long and Medium range (CALM) standard. Each carrier is typically developed for a particular purpose and as such they are best if used for this purpose. Thus, a short description together with the pros and cons of each carrier with respect to the communication requirements is provided. Further details can be found in (7).

1. *Cellular networks (2G/3G)*: include e.g., the Global System for Mobile communications (GSM) second generation 2G, the General Packet Radio Service (GPRS) i.e. 2.5G, and the Universal Mobile Telecommunications System (UMTS) third generation 3G. Cellular networks are developed for voice applications and consequently they provide low delay time-critical support at the expense of reduced reliability. Note however, that the reduced reliability can be

tolerated for voice applications whereas this is not the case for most applications carrying data traffic. In general, cellular networks have several attractive characteristics like large-scale usage, long range communication and the ability to offer continuous access to secure data. Nonetheless, the technology still has some disadvantages that prevent or restrict its use for some ITS applications:

- the technology is currently too slow for low-delay time-critical information, because of the large end-to-end delay (i.e. often several seconds since the data needs to be sent via a base station rather than direct V2V or V2R communications);
- voice has higher priority than data packets (which further increases latency during periods of high voice traffic);
- there is generally a need to obtain the phone number to the destination (which is difficult for vehicular communications, geographical addressing as well as broadcasting);
- the use of cellular technology typically requires operation fees and an agreement with an operator (5), (8).

This is a feasible carrier for moderate delay, low rate inter-vehicle communications (note though that the inter-vehicle communication takes place via a base station).

2. *Wireless LAN (IEEE 802.11)*: consists of a number of different physical layer protocols like 802.11a, 802.11b and 802.11g. Wireless LAN IEEE 802.11 could in theory be used for direct V2V communication as it supports two basic network topologies: the infrastructure basic service set (BSS) and the independent basic service set (IBSS). An IBSS is a set of stations that communicate directly with each other without an access point (AP). However, it is only the BBS topology that is mandatory in the standard and as a consequence most WLAN products do not support direct communications without an AP (9). With the BSS topology, WLANs are similar to cellular networks, with the difference that they are developed for high rate internet applications and therefore usually provide high rate and high reliability communications but no support for time-critical communications. Consequently, the user is assumed to be stationary and there is very limited support for handover between APs. For this reason a new WLAN standard IEEE 802.11p is under development (9). It is intended for applications in a vehicular environment, e.g., traffic safety and emergency services requiring high reliability and low delay. The 802.11p will operate with IBSS network topology using the physical layer IEEE 802.11a and quality of service enhancements of IEEE 802.11e. It further introduces a number of changes to parameters in IEEE 802.11a necessitated by the need for latency minimization, support of communications at high vehicle speed, authorization and anonymity while in the same time not affecting or influencing the messaging reliability and integrity, content, security, or robustness. The drawback is that the medium access method CSMA of IEEE 802.11 will be used and this can lead to many collisions when the senders want to access the medium at the same time (10-11). Some studies have been carried out to evaluate the performance of IEEE 802.11a (12), IEEE 802.11b (10) and IEEE 802.11p (11) for inter-vehicle communication. The IEEE 802.11p is a good carrier for traffic safety applications and direct V2V and V2R communications as long as the system load is reasonable, whereas the IEEE 802.11a/b/g is a good for internet access and high speed data communications when vehicle speeds are low.

3. *Dedicated Short Range Communication (DSRC)*: was from the beginning synonymous with radio frequency identification (RFID), which is a form of wireless identification. DSRC is defined as a short to medium range communication services that typically supports both public

safety and private operations in V2R communication environments. Today there are different DSRC standards for Europe (CEN) and Japan (ARIB) as well as a completely different definition of DSRC in the US (9). DSRC is largely used for toll collection in Europe and thus a roadside station is needed which acts as a master whereas the vehicle and mobile stations act as slaves. This is a good carrier for collecting information from passing vehicles or for informing passing vehicles about local conditions around the roadside station. The roadside station may or may not be further connected to a server or to the internet. Some of safety applications have been demonstrated in Japan using DSRC at the Smartway project, 2007. In US, the abbreviation DSRC refers to the IEEE 802.11p (9).

4. *Infrared (IR)*: has been used successfully in several projects, such as Electronic Toll Collection in Malaysia and Korea, Truck Tolling Scheme in Germany, and Vehicle Information and Communication Systems (VICS) in Japan. An important feature of this media is its high beam directivity which is useful in applications where lane dependent messages have to be transmitted. Directional communication can be used for many purposes such as sending position dependent messages, increasing the data traffic transfer rate or the data reliability at the expense of narrow transmission cones, and to achieve high privacy. Additional attractive features of IR are: no license or agreement with providers is required, and there are no bandwidth allocation restrictions (8). The typical range of infrared is up to 100 m with a data rate of 1 Mbps.

5. *Millimeter-waves (MM)*: Millimeter-wave band is defined as the frequencies between 60-64 GHz or bands at 30- and 40 GHz. Millimeter wave at 60 GHz can support direct communication between vehicles to form inter-vehicle communication without the use of a fixed infrastructure. Compared to IR, MM at 60 GHz has three main advantages: it is less affected by weather conditions, less prone to interference from sunlight, and can provide communication links even in case of nonline-of-sight conditions by use of multipath propagation (13-14). Other advantages of millimeter wave are:

- high capacity for high-speed broadband communications;
- possibility of a lower number of interfering signals due to the high level of attenuation;
- has a possibility of integration with radar systems where it shares circuit with the on-board radar system;
- ability to use small antenna sizes and radio-frequency circuits that can be easily integrated in the vehicle and infrastructure (13-15).

However, some of the disadvantages are: communication can be affected by the relative movement between the vehicles (due to the short wave length), strong signal fading can occur (due to the interference between the direct and reflected waves) and it is difficult to provide long distance transmission (since the radio waves are attenuated in space). The latter has been considered as additional advantage due to the high reuse efficiency of frequency and added security. Consequently, millimeter wave is best used to service either short or medium range applications. The data rate can be in the order of few megabits per second with the range from few meters to one kilometer (13-14).

6. *Communication Air-Interface Long and Medium (CALM)*: according to (16), the scope of 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 transfer between media. Due to the

different choices of ITS media and frequencies in different countries, CALM includes several different carriers in order to be able to operate in any place at any time. This combination of media is also due to the fact that different ITS applications have different requirements, where a single carrier can not support all types of applications. The media used inside the CALM includes 2G and 3G cellular systems (for long distance), CALM IR and 60 GHz MM (for directed communication, short and medium distances), CALM M5 (for omni-directional short and medium distances).Other carriers are to be added in the future such as PAN technologies (Bluetooth) and WiMAX (IEEE 802.16e). The media currently considered inside CALM are described below:

1. *CALM 2/2.5G and 3G*: defines the air interfaces using different cellular networks. The aim is to utilize existing 2G and 3G coverage for long range seamless ITS connectivity with medium data transfer speed.
2. *CALM IR*: specifies the air interface by using infrared systems operating in the range of 820 to 1010 nanometers. CALM IR supports 2 Mbps with 10 ms latency.
3. *CALM 60 – 70 GHz*: this is defined as a millimeter wave band and has been included in the CALM media because of its high data rate and high directivity.
4. *CALM M5*: this standard specifies the air interface by the use of microwave systems operating in the 5 – 6 GHz frequency range. The idea is to support medium range, direct V2V communications without communication infrastructure the same way as IEEE 802.11p (15). Collaboration between standardization bodies (ISO, IEEE etc) is ongoing.

The service of CALM includes different communication modes such as V2V, V2R, R2R, V2C and R2C. Various applications (traffic safety, efficiency and commercial applications) are expected to be supported by CALM using its different communication modes.

In table 2 below, the discussed carriers are listed together with some of the communication requirements. Not all of the communication requirements defined earlier are included in the table, since some can be supported by all considered carriers (time triggered/event driven communication), whereas others can be enforced by upper layers (connection oriented/ connectionless, real-time/storage and priority) and hence they do not affect the choice of carrier. Regarding the reliability requirement when seen from an application viewpoint, it defines the level of reliability required by the specific type of application (high, medium, and low), whereas from a carrier perspective it relates to the range and the data rate (i.e., in order to say that a specific rate or a specific range is supported, the carrier also needs to provide communication above a certain acceptable reliability threshold for that particular rate or range). Note also that a higher reliability can be achieved by retransmissions implemented in higher layers at the expense of increased latency.

Carriers	Communication mode	Addressing	Directionality	Latency	Data rate	Range
2G/3G	V2V* V2R R2R V2C R2C	P2P	One-/two-way	M-L	80 kbps (2G) 384 kbps (3G) 14.4 Mbps (HSPA)	L
IEEE 802.11a/b/g	V2V* V2R R2R	P2P	One-/two-way	M	802.11a: 54 Mbps 802.11b: 11 Mbps 802.11g: 54 Mbps	M
IEEE 802.11p	V2V V2R R2R	P2P/ P2multiP	One-/two-way	VS-S	~ 6 Mbps	S-M
DSRC	V2R	P2P/P2multiP	One-/two-way	VS-S	500 kbps	S-M
IR	V2V V2R**	P2P/P2multiP	One-/two-way	VS	1 Mbps	S
MM	V2V V2R**	P2P	One-/two-way	VS	Few Mbps	S
CALM M5	V2V V2R R2R	P2P/P2multiP	One-two-way	VS-S	~ 6 Mbps	S-M
CALM 2G/3G	V2V* V2R R2R V2C R2C	P2P	One-/two-way	M-L	80 kbps (2G) 384 kbps (3G) 14.4 Mbps (HSPA)	L
CALM IR	V2V V2R**	P2P/P2multiP	One-/two-way	VS	2 Mbps	S
CALM MM	V2V V2R**	P2P	One-/two-way	VS	Few Mbps	S

* Note that the V2V communication takes place via the base station or the access point (the communication infrastructure). See latency.
** Limited support for V2R depending on vehicle speed, i.e., a connection needs to be established and data transferred while in line of sight. See range.

Table 2: Carriers' Summary

ANALYSIS AND RESULTS

Finally, we are ready to establish the relations between the applications and the carriers based on the communication requirements. These are illustrated in Table 3 which lists the applications together with their recommended carriers.

Applications	Carriers
CVIS CURB: Flexible Lane Allocation	2G/3G (CALM 2G/3G)
CVIS CURB: Network Management	2G/3G (CALM 2G/3G)
CVIS CURB: Area Routing and Control	2G/3G (CALM 2G/3G) and/or IEEE 802.11p (CALM M5)
CVIS CURB: Local Traffic Control	IEEE 802.11p (CALM M5)
CVIS CINT: Enhanced Driver Awareness	IEEE 802.11p (CALM M5) and/or IR (CALM IR) and/or MM (CALM MM)
CVIS CFF: Monitoring and Guidance of Dangerous Goods	2G/3G (CALM 2G/3G)
CVIS CFF: Parking Zone Management	2G/3G (CALM 2G/3G)
CVIS CFF: Access Control to Sensitive Infrastructures	2G/3G (CALM 2G/3G) and/or IEEE 802.11p (CALM M5) and/or DSRC
SAFESPOT / General Active Safety Applications	IEEE 802.11p (CALM M5) and/or IR (CALM IR) and/or MM (CALM MM)

Table 3: Application and Carrier Matching

When selecting suitable carriers for the different applications, range was an important factor. If long range communication or V2C and R2C communications is required, 2G/3G is the only choice among the considered carriers. Vise versa, when short range, low delay V2V communication is required, 2G/3G is no longer an option.

Further, different requirements profiles can be observed. Traffic safety applications typically have a communication requirements profile which includes event driven, point-to-multipoint, one-way communication, real-time transmission, very low or low latency, small bandwidth, short communication range, high reliability, and high priority. Most general active safety applications as well as applications from the SAFESPOT project can be found in this profile. Examples of applications are: *black spot warning*, *read-end collision* and *lane change assistance*. Individual differences can then be found depending on, e.g., if communication takes place in-between vehicles only or if it also includes roadside stations. For these types of applications, carriers that enable direct V2V or V2R communications and does not rely communications infrastructure such as base stations or APs are best suited (e.g., IEEE 802.11p, CALM M5 or CALM IR).

Traffic management and efficiency applications typically includes requirements such as event driven, point-to-point, two-way communication, real-time transmission, medium latency, medium bandwidth, medium communication range, medium reliability, and medium priority. The relaxed requirements on latency introduce 2G/3G as an option. However, depending on how "local" the application is, carriers such as IEEE 802.11p and CALM M5 are also possible.

Finally, if the application relates to a fixed geographical location, infrastructure based carriers such as DSRC can also be considered.

CONCLUSION

The contribution of this work is twofold; firstly, identifying and evaluating different communication requirements, and secondly, classifying a range of diverse applications and wireless carriers based on these requirements. It was concluded that some applications could be merged together due to similar communication requirements. For example, all safety applications implying different warnings can largely be grouped into one requirements profile. Further, some applications may need more than one carrier to fulfill their full function (e.g., CVIS CFF: Access Control to Sensitive Infrastructures). Finally, for other applications, more than one suitable carrier could be recommended.

The concept of profiling communications requirements used here can also be helpful for non-technical requirements of ITS applications. For example, organizational and legislations issues that include all stakeholders involved in the development and deployment of ITS applications, requires cooperation between public and private sectors. The applications can then be divided into different profiles according to their non-technical requirements. This will simplify the decision on which requirements are most common. Accordingly, companies, government and road operators will be encouraged to make these requirements available and hence accelerate the deployment of ITS applications. Applications profiling can also be helpful in developing a roadmap for future ITS applications deciding, according to the technical and non-technical requirements, which application will most likely be implemented first.

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