Wireless Communication Technologies for ITS Applications

Kashif Dar, Mohamed Bakhouya, Jaafar Gaber, and Maxime Wack,
University of Technology of Belfort-Montbéliard
Pascal Lorenz, University of Haute-Alsace

ABSTRACT

Intelligent transport systems are the rising technology in the near future to build cooperative vehicular networks in which a variety of different ITS applications are expected to communicate with a variety of different units. Therefore, the demand for highly customized communication channel for each or sets of similar ITS applications is increased. This article explores the capabilities of available wireless communication technologies in order to produce a win-win situation while selecting suitable carrier(s) for a single application or a profile of similar applications. Communication requirements for future ITS applications are described to select the best available communication interface for the target application(s).

INTRODUCTION

With the growth and expansion of wireless communication technologies, considerable research efforts have been made in the area of intervehicle communication (IVC). The objective is to increase driver safety and comfort by relaying required information from vehicle to vehicle. Future vehicles are expected to anticipate and avoid possible collisions, navigate the quickest route to their destination making use of up-to-the-minute traffic reports, identify the nearest available parking slot, and minimize their carbon emissions. One of the most important challenges to convert all these dreams into reality is that these future applications have diverse communication requirements and will be used in different countries following different traffic rules and even different legal frequency bands. Therefore, understanding the communication requirements of target applications is key to selecting an appropriate communication channel. To achieve this, we need to define a set of communication parameters on the basis of which we can judge the suitability of a communication medium within a particular environment.

In this article we analyze the communication requirements for intelligent transport system (ITS) applications and give some guidelines to select suitable technologies to fulfill their communication needs based on the following parameters.

While talking about vehicles' communication to the outside environment, *communication mode* is divided into two types: vehicle to Infrastructure (V2I)[1] and vehicle to vehicle (V2V) communication. The later is further divided into two types:

- V2V direct communication in which a vehicle communicates directly with another vehicle without third party involvement
- V2V indirect communication in which two vehicles communicate by third party mediation

Directionality includes one-way and two-way communication. The first is used for informative applications, while the second is used for interactive applications. *Operating band* is the range of frequencies within which the communication channel will operate. *Transmission mode* could be either unicast: data is transmitted to only one particular destination unit, broadcast: data is transmitted to multiple destination units, or geocast: data is transmitted to only those destination units lying in a particular vicinity. *Latency* defines the time interval between data packet generation by the transmitter and the time it is delivered to the recipient. *Data rate* represents the number of bits transmitted in a unit of time. *Communication range* is the maximum distance between two communicating units that can be supported by a communication medium. *Mobility* represents support for mobility of communicating units. *Reliability* of a communication system ensures that data reaches its destination with a sufficiently low error rate. Lastly, the *priority* mechanism defines which application is more delay-sensitive, should have preference in acquiring the communication channel, or should have the highest bandwidth at a particular moment.

We first classify ITS applications and analyze their communication requirements. The most common wireless communication technologies are then classified and described briefly in the context of automotive usage. Finally, potential wireless technologies are identified to be considered in the design and deployment of ITS applications.

ITS APPLICATIONS

ITS applications have generally been classified into three main categories with respect to their functionalities: safety, efficiency, and comfort

[1] I *stands for a backend infrastructure or roadside unit.*

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applications [1–4]. Figure 1 illustrates the whole picture of this classification.

SAFETY APPLICATIONS

Safety applications minimize the risk of accidents and, most important, reduce the severity of the accident if it still occurs (collision avoidance, incident management, etc.).

Collision Avoidance — Collision avoidance applications are used to warn a driver when a collision at an intersection is probable. For example, a *safe distance application* is used to dynamically adjust distance (from the vehicles ahead) and speed to a recommended value dependent on the actual traffic situation. Typically, this is a V2V application that requires short range to monitor the inter-distance length of vehicles in front; however, the response time should be minimal, resulting in low latency demand in microseconds. Another application is *intersection collision avoidance*, which assists drivers in make left or right turns at intersections. The infrastructure and/or in-vehicle unit determines when a collision is imminent and issues a warning to either a specific vehicle or all vehicles in the vicinity. Hence, this application demands a communication channel that can support a medium data rate, with short communication range (maximum 500 m) and low latency. There is no need for a high data rate due to the limited and small amount of data to be transferred between vehicles and roadside unit (RSU).

Road Sign Notifications — Road sign notifications (RSNs) are used to inform drivers about the traffic signs further down the road so that they become attentive to the road signs. For example, an *in-vehicle signage* application provides information to a driver that is typically conveyed by traffic signs. Therefore, it requires a medium data rate with low latency and high reliability within a range of 500 m. Similarly, *curve speed warning* is another application in this category that uses the information (e.g., curve speed limit, curvature, and road surface condition) communicated from roadside beacons located ahead of approaching curves. Thus, the in-vehicle system would be able to determine and inform the driver of the recommended speed to pass through the curve. The information sent by RSUs should have high priority and reliability. Furthermore, latency should also be low at the expense of a medium data rate.

Incident Management — The third type of safety application is related to intelligent incident handling after an unfortunate accident. For example, *emergency vehicle warning* provides the driver a warning to yield the right of way to an approaching emergency vehicle. This application requires medium data rate, low latency, high message priority and reliability, and multicasting/geocasting support. Another example is *post crash warning*, which warns approaching traffic about a vehicle having an accident or a mechanical breakdown stuck within traffic lanes. This application demands medium data rate, low latency, and broadcast within a range of 1 km.

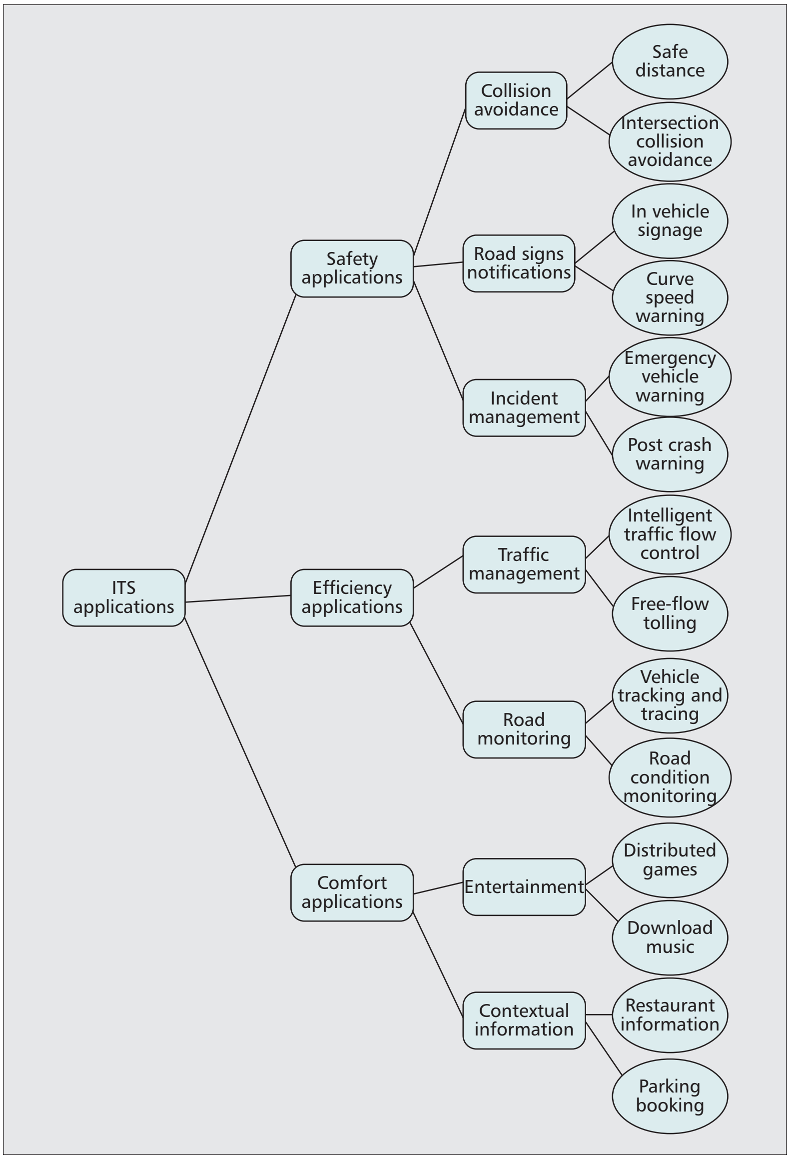

Figure 1. *A classification of the existing ITS applications.*

EFFICIENCY APPLICATIONS

The second major category includes applications that increase traffic efficiency by managing the traffic flow, and monitoring vehicles and road conditions.

Management Applications — This type of applications is used to manage the traffic flow on roads. For example, *intelligent traffic flow control* is an infrastructure application that makes periodic broadcasts requesting the information from nearby vehicles. This application then uses traffic flow information provided by nearby vehicles to dynamically conform the traffic light signal phasing based on real-time traffic flow. The data rate requirement for such an application is medium with communication range from 200 to 400 m. *Free-flow tolling* is another infrastructure application that works on toll roads and communicates with vehicles for electronic toll collection. This application requires two-way communication between vehicle and infrastructure, low latency, high message reliability, medium data rate, and a range of around 70 m.

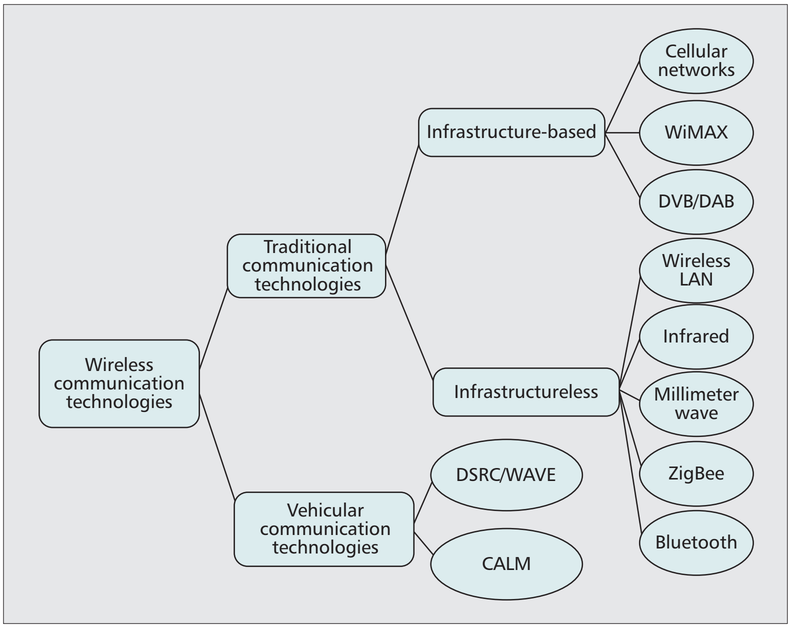

Figure 2. *A classification of wireless communication technologies.*

Monitoring Applications — These applications help monitor vehicles and road conditions. For example, *vehicle tracking and tracing* (T&T) is an application that assists in remotely detecting both spatial and speed traffic rule violations by vehicles. Vehicle T&T is an infrastructure-based application that requires a channel to support long-range communication with the backend infrastructure. Therefore, an infrastructure-based technology like cellular networks would be suitable for such an application because it requires moderate data rate, tolerable latency, and increased data reliability.

Another monitoring application is *road condition monitoring* (RCM), which provides road condition information to be used by vehicle safety applications. For example, an onboard application can detect marginal road conditions using in-vehicle systems and sensors, and transmit a road condition warning to approaching vehicles using a suitable air interface and data dissemination protocol. RCM is an onboard application that usually requires direct or indirect V2V communication, and thus demands medium range with medium data rate and latency.

COMFORT APPLICATIONS

The purpose of comfort applications is to provide entertainment facilities and up-to-date contextual information to passengers by means of Internet access, such as distributed games and tourist information.

Entertainment Applications — Entertainment applications include *distributed games*, which allow passengers in one vehicle to use onboard/nomadic devices and play games with passengers in surrounding vehicles. *Downloading music* is another entertainment application that requires Internet access to allow passengers to download their favorite songs or videos using in-vehicle nomadic devices. This type of application requires high-speed nomadic Internet access like WiMAX. Higher latency and less data reliability can be tolerated by non-safety applications.

Contextual Applications — These applications increase driver awareness about local attractions during a journey. For example, *parking booking* can assist a driver in finding a nearby parking place and booking the parking slot. *Restaurant information* applications are especially designed for highway road users interested in finding out the nearest restaurant with some additional information (e.g., food prices and menu). Contextual applications need to establish communication with local RSUs to collect local information, or backend infrastructure like a traffic management center can also assist drivers in updating information on the local environment. In the first case, a short-range communication channel is enough to fulfill the V2I communication needs, while in the latter case, a long-range communication system like Internet connection, a cellular network, or WIMAX-based Internet would be the preferred technologies.

Table 1 summarizes the communication characteristics and features of ITS applications. Abbreviations used are described in Table 2.

WIRELESS COMMUNICATION TECHNOLOGIES

Wireless communication technologies can be divided into two main categories: Traditional wireless technologies and vehicular communication technologies (VCTs) [5–7]. Figure 2 depicts the whole picture of this classification. A short description together with the pros and cons of each communication medium are provided below.

TRADITIONAL WIRELESS TECHNOLOGIES

Traditional wireless technologies are mainly divided into infrastructure-based and infrastructureless technologies. The former is used for long-range communication, while the latter is used to support 1 km maximum range.

Infrastructure-Based Technologies — Infrastructure-based technologies are equipped with several base stations to relay communication signals and cover a long range. *Cellular networks* (e.g., GPRS, EVDO, and 3G) are designed for voice data exchange. Due to time-critical support, they have low latency at the expense of reduced reliability. Usually, cellular networks have several appropriate characteristics like large-scale usage and long-range communication; however, some drawbacks are summarized below:

- They provide so-called low latency because voice data has higher priority than text data, which increases latency. In addition, latency is further increased as the data is sent via base stations instead of direct V2V or V2I communication.
- They are not suitable for broadcasting purposes since they support point-to-point communication.
- The use of cellular technology requires operation fees and an agreement with an operator.

Communication requirements	ITS applications						
	Safety applications			Efficiency applications		Comfort applications	
	Collision avoidance	Road sign notifications	Incident management	Traffic management	Road monitoring	Entertainment	Contextual information
Communication mode	V2V/ V2I[d]	I2V[d]	V2V/ I2V[d]	V2I/ V2I[d]	I2V/ I2V[d]	I2V	I2V/ V2V[d]
Directionality	1/2	1	1	1/2	1	1/2	1/2
Latency	Very low	Low	Low	Low-medium	Low	Average	Medium
Data rate	Medium	Medium	Medium	Low-medium	Low-medium	High	Low-medium
Range	Short	Short	Short-medium	Short-medium	Short-medium	Long	Medium-long
Transmission mode	1	1/3	1/2	1	1/3	1	1
Message reliability	High	High	High	Medium-high	Medium-hgh	Average	Average
Message priority	High	High	High	Medium	Medium	Average	Average

Table 1. *Communication requirements for ITS applications.*

Communication mode		Directionality		Latency		Range		Transmission mode		Data rate	
V2V[d]	Vehicle-to-vehicle direct communication	1	One-way	Very low	In microseconds	Short	< 500 m	1	Unicast	High	> 6 Mb/s
V2V[i]	Vehicle-to-vehicle indirect communication	2	Two-way	Low	In milliseconds	Medium	~ 1 km	2	Geocast	Medium	1–6 Mb/s
V2I	Vehicle-to-infrastructure	1/2	Both	Average	In seconds	Long	> 1 km	3	Broadcast	Low	< 1 Mb/s

Table 2. *Abbreviations used in Tables 1 and 3.*

However, despite all these drawbacks, cellular networks are feasible for ITS applications (e.g., entertainment and contextual information) that require moderate delay, long-range communication, and low data rate.

Worldwide Interoperability for Microwave Access (WiMAX), based on the IEEE 802.16 standard, is a telecommunications technology aimed at providing wireless data over long distance in a variety of ways, from point-to-point links to full mobile cellular type access. Mobile WiMAX, defined by IEEE 802.16e, provides support for mobility. WIMAX offers portable connectivity, high-speed data, and a wireless alternative to cable/DSL for last mile broadband access. Moreover, this potential technology can also be used with cellular networks as a layover to increase capacity. Like cellular networks, WiMAX can be used for V2I or I2I long-range communication to provide, for example, high-speed Internet access to mobile users.

Digital Video Broadcasting (DVB) is an industry-led consortium committed to designing a family of standardized technologies to support global delivery of digital multimedia services. Three key standards in this technology include DVB-T, DVB-C, and DVB-S, which provide the delivery of program content by terrestrial, cable, and satellite, respectively.

DVB-T is used to broadcast land-based signals. The purpose of digital terrestrial television is reduced use of spectrum and more capacity than analog, better-quality picture, and lower operating costs for broadcast. The United States has switched from analog to digital terrestrial television, while Europe is hoping to have mostly completed its switchover by 2012. DVB-S allows transmission of MPEG-2/MPEG-4 family audio/video streams via satellite, while DVB-C enables the transmission of the same digital audio/video stream over cable. Both DVB-S and DVB-C are now replaced by DVB-S2 and DVB-C2 with enhanced features.

Recently, *DVB-Handheld* (DVB-H) was introduced for bringing broadcast services to mobile handsets. DVB-H was formally adopted as European Telecommunications Standards Institute (ETSI) standard EN 302 304 in November 2004. Beside DVB, Digital Audio Broadcasting (DAB) technology was also evolved for the purpose of digitizing audio programming in order to offer high-quality distortion-free reception of voice signals. However, this technology can be customized to carry any form of data (e.g., text, pictures, and even video).

Infrared technology has been used successfully in several ITS projects in Malaysia, Japan, and Germany. It can also be used for line of sight communication between RSUs and vehicles while far-infrared can be used for video surveillance.

DVB/DAB can be used for centralized broadcasting (e.g., traffic management and road condition monitoring applications), whereas DVB-H can be used for broadcasting audio/video programs for in-vehicle infotainment applications.

Infrastructureless Technologies — Technologies in this category do not require any infrastructure to operate. Therefore, these are easy to install and become ready to use within short period of time.

Wireless local area network (WLAN) technology supports IEEE 802.11a/b/g/n. Since this technology is designed for high data rates and reliability, with slight modifications it could be used for V2V direct communication. However, it provides less support for applications with time-critical communication and mobility of communicating nodes since it does not yield good results for frequent handover between different access points (APs). Another shortcoming in WLAN is that it does not provide good support for parallel medium access attempts by senders because it uses carrier sense multiple access (CSMA) for physical medium access. WLAN gives their users access to broadband communications in a nomadic environment. Today, radio LANs (RLANs) at 5 GHz (also known as Wi-Fi) gives a nomadic Internet access to users with portable or handheld devices such as PDAs or laptops. Wi-Fi is a shorter-range system (~ 250 m) with data rates varying from 6 to 54 Mb/s and uses unlicensed spectrum to provide network access. WiFi users can work from any location where they get Wi-Fi signals, and it is easily installable with reduced cabling cost.

Infrared (IR) is most suitable for applications requiring lane-specific communication due to its highly directional nature, increased data transfer rate (1 Mb/s) up to 100 m, and maximum data reliability. Furthermore, there is no need for licenses and agreements with providers, and no restrictions on bandwidth allocation [8]. Infrared does not penetrate walls, so it does not interfere with other devices in adjoining rooms. Infrared is the most common way for remote controls to command appliances (e.g., home electronics). Infrared technology has been used successfully in several ITS projects in Malaysia (electronic toll collection), Japan (Vehicle Information and Communication System [VICS]), and Germany (Truck Tolling Scheme), among others. It can also be used for line of sight communication between RSUs and vehicles while far-infrared can be used for video surveillance.

Bluetooth technology facilitates both voice and data transmission, and operates in the unlicensed industrial, scientific, and medical (ISM) band at 2.4 GHz over small distance (~10 m) using short-range radio links. Bluetooth has a lower data rate than Wi-Fi (less than 3 Mb/s), and its indoor range is typically 2–10 m. This technology is intended to provide cable free connection between different portable and/or fixed electronic devices. The main characteristics of Bluetooth technology include low power, low cost, low complexity, and robustness. Additionally, it can be used for mobile and wireless access to LANs, and Internet over mobile and other existing networks, where the backbone is wired but the interface is free to move. Bluetooth can be used for in-vehicle nomadic devices that provide cable free interface for onboard applications.

ZigBee technology supports IEEE 802.15.4 and is designed as a low-cost and flexible wireless medium; it offers low power consumption, reliability, and interoperability with small to medium data rates. This innovative technology has the following characteristics that recommend its usage for energy-efficient sensor-based applications:

- Dual physical (PHY) modes: 2.4–2.4835 GHz and 868–915 MHz
- Data rate: 20–40 kb/s @ 868–915 MHz and 250 kb/s @ 2.4 GHz within the range of 50–76 m
- High throughput and low latency
- Supports different network topologies like star, peer-to-peer, and mesh

Keeping in mind the above promises of ZigBee, this technology could be used for sensor-based ITS applications having low-energy devices requiring time-critical, medium data rate, non-line-of-sight, and reliable communication.

Millimeter-wave (MMWAVE) technology is a next-generation wireless technology that can provide up to multigigabit-per-second wireless connectivity for short distances between electronic devices. The data rate is expected to be 40–100 times faster than today's WLAN technologies, transmitting an entire DVD's data in roughly 15 s. This will be like having leading-edge wireline connectivity without worrying about cable connections. The MMWAVE band operates between 60–64 GHz, which can independently support direct V2V communication. Compared to IR, MMWAVE has three main advantages:

- Less affected by weather conditions
- Less prone to interference from sunlight
- Support for non-line-of-sight communication

Furthermore, MMWAVE can support small antenna sizes and radio frequency that can easily be integrated in the vehicle. Thus, MMWAVE is best suited for short-range applications with high data rates, especially for infotainment purpose.

VCTs

VCTs came into existence due to additional communication requirements of the ITS applications. The demand for mobility, dynamicity in IVC, and support for resource-constrained sensor-based applications necessitates the emergence of new communication standards and technologies that are most fit for automotive use. To fulfill this purpose, the following major communication technologies are currently under development.

DSRC/WAVE — Due to limited support for mobility by WLAN, extensions to WLAN IEEE 802.11 are being made, and a new standard, IEEE 802.11p, is currently under development. It is intended for applications in a vehicular environment (e.g., traffic safety and emergency services) requiring high reliability and low delay. This new standard, known as dedicated short-range communication (DSRC), will use the physical layer of IEEE 802.11a and quality of service enhancements of IEEE 802.11e.

Communication characteristics	Communication technologies									
	Traditional communication technologies								Vehicular communication technologies	
	Infrastructure-based				Infrastructureless					
	GSM/GPRS	WiMAX	DVB/DAB	WLANs (a/b/g/n)	MM Wave	IR	ZigBee	Bluetooth	DSRC/WAVE	CALM (M5)
Communication mode	V2I/V2V^i	V2I/V2V^i	I2V	V2V^i	V2R/V2V^d	V2R/V2V^d	V2V^d	V2R	V2R/V2V^d	V2R/V2V^d
Directionality	2	2	1	1/2	1/2	1/2	1/2	2	1/2	1/2
Latency	1.5–3.5sec	~110 ms	10–30 sec	~46 ms	~150 μs	Very Low	~16 ms	~100 ms	200 μs	200 μs
Data rate	80–384 kb/s	1–32 Mb/s	~1.73 Mb/s	54–600 Mb/s	~1 Gb/s	~1 Mb/s	20–250 kb/s	1–3 Mb/s	~6 Mb/s	~6 Mb/s
Range	10 km	15 km	40 km	250 m	~10 m	~10 m	~100 m	~10 m	~1 km	~1 km
Transmission mode	1/2	1/2	3	1	1	1	1	1	1	1
Mobility	Yes	Yes	Yes	Limited	Limited	No	Yes	Limited	Yes	Yes
Operating band	0.8–1.9 GHz	5.x GHz	6–8 MHz	2.4–5.2 GHz	60–64 GHz	2.6 GHz	2.4–2.5 GHz	2.4 GHz	5.8–5.9 GHz	5–6 GHz

Table 3. *Wireless communication technologies: characteristics and features.*

DSRC is defined as a short-range communication service designed to support communication requirements for safety applications used in the V2I communication environment. This technology is currently being used in Europe for electronic toll collection. Since, different countries are using different operating bands for DSRC, frequency harmonization efforts are being carried out, and a uniform 5.9 GHz band has been proposed.

Wireless access in the vehicular environment (WAVE) is the next-generation DSRC technology, which provides high-speed V2V and V2I data transmission [9]. The WAVE system is built on IEEE 802.11p and IEEE 1609.x standards operating at 5.850–5.925 GHz with data rates of 6–27 Mb/s, covering a range of up to 1 km. DSRC/WAVE can be used by roadside equipment to collect useful information about road conditions from passing vehicles and ultimately propagate that information to relevant vehicles.

Communication Air-Interface for Long- and Medium-Range Communication — The goal of the communication air interface for long- and medium-range (CALM) communication standard is to evolve an integrated technology to provide a set of air interface protocols and parameters for medium- and long-range high-speed ITS communication using one or more of several media. This standardization effort has the following major motivations:
- Different countries use different choices and frequencies for ITS media.
- Different ITS applications have different requirements; thus, it is impossible to use a single carrier to support all types of applications.

Thus, CALM will provide application-friendly communication services for a variety of ITS applications at any place and at any time. The media used inside the CALM includes:
- CALM 2G/3G mobile networks to support long distance communication with medium data transfer rate capability.
- CALM IR and MMWAVE operating at 60 GHz to support short- and medium-range directed communication. CALM IR operating in the range of 820–1010 nm supports 2 Mb/s with 10 ms latency.
- CALM M5 operating in the frequency range of 5–6 GHz is used for short- and medium-range omnidirectional communication.

CALM M5 is intended to enable direct V2V communication and is basically derived from DSRC/WAVE technology. Other media such as Bluetooth and WiMAX (IEEE 802.16e) are also expected to be integrated in future.

Table 3 presents communication characteristics and features of each wireless medium. Readers are referred to the documentation of each technology for more information.

Summary and Discussion

In the past few years, several projects around the globe have been carried out to develop ITS standards, technologies, and applications. The most common initiatives include CVIS, COOPERS, SAFESPOT, PreVENT, COMeSafety, PATH, VSC, and Smartway [10]. However, as of this writing, there is neither any ITS standard that is available for commercial usage, nor any specification of the communication medium to support communication requirements for ITS applica-

CALM integrates all potential wireless technologies. However, methods to transmit and receive data across wireless medium are required to avoid collisions and interferences. Security requirements must also be considered.

Functionalities	ITS application categories	Recommended carrier(s)
Safety	Collision avoidance	DSRC, WAVE
	Road sign notifications	DSRC, WAVE, CALM (M5)
	Incident management	WiFi, DSRC, WAVE, cellular network
Efficiency	Traffic management	DSRC, WAVE, cellular network, DAB
	Road monitoring	IR, ZigBee, DSRC, WAVE
Comfort	Entertainment	MMWAVE, WLAN, WiMAX, DVB, DVB-H
	Contextual information	DSRC, WAVE, cellular network, DAB

Table 4. *Potential wireless communication technologies for ITS applications.*

tions. Here, we provide a mapping methodology that allows the selection of suitable media for each class of applications.

Table 4 maps each category of ITS applications with potential carriers. DSRC/WAVE is a common technology that can be used by all safety and efficiency applications, especially when an application requires only V2V and V2I direct communication within a limited range not greater than 1 km. Cellular and WiMAX technologies can be used in case of V2I or I2I long-range communication. Cellular technologies are a good option for Internet access with medium data rates and have pre-installed infrastructure provided by a network operator. WiMAX, as an alternative, can also be used to provide high-speed Internet access to mobile users; however, this technology needs WiMAX base stations installed before its use. DVB/DAB technology has potential to be used within ITS applications for broadcasting purposes (e.g., traffic management and road condition monitoring applications), whereas DVB-H can be used for broadcasting audio/video programs for infotainment. Lastly, MMWAVE can be used as a high-speed air interface for nomadic devices within vehicle.

To support ITS applications, vehicles will communicate across multiple data links. For example, SAFESPOT builds on IEEE 802.11p and integrates other technologies such as GPRS. COOPERS has also defined architecture for an onboard unit supporting multiple carriers. CVIS, with the help of SAFESPOT and COOPERS, has defined the CALM architecture, which is expected to be a future ITS communication technology. To provide a single platform for a wide range of future communications requirements for ITS applications, CALM integrates all potential wireless technologies. However, methods to transmit and receive data across wireless media are required to avoid collisions and interference. Security requirements must also be considered to prevent attacks on the system such as fake message injection, message confidentiality and integrity, and privacy violation.

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Biographies

KASHIF DAR is a research scientist at the Univ. of Technology of Belfort-Montbéliard (UTBM), France. His research interests include secure communication, access control, vehicular communication technologies, and information dissemination.

MOHAMED BAKHOUYA is a research scientist at UTBM. His research interests include distributed/parallel algorithms, mobile computing, ubiquitous and pervasive computing, and artificial intelligence.

JAAFAR GABER [M] is an associate professor at UTBM. His research has been supported by many European grants within FP6 and FP7 projects. His research interests include distributed algorithms and mobile computing, computer networks, and communications. He is a member of the ACM.

MAXIME WACK is an associate professor at UTBM. He heads the Geopositioning, Embedded Systems, and Mobility team. His research interests include intelligent transportation systems, digital signature and certification, location-based services, and distributed systems.

PASCAL LORENZ [SM] (lorenz@ieee.org) is a professor at the University of Haute-Alsace and responsible for the Network and Telecommunication Research Group. His research interests include QoS, wireless networks, and high-speed networks. He is a member of many international program committees and has served as a guest editor for a number of journals, including *Telecommunications Systems*, *IEEE Communications Magazine*, and *Lecture Notes in Computer Science*.