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PROFESSIONAL PAPER

Application of Advanced Communication Technologies in the Improvement of Traffic Safety

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Abstract: Incorporation of advanced info-communication technologies into vehicular environment currently captures a large attention by numerous investigators, telecommunications operators, traffic safety regulatory institutions, car industry manufacturers and other interested participants. In this paper, we overview of some prospective wireless communication technologies, such as the DSRC (Dedicated Short Range Communications) and advanced LTE (Long Term Evolution) mobile communication systems, which are considered as two promising candidates to support future traffic safety applications in vehicular environment is presented. The communication requirements of some active traffic safety applications are pointed. A summary of various types of communications for intelligent VCS (Vehicular Communication System) applications is given. Some future directions and challenging issues for implementing traffic safety applications are also discussed. Our goal is to demonstrate the growing impact and importance of modern communication technologies in achieving future traffic accident-free roads.

Keywords: Traffic safety applications, vehicular communication system (VCS), dedicated short range communications (DSRC), LTE (Long Term Evolution) mobile cellular network, vehicle-to-everything (V2X) communication.

INTRODUCTION

The increasing number of vehicles on roads results in a greater number of traffic accidents with more and more injured and dead persons causing also huge financial costs. To improve traffic safety and consequently reduce the incurred costs, beside the traditional methods it is necessary to apply new and more sophisticated approaches. Rapid technological transformation that occurred during the last decade in automotive industry supported by an accelerated development and convergence of information and communication technologies (ICT) enable that the increasing number of vehicles are becoming nowadays connected to the Internet and to each other enabling the futuristic IoV (Internet of Vehicles) idea to be practically feasible [1]. The IoV concept of inter-connected vehicles is considered as a promising approach to improve traffic safety and save human lives.

The majority of modern automobiles are becoming equipped with numerous electronic sensors and devices enabling various advanced driver assistance systems. Furthermore, contemporary OBUs (On-Board Units) installed in vehicles are equipped with a number of communication interfaces, which enable information exchange between devices inside the vehicle, direct communications between vehicles V2V(Vehicle-to-Vehicle) as well as communications between vehicles and infrastructure equipment or RSUs (Road Side Units) in form of V2I/R (Vehicle to Infrastructure/Roadside). This offers drivers the ability to receive various useful data about current traffic environment (e.g. potential hazards, accidents, road or weather conditions etc.) as well as numerous driving information (such as the current vehicle position, velocity, acceleration etc). Based on such data, the OBUs are able to make intelligent (cooperative) decisions and adapt vehicle movements to the current traffic road conditions or to keep away vehicles from probable accident. By exchanging traffic related information between vehicles in real-time, road safety could be significantly improved.

Active traffic safety applications are based on possibility to avoid probably incident situations (such as collisions, slow moving or poorly visible vehicles, unexpected obstacles on roads, etc.) by alerting drivers promptly about such situations in their neighbourhood. Recent studies show that up to 82% of all traffic incidents could be prevented by implementing active traffic safety applications [2]. Besides V2V and V2I/V2R communications, which allow drivers to be informed about possible incident situations on roads, current massive usage of mobile smart phones opens an additional opportunity to make direct interactions between vehicles/drivers and pedestrians (V2P, Vehicular to Pedestrian) so as to prevent their possible mutual incidents, which is frequently the case on urban streets or crossovers. The forthcoming concept of human to vehicle cooperation, which includes communications between vehicles/drivers, roadside equipment and pedestrians is known as cooperative vehicle infrastructure system (CVIS) [3] or C-ITS (Cooperative Intelligent Transportation Systems) [4].

Beside the vehicle safety applications, drivers could also access to different information services and passengers could employ various multimedia entertainment applications using the V2N(Vehicle-to-Network) type of communication. It is expected that progressively more vehicles in near future will be connected using heterogeneous communication types, such as V2V, V2I, V2R, V2P, V2N etc. To cover such broad range of communication in vehicular environment, the term Vehicle-to-Everything (V2X) is commonly used [5]. However, interconnecting ever-increasing number of vehicles will generate rigorous requirements from telecommunication network infrastructure to support various future intelligent traffic applications [6]. The crucial issues for implementing traffic safety application assume fast (on-line) data acquisition, low communication latency, high reliability of data transmission, as well as high security and privacy of communications. Recent development and implementation of traffic safety applications enabled by advanced VCS (Vehicular Communication System) technologies currently capture large attraction by numerous academic researchers, making manufacturers and consortiums in automobile industry, telecommunication operators and service providers, regulatory institutions consider traffic safety and other interested participants. Numerous research projects related to vehicular networking in Europe, USA and Japan have been completed during last few years [6]. In addition, the international harmonization of standards for vehicular networking currently occupies huge attention [7].

TYPES OF COMMUNICATION IN VEHICULAR ENVIRONMENT

Recent advances of various wireless communication technologies enable different types of communications to be used in vehicular environment [8-13]. The VCS communications could be broadly classified into following wide categories:

- infrastructure-less (or *ad-hoc*) communication,
- infrastructure-based communication, as well as
- hybrid communication, which integrate both types of communication.

Infrastructure-less communications is implemented over self-organized *ad-hoc* communication networks, spontaneously created from near-by moving vehicles in mesh configurations without using any pre-installed infrastructure equipment. They are also known as VANET (Vehicular Ad-hoc NETwork) [8]. VANETs are highly suitable to be utilized for a broad range of traffic safety applications primarily due to its ability to provide direct V2V communication, which contributes to much lower latency compared to an indirect transmission via infrastructure based networks. In addition, VANETs could be also used for non-safety applications, such as those related to traffic efficiency (congestion control) and various comfort/infotainment applications intended for passengers [9].

V2V communication could be implemented as single hop or multi-hop communications. Single-hop communication is are established between nodes (vehicles) located in the vicinity, i.e. within the line of sight (LoS), while multi-hop communications could be used between more distant vehicles. In the latter case, a vehicle that is currently positioned between two distant vehicles behaves as a relay station, i.e. it receives the messages from near-by vehicle(s) and re-transmit them to other vehicles, which are currently in its LoS area. In such a way, using the relay transmission mode, a multi-hop communication could be established between distant vehicles, which are even much more away than the LoS range. However, to maintain the permanent communication between vehicles which are not in direct LoS, it is necessary to exist always at least one intermediate vehicle which is mutually in the LoS visibility to other vehicles. Hence, multi-hop communication could be used to increase the communication range outside the LoS and enable information dissemination in wider geographical areas.

Infrastructure-based communication (V2I) is realized over previously built communication infrastructure, such as the mobile cellular networks or dedicated communication networks based on RSUs to provide V2N or V2R communication. Unlike *ad-hoc* networks, all tipes of communication in infrastructure networks are realized using multiple network segments (such as the uplink and downlink transmission links in access network and transmissions over core network), which could significantly increase the communication latency compared to direct V2V communication. This is currently the main constraint of V2I communication to support time-critical traffic safety applications.

VEHICULAR TRAFFIC SAFETY APPLICATIONS

Traffic safety applications for vehicles are focused on decreasing the probability of accidents between vehicles. Such applications are based on transmission of safety warning messages to vehicles/drivers about various possible incident situations, such as the collision avoidance, lane changes, overtaking vehicle warning, emergency electronic brake lights, emergency vehicle warning, wrong way driving warning, stopped or slow moving vehicle warning, traffic condition warning, hazard warnings etc. [6].

A robust wireless communication network is required to enable traffic safety applications. The most significant network requirements for traffic safety applications include following [6,11]:

- traffic safety messages should have maximum end-to-end latency of 100 ms,

- messages generation frequency is up to 10 messages per second (10Hz),
- messages should be transmitted accurately on short to long coverage distances (300 m up to 20 km),
- low data rates are usually required (1 to 10 kb/s).

In addition, some other network requirements should be fulfilled for implementing traffic safety applications, such as the following [4]:

- high communication reliability (10-x): express a maximum tolerable packet loss ratio (PLR), for example, with PLR=10-5 (only one packet from 100 000 received packets is not successfully received within the maximum tolerable latency) the reliability is as high as 99.999%.
- high node mobility (km/h): maximum relative speed under which the specified reliability should be achieved,
- high network density (vehicles/km2): maximum number of vehicles per unit area,
- high positioning accuracy (cm): maximum positioning error tolerated by the application,
- high security: specific security features required by the application.

Table 1 illustrates specific communication requirements for some traffic safety applications [13]. To meet stringent requirements for traffic safety applications, VCS system designers are faced with serious and challenging issues that need to be carefully addressed.

Table 1. Communication requirements for some vehicle safety applications [13]

Safety application	Communication mode	Security/ reliability	Minimum messages frequency	Maximum latency
Emergency electronic brake lights	Time limited periodic broadcast on event	High/high	10 Hz	100 ms
Emergency vehicle warning	Periodic triggered by a vehicle mode	High/high	10 Hz	100 ms
Slow vehicle warning	Periodic triggered by a vehicle mode	High/high	2 Hz	100 ms
Wrong way driving	Time limited periodic broadcast on the event	High/high	10 Hz	100 ms
Stationary vehicle warning	Time limited periodic broadcast on the event	High/high	10 Hz	100 ms
Traffic condition warning	Time limited periodic broadcasting	High/high	1 Hz	100 ms
Roadwork warning	Temporary broadcasting on the event	High/high	2 Hz	100 ms
Overtaking vehicle warning	V2X cooperative awareness	High/high	10 Hz	100 ms
Lane change assistance	V2X cooperative awareness	High/high	10 Hz	100 ms
Pre-crash sensing warning	Broadcast of pre-crash state	High/high	10 Hz	50 ms

PEDESTRIAN TRAFFIC SAFETY APPLICATIONS

Probably the most attractive traffic safety application in vehicular environment relates to the collision avoidance between automobiles and pedestrians, as well as cyclist and motorcyclists. It is particularly attractive to be used in large cities with streets crowded by pedestrians/cyclists. As a result of massive usage of modern smart mobile devices by pedestrians, as well as due to extensive implementation of Wi-Fi interfaces in modern vehicles, it will be possible to establish direct communications between vehicles (drivers) and pedestrians (V2P) and thus to prevent their potential collisions. The traditional way of warnings between pedestrian and vehicles by sirens become inefficient nowadays taking into account that pedestrians are now more focused on their mobile phones than to the neighborhood traffic situations. Furthermore, they usually use the headphones while listening the music or making the conversations with other people and consequently don't hear or register the sound warning signs emitted by vehicle drivers. Hence, implementing of V2P applications to warm no-awareness pedestrians could be an efficient approach to improve pedestrian safety [14].

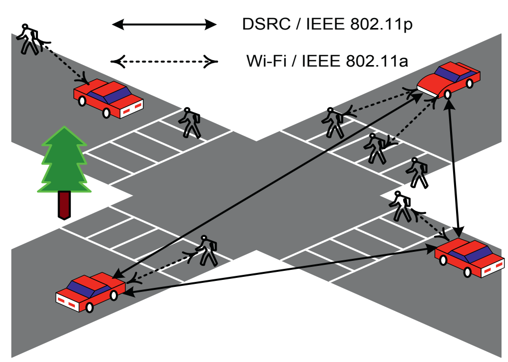

Figure 1. Illustration of V2P communications for pedestrians safety application

The architecture of V2P communication system for pedestrian safety applications contains the following components [14]: (*i*) OBU modules installed in vehicle, (*ii*) driver's tablet or smart-phone and (*iii*) pedestrians' mobiles. Communications between vehicles (i.e. OBU module) and pedestrians are established using the standardized Wi-Fi radio interfaces, such as the IEEE 802.11a, while the communications between vehicles (i.e. OBU-OBU modules) could be performed using the DSRC system based on IEEE 802.11p standard (Figure 1). Besides, OBU modules could be equipped with various additional radio interfaces, such as for mobile Internet access, GPS navigation (for location and speed measurements) as well as with Bluetooth interfaces intended for gathering data obtained by various in-vehicle sensor devices. Based on the gathered data of actual positions and speed of pedestrians and vehicles in their near range, driver's mobile smart phone or tablet device performs the processing of such data to estimate possible incident situations between vehicles and pedestrians. If a possible collision is estimated, warming messages are transmitted to mobile phones of drivers and vulnerable pedestrians (using the Wi-Fi connections) to avoid their possible conflicts. V2P applications are currently in research focus of various studies and numerous challenging issues have to be solved before implementing such applications. Beside the strict requirements related to delay constraints and communication reliability, particularly important issues are related to efficiency and scalability of V2P communications in situations of large number of pedestrians, such as the usual case on crowded crossovers in large cities [14].

COMMUNICATION TECHNOLOGIES FOR TRAFFIC SAFETY APPLICATIONS

Various wireless communication technologies, such as DSRC (IEEE 802.11p), Wi-Fi (IEEE 8021.11a/n), WiMAX (IEEE 802.16m) or public mobile cellular networks, could be used for implementing of different intelligent VCS applications. However, two technologies that are currently imposed as the most favourite candidates to support future traffic safety applications are DSRC and advanced mobile cellular networks based on LTE (Long Term Evolution) and LTE-Advanced (LTE-A) technologies [11].

Dedicated Short Range Communications (DSRC)

DSRC are favorable communication systems for V2X communications in short coverage areas [7]. They are primary characterized by low communication latency (less than 100 ms), which is the key requirement to support (time critical) traffic safety applications. DSRC is the most suitable candidate to enable direct V2V communications within short distances (up to 1000m), but possible obstacles in the line of sight could reduce the communication range significantly. Besides V2V, DSRC also supports infrastructure based communications (V2I/R) between vehicles and dedicated RSUs installed along the roads/streets. RSUs can be deployed to increase the communication range, especially in non-line-of-sight (NLOS) scenarios, such as at urban intersections or in areas with small vehicle density.

A widespread accepted standard for DSRC is IEEE 802.11p [8]. It represents an extension of the former IEEE 802.11a WLAN (Wireless Local Area Network) standard applied to vehicular environment. It operates in 5.8 GHz band in Europe and Japan and 5.9 GHz in USA (U-NII frequency bands). Some specifications of IEEE 802.11p standard used in different world regions are given in Table 2.

Table 2. World-wide specifications of DSRC standard [8]

Specification	Europe	USA	Japan
Frequency band	5.8 GHz (5.795 - 5.815) GHz*	5.9 GHz (5.850 - 5.925) GHz	5.8 GHz (5.770 - 5.850) GHz
Bandwidth	20 MHz*	75 MHz	80 MHz
Number of channels	4	7	7 downlink; 7 uplink
Channel width	5 MHz	10 MHz	5 MHz
Type of communication	half-duplex	half-duplex	half-duplex (OBU); duplex (RSU)
Bit-rate	500 / 250 kb/s (downlink / uplink)	3-27 Mb/s (downlink/uplink)	4/1 Mb/s (downlink/ uplink)
Communication range	15-20m	< 1000m	30 m

* Additional 30 MHz is allocated in frequency band (5.875 - 5.905) GHz with possible 20 MHz extensions below and above this band.

DSRC systems are *de-facto* predetermined solution for traffic safety applications duo to their inherent ability to make direct V2V communications, which offer low latency and fast network connectivity [11]. Due to fully distributed operation mode, there isn't requirement for coordinating network infrastructure. In addition, network management is reduced to minimum, which enables immediate exchange of data among vehicles without complex signaling procedures. Nevertheless, there are numerous challenge issues which have to be solved to enable practical implementation of traffic safety applications using DSRC, such as the following [7,8,9,12,15]: *i*) reliable delivery of messages, *ii*) high vehicle mobility (100-200km/h) and dynamic network topology, *iii*) scalability issues or performance degradation in presence of high vehicle density (the probability of data collisions increases rapidly with the large number of vehicles in a network, resulting in large end-to-end latency and low channel utilization) as a result of un-coordinated probabilistic CSMA/CA(Carrier Sense Multiple Access/Collision Avoidance) medium access control mechanism, *iv*) routing protocol issues as well as *v*) privacy and security issues. In addition, it is evident that not all vehicles will be equipped with IEEE 802.11p communication interfaces in the initial phase of traffic safety applications implementation. It could produce serious troubles, because such vehicles are not able to transmit safety messages to other near-by vehicles with installed 802.11p communication equipment. However, this scenario could be avoided by installing particular RSU units equipped with short range radar sensors to detect precisely the position or movement of vehicles in its neighborhood and after that to broadcast such collected data to all vehicles equipped with 802.11p interfaces which are in the range of such RSU.

Although the main advantages of DSRC are the ubiquitous communication availability (it can operate without coverage by an infrastructure network) and fully distributed operation mode, there are several major weaknesses of DSRC systems [6,7,11,12], such as the limited communication range (typically 50-100m in urban areas and several 100 meters on highways), prohibitive infrastructure costs (a number of RSUs is required to cover large portions of road networks), QoS (Quality of Service) is not guaranteed (due to uncoordinated probabilistic CSMA/CA contention based access strategy, throughput and delay performances degrades significantly with increasing network load, i.e. with high vehicle density). To overcome some limitations, mobile cellular communication systems could be used, particularly due to their already widespread deployment.

Mobile communication systems

Advanced mobile communication networks are becoming highly suitable candidate to be used as a complement (or even a concurrent) to DSRC systems. Contrary to DSRC, mobile cellular networks provide almost full radio coverage and usually do not require installation of additional equipment to support intelligent vehicular traffic applications. They could be used to extend the communication range of DSRC systems or as augment of RSUs (to reduce the installation costs). Recently, there is an increasing interest in adopting the LTE mobile cellular technology to support V2X applications [10,11]. However, due to infrastructure based type of communications, mobile cellular systems require serious technical challenges, primarily related to latency and scalability issues, to be carefully addressed.

Contrary to IEEE 802.11p standard used in DSRC, cellular communication systems are based on coordinated channel access strategy (i.e., involving a network scheduler) and with admission control, which avoids possible collisions and minimizes the mutual interference [4]. Hence, the mobile communication system is able to provide the QoS guarantees, such as the end-to-end delay or data rates performances, highly essential for traffic safety applications. Network scheduler is able to provide QoS guarantees by allocating radio resources based on the priority and QoS class parameters and by performing admission control, which is a major drawback of CSMA/CA access mechanism used in IEEE 802.11p standard.

However, there are also some limitations when using the mobile cellular systems for V2X communications [10]. For example, to enable the communication between vehicle and base station, a vehicle has always to be synchronized and registered to the cellular network. It could be troublesome if a vehicle is out-of-radio coverage of base station, such as in areas with poor radio coverage (for example, on hills, mountains, in tunnels etc.). Moreover, the signaling overhead and data transmission over cellular network architecture result in much larger communication latency than the tolerable latencies for traffic safety applications [7].

Although various prior mobile network technologies, such as the GSM, GPRS, EDGE, W-CDMA and HSPA have been to some extent used for different traffic intelligent applications, only with implementation of advanced mobile communication technologies, such as the 3GPP LTE and LTE-A a wide range of opportunities for the implementation of active traffic safety applications is enabled. The flat architecture of LTE system enables significantly reduced communication latency compared to previous generations of mobile technologies (theoretical LTE round-trip time is lower than 10 ms and the transmission latency in the RAN (Radio Access Network) is up to 100 ms [10]). Hence, LTE is intended to become the preferred solution for vehicle to RSU communications (V2R). However, some important issues have to be solved to support time critical traffic safety applications using LTE networks [4]:

- communication latency increases significantly with the numbers of mobile users in a cell, which could be a challenging issue, particularly in high vehicle density areas,
- data packets (even between two nearby vehicles) have to be transmitted through multiple network hops to the central server that each add its own latency, resulting in much higher delays compared to direct communications between vehicles (V2V) enabled by DSRC systems,
- since the LTE system was mostly designed to offer broadband services, it may not always be the optimal solution for frequent transmission of small amounts of data between large numbers of devices required for various intelligent vehicle applications, leading to scalability issues,
- a set of signalling messages have to be shared among all mobile users in a cell before the actual payload data are transmitted, which could introduce additional delays and downlink capacity limitations if the number of users per cell increases,
- in areas with weak radio coverage, network services are not available or reliability requirements could not be well satisfied. It requires additional equipment to be installed to enable traffic safety applications in such areas.

However, the advanced mobile communication technologies, such as the most recent LTE-A (4G) and next generation heterogeneous wireless networks (5G), will be able to provide direct device to device (D2D) communication between mobile terminals in close proximity (regardless of whether they are in or out of a base station coverage) without traversing the network infrastructure, which will enable direct communications between vehicles (V2V). By enabling V2V communication, future LTE mobile communication networks will provide much lower communication latencies and can become even a competitive alternative to DSRC systems. However, some challenging problems, such as the interference and node (vehicle) mobility issues have to be solved efficiently before D2D communication over LTE networks could be widely used [4].

Currently deployed LTE-A mobile technology is considered as an encouraged candidate for implementing active traffic safety applications due to its outstanding network performances, such as high peak data rates (up to 1Gb/s) and user experienced data rates (up to 10Mb/s), low latency (up to 10ms), high node mobility (up to 350km/h), high node density (up to 10^5 devices per km^2), high spectrum efficiency etc. Furthermore, it is expected that future 5G networks will still improve the performances of current 4G mobile technology in terms of more peak throughput (up to 10Gb/s) and user experienced data rates (up to 100Mb/s), yet lower latency (5 ms end-to-end latency for infrastructure mode and 1 ms end-to-end latency for direct mode), ultra-high reliability (with a 10^{-5} packet loss rate for road safety-critical services up to even 10^{-9} for some industrial automation applications, such as automated driving), higher mobile nodes density (up to 10^6 devices per km^2), higher node mobility (up to even 500 km/h for high-speed trains), higher spectrum efficiency (3 times greater), high precision of positioning (with accuracy of 1m), which will be highly appropriate for implementation of vehicle safety applications [4]. 5G will also provide a better network coverage through the integration of various wireless access technologies (such as cellular, WLANs, broadcast, etc.) including direct D2D communication. Such heterogeneous (dynamic and flexible) network paradigm, called the Heterogeneous Vehicular NETwork (HetVNET), assumes that different network technologies suitable for diverse applications are combined to fulfill specific requirements [12,13,14,15]. One of the key challenges in future (5G) wireless networks operation is related to spectrum usage. It is envisioned that both, current mobile communication bands as well as new spectrum bands that could go as high as to the millimeter wave range (up to 6 GHz or even above) will be used. It is evident that current fixed frequency allocation scheme could not be a sustainable solution for future massive deployment of numerous wireless technologies and applications. Instead, the implementation of cognitive radio network technology is considered as a promising upcoming solution for better frequency spectrum usage and QoS guarantees [16].

CONCLUSION

Rapid development and integration of information and communication technologies with road network infrastructure and vehicles open broad possibilities to implement various intelligent vehicular applications related to road safety and traffic efficiency improvement. Active road safety applications have stringent requirements from telecommunication network infrastructure, primarily from the point of low latency and high reliability of communications. Various wireless communication technologies could be used to implement V2X commmunication. Currently, the most promising candidates to support traffic safety applications are DSRC and LTE mobile cellular communication systems. However, it could be observed that both technologies have their own limitations when used in vehicular environments and hence they are not suitable to support challenging future traffic safety applications. Although DSRC are well-designed for short-range communication offering low latencies, they have still serious shortcomings related to scalability issues (quick network performance degradation with increasing number of vehicles), supporting of limited vehicle mobility and possibly huge costs to cover wide areas. On the other hand, LTE mobile cellular networks are already widely deployed and can provide ubiquitous geographical coverage, high data rates, reliable communication and QoS support. However, they are not able to provide very short end-to-end latencies required by traffic safety applications due to infrastructure based network architecture. Although the latency in LTE networks is significantly reduced compared to previous mobile generation (3G WCDMA), there are also some scalability issues (quick rise of latency by increasing the number of vehicles), which have to be carefully solved to enable well performances in high density vehicle environments, such as the usual case in urban areas. It is noticeable that mobile cellular systems are much more suitable for V2I type of communications than DSRC. On the other side, DSRC is more suitable for V2V communication than D2D communications enabled by LTE mobile cellular networks. Hence, both existing (DSRC and LTE) together with some other candidate technologies, such as the Wi-Fi or Wi-Max, have to be improved and integrated to provide a robust next generation communication network intended to support efficiently various future intelligent traffic applications under dense (possibly thousands of vehicles) and highly dynamic vehicular environment leading to the forthcoming concept of HetVNET [13]. In HetVNETs, various wireless communication technologies will coexist and cooperate, which will require their full interoperability. An efficient and suitable wireless communication technology will be chosen such as to best capture the QoS requirements for a given vehicular application. However, there are numerous challenging issues which have to be answered in order to provide that HetVNETs be practically implemented [13,14,15]. One of the key topics is related to the intersystem handover, i.e. frequent handovers between various wireless technologies at high vehicle mobility. To overcome the consequent higher latencies, it will be necessary to develop more sophisticated handover protocols, based on compromises between QoS requirements, implementation complexity and signalization overhead. In addition, various other issues have to be researched, such as high vehicle mobility (up to 250km/h or even above), dynamic network topology, ultra-high communication reliability, cooperation issues (in order to minimize end-to-end latency and maximize throughput over unstable and capacity constrained wireless channels, various cooperative approaches could be employed, such as the spatial diversity technique, multiple antennas technique, dynamic spectrum access techniques using cognitive radio technology etc.). Since numerous challenging technical issues have to be resolved before the VCS applications could be practically implemented, it is of particular importance to provide harmonization and coordination of worldwide ITS initiatives and development of standards, which currently capture extensive attention by numerous stakeholders and researchers in automotive and telecom munications industries.

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