Information exchange in vehicles ad-hock networks

Tomas ZELINKA
Faculty of Transportation Sciences, Czech Technical University in Prague
Konviktska 293/20, 110 00 Prague 1, Czech Republic:
zelintom@fd.cvut.cz

Abstract

For wireless vehicular communication both Europe and USA adopted IEEE802.11-2012 (WiFi) based communication systems. These systems are road infrastructure independent type of communication enabling both vehicle with vehicle communication as well as vehicles communication with infrastructure. However, as WiFi radio system architects stressed low system complexity, adopted communication system reaches the only sub-optimal performance with relatively low spectral efficiency, limited communication capacity and principally reduced services guaranteed performance as well as the only restricted possibility of farther system performance enhancement. New generation of 3GPP cellular networks with progressively growing services availability can in future offer alternative solution to WiFi based systems with much higher spectral efficiency and communication capacity and with possibility to guarantee communication services performance. Recently were introduced 3GPP proximity services and their extension devoted for vehicular communication. Such communication system augmentation opens possibility of full 3GPP communication systems engagement in the extensively growing vehicular communication. In this paper is discussed future expected development in this systemic area as well as both communication systems potential coopetition.

Keywords: C-ITS, CAD, DSRC, ITS-G5, V2X.

1. Introduction

C-ITS (Cooperative Intelligent Transport Systems) solutions represent one of the key essentials of the smart cities/planet solutions understood as smart mobility. An important benefit of smart mobility is in ability to increase the efficiency and security of transport systems without need of infrastructure extensive growth. Improvement of transport systems security and efficiency is principally dependent on reliable and effective sharing of relevant to services information between network members [1].

Infrastructure and police authorities have been continuously collecting a considerable amount of information about traffic conditions, road stage, police activities, accidents on the road etc. However, such massive volumes of information are the only partially available to drivers e.g. via radio services or via intelligent navigation systems distributed via wireless internet services. Signal coverage and provided data services performance of existing widely spread mobile networks has been limited and even critical information might easily need seconds to be delivered to driver.

In order to improve road safety and traffic efficiency standardized telecommunication solutions for direct communication between vehicles as well as between vehicles and roadside infrastructure adopted both USA and Europe on very similar radio basis and their massive unconditional implementation is on the way. VANET (Vehicle Ad hock Network) communication V2X includes V2V (Vehicle to Vehicle), V2I (Vehicle to Infrastructure), V2N (Vehicle to Network) and V2P (Vehicle to Pedestrian).

Performance of C-ITS solutions depends on quality of information exchange both between VANET members as well as between VANET and infrastructure or e.g. pedestrians. In such systems information flows between driver and HMI (Human to Machine Interface) of vehicle management system and by means of vehicle management system between road C-ITS management system, as well. Due to it there can be expected progressively growing demand on the M2M (machine to machine) type of communication.

Even though autonomous vehicles already reached remarkable successes, theirs massive penetration in the real transport traffic will not come as soon namely due to existing complex issues to be resolved. Far not only the technical details, but also serious ethical and legal issues have to be resolved before such regime on roads may be accepted.

Significance of information exchange in VANETs will continuously grow and it has been crucial condition for C-ITS future development to identify and anddopt appropriate long-term telecommunication strategy for this area.

2. The different approaches to communication systems architecture design

Telecommunication systems designers typically adopt one of two following alternative approaches to system development:

- System architects in introductory system design minimize performance expectations with goal to reduce system architecture complexity. Such approach simplifies possibility to penetrate on market with very competitive pricing and with good potential of spontaneous market acceptance (see e.g. WiFi or Ethernet). Even though potential of the future growth in system performance is expectable, the initially reduced system architecture may cause "genetic" future development barriers.

- System architect accepts full system complexity, sometimes with even overestimated expectations. System architects design complex system with attempt to minimize potential of any functional compromise acceptation. Potential of system modification or reduction is expectable in future and such approach can lead to actual optimized system configurations.

Fig. 1 Two approaches to C-ITS communication model

2.1 Low end communications system based on IEEE 802.11p

In area of V2X communication both Europe as well as USA accepted communication systems based on IEEE 802.11p radio – in USA DSRC 5.9 [3] and in Europe ITS-G5 [4]. These systems offer affordable features to resolve communication support of wide range of safety and traffic management services. Remarkable advantage of DSRC 5.9 or ITS-G5 systems lies in fact that there is not required any infrastructural support for radio systems operation due to adoption of fully distributed resources management [5].

IEEE 802.11p is an amendment to family of IEEE 802.11 with successful straightforward designers approach. System architects stressed the low complexity of radio design payed by the only sub-optimal radio system performance and relatively low spectral efficiency and communication capacity. Such approach made happen relatively low complexity of system architecture leading at the end to amazing mass acceptance of the wireless access systems market.

IEEE 802.11 concept was designed for stationary reception, only and system has not been equipped with any possibilities to adopt its performance in dynamically developing conditions via tools like feed-back adjustment of channel coding, modulation and transmitting power known e.g. from WiMax (IEEE 802.16) concept.

Additionally, radio system applies distributed channel access concept EDCA with CSMA/CA principles (IEEE 802.11e) resulting progressive service latency growth in case the number of active network members extends the critical level. In 10MHz frequency band no more than tens of vehicles (in accordance to message size) can be served with 100ms service period and relevant to service period latency [6]. Service capacity can be increased e.g. by multiband application, however, due to “genetic” low spectral efficiency it can hardly compete in capacity with coming alternative system based e.g. on 3GPP proximity services solutions.

There is possibility to apply additional protocols to maintain network stability and keep fair network resources availability. Such approach, however, causes additional network load and higher delivery latency must be expected, as well.

On Figure 2 is typical V2X communication solution structure applicable with communication system 802.11p based radio.

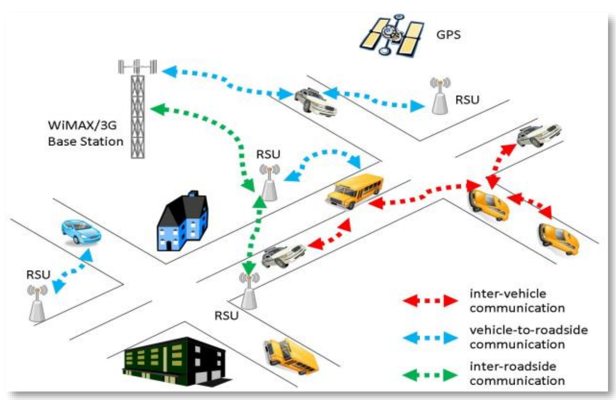

Fig. 2 In city V2X communication

Pointed Channel Access approach defined in IEEE 802.11e amendment as HCCA (Hybrid coordination function Controlled Channel Access) represents another possibility of more effective resources availability management. Such alternative approach offers much lower additional overhead and enables even limited potential to guarantee service performance [7]. However, it requires application of RSU - Road Side Units - acting as pointed authorities. Theirs distribution all around road network is un-realistic between others also due to RSUs density and no potential of synergetic effects with other services provisioning. On the other hand RSUs appearance can be expectable in areas of the high traffic and so also communication concentration.

2.2 Robust 3GPP OFDM/SC-FDMA based cellular mobile

3GPP cellular networks already reached in Europe and USA substantial part of populated areas with reasonable potential to improve road network coverage, if it economically and/or legally justified. Extensive development of LTE cellular communication systems (3GPP Rel. 8 and higher) was adopted both by technology as well as services providers with top priority and LTE is reaching dominance on the mobile data services market.

This system strictly adopted network pointed coordination principles operated by cellular base stations (eNodeB with LTE). LTE systemic architecture of access to resources in radio network practically eliminated collisions and interference was minimized, as well. Such accepted principles offer possibility to guarantee service performance parameters like data rate or latency.

System architects initially designed LTE to address namely public high rate IP mobile data services provided with high spectral efficiency. There does not exist any service without base station (eNodeB) support. Every communication event is coordinated by base station based on request of the initiating end-user and data flows always via eNodeB even to the end-user located next to the initiating one. Service can be provided exclusively in the double hop regime. Maximal throughput (3GPP Rel. 10) reaches hundreds of Mbps, typically 100Mbps per 20MHz frequency band.

In the recent 3GPP Release No. 12 (2016) were introduced proximity services (ProSe) with the D2D (device to device) organization structure. There principles enable possibility for end-user to identify other required for communication end-user and apply sidelink radio regime (PC5) for mutual data exchange directly between end-users without obligation to operate in the double hop regime via eNodeB. In sidelink regime end-user use dedicated by eNodeB frequency and time resources and uses transmission scheme like the one in the up-link regime, i.e. in SC-FDMA scheme. Dedication of frequencies and time windows delivers to the end-user eNodeB as the response on the end-user request. 3GPP Rel. 12 also offers possibility to provide service without eNodeB assistance. In this case end-user applies frequencies and time windows from in advance agreed resources pool.

Proximity services introduced by 3GPP Rel 12 (2016) are not dedicated for dynamically developing vehicles ad-hock networks communication with defined and guaranteed performance parameters like latency or service availability. Concentration on dynamic services performance is coming with the next 3GPP releases. 3GPP recently introduced preliminary version of coming standard enabling provisioning of full services enhancements ready for vehicular communications [13]. The initial version of the V2X standard is expected to be finalized and included in the 3GPP Rel. 14. This standard focuses on full Vehicle-to-Vehicle (V2V) communication as it is illustrated on Figure 3.

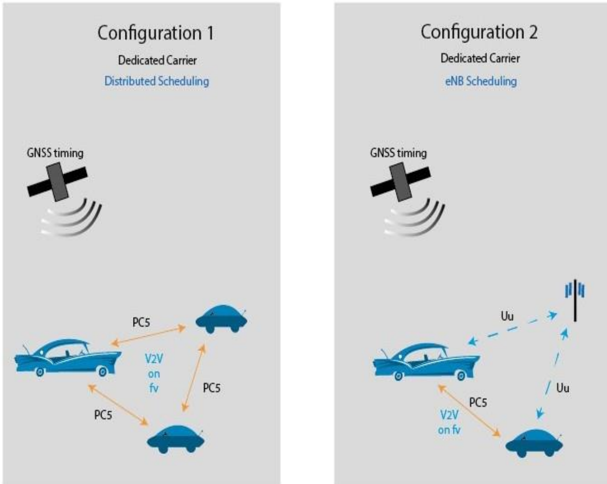

Fig. 3 V2V configuration ref. to 3GPP 3GPP RP-161894

Both configurations apply modified PC5 (Prose) based V2V communication and Uu is used only in case of end-user to eNodeB communication. In both configurations of Figure 3 GNSS services are applied for the end-user units precise time synchronization.
Further 5G communication systems expectations (Fig. 4) include provisioning of wide range of both human-type and machine-type of communication. Former dominant concentration on maximal data throughput is extended with afford to meet expectations on defined reliability, low latency and massive number of connected devices [16].

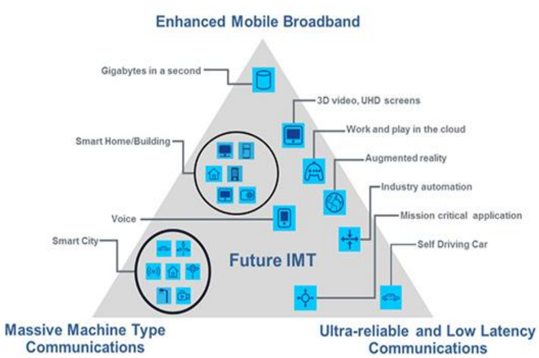

Fig. 4 5G services portfolio.

It is clear that V2X communication represents one of the key focusses of 5G strategy. New radio system are expected to come as well as principle makeovers of existing solution are projected. Wide extension of frequencies band will also reach millimeter wave range even with limited applications range.
It is for sure that introduced multiple radio access technologies (M-RAT) will represent one of key affords of 5G R&D. 5G expects IEEE 802.11-2012 based systems migration into cellular networks. Such strongly supported approach opens also good potential to migrate DSRC 5.9/ITS-G5 in 5G, as well. Such migration shall effectively capitalize experiences reached in V2X solutions based on traditional DSRC 5.9/ITS-G5 systems and it will open promising future for heterogeneous 5G VANET solution.
There remains very important question who will play role of the future V2X communication solution system integrator authority – both entities (ETSI and 3GPP) proclaim their ability to act so, but finally the only one can finally act so.

3. C-ITS requirements

Progressively growing demand on transportation namely in Urban areas can be resolved by

- extensive expansion of transport infrastructure,
- users migration to public transport,
- P&R - car and public transport combination or
- more efficient utilization of existing infrastructure.

We will be discussed the last alternative, i.e. potential of intensification of the road capacity specifically by increasing density of vehicles without generally expected relevant decrease of vehicles speed on the road - see fig. 5.


Fig. 5 Different vehicles density on the road

Figure 6 presents relation between vehicles density on the road and reachable road vehicles intensity. Such relationship relates to full engagement of human being – i.e. driver - in driving processes.

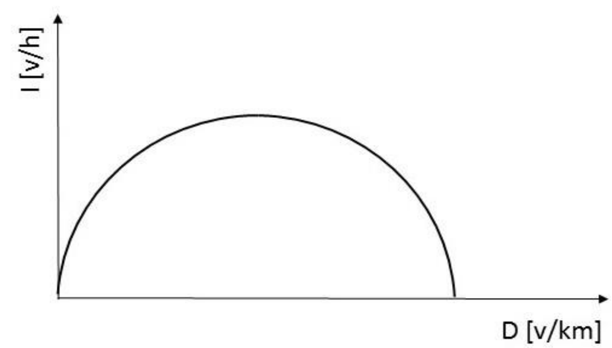

Fig. 6 Dependence of road vehicles traffic intensity on vehicles density

Principal positive improvement of vehicles road traffic intensity could be reached only in case if driver negative impact is either reduced or even totally eliminated – see Figure 7.

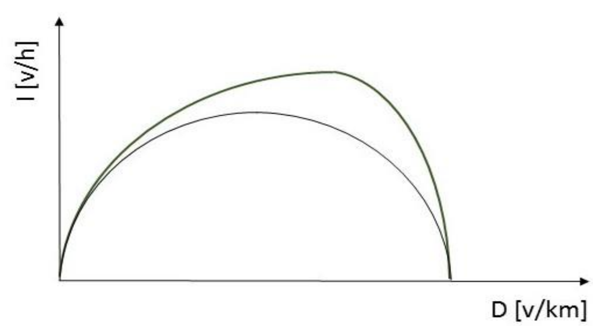

Fig. 7 Dependence of road vehicles traffic intensity on vehicles density with reduced human impact

Autonomous driving can reduce or fully eliminate negative driver impact on effective usage of the roads infrastructure. It was massively communicated that vehicles with fully automatized driving abilities without any information exchange with theirs neighbors were already introduced and tested in the real road traffic. Wide range of sensors (Figure 8) was integrated in the decision processes to be fully autonomous with strong accent to obey or at least principally reduce potential of collision on the road.
Wide range of experiments results with no connected vehicles in real traffic prove as more effective and more promising concept of connected automated driving (CAD) approach. CAD concept seems to be the only future alternative being able to penetrate efficient and safe enough car driving automation on the roads.

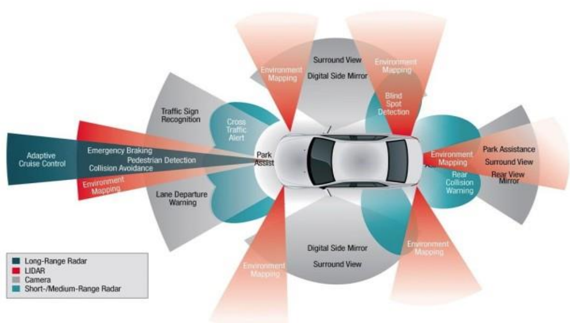

Fig. 8 Sensors of autonomously driven no connected vehicle

Communication V2V, V2I is in CAD solutions extended also to V2N (networking) or V2P (pedestrians) to maximize driving efficiency and minimize potential of collisions – see Figure [9].

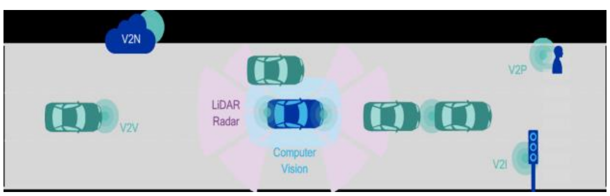

Fig. 9 Connected vehicles

4. Communications performance for C-ITS/CAD

Fig. 10 displays generally accepted five steps to fully automatic accident-free driving.

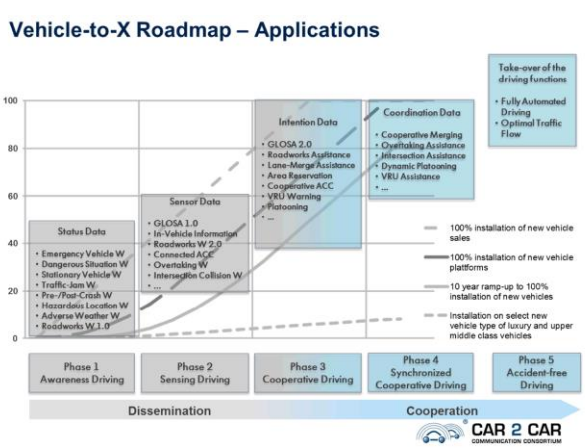

Fig. 10 C2C CC V2X roadmap (C3C CC)

Both Europe and USA are now in Phase 1 of C2C V2X roadmap. Recently started first V2X projects like the European Day 1 applications in the Amsterdam group [11] or the similar projects in USA still do not explicitly specify minimal set of communication performance parameters requirements for awareness driving. We can adopt in conciderations that typical driver reactivity times is not much faster than 1s, however, sensors data transmission can easily be repeated with 100ms period. As each vehicle in group transmit sensors data several times within the driver reactivity period, there can be principally reduced requirement on communication service reliability. Nevertheless, in the next phases of the V2X roadmap diver´s responsibility in vehicle driving will be step by step reduced and consequently communication services reliability expectations will progressively grow.
Next phases of V2X roadmap will represent remarkable increase of system performance parameters requirements. It is important to understand that in automated driving any uncertainty has to be taken in account since it is not 100% certain what another vehicles intends to do in the near future. If all vehicles are able to disseminate their own status and plans, the other vehicles can use this information to reduce their uncertainties. Principally reduced uncertainties enable automated driving vehicles to react better on other vehicles maneuvers to be able to prevent collisions or even enables vehicles to drive closer to each other and in this way to improve usage of the roads capacity.

- In Cooperative Collision Avoidance under complex and dynamic environment, vehicles cannot do decisions individually and vehicles have to act under their prior coordination. All involved vehicles must synchronize computing of the optimal collision avoidance actions and they also have to apply computed results in a cooperative manner. Vehicles synchronization requires continuous extensive situational information exchange.
- Another key application - platooning - requires close cooperation among participating vehicles in dynamic road situations. To reduce within a platoon vehicles mutual distance between vehicles engaged vehicles must continuously exchange their detailed kinematic information. Availability of neighbor kinematic information allows vehicles to adopt relevant cooperative vehicle control keeping vehicles distance continually low. Such approach, however, principally extends requirement on shared data volume.

Estimated requirements on communications system performance in Phase 5 of C2C CC V2X roadmap with included between other discussed above functionalities of cooperative collision avoidance and platooning are, however, above abilities of available or even foreseen mobile communication systems. Estimated data transmission rates are in tens of Mbps, expected reliability of communication services must be better than 10^{-5} (99.999%) and minimal accuracy of GNSS position should be better than 0.3m.
Such requirements represent remarkable challenge for both communication as well as for automotive solutions. Future afford must be carefully concentrated on selection and volume reduction of required data flow and communication system are challenged in additional growth in their system parameters.

5. Conclusion

Smart mobility as a part of Smart City or Smart Planet initiative can lead to higher road transportation efficiency. However, for smart mobility implementation widely available coverage of powerful and reliable V2X communication will be urgently needed. Contemporary adopted communication alternative ITS-G5/DSRC 5.9 represents flexible, powerful and useful communication tool with potential independence of WAVE/TS-G5 on any infrastructural support. However, this concepts based on IEEE 802.11p radio architecture will hardly meet some of key future C-ITS expectations. Future communication solution will require adoption of communication system based on 3GPP proximity services with coming soon 3GPP V2X communication mobile systems extension. However, due to by state authorities constrained progressive ITS-G5/DSRC 5.9 communication systems penetration there is hardly expectable future unconditional replacement of G5/DSRC 5.9 systems by even much more effectual 5G grade solutions and integration of both system can be foreseen as the most probable alternative. There remains question who will play role of the system integrator authority – both entities proclaim their ability to act so, but finally the only one can finally do it.

3GPP 5G in heterogeneous coexistence with G5/WAVE will open space for ambitious and highly demanding connected automatized driving, nevertheless, still with lower than foreseen communication capacity. Such results are challenging both new solutions or principally modified communication system, but it is also challenging automotive approaches where structure and volumes of data exchange within C-ITS/CAD solutions must be reevaluated to reduce requirements on the communication systems on resolvable level.

References

[1] Zelinka, T., Lokaj, Z., Srotyr, M.: Service Quality Management in the ITS Telecommunications Systems. Journal of Systemics, Cybernetics and Informatics, Orlando, FL, 2013, Vol. 11, No. 8, pp 29-36, ISSN: 1690-4524

[2] Svítek M.: Towards complex system theory, Tutorial, In: Neural Network World 2015, vol.25, no.1, pp. 5-33, 2015

[3] Kenney, J. B.: Dedicated Short Range Communications standards in the United States. Pcod. IEEE 97(7), 1162-1182

[4] Intelligent Transport Systems (ITS), Communications Architecture, ETSI EN 302 665

[5] Festag, A.: Standards for vehicular communication – from 802.11p to 5G, Elektrotechnik&Informationtechnik, Springer, Vol. 132, Issue 7, pp. 409-416.

[6] M. and Filali F.: LTE and IEEE 802.11p for vehicular networking: a performance evaluation. Springer Open, EURASIP Journal on Wireless Communications and Networking20142014:89 DOI: 10.1186/1687-1499-2014-89

[7] IEEE 1609 standard - system architecture https://standards.ieee.org/findstds/standard/1609.0-2013.html

[8] IEEE Guide for Wireless Access in Vehicular Environments (WAVE) Architecture, IEEE , NY, 2013, IEEE Standard for Message Sets for Vehicle/Roadside Communications, IEEE , NY, 2006, http://standards.ieee.org/findstds/standard/1455-1999.html

[9] ETSI DSRC Standard, No. TS 102 792, Intelligent Transport Systems (ITS); Mitigation techniques to avoid interference between European CEN Dedicated Short Range Communication (CEN DSRC) equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range, 2015, http://www.etsi.org/deliver/etsi_ts/102700_102799/102792/01.02.01_60/ts_102792v010201p.pdf

[10] European profile standard for the physical and medium access control layer of Intelligent Transport Systems operating in the 5 GHz frequency band, ETSI ES 202 663 V1.1.0 (2009-11),

[11] ETSI DSRC Standard, No. ES 200 674-1, Intelligent Transport Systems (ITS); Road Transport and Traffic Telematics (RTTT); Dedicated Short Range Communications, 2013

[12] Morgan, Y. L.: Notes on DSRC & WAVE Standards Suite: Its Architecture, Design, and Characteristics," in IEEE Communications Surveys & Tutorials, vol. 12, no. 4, pp. 504-518, Fourth Quarter 2010

[13] V2X Initial Cellular V2X standard - http://www.3gpp.org/news-events/3gpp-news/1798-v2x_r14

[14] M. and Filali F.: LTE and IEEE 802.11p for vehicular networking: a performance evaluation. Springer Open, EURASIP Journal on Wireless Communications and Networking20142014:89 DOI: 10.1186/1687-1499-2014-89

[15] Vinel, A.:3GPP LTE Versus IEEE802.11p/WAVE: Which Technology is Able to Support Cooperative Vehicular Safety Applications? IEEE WIRELESS COMMUNICATIONS LETTERS, VOL. 1, NO. 2, APRIL 2012 125

[16] 5G automotive Vision https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf 3/2017

[17] Roadmap between automotive industry and infrastructure organizations on initial deployment of C-ITS in Europe, version 1.0 – hppp://amsterdamgroup.mett.nl (June 2013)

[18] Taxonomy and Definitions for Terms Related On-road Motor Vehicle Automate Driving Systems, SAE J3016, 2014