Vehicular Networks and Applications - Challenges, Requirements and Service Opportunities

Junyi Li
Qualcomm, USA
Email: junyil@qualcomm.com

Michał Wódczak
Ericsson, Poland
Email: michal.wodczak@ericsson.com

Xinzhou Wu
Qualcomm, USA
Email: xinzhouw@qualcomm.com

T. Russell Hsing
Telcordia Technologies, USA
Email: thsing@telcordia.com

***Abstract*— A very challenging and up-to-date topic of vehicular communications brings about certain challenges in terms of radio access technologies, spectrum allocation, networking and automation aspects. This paper provides an insight into the relevant technologies of both the physical and medium access control layers, as well as the network layer. In particular the topic of transmission bandwidth and latency is discussed for the former and the question of autonomic and cooperative networking is analyzed for the latter. The discussed aspects are presented from the perspective of the challenges, requirements and service opportunities for vehicular networks and their applications.**

***Index Terms*— V2V/V2I Communications, Autonomic Cooperative Networking**

I. Introduction

As the latest cutting edge technologies for mobile communications, offering better transmission capabilities, are being devised globally, the concept of real-world deployment of efficient vehicular systems is becoming more and more crystallized. Advancements towards this direction may be observed both in the case of the physical and medium access control layers, where the emphasis is generally laid on wider bandwidth and lower transmission latencies, and the network layer, where the aspects of autonomic networking and cooperative communications seem to gain increasingly significant attention these days [1].

As for the physical layer, the candidate standards include both the 3GPP Long Term Evolution (LTE) and the Mobile WiMAX (IEEE 802.16e). It is crucial to note that the latter requires a new network to be deployed, whereas LTE offers an incremental update to the existing cellular networks [2]. In fact, LTE is now on its evolution path towards IMT-Advanced while its 10th Release (LTE Rel-10) already provides support for carrier aggregation, enhanced multi-antenna techniques, heterogeneous deployments and relaying technologies [3]. LTE is claimed to be a good choice for the inclusion of safety applications in vehicular systems such as intersection collision reduction [4]. In the cited case, for example, LTE is proposed to be used for communication between vehicles where a cellular based vehicle collision avoidance system together with a traffic management center informs vehicles about the traffic situation so that they can determine potential dangers at the cross-roads. Significant number of vehicles means, in turn, that vehicular systems need incorporate certain network layer mechanisms that would complement the demands by enabling the notion of self-management [1]. This is where the paradigm of autonomic communications comes into play to help with the provision of system scalability and stability. Following, autonomicity may be perceived as an enabler for cooperative behaviors which can be in turn expressed by cooperative transmission, and so easily translated into cooperative networking [5].

The text is organized as follows. First, after the introductory part, the aspects of physical and medium access control layers are outlined in Section II. Following, the topics of autonomic networking and cooperative transmission are detailed in Section III, and the paper is concluded in Section IV.

II. Vehicle-to-Vehicle/Infrastructure Communications

Compared with cellular wireless wide-area-network (W-WAN) and ad hoc networks, V2V/V2I communica-

© 2012 ACADEMY PUBLISHER
doi:10.4304/jcm.7.5.365-373

tions faces unique challenges [1]. In cellular W-WAN, devices communicate with base stations deployed at fixed locations, and the deployment of base stations is well planned to maximize the coverage of the network. V2I communications is similar to cellular W-WAN, except that the infrastructure nodes may be installed in an ad hoc manner in many deployment scenarios. Compared with cellular W-WAN, a large fraction of V2I communications may take place in the low SINR regime, making it challenging to ensure link reliability. V2V communications is similar to ad hoc networks, except that V2V communications has to deal with high mobility, resulting in challenges due to not only time varying wireless channel but also rapid change of network topology. In a sense, V2V/V2I communications exhibit combined complexity of both cellular W-WAN and ad hoc wireless networks. We next elaborate on some specific challenges related to the physical and medium access control layers, while the network layer topics are discussed in Section III.

A. Wireless Channel

In many practical scenarios, the wireless channel is non-LOS and is characterized with variation over time (Doppler spread effect) and over frequency (delay spread effect) [1]. In order to coherently recover the signal from the transmitter, the receiver tracks the channel using a known signal, called a pilot. Figure 1 illustrates a pilot signal in an OFDM system. In OFDM, the wireless channel is represented with one complex number, $H_{i,j}$ in subcarrier i over symbol j. The receiver first estimates $H_{i,j}$ at the pilot position (i, j) from the received symbol $y_{i,j}$:

$$H_{i,j} = \frac{y_{i,j}}{x_{i,j}} \tag{1}$$

with $x_{i,j}$ the known complex symbol transmitted at the pilot. Then, the channel at a data position (i', j') is interpolated from the pilot channel estimates at (i, j) assuming channel coherence in time and in frequency. The channel estimates at data positions are used to decode the data signal. Clearly the quality of channel estimation limits the decoding performance. Channel estimation errors are mostly attributed to the noise at the pilot positions and the modeling uncertainty of channel coherence from pilot positions (i, j) to data (i', j'). The former depends on the pilot SNR and the latter can be roughly determined by how well the pilot covers the two-dimensional time/frequency grid of Figure 1. Apparently, given pilot density (and therefore overhead), it is desired to place the pilot so as to minimize the channel discrepancy between (i, j) and (i', j'). The pilot example depicted in Figure 1(a) represents the design in the Dedicated Short-Range Communications (DSRC) system. As a comparison, Figure 1(b) illustrates the pilot pattern of an LTE system, which is also targeted at high mobility usage. We observe that the pilot in DSRC is much more sparse in frequency - adjacent pilot subcarrier space is more than 2 MHz as opposed to 45 kHz in LTE. This can lead to large channel estimation errors in the presence of both delay and Doppler spread, especially with a significant packet transmission time length [1].

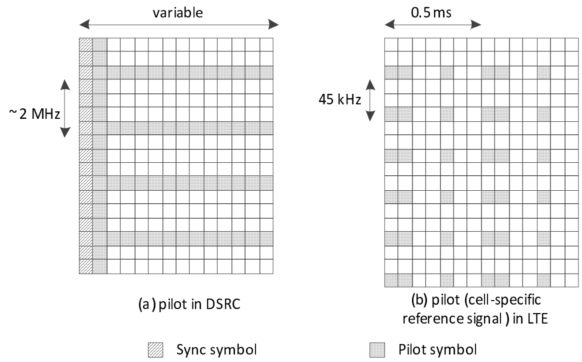

Figure 1. Comparison of pilot design: DSRC versus LTE

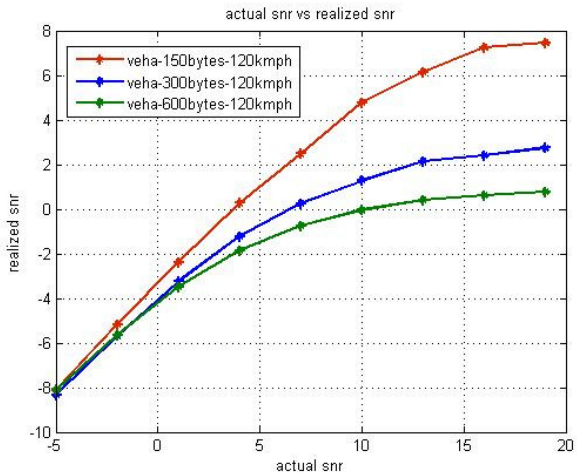

Figure 2. Effective SINR versus SNR due to self noise caused by channel estimation errors

Channel estimation errors result in a self noise at the receiver in addition to the usual additive white Gaussian noise (AWGN). The power of the self noise depends on the signal power and channel estimation errors [1]. The self noise term becomes dominant when the signal is much stronger than additive noise (high SNR regime), in which case the effective SINR is saturated by the self noise. Figure 2 plots the effective SINR versus SNR for the vehicular A model [6] at 120 km/hour speed. We observe that as the length of packets increases from 150 to 300 and then 600 bytes, the adverse impact of the self noise is more significant.

The above channel estimation problem is well known in the society. The off-the-shelf 802.11p (11a) chips are usually implemented to deliver good performance in benign channel models with small delay spread ($\sim$ 10 ns) and very low mobility ($<$ 5 m/s), and in general not optimized in performance for the vehicular communication environment [1]. To illustrate the channel estimation problem, let us look at the pilot structure in the 802.11p physical channel and pilot signal as shown in Figure 2. Specifically, an 802.11p packet starts with a few wideband pilot symbols and then in the subsequent data symbol

© 2012 ACADEMY PUBLISHER

only four out of 52 subcarriers are used for pilots. In other words, for the 10 MHz operation in 802.11p, two adjacent subcarriers are 2.4 MHz away.

Typical 802.11p chip estimates the channel as the following: it first obtains a wideband channel estimate from pilot symbols, and then monitors the residual channel variation using the pilot subcarriers. The latter is usually referred as pilot tracking. In benign channel models in an indoor stationary environment, such algorithms are usually sufficient. However, in a typical vehicular environment, the communication channels have both time-selective fading due to mobility and frequency selective fading due to multi-path and delay spread. Two observations one can make here:

1) The interspacing between two pilot subcarriers are much larger than the coherence bandwidth;
2) The packet transmission time can be longer than the channel coherence time. For example, a 300-byte packet requires 0.5 ms transmission time, while the channel coherence time can be as small as 0.3 ms.

When both conditions happen, the off-the-shelf chip has a large probability of failing the received packet [1]. Simply put, after the coherence time, the channel estimate one can obtain from the pilot symbol becomes obsolete. On the other hand, the sparse pilot subcarriers are not sufficient to track the channel on its own. Thus, the algorithm of combined estimation and tracking is indeed unable to track the channel and the packet reception fails, even when the received power of the packet is well above the thermal noise.

Fortunately, there are a few tools one can use from modern coding theory to deal with the channel estimation error. One such method is to introduce a Turbo receiver approach, which iterates between channel estimation and decoding, instead of carrying out the two steps in a sequential order as in conventional receivers. For 802.11p, there is a natural way of implementing such a scheme due to the nature of 802.11p coding and modulation. In particular, 802.11p uses convolutional code with a short constraint length equal to 7 and furthermore, no time interleaving is allowed. This means that the receiver can reliably decode information bits coded and transmitted earlier in the packet during which the channel estimation is still reliable, without waiting for the reception of the whole packet [1]. Subsequently, one can use the already-decoded bits as new pilots for the remaining packets and improve the channel estimation along the way. Such a scheme can indeed track the channel variations much better as compared to the standard non-iterative scheme and almost removes the channel estimation error caused by time and frequency selective fading.

We next show the simulated results of the packet drop rate at different delay spread and mobility. Figure 3 is from a typical 802.11p receiver with conventional channel estimation implementation where the packet drop rate is mostly caused by channel estimation errors which rise sharply with a combination of delay spread and mobility. Figure 4 shows that a Turbo receiver drastically reduces the packet drop rate to virtually zero in the same delay spread and mobility setup.

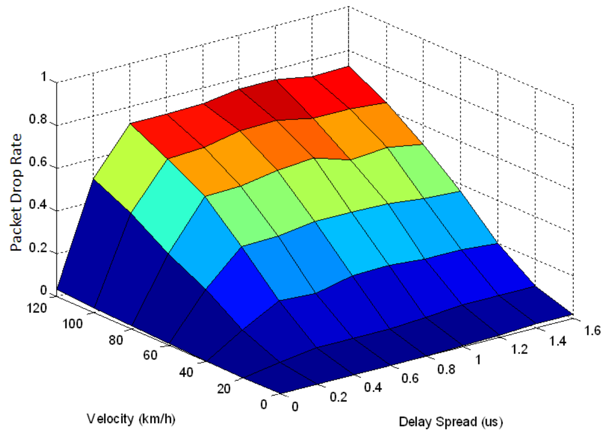

Figure 3. Packet drop rate using a conventional channel estimator in the presence of both mobility and frequency selective fading

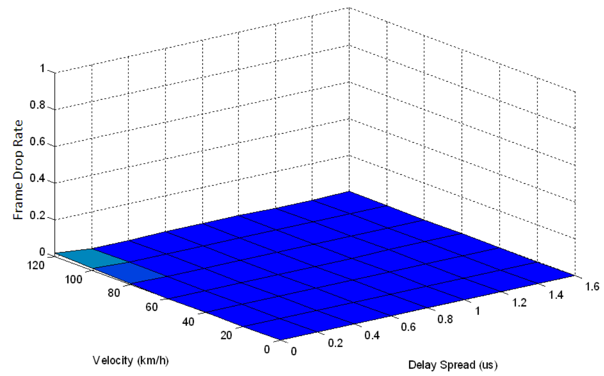

Figure 4. Packet drop rate using a Turbo receiver in the presence of both mobility and frequency selective fading

B. Interference

The ad hoc nature of V2V/V2I communications makes interference management a great challenge. Take V2I for example. At first, it may appear that one can apply cellular frequency reuse here. However, there are two inherent difficulties. First, restrictive association. That is, since there are many kinds of infrastructure nodes with different service purposes, a vehicle may not always communicate with the closest infrastructure node. This leads to much greater interference than what is expected in a cellular W-WAN. Second, the deployment of infrastructure nodes is usually ad hoc [1]. Even if vehicles only communicate with the closest infrastructure node, the SINR distribution exhibits a heavy tail in the low SINR regime. Figure 5 compares the SINR distributions with universal spectrum reuse among all the infrastructure nodes when they are deployed in randomly selected locations versus when they are placed at the hexagonal vertices. Hence, it seems hard to apply cellular frequency reuse here.

This naturally leads us to CSMA/CA, a very different interference management technique designed for ad hoc networks. In CSMA/CA, before sending its only signal, a

© 2012 ACADEMY PUBLISHER

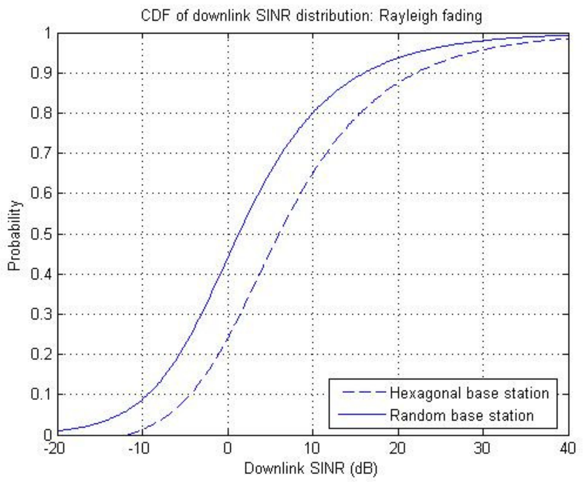

Figure 5. Comparison of SINR distribution: V2I versus cellular communications

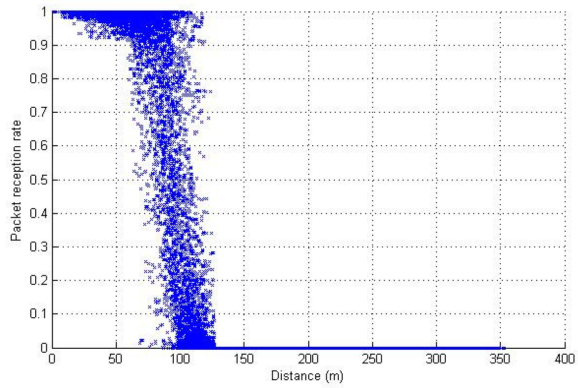

Figure 6. Scatter plot of packet reception rate versus distance

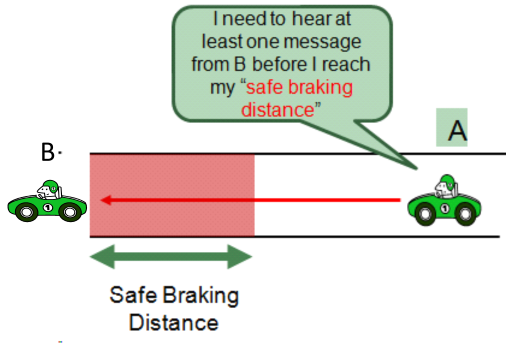

Figure 7. Forward collision warning application

transmitter first senses the wireless channel for a window time period of randomly chosen length. It only transmits when the channel is considered idle. However, carrier sensing is not perfect and collision occurs mostly due to the following two reasons. Two transmitters both sense the channel to be idle and start to transmit simultaneously. The receiver is not protected (hidden terminal problem[1]). For example, when device A is transmitting to B, another device far from A may sense the channel to be idle and start to transmit thereby causing interference at B.

The probability of collision increases with the size of the network, which leads to the issue of scalability. We use the NS-2 simulator to model a 500 m by 500 m field with wraparound. A number of 196 cars are dropped at random locations. The wireless channel between any two cars is characterized with the ITU 1411 LOS propagation model [7]. Each car is to transmit a 300-byte packet of safety applications at 6 Mbps every 100 ms. In a 100 ms interval, 50 ms is used solely for safety applications. From the simulation of 100 seconds, during which the maximum number of 1000 packets received between from one car to another. Figure 6 plots the percentage of packets successfully received (packet reception rate) as a function of the distance between any two cars. We observe that the reliability deteriorates rapidly with the distance [1].

Is the link reliability shown in Figure 6 adequate? To answer this question, let us start with performance metrics at application level. Consider collaborative forward collision warning (FCW) application shown in Figure 7. Given two cars are in the course of colliding into each other, suppose that the target is to avoid the collision with 99% the probability. We next translate the application level requirement to the link reliability requirement by assuming typical parameters of this application.

In particular, we assume the velocity of vehicle A is 100 km per hour and vehicle B is fully stopped. Vehicle B is sending out WSMs broadcasting its location at a frequency of once per 100 milliseconds. A necessary condition to avoid the accident is that vehicle A has to receive at least one message from vehicle B before it reaches the safe braking distance, which is defined to be minimum distance a vehicle needs to get to full stop.

At a speed of 100 km per hour, the safe braking distance is around 115 m. Further, every 100 ms, the vehicle can move 3 m. With this assumption, we can calculate the collision probability as follows

$$\begin{aligned} & \mathbb{P}(\text{Collision}) \\ = \; & \mathbb{P}(\text{No packet received before 115 m}) \\ = \; & \Pi_{k=0}^{\infty}\mathbb{P}(\text{Packet sent at } 115+3k \text{ m failed}). \quad (2) \end{aligned}$$

Assuming the packet delivery errors are i.i.d., the required error rate of each packet is $(1-0.99)^{1/N}$, where N is the number transmission opportunities in (2). From Figure 6, the packet reception rate drops to zero when the distance exceeds 125 m. So $N = 3$ and the required error rate is about 0.2, which is much lower than what can be achieved in Figure 6 at a distance between 115 m and 125 m.

III. AUTONOMIC COOPERATION IN SELF-MANAGING VEHICULAR SYSTEMS

Self-management and the concept of autonomic systems are perceived as the core elements of the ubiquitous

[1]The RTS/CTS protocol solves the hidden terminal problem for unicast traffic, but is not effective for broadcast.

© 2012 ACADEMY PUBLISHER

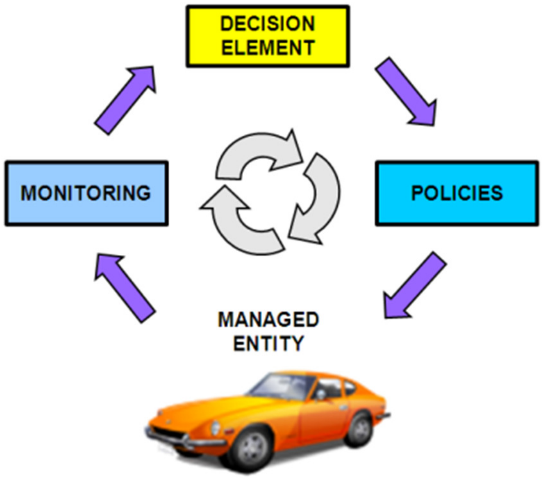

Figure 8. Autonomic control loop

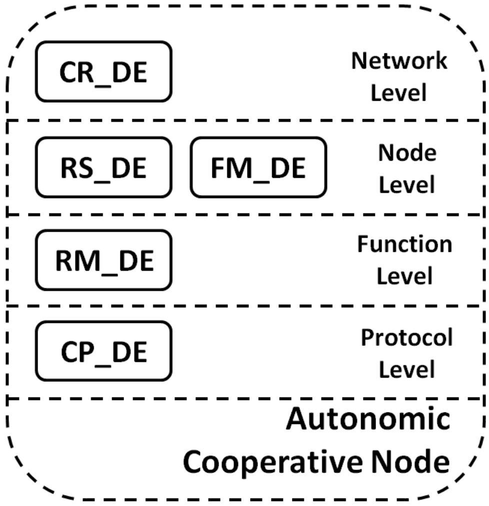

Figure 9. Architectural perspective

network of the future [8]. There is no doubt that vehicular systems will become the key element of the global networking ecosystem and it is crucial to ensure that the relevant technologies are included in their development from the very outset. A distinctive feature of vehicular networks, already pointed out in the introduction, is their envisaged high complexity in terms of topology control and service provision [1]. Therefore, certain dose of automation is required for the purposes of guaranteeing smooth and robust system operation. First, it is expected that there will be a need for the vehicles to express autonomic configuration capabilities in order to address the issues of rapid topology changes and distributed nature of the network. Second, a very relevant question of self-management needs to be answered so it is possible to understand how network nodes, i.e. vehicles, can express cooperative behaviors, manifested through, for example, the ability of performing autonomic cooperative communications and routing [9]. There is also an urgent need for cross-layer design featuring both these components.

A. Autonomic System Design

The system needs to be stable and scalable, and so large-scale vehicular networks should express self-management through efficient and effective auto-configuration. The behavior of the future vehicular network may be actually even expected to somewhat imitate and resemble the behavior expressed by living organisms. In other words, such a network should be capable of functioning by itself without any necessity for a specific external human intervention during the majority of its operation time [8]. This may be facilitated with the autonomic network architectural extensions which are currently being developed with the aid of the concept of decision elements and control loops [10]. In other words, as outlined in Figure 8, the basic idea is that every single decision element uses a control loop to interact with its managed entity, e.g. a network layer protocol, such as the Optimized Link State Routing protocol (OLSR) [11].

OLSR is a proactive solution devised for mobile ad-hoc networks and it would fit autonomic vehicular environment after the relevant alignment, as it could be implemented into an On-Board Unit (OBU) and assume the role of a managed entity [12]. This protocol appears of special interest because it is not only already integrated with cooperative transmission [13], [14], but also very well aligned with the paradigm of autonomic networking. For example, it allows for a network node to decide on its willingness to carry and forward traffic, which is exactly what is meant by an enabler for autonomic behaviors [1]. It is then not necessary to make OLSR more autonomic but exploit its already existing internal capabilities by a proper interfacing with the relevant decision elements.

Obviously, such decision elements can also interact among themselves and form hierarchical management structures. Control loops, instead, would aim to collect monitoring data and apply the policing related information [15]. This is a very important aspect because monitoring is necessary for acquiring up-to-date data pertaining to the network topology, which may positively affect the safety situation on the road [1]. At the same time, policing might be used to impose certain behaviors on distinct vehicles, groups of vehicles or even the whole network in order to address certain objectives, related for example to the traffic load optimisation.

In particular, as outlined in Figure 9, starting from the protocol level a Cooperative Processing decision element (CP_DE) is instantiated having responsibility of controlling the aspects pertaining to cooperative transmission protocol and so related to the physical emulation of the distributed spatio-temporal encoder. This operation is equivalent to the processing of the relayed signal according to the operation of a given spatio-temporal encoder, either block or trellis one. The operation of CP_DE would need to be aligned with a Routing Management decision element RM_DE, overseeing the behavior and performance of the network from the function level perspective. This is necessary for the proper synchronisation

© 2012 ACADEMY PUBLISHER

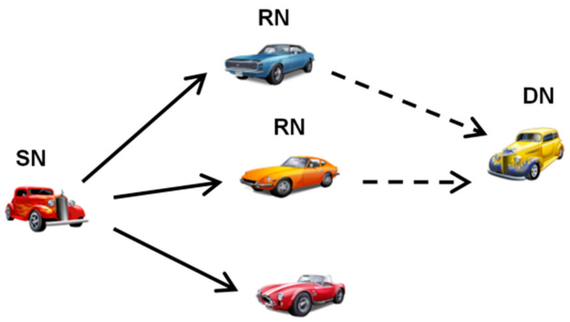

Figure 10. Cooperative communication in vehicular networks

of the routing tables maintained at the cooperating nodes. Moreover, the RM_DE also needs to act pursuant to the interactions with other necessary DEs, such as Resilience and Survivability decision element RS_DE or Fault Management decision element FM_DE [16], [17]. In this case, the RS_DE would cover the aspects of service resilience and survivability. For this it would interact with FM_DE controlling the symptoms suggesting that a failure, e.g. in terms of service, may be imminent. Finally, while these DEs are located at autonomic cooperative nodes, it is still necessary to provide substantial coordination at the network level. This task would be accomplished by the Cooperative Routing decision element CR_DE being responsible for overseeing the situation from a higher level perspective and orchestrating the concurrent cooperative and non-cooperative transmissions among vehicles, as well as instantiating cooperative re-routing [18], for example.

B. Cooperative Transmission

The second major component is constituted by the aspect of cooperative networking. Being in line with the paradigm of autonomic systems, cooperative transmission seems to be emerging as the key enhancement to vehicular systems of the future in terms of increased safety and sustainability [1]. In general, cooperative transmission is a very promising technology for improving the performance of wireless communications through the use of transmission diversity offered by relay nodes [19]. In fact, relay nodes are forming virtual antenna arrays [20] and so they are creating a Virtual MIMO radio channel. It is especially interesting in the case of vehicular networks where system dynamics requires a special logic to be deployed to be able to handle the changing network configuration. This can be achieved through cross-layer operations at the link and network layers [21]. Particularly, Figure 10 illustrates such a set-up where a direct link between the source vehicle SN and the destination vehicle DN does not exist [4]. This results in a two-hop transmission, assisted by a group of intermediate vehicles, playing the role of relay nodes (RN). The communication gets improved when cooperation is enabled among those RNs.

In particular, although, due to the broadcast nature of the wireless channel, many intermediary nodes typically receive the radio transmission originated by one of the neighboring nodes, it makes sense only for some of them to participate in cooperative relaying. Routing mechanisms can be used to facilitate this process, so information available at the network layer may be exploited for the purposes of coordinating the transmission at the link layer [14]. The selected relay nodes may form the aforementioned virtual antenna array(s) and so perform the operation of distributed space-time processing (i.e. emulate a space-time block encoder) [22]. There are a number of solutions in this area and in this paper the reference curves are provided for space-time block codes G_2 (3), G_3 (4), and H_3 (5) [23], [24], which would be of interest here.

The baseline G_2 code may be used in a distributed system where the number of transmitters (i.e. relays) is equal to two. In the first time-slot the x_1 and x_2 symbols are sent by the first and second relay node and then, in the second time-slot, the $-x_2^*$ and x_1^* symbols are transmitted in the same manner. The other codes may be applied following the very same approach but using three relaying nodes. There is also an increase in the number of time-slots, which affects the code rate. Only for the G_2 code is it equal to 1, while the G_3 and H_3 codes are characterized by the rates of 0.5 and 0.75, respectively.

$$G_2 = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \tag{3}$$

$$G_3 = \begin{bmatrix} x_1 & x_2 & x_3 \\ -x_2 & x_1 & -x_4 \\ -x_3 & x_4 & x_1 \\ -x_4 & -x_3 & x_2 \\ x_1^* & x_2^* & x_3^* \\ -x_2^* & x_1^* & -x_4^* \\ -x_3^* & x_4^* & x_1^* \\ -x_4^* & -x_3^* & x_2^* \end{bmatrix} \tag{4}$$

$$H_3 = \begin{bmatrix} x_1 & x_2 & \frac{x_3}{\sqrt{2}} \\ -x_2^* & x_1^* & \frac{x_3}{\sqrt{2}} \\ \frac{x_3^*}{\sqrt{2}} & \frac{x_3^*}{\sqrt{2}} & \frac{(-x_1-x_1^*+x_2-x_2^*)}{\sqrt{2}} \\ \frac{x_3^*}{\sqrt{2}} & -\frac{x_3^*}{\sqrt{2}} & \frac{(x_2+x_2^*+x_1-x_1^*)}{\sqrt{2}} \end{bmatrix} \tag{5}$$

The signal received by a receiving antenna j at the destination node may be written as (6) [24]:

$$r_t^j = \sum_{i=1}^{N} h_{i,j} s_t^i + \eta_t^j \tag{6}$$

where $h_{i,j}$ denotes a channel coefficient, s_t^i represents the symbol transmitted by antenna i at a relay node and the noise samples η_t^j are modeled by the complex Gaussian process with zero mean and $N_0/2$ variance per dimension. The main feature of space-time block codes, being also the main condition, under which the operation of decoding may be successfully performed, is their orthogonality. This condition is defined as (7) [23], [24]:

$$G_N G_N^H = \left(\sum_{i=1}^{N} |x_i|^2 \right) I_N \tag{7}$$

© 2012 ACADEMY PUBLISHER

where N is equal to the number of transmitting antennas and I_N is an $N \times N$ identity matrix. The process of decoding is based on a maximum-likelihood detection aiming at minimising the decision metric given by the formula (8) [24], which can be easily derived on the basis of the theory given for example in [25].

$$z = \sum_{t=1}^{L}\sum_{j=1}^{M}\left| r_t^j - \sum_{i=1}^{N} h_{i,j} s_t^i \right|^2 \tag{8}$$

It means that, for a given code, these potentially transmitted symbols are chosen, which minimise this metric. The reference evaluation results for the aforementioned codes are presented in Figure 11, Figure 12, and Figure 13. The curves were obtained for up to 4 receive antennas and each time 30 million bits were transmitted in the Additive White Gaussian (AWGN) channel and using the QPSK (Quadrature Phase Shift Keying) modulation scheme [13], [26]. The power emitted by each of transmit antennas was always normalized and as a result its total transmitted value was equal to 1. The SNR at the receive antenna j was defined as the total received signal power to the noise power ratio. During simulations the equations and code matrices cited in this section were applied.

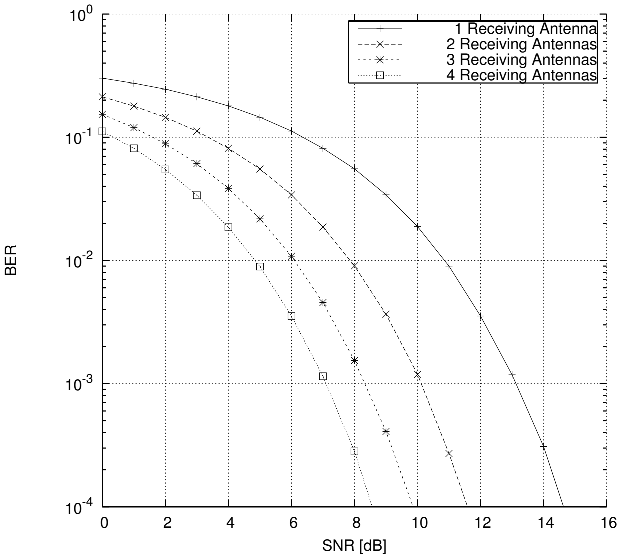

Figure 11. Reference curves for G_2 equivalent system with 1, 2, 3 and 4 receive antennas

The reference curves indicate gains achievable in an equivalent vehicular system where vehicles would play the role of network nodes and so instantiate cooperative transmission [1]. In such a case dynamic switching would be available between different codes, and so different sets of virtual antenna arrays on the basis of steering information coming from the autonomic decision entities orchestrating the behavior of the routing protocol.

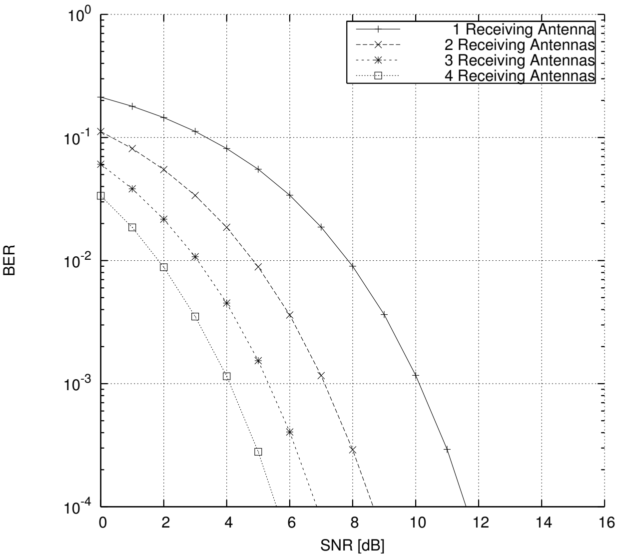

Figure 12. Reference curves for G_3 equivalent system with 1, 2, 3 and 4 receive antennas

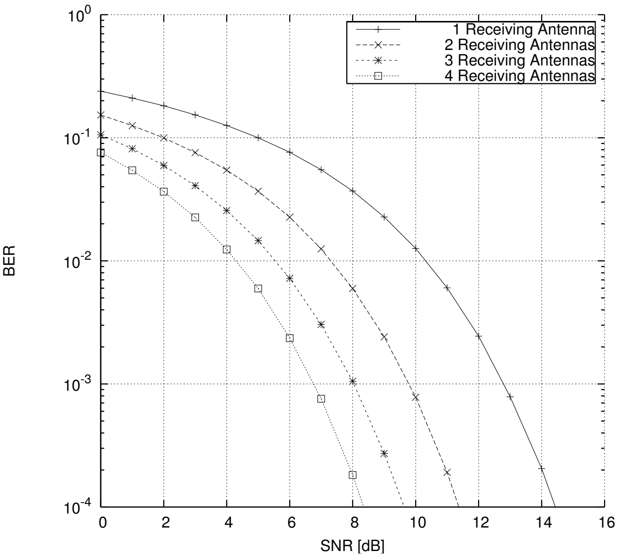

Figure 13. Reference curves for H_3 equivalent system with 1, 2, 3 and 4 receive antennas

IV. Conclusion

In spite of the potential of providing a rich set of service opportunities in the future, vehicular networks face significant technical challenges. In this paper, we compare vehicular networks with cellular W-WAN and traditional ad hoc networks, and highlight the challenges arising not only from the wireless channel and interference but also from rapid network topology changes. The packet reception rate is a key of delivering reliable services, and we show, by an example, that the required packet reception rate depends on application level requirements. Finally we point out a few promising techniques including self-management and cooperative networking to tackle the complexity of vehicular networks.

References

[1] J. Li, M. Wódczak, X. Wu, and H. T. R., "Vehicular Networks and Applications: Challenges, Requirements and

© 2012 ACADEMY PUBLISHER

Service Opportunities," *International Conference on Computing, Networking ans Communications (ICNC), Maui, Hawai, USA*, 30 January - 2 February 2012.

[2] J. Mosyagin, "Using 4G wireless technology in the car," *12th International Conference on Transparent Optical Networks (ICTON)*, 2010.

[3] S. Parkvall, E. Englund, A. Furuskar, E. Dahlman, T. Jonsson, and A. Paravati, "LTE evolution towards IMT-advanced and commercial network performance," *IEEE International Conference on Communication Systems (ICCS)*, 2010.

[4] I. Y.-Y. Hsu, M. Wódczak, R. G. White, T. Zhang, and T. R. Hsing, "Challenges, approaches, and solutions in intelligent transportation systems," *Second International Conference on Ubiquitous and Future Networks (ICUFN)*, 2010.

[5] M. Wódczak, "Future Autonomic Cooperative Networks," *Second International ICST Conference on Mobile Networks and Management, Santander, Spain*, Sep. 2010, published in Springer Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering (LNICST): Mobile Networks and Management, Vol. 68/2011, edited by K. Pentikousis, R. Aguero, M. Garcia-Arranz, and S. Papavassiliou.

[6] I. I.-R. M.1225, "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz," *International Telecommunication Union, ITU-R Recommendation*, 2005.

[7] I. I.-R. P.1411-3, "Guidelines for evaluations of radio transmission technologies for IMT-2000," *International Telecommunication Union, ITU-R Recommendation*, 1997.

[8] R. Chaparadza, S. Papavassiliou, T. Kastrinogiannis, M. Vigoureux, E. Dotaro, K. A. Davy, M. Quinn, Wódczak, and A. Toth, "Creating a viable Evolution Path towards Self-Managing Future Internet via a Standardizable Reference Model for Autonomic Network Engineering," *Chapter in the book: "Towards the Future Internet - A European Research Perspective" edited by G. Tselentis, J. Domingue, A. Galis, A. Gavras, D. Hausheer, S. Krco, V. Lotz, and T. Zahariadis, published by IOS Press, ISBN: 978-1-60750-007-0*, May 2009, also published at the Future Internet Assembly 2009 in Prague.

[9] M. Wódczak, "Autonomic Cooperative Networking for Wireless Green sensor Systems," *International Journal of Sensor Networks (IJSNet)*, vol. 10, no. 1/2, 2011.

[10] M. Wódczak, T. B. Meriem, R. Chaparadza, K. Quinn, B. Lee, L. Ciavaglia, K. Tsagkaris, S. Szott, A. Zafeiropoulos, B. Radier, J. Kielthy, A. Liakopoulos, A. Kousaridas, and M. Duault, "Standardising a Reference Model and Autonomic Network Architectures for the Self-managing Future Internet," *IEEE Network*, vol. 25, no. 6, pp. 50–56, November/December 2011.

[11] T. Clausen and P. Jacquet, "Optimised Link State Routing Protocol (OLSR)," *RFC 3626*, Oct. 2003.

[12] M. Wódczak, "Autonomic Cooperation in Ad-hoc Environments," *5th International Workshop on Localised Algorithms and Protocols for Wireless Sensor Networks (LOCALGOS) in conjunction with IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS), Barcelona, Spain*, 27-29 June 2011.

[13] ——, "On Routing information Enhanced Algorithm for space-time coded Cooperative Transmission in wireless mobile networks," Ph.D. dissertation, Faculty of Electrical Engineering, Institute of Electronics and Telecommunications, Poznań University of Technology, Poland, Sep. 2006.

[14] ——, "Extended REACT - Routing information Enhanced Algorithm for Cooperative Transmission," *16th IST Mobile & Wireless Communications Summit 2007, Budapest, Hungary*, 1-5 July 2007.

[15] A.Liakopoulos, A.Zafeiropoulos, A.Polyrakis, M.Grammatikou, J.M.Gonzalez, M. Wódczak, and R.Chaparadza, "Monitoring Issues for Autonomic Networks: The EFIPSANS Vision," *European Workshop on Mechanisms for the Future Internet*, 2008.

[16] M. Wódczak, "Resilience Aspects of Autonomic Cooperative Communications in Context of Cloud Networking," *IEEE First Symposium on Network Cloud Computing and Applications, Toulouse, France*, 21-23 November 2011.

[17] ——, "Convergence Aspects of Autonomic Cooperative Networking," *IEEE Fifth International Conference on Next Generation Mobile Applications, Services and Technologies, Cardiff, Wales, UK*, 14-16 September 2011.

[18] ——, "Cooperative Re-Routing," *full patent application no. 13/042701 filed to the United States Patent and Trademark Office*, 8 March 2011.

[19] K. Doppler, S. Redana, M. Wódczak, P. Rost, and R. Wichman, "Dynamic resource assignment and cooperative relaying in cellular networks: Concept and performance assessment," *EURASIP Journal on Wireless Communications and Networking*, Jul. 2007.

[20] M. Dohler, A. Gkelias, and H. Aghvami, "A resource allocation strategy for distributed MIMO multi-hop communication systems," *IEEE Communications Letters*, vol. 8, no. 2, pp. 99–101, Feb. 2004.

[21] M. Wódczak, "Aspects of Cross-Layer Design in Autonomic Cooperative Networking," *IEEE Third International Workshop on Cross Layer Design, Rennes, France*, 30 November - 1 December 2011.

[22] J. N. Laneman and G. W. Wornell, "Distributed space-time-coded protocols for exploiting cooperative diversity in wireless networks," *IEEE Transactions on Information Theory*, vol. 49, no. 10, pp. 2415–2425, Oct. 2003.

[23] S. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications," *IEEE Journal on Selected Areas in Communications*, vol. 16, no. 8, pp. 1451–1458, Oct. 1998.

[24] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block codes from orthogonal designs," *IEEE Transactions on Information Theory*, vol. 45, no. 5, pp. 1456–1467, Jul. 1999.

[25] A. Goldsmith, *Wireless Communications*. Cambridge University Press, 2005.

[26] M. Wódczak, *Autonomic Cooperative Networking*. Springer-Verlang New York, 2012.

Dr Junyi Li is a Vice President of Engineering at Qualcomm Flarion Technologies, responsible for conceptualizing and developing next-generation wireless networking solutions. He was a key inventor of Flash-OFDM, arguably the first commercially deployed OFDMA-based mobile broadband wireless communications system. He holds over 120 U.S. patents and has more than 400 pending patent applications. He was a founding member of Flarion Technologies, a startup acquired by QUALCOMM in 2006. Prior to that, he was with Bell-Labs research in Lucent Technologies. He has a Ph.D. degree in E.E. from Purdue University and an MBA from the Wharton School at University of Pennsylvania. He is a Fellow of IEEE.

Dr Michał Wódczak is Senior Research Scientist, Program Manager at Ericsson and previously Telcordia Technologies. He obtained M.Sc. and B.Sc. degrees in Telecommunications in 2001 and Ph.D. degree in Wireless Communications Systems in 2006 from Poznan University of Technology. His primary area of research involves Autonomic Cooperative Networking. He is Vice Chairman of ETSI ISG AFI, as well as Rapporteur of ETSI ISG AFI on Autonomic Ad hoc, Mesh and Sensor networks. He is also Senior Member of IEEE and he acted as Editor-in-Chief of NEWCOM Newsletter. Additionally, he

© 2012 ACADEMY PUBLISHER

serves as Board Member of the Association of Polish Translators and Interpreters.

Dr Xinzhou Wu is currently a Principal Engineer/Manager at Qualcomm Flarion Technologies. From 2005 to 2006, he was a Member of Technical Staff at Flarion Technologies, which pioneered in OFDMA based cellular technologies. He holds 22 U.S. patents and has more than 110 pending patent applications in the area of wireless communications and wireless networking. His current research interests are in ad hoc wireless networks, resource allocation in cellular networks, and information theory. He received the B.E. degree from Tsinghua University, China in 1998, the M.S. and Ph.D. degrees from University of Illinois at Urbana-Champaign in 2000 and 2004, all in electrical engineering.

Dr T. Russell Hsing is a Fellow of the IEEE, British Computer Society and SPIE, is an Executive Director for Emerging Technologies and Services Research in Telcordia Technologies. He supervises the Directors of Telcordia Research Centers in Taiwan and Poland. He accumulated expansive background in R&D through affiliations with Burroughs, Xerox, GTE Labs, Telco Systems, and TASC. He pioneered the technology transfer, evaluation and commercialization through joint business ventures globally. He has 35 years of the ICT industry experiences. He holds a B.Sc. (1970) from the National Chiao Tung University in Taiwan, M.Sc. (1974) & PhD (1977) in Electrical Engineering from the University of Rhode Island in US.

© 2012 ACADEMY PUBLISHER