A Survey of Research in Inter-Vehicle Communications

Jun Luo and Jean-Pierre Hubaux

School of Computer and Communication Sciences
EPFL, CH-1015 Lausanne, Switzerland
{jun.luo, jean-pierre.hubaux}@epfl.ch

Summary. As a component of the *intelligent transportation system* (ITS) and one of the concrete applications of mobile ad hoc networks, *inter-vehicle communication* (IVC) has attracted research attention from both academia and industry of, notably, US, EU, and Japan. The most important feature of IVC is its ability to extend the horizon of drivers and on-board devices (e.g., radar or sensors) and, thus, to improve road traffic safety and efficiency. This chapter surveys IVC with respect to key enabling technologies ranging from physical radio frequency to group communication primitives and security issues. The mobility models used to evaluate the feasibility of these technologies are also briefly described. We focus on the discussion of various MAC protocols that seem to be indispensable components in the network protocol stack of IVC. By analyzing the application requirements and the protocols built upon the MAC layer to meet these requirements, we also advocate our perspective that ad hoc routing protocols and group communication primitives migrated from wired networks might not be an efficient way to support the envisioned applications, and that new coordination algorithms directly based on MAC should be designed for this purpose.

1 Introduction

Inter-vehicle communication (IVC), on one hand, is an important component of the *intelligent transportation system* (ITS) architecture. It enables a driver (or its vehicle) to communicate with other drivers (or their vehicles) that locate out of the range of *line of sight* (LOS) (or even out of radio range if a multihop network is built among several vehicles). As a result, information gathered through IVC can help improve road traffic safety and efficiency. On the other hand, moving vehicles equipped with communication devices form an instance of long-envisioned mobile ad hoc networks [25]. Benefiting from the large capacities (in terms of both space and power) of vehicles, the nodes of these networks can have long transmission ranges and virtually unlimited lifetimes. Also, many existing protocols designed for ad hoc networks and experiences learned from the related research can be applied. One of the earliest studies on IVC was started by JSK (Association of Electronic Technology for Automobile Traffic and Driving) of Japan in the early 1980s. Later, well-known research results on platooning[1] have been demonstrated by the California-based PATH project [13] and the Chauffeur EU project [12]. The cooperative driving systems of Japan in the late 1990s and 2000 (e.g., DEMO 2000 [34]) exhibit another set of important applications of IVC. A related topic is *adaptive cruise control* (ACC). Traditional solutions to this issue involve mainly automatic control systems for individual vehicles [35], but IVC can help to make the coordination more efficient. Recently, the transmission of information about incidents, emergencies, or congestion from (a) preceding vehicle(s) to vehicles following behind also became an important application of IVC (e.g., [24]). The newly initiated European Project CarTALK 2000 [27] tries to cover problems related to safe and comfortable driving based on IVC. It focuses on the design, test and evaluation of co-operative driver assistance systems by taking into account both IVC and *road-to-vehicle communication* (RVC), where RVC is used to provide vehicles with access to fixed networks [23]. CarTALK 2000 also co-operates with other projects such as the German FleetNet [9] and NOW (Network on Wheels: `www.network-on-wheels.de`) for the development of IVC.

The main applications of IVC, as summarized by [27], can be roughly categorized into three classes:

- **Information and warning functions**: Dissemination of road information (including incidents, congestion, surface condition, etc.) to vehicles distant from the sites of interest.
- **Communication-based longitudinal control**: Exploiting the "look-through" capability of IVC to help avoiding accidents and to arrange platooning.
- **Co-operative assistance systems**: Coordinating vehicles at critical points such as blind crossings (a crossing without light control) and highway entries.

There are also "added value" applications, such as location-based services and multiplayer games. Considering the tight coupling between a specific application and its supporting mechanisms, we will not devote a section to describe applications, but rather mention applications when their enabling mechanisms are discussed. The remainder of this chapter is structured as follows. Section 2 discusses the radio bands used in IVC physical layer. Section 3 details various proposals for IVC MAC. Section 4 presents several routing protocols dedicated to IVC. Section 5 describes application of group communication in IVC. Section 6 discusses security issues. Section 7 briefly describes different mobility models used in IVC simulations. Finally, Section 8 makes conclusions.

[1] Platooning is by definition the technique of coupling two or more vehicles together electronically to form a train. This means that the total headway for vehicles going in the same direction could be reduced, and the capacity of the road would consequently be increased.

2 Radio Frequency Spectrum

In this section, we discuss the frequency spectra used by different IVC systems; we do not address technical issues such as the antenna and modulation in the physical layer. As the media for the IVC, both infrared and radio waves have been studied and employed for experimental systems. The radio waves include VHF, micro, and millimeter waves. The communication with infrared and millimeter waves are within the range of LOS and usually directional, whereas those with VHF and microwaves are of broadcast type. Although VHF waves such as the 220 MHz band have been used because of their long communication distance, the mainstream nowadays is microwaves. The *dedicated short-range communication* (DSRC) in the USA, allocated by FCC, spans over 75 MHz of the spectrum in the 5.9 GHz band. In Japan, 5.8 GHz DSRC was used by DEMO 2000 and 60 GHz millimeter wave has been tested to evaluate its performance under the hidden terminal situation. In Europe, Chauffeur chose 2.4 GHz at the beginning; it also changed to 5.8 GHz later. CarTALK/FleetNet chose UTRA TDD because of the availability of an unlicensed frequency band at 2010–2020 MHz in Europe. It is worth noting that infrared, in spite of its various drawbacks, has been adopted by most projects including JSK, PATH, and CarTALK, typically for co-operative driving.

3 MAC/PHY Layer: (W)LAN vs. 3G

Currently, there are two main approaches in developing wireless MAC for IVC. They differ in the adopted radio interface. One approach is based on existing wireless LAN physical layers, such as that of IEEE 802.11 or Bluetooth. An alternative approach is to extend 3G cellular technology, i.e., CDMA, for decentralized access. The advantage of the first approach is its inherent support for distributed coordination in ad hoc mode, but the flexibility of radio resource assignment and of transmission rate control is low. On the contrary, 3G extensions have the potential of high granularity for data transmission and flexible assignment of radio resources due to the CDMA component, but suffer from the complexity of designing coordination function in ad hoc mode. We now discuss these two approaches separately.

3.1 WLAN Extension

Although it is possible to use WLAN standards directly for RVC [23], the outcome might not be satisfactory for IVC since, for example, these mechanisms are designed without having mobility in mind. Migrating a WLAN technology for vehicular applications requires development in the following areas:

a. Resistance to potentially more severe multipath effects
b. Time synchronization between nodes susceptible to move rapidly

c. Distributed resource allocation in a network of highly dynamic topology.

While (a) depends much on the development of hardware and proper physical layer, there are proposals that tried to solve (b) and (c) solely within the MAC layer. We hereafter discuss several proposals that inherit certain parts of the existing standards but try to solve some aforementioned aspect(s) by adding new features. Lee et al. [16] from PATH suggest the use of a token ring protocol similar to IEEE 802.4 to solve the contention of radio resources. The protocol includes the mechanism to construct, recover, join, and leave a ring, as well as the token circulation and multiple token resolution in the ring. Although this protocol is claimed to be adaptive to dynamic topology and rely only on the physical layer of IEEE 802.11, the performance evaluations did not take mobility into account and the protocol evaluated is implemented on top of IEEE 801.11 DCF. Therefore, a convincing proof is still necessary to show that this protocol is suitable for IVC. Katragadda et al. [15] propose a Location-based Channel Access (LCA) protocol. Assuming the availability of location-aware devices with each node, the LCA protocol divides a geographical area into cellular structure with each cell having a unique channel associated with it. Within a given cell, any multiple access schemes, including CSMA, CDMA, and TDMA, can be used. In this sense, LCA is not simply an extension of WLAN. Considering the similarity between LCA and the spatial division multiple access (SDMA) in traditional cellular networks, a doubt may be raised about the protocol's adaptability to high mobility scenarios like in IVC. There are other proposals based on some traditional LAN technologies such as the non- or p-persistent CSMA used by DOLPHIN [33]. The contribution of this work is to show that the non-persistent CSMA outperforms the p-persistent one regarding packet loss in those cases usually involved in IVC. As a result, the non-persistent CSMA is adopted as the IVC protocol of the DEMO 2000 co-operative driving [34].

Numerous proposals are concerned with modifying IEEE 802.11 for some specific case(s). We do not discuss them here due to their minor significance to IVC.

3.2 3G Extension

It is impossible to directly apply 3G technologies, because they are designed for cellular networks, which are inherently centralized. The following problems have to be addressed in order to extend 3G technologies for IVC:

a. Distributed radio resource management
b. Power control algorithms
c. Time synchronization.

All these problems are due to the absence of centralized infrastructure. Therefore, the solution should rely on distributed media access control. Many proposals suggest using Reservation ALOHA (R-ALOHA) for distributed channel assignment. R-ALOHA has higher throughput than slotted-ALOHA, since a node that catches a slot can use it in subsequent frames as long as it has packets to send. However, there are two problems to be solved in order to make traditional R-ALOHA work for IVC. On one hand, R-ALOHA has a potential risk of instability in the case of many participating nodes and frequent reservation attempts due to short packet trains. Lott et al. [17] solve this problem by letting every node reserve a small part of transmit capacity permanently even if it has no packets to send. This results in a circuit-switched broadcast connection primarily used for signaling purposes. The time synchronization is built upon the information from GPS and additional synchronization sequence in parallel to data transmission. Further system evaluation under high node mobility can be found in [28]. On the other hand, traditional R-ALOHA needs a broadcast environment for all nodes to receive all the transmitted signals and, most important, to get the status information of slots. Since IVC suffers from the hidden terminal problem, destructive interference with already established channels can occur and accessing nodes have no idea about the outcome of their transmission. To overcome these problems, Borgonovo et al. [4] have studied a new protocol, named Reliable R-ALOHA (or RR-ALOHA). This protocol transmits additional information to let all nodes be aware of the status of each slot, thus safely allowing the same reservation procedure of R-ALOHA to occur in IVC. The two-hop relaying that propagates the status information is very similar to what is used in ad hoc routing to let a node know the neighbor information of its neighbors. However, since this work is very recent and is still under study, no field test or simulation results are reported, leading to the question about its performance under high mobility networks. Both protocols are based on UTRA TDD, which is chosen by CarTALK/FleetNet as the target system. Several MAC protocols for ad hoc networks combine CDMA with random channel access (e.g., [30]). These protocols usually start their transmission immediately, irrespectively of the state of the channel. Under appropriate code assignment and spreading-code schemes, *primary collisions* (i.e., two nodes with the same code try to access the channel together) can be avoided. However, Muqattash and Krunz [21] pointed out that RA-CDMA (*random access* CDMA) suffers from *multi-access interference* (MAI), resulting in *secondary collisions* (also known as *near–far problem* in the literature) at a receiver. As a consequence, CA-CDMA [21] uses a modified RTS/CTS reservation mechanism. The channel is split into control and data channels. RTS/CTS is transferred over control channels to let all potentially interfering nodes be aware of the channel status. In contrast to IEEE 802.11, interfering nodes may be allowed to transmit concurrently, depending on some criteria. The protocol also exploits knowledge of the power levels of the overheard RTS/CTS to perform power control that intends to alleviate the near–far problem. According to the simulation results (especially the comparison between CA-CDMA and IEEE 802.11), this protocol is a quite promising MAC for ad hoc networks, but simulations (or even field tests) that take mobility into account are necessary to justify its deployment in IVC.

Summary

Although a number of MAC protocols have been proposed, more efforts are needed to put them into practice. Currently, IEEE 802.11b is still the one used for demonstration [10], and IEEE 802.11a is chosen by ASTM (American Society for Testing and Materials) to be the basis for its standard of DSRC [1]. However, the MAC protocol based on UTRA TDD, promoted by CarTALK, could be another promising solution for IVC (at least in the EU).

4 Network Layer: The Role of Location Awareness

Almost all unicast routing protocols proposed for IVC are position-based. Basically, any existing position-based routing protocol for ad hoc networks [31] can be applied to IVC, but the protocols can be optimized by taking into account the special features of vehicles. For example, GPS, Geographic Information System (GIS), and digital maps can help a node to be aware of its location and the surroundings, such as the road topology. Since the road topology has a strong influence on the network topology in IVC, this knowledge does help to make the routing protocol more efficient [32, 7]. Furthermore, one of the most recent results on position-based routing [11] proposes a forwarding scheme avoiding the need of beacons for improved efficiency. One of the real implementations, demonstrated by FleetNet [10] (see also [20]), has not exploited these special features of vehicles yet. Their protocol behaves like a reactive routing protocol by requesting the location of a destination when sending a packet. Then greedy geographical forwarding is used to forward packets. We also notice that most people try to solve the problem of unicast routing just because “it is challenging in ad hoc networks". Actually, considering the applications mentioned in Section 1 (which involve more group-oriented rather than pairwise communications), we are really wondering if unicast routing still has the same significance as in “general" ad hoc networks. The application of broadcasting is usually to disseminate traffic information. Most solutions suggest scoped-flooding for broadcasting. Thanks to the peculiarity of this application, certain optimizations can be applied. For example, Wischhof et al. [36] adaptively change the inter-transmission interval according to the significance of the event conveyed by the message in transmission, while Briesemeister et al. [6] use a randomized interval. If the locations of vehicles are again taken into consideration, a multiresolution data structure can be used to express information in the message [19]. The intuition here is that the further a vehicle is from the event, the less detail it needs.

Summary

Considering the application requirements for IVC, broadcast/geocast routing that disseminates information to a set of nodes that are located in the neighborhood seems to be a necessary mechanism; it could be optimized according to the requirements of an application. On the contrary, unicast routing might be superfluous in most cases.

5 Group Communication: Promising but Unattended Research Area

Although two of the main applications of IVC, namely platooning and co-operative driving, imply the need for group communication, researchers seldom pay attention to this area. While broadcast protocols mentioned in the previous section perform group-oriented information dissemination, group communication primitives would still be welcome for IVC, because reliability could be important in certain critical situations. We hereby discuss a few related works and try to envision some potential research aspects. Briesemeister [5] suggests reducing the group membership service to the local environment of a node, because of the impossibility result of primary-component group membership in asynchronous systems with crash failures (which is the situation with IVC). The *localized group membership service* (LGMS) only tracks the membership of neighbors and installs a local view at each node. Obviously, the views of different nodes differ from each other. Although LGMS provides an interesting solution to the problem that the author aims at, i.e., congestion area detection, its weak properties (e.g., no agreement on the membership) make it hard to apply to a broad context. Actually, this service does not support any functions with a reliability requirement due to the lack of global view of the group. Gorman [22] raises a very interesting problem about coordinating vehicles at a blind crossing, which he terms 4-way stop (4WS) problem, and tries to apply group communication to perform coordination functions. While the problem itself is intriguing since it is an important aspect of co-operative driving, the proposed solution needs further improvement. It is not yet clear whether all the properties mentioned in the thesis, which are direct migrations from traditional group communication, could really work in IVC environment. Some researchers from the theoretical area of distributed computing also noticed the importance of applying group communication in IVC. Meier and Cahill [18] proposed an event-based middleware to support group-oriented applications. They focus on small groups that are apparently abstracted from scenarios in IVC.[2] However, the underlying membership service that attempts to locate all nodes in a given geographical area is a bit costly (in terms of communication consumption), and it is not clear if applications really need this kind of membership service. Baehni et al. [2] consider the problem of sharing certain resources among a group of vehicles. They propose an algorithm that solves the problem in a synchronous model. Another important contribution is to prove the impossibility of achieving fairness and concurrency as well as the impossibility of solving the problem in an asynchronous model.

[2] Unfortunately, they implement their experiments only in an RVC scenario.

Summary

Group communication is definitely an important component of IVC, but it has seldom been addressed. Existing proposals show that potential design considerations could include: (i) building the system directly upon the MAC layer and (ii) tracking membership in a more lightweight way than a global tracking.

6 Security: An Emerging Research Topic

Security of IVC has been ignored so far by the research community. The only publication we could find is by El Zarki et al. [37]. The paper proposes a system called DAHNI (Driver Ad Hoc Networking Infrastructure), to be mounted (in the long run) on each vehicle. DAHNI includes both processing and wireless communication facilities, allowing each car to constitute a local communication area around itself. In this way, each car can exchange vital signs with the neighboring vehicles. The authors discuss the security implications of such a solution. One of their conclusions is a bit surprising: they mention that no confidentiality is needed, thereby neglecting the tremendous privacy concerns that such a solution is likely to raise. They mention that no key distribution is necessary, which is true for the scenarios they consider; but if vehicles need to securely estimate the distance between them, the establishment of symmetric keys is required. In [14], we have shown that the wireless identification of vehicles is likely to rely more and more on *electronic licence plates*. We have identified the attacks against such a scheme, including those against the privacy of vehicle drivers; we have sketched appropriate techniques to thwart them. We have shown that this principle enables fundamental mechanisms such as location verification; it also supports secure distance estimation. Finally, we have explained how these mechanisms can support cooperative driving. More recently, we have proposed a security architecture that is compliant with the constraints of privacy preservation [26].

7 Mobility Model: Basis of Protocol Simulation

The mobility pattern underlying an inter-vehicle network is quite different from the "random waypoint" model that is intensively used for ad hoc network simulations. Fortunately, researchers of applied mathematics have already proposed many tools for traffic modeling (e.g., [3] provides a survey of these approaches), which can be used to extend network simulators such as *ns*-2 and GloMoSim. Note that the simulations for MAC protocols of IVC must also take mobility into account [28], which is not necessarily the case for the traditional MAC protocol (even wireless MAC like IEEE 802.11). Usually, mathematical modeling for traffic can be classified into three categories [3], according to the phenomenological observation of the system: (i) microscopic modeling, (ii) statistical description, and (iii) macroscopic description. We are not going to give details about each method, but rather provide examples where certain protocols are simulated. Microscopic modeling is suitable for simulating group communications, because the applications of these protocols are often concerned with local behaviors of vehicles. For example, Briesemeister applies a microscopic model in her thesis [5], which describes the velocity and position of each vehicle at a given time. Many other papers discussing routing protocols use macroscopic models where the mobility pattern is defined by four parameters: average vehicle speed v in m/s, traffic density ρ in vehicles/km, traffic flow q in vehicles/s, and net time gap τ in seconds. Usually, assumptions are made on two of them since the other two can be calculated subsequently. For example, Rudack et al. [29] assume a v of normal distribution and a τ of exponential distribution, while Briesemeister et al. [6] assign uniform distribution for both v and ρ. All the aforementioned models deal with one-dimensional cases, but the real mobility pattern of a vehicle is in a two (even three) dimensional space. To this purpose, the cellular automaton approach [8], combined with road patterns created based on certain maps, is adopted by FleetNet to simulate their Self-Organizing Traffic Information System (SOTIS) [36]. This approach is based on Markov chain theory to emulate the vehicles' behavior at a cross road.

Summary

The application context has to be taken into account when choosing a mobility model to evaluate certain protocols.

8 Conclusion

Various aspects of IVC are surveyed in this chapter. The chaper shows that the design of communication protocols in the framework of IVC is extremely challenging due to the variety of application requirements and the tight coupling between an application and its supporting protocols. Most existing proposals are concerned with MAC and routing protocols. While MAC is definitely an important component of the IVC protocol stack, we are not convinced that routing protocols are necessary in most cases, as they are supposed to be in general ad hoc networks. In many situations, especially those related to co-operative driving, local but distributed coordination functions sitting directly upon MAC would be more efficient solutions. In addition, since vehicles will become "smarter", partially due to the installation of IVC systems, security and privacy are becoming new concerns that both academia and industry should pay attention to. Finally, mathematical models for road traffic are important tools in developing IVC systems, because simulations are still necessary in testing large-scale communication systems.

References

1. ASTM E 22123-02. Telecommunications and information exchange between roadside and vehicle systems. In *ASTM International*, 2001. `www.astm.org`.
2. S. Baehni, R. Baldoni, B. Pochon, and R. Guerraoui. The driving philosophers. Technical Report IC/2004/15, EPFL, 2004.
3. N. Bellomo and M. Delitala. On the mathematical theory of vehicular traffic flow I: Fluid dynamic and kinetic modelling. *Mathematical Models and Methods in Applied Sciences*, 12(2):1801–1843, 2002.
4. F. Borgonovo, A. Capone, M. Cesana, and L. Fratta. ADHOC MAC: A new, flexible and reliable MAC architecture for ad-hoc networks. In *Proc. of IEEE Wireless Communications and Networking Conference (WCNC'03)*, 2003.
5. L. Briesemeister. *Group membership and communication in highly mobile ad hoc networks.* PhD thesis, School of Electrical Engineering and Computer Science, Technical University of Berlin, 2001.
6. L. Briesemeister, L. Schafers, and G. Hommel. Dissemination messages among highly mobile hosts based on inter-vehicle communication. In *Proc. of IEEE Intelligent Vehicle Symposium (IV'00)*, 2000.
7. A. Cheng and K. Rajan. A digital map/GPS based routing and addressing scheme for wireless ad hoc networks. In *Proc. of IEEE Intelligent Vehicle Symposium (IV'03)*, 2003.
8. B. Chopard, P.O. Luthi, and P.-A. Queloz. Cellular automata model of car traffic in a two-dimensional street network. *Journal of Physics A: Mathematical and General*, 29(10):2325–2336, 1996.
9. W. Franz, R. Eberhardt, and T. Luckenbach. Fleetnet – internet on the road. In *Proc. of the 8th World Congress on Intelligent Transportation Systems (ITS'01)*, 2001. `www.fleetnet.de`.
10. H. Fubler, H. Hartenstein, W. Franz, W. Enkelmann, M. Moske, and C. Wagner. The Fleetnet demonstrator. In *Demos of the 9th ACM/IEEE international conference on Mobile Computing and Networking (MobiCom'03)*, 2003.
11. H. Fubler, J. Widmer, M. Kasemann, M. Mauve, and H. Hartenstein. Contention-based forwarding for mobile ad-hoc networks. *Elsevier's Ad-Hoc Networks*, 1(4):351–369, 2003.
12. O. Gehring and H. Fritz. Practical results of a longitudinal control concept for truck platooning with vehicle to vehicle communication. In *Proc. of the 1st IEEE Conference on Intelligent Transportation System (ITSC'97)*, pages 117–122, 1997.
13. J.K. Hedrick, M. Tomizuka, and P. Varaiya. Control issues in automated highway systems. *IEEE Control Systems Magazine*, 14(6):21–32, 1994.
14. J.-P. Hubaux, S. Čapkun, and J. Luo. The security and privacy of smart vehicles. *IEEE Security & Privacy Magazine*, 2(3), 2004.
15. S. Katragadda, G. Murthy, R. Rao, M. Kumar, and R. Sachin. A decentralized location-based channel access protocol for inter-vehicle communication. In *Proc. of the 57th IEEE Semiannual Vehicular Technology Conference (VTC'03 Spring)*, 2003.
16. D. Lee, R. Attias, A. Puri, R. Sengupta, S. Tripakis, and P. Varaiya. A wireless token ring protocol for intelligent transportation systems. In *Proc. of the IEEE Intelligent Transportation System Conference (ITSC'01)*, 2001.

17. M. Lott, R. Halfmann, E. Schulz, and M. Radimirsch. Medium access and radio resource management for ad hoc networks based on UTRA TDD. In *Proc. of the 2nd ACM/SIGMOBILE Symposium on Mobile Ad Hoc Networking & Computing (MobiHoc'01)*, 2001.
18. R. Meier and V. Cahill. Exploiting proximity in event-based middleware for collaborative mobile applications. In *Proc. of the 4th IFIP International Conference on Distributed Applications and Interoperable Systems (DAIS'03), LNCS 2893*, 2003.
19. L.B. Michael. Adaptive layered data structure for inter-vehicle communciation in ad-hoc communcation networks. In *Proc. of the 8th World Congress on Intelligent Transportation Systems (ITS'01)*, 2001.
20. M. Moske. Real-world evaluation of a vehicular ad hoc network using position-based routing. Master's thesis, Department of Computer Science, University of Mannheim, 2003.
21. A. Muqattash and M. Krunz. CDMA-based MAC protocol for wireless ad hoc networks. In *Proc. of the 4nd ACM/SIGMOBILE Symposium on Mobile Ad Hoc Networking & Computing (MobiHoc'03)*, 2003.
22. Eoin O'Gorman. Using group communication to support inter-vehicle coordination. Master's thesis, Department of Computer Science, University of Dublin, 2002.
23. J. Ott and D. Kutscher. Drive-thru Internet: IEEE 802.11 for "Automobile" users. In *Proc. of the 23rd IEEE INFOCOM*, 2004.
24. C. Passmann, C. Brenzel, and R. Meschenmoser. Wireless vehicle to vehicle warning system. In *SAE 2000 World Congress*, 2002.
25. C. Perkins, editor. *Ad hoc networking*. Addison-Wesley, 2001.
26. M. Raya and J.-P. Hubaux. Security Aspects of Inter-Vehicle Communications. In *Proc. of the Swiss Transport Research Conference (STRC)*, 2005.
27. D. Reichardt, M. Miglietta, L. Moretti, P. Morsink, and W. Schulz. CarTALK 2000 – safe and comfortable driving based upon inter-vehicle-communication. In *Proc. of the IEEE Intelligent Vehicle Symposium (IV'02)*, 2002. `www.cartalk2000.net`.
28. M. Rudack, M. Meincke, K. Jobmann, and M. Lott. On traffic dynamical aspects inter-vehicle communication (IVC). In *Proc. of the 57th IEEE Semiannual Vehicular Technology Conference (VTC'03 Spring)*, 2003.
29. M. Rudack, M. Meincke, and M. Lott. On the dynamics of ad-hoc networks for inter-vehicle communications. In *Proc. of the International Conference on Wireless Networks (ICWN'02)*, 2002.
30. E. Sousa and J.A. Silvester. Spreading code protocols for distributed spread-spectrum packet radio networks. *IEEE Transactions on Communications*, 36(3):272–281, 1988.
31. I. Stojemenovic. Position-based routing in ad hoc networks. *IEEE Communications Magazine*, 40(7):138–134, 2002.
32. J. Tian, L. Han, and K. Rothermel. Spatially aware packet routing for mobile ad hoc inter-vehicle radio networks. In *Proc. of the IEEE Intelligent Transportation System Conference (ITSC'03)*, 2003.
33. K. Tokuda, M. Akiyama, and H. Fujii. DOLPHIN for inter-vehicle communications system. In *Proc. of IEEE Intelligent Vehicle Symposium (IV'00)*, 2000.

34. S. Tsugawa, K. Tokuda S. Kato, T. Matsui, and H. Fujii. An overview on DEMO 2000 cooperative driving. In *Proc. of the IEEE Intelligent Vehicle Symposium (IV'01)*, pages 327–332, 2001.
35. A. Vahidi and A. Eskandarian. Research advances in intelligent collision avoidance and adaptive cruise control. *IEEE Trans. on Intelligent Transportation Systems*, 4(3), 2003.
36. L. Wischhof, A. Ebner, H. Rohling, M. Lott, and R. Halfmann. Adaptive broadcast for travel and traffic information distribution based on inter-vehicle communication. In *Proc. of IEEE Intelligent Vehicle Symposium (IV'03)*, 2003.
37. M. El Zarki, S. Mehrotra, G. Tsudik, and N. Venkatasubramanian. Security issues in a future vehicular network. *European Wireless*, 2002.