A Communication Network for Safe Traffic and Efficient Transportation

Arne Svensson, *Fellow, IEEE*, and Mats Rydström
Communication Systems Group, Department of Signals and Systems,
Chalmers University of Technology, SE-412 96 Gothenburg, Sweden
{arne.svensson, mats.rydstrom}@s2.chalmers.se

***Abstract*— The main aim with this paper is not to present hard results and requirements, but to propose a new area of research for joint efforts in WWRF. Work is ongoing throughout the world in the area of communications between vehicles and between vehicles and the road infrastructure. We strongly believe that a completely self-organized wireless communication network connecting all road-users would have great abilities to reduce the total cost of traffic, which currently is a big burden to society. We further believe that automotive safety though wireless communications will become an important area for WWRF in the future. Currently, only a few actors from the telecommunications arena are involved in this work, which could be changed a lot if WWRF started to play a more important role. In this paper we describe the idea of a communications network for traffic safety and discuss some of the related work. We also express some of our ideas and opinions on such a system.**

I. Introduction

Some of the major problems facing societies around the world today are caused by traffic. The most serious of these are no doubt the accidents that occur every year on or near our roads, railroads and coastal sea-routes. In Sweden alone land-based traffic accounted for 520 deaths and 4604 serious injuries in 2003 [1]. In the EU 39757 fatal accidents occurred in 2001, in the U.S. this figure was 42116 for 2001 [1]. The emotional burden and financial costs imposed on the tax-payers from these accidents are tremendous. Enormous sums are spent each year in caring for the injured and replacing damaged equipment. Traffic accidents resulting in personal injury and death are, however, not the only problems caused by the ever increasing number of vehicles on our roads. We also see traffic congestions resulting in heavy delays for the travellers as well as an unnecessarily high emission of substances harmful to the environment. In the coastal area we have lately seen ships colliding and causing environmental disasters.

To counter the negative effects of our modern infrastructure we believe that traditional measures such as public information, speed limits and road-barriers are justified and important but nowhere near enough if our goal is a safe and environmentally friendly transportation infrastructure as it has to be. To really solve the problems we have with traffic today we strongly believe the whole infrastructure has to be made more intelligent. To this end we believe a novel communication network[1] would be a key component. This communication system would provide all vehicles, persons and other objects located on or near a road[2] with the necessary information needed to make traffic safer. To become successful we believe the network must 1) operate without infrastructure, 2) not require a license fee to be operated, and 3) have no operator. Thus our conclusion is that it must be a completely self-organized network with radio links using license-exempt frequency bands. In principle, the network should make the driver obsolete when combined with automatic collision avoidance systems, but we will not here discuss whether one should use automatic systems or not. Our intention is instead to develop the communication network and demonstrate the abilities of such a system. It will then be up to decision makers to decide if and how this network will be used.

In a recently started project, we will concentrate on the actual network. The initial requirements of the network we are proposing will primarily be set to fulfill the safety aspect (reduce the number of traffic-related deaths and injuries), but once a network exist that connects all road-users, the possibilities for additional applications are endless. From an economic viewpoint we strongly believe large savings will come, not only from the lowered number of accidents but also from the fact that sensors for traffic monitoring, traffic-light coordination, emergency services and highway surveillance [2] can be incorporated in our system. The system we are proposing could also offer Internet access and multimedia services such as video-on-demand and real time games for commercial and personal benefits. Although not necessary from a safety application point-of-view, we believe such additional services will enable a more swift and less costly deployment of a nation-wide or global network.

A communication network for safe traffic and efficient transportation needs to be standardized to become successful. Thus we strongly believe that WWRF has an important role to play. As will be seen from section II, currently few players from the telecommunications arena are involved in studying and designing this type of network. We think telecommunications

[1]We decided to refer to the proposed system as a wireless communication network. With another research background, it could also be referred to as a wireless sensor network, wireless ad-hoc network, or a wireless traffic safety system.

[2]The term road-user will be used to refer to any person or object located near or on a road or other location where critical situations could occur.

companies should start to cooperate with the vehicle and telematics industry in this matter. This might also make it possible to attract far more vehicle and telematics companies to become members of WWRF, and thus increase the experience of wireless systems to more areas and applications. This would be very beneficial for traffic safety applications, where knowledge from many diverse areas are of importance.

II. Previous related work

The idea of connecting vehicles or other nodes in multi-hop inter-vehicle ad-hoc networks is, of course, not new. In [3], it is stated that "the ad-hoc connection of vehicles within a limited area is a technology that promises a lot of innovative and exciting services". The paper discusses some of these services and some of the challenges of such a network. We believe this paper gives strong support for a system like the one we propose and also clarifies that a lot more research is needed to make such a network available.

The fundamental component of the system, the wireless communication network, is of course not a new concept. Much has been done and great progress in this area has been made in recent years. There is also a significant amount of research and development worldwide on increasing traffic safety by means of wireless communications. Little of this is however looking as far into the future as we propose to do in our project.

A. The lower layers

We refer to the physical and data-link layers in the communication link as the lower layers. In recent years the communications field have seen tremendous progress in the research of new fast digital wireless communication links. Much of the effort has been spent in developing technology for use in personal communications such as GSM, the recently introduced 3G spread spectrum systems and future 4G systems. A significant and important development in the area of Wireless Local Area Networks (WLAN) is also in progress. There are many ideas for using current wireless communication systems for distribution of road information. Such systems may have some effect on traffic safety but will never be able to solve all of the problems related to traffic, since the set-up and response times are far too long.

In the system we are proposing the requirements on low latency will be strict. To see this, consider a common scenario where two cars collide in a road-crossing or, even worse, collide front-to-front on a highway. In order to avoid this type of accident a chain of events will have to take place in a timely and robust manner so that both cars are left with enough time to take measures in order to avoid an accident. The first step is that the road-users must detect each other and set up some form of communications link. Once a link has been established, the vehicles must exchange information on, or in some way determine, the location of the other vehicle. The vehicles must then start a tracking algorithm to keep track of each other in real-time. Finally this chain of events must be completed in such time as to leave room for manoeuvering or automatic collision avoidance algorithms. This will never be possible in all traffic scenarios in systems based on current GSM, 3G, or WLAN technology. With current systems the cars might be able to communicate with each other long before they meet on the road. But, in order to perform real-time algorithms for tracking, collision detection and collision avoidance the wireless link must be much more dynamic (fast) and have a lower latency (both initial synchronization and set-up time as well as response time during active transmission).

We also think the technology used in the wireless link between road-users must be able to determine the distance to other nodes with a relatively high accuracy. This would become a requirement if not all nodes are equipped with self-sufficient means of deciding location. Judging from the cost and power-consumption of today's GPS receiver chips we find it highly unlikely that every node in our proposed network can be equipped with a GPS receiver and so some other means of locating nodes must be developed. Even if all nodes was equipped with GPS receivers the precision, time consumption and availability issues of GPS would still be a major concern [4], [5].

With 3G, GSM, and WLAN on the other hand a lot of useful information, with low demands on latency, on traffic congestion, already appeared accidents, animals on the road, ice-glaced roads, etc. can be provided which helps individual road-users to avoid particular areas. They will however not be of much help for avoiding the majority of traffic accidents, which have to be the goal of a future system. The combination of the communications network that we propose with active or semi-active (system that reduce the possibilities of the driver) collision avoidance systems will on the other hand have the prospect of significantly reducing the effects of accidents, and therefore the costs for society. It should however not be forgotten that the combination of new and current systems might be the best overall solution and this combination has the advantage that it serves many other applications too. It is however important to make all the options or components of the system transparent to the user.

B. The higher layers

When we talk about higher layers we refer to the networking layer and layers above. For relevant research on the higher layers in our proposed system, and the networking layer in particular, we mostly have to look into the work done by the computer networking community on ad-hoc and sensor networks where much effort has been spent on issues such as routing and location determination [6]–[8]. It should however be noted that the field of ad-hoc and sensor networks is relatively fresh and new findings and results are published at a high rate. We will however have to adapt the recently proposed algorithms suited for ad-hoc and sensor networks to our system. Most likely new, not previously encountered problems will emerge that will have to be solved before a network of the type we are proposing can be realized. We have to keep in mind that the previously described scenarios with two involved vehicles will not be very likely in urban areas where a large number of road-users will exist in the same area. This complexity will have to be handled primarily by the networking layer. Again low latency is of utmost importance and current protocols are far too slow in this aspect. Protocols that are able to handle high mobility must also be developed.

C. Some related projects

There are many projects related to communication networks among road-users and at least two projects that are more closely related to ours. They are both in some sense concerned with increasing safety in the transportation infrastructure and bringing down the number of traffic-related accidents. None of the projects however has this as its main goal and will not offer the kind of real-time services our system will be capable of. The two projects are FleetNet [9]–[13] and CarTALK 2000 [14]–[17]. FleetNet is a German project for Internet on the road and is about an ad-hoc radio network for inter-vehicle communications. Among the participants, we find Siemens, NEC, Bosch, DaimlerChrysler, and three German universities. They plan to use the UTRA TDD radio hardware. UTRA TDD is one of the 3G systems defined by ITU. From the information available about the project, it appears that the FleetNet system (like many others) is more about connecting vehicles to internet and not that much to avoid traffic accidents, which will not be possible by using UTRA TDD as discussed above. Another difference is that they only seem to consider vehicle-to-vehicle communications and not communication between all road-users. Many of their ideas on ad-hoc networking might however be useful also in a system designed primarily for traffic safety and should be considered further. This is especially true for their approach to location-based routing [11]. The FleetNet project was concluded in December 2003.

CarTALK 2000 is an EU-IST funded project in the fifth framework program, started August 2001 and funded for three years. It is focussing on new driver assistance systems which are based upon inter-vehicle communication. The main objectives are the development of co-operative driver assistance systems and the development of a self-organizing ad-hoc radio network as a communication basis with the aim of preparing a future standard. As for the assistance system, the main issues are:

- assessment of today's and future applications for co-operative driver assistance systems,
- development of software structures and algorithms, i.e. new fusion techniques,
- testing and demonstrating assistance functions in probe vehicles in real or reconstructed traffic scenarios.

To achieve a suitable communication system, algorithms for radio ad-hoc networks with extremely high dynamic network topologies are developed and prototypes are tested in probe vehicles. The considered applications are:

- information and warning functions,
- communication-based longitudinal control systems, and
- co-operative assistance systems.

Thus there is some similarity with the project we propose.

Apart from the technological goals, CarTALK 2000 actively addresses market introduction strategies including cost/benefit analysis and legal aspects, and eventually aims at the standardization to bring these systems to the European market. DaimlerChrysler, Bosch, and Siemens are also partners in this project together with Centro Ricerche Fiat, and three research institutes/universities.

There are also other suggestions in the literature for vehicle-to-vehicle communications. However, no work has been found that would satisfy or even come close to the requirements we have in our project. Recently, we also learned that standardization is ongoing within IEEE for a system with similar goals. Dedicated Short Range Communications (DSRC) is a short to medium range communications service, focused on the transportation and traffic environment. It will operate in the 5.9 GHz band with a bandwidth of 75 MHz [18]. DSRC is based on existing technology, namely the 802.11a WLAN standard from IEEE. An exciting development regarding DSRC is the FCC report and order FCC 03-324 [19], implementing new rules for DSRC. This report and order was released in February 2004 and will surely bring even more activity to the wireless automotive safety field.

We believe the DSRC standard and the high activity in this field shows that the area of automotive safety through wireless communications is important. We further believe a visionary project (like ours) is justified in order to maintain the momentum of developing new and better technology for this field, not just using technology already available.

III. Networking components in Safe Traffic

In this section we describe what we currently see as the principal components of a future safe traffic network. The goal is to offer a stable platform that various safety-related applications can stand on to perform their task. Basically, the platform should make all necessary information about neighboring road-users available to an application that requires this information. Further, the information supplied must be current and reliable, otherwise it would be impossible to design a working collision avoidance scheme or other real-time top-level applications, such as the automatic loading of cars on a ferry etc. Below we list what we believe are some of the most important components in the network as well as some important requirements for each component.

A. The physical and data-link layers

One of the most important parts in the system will be the actual communications link. The exact specifications for this part have not yet been defined. We can, however, already give some notion of the needed properties of the safe traffic physical and data-link layers. As described in section II-A the lower layers of the safe traffic system have to be designed with a very low link setup-time in mind, meaning we cannot afford to spend a lot of time on synchronization etc. Further, the lower layers will (together with the networking layer) have to provide a fast and efficient (energy-wise) means of neighbor detection. If we cannot detect a new neighboring node fast enough, precious time needed for link-setup will be lost. Once a link has been established it must provide a reliable transfer of data, perhaps with a variable bit-rate to increase the transmission range when needed, for instance in sub-urban areas. Learning from the experience of the recent deployment of newer mobile communications system (3G) that uses licensed radio spectrum we believe much can be gained from using license-exempt spectrum. This is really mandatory if the system should be operator-free, which we believe is necessary.

B. The networking layer

On top of the layer that will provide the wireless link is the networking layer. This component will be one of the most challenging to design. The networking layer will have to incorporate many functions crucial to a successful safe traffic network. One of the most important properties, we believe, will be the near-area routing or relaying of critical messages. For instance in road-crossings where there is no fixed infrastructure and cars are hidden from each other by large buildings etc. In this type of scenario messages transmitted between road-users that have no direct communications link will have to be forwarded with minimum processing latency. We also believe that a reliable and fast node location algorithm will have to be incorporated in this layer. The networking layer will also handle long-range, or multi-hop, routing of messages and, since this type of information exchange will have a lower demand on latency, we strongly believe our network will need some form of priority forwarding among its nodes. These services may alternatively be offered by cellular or other networks if these are available. Learning from the work done in the FleetNet project [9], [13] we believe a location based routing scheme would be suitable for our needs. Lately much attention has been given to privacy issues in the networking community. In a system where the location and 'behavior' of various nodes are communicated on a regular basis, privacy issues are bound to crop up. It is therefore highly likely that our networking layer also will have to take care of this aspect, by encryption or other forms of information concealment. Of course a closely linked issue is the possibility of sabotaging this system. Most certainly, methods preventing rogue nodes from disturbing the function of the network will have to be developed.

C. Networking nodes

Many would say that to bring the safe traffic network on-line too many networking devices would have to be manufactured and sold. Some would argue against the feasibility of a system where every road-user is equipped with a networking capable device. We believe that the network we are proposing is not only feasible but also that it could be deployed with a reasonably low additional cost compared to ongoing investments in infrastructure technology. Today we see networking capable technology getting smaller and less costly. Wireless networking devices are already being added to clothes and watches. Together with the advance of software-defined radio systems we believe our system could be introduced in many cases as an update to existing systems without the need for new devices. Further, our network could do the same job as many costly traffic systems deployed today. Examples include traffic monitoring, planning and surveillance. In order to make the safe traffic network feasible we will, however, have to limit the cost as well as the size of the individual nodes that make up the network. In some cases, power-consumption will obviously be of great concern. If we divide all the network nodes after performance and purpose in the network we arrive at four different types:

- Type A: Vehicles with power-supply.
- Type B: Pedestrians, bicycles, animals etc.
- Type C: Fixed objects without power supply.
- Type D: Fixed objects with power supply.

The general idea is to put as much of the complexity as possible in the nodes with a permanent power supply where size and weight of the component is not an issue. Also, complexity and functionality should be based on the nodes purpose. For instance, the purpose of a traffic sign is to warn or provide information about its neighborhood. It cannot relocate itself, may have limited power and so should not be burdened with collision avoidance. A traffic light on the other hand already has a good power supply and its purpose is to direct the traffic entering the area. In our network this type of node should play an important role in making sure road-users entering the area will be safe from collisions.

1) Type A nodes: The type A nodes will make up the core in the network. This type of node will be mounted in cars, trucks, trains, mopeds and possibly airplanes and ships. In this environment there is ample power and weight is not an issue. An A-type node can be expected to move rapidly, possibly be equipped with a GPS receiver and transmit a 'near continuous' beacon. Type A nodes should provide the base for the network routing scheme. A variable rate transmitter will allow this type of node to adapt its transmission range, based on scenario requirements.

2) Type B nodes: Type B nodes can be expected to move with significantly less speed than nodes of type A. They will be 'hand-held' and powered by rechargeable batteries so power will be limited and weight will be an issue. Perhaps GPS receivers can be included in this type of node but preferably some other means of deciding location should be implemented, perhaps aided by other types of nodes. We believe this type of node will be the most widely deployed (millions of units will be needed) so its cost should be minimized. They should not transmit a beacon continuously but lie dormant until a type A node's beacon is detected. This way power will be conserved. Also, accidents where two pedestrians or a jogger and a traffic sign collide can not be considered very serious.

3) Type C nodes: In the C-class we include fixed objects without a permanent power-supply. This includes, among others, traffic signs and various road sensors. They will not be equipped with a GPS receiver and instead store their location in some sort of memory (ROM), flashed or written at installation. Like the type B nodes they will only transmit when a type A node is detected. Solar power might be a reasonable assumption depending on cost. Possibly they should be capable of relaying the transmissions of type A nodes to extend coverage of the network. Also, a variable-rate transmitter should be implemented so this type of node can make itself known to type A nodes at larger distances while minimizing transmission power.

4) Type D nodes: The last type of node will be a fixed node with a permanent power supply. They might for instance be used to advertise locations of hospitals and other important locations such as emergency exits in a long tunnel or provide gateways to other networks such as the Internet or the cellular phone network. In this group we also include traffic lights, parking meters and other urban road-signs located close to power sources. Traffic lights will play an important role in our network from a safety point of view. Parking meter nodes may be used for keeping track of available parking spots and also for charging parked cars by the hour and detecting cars parked in dangerous locations or without a parking permit. While functions such as the parking meter function and the Internet access does not play an important role in reducing the number of accidents we believe the network will be easier to introduce to the public if it offers services that are in demand and increases the value of a car equipped with a type A node.

D. Information exchange

Because we are dealing with messages that need to be delivered with a minimum latency in order to provide enough time for collision avoidance etc. our network will have to provide some form of priority forwarding or Quality of Service (QoS) scheme. At this point we think it would be appropriate to divide QoS into two separate categories: delay and message loss. It is our thought that delay priority can be directly related to transmission distance and fairly easily implemented with priority queuing at the forwarding nodes since each node can calculate the total transmission distance. Nodes located close to each other and communicating to decide how a collision can be avoided obviously need a minimum latency maximum reliability link. On the other hand, a message transmitted to nodes some 5 km away informing them of a traffic jam up ahead will have lower demands on latency but may have higher demands on reliability. Also, the greater the distance the more time a node has to decide what to do and possibly initiate retransmissions. For now we choose to divide the traffic into three different groups:

- Type 1: High priority, short range messages
- Type 2: Informational broadcasts
- Type 3: Multiple-hop point-to-point sessions

Because the most strict demands on latency and reliability will be placed on the short-range messages we will avoid many problems associated with ad-hoc routing. All ad-hoc routing schemes suffers from the fact that longer routes are, due to the movement of the nodes, hard to maintain without high complexity, high overhead routing schemes.

E. Locationing

The corner stone of any collision detection and/or avoidance system is obviously how to determinate the location of the participating objects, their direction of travel and speed. Without this data the detection of critical situations will become impossible, just imagine trying to manage an airports traffic-control system without any data on where the airplanes are located and where they are heading. We believe that a node locationing system with high accuracy, reliability and availability will be a very essential part of the system for traffic safety we are proposing. For traffic safety and navigation systems in particular, GPS has been suggested as a means to determine vehicle location, direction of travel and velocity [5], [9]. GPS may, especially when augmented with additional sensors such as odometers and gyros provide an acceptable rate of location updates for navigation purposes [4], but for a collision avoidance system both the location update rate of modern GPS baseband processors (about one fix/second) and the accuracy of each fix (around 10 m in good conditions) will not be enough. Also, the GPS system needs a clear unobstructive view of the sky to function properly. This means that the GPS system's performance is severely limited in urban environments where buildings are tall and does not function at all in indoor environments such as road-tunnels and indoor parking areas. The sensitivity and accuracy of the GPS system may be enhanced by longer periods of integrating the received signal [4]. This would however not be of much use in a system for traffic safety since the update-rate is of paramount importance, two cars travelling on a Swedish highway will decrease their relative distance by about 70 meters in one second. A GPS receiver is also sensitive to multipath phenomena, something often experienced in urban environments, that may limit the position-fix accuracy to hundreds of meters. It is our thought that a system for traffic safety, including collision detection and avoidance will need a "worst-case" accuracy in the position-fixes of about 2-3 meters. Further, the update-rate at which position updates are obtained will have to be less than one second.

There is, however, still hope. Much of the recently developed theory on sensor networks may, we believe, also be applied to a system for traffic safety. Because actual geographic location is much less important than relative (local) location in a cluster of nodes, we believe it would be possible to implement a distributed algorithm for node-location determination using inter-node communications such as round-trip time or received signal strength. Doing this in a distributed fashion would mean that nodes with higher processing power would carry more computational work than nodes with less processing power. Also, since some nodes will be fixed and therefore can supply an exact position or reference to the global geographical coordinate system, we believe a sufficiently exact and fast locationing-system is possible. More on the location problem with some solutions can be found in an accompanying paper [20].

F. Top-level applications

What top-level applications should be developed remains to be seen. Once the network is in place and functional the possibilities are endless. Primarily the top-level applications should increase safety in some way, either by direct collision avoidance or by distributing information that will help avoid future critical situations.

IV. Summary

In this paper we propose a wireless communications network to be designed primarily for traffic safety. The network aims at becoming a global network for the exchange of critical information between vehicles, persons and other objects located near or on a road. When all objects located near a road has real-time access to information on neighboring objects such as their position, direction of travel and speed, successful collision detection and avoidance schemes will become possible to implement. When this type of network is realized, fatalities caused by traffic accidents should be drastically reduced and eventually, the long sought "zero-vision" reached[3]. We also argue that reaching a low number of accidents each year will not be possible without a network similar to the one we are proposing, our main arguments for this is that traditional measures such as public information, road-barriers and speed-limits have been tried for many years now and, while accidents have decreased, we still see far too many traffic related incidents. Although safety is the main object of the network we argue that once a network of this kind is available the additional possibilities are endless. Mobile Internet access, video-on-demand and other digital services will be possible additional benefits of the network.

We present some related work that has been and is being done in related areas including two projects aimed partly at increasing traffic safety by wireless networking. We also conclude that even though some projects exist and have existed that are related to our suggestion, no work has been done so far that would fulfill the requirements of a network like the one we propose. The most challenging requirement is certainly latency, and in principle more and more accidents can be avoided by using the network, when the latency is reduced further and further. Thus solutions with a minimal latency should be developed.

A description of the different key-components in the network is given where some of the requirements for various components are listed. Our views so far on what components should be part of the network are also given.

Society and every citizen should be interested in this system, since it makes life much more safe and still allows us to travel anywhere we like, without the risk of being killed or seriously injured in a traffic accident. In the long run, it is expected that society will save a lot of money from much fewer accidents and this money can instead be used for more useful things like education, health care, elderly care, etc.

Currently we see few players from the telecommunications arena involved in wireless networks for traffic safety. We strongly believe that more telecommunications knowledge is important for the developments of these systems and believe that WWRF should take a more active role in their development. This could lead to more cooperation between the vehicle and telecommunications industry and would make the role of WWRF even more important than it is today.

[3]The National Swedish Road Administration has defines the zero vision as a goal to reach a lower number of killed people in traffic. Currently it is defined as at most 250 people killed in traffic accidents per year in Sweden.

References

[1] www.vv.se.

[2] L. Klein, *Sensor Technologies and Data requirements for ITS*. Artech House, 2001.

[3] T. Kosch, C. Schwingenschlögl, , and L. Ai, “Information dissemination in multihop inter-vehicle networks,” in *Proceedings IEEE International Conference on Intelligent Transportation Systems*, Singapore, 2002.

[4] G. MacGougan, G. Lachapelle, R. Klukas, and K. Siu, “Degraded GPS signal measurements with a stand-alone high sensitivity receiver,” in *Proceedings ION National Technical Meeting*, San Diego, California, USA, Jan. 2002.

[5] O. Mezentsev, Y. Lu, G. Lachapelle, and R. Klukas, “Vehicular navigation in urban canyons using a high sensitivity GPS receiver augmented with a low cost rate gyro,” in *Proceedings GPS Conference*, Portland, Oregon, USA, Sept. 2002.

[6] C. Perkins, *Ad Hoc Networking*. Addison-Wesley, 2001.

[7] C.-K. Toh, *Ad Hoc Mobile Wireless Networks: Protocols and Systems*. Prentice Hall, 2002.

[8] A. Hać, *Wireless Sensor Network Designs*. Wiley, 2004.

[9] www.fleetnet.de.

[10] A. Ebner and H. Rohling, “A self-organized radio network for automotive applications,” in *Proceedings World Congress on Intelligent Transportation Systems*, Sydney, Australia, Oct. 2001.

[11] A. Ebner, H. Rohling, R. Halfmann, and M. Lott, “Synchronization in ad hoc networks based on UTRA TDD,” in *Proceedings International Symposium on Wireless Personal Multimedia Communications*, Honolulu, Hawaii, USA, Oct. 2002.

[12] L. Wischhof, A. Ebner, H. Rohling, M. Lott, and R. Halfmann, “SOTIS – a self-organizing traffic information system,” in *Proceedings IEEE Vehicular Technology Conference Spring*, Jeju, Korea, May 2003, pp. 2442–2246.

[13] M. Mauve, J. Widmer, and H. Hartenstein, “A survey on position-based routing in mobile ad hoc networks,” *IEEE Network*, vol. 15, no. 6, pp. 30–39, Nov./Dec. 2001.

[14] www.cartalk2000.net.

[15] L. Coletti, N. Riato, A. Capone, and L. Fratta, “Architectural and technical aspects for ad hoc networks based on UTRA TDD for inter-vehicle communications,” in *Proceedings IST Mobile Summit*, Aveiro, Portugal, June 2003.

[16] J. Tian and L. Coletti, “Routing approach in CarTALK 2000 project,” in *Proceedings IST Mobile Summit*, Aveiro, Portugal, June 2003.

[17] P. Morsink, R. Hallouzi, I. Dagli, C. Cseh, L. Schäfers, M. Nelisse, and D. de Bruin, “CarTALK 2000: Development of a co-operative ADAS based on vehicle-to-vehicle communications,” in *Proceedings World Congress and Exhibition on Intelligent Transportation Systems and Services*, Madrid, Spain, Nov. 2003.

[18] www.leearmstrong.com/DSRC/DSRCHomeset.htm.

[19] hraunfoss.fcc.gov/edocs_public/attachmatch/FCC 03-324A1.pdf.

[20] M. Rydström, A. Urrulea, and E. S. A. Svensson, “Node-aided locationing and tracking for low cost ad-hoc automotive sensor networks,” in *Proceedings WWRF meeting*, Oslo, Norway, June 2004.