Car-to-Car Communications

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Abstract
Due to the rapid development of technologies, transportation in general is still an expanding technical and economical segment. Practical application of intelligent transportation systems can significantly improve the efficiency of cars, trains, ships, and air planes. A relatively new development in the automotive sector is the application of wireless communication technologies for inter-vehicle and vehicle-to-roadside communication. Self-organizing wireless networks have already been successfully applied in the fields of maritime and air traffic control. Based on these experiences, the next logical step is car-to-car communication which will lead to improved safety and comfort of the passengers. Besides the development of a suitable wireless air interface, new protocols and applications for car-to-car communication need to be investigated which can successfully disseminate information in these highly mobile ad-hoc networks. One application which is based on car-to-car communications is the so-called Self Organized Traffic Information System (SOTIS). This tutorial provides a comprehensive overview concerning the development and technical principles of car-to-car communications. Moreover the SOTIS application is explained in detail.

Keywords
Car-to-car, car-to-X, intelligent transportation, self-organization, SOTIS

Objectives and Scope
The objective of this tutorial is to give the audience an in-depth view into principles of car-to-car communications. In the first part, the general concepts and possible technical solutions of such communication systems are introduced, and the pros and cons are discussed. The second part deals with a specific system called “Self-Organizing Traffic Information” (SOTIS). This system is discussed in detail in the tutorial; in the following, a brief motivation and outline of SOTIS is provided.

With increasing traffic density on highways and inside the cities, the traffic situation becomes more and more complex for today’s drivers. Vehicle navigation systems, which are already integrated into many vehicles, can assist the driver by combining the use of digital maps with information about the current position available via the Global Positioning System (GPS). This is a very useful system, which is technically based on the assumption that all streets of the digital map can be considered as currently available for route planning. Information about traffic conditions is not available in this basic system and cannot be used to find optimized routes. More advanced navigation systems therefore integrate Traffic and Travel Information (TTI) into the route planning. The user is able to select alternative routes in order to avoid congested streets and can be warned about potentially dangerous road conditions ahead. In this case, a short delay between sensing the current street conditions and the traffic messages is the major system requirement. Delay and level of detail of these TTI messages determine the utilizable value of a Traffic Information System (TIS). The TIS can also be integrated into vehicles independent of a navigation system, if a driver just wants to be informed about the current traffic conditions.

Conventional TIS are organized in a centralistic way as illustrated in Figure 1 a): Sensor-based traffic monitoring systems deployed directly at the roadside collect information about the current traffic density. The measured data is transferred to a central Traffic Information Center (TIC), where the data packets from all sensors are received and the current traffic situation is analyzed. The result of this situation analysis is packed into messages for the Traffic Message Channel2 (TMC), forwarded to the FM radio broadcast station and transmitted via Radio Data System (RDS) to the driver. Alternatively, the traffic messages can be transferred on demand via a cellular mobile phone network.
A centralized service for distributing traffic information, such as the traffic news or the TMC broadcasted by a radio station, has several technical disadvantages:

- A large number of sensors is needed to be deployed in order to monitor the traffic situation. The traffic information service is limited to streets where sensors are integrated.
- The recorded traffic density data is transmitted to a central unit and evaluated, before it is broadcast to the drivers.
- Traffic information is distributed with a relatively high delay (typically in the range of 20-50 minutes). The time delay before receiving an update of the current traffic situation (especially for the local area) is the most crucial point in all TTI systems.
- It is not suited for vehicle-to-vehicle emergency notifications.
- Since a central unit covers a relatively large area and due to the limited bandwidth for transmitting the traffic messages, the broadcasted information needs to be general and cannot include specific details on the area close to the current position of the driver.
- An extremely large investment for the communication infrastructure (sensors, central unit, wired and wireless connections) is necessary.

For all these reasons, an alternative and completely different approach for monitoring the traffic situation and distributing the traffic messages to vehicle drivers is presented in this tutorial. The general objectives are unchanged compared to the conventional TTI system, but the technical solution is completely different. The SOTIS system is mainly based on a simple wireless interface inside each vehicle and a self-organizing radio network formed by the locally available individual vehicles. There is absolutely no communication/sensor infrastructure needed.

The general objectives of a conventional TTI system are unchanged for the SOTIS design. Therefore, the functionality of the centralized system must be reorganized (Figure 1b): The traffic conditions (e.g. average velocity) are not any longer measured by external sensors but alternatively by the SOTIS vehicles itself. The position of each vehicle is known from the GPS receiver. This position and additional vehicle individual information is transferred via digital radio link to all surrounding vehicles. Thus, traffic information is directly available for all vehicles in a local environment.

The functionality of the central unit to process the received data and generate a traffic situation analysis is now implemented in each individual vehicle. Whereas in the conventional TTI system the traffic situation is described on a global basis, this is changed in the SOTIS technique into a local description of the traffic situation inside a radius of approximately 50-100 km. The knowledge about the current
traffic situation is therefore available on an individual vehicle basis. The wired and wireless connections in the conventional TTI system are replaced by a wireless network interface, which is based on a TDMA channel access technique.

The SOTIS technique is based on a combination of GPS receiver and simple digital radio equipment. In the current implementation, it is assumed that each vehicle is additionally equipped with a simple digital map. Therefore, the available traffic information can be visualized and stored based on road identifiers of the digital map instead of its raw geographical position.

![Figure 2: Block diagram of SOTIS structure](image)

Collected traffic information is processed individually in each vehicle, and all nodes (SOTIS vehicles) have the same internal structure (Figure 2): All currently available traffic information of a node is stored in the Knowledge Base (KB), e.g. in form of a database containing roads and information for each segment of the road.

In order to reduce the amount of geographical information that has to be transmitted via digital radio, each road is divided into several segments and traffic information is sent on a per-segment basis only. The length of a segment can depend on its distance from the transmitting vehicle – thus, the level of detail is increased for the area that is close to the current position. The amount of information that is stored in the KB is limited to a specific area around the current position of the vehicle (e.g. a radius of 50 km), information in received SOTIS packets regarding segments outside this area is discarded.

Each SOTIS vehicle transmits an update of its current position and traffic information recurrently (e.g. with an inter-transmission interval of 5 s) in form of a regular SOTIS packet (Periodic Report), in order to inform surrounding vehicles about the individual knowledge. Such data packets contain TTI measured by the transmitting vehicle (e.g. position, velocity, heading, etc.) and a short traffic situation analysis based on the information stored in the KB. Time intervals, in which these reports are generated, can vary based on the priority of the information (e.g. a near accident has a higher priority than weather information for a road 20 km away) and the utilization of the wireless medium observed by the radio hardware. Furthermore, adaptive broadcast schemes, which adapt the inter-transmission interval based on TTI in packets recently received, can significantly reduce the required bandwidth.

In addition to the Periodic Reports, an emergency causes a vehicle to send an Emergency Report immediately. Therefore, a medium access control protocol is assumed that can guarantee an immediate access to the wireless channel, e.g. by constantly reserving a specific capacity for emergency reports.

Upon reception of any of these two types of data packets, the information in the KB is updated and can be used to perform a traffic analysis at any time, e.g. in order to display the traffic situation in the surrounding area in the man-machine interface (MMI) of the in-vehicle navigation system.
Syllabus

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- Summary

Prof. Dr. Hermann Rohling is with the Technical University Hamburg-Harburg, Germany. He is head of the Telecommunications department where he has developed an international reputation for Mobile Communication (4G) and automotive radar systems. Previously Prof. Rohling was with the AEG Research Institute, Ulm as a researcher working in the area of digital signal processing for radar and communications applications. His research interests have included Wideband Mobile Communications especially based on Multicarrier Transmission Techniques (OFDM) for future broadband systems (4G), signal theory, digital radar signal processing, detection, estimation and differential GPS for high precision navigation. Prof. Rohling is a member of Informationstechnische Gesellschaft (ITG), president of the German Institute of Navigation (DGON) and a Fellow of IEEE. He is a chairman of the Workshop of Intelligent Transportation (WIT 2011), the International OFDM Workshop (InOWo 2011) in Hamburg and the International Radar Symposium (IRS 2011) in Leipzig, Germany. Prof. Rohling is the Vicepresident of the Technical University Hamburg-Harburg.