

CAR-2-X Communication for Safety and Infotainment in Europe

Dr. Andreas Festag, Roberto Baldessari, Dr. Wenhui Zhang
 Dr. Long Le, Amardeo Sarma, Masatoshi Fukukawa

Abstract

Vehicular communication based on short-range wireless technology opens up novel applications improving road safety and travel comfort. Ad hoc networking enables a direct communication among cars as well as between cars and road-side communication devices. Geocast is an ad hoc routing scheme which is specifically considered in Europe as a core networking concept for future CAR-2-X systems. It provides wireless multi-hop communication and allows for geographical addressing and routing. This paper describes advanced concepts and mechanisms to deploy Geocast in realistic environments and presents NEC's CAR-2-X platform.

Keywords

short-range wireless technology, car-to-car and car-to-infrastructure communication, ad hoc networking, Geocast, multi-hop communication, IEEE 802.11, CAR-2-X communication, CAR-2-X platform, C2C-CC

1. Introduction

Among the emerging wireless technologies used by drivers and passengers, short-range wireless communication based on IEEE 802.11 has received considerable attention worldwide. Due to its low costs, availability and wide deployment, it is expected that future cars will be equipped with on-board units offering IEEE 802.11 wireless interfaces and antennas. The wireless technology enables a fully distributed vehicular communication network based on self-organization and self-coordination of the network nodes which is commonly referred to as ad hoc networking. The combination of both short-range wireless technology and ad hoc networking facilitates car-to-car and car-to-infrastructure communication - subsumed under CAR-2-X.

CAR-2-X communication is regarded as a cornerstone of future Intelligent Transportation Systems (ITS) (Fig. 1). A major goal of CAR-2-X and ITS is the improvement of road safety and sustainable reduction of fatalities due to road accidents ¹⁾. Moreover, CAR-2-X communication enables various applications to improve traffic efficiency and infotainment, where dedicated frequencies will be allocated for safety and traffic efficiency (see Fig. 2⁴⁾ for the considered frequency allocation in Europe). Due to the wide range of opportunities, a strong and common interest from public, governments, and industry to develop, standardize and deploy CAR-2-X communication technology exists.

Applications and peculiarities of the vehicular communication environment put specific requirements on networking. In

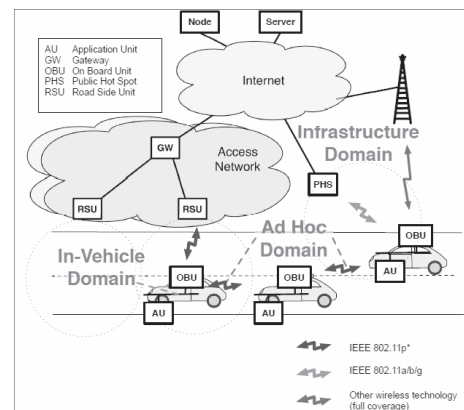


Fig. 1 Car-2-X communication scenario.

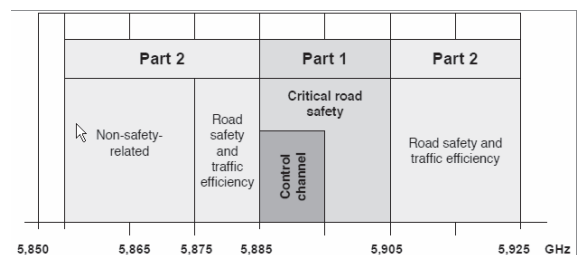


Fig. 2 Proposed spectrum allocation for safety and traffic efficiency applications in Europe.

principle, the ad hoc networking provides a spontaneous and direct communication of a car with other cars or with fixed road-side access points in its vicinity. For communication beyond the transmission range of the wireless technology (typically around 500m), the network nodes (on-board units in cars or road-side units) cooperate and relay data on behalf of other nodes. This multi-hop communication enables the distribution of data in a geographical region and also the forwarding of data towards the geographical position of a single destination node for unicast communication. Unlike in cellular networks, road-side units execute a multitude of functions: they forward data to increase the coverage of the ad hoc network, send or receive application data (e.g. warning from road construction), or provide cars with access to the Internet.

To meet the specific requirements of vehicular communication on support of highly mobile vehicles, frequent topology changes, and scalability with potentially very large number of nodes, the concept of geographical routing was applied and extended to vehicular environments and use cases. Results from extensive network simulations and first measurement of this Geocast approach have indicated good performance in realistic environments²⁾. Therefore, Geocast was chosen as the core networking protocol for vehicular communication based on IEEE 802.11 technology promoted by the Car-to-Car Communication Consortium (C2C-CC) in Europe, the major European industry consortium for vehicular communication³⁾.

The following two sections of the paper present advanced solutions for Geocast as the core concept of CAR-2-X communication (Sec. 2) and NEC's CAR-2-X platform (Sec. 3).

2. CAR-2-X Communication Technology

Basically, Geocast is an ad hoc routing protocol utilizing geographical positions for data transfer. Its basic principles were originally proposed as alternative to pure topology-based internetworking⁵⁾ and in mobile ad hoc networks⁶⁾. Geocast assumes that vehicles acquire information about their position (i.e. geodetic coordinates) via GPS or any other positioning system. Every vehicle periodically advertises this information to its neighboring vehicles and hence, a vehicle is informed about all other vehicles located within its direct communication range. If a vehicle intends to send data to a known target geographic location, it chooses another vehicle as message relay, which is located in the direction towards the target position. The same procedure is executed by every vehicle on the multi-hop path until the destination is reached. This approach

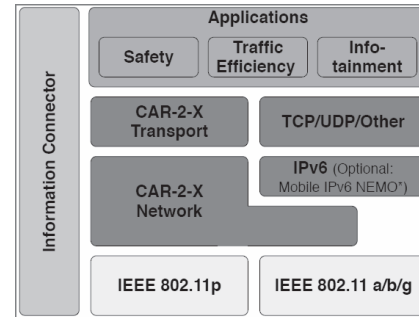


Fig. 3 CAR-2-X protocol architecture.

does not require establishment and maintenance of routes. Instead, packets are forwarded 'on the fly' based on most recent geographic positions (Fig. 3).

In detail, Geocast assumes that every node knows its geographical position and maintains a location table containing other nodes and their geographical positions as soft state. Geocast supports point-to-point and point-to-multipoint communication. The latter case can be regarded as group communication, where the endpoints are inside of a geographical region.

Core protocol components of Geocast are beaconing, a location service, and forwarding. With beaconing, nodes periodically broadcast short packets with their ID, current geographical position, speed and heading. On reception of a beacon, a node stores the information in its location table. The location service resolves a node's ID to its current position. When a node needs to know another node's position that is currently not available in its location table, it issues a location query message with the sought node ID, sequence number and hop limit. Neighboring nodes rebroadcast this message until it reaches the sought node (or the hop limit). If the request is not a duplicate, the sought node answers with a location reply message carrying its current position and a timestamp. On reception of the location reply, the originating node updates its location table. Forwarding basically means relaying a packet towards the destination.

But the most innovative method for distribution of information enabled by geographical routing is the addressing of geographical areas as target of data packets. In practice a vehicle can select and specify a well delimited geographic area to which the messages should be delivered. Once again the intermediate vehicles serve as message relays and only the vehicles located within the target area process the message and show it to the driver. In this way, the vehicles that are actually affected by a dangerous situation or a traffic notification are

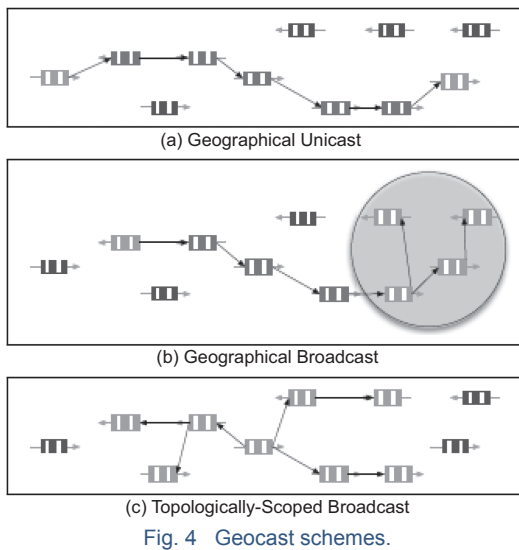


Fig. 4 Geocast schemes.

notified, whereas vehicles unaffected by the event are not targeted.

In summary, Geocast comprises the following forwarding schemes:

- GeoUnicast (Fig. 4) provides packet delivery between two nodes via multiple wireless hops. When a node wishes to send a unicast packet, it first determines the destination's position (by location table look-up or the location service) and forwards the data packet to the node towards the destination, which in turn re-forwards the packet along the path until the packet reaches the destination.
- GeoBroadcast (Fig. 4(b)) distributes data packets by flooding, where nodes re-broadcast the packets if they are located in the geographical region determined by the packets. This simple flooding scheme is enhanced with techniques based on packet numbering to alleviate the effects of so-called broadcast storms that are a typical problem in wireless ad hoc networks. GeoAnycast is similar to GeoBroadcast but addresses a single (i.e., any) node in a geographical area.
- Topologically-scoped broadcast (TSB) (Fig. 4(c)) provides rebroadcasting of a data packet from a source to all nodes in the n-hop neighborhood. Single-hop broadcast is a specific case of TSB which is used to send periodic messages (beacons or heartbeats).

The concepts of geographical networking serve as a basis for NEC's approach to CAR-2-X communication (Fig.3). NEC has developed advanced solutions, which enhance the basic Geocast and target the numerous challenges of this field. In this

paper we highlight robustness and reliability, security and privacy, and Internet integration.

1) Robustness and Reliability

NEC has implemented several enhanced mechanisms for improving robustness and reliability of packet delivery in vehicular communication.

The main enhanced mechanisms for robustness and reliability are briefly discussed here: detection and suppression of duplicated packets, temporary caching of data packets, and transmit power control for beacon and data packets.

In order to alleviate the broadcast storms where each node rebroadcasts data packets that it receives and potentially causes duplication of data packets, each node caches the sequence numbers of data packets that it receives. This caching mechanism allows nodes to detect and drop duplicated packets.

Temporary caching of data packets can potentially improve the reliability of packet delivery when the density of vehicles is low. For unicast communication, a node temporarily caches a packet when no vehicles closer to the destination are available. When a new neighbor arrives, the node forwards the cached packet to the neighbor if this new neighbor is closer to the destination. A similar technique is also applied for Geocast where a node retransmits data packets upon detection of new neighbors. Reliability is further improved by combining geographical routing with contention-based routing and controlling dynamically the level of redundancy ⁷⁾.

To increase the system robustness NEC has developed a mechanism to control the IEEE 802.11 radio on a per-packet basis. This mechanism allows to control the transmit power for every individual data packet, which in turn enables the implementation of distributed transmit power control algorithms ⁸⁾ and efficient coupling with the routing scheme ⁹⁾. These schemes reduce the physical radio interference among the nodes which results in better overall network performance.

2) Security and Privacy

NEC has developed a solution for data security that is based on asymmetric cryptography and digital certificates ¹⁰⁾. NEC's solution guarantees authentication and non-repudiation of the information exchanged between vehicles and protects against malicious users. Furthermore, plausibility checks based on timestamp and communication ranges are performed for every received packet. Packets that fail the plausibility checks are simply dropped. Each node also uses results of the plausibility checks as input for the confidence

assessment of its neighbors. A node originating too many packets that fail the plausibility checks is classified as untrusted. Packets from untrusted nodes are simply dropped. Privacy protection has also been studied by NEC and a method based on variable network identifiers (pseudonyms) has been developed ¹¹⁾.

3) Internet Integration

Solutions for integration of the IPv6 protocol and geographical routing have been developed. This enables vehicles to use traditional applications based on the Internet protocol (IP), as well as to gain Internet connectivity directly or even via multi-hop communication. The usage of IP solutions for mobility like Network Mobility (NEMO) support are also investigated ¹²⁾. In this matter, NEC has promoted an initiative together specific requirements from the automotive industry ¹³⁾.

3. CAR-2-X Communication Platform

NEC's offer for international research activities and field trials deploying vehicular communications comprises a hardware platform, called LinkBird-MX, and a software package called CAR-2-X communication SDK. LinkBird-MX is a



(a) Front view



(b) Rear view

Photo NEC CAR-2-X hardware platform LinkBird-MX.

pre-product hardware platform designed for maximum flexibility and programmability and meets the requirements for CAR-2-X field trials. **Photo** shows the preliminary exterior of LinkBird-MX.

The current hardware of LinkBird-MX is comprised of a 64bits MIPS microprocessor, 512MB NAND-Flash, 16MB Nor-Flash and 128MB SDRAM. It supports Linux operation systems, currently with the kernel version 2.6.19. In addition, it provides test program modes and hardware diagnosis functions. With physical dimensions of 153.5mm(W) × 118mm(D) × 43mm(H), the LinkBird-MX is relatively small and ideal for usage as an on-board unit in a vehicle. Industrial operation temperature in the range between -20 and +65 C will be guaranteed. Also, it will have hibernation technology for reduction in start-up time and features a low power consumption at maximum 5W.

The LinkBird-MX is equipped with various interfaces. In addition to the widely used interfaces RJ-45 and USB, it is also mounted with more advanced interfaces, which are the VICS (Vehicle Information and Communication System), Integrated UART (Universal Asynchronous Receiver Transmitter) and MOST (Media Oriented Systems Transport) interfaces. For wireless interfaces, the LinkBird-MX follows the flexible design principle in that different wireless interface cards can be plugged in. In the first version, a miniPCI card based on Atheros chipset and a IEEE 802.11p compatible driver will be delivered. For further extensions two PCMCIA card slots are available. In addition, two RP-SMA connectors for antennas are installed on the LinkBird-MX. The various interfaces of the LinkBird-MX are summarized in **Table**.

Vibration resistance from both engine and road noise is one of the most important factors for vehicular environments. Weak structure design can lead to loose connections of IC chips to the PWB (Printed Wiring Board). LinkBird-MX is well designed against such vibrations. In addition to that, it will be certified by CE marking, VCCI ^{*1}, and FCC ^{*2} in order to be introduced to the global ITS market. All devices will be fully compliant with EU directives such as ROHS ^{*3} and ELV ^{*4}.

The hardware platform executes the NEC CAR-2-X protocol stack, which enables wireless ad hoc and multi-hop communication based on Geocast as described in Sec. 2. The protocol stack implements enhanced algorithms and protocol mechanisms, which ensure efficient and reliable data

*1 Voluntary Control Council for Interference

*2 Federal Communication Commission

*3 Restriction of the Use of Certain Hazardous Substances in electrical and electronic equipment

*4 End of Life Vehicles

Table LinkBird-MX interfaces.

Interface	Specification
Rj-45 Ether port	10/100Base-T, 1 port
USB	Version 2.0, 2ports
VICS	1 port
Integrated UART	GPS,CAN,DSRC,232C
MOST	1 port
ANT RP-SMA connector	2 ports
PCMCIA	2 slots
Mini-PCI: IEEE802.11p or a/b/g	1 slot
Power(DC12V)	1 port

communication, protect security and privacy, and support safety and infotainment applications based on IP version 4 and 6. The protocol stack enables two main configurations. In the co-located configuration, LinkBird-MX executes the communication protocols and applications. In the stand-alone configuration, LinkBird-MX handles only the communication protocol stack and connects to one or more application units (such as safety-enhanced navigation devices, telematic units, or mobile phones).

The NEC CAR-2-X communication SDK (<http://c2x-sdk.neclab.eu>) is a toolkit, which provides the protocol stack as well as an open API to easily and rapidly write applications for road safety, traffic efficiency and infotainment. It is offered to partners of the Car-to-Car Communication Consortium and used by various European research projects.

4. Summary

CAR-2-X communication based on short-range wireless technology devices and ad hoc networking is commonly regarded as an enabling technology for future ITS. We have presented NEC's advanced networking approach and illustrated NEC's CAR-2-X platform. Both, the software and hardware platform will be used in field operational tests (FoTs) for CAR-2-X communication starting 2008 in Germany and 2009-10 on a European scale.

References

- 1) E. Commission, "White Paper: European Transport Policy for 2010: Time to Decide," 2001.
- 2) A. Festag, H. Fußler, H. Hartenstein, A. Sarma, and R. Schmitz, "Fleet-Net: Bringing Car-to-Car Communication into the Real World," in Proceedings of 10th ITS World Congress and Exhibition, Nagoya, Japan, November 2004, 8 pages.
- 3) Car-to-Car Communication Consortium, "C2C-CC Manifesto," Version 1.0, July 2007, available at http://www.car-to-car.org/leadadmin/dokumente/pdf/C2C-CC_manifesto_v1.0_2007-05-17.pdf.
- 4) ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM), "Technical Characteristics for Pan-European Harmonized Communication Equipment Operating in the 5 GHz Frequency Range and Intended for Critical Road-Safety Applications," ETSI, Tech. Rep. ETSI TR 102 492-1/2, 2005.
- 5) G. Finn, "Routing and Addressing Problems in Large Metropolitan-Scale Internetworks," University of Southern California, ISI Research Report ISI/EE-87-180, March 1987.
- 6) B. Karp and H. Kung, "GPSR: Greedy Perimeter Stateless Routing for Wireless Networks," in Proceedings of the 6th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom '00), Boston, Massachusetts, USA, August 2000, pp. 243-254.
- 7) M. Torrent-Moreno, "Inter-Vehicle Communication: Achieving Safety in a Distributed Wireless Environment, Challenges, Systems and Protocols," Ph.D. dissertation, University Karlsruhe, Karlsruhe, July 2007.
- 8) M. Torrent-Moreno, P. Santi, and H. Hartenstein, "Distributed Fair Transmit Power Adjustment for Vehicular Ad Hoc Networks," in Proceedings of 3rd Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON 2006), Reston, VA, USA, September 2006, p. 10 pages.
- 9) A. Festag, R. Baldessari, and H. Wang, "On Power-Aware Greedy Forwarding in Highway Scenarios," in Proceedings of 4th International Workshop on Intelligent Transportation (WIT), Hamburg, Germany, March 2007, pp. 31-36.
- 10) C. Harsch, A. Festag, and P. Papadimitratos, "Secure Position-Based Routing for VANETs," in VTC Fall, Baltimore, MD, USA, October 2007, 5 pages.
- 11) E. Fonseca, A. Festag, R. Baldessari, and R. Aguiar, "Support of Anonymity inVANETs - Putting Pseudonymity into Practice," in Proceedings of IEEE Wireless Communications and Networking Conference (WCNC), Hong Kong, March 2007.
- 12) R. Baldessari, A. Festag, and J. Abeille, "NEMO meets VANET: A Deployability Analysis of Network Mobility in Vehicular Communication," in Proceedings of 7th International Conference on ITS Telecommunications (ITST 2007), Sophia Antipolis, France, June 2007, pp. 375-380.
- 13) R. Baldessari, T. Ernst, A. Festag, and M. Lenardi, "Automotive Industry Requirements for NEMO Route Optimization Internet Draft," draft-ietf-mext-nemo-ro-automotive-req-00, work in progress, February 2008.

Authors' Profiles

Dr. Andreas Festag

Senior Researcher,
NEC Deutschland GmbH

Roberto Baldessari

Research Scientist,
Ubiquitous and Secure Communication,
Networking,
Network Research Division,
NEC Laboratories Europe, NEC Europe

Dr. Wenhui Zhang

Research Scientist,
Ubiquitous and Secure Communication,
Networking,
Network Research Division,
NEC Laboratories Europe, NEC Europe

Dr. Long Le

Research Scientist,
Ubiquitous and Secure Communication,
Networking,
Network Research Division,
NEC Laboratories Europe, NEC Europe

Amardeo Sarma

Senior Manager,
Ubiquitous and Secure Communication,
Networking,
Network Research Division,
NEC Laboratories Europe, NEC Europe

Masatoshi Fukukawa

Assistant Manager,
ITS Business Promotion Center,
Broadcast and Control Systems Operations Unit,
NEC Corporation