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

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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. 2) 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 be-
- yond the transmission range of the wireless technology (typi-
cally 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 distribu-
tion of data in a geographical region and also the forwarding
do communication. Unlike in cellular net-
works, 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 con-
struction), or provide cars with access to the Internet.

To meet the specific requirements of vehicular communica-
tion 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 real-
istic environments. Therefore, Geocast was chosen as the
core networking protocol for vehicular communication based
on IEEE 802.11 technology promoted by the Car-to-Car Com-
munication Consortium (C2C-CC) in Europe, the major Euro-
pean industry consortium for vehicular communication.

The following two sections of the paper present advanced
solutions for Geocast as the core concept of CAR-2-X com-
munication (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
graphical positions for data transfer. Its basic principles
were originally proposed as alternative to pure topology-based
internetworking and in mobile ad hoc networks. 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 informa-
tion to its neighboring vehicles and hence, a vehicle is informed
about all other vehicles located within its direct communica-
tion range. If a vehicle intends to send data to a known target
geographic location, it chooses another vehicle as message re-
lay, which is located in the direction towards the target posi-
tion. The same procedure is executed by every vehicle on the
multi-hop path until the destination is reached. This approach
does not require establishment and maintenance of routes. In-
stead, packets are forwarded ‘on the fly’ based on most re-
cent geographic positions (Fig. 3).

In detail, Geocast assumes that every node knows its geo-
graphical position and maintains a location table containing
other nodes and their geographical positions as soft state. Ge-
ocast supports point-to-point and point-to-multipoint commu-
nication. The latter case can be regarded as group communi-
cation, where the endpoints are inside of a geographical region.
Core protocol components of Geocast are beaconing, a lo-
gation service, and forwarding. With beaconing, nodes period-
ically 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 rea-
ches the sought node (or the hop limit). If the request is not a
duplicate, the sought node answers with a location reply mes-
sage carrying its current position and a timestamp. On recep-
tion 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 informa-
tion enabled by geographical routing is the addressing of geo-
graphical 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 inter-
mediate vehicles serve as message relays and only the vehi-
cles located within the target area process the message and
show it to the driver. In this way, the vehicles that are actu-
ally affected by a dangerous situation or a traffic notification are
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.\textsuperscript{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.\textsuperscript{12} In this matter, NEC has promoted an initiative together specific requirements from the automotive industry.\textsuperscript{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 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 64bit 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\textsuperscript{*1} and FCC\textsuperscript{*2} in order to be introduced to the global ITS market. All devices will be fully compliant with EU directives such as ROHS\textsuperscript{*3} and ELV\textsuperscript{*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.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{Label} & \textbf{Description} \\
\hline
VICS & Vehicle Information and Communication System \\
Integrated UART & Universal Asynchronous Receiver Transmitter \\
MOST & Media Oriented Systems Transport \\
miniPCI & Mini PCI card based on Atheros chipset \\
IEEE 802.11p & IEEE 802.11p compatible driver \\
PCMCIA & PCMCIA card slots \\
RP-SMA & RP-SMA connectors \\
CE marking & CE marking certification \\
VCCI & VCCI certification \\
FCC & FCC certification \\
ROHS & ROHS compliance \\
ELV & ELV compliance \\
\hline
\end{tabular}
\caption{Summary of Various Interfaces}
\end{table}

\textsuperscript{*1} Voluntary Control Council for Interference
\textsuperscript{*2} Federal Communication Commission
\textsuperscript{*3} Restriction of the Use of Certain Hazardous Substances in electrical and electronic equipment
\textsuperscript{*4} End of Life Vehicles
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

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