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’NoW – Network on Wheels’: Project Objectives, Technology and Achievements

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***Abstract*— *NoW – Network on Wheels* is a German research project carried out by major car manufacturers, suppliers, research institutes and universities, and supported by the German government. The project develops a vehicular communication system for car-to-car and car-to-infrastructure communication based on ad hoc principles and wireless LAN technology for road safety and infotainment applications. The paper *(i)* gives a project overview and recalls its motivation, *(ii)* outlines the developed system and technology, and *(iii)* summarizes the project achievements.**[1]

***Index Terms*— CAR-2-X communication, information dissemination, infotainment**

I. Introduction

Road safety and traffic efficiency concern everyone. Therefore, a strong interest of the public, governments, and industry exists to make vehicles safer, cleaner and smarter. More and more cars are equipped with active safety systems, such as radar, lidar and camera that sense a car’s environment. These safety systems are limited in their range and therefore also in the time for a driver to react to dangerous events. Wireless radio technologies increase the effective range, which provides more time for preventive driver actions and improves road safety. Cars would change from autonomous and isolated systems to cooperating nodes forming a network on wheels and exchanging data about their state, behaviour and environment.

Nowadays, FM radio broadcasting provides road traffic information, such as TMC and TMC Pro (in Europe). Wide-area cellular communication (3G) technologies transmit incident reports, estimated travel delays and alternative routes to drivers at a reasonable timeliness. They also offer traffic telematic services ranging from breakdown assistance and emergency call to location-based information and news. It is common to all these services that they are based on *(i)* server-oriented communication via a 3G access network and *(ii)* subscription where the driver pays for usage and data transmission.

Fig. 1. Use cases of vehicular communication and WLAN

Unlike existing approaches, the German research project *NoW – Network on Wheels* took an alternative approach that is based on direct and rapid communication among cars as well as between cars and road side communication equipment (subsumed under *CAR-2-X*), without the need for a coordinating infrastructure (Fig. 1). The approach was enabled by proliferation of two main technologies: Wireless LAN IEEE 802.11 and positioning devices based on GPS. By exchange of position and sensor data over (potentially multiple) wireless links, car drivers can

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be warned of emergency situations ahead of time. Similarly, cars can directly share route information, thereby reducing road traffic congestion and transmitting infotainment data. The communication technology allows novel peer-to-peer applications, makes service fees and data transmission costs obsolete, and boosts car telematics to a new level.

The project *NoW – Network on Wheels* was started in May 2004. Supported by the German Ministry of Education and Research (BMBF), project partners are car manufacturers BMW AG, Daimler AG (coordinator of the project), and Volkswagen AG together with Fraunhofer FOKUS, NEC Deutschland GmbH, Siemens AG (until 2006), IMST GmbH (from 2006), and Embedded Wireless GmbH (from 2006). Besides, the Universities Mannheim, Karlsruhe, and München and Carmeq GmbH co-operate within *NoW*. The project will end in May 2008.

The project *NoW* is the successor of the pioneering research project *FleetNet – Internet on the Road* [2] (2000 – 2003), which successfully studied and demonstrated the feasibility of vehicular communication based on IEEE 802.11 and ad hoc networking to support safety, floating car data, and Internet access. NoW also inherited key results from the project *SOFTNET*, which main focus was on interworking of distributed, mobile systems and components in a heterogeneous environment [3]. Based on the results of these projects, *NoW* has developed an open communication platform for safety, traffic efficiency and infotainment applications which completes and consolidates the technical basis of vehicular communication based on WLAN. Besides technical aspects, the *NoW* project has analyzed market introduction strategies of *CAR-2-X* communication and contributed to the efforts of the *Car-2-Car Communication Consortium (C2C-CC)* [4], which promotes an open European industry standard for *CAR-2-X* communication.

As the *NoW* project will end in May 2008, this paper gives a project overview and brings the various project contributions into context. The following two sections describe the developed *CAR-2-X* technology and summarize the main project achievements.

II. Car-2-X Technology

CAR-2-X communication following the *NoW* concepts is composed of main technological components for *(i)* safety, traffic efficiency and infotainment applications, *(ii)* networking, *(iii)* radio, and *(iv)* security and privacy. We describe the overall system and protocol architecture and give some details to every technology component.

The *NoW* architecture involves several entities and network domains, as depicted in Figure 2. Vehicles are equipped with devices termed *On-Board Units* (OBU), which implement the communication protocols and algorithms. Units of different cars can communicate with each other or with fixed stations installed along roads termed *Road Side Units* (RSU). OBUs and RSUs implement the same protocol functionality and form a self-organizing network, here referred to as the *Ad-hoc Domain*. OBU and RSU differ from each other with respect to the networks they are attached to: OBUs offer an interface to driver and passenger devices – called *Application Units* (AUs) – present in a car. The mobile network, composed of AUs, defines a domain termed *In-Vehicle Domain*. RSUs can either be isolated or attached to a larger structured network. In the first, *isolated*, case, their function is to distribute information (e.g. dangerous curve, construction site ahead) or simply to extend the OBUs' communication range by acting as forwarding entities. In the latter, *attached*, case, RSUs distribute information towards or from a remote entity (e.g. control center). They can also interconnect the vehicular network to an infrastructure network and the Internet, which is generally referred to as *Infrastructure Domain*.

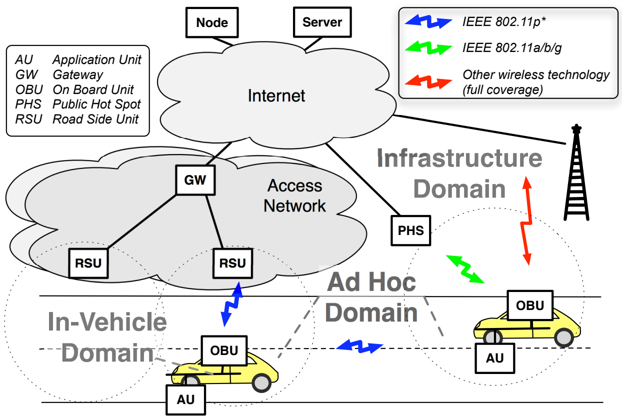

Fig. 2. NoW System Architecture

Applications for road safety and infotainment have fundamentally different communication requirements. Safety applications typically disseminate information about events or other vehicles in the local vicinity or a certain geographical region. Vehicles either broadcast short status messages periodically and with high frequency (so called *awareness messages*), or they generate messages when they detect a safety event and distribute them by multi-hop communication in a certain geographical area (*event-driven messages*). In contrast, infotainment applications typically establish sessions and exchange unicast data packets in greater numbers, bidirectionally, and over multi-hop.

Fig. 3 depicts the protocol architecture of an OBU, which is designed to satisfy and differentiate the requirements of both types of applications. It is basically a dual stack, dedicated to road safety (incl. traffic efficiency) and infotainment applications. For road safety, novel network and transport protocols are developed and provide ad hoc communication among OBUs as well as among OBUs and RSUs over IEEE 802.11p* radio. Infotainment applications access the traditional IP protocol stack and can use the ad hoc and multi-hop capabilities of the *NoW* networking protocol as a sub-IP layer. The information connector, drawn vertically in Fig. 3, offers efficient and structured information exchange among the protocol layers.

The *NoW* architecture assumes that the two stacks are not fully integrated, but rather loosely coupled. On the one hand, this allows safety applications to transceive safety information via the stack for infotainment applications, and infotainment applications to access data structures (e.g., a location table) of the safety stack. On the other hand, we can easily define basic systems (where only the safety stack is present) and extended systems (safety and infotainment).

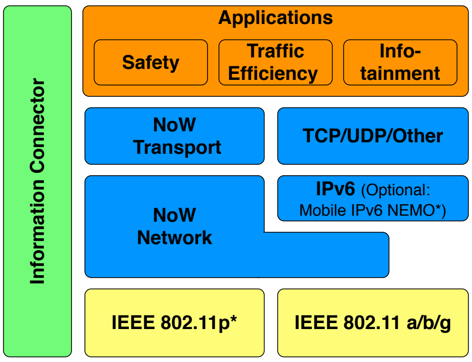

Fig. 3. NoW Protocol Architecture

For addressing and multi-hop routing using geographical positions, the concept of *Geocast* was developed. Originally proposed for mobile ad hoc networksand applied to vehicular environments in *FleetNet* [2], the *NoW* project has further developed the concept to a comprehensive network protocol which provides various communication modes:

- *GeoBroadcast* for flooding-like distribution of data packets in a geographical region,
- *GeoAnycast* to address any single node inside a geographical region,
- *GeoUnicast* for packet transport between two nodes via multiple wireless hops,
- *Topologically-scoped broadcast* (TSB) to broadcast a packet to all nodes in an n-hop neighborhood.

For the radio technology, we assume that each node is equipped with Wireless LAN devices, i.e., IEEE 802.11p* radio[2] for road safety and IEEE 802.11a/b/g for infotainment, as well as with omni-directional antennae. We use the IEEE 802.11 modules in a simplified *ad hoc* mode disabling channel scanning and switching and association procedures. For the 802.11p interface we preclude WAVE transactions. The *NoW* project has studied specific, IEEE 802.11 compatible extensions, such as transmit power control and prioritization, in order to overcome radio technology limitations and to address the vehicular requirements.

Finally, security and privacy represent an integral part of the *NoW* system and affects all parts of the system. In general, it covers aspects ranging from sensor data protection and secure communication to tamper-proof hard- and software. Security measures prevent privacy violations, denial of service attacks against the system, and the insertion of forged data into the system. Cryptographic protection based on digital signatures and certificates provides data integrity, authentication and non-repudiation. In order to protect the driver privacy, the use of changing and revocable pseudonyms are assumed.

III. Project Achievements

The *NoW* project has developed numerous novel technical solutions that significantly go beyond state-of-the-art vehicular communication based on WLAN technologies. We highlight technical contributions to architecture design and protocol development, summarize system development and integration efforts, and outline the sustainability of the project results.

A. Architecture Design and Protocol Development

As a major design goal for the NoW system, we have identified its smooth introduction and sustainable deployment. Consequently, the NoW system is designed to provide efficient, scalable and adaptive communication in two main scenarios: In sparse network situations, intelligent store-and-forward algorithms provide packet transport even when the connectivity among cars is low. Additionally, designated locations along the road, for example intersections,

[2]The * denotes possible adjustments of the standard to Europe.

can be equipped with low-cost RSUs in order to increase the coverage of the ad hoc network and to improve connectivity. In dense network situations, such as in a traffic jam or city scenario with a fully deployed system, nodes control the data load, which is offered to the network.

For dissemination of safety information, the *NoW* project has developed a hybrid scheme of network-layer and application-layer forwarding [5], [6], [7]: The network layer protocol provides a sender-oriented and geo-addressed distribution of data packets (Geocast) based on traditional packet-switching concepts. Applications enable a receiver-oriented scheme for dissemination, in which every node decides individually about information re-broadcasting. The latter approach enables flexibility as well as aggregation and modification of the information carried in the message payload. The combination of both schemes results in a hybrid approach, which enables both, *(i)* rapid distribution of data packets by Geocast and *(ii)* adaptive dissemination of information. The schemes can be complementarily applied. In an exemplary but typical scenario, a safety application defines a core dissemination area, in which a safety information is disseminated using Geocast. Beyond the core area, the application in every node decides individually whether to re-broadcast, and is able to aggregate the information for higher efficiency.

For application-level forwarding of safety information, the *NoW* project has investigated a *relevance-based* concept to improve the overall network utility. In this scheme a relevance value is calculated for every message, specifying its importance for the neighbor nodes if the information would be re-broadcasted. The relevance value is calculated by a single system-specific and parametrized mathematical formula, taking into account various parameters, such as vehicle context, message content and network situation. If the relevance value exceeds a threshold, the application domain passes the message with a corresponding priority value to the lower protocol layers. By integrating application specific relevance functions on top, the sequence of message transmissions can be optimized and therefore the re-broadcast strategy of event messages can be significantly improved. As a result, the overall network utility is increased, and in particular the efficiency of information dissemination in situations with high network load improved [8].

Several enhancements improve the GeoUnicast scheme. For city scenarios, a novel scheme - termed *Greedy Routing with Abstract Neighbor Table (GRANT)* - extends the greedy forwarding by exchange of location table information in a compact format [9]. With the developed scheme, nodes utilize this additional information in their forwarding decision. The *Power-aware Greedy Forwarding* scheme minimizes the transmit power required to send a data packet to the chosen next hop node and reduces unnecessary harmful interference to other nodes [10] without impairment of the reception probability.

Another project achievement is a solution for security and privacy. Based on an analysis of requirements [11] and possible attacks [12], we have developed a comprehensive security architecture [13] that includes stakeholders and functional aspects, and covers a specification of local and infrastructure components. The developed security and privacy solution includes digital signature and certificates based on the WAVE certificate format with specific extensions to secure Geocast with immutable and mutable field protection [14]. Plausibility checks locally assess received data at network and application layer. Finally, privacy concepts such as network layer pseudonyms [15] and context mixes [16] are introduced. The architecture and protocol functions achieve a high level of privacy, as well as the authorization of nodes for participating in network operation, authenticity and integrity protection, and the detection of manipulated data.

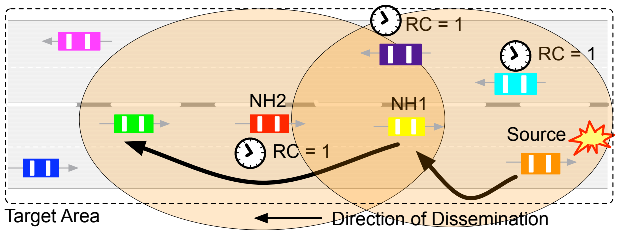

Fig. 4. GeoBroadcast in a target area with EMDV for rapid dissemination and re-transmission control. *Simplified description of the scenario: The source selects NH1 as next hop within its forwarding range and broadcasts the information. NH1 immediately re-broadcasts selecting NH2 as next hop. Nodes receiving the message cache it, set the retransmit counter RC (RC=1) and start a timer. When a timer expires, the node re-broadcasts the packet to improve the robustness of the protocol. RC is incremented each time a packet is overheard and when RC exceeds a threshold, it is discarded.*

The *NoW* project has developed network algorithms to optimize Geocast for realistic environments: *DFPAV (Distributed Fair Power Assignment in Vehicular environments)* [17], [18] solves the problem of periodic status messages congesting the wireless channel by means of transmit power control. The distributed algorithm assigns a transmit power such that the overall bandwidth of the periodic messages at node's location do not exceed a system-specific threshold and bandwidth resources are shared fairly among the network modes. *EMDV (Emergency Message Dissemination in Vehicular environments)* [19] prevents broadcast-storm problems, which occur when simple GeoBroadcast is applied in dense network scenarios (Fig. 4).

In order to assure the operation of the developed algorithms and protocols under realistic conditions, their performance has been studied by simulation and measurements. The network simulation tool `ns-2` was significantly enhanced by specific modules for radio propagation and medium access models, a protocol stack for CAR-2-X communication and realistic mobility patterns, see [20], [19]. The gained simulation results have supported the investigation of scalability effects, such as in [17], [18]. For measurements, a real testbed was set up and tests in different environments (rural, highway and urban) were conducted in order to evaluate network performance [21] and characterize the radio channel.

B. System Development and Integration

The *NoW* project has implemented a software prototype of the developed system covering radio, networking and applications.

The radio subsystem implements IEEE 802.11 physical and MAC layer based on commercial WLAN chip-sets and the MADWIFI multi-mode software driver. For IEEE 802.11p compatibility, the driver is significantly enhanced, including extensions to operate at the protected 5.9 GHz frequency band,[3] control of selected radio parameters on a per-packet basis from the network layerand exchange of signaling data between the MAC and upper protocol layers.

The prototype implementation of the networking protocols covers Geocast in its different variants for unicast, broadcast and anycast. The prototype also supports IP version 6, and version 4 for backward compatibility, by encapsulation and transport of IP in Geocast packets. Numerous advanced solutions are implemented, such as intelligent store-and-forward for sparse scenarios, distributed transmit power control for periodic status messages and power-aware greedy forwarding. The information connector is implemented using a publish/subscribe pattern for asynchronous event notification, which ensures an efficient and structured information exchange across the protocol layers. For efficient single-hop broadcasting, an application library *information handler* is implemented, which dynamically composes application messages with minimal information sets so as to meet the requirements of all registered systems [22]. Cryptographic protection using digital signatures and certificates secures the Geocast with specific protection for multi-hop communication, and optionally protects the application payload. Privacy is ensured by frequent changes of pseudonyms which triggers the substitution of addresses on all protocol layers and the certificate in a node.

[3] This is the proposed frequency band for road safety in Europe.

Fig. 5. System integration with HMI from different car makers

The prototype communication platform serves as a basis for the various developed applications *Emergency Vehicle Warning*, *Hazard Location Warning*, *Lane Change Warning*, *Extended Emergency Brake Light*, *Obstacle Warning*, *Hazard Lights Announcement*, *Forward Collision Warning*. Additionally, a dedicated road side unit, named *PoILone*, is developed, which combines safety applications (pylon) with point-of-interest (PoI) information.[4] As infotainment applications, *MP3 music download*, *route review* and *drive-trough payment* [23] are implemented. Finally, a UPnP/AV based approach is developed enabling media data synchronisation between in-vehicle, residential and road-side infrastructures, compatible with existing commercial UPnP devices and services.

The communication system is mainly developed in C for the Linux operating system. Applications are implemented in Java/OSGI. The different components are assembled into an overall software reference system, ported to different hardware platforms and integrated into test vehicles. The *NoW* project provides a reference implementation of a CAR-2-X system that represents state-of-the-art technology and is ready for deployment.

[4] The PoILone provides multiple services, such as Geocast of TMC or TPEG messages, and information services, which enables a car to request more information upon issued warning messages.

C. *Sustainability of Project Results*

The *NoW* project works in close cooperation with the C2C-CC and transfers results directly into the C2-CC working groups. As a result, the technical basis of the C2C-CC [4] strongly relies on concepts developed in the *NoW* project. Moreover, the *NoW* project actively contributes to ongoing activities of standardization bodies. In ETSI, the efforts for frequency allocation and harmonization for CAR-2-X communication have been supported in the ERM technical committee. Standardization of communication protocols has started recently in the newly created ETSI TC ITS. The *NoW* project results have a strong impact on related R&D projects: In the past, the European project *PREVENT WILLWARN* [24] has applied the *NoW* platform, and other ongoing projects utilize the concepts and platform for further enhancements such as the European projects *SAFESPOT*, *SEVECOM*, and the German project *AKTIV* [25]. Finally, the experiences from the *NoW* project will be of great importance for upcoming field operational tests (FoTs).

IV. Summary and Conclusions

CAR-2-X communication based on WLAN, positioning technology and ad hoc networking are commonly regarded as a cornerstone of future systems for safer, cleaner and smarter transport. The research project *NoW – Network on Wheels* has developed an open, innovative and comprehensive system, which unifies safety and infotainment. The system covers an integrated and harmonized approach of radio, networking and applications including security and privacy. Numerous novel solutions for use of CAR-2-X communication in realistic environments are designed, implemented and examined. Efforts to disseminate results to related R&D projects, the industry consortium C2C-CC, and standardization bodies ensure a sustainable utilization of the project results.

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