Safety and Traffic Efficiency Applications for GeoMessaging over Cellular Mobile Networks

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Abstract
Vehicular communication for road safety and traffic efficiency applications based on short-range wireless communication (IEEE 802.11p/ITS G5) and ad hoc networking has been extensively studied and is being tested in major field trials. For the same purpose, the usage of cellular mobile networks has recently received more attention. This paper investigates a case study of a road-works warning and an obstacle warning application that applies GeoMessaging over cellular mobile networks. We present a system architecture based on a GeoService Backend concept and a protocol design. Our approach enhances existing protocols for safety and traffic efficiency messages, originally developed for ad hoc communication over short-range radio, and integrates cellular mobile networks and ad hoc networks. The approach introduces two types of messages that tradeoff between dissemination area and validity time. Finally, the paper presents the implementation design of the GeoService Backend and gives an outlook to the tests that will be carried out in the DRIVE C2X project, a pan-European field trial for vehicular communication.

Keywords:
SAFETY, TRAFFIC EFFICIENCY, CELLULAR MOBILE NETWORK, GEOMESSAGING

Introduction

After several years of research and development, major field trials study vehicular communication in order to validate the matureness of the technology and to assess the expected impact on road safety and traffic efficiency. One of these world-wide activities is DRIVE C2X [1], a pan-European field operational test (FOT) for cooperative Intelligent Transport Systems (ITS). DRIVE C2X studies selected applications for three categories: Safety (e.g. traffic jam ahead warning, emergency electronic brake lights), traffic efficiency (e.g. In-vehicle signage/speed limit, green-light optimal speed advisory), and also infotainment & business (e.g. insurance and financial services, Point of interest notification).

The communication technology used in the DRIVE C2X FOT is primarily based on short range wireless radio operating in the 5.9 GHz frequency band dedicated to safety and traffic efficiency applications and using multi-channel and multi-transceiver systems. The radio is used for vehicle-to-vehicle and vehicle-to-infrastructure communication enabling efficient and scalable single-hop and multi-hop communication. Specifically, ad hoc communication including vehicle positioning enables packet-oriented distribution of information by means of geographical addressing and forwarding. The project follows emerging standards developed by ETSI TC ITS [2], such as IEEE 802.11p/ITS-G5 (ETSI EN 202 663), GeoNetworking (ETSI TS 102 636) and facilitates messages, including Cooperative Awareness Message CAM and Distributed Environmental Notification Message DENM (ETSI TS 102 637) [5].

In DRIVE C2X, the ad hoc communication technology is mainly used by the safety and traffic efficiency applications. In contrast, infotainment & premium applications fully rely on cellular mobile networks for server-based communication over Internet protocols. However, for safety and traffic efficiency applications also the use of cellular mobile networks has recently been studied [6][7][8][9][10][11]. These approaches assume that vehicular communication is realized over the communication infrastructure of mobile network operators. With the deployment of 3GPP LTE (also referred to as 4G mobile networks) for mobile high-speed Internet [3], cellular mobile networks will provide small end-to-end delay and high data throughput compared to previous generation UMTS and HSDPA. In order to use safety and traffic applications in such a setting, the underlying cellular mobile network must be capable to distribute vehicle data real-time and reliably to a large number of vehicles located in a geographical area.

This paper presents a system architecture for safety and traffic efficiency applications over cellular mobile networks and specifically considers Road Works Warning (RWW) and Obstacle Warning (OW). It outlines the used communication protocols that are derived from ad hoc communication and adapted for the use in cellular mobile networks. The paper then focuses on implementation and testbed setup in the context of DRIVE C2X project and discusses deployment aspects.

System Architecture

RWW and OW provide information about road works or obstacles on a driver’s route. The warning can include additional information, such as reduced speed limits, closed lanes, deviated lanes, or extended travel times caused by the road works or obstacle. Upon reception of a warning, the driver has an increased awareness, is informed of potential dangerous conditions and prepared for an imminent danger. As a reaction, the driver may slow down the vehicle or make a detour.

Following the international ITS architecture standards (e.g. ISO 21217, ETSI EN 302 665), core elements of the architecture are Vehicle ITS station (VIS) in the vehicles and the Central

ITS Station (CIS) located in the communication infrastructure. VIS and CIS are interconnected by the cellular mobile network and the Internet, where the CIS can also be integrated into core network of the mobile operator [10]. The CIS includes a GeoService Backend that maintains the positions of vehicles and distributes information to vehicles in a geographical area, as well as components for application-specific information handling, here for RWW and OW (Figure 1**Error! Reference source not found.**).

The RWW and OW applications work VIS and CIS-triggered. In the VIS-triggered scenario, the vehicle detects the road works or obstacle by any means (local sensors, communication over other media or user input), triggers a DENM and sends it to the CIS that executes the RWW/OW applications, which forwards the messages to the destination area. In the CIS-triggered scenario, the application server acts as originator of the DENM, based on data aggregation or information from a traffic management center or static configuration.

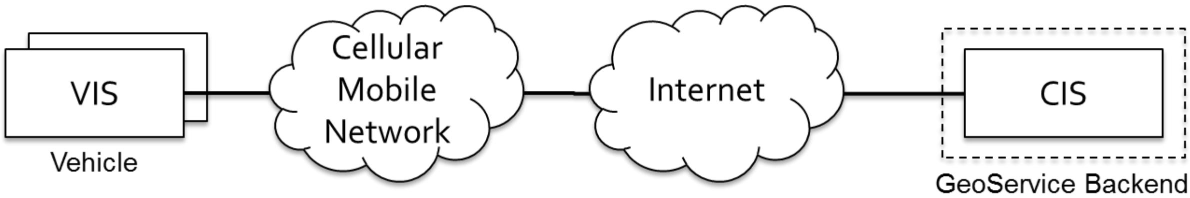

Figure 1 - System architecture for RWW/OW applications over cellular mobile networks

The scenario requires three main communication tasks: location updates, event reporting and geographical messaging (GeoMessaging). Location updates are periodically sent from the VIS to the GeoService Backend. Their transmission can be triggered query-based, time-based, distance-based, grid-based (or a combination) (see [12]). If the driver or the VIS detects an event, then the event will be reported to the GeoService Backend in the CIS. The GeoMessaging is a service of the GeoService Backend that enables the distribution of messages to vehicles in a geographical area. The GeoService Backend also takes care of periodic re-transmission of the warning during the lifetime of the event, i.e. the repetition of the messages in order to keep the information alive in the destination area when vehicles start their journey or enter the area.

Protocol Design

For the dissemination of information over the mobile cellular mobile networks, the Internet protocol (IP) plays a predominant role. In particular, 3GPP LTE is optimized for high data rates and low access delays. However, two main design options exist: (i) End-to-end IP with the distribution of OW/RWW information in the payload of IP packets and (ii) ITS specific communication protocols for safety and traffic efficiency on top of IP, enabling specific processing of the message content in the GeoService Backend. In the latter option, IP is still the carrier of RWW/OW messages, but existing features of the ITS communication protocols, such as periodic message repetition, information retrieval on demand (pull of information from vehicles) and data aggregation, potentially optimize the communication and save system resources.

In the context of this work, we re-use the existing ITS protocols that were originally developed for ad hoc communication over IEEE 802.11p/ITS-G5 by ETSI TC ITS (Figure 2). For location updates, the *Cooperative Awareness Message*, CAM (ETSI TS 102 636-2) and for event reporting and GeoMessaging, the *Distributed Environmental Notification Message*, DENM, (ETSI TS 102 636-3) is re-used. A CAM is broadcasted periodically by every vehicle and carries various fields, such as vehicle position, speed and driving direction. A DENM is event-driven and distributes information about a particular situation described by event type (encoded as cause code), position or relevance area, detection time, event expiry time and so on. A DENM is triggered by an application, whereas the application can also update (e.g. the relevance area when the affected area is enlarged or shrunk) or even send a cancelation message. To achieve this, an event gets assigned an action ID, which – in combination with the originator ID of the DENM – is a unique event identifier. In addition, a data version field distinguishes different updates of the same event.

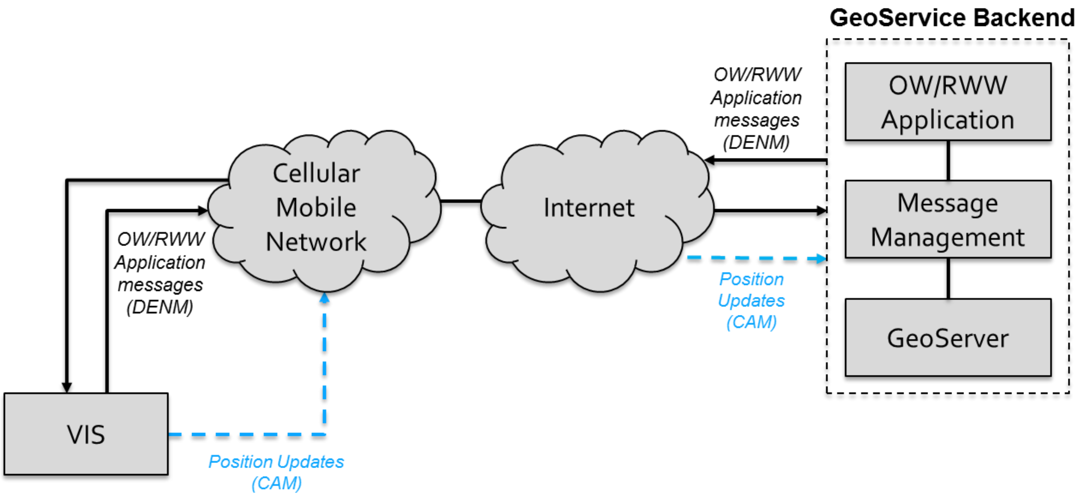

Figure 2 – Information flow between VIS and GeoService Backend

For its original purpose of informing neighbor vehicles of its presence, the CAM carries various information including direction, lane number and steering wheel angle and many others. These fields go far beyond the information required for location updates; however, we argue that the message can be used for other applications, such as floating car data. Moreover, the CAM message is organized in containers, where only the basic container is mandatory, and all others optional. Compared to the CAM for ad hoc communication, we (i) lower the CAM rate from 1 – 10 msg/s to 0.1 – 1 msg/s (min–max), (ii) diminish the latency requirements to 1-10 s and (iii) trigger the CAM transmission based on a combined time-/distance-based update policy instead of a time-/application update policy.

With DENM for RWW/OW over cellular mobile networks, we make the following modifications and enhancements to the original protocols:

- Application-specific data in the DENM (`a la carte` container) for additional RWW/OW-specific data,
- Destination area is carried in the location container of the DENM instead of relying on lower layer protocols, such as GeoNetworking for ad hoc communication,
- Data aggregation of messages for the same event based on cause code/sub-cause code, relevance area and lifetime as well as action ID using OW/RWW application logic,
- Specific forwarding procedures for DENM by the message management in the GeoService Backend.

For the distribution of DENMs in geographical areas, messages can be transported by IP unicast to individual vehicles or utilize cellular broadcast such as the Multimedia Broadcast Multicast Service (MBMS) from UMTS and its enhanced version in LTE.

OW/RWW Message Handling in the GeoService Backend

In cellular mobile networks, messages can potentially be distributed in huge geographical areas, but their frequent transmission and repetition would exceed the capacity of radio links and access networks by far. In order to restrict the size of the destination area and validity time, as well as to meet the application requirements, we introduce two types of messages that are handled differently by the GeoService Backend. The two message types represent a tradeoff between dissemination area and validity time (the time duration the event is valid and kept alive in the dissemination area).

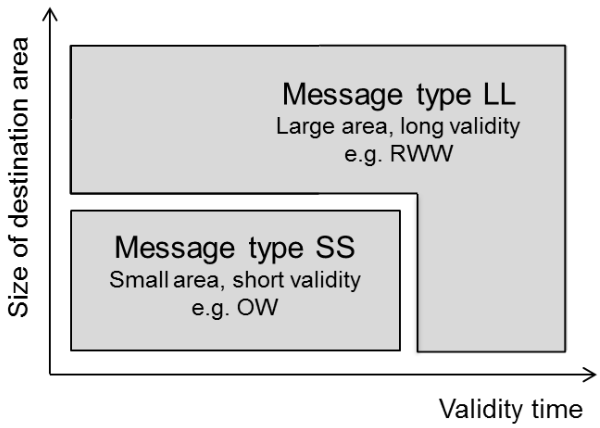

Figure 3: LL and SS messages - two classes of application messages (DENM)

As illustrated in Figure 3, we distinguish two different message types for warnings. The first message type with a far reach (radius 50 km) and long validity time (20 minutes), e.g. a RWW message, can be sent into a large geographical area as the chance for a vehicle to come along this event is larger. The other message type –e.g. an OW message – has a short validity time (min 10 s – max 300 s) and small reach (radius 400 m to 2km) should be sent out to a smaller region as the chance to come along this event is lower. Intuitively, we name these two message types `LL` and `SS` messages (**L**arge area, **L**ong validity vs. **S**mall area, **S**hort validity).

While the GeoService Backend enables the periodic re-transmission of messages to a geographical destination area during the event's validity time, it also allows that vehicles pull the information that is saved in the GeoService Backend and relevant for the vehicle's current location area and driving direction. The pull of information is relevant when a vehicle starts its travel or enters a new location area. The pull option for driving vehicles is enabled only for SS messages due to their requirement for lower latency. While the SS messages are transmitted by a combination of push and pull, LL messages use only the push option. Therefore, the latency between the point in time when the vehicle enters a location area until it receives the relevant message is for the LL message on average higher than for the SS message.

DRIVE C2X Testbed and Tests

The implementation of the VIS follows the ITS reference protocol stack in ETSI EN 302/ISO 21217 and extends the DRIVE C2X project system for ad hoc communication by functionality required for the transmission of messages (modified CAM and DENM) over cellular mobile networks as well as management functions for 3G/LTE network interfaces. Figure 4 shows how the software components for communication of RWW/OW over cellular (bold) embed into the overall implementation design of the VIS in the DRIVE C2X project.

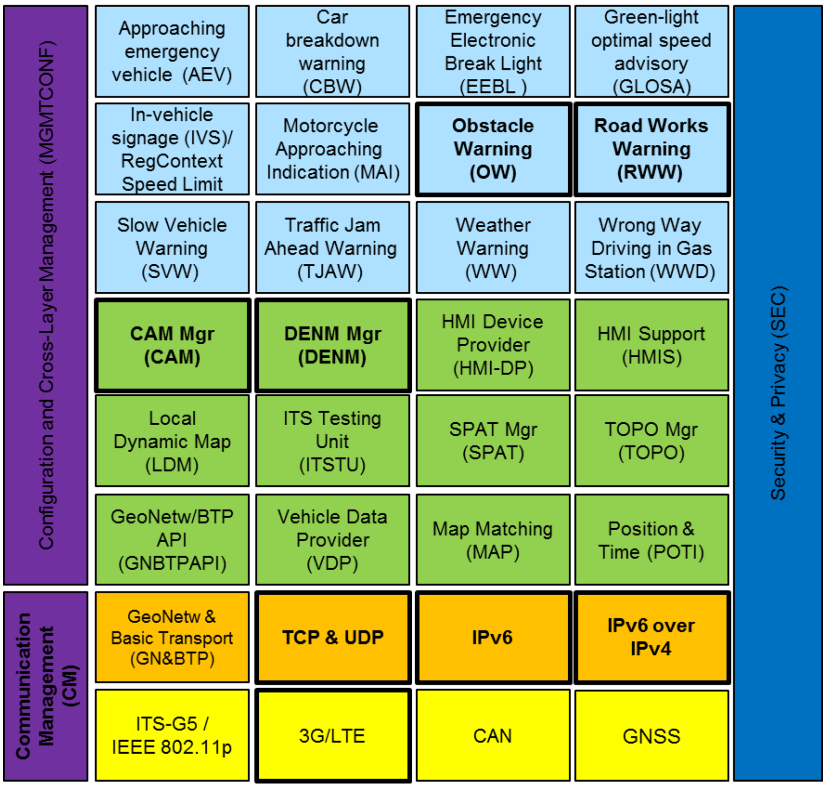

Figure 4: VIS Implementation design in DRIVE C2X

The VIS implementation of the protocol stack uses the CAR-2-X communication SDK (http://c2xsdk.neclab.eu). Facilities (CAM, DENM, etc.) and applications, as well as the GeoService Backend, are implemented in Java/OSGi using the Knopflerfish OSGI execution platform (http://www.knopflerfish.org). For the implementation of the messaging protocols – CAM and DENM – a standard compliant ASN.1 encoder/decoder is used.

Enhancements to the VIS reference system have been made to support IPv6 communication between the VIS and the GeoService Backend. Since IPv6 is not fully available at the DRIVE C2X test sites, OpenVPN and tunneling (6to4) are considered as a temporary solution to transport IPv6 packets over the IPv4 cellular mobile network. More advanced scenarios require continuous and seamless communication between VIS and GeoService Backend, even when IP mobility is present.

The initial testbed setup considers several vehicles driving on a predefined route where events – RWW and OW – are simulated. The vehicles should be outside of direct communication range of the IEEE 802.11p/ETSI ITS G5, so that all communication takes place over cellular mobile network and the GeoService Backend. In this setup, the physical location of the GeoService Backend is of less importance, as long as the vehicles and the GeoService Backend are reachable over IP with a reasonable communication delay. With this testbed setup the basic functionalities of the GeoService Backend – maintaining position updates, aggregation and dissemination of events – have been tested and are further extended.

In the DRIVE C2X project, the RWW and OW applications are implemented for both networking technologies, ad hoc and cellular mobile, and tests are planned to be carried out for both scenarios, the resulting metrics for the impact assessment can be directly compared. Also, more advanced scenarios are foreseen that integrate cellular mobile and ad hoc communication. In such scenario, a vehicle receives basic RWW information via the cellular network when it is still distant from the road works. The vehicle may receive further warnings via ad hoc over IEEE 802.11p/ETSI ITS G5 with approaching distance, when it enters the road works with reduced speed and about the change in the lane geometry. After entering the road works, the vehicle will also receive information about the remaining distance of road works with reduced speed.

Conclusions

We have presented an overview of the system architecture for RWW/OW applications over cellular mobile networks and described the relevant communication protocols. Unlike a generic solution for the dissemination of RWW/OW messages, the presented solution makes use of messaging protocols – CAM and DENM – that have been originally developed for ad hoc communication over IEEE 802.11p/ETSI ITS-G5 and are adapted to the cellular scenario. We introduce two types for event-driven messages that tradeoff the size of the destination area and the validity time.

The present system is implemented in DRIVE C2X for the RWW/OW use cases. Tests are planned for the technical validation and for the assessment of the impact of the RWW and OW applications on safety and traffic efficiency. The tests also allow comparing the scenarios with ad hoc and cellular mobile networks.

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