

Vehicle to infrastructure communication with today's telecommunication systems

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Abstract

At the hand of an example 'intersection assistant' application, we describe how the communication network architecture should look like to support driver awareness and assistance functions. We discuss extensions to the network to alleviate any bottlenecks, and focus on optimizations to minimize the amount of data to be sent over the wireless communication link to the vehicle. We make a comparison between 3G cellular and WLANp (IEEE 802.11p) based systems with respect to deployment and. We argue that today's 3G cellular technology can already be used to realize (a set of) connected driver assistance functions, as typical message latency for our example intersection assistant application, being realized within the Visionⁱ project by Flanders' DRIVE and project partners, is only 40 ms between infrastructure and vehicle using a 3G connection.

Introduction

One way to increase traffic safety is by the application of cooperative driver awareness and assistance functions. These functions provide the driver with information to anticipate upcoming situations (awareness) and prevent accidents (assistance). A contemporary example of awareness functionality is a navigation system which receives up-to-date traffic information by radio broadcast standards such as RDS or TPEG, or via cellular networks for mobile communication (GSM-GPRS). Typically, information rates are low and latencies tend to be high.

Alternatively, vehicles themselves could send or the infrastructure could relay, warning messages to other vehicles for dangerous situations ahead. The communication protocol proposed for this communication is the IEEE 802.11p standard, also known as WLANp [1]. This standard is designed for fast, time critical communication and uses an open access network.

Evolutions in wireless technology and investments in the expansion of cellular networks brought high-speed and affordable data communication over large areas. Boosted by the deployment of small cells (pico or femto cells), the performance difference between the two communication systems, WLANp and cellular, is diminishing and even turning in favor of 3rd (UMTS, 3G) and 4th (LTE, 4G) generation cellular systems. UMTS networks already offer sufficient data rates for driver awareness and mobility applications. 4th Generation cellular systems (LTE), currently being rolled out by telecom operators, offer further increased bandwidths at lower latencies than UMTS. These evolutions in telecom infrastructure create the possibility for implementing a set of cooperative driver assistance functions using today's cellular systems.

Apart from the fact that it is technically feasible to implement cooperative driver assistance functions using cellular communication, there are a number of practical reasons why it is a good idea to start implementing these functions based on existing cellular communication networks rather than waiting for WLANp to mature. All issues such as handling (soft-) handover, standards-compliance testing, authentication, roaming and even billing are common practice for 3G networks and devices, yet still have to be tackled for WLANp. Handling network overload is tackled in 4G (LTE) networks, as described in release 10 of the 3GPP standard [2]. Most important of all is the likelihood of building a

valid business case for driver awareness and cooperative assistance functions using current cellular systems. With the increase in the number of people using smart phones, there is a potential user base of communicating devices on the market, capable of implementing driver awareness functionality today. If only the infrastructure would provide the necessary information, the market for connected assistance functions could really take a head-start once the (downloadable) applications are provided, paving the way for the proliferation of enhanced driver assistance functions which require in-vehicle integration by the OEM.

In the remainder of the paper we will first discuss some practical issues for realizing connected driver assistance functions using mobile communication networks. We discuss deployment aspects as well as network architectural aspects, and discuss possible solutions for handling large sets of communicating devices with reduced communication latency.

Example application: Intersection assistant

Numerous examples of driver assistance applications can be imagined within the domain of Intelligent Transport Systems (ITS) [6]. In this paper, we focus on “road intersection assistance” as a typical example of a (connected) driver assistance function. It covers less time critical awareness functions like an intelligent speed advice to pass upcoming traffic lights at green without stopping (Green Wave). This function is comparable to e.g. an optimal lane or speed advice on the highway to minimize congestion. The intersection assistant also covers time-critical use cases, such as warning the driver for local hazards. This could be a potential accident with e.g. crossing pedestrians, bicyclists or vehicles, which may be difficult to see from the driver’s point of view. This part of the assistance function is similar to e.g. a warning for local hazards on a highway such as an accident or sudden traffic jam. Note that for many connected driver assistance functions, it is not the reception of a hazard warning which is the bottleneck, but the timely detection and generation of the hazard warning. For our intersection assistant application, we addressed the detection bottleneck by using infrastructure cameras for detecting sudden hazards, like crossing pedestrians, and we focus on the incident analysis and subsequent fast communication to the impacted vehicles of these sudden events to provide an in-vehicle driver warning.

The intersection, time criticality and role of infrastructure

Generally speaking, the time-criticality of a hazard warning depends on the time to react and reach the hazard location and whether that hazard then still exists. Note that most of the time critical information is required on a small geographical scale only, indicated by the yellow circle in Figure 1. Relaying a warning to a driver for a crossing pedestrian on an intersection is only helpful if the vehicle receives this message *before* the physical encounter with pedestrian. This limit, defined by communication latency and reaction time, is indicated by the red circle in Figure 1. Likewise, data will by nature be less time critical on larger distances from the intersection, e.g. the crossing pedestrian would already have crossed the road before the vehicle would have reached him. Data for anticipating traffic lights remains relevant on this distance, as the duration of those events is longer. This is indicated by the green circle in Figure 1. On even larger distances, the individual timing of the longer events becomes less relevant for the driver, and it is more useful to receive statistical data, e.g. the average time to pass a certain area, such that an alternative route might be selected.

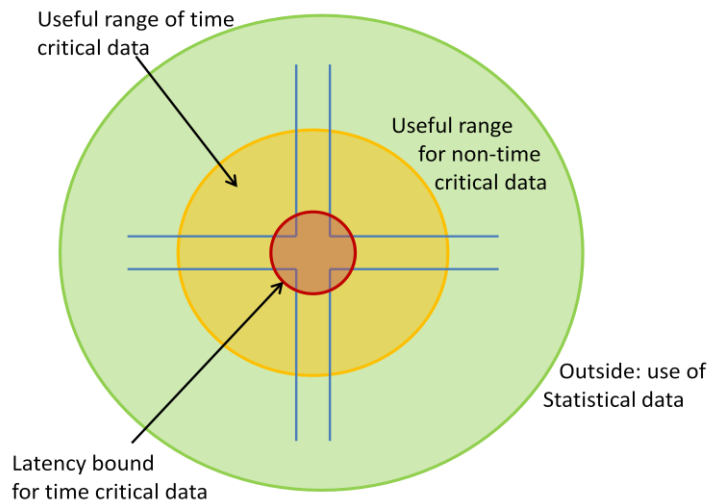


Figure 1: Time criticality of v2i data around an intersection

It is important to realize that on an intersection, the infrastructure has unique knowledge of the current and future status of traffic lights and their timing. The infrastructure can be extended with sensors to detect other road users, such as pedestrians, bicyclists or approaching vehicles. As all connected vehicles need to contact the infrastructure for this information, it is a small step to aggregate the information from these vehicles with the information already present. The infrastructure can use this information about all objects at the intersection to control the traffic lights 'on demand', and redistribute the assembled information to all approaching vehicles by either broadcast or point-to-point communication. The infrastructure can filter, process and even prioritize and predict information to be sent to approaching vehicles. E.g. information about vehicles leaving the intersection is of no use to other vehicles and could be left out to save bandwidth. For point to point communication, the infrastructure could prune this information even further, by selecting only the relevant information for *this specific vehicle*, leaving out all information which is only relevant to other vehicles. This further reduction of the data to be communicated reduces the required bandwidth and communication delay.

Communicating less data is especially important in environments with low signal-to-noise ratios, as larger packets would require more retransmits causing a larger delay and larger bandwidth utilization [7]. Pre-processing data in the infrastructure has the additional advantage that it reduces the processing power required in vehicle, as less data needs to be handled.

Requirements on communication

The delay on the communication path to the vehicle (which can include the setup time of the radio link) will be limiting the usefulness of sharing time-critical and time-bound-events, and by that, limiting the realization of driver assistance applications. To minimize latency and maximize data routing efficiency, the functional topology of the intersection assistance application is preferably reflected in the architecture of the communication network. A local compute resource in the infrastructure, usually called road side unit (RSU), can be used at the intersection to collect and process local traffic data and prepare the data for the approaching vehicles. This RSU has to communicate time critical data with the nearby vehicles and the less time critical data with all the

vehicles approaching the (set of) intersection(s) covered by this server.

Preferably, the RSU has a local transmitter for communicating this data. A backhaul network is needed for communicating less time critical data to other transmit stations for approaching vehicles outside the coverage of the local transmitter, and to systems higher in the traffic flow management hierarchy. Besides technical requirements derived from the application domain, there are economical and other non-functional requirements which influence the topology of the communication network for connected driver assistance applications.

Non-functional requirements: Authentication, roaming and link handover

An important, yet often forgotten aspect of wireless communication is *authentication* and *roaming*. By authentication, both ends of the wireless communication link obtain certainty about the identity (and validity) of the other side. Roaming is the opportunity to obtain access to a local communication network for devices managed by other or foreign operators. Authentication and roaming are essential items for trustworthy communication: If the sender of the data cannot be authenticated, the data received cannot be trusted. The data received on the status of traffic lights or crossing pedestrians, would be totally void if the vehicle cannot authenticate the sender of the information (infrastructure). Likewise, the infrastructure could not trust the information received from the vehicle if it could not authenticate the sender.

For cellular networks as used by mobile phones, authentication is done by checking secret keys in the SIM-card against secret keys in the Mobile core (Serving GPRS Support Node, SGSN (see Figure 2)) of the operator network via secured connections. Roaming requires even more time and effort: an authentication at the foreign operator's Mobile core, and a check to decide whether this device is allowed to connect to the local network.

For an open access network like WLANp, connecting to and communicating over the network is unsecured to allow fast attachment to the network. As received data cannot be trusted without authentication [6], the IEEE 1609.2 draft standard proposes additional measures. Based on this standard, concepts for security are being proposed by the Car2Car consortium. Nevertheless, the authentication process requires time [8], processing power on both ends and a backhaul connection from the RSU to, speaking in cellular terms, the mobile core of the RSU-operator. As devices from other or foreign operators need to be authenticated as well (roaming), similar agreements, standards, procedures and implementations are required similar to those currently in place for cellular communication.

The process of authentication takes time, varying between hundreds of milliseconds to even seconds, and needs to be performed each time the vehicle attaches to a network. When the coverage ranges is relatively small, the overhead in re-establishing the wireless link, redoing the authentication and the preparation for data exchange would limit the usefulness of the system. Too much time is spent in link overhead and the actual data would no longer arrive in the vehicle on time. To avoid/minimize the overhead, the communication network should support 'handover' as is current practice in mobile cellular networks. With handover, the wireless connection with the mobile device is passed on to another base station of the same operator. Security context transfer as specified by 3GPP [2] greatly reduce the setup latency due to authentication. Furthermore, research is ongoing to optimize the handover authentication even further [1]. With 'soft' handover ("make before break") as is supported in current 3G cellular systems, even the data link can remain active during the handover.

Implementing features like handover, roaming and authentication is quite complex. It has taken 5 to 10 years before these issues were solved and implemented in a proper standardized way for cellular networks. Development for WLANp is ongoing [9] though standardization of these aspects for WLANp are still needed.

Financial constraints: Incremental investments, expansion and deployment

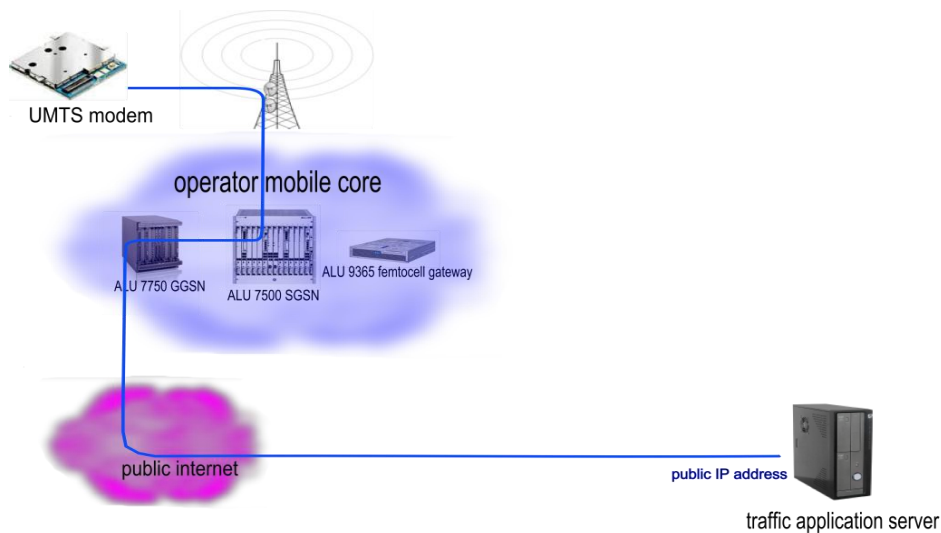
Financial constraints are one of the most important, non-technical requirements impacting the realization of a communication network for 'connected driver assistance' functions. Realizing a country-wide mobile communication network from scratch requires an enormous up-front investment. Revenues from this network, either in Euros by paid subscribers, by the reduction of (deadly) accidents or by improving traffic flow efficiency, will only come *after* the network is operational and services are deployed, and only once there is a sufficiently large group of drivers using the connected driver assistance functionality.

Providing coverage only in (a part of) a single city would not attract many consumers to pay for equipment for connected driver assistance and services, as they would have only marginal return on their investment. Either the consumers' investment has to be significantly lower (e.g. by using devices they already have) or the service needs to add more value, e.g. being available on a wider scale.

Let's assume that a provider or road-operator wants to enable a connected driver assistance such as 'intelligent speed advice and local hazard warning' along the 15000 km of German highway [4]. Assume further that a single WLANp equipped RSU typically covers a range of 1.5 km of bi-directional highway, and that installing an RSU next to the highway costs € 30000 when buying and installing them in large quantities. The upfront investment then easily rises to 300 M€ for providing basic coverage. Assume further that setting up a backhaul network and the connected services incorporates similar cost. Considering only capital expenditure costs of 5% of the 600 M€, and system depreciation and maintenance cost of 10%, easily brings the total cost of ownership for the provider to *at least* 90 M€ per year to support connected driver assistance functions. If 1 Million drivers would pay for this service, each of them has to pay € 7.5 *per month* to cover only basic costs of this service, without provisions for accumulated interest and profit margin for the service provider and excluding the cost of the required in-vehicle equipment.

Incremental investments, expansion and deployment using cellular networks

Current 3G cellular networks were designed voice-centric, with a possibility for high-throughput data connections. Figure 2 sketches the data routing from a mobile device to the traffic application server providing the traffic data. The flows over the operator's network, through the SGSN to the Gateway GPRS Support Node (GGSN), which separates the operator network from the public internet, from where the routing continues over the public internet. As the operator invests in extending network capacity in pace with the growing number of (paying) users, the financial risk of the network operator and/or service provider remains limited. Deploying services on today's cellular networks and existing devices in the market, avoids large upfront investments and the need of the consumer to invest in new (dedicated) equipment, and is illustrated by the following examples.



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Figure 2: The connection and data path between the mobile device to the traffic application server

A navigation provider, offering a navigation service which is augmented by real-time traffic congestion data (e.g. TomTom HD Traffic), could extend his product by including intelligent speed or lane advice to maximize traffic flow, or by adding a warning for local hazards such as road-works, or sudden traffic jam build up. The input data for their traffic application server would be obtained from either the regular channels (predictable, planned road works), or by further processing the received floating car data. The (finer grained) floating car data could indicate a traffic jam build up, or show sudden speed variation, which could be used to alert the drivers upstream of this location using the regular cellular communication as is depicted in Figure 3 for the vehicle (UMTS modem) just below Bonn on the A61. This only requires an incremental investment in service and application development. When the number of users would grow to a level that the number of simultaneous connections becomes a bottleneck in the communication network [10], the network capacity could be extended incrementally [11] by adding additional transmitters (e.g. femto cells) at locations with intense traffic, as indicated in Figure 3 on the A3 just above and below Dreieck Dernbach (A48).

With a further growth and intensification of data connections, the aggregated data rates and latencies in the operator network may cause a bottleneck at the telecom operator's internet gateway. A logical step to tackle this problem is to build the network with a less centralistic routing of data, such that data on the network can be handled as local as possible or be routed to the internet on multiple locations to eliminate the concentration on single hotspots in the network.

4th Generation cellular systems (4G, LTE [12]) as currently being deployed by telecom operators, are designed for data transport. It provides low latency data transport [13] and support this decentralized data break out, which makes this architecture ideally suited for providing connected driver assistance functionality.

To overcome this bottleneck and single point of failure in current 3G networks, the 3G networks can be augmented with femto cells providing the local wireless link to the mobile devices in their coverage area [11]. Femto cells according to release 10 of 3GPP standard [2] offers the architectural advantage of 4th generation local data break-out, but are already available with 3G radio technology.

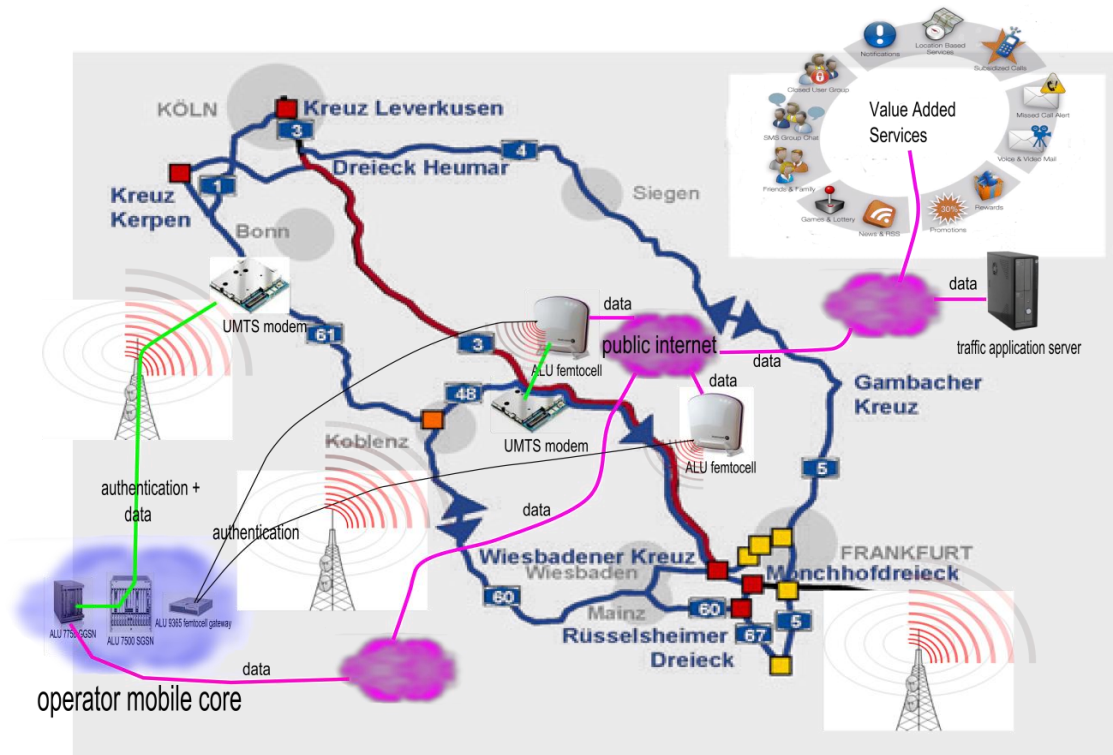
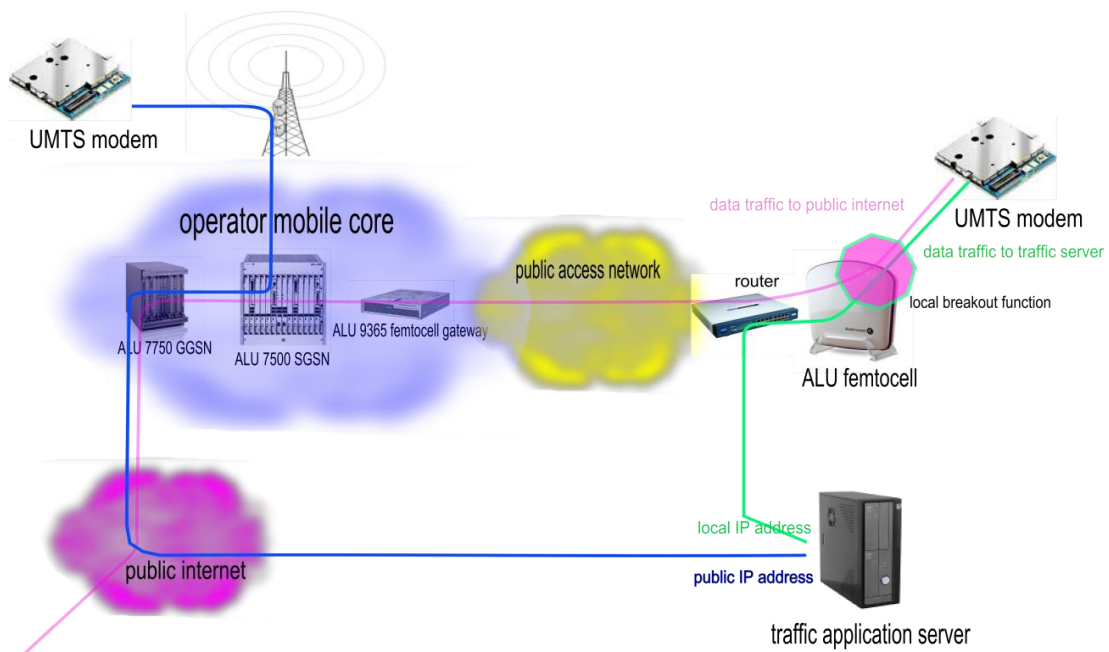


Figure 3: Using existing cellular systems to deploy driver assistance functions



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Figure 4: Femto cell augmented 3G network

With femto cells, one could create a cost effective high performance low latency local 3G connection to a (local) traffic application server, such as an RSU. Figure 4, depicts this solution. The mobile device (UMTS modem) connects wirelessly to the femto cell at the right-top in Figure 4. For authentication and handover, it requires services from the operator network, for which the femto cell either uses a dedicated connection or a public internet connection (left branch from top-right, in Figure 4). The data connection can be re-routed locally to connect to the nearby server with traffic data, allowing fast sustainable low-latency access to local traffic data and offloading the main internet connection of the operators network (Branch from right-top to right bottom in Figure 4).

The mobile client, in-vehicle device

If the in-vehicle device needs to communicate directly with all other (moving) in-vehicle devices in its surrounding, it needs to authenticate with all of them, process their data, and calculate whether one of those objects might be on a collision course. The requirements for this device will be high and lead to a costly *thick client* and likely to high latency in communication due to complex authentication schemes. Standardization wise, this solution is challenging as somehow, it has to be guaranteed/verified that each in-vehicle device is able to set-up and maintain time critical communication with all other devices of all vendors and for all the hardware and software versions of this set. The complexity of this problem is of the order $n(n-1)/2$, where n is the number of devices in the set. Limiting the in-vehicle device's communication to infrastructure only reduces this problem, to testing against the much smaller set of infrastructure equipment. The fact that compliancy testing could be based on existing and proven standards is an additional argument in favor of cellular networks.

The mobile client needs to establish the wireless connection to the infrastructure, exchange data and interfaces with the driver. For our intersection assistant, the client device has e.g. to inform the driver on the appropriate speed to pass the intersection smoothly and efficiently and warn the driver for potential hazards like crossing pedestrians, bicyclists or vehicles. For integration into vehicles, this device should preferably be reasonably low cost. This implies that it has to fulfill its function with limited compute and memory resources (*thin client*) and that the technology used is preferably based on mass-market developments. Preferably, the assistance functionality can be merged with other connected processing capable devices inside the vehicle, e.g. navigation system or eCall unit, or on a personal portable device of the driver.

Realization of intersection assistant using 3G communication

The intersection assistant developed by Flanders' DRIVE and partners within the Vision project¹, is based on the reuse of available cellular communication infrastructure. With the example intersection assistance application, we target non-time critical driver awareness functionality as the Green Wave speed advisory, of which the user interface is shown in Figure 5. We also investigate the limits of using cellul communication for non-predictable time-critical driver assistance functionality such as a local hazard warning for a crossing pedestrian. In a next phase, we will target faster moving objects such as crossing bicyclists and vehicles.

We use a Samsung Galaxy Nexus (running Android 4.0) as our development platform for the JAVA based intersection assistant application. Although we use the smart phone for user interfacing, application testing and as an example of an existing mobile device on which this kind of applications

can be deployed, we foresee a migration of the application code to thin-clients (vehicle integrated M2M devices) such as navigation systems and eCall units in the near future.

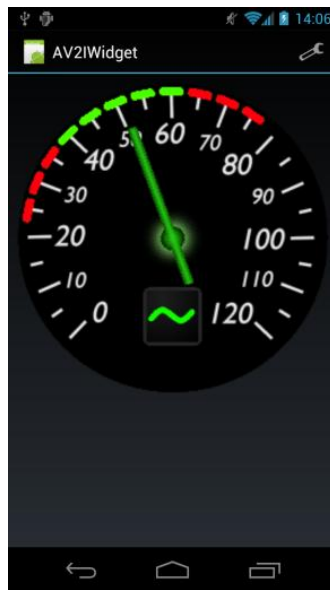


Figure 5: User interface for the Green Wave Speed Advice

A test intersection has been created at Lommel Proving Ground, which is being equipped with sensors for detecting pedestrians, bicyclists and vehicles. The sensors are connected to a traffic application server (TAS), which also controls the installed traffic lights. The mobile device sets up a data link (IP connection) via a 3G wireless link to the TAS which is kept open. The device periodically sends its position, speed and heading to the TAS, such that the TAS knows from where the vehicle is approaching the intersection. The TAS selects the relevant information for this approaching vehicle, such as traffic light status and advised speed to the vehicle. As soon as e.g. a crossing pedestrian is detected by one of the infrastructure sensors, the TAS checks for which vehicles this event is relevant, and sends those vehicles the information (location and type of event). As the data link is kept open, the latency on the communication link is very low, especially with a state of the art device, operating system and telecom stack.

Measurements in the surroundings of Lommel (Belgium) showed a typical one way latency of 40 ms for communicating our speed advice message between the TAS and our mobile device using a 3G connection. For 2G communication (EDGE), we measured a typical latency of 126 ms, which seems even fast enough for time critical applications like the pedestrian warning. The remainder of the project is directed on exploring the limits of communication, by testing different user scenarios, under different network load conditions, using standard 3G cellular networks as well as femto cell equipped networks.

Conclusions

3G cellular networks are mature and abundantly available throughout the world and rapidly being expanded in coverage and performance or upgraded to 4G by telecom operators. In our project we show that it is feasible to run the Green Wave Speed Advice driver awareness function on smart phones with a communication latency of typical 40 ms on a 3G (UMTS) data link.

As we have discussed, investments in the roll-out of services and infrastructure remain low when reusing existing 3G and 4G cellular communication networks, and exploiting the large existing user base of smart phones (44% of the population in the US uses a smart phone [5]). This base offers a quick start for deploying ITS services in the area of connected driver awareness.

Once the services are offered, the market is opening for OEMs to integrate services in their advanced telematics platforms in their vehicles.

Without communication infrastructure, the economical interest for an OEM to integrate the intersection assistance function into a vehicle might be questionable. When using 3G communication, the investments in systems and services can be gradually increased when the number of users increases. Network data transport capacity can be further improved and communication latency reduced with distributed (local) traffic application servers connected to femto cells, such that connected driver awareness functions may evolve in true driver assistance functionality.

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ⁱ These are the partners who collaborate with Flanders' DRIVE in the Vision Project: Alcatel-Lucent, Ford Lommel Proving Ground, Mobistar, NXP, TomTom, Traficon, LMS, Melexis and Tenneco. The project is financially supported by the Flemish government, and runs until the end of september 2012. For more information on Flanders' DRIVE: www.flandersdrive.be.