Vehicular Networking Pilot System for Vehicle-to-Infrastructure and Vehicle-to-Vehicle Communications

Timo Sukulaara1 and Carlos Pomalaza-Ráez2

1Finnish Meteorological Institute, Arctic Research Centre, Tähteläntie 62, 99600 Sodankylä, Finland
timo.sukulaara@fmi.fi

2University of Oulu, P.O. Box 4500, FIN-90014 University of Oulu, Finland
carlos@ee.oulu.fi

Abstract: Modern society is built on good roads and efficient transportation systems. Road safety has become the primary development issue within road infrastructures. Safety and mobility can, however, be jeopardized by poor highway design and construction or by operating procedures which allow unsafe driving conditions e.g. construction work zones, incident management or response to emergencies caused by adverse weather. During recent years weather conditions in winter, especially when rapidly changing, have been an important factor behind numerous disastrous traffic accidents in northern regions of Europe and America as well as in the Alpine region in Europe. Information about hazardous weather conditions is often potentially available but difficult, or sometimes even impossible, to deliver to the drivers in the target area. Without a procedure to deliver instant accident and incident warnings directly to vehicles, accidents (and traffic accidents in general) can quickly change into a chain event. The Carlink project was established to overcome such information gap and to provide guidance to drivers.

In the Carlink project we have developed a wireless traffic service platform between vehicles, supported with roadside base stations. The platform is open for any kind of third-party services, but with the project team we have generated several specific services especially tailored to improve traffic safety. The final goal is to enhance traffic safety and smoothness, but also to generate a completely new communication entity, allowing for a new type of applications, services and business opportunities. All this requires a smoothly operating wireless communication platform supporting both vehicle-to-vehicle and vehicle-to-infrastructure communication.

In this paper we briefly present the concept of the platform and pilot system deployment, and concentrate on the wireless vehicular networking dilemma. Traditional wireless networking systems are designed for an office environment, completely different than a vehicular network of fast-moving objects. We have chosen the upcoming IEEE 802.11p vehicular networking standard as the final solution, but we have used the IEEE 802.11g standard Wi-Fi networking system as a current operational solution. In this paper it is shown, that despite the deficiencies of IEEE 802.11g in a vehicular communication environment, when working together with a GPRS alternate communication channel, it can provide a reliable and efficient vehicular networking solution for a Carlink type of wireless communication platform.

We have developed wireless traffic service platform to enhance traffic safety and operation. Our pilot system has proven the basic functionality; the operability can only be seen ultimately in an operative, commercially deployed platform. The presented approach represents a candidate solution for a comprehensive vehicular communication entity for enhancing traffic safety.

Keywords: Carlink, Vehicular networking, Wi-Fi, traffic safety

1. Introduction

Increasing traffic, congestion, pollution and changes in the climate causing hazardous weather and road conditions are reasons for a growing need of an advanced real-time traffic-related information systems, warnings and services. Vehicular networking is nowadays a widely studied research field, and a large number of suggestions for vehicle-to-vehicle and vehicle-to-infrastructure communication have been presented. The focus is typically a bilateral communication between two vehicles or on broadcasting information from one vehicle or infrastructure to vehicles in the surrounding area. In the Carlink project [1][2] of the European Celtic program call 3 we have developed an intelligent hybrid wireless traffic service platform between cars supported with wireless roadside base stations. The concept platform consists of a specific set of services (like local road weather service and incident warning service, traffic data applications, urban transport traffic management and information broadcasting/sharing applications). A variety of other services can be integrated into this kind of a system. In the pilot system deployed during this project, the focus was on several safety specific services and improved traffic safety. It is expected that a system with a set of safety related services, which ultimately saves lives, can be a driving factor to have it implemented and justify its installation costs. While the ultimate goal is indeed to enhance the traffic safety, this platform can be used to generate a variety of additional related services e.g. traffic smoothness, but it can also generate a completely new communication entity, allowing new type of applications, services and business opportunities.

Communication between cars is arranged in an ad-hoc manner with an IEEE 802.11g based Wi-Fi communications system, supported with a wireless roadside base station network. Wi-Fi has been designed for office environment, so the problems found in vehicular communication were
expected. The optimal networking solution for the platform is expected to be the IEEE 802.11p standard, but this technology was unavailable during the project, as well as the supporting equipment. IEEE 802.11g was the best alternate solution available, and therefore it was decided to use it in the pilot platform and preliminary deployments. It will be replaced by IEEE 802.11p as soon as it is commercially available. In the test measurements conducted it was seen that with the support of GPRS communications, an appropriate level of operability with pilot services can be achieved even with IEEE 802.11g.

The concept of a car-to-car communications platform has different approaches with a slightly different focus for each one. A common view for this kind of networking topology is Vehicular MANET (VANET), where MANET stands for Mobile Ad-Hoc Networks [3]. Traffic safety enhancement is the driving factor in many approaches, typically leading to solutions where sensor data from vehicles and roadside units are used for providing accident and/or weather warnings to road side units and vehicles. Similarly, observations and traffic information are used to increase the efficiency of the road network usage. The capability for continuous communication is also an important goal. However, bringing all these competing goals together has not gained too much attention.

In the Carlink project the aim is to build a more comprehensive solution for car networking and car-to-car communication purposes. The main challenge in our approach is to take into account the hostile communication environment that exists between fast and independently moving vehicles, and provide efficient and fast delivery of critical data regardless of the location or presence of the other vehicles. In addition we want to generate services which not only enhance traffic safety and efficiency but also exploit our platform capabilities as much as possible. We have also considered the special case of a commercial platform deployment phase and operation in rural areas as a scenario where there is not a high density base station network in use, but still the proposed solution should be able to provide an acceptable level of services.

We have created the concept of an intelligent hybrid wireless traffic service platform between cars, supported with wireless access points along the roads. The ultimate goal of this concept is to allow vehicle-to-infrastructure and vehicle-to-vehicle communications. By aiming to the architecture for a commercial platform, we can not expect any company to deploy a high density network thorough the operating area instantly, but instead we want to offer a solution which can provide an acceptable level of operability in minor installations (a coarse base station network) and expand it based on its commercial success. For this purpose we have employed a hybrid system of GPRS and wireless networking. Wi-Fi networking stands for the primary communication platform, while GPRS main purpose is to provide an alternate communication solution for the cases of system failures or out of range locations. Especially in the platform deployment phase and in rural areas, GPRS plays an important role.

In this paper the concept of the Carlink platform and the deployment of a safety-oriented pilot system are described. Using the pilot system structure, we have conducted a set of communication measurements to study the capabilities of an IEEE 802.11g based system to operate the platform with pilot services.

The rest of the document is arranged as follows. Related work is presented next. An overview of the platform with a pilot system and its services is given in the following section. Then we present an overview of the technical requirements of the communication platform, followed by an overview of wireless technologies. The evaluation of the pilot platform data throughput measurements are finally presented, with a discussion of the results. A performance analysis and discussion lead to the conclusions of our work.

2. Related Work

Vehicular networking, that provides safety related applications, has gained a lot of international attention in recent years. There is a variety of different approaches to this topic. One of the major activities in this area is the Car-to-Car Communication Consortium (C2C-CC) driven by major car manufacturers, aiming at generating decentralized floating car data (FCD) communication capabilities between cars [4]. The objective in C2C-CC is to provide mainly broadcast-type of services, such as broadcasting accident warnings from car-to-car and roadside information from traffic infrastructure to cars. In telecommunications its aim is to support the standardization activities driven by IEEE (WAVE standards IEEE 802.11p and IEEE 1609, IEEE 802.11 a/b/g) [4][5][6][7]. In our work the compatibility with WAVE standards and C2C-CC work in general has always been an essential issue, and participation in C2C-CC work (by the first author) is highly important.

In the United States, the Department of Transportation is coordinating the Vehicle Infrastructure Integration (VII) program which is closely related to the C2C-CC except for the fact that it is government supported and coordinated. VII supports vehicle-to-infrastructure and vehicle-to-vehicle communications in the federally allocated 5.9 GHz frequency with 70 MHz bandwidth (recently also allocated by EU, but with 30 MHz bandwidth). The communication between vehicles and infrastructure is operated via DSRC (Dedicated Short-Range Communication) protocol defined in IEEE 1609. Primary applications and targets are advisory (usually safety-related) messaging from infrastructure to vehicles, probing the anonymous data from vehicles to infrastructure and other vehicles in a secured manner [8][9]. In our work the VII has been seen as a parallel and mutually compatible approach with the C2C-CC work, and therefore the compatibility with VII is maintained as much as possible. It is worth of noting that in the United States there is numerous ongoing activities in different states, providing vehicle messaging systems at the “state-level”. The European CVIS project generates open standards-based communications, positioning and networking platforms for both vehicle-to-infrastructure and vehicle-to-vehicle communication. Services provided are mainly related to traffic safety and control. The communication architecture is based on the CALM standard, bringing together different communication methods (IEEE 802.11p networking, 2G/3G GSM based communication and infrared communications)
into a single architecture. The ultimate goal of parallel solutions is to provide an “always-connected” system [10]. In Japan a similar kind of traffic service communications platform is called VICS. VICS is a slightly older system, in which the main architecture is focused on the communication between vehicles and the infrastructure. However the deployment rate of this solution is much higher when compared to solutions in the USA and Europe [10][11]. The European COOPERS project is also developing a communications system for traffic environment, mainly to generate services relying on vehicle-to-infrastructure communication (although vehicle-to-vehicle communication is also supported). The goal is to provide continuous wireless communications via DSRC technology, for services like accident and weather warnings and traffic management. COOPERS solution uses multiple wireless technologies like the CALM standard based IR Wi-Fi communications and GSM/GPRS [12].

While CVIS and COOPERS projects are mainly focused on increasing the efficiency of the road network in Europe, the e-Safety initiative [13] of the European Union and the EU’s COMeSafety project are tightly focused on road safety enhancement. Recently COMeSafety have published the architecture for ITS communications in Europe, to be used as framework in related standardization work [14]. While the COMeSafety is acting merely as coordinating forum for related research, the SAFESPOT project represents the technical approach. SAFESPOT combines the sensor information gathered from both vehicles and roadside units into traffic incident and accident warnings [15]. The mutual analysis of CVIS, SAFESPOT and COOPERS presented in [16] sees CVIS as core co-operative technology (with concept proofing of CALM standard), SAFESPOT as co-operative systems to process highly critical (vehicular) tasks and COOPERS as road operators interface to the co-operative vehicular networking. Our approach combines these elements in its own way. A similar approach of cars distributing accident warning data vehicle-to-vehicle and even forwarding warnings car by car is presented in [17]. The LIWAS traffic warning system [20] is designed to provide early warnings to vehicles about adverse road conditions like a slippery road surface. It will consist of sensors for determining the state of the road, and communication infrastructure supporting inter-vehicle communication. Other approaches exist also, the most important ones being PReVENT (aiming to control vehicle directly e.g. breaking without driver command to avoid accident), GST, NOW and Sevecom. Most of the European activities in this area are more or less related to the C2C-CC work.

An example of a national level research project is the Finnish national “VARO” project where safety is being improved by delivering warnings and route guidance to the end-user devices located in cars. Other examples are the weather dependent dynamic speed limit system in Netherlands [18] and the environmental sensor network in United Kingdom [19].

One approach to provide traffic services is to equip a mobile handheld terminal with a transceiver being able to receive broadband data. Traffic and accident data can be obtained directly over the Internet with this equipment. The Celtic Wing TV project is researching this scenario, relying on the DVB-H broadcasting standard. Similar studies are being carried out by mobile communication device manufacturers worldwide.

3. The Platform

The Carlink platform is designed to provide an infrastructure to a wide community of commercial and governmental traffic safety and management services. The platform itself is the key element in Carlink, but the services, especially safety related services, created for the platform have also a crucial role. On the one hand, they generate different ways to use and exploit the platform, proving its efficiency. But on the other hand the services are the platform’s showcase to the consumers. In order to make the consumers keen to purchase the platform’s services (and furthermore for the vehicle industry to integrate the platform equipment into the vehicles) we need to have some services that are interesting enough for the consumers. Ultimately, the safety services are the key of our system, directed to governments with the promise of saving lives in traffic situations, and therefore making easier the decision to invest in a rather expensive roadside and central system equipment. We have not defined an extensive package of services, but just a couple of key services to prove the applicability, usefulness and necessity of the platform. Furthermore, in the pilot system that we have constructed we have completely focused on safety related applications. The (hybrid) platform with a couple of safety enhancing applications even with low deployment rate is in our visions of the so-called “killer-application” raising the public interest (both from governments and consumers) and therefore its commercial success, leading to large scale deployment and generation of a wide spectrum of independent services.

The platform is divided into three parts: Traffic Service Central Unit (TSCU), the base station network with Traffic Service Base Stations (TSBS), and Mobile End Users (MEU) with ad-hoc connectivity and (non-continuous) backbone network connectivity.

The platform is presented in Fig. 1. The platform consists of MEU units embedded into vehicles (at the lowest part of the figure), TSBS base stations beside the road (in the middle of figure) and the host system TSCU beyond the base station network (topmost part of the figure). The MEUs form a wireless vehicular network together with TSBS base stations. They do not have continuous connectivity but operate in ad-hoc manner with each other (typically) when two cars pass each other. Always when a vehicle with a MEU passes a TSBS, it will get up-to-date traffic platform information stored into the TSBS. The TSBS receives regular updates to the traffic platform information from the TSCU, located in the fixed network beyond the TSBS. The TSCU operates in the fixed network relying exclusively on the existing communication solutions of the fixed network. The TSBS acts as an interface between the fixed and wireless networks. The MEU also transmits data to/from TSCU over the lower capacity (GPRS) alternative connection when critical weather, warning, or accident information emerges, or in case the TSBS density is low (in the early deployment phase).

We have defined a simple set of services for the platform which are listed in Table I. There are two types of services, general services and pilot system specific services. The
general services are defined and developed for the platform at a general level, but not built in the pilot system. The pilot system specific services are derived from the general services into specific operational services, which have been implemented in the pilot system and used in practice. The accident and incident warning services use vehicle data to generate warnings related to exceptional traffic conditions or accidents. The local road weather service (RWS) collects observed weather data from vehicles and TSBSs installed by the roads. These observations together with weather information from other sources are used to generate a comprehensive precise local road weather analysis and forecasts that can be forwarded back to cars. The traffic service will generate traffic logistics data for the public authorities. Finally, the remaining services listed deliver commercial-like travel data to users on the move.

Let us now consider in detail the general services used in the pilot, and study the pilot system specific services later on. The operation of the local RWS, accident warning and incident warning services are closely related to each other, as

<table>
<thead>
<tr>
<th>General services</th>
<th>Pilot system specific service</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accident warning</td>
<td>Emergency button</td>
<td>Button pushed in vehicle, accident location distributed throughout the platform</td>
</tr>
<tr>
<td></td>
<td>Airbag burst</td>
<td>When airbag bursted in vehicle, accident location distributed throughout the platform</td>
</tr>
<tr>
<td>Incident warning</td>
<td>Vehicle throwing</td>
<td>When vehicle gyroscope registers lateral movement, incident location distributed throughout the platform</td>
</tr>
<tr>
<td></td>
<td>Sudden break</td>
<td>When vehicle gyroscope registers rapid decrease of speed, incident location distributed throughout the platform</td>
</tr>
<tr>
<td>Local Road Weather</td>
<td>Current local road weather information</td>
<td>Weather data from TSBS and exceptional weather data from vehicles distributed throughout the platform</td>
</tr>
<tr>
<td>Positioning</td>
<td>Embedded to other services</td>
<td>Vehicle positioning</td>
</tr>
<tr>
<td>Transport</td>
<td>-</td>
<td>Transport guidance and real-time timetables</td>
</tr>
<tr>
<td>Traffic</td>
<td>-</td>
<td>Traffic logistics for traffic control centre</td>
</tr>
<tr>
<td>Route</td>
<td>-</td>
<td>Planning route to expected</td>
</tr>
</tbody>
</table>

Table I. Carlink services

<table>
<thead>
<tr>
<th>service</th>
<th>planner</th>
<th>destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parking places</td>
<td>-</td>
<td>Real-time parking place availability info</td>
</tr>
<tr>
<td>Point of Interest</td>
<td>-</td>
<td>Guidance to point of interest</td>
</tr>
<tr>
<td>Geo-coding</td>
<td>-</td>
<td>Geometric data</td>
</tr>
</tbody>
</table>

Figure 1. Carlink platform and pilot system structure.
they are all using vehicle initiated data to either enhance (local RWS) or create (accident and incident warning) observation of weather- or incident-related event. Therefore we have combined these (general) services together into
combined services, operating through the common procedure presented in the Fig. 2. The service operation proceeds in the figure downwards from the top. The TSCU maintains up-to-date RWS information, forwarded regularly to the TSBSs in
the area of interest. Each TSBS has therefore up-to-date
local RWS information, which is delivered to every MEU
passing by. The MEU receives and consumes the weather
data but in exchange it forwards the collection of its own
weather and traffic related measurements. This data is
delivered back to the TSCU, used to update the RWS data
to generate potential additional warnings. The MEUs also
exchanges data
during the encounters, so each MEU has up-to-date data. In
the case of emergency or unavailability of nearby TSBSs, the
two-layer networking procedure can be bypassed with a
parallel GPRS based communication between the TSCU and
the MEU. This channel may not be adequate for the full
scale data but, due to its practically complete coverage
(epecially in rural areas), critical emergency data is
delivered without delay. Also in the early deployment phase
of the platform, the GPRS channel is used as primary
wireless channel, as long as the TSBS network is too coarse
to be exploited.
The local RWS is derived from FMI’s (Finnish Meteorological Institute) road weather model [21] presented
in the Fig. 3. The effects of atmosphere, traffic, turbulence, ground heat transfer and surface heat transfer are considered, and presented in the figure. It is a one-dimensional energy balance model which calculates vertical heat transfer in the ground and at the ground-atmosphere interface, taking into account the special conditions prevailing at the road surface and inside the ground below. The model also accounts for the effect of traffic volume on the road. Output from a Numerical Weather Prediction (NWP) model is typically used as a forcing at the upper boundary. This input provides also the horizontal coupling between individual computational points of the model. The basic horizontal resolution of the FMI’s present road weather model is as sparse as 10 km which means that in principle the model cannot resolve meteorological features beyond this spatial scale. The majority of calculations are related to conditions
within the ground, where the vertical temperature distribution is solved to a depth of approximately six meters. The atmosphere model is considered as a forcing factor having an effect on the ground surface through a number of variables like ambient temperature, relative humidity, wind speed, short- and long-wave radiation, and precipitation. The values of these variables can be inferred from observations or from a forecast, i.e. the model does not make a distinction as to the source of the input data. The heat balance at the ground surface is solved on the basis of these variables and takes into account such additional factors as sensible and latent heat fluxes as well as atmospheric stability. The effect of melting and freezing is also included in the energy balance.
An additional forcing at the surface is the traffic volume, which causes not only increased turbulence but also mechanical wear of e.g. snow, ice or frost that prevails on the surface. A spatially constant traffic effect is assumed in the model, and during night time a smaller traffic factor is used. In addition to calculating ground and road surface
In this paper we have analyzed 802.11g with field representation an interesting future alternative. The existing communication product, while IEEE 802.11p is not available early enough for our pilot systems. Therefore, it is not officially approved yet, and nevertheless this solution was the 802.11n standard, downward compatible follower of IEEE 802.11g standard. However this standard has not been adopted by the IEEE 802.11 standardization forum has just recently published equipment supporting the IEEE 802.11g standard family. The most common current versions are the 802.11b and 802.11g standards operating in the 2.4 GHz bandwidth and capable of up to 54 Mbps (11g) or 11 Mbps (11b) data speeds, respectively. Recently also some devices supporting forthcoming (11n) standard have been published, expected to be able to provide up to hundreds of Mbps data speeds. However as this standard is not yet approved the compatibility of different devices between each other and with the final standard remains as an open issue.

The IEEE 802.16 family of standards specifies the air interface for both the fixed and the mobile broadband wireless access (BWA) systems supporting multimedia services. The WiMAX system is based on these technologies. IEEE 802.16-2004 for fixed and IEEE 802.16e for mobile access, respectively, are the IEEE standards which define the current structures of the WiMAX system. WiMAX has licensed worldwide spectrum allocations in the 2.3 GHz, 2.5 GHz, 3.3 GHz and 3.5 GHz frequency bands and is capable of up to 31.68 Mbps data rates with a single antenna system and up to 63.36 Mbps with a multiple antenna system. The WiMAX is capable of supporting fast moving users in a mesh network structure. Systems with users moving at speeds up to 60 km/h have been reported [22]. However just recently there has been lot of discussion whether the WiMAX will ever achieve commercial success, due to long delivery delays and problems in large scale WiMAX network deployment projects (e.g. Sprint nationwide WiMAX network in U.S.A.).

The IEEE standardization activity for the car-to-car communication environment is named as WAVE (IEEE 802.11p) [5]. The underlying technology in this standardization work is called Dedicated Short-Range Communication (DSRC) presented in the IEEE 1609 standard [6], which is essentially the IEEE 802.11a standard adjusted for low overhead operations. The primary purpose of the DSRC is to enhance public safety applications, to save lives and to improve traffic flow by vehicle-to-vehicle and infrastructure-to-vehicle communications. The ultimate goal in the design of IEEE 802.11p has been flat distributed
communication, achieved by avoiding channel scanning, association process and authentication process prior to data exchange. In the U.S. a 75 MHz channel has been allocated for the DSRC in the 5.9 GHz spectrum [23]. During the autumn of 2008, a 30 MHz channel has been allocated for vehicular communication in Europe, in the 5.875-5.905 GHz bandwidth.

6. Carlink Pilot System

Based on the technical requirements presented, we have created the platform structure illustrated in the Fig. 1, and constructed a pilot deployment of key parts of the system to validate the operability and performance. The TSCU is on the top with connections to the underlying service cores, the local traffic weather service, the accident warning and incident warning services. The TSCU takes care of user management. As a central unit of the system, the TSCU maintains the interdependencies of all the platform elements.

It also stores all data gathered from the platform and forwards the appropriate data to the services. The accident and incident warning services parameters are an airbag blast, a push of the emergency button in the car, gyroscope status (indicating possible swinging, sliding or sudden stopping of vehicle), all of them including the GPS-location of the observed issue. The RWS core includes a weather forecast model generating local road weather outlook based on FMI’s operational measurements. This model is supplemented with car measurements (temperature and GPS-location of observations) to complement the weather information. The resulting local road weather information is delivered to the TSCU, responsible for forwarding this data to the vehicles through the platform.

Similarly, the accident and incident warning services collect vehicle data to build up warnings for exact locations, returned to the TSCU. Depending on the significance of the warning the TSCU selects the appropriate path for the warning data distribution. The most critical warnings (e.g. accident location) are delivered through the GPRS connection as rapidly as possible, while the more informative-like warnings can be distributed through the base stations.

The network of TSBSs below the TSCU (Fig. 1), mainly act as a data transmitter from the TSCU to the MEUs and vice versa. The TSBS is also collecting weather data itself and delivering it to the TSCU.

The MEUs in vehicles are the users of the Carlink platform, gathering data along the roads they are driving, delivering it up to the TSCU and the underlying services and, finally, consuming the weather and warning information (partially) derived from the vehicle based data. The parameters gathered from the vehicle are: temperature, car gyroscope information, airbag blast notification, push of emergency button notification and the GPS location for each data source. The gyroscope and the GPS-system each have their own interfaces, while the push of the emergency button will be gathered from the drivers user interface. The remaining parameters (temperature, airbag blast notification) are coming from the vehicle CAN-bus gateway. The Wi-Fi and the GPRS interfaces are used for the communication with the TSBSs and the TSCU.

7. Performance Analysis and Discussion

The platform framework has been studied via field measurements and an evaluation of the service operability has been carried out. The focus has been on rural areas with low base station density, since that is the challenging scenario in the deployment phase. The field measurements presented in this chapter addresses the basic operability when using IEEE 802.11g wireless networking. The pilot system, using supplemental GPRS data communication, gives an overview of the true operability of system with pilot services.

The field test measurements were conducted in the Sodankylä area during the autumn of 2008. The field tests consisted of two scenarios, base station-to-vehicle and vehicle-to-vehicle, as presented in Fig. 4. The base station was located in an open area, without any physical obstacles nearby between the vehicle and the base station (at least not in the close range, i.e., less than 500 meters). We started the measurements varying the delay and data packet size, but soon concentrated to repeating scenarios as shown in Figure 4. With these basic communication scenarios we aimed to test the basic operability of IEEE 802.11g in a vehicular networking environment, focusing on the type of services we intend to provide in the Carlink pilot.

In the first scenario we emulated the typical Carlink platform operation of a vehicle passing by the base station and exchanging platform data. For this scene the vehicle drove back and forth through the location of the base station with a pre-defined speed, and during this drive we captured the instances of successful data transmission delivered in a pre-defined pattern from base station to the vehicle. We tried to deliver as much data as possible, but especially chose two packet sizes to transmit (in separate measurements) in order to find the optimal delivery type. A 315 byte packet is the standard size of a weather station report, representing a small packet size in our measurements. A large packet size in our measurements is 1202 bytes, simply constructed from four small packets (with just one packet header). For the large packets we also tried to find the effect of packet transmission interval to delivery rate by using two clearly different delays between consecutive packets, 1 ms and 10 ms, respectively.

Obviously the packet sizes used as well as the transmission intervals are not necessary the optimal ones, but rather pointing to the parameter space where the optimal values are likely to be found.

On the second scenario we had two vehicles passing by each other with pre-defined speeds, one of the vehicles is sending data in a pre-defined pattern and the other one capturing the successfully received data. The same variations of packet size were used here, but the delay was kept constant as the communication window during the bypass was expected to be too small for a large delay.

The main results of base station to vehicle scenario are briefly illustrated in Figs. 5-7. In Fig. 5 we show the connection availability percentage during the route simply as a relation between the time when the connection is available and the total time spent in driving the route. It can be seen that the size of data packets does not affect too much the connection availability. The same share of time during the base station passing is available for actual communication, regardless of the packet size. With small 315 byte packets the connection availability (and the underlying connection...
uptime during the base station passing) is lower with speeds lower than 80 km/h. The reason for this phenomenon is not clear, but we assume that one reason might be that the transmitter is trying to minimize the transmit power, and by using less power at lower speed it also loses the connection more easily. If this is the reason, it can be solved by using a power controlling scheme. Nevertheless, we can conclude that the delay between packets should be small, as it allows for more capacity. In fact, we noticed that the data throughput after the connection is established was rather steady (varying between 4.8 and 5.0 Mbps) regardless of the vehicle speed, but with a higher speed the connection establishment takes a higher share of time spent when the base station is within range, therefore leading to a lower connection availability time share. Based on this result it is rather obvious that the average throughput is better with larger data packets delivered with short delay in between, which can be clearly seen in Fig. 6. The average throughput during the measurement session presented in Fig. 6 consists of not only the throughput during the connection time, but also during the connection establishment time and also during time with no connectivity.

![Base station to vehicle](image1)

**Figure 4.** Field measurement scenarios.

![Vehicle to vehicle](image2)

**Figure 5.** Base station to vehicle data transmission, connection

The same phenomenon visible in Fig. 5 can be seen here also, and the assumption described above remains the same. A final observation for this scenario is that with smaller packets the data payload transmission success rate is clearly better, which can be seen in Fig. 7. In this figure we have compared the relation between data packets successfully received by the receiver and the total amount of packets sent by the transmitter. The final lesson learned from the first scenario was that packet delivery rate during the pass by is rather constant, regardless of the packet size. The preferred packet size is then dependent on its intended use; for TCP-like delivery (like file transfer) where all bits availability must be delivered successfully smaller packets are preferred, while with streaming type of delivery it is better to use large packets, allowing higher delivery rate. Also it is noted that an increase of the delay between packets did not bringing any added value, so we yielded further use of large delays in the vehicle to vehicle scenario.

![Base station to vehicle](image3)

**Figure 6.** Base station to vehicle data transmission, average throughput during the pass.

In the Fig. 8 we briefly present the main results of vehicle to vehicle data transmission, data throughput and connection...
availability share percentages. Similar as with the base station scenario, we have compared the connection availability time to the total route driving time, and data successfully received to the total data sent, respectively. Again we can see that the packet size does not affect the connection availability time. A final note of these results is that the data rates decrease with higher speeds, but the measurements so far have not revealed a saturation point. One can see certain mild jitter in all curves. This phenomenon is probably caused by the operating system (Microsoft Windows XP), having the connection establishment process as one of many processes and therefore not continuously attempting to maintain the connection. This jitter can be removed by increasing the number of measurement of the same scenarios.

![Figure 7](image)

**Figure 7.** Base station to vehicle data transmission, successful data delivery percentage.

![Figure 8](image)

**Figure 8.** Vehicle to vehicle data transmission, throughput percentage and connection availability percentage.

Although the field measurement scenario of base station to vehicle transmission was clearly oversimplified, it shows that with an effective connection handoff and a connection establishment process the connection breaks in the presented scenarios can be almost completely removed. Especially with GPRS backup connection the Carlink traffic service platform can operate with appropriate reliability with IEEE 802.11g, even if this protocol is designed for office environment. The capacity of the system can be enhanced by increasing the amount of base stations and by updating their transceivers with directional antennas and multiple antenna systems. If the data bandwidth usage can be maintained at rather low level, as well as the tolerance for connection breaks, the vehicular network based on IEEE 802.11g can be used for creating large-scale Carlink wireless traffic service platform. Obviously, critical data such as warnings of accidents cannot tolerate any delays caused by higher distances between base stations during deployment phase or in the rural areas, but for that purpose we have defined the lower capacity GPRS connection. As the future IEEE 802.11p standard focus on enhancing operation in vehicular networking conditions, it is likely that IEEE 802.11p in operation will allow reliable and smooth operation of the vehicular networking platform. It was, however, unavailable during this project.

The pilot platform was built in the city of Kaarina, Finland on September 2008. An overview of the pilot deployment is shown in Fig. 9. In the pilot system we deployed the specific services listed in Table I into a simple pilot platform, consisting on a TSCU, two TSBS base stations and two operating vehicles. The main data channel was Wi-Fi, but due to extremely low density of base stations, we were relying on GPRS data communication most of the time. For the communication between vehicles we used GPRS communication only, as we were concentrated on showing the pilot services operability in general. The specific pilot services were tested one by one, and were found operating adequately. We defined the service operation being “adequate” when a) the service response to “impulse” (e.g. vehicle throwing is noted when driver turns wheel roughly) is reliable (at least 90% success rate expected) and b) service data (incident/accident warning, weather data) is delivered to all vehicles/devices in the network within 5 seconds. Wi-Fi communication clearly sped up the data delivery to be a “nearly instant” response. With GPRS, it took several seconds from initiating “warning condition” to see the warning on the screen, and for example for the dangerous case of a chain accident of vehicles, the delay is too long. In the end the pilot system was proved to have satisfactory performance in this limited scale. Based on the pilot system operability, and assuming a dense network of TSBS base stations in use, we estimated the effect of our pilot system on traffic fatalities. We used the statistics of fatalities in Finland for the year 2008, and estimated the effect of our services to...
each type of traffic fatality. As a result, based on the values shown in the Table II, we have estimated a 17% decrease of lives lost in the traffic, which translates into more than 50 persons in Finland at year 2008. Even if we had to make lot of assumptions due to the amount of details regarding the accidents are missing, we found our estimation suggestive and truly meaningful in the area of improving traffic safety. Obviously only the operative final system will eventually prove the quality of these estimations.

8. Conclusions

We have presented the Carlink concept of a hybrid wireless traffic service platform between cars, and a safety-oriented pilot system deployment. The ultimate goal has been to create a safety-enhanced intelligent communication platform for vehicles where they can deliver their own observations of traffic and weather conditions to the platform core. This information is delivered back to the vehicles as analyzed (and forecasted) information about road weather conditions and as immediate accident and incident warnings. Compared to competitive solutions presented in the related work section, the Carlink solution has successfully showcased a true bidirectional communication entity for variety of traffic and safety services. The solution has been presented at a concept level with support of a true pilot deployment, and the performance is evaluated with supporting field measurements. Although the focus has been on the vehicular networking, the platform solution is also adaptable to conventional networking. Regardless of the success in the platform development, direct transformation into a commercial system is not likely in the very near future, due to several reasons. Some car manufacturer should take active role as developers and investors of such systems, and in the current situation where the whole vehicle industry is having its largest economical crisis ever, such investment is not expected. The fixed (road-side and central unit) infrastructure is expected to be funded and developed by government(s) and national authorities, and even if clear impacts are reachable in the form of saved lives and saved vehicle infrastructure, the emerging economical depression decreases investing willingness in this sector as well. Also it is noted that using the yet-to-come IEEE 802.11p standard solution as underlying wireless communication technology would clearly benefit the system performance. However by relaying only in GPRS, a system can be installed with a rather small investment, since GPRS service is already covering all areas (at least in Finland). Furthermore, compliant vehicle equipment exists in wide range of taxis in Finland and worldwide, so a basic set of users can also be employed with minor costs. A basic functionality of the system can be achieved with this simple construction, but the vehicle data is coarse and deliveries of warning data are rather slow (couple of seconds from initiating accident/incident). These are, however, relative easy steps to take towards a large-scale system, and Carlink members are discussing this issue with local authorities in Finland. It remains to be seen how the deployment of the platform will proceed. Whatever the case, it has been shown that our approach presents a considerable candidate solution for a comprehensive vehicular communication entity, with clear potential of avoiding traffic accidents and saving lives.

<table>
<thead>
<tr>
<th>Accident type</th>
<th>Registered fatal accidents in Finland 2008 (*)</th>
<th>Estimated to be prevented with Carlink</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same direction (driving straight)</td>
<td>8</td>
<td>50%</td>
<td>Assumed to be entirely chain accidents (detailed facts missing). With Carlink accident/incident warning chain accidents avoided, unless the following vehicle already too close to react.</td>
</tr>
<tr>
<td>Opposite direction (driving straight)</td>
<td>83</td>
<td>30%</td>
<td>The case of losing control of vehicle due to road conditions can be avoided with Carlink pre-warnings, unless the condition has just emerged and not yet observed by other vehicles or weather forecasts. For this particular occasion Carlink warning is effective, if obeyed by the driver(s).</td>
</tr>
<tr>
<td>Opposite direction (turning)</td>
<td>9</td>
<td>30%</td>
<td>Same assumptions as in the previous accident type.</td>
</tr>
<tr>
<td>Crossing direction (driving straight)</td>
<td>30</td>
<td>10%</td>
<td>Crossing direction accident typically caused by driver not noting the crossing car. Minority of accident (detailed facts missing) assumed to be caused by slippery road in crossroads, and in this particular case Carlink warning is effective, if obeyed by the driver(s).</td>
</tr>
<tr>
<td>Crossing direction (turning)</td>
<td>9</td>
<td>10%</td>
<td>Same assumptions exist as in the previous accident type.</td>
</tr>
<tr>
<td>Walking persons</td>
<td>45</td>
<td>0%</td>
<td>Current set of services does not provide safety improvements to walking persons, and therefore Carlink warning system likely not helping.</td>
</tr>
<tr>
<td>Falling off road</td>
<td>110</td>
<td>20%</td>
<td>Caused by either driver loss of concentration or sleeping, dodging animal or other objects in the road or slippery road. Only the last case can be avoided with Carlink warning, if obeyed by the driver(s). As detailed facts are missing, we assume 30% of accident caused by slippery road and two third of them avoided by weather warning.</td>
</tr>
<tr>
<td>Other</td>
<td>40</td>
<td>0%</td>
<td>As type unknown, we assume no effect by Carlink system.</td>
</tr>
<tr>
<td>Total</td>
<td>344</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td>100</td>
<td>17%</td>
<td>The amount of fatalities calculated from the individual accident types above and summed up.</td>
</tr>
</tbody>
</table>

(\* source: Tilastokeskus; tilikenttäesi onnettomuustyyppien mukaan 2008)

Table II. Estimated effect of Carlink pilot system to the number of fatal accidents based on accident statistics in Finland.

9. Acknowledgements

This work has been supported in part by the Technology Advancement Agency of Finland (TEKES) and the European Union Eureka cluster program Celtic. The authors wish to thank all the partners of the Carlink project, especially Pertti Nurmi, Marjo Hippi, Sami Suopajärvi and Timo Ryppö from FMI, Pekka Eloanta and Tommi Joutsiniemi from Mobisoft, Kimmo Ylisiurunen and Juha Laakso from Infotripla and Esa Suutari from Sunti.
References


