Car-to-Car Communication – Market Introduction and Success Factors

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Summary

The potential of the Car-to-Car Communication technology to improve road safety as well as to provide a platform for a multitude of other applications is not questioned. What is missing is a suitable market introduction strategy that overcomes the problems of the initial market distribution that many of the envisioned applications require. This paper investigates the specific market properties of the Car-to-Car Communication technology and outlines a strategy for market introduction.

1. Introduction

The Car-to-Car Communication (C2CC) technology is a communication media that enables the autonomous exchange of data between vehicles. This allows e.g. to extend the sensor data base of one vehicle by the data bases of others. Dangerous or undesired hindrances like bad road conditions, unexpected driving behaviour, very recent accidents, or sudden end of traffic jams might be perceived the possibly vital seconds earlier. This offers the chance to significantly reduce the probability of accidents[1]. In its safety functionality C2CC excellently complements other driver assistance systems based on radar, infrared, ultrasound or video [AMS-n1.04] [PBM-a3.00]. Additionally, the C2CC technology can be used as a platform to realise applications in the area of traffic flow, comfort and entertainment.

The potential of C2CC to significantly reduce the number of accidents on ever more crowded roads is not questioned [Hor-a9.04] [Min-s9.04] and respective activities are funded accordingly [BMBF-p12.04] [FN-w2.05] [Pan-s11.03]. No unambiguous view though exists on the economic use of C2CC, as C2CC holds one substantial problem: It is a technology with network effects. Network effects mean that the larger the distribution of a technology, the larger its value for every user (telephones are a good example for a technology with network effects). The situation for C2CC is specifically difficult, as a minimum distribution has to be given before a reliable functionality can be sold. This means that the first owners of C2CC enabled vehicles cannot profit from the technology. They are thus unlikely to pay for it, which again forestalls to achieve the required distribution.

The aim of this paper is to communicate the market properties of the C2CC technology and to provide answers to the questions of market introduction and success factors.

The paper is structured as follows. Chapter 0 discusses the matter of required penetration rates. Chapter 0 describes the economic consequences from dealing with a technology with network effects. Chapter 0 discusses possible solutions, technological as well as economic. Chapter 0 closes this paper with a summary.

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[1] [KT-a3.03] states that 60% of rear end accidents, 1/3 of head-on accidents, and every second accident at cross roads could be avoided, if the driver was brought in a position to react half a second earlier. [NOW-e10.03] states that in 2002 the probability of about 225.000 accidents would have been significantly reduced, if the driver had been warned earlier.

2. Required Market Penetration

The acceptance of the C2CC system is based on the reliability of the different functions. For example, if a driver is warned in time that a car ahead is making an emergency stop, this will have a very strong positive impact. Being not informed about some POI (point of interest) on the other hand will have a negative, but very small influence on the driver.

A malfunction of a C2CC application can have different reasons:

- Software, hardware or transmission failures
- Some kind of malevolent attack on the system
- Not enough equipped cars in a certain area

The first two points are subjects of technical research and development work, while the third point depends on the system penetration and thus has to be handled by an appropriate market introduction strategy.

There are three arguments, which identify the penetration rate as a very crucial point in matters of reliability:

(1) First of all we need an equipped car, which generates the relevant information. An accident warning for example should be generated by one of the cars involved in the collision.

(2) We also need enough system penetration so that information is kept in a specific area. E.g. the information about an iced road sector has to be accessible for cars coming through this area later on. To reach this goal without additional infrastructure, we need enough cars bringing this message back into the target area.

(3) In some cases it is important to distribute information over a large area or distance. Apart from using an intelligent store and forward algorithm, still a specific penetration is needed to reach this goal in an acceptable amount of time, so that the driver can benefit from it.

It depends on the type of application, which points are relevant. Time-critical applications like the extended emergency brake lights use direct communication – the braking car has to be equipped (1). Hazard warning in general additionally needs to keep information in a certain area (1, 2). All three points are important for traffic flow (mobility) appliances of the C2CC system, like the Self-Organising Traffic Information System (SOTIS) [WER-a4.03]. The minimum required penetration rates are highly application and traffic scenario dependent. Therefore we raise concrete figures for SOTIS and local hazard warning.

In SOTIS every equipped vehicle monitors the locally observed traffic situation by saving its own position and velocity as well as recurrent data packets with Travel Traffic Information (TTI) from other vehicles. A traffic situation analysis is performed in each vehicle and the result is distributed to the local neighbourhood. SOTIS can provide information for each vehicle with an individual information range of more than 50 km from the current position with high accuracy [WER-a4.03].

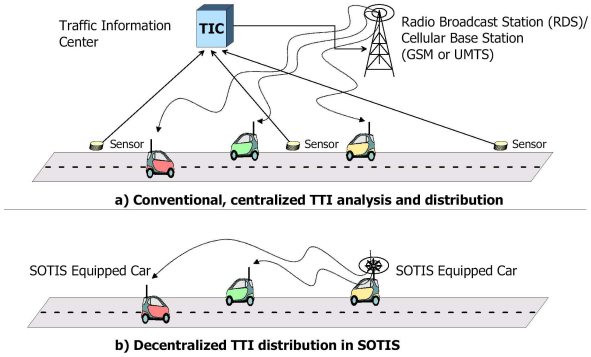

Figure 1: Comparison of the conventional, centralised approach for Traffic Information distribution with the decentralised SOTIS technique [WER-a4.03]

The time delay is system penetration dependent and is considered as sufficient, if it is smaller than the usual delay of traffic information broadcasted by radio stations via traffic news or TMC, varying between 20 and 50 minutes. This dependency is examined by simulating a freeway section with two

lanes in each direction. The simulation deploys the network simulator ns-2, extended by a simple microscopic traffic simulation. The probability for a vehicle to be equipped with SOTIS is varied from 2-10%. The result is shown in Figure 2. The information a driver receives from SOTIS about a traffic jam e.g. 50 km ahead is approximately 25 minutes old, if 2 percent of all vehicles are equipped. If the penetration rate is 10 percent, the age of this TTI is only 3 minutes.

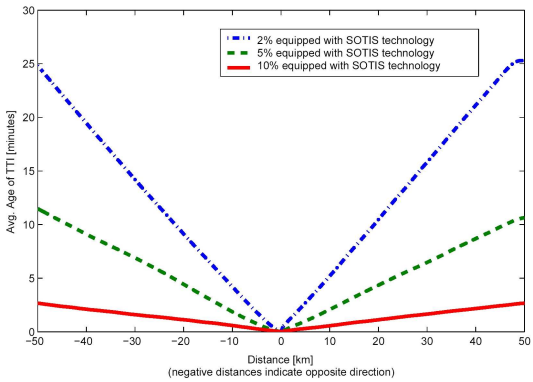

Figure 2: Dependency of the delay of the traffic information on the distance to the current position and the equipment rate [WER-a4.03]

Even in situations where only a small fraction of all vehicles (in this scenario only 2%) is equipped with the SOTIS system, the traffic information is provided with a reasonable delay. Thus the minimum penetration rate for SOTIS (and other traffic flow applications) is classified as “low”.

The local hazard warning will warn the driver about some kind of danger ahead. With help of a driving simulator as well as in a field trial it was shown that a driver warned in time indeed reduces the vehicle velocity to an appropriate, i.e. safe, level [DSKMZ-a5.03]. A simulation of the local hazard warning [Ben-a3.02] in different traffic flow scenarios based on this result shows a positive effect for the equipped vehicles starting from a penetration rate of about 10%. The benefit is measured in Time to collision (TTC – ratio of relative velocity to netto-distance to the vehicle in front). The simulation shows, that drivers of equipped vehicles have more time to avoid a possible collision than those of non-equipped vehicles. With an increasing penetration rate, the benefit for non-equipped vehicles also increases. This effect becomes very clear for scenarios with a high traffic flow. Thus the minimum penetration rate is defined as “mid”.

All applications that are reliable only in case of 100% equipped vehicles are classified as needing a (very) “high” penetration rate – they will be introduced very late. One example is automatic merging at a merging area. This application belongs to the category Co-operative Driving. Since it takes responsibility off the driver, based on C2CC data, the information has to be 100 % reliable. Table 1 classifies the possible C2CC applications.

Exemplary Applications	**Required penetration rate**
Decentralised Floating Car Data	low
Local Hazard Warning	mid
Co-operative Driving	high

Table 1: Exemplary applications and the required penetration rates

3. Economic Background

For every new technology there are two mechanisms that lead to a successful market introduction:

Either

- there is a **visible added value** of the technology for the customer and/or
- a **regulative order** without alternatives requires its use (see also Figure 3).

The regulative introduction seems to speak for itself. Nevertheless, there are two catches to it. First, the normal market mechanisms of price and value are no longer valid. Whoever has to bear the resulting costs will unlikely appreciate it. Second, the effectiveness of the C2CC technology has to be proven before an order can be issued. In case of technologies without network effects (like e.g. safety belts) this might be achieved by crash tests and the limited introduction in the field. But in case of C2CC this is – due to the required penetration rates – more difficult to be unambiguously done in advance. Naturally, governmental support is appreciated and a respective information policy should be pursued, but it cannot be relied upon for market introduction.

Concerning the market introduction by means of a visible added value of C2CC applications, the problem is caused by the – already mentioned – network effects and the required minimum penetration.

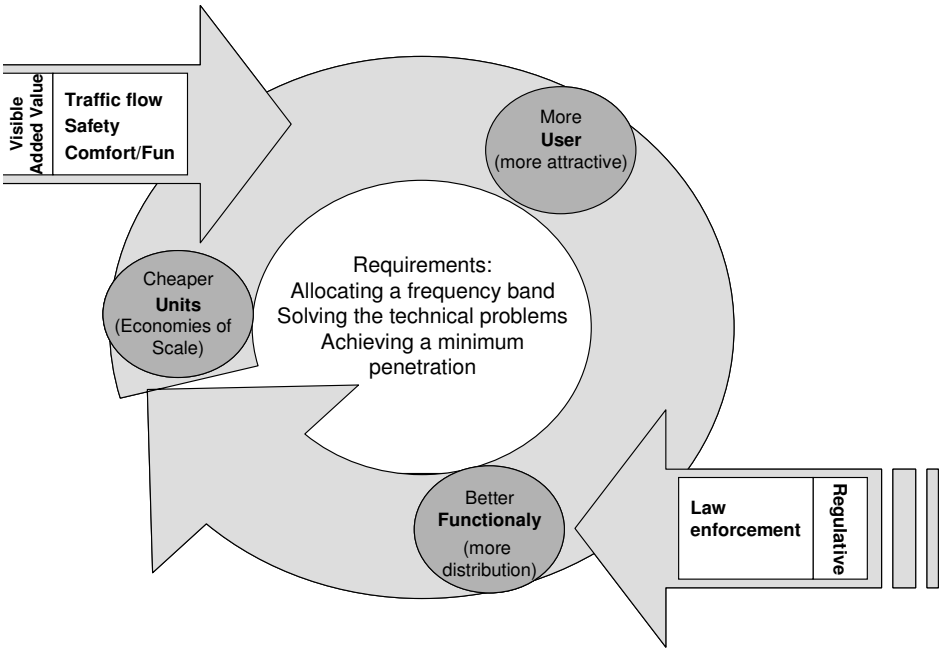

Figure 3: Market relations in case of C2CC

Figure 4 shows the time needed to reach specific penetration rates depending on the vehicle equipment rates for the German market. When equipping e.g. 25% of all cars 5% market penetration is reached in three years[2]. When equipping upper and upper middle class vehicles only, 5% market penetration is reached in about 10 years.

[2] This calculation assumes that car manufacturers are in a position to equip their vehicles at once. Generally though, this is not possible; new features are affiliated to new vehicle models. When taking this into consideration the time values increase accordingly.

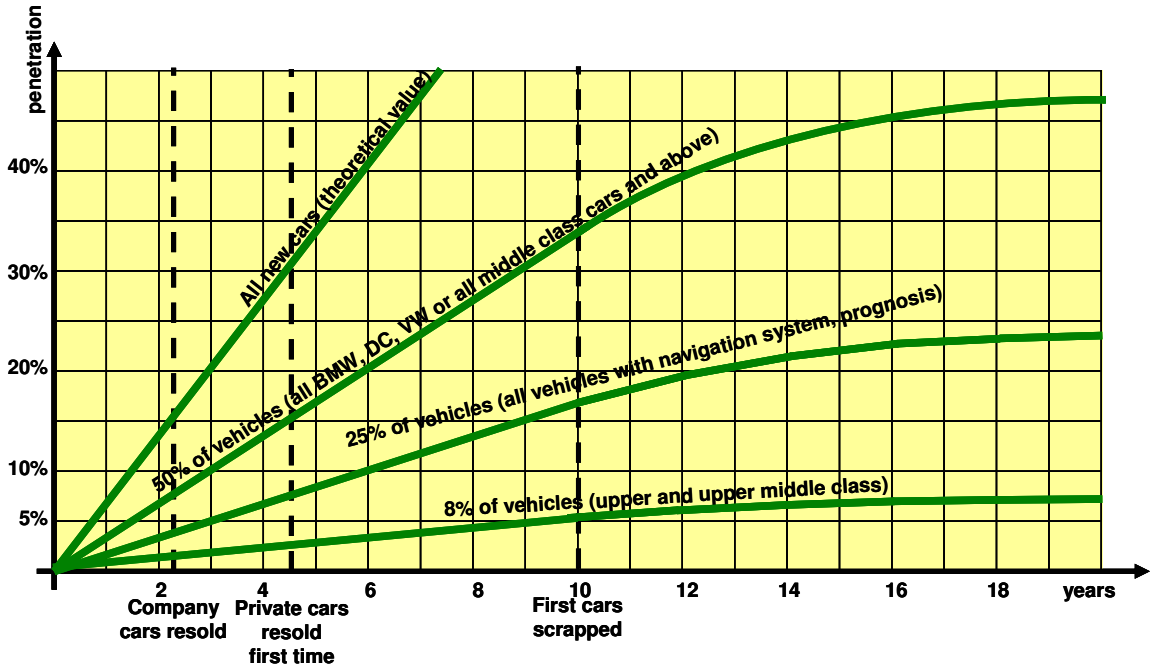

Figure 4: *Equipment rates and duration needed to reach specific penetration rates for the German market [KBA-r99] [KBA-w04]; the prognosis for navigation systems taken from [ADAC-p4.04]; currently there are about 47 million vehicles registered in Germany.*

This brief discussion already shows that C2CC is fundamentally different from anything else the automotive industry has introduced until now:

- The classical top down approach employed for the introduction of new technologies in the automotive industry is unsuitable for C2CC. The number of upper class vehicles sold is simply too small.
- The C2CC functionality cannot be used as a differentiating feature. No car manufacturer will be in an advantageous position by penetrating the market on his own or offering C2CC first. On the contrary: A standardised, widespread implementation agreed on by all manufacturers is a fundamental requirement for the functionality.
- To be able to profit from C2CC in an acceptable amount of time quite a large number of vehicles needs to be equipped with C2CC units. The anticipated 25% equipment rate of vehicles with navigation system seems a reasonable compromise between the duration it takes to get 10% market penetration and the number of vehicles needing to be equipped.
- Furthermore, the car manufacturers have to commit themselves to specific equipment rates. If not, it is advantageous for a car manufacturer to wait until the other manufacturers have created the required initial distribution and enter the market only then. Even if an agreement exists that only those manufacturers contributing to the initial equipment rate can sell C2CC applications later on, this is not enough, as it still might be advantageous to contribute with little effort.

It is vital that these aspects are thoroughly understood by everyone involved, because – as has been said – car manufacturers need to operate jointly. Once this is agreed upon every manufacturer has different choices on how to proceed with achieving the agreed equipment rates:

(1) A manufacturer can advance the requested C2CC units until the minimum penetration is reached and then sell the C2CC functionality to the customers (possibly also retrospectively to customers whose cars have been equipped before the required penetration was reached[3]. This is like

[3] This requires that displaying the C2CC functionality to the driver can be regulated independently from the basic functionality of generating, sending, receiving and, if valid, forwarding messages.

investing in an “infrastructure”, only that the infrastructure consists of units installed in vehicles. This method has the advantage that the equipment rate is surely met and that the car manufacturers can rely on the existence of the C2CC units for optimising their own processes. It has the disadvantage that the advanced costs have to be met by one-time profits from selling the C2CC units to customers in a later phase. C2CC cannot be sold on a pay-per-use or subscription basis. This would jeopardise the safety effect.

(2) Manufacturers can combine the C2CC functionality with additional functionality that can be used and thus sold at once. The communication with units other than cars has the advantage that these other units can be provided independently from the equipment rates of the vehicles. For these C2X applications there are two (complementary) variants:

   a. The vehicles can communicate with traffic infrastructure like traffic lights, road signs, etc. These Car-to-Infrastructure (C2I) applications annihilate the problems of the direct network effects, in exchange for facing indirect network effects: The traffic infrastructure yet needs to be equipped with communication counterparts. This requires either direct investments by the car manufacturers or the persuasion of government agencies to do so. The European directive for reducing the road fatalities by 50% within the next 10 years [EC-e01] (by now 6 years) can motivate such an investment. It is unlikely though that it will go without any commitment by the car manufacturers to equip a certain number of vehicles. The advantage over Choice (1) is that the one-time profits from selling the C2I units can be obtained at once and not with a delay. Achieving a 25% equipment rate by selling C2I applications only is ambitious though, when considering the history of automotive features in general [CKKW-a5.03].

   b. The C2X applications can profit from the C2CC technology being an IEEE 802.11 standard (IEEE 802.11p). Car-to-WLAN (C2WLAN) applications can enable the communication between the vehicle and IEEE 802.11a/b/g equipped units like laptops, smart phones, PDAs, public or private hotspots etc. This has the advantage that these units already exist and that other business models including subscriptions or pay-per-use models can be considered in addition to the one-time profits obtainable by selling the hardware. The catch to this choice is that the C2CC technology is not *the same* as IEEE 802.11a, b, or g(a, b, g also have some differences among themselves). This means that a car manufacturer offering C2WLAN applications *without* integrating the basic C2CC functionality will be in the position to offer this application cheaper than someone who integrates the C2CC functionality and thus contributes to the initial distribution of C2CC units. This backs the two main success factors of C2CC: The manufacturers have to commit to specific equipment rates and it is necessary to specify the basic C2CC functionality, such that all “C2CC enabled vehicles” support the same applications. The basic functionality needs to be as cheap to realise as possible.

4. Details

Application Roadmap

Figure 5 sorts several C2I and C2WLAN applications according to the distribution of the applications/units required to be able to deploy the application and the networking effort needed for realizing the application. For distributing traffic sign information e.g. little networking is required as the sign can simply continuously broadcast its information (while some networking is needed to be able to maintain the functionality), but a large number of signs have to be equipped.

The diagram also shows a basic order in which it makes sense to offer the applications. An almost natural evolution to what is visible today is Car-to-Personal Equipment (Circle 1). While today car manufacturers integrate personal units like PDAs, mobile phones, iPods and alike with help of, cables, cradles or Bluetooth, Car-to-Personal Equipments can use the WLAN interface to enable e.g. file exchange and synchronisation functionality. The advantage of this group of applications is that it is self contained and entirely up to the driver to make use of it.

The next group of applications allows the vehicle to communicate with a more or less specific WLAN unit outside the vehicle (Circle 2). This might be to download entertainment or route information from the home computer into the car before leaving the house (Car-to-Home). This might be fleet managers receiving digitally vehicle and load status information as soon as the transport vehicle enters the premises. This might be a car rental company optimising its return processes or a company organising its parking lot access. For this group of applications specific synchronisation software is required. Also

here the users can decide independently of other users on using the applications, though some more installation efforts might be required if e.g. company premises need to be equipped.

The situation changes for the next group of applications (Circle 3). These applications rely on the existence of more publicly available WLAN equipment. Car-to-Hotspot, delivery control in city areas, MP3 music download and alike all require that the vehicle can connect at more or less regular intervals. The more users are interested in these types of applications the more publicly available access points will exist. The standard authentication mechanisms and interface for internet applications have to be available.

A somewhat different situation is found for Drive-Through-Payment applications (Circle 4). In principle a parking lot or gas station owners can decide individually on providing the functionality on their sites, but they are unlikely to do so until a certain penetration rate of enabled vehicles is found on the market. These applications need authentication and e-commerce software

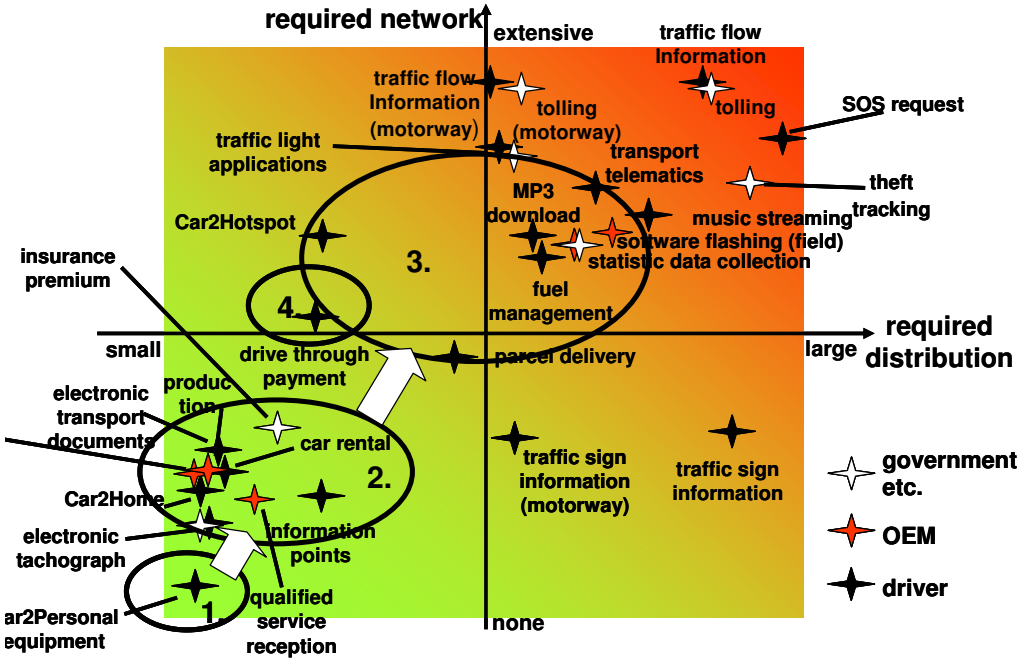

Figure 5: C2I and C2WLAN application roadmap

Technological Approach

As shown in the previous chapters, for some applications a certain penetration rate on the road is needed and this rate must be reached in a certain time. To achieve this objective the technical approach for the Car-to-Car Communication System must meet the following requirements derived from the aspects of market introduction and business models[4]:

- The car is part of the "Connected World". A well established consumer standard should be the technological basis for the communication system.
- The communication itself must be free of charge. That does not mean that all service must be gratis.
- There must be a separation between the communication system and the applications. The aim is to have only one (short- and medium range) radio communication system for today's and tomorrow's applications.
- To reach the required market penetration and to make some applications useful a Basic System should be integrated in all cars. This system should be as simple as possible.

[4] There are additional technical requirements like communication range, latency, data rate, availability and other. These requirements are not in the focus of this paper.

Because of the first two requirements IEEE 802.11, often called Wireless LAN[5], is chosen as technological basis. When not considering the technical attributes 3G mobile phone standards like UMTS also fulfil the first requirement, but generally result in a fee to a provider.

With Wireless LAN inside the car it is possible to communicate with public or private access points, personal computers, notebooks and personal equipment like PDA's or mobile phones. That does mean the car is a part of the "Connected World".

To fulfil the third requirement just developing a communication system with a layered structure as specified in the ISO/OSI reference model is not possible, because of the different requirements of safety relevant and entertainment applications.

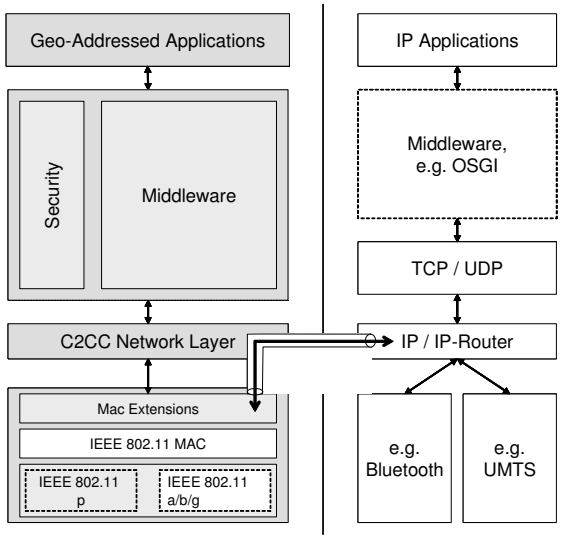

Figure 6: Proposal of an architecture for the Car-to-Car Communication System

A schematic overview over an architecture proposal is given in Figure 6. The left part shows the Car-to-Car Communication System with the new geo-addressed applications[6]. Everything that might be part of the new standard is marked grey. The right part shows the internet applications and the associated communication systems with the exception Wireless LAN.

The basic idea of the architecture is to have two more or less parallel systems: One system for internet applications with protocols like TCP and UDP, an IP-Router and radio systems like Bluetooth or UMTS. The only radio system not part of the internet-line is Wireless LAN. The Wireless LAN radio module is part of Car-to-Car Communication System and within the line for geo-addressed applications. This line also includes the necessary security mechanisms, a network layer called C2CC Network Layer and the necessary MAC extensions for the Wireless LAN protocol.

The way for an internet application to use Wireless LAN in the upper layers is the regular way. If the IP-Router in layer 3 decides to use Wireless LAN it passes the data to the C2CC Network Layer. This layer routes the data transparent to the standard 802.11 a/b/g radio hardware. With receiving data it goes the other way round.

The proposed architecture has some advantages in comparison with other possible ideas:

- Only one single module that integrates IEEE 802.11 a/b/g and p is necessary inside the car. This helps to reduce cost and is pushing the market introduction.
- An internet application must be implemented and installed only in a single version. It can use Wireless LAN the same way as other radio systems supporting IP.

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[5] When using the term „Wireless LAN" within this paper, it always means a wireless network compatible to the standard IEEE 802.11. For other wireless technologies like Bluetooth the proper name is used.

[6] Geo-addressed applications use the position of the car instead of an IP-address to set up the receivers of a message. An example is an emergency brake warning that is relevant for all cars in a specific range behind the sender.

- The system has well defined limits. It is responsible only for what is necessary to ensure safety and security. It has full control of the Wireless LAN radio module, but the internet applications and other radio systems are not restricted by the system.

On the other hand, this architecture shows that the geo-addressed applications can only use the Car-to-Car Communication System and that the system itself is responsible for update-mechanisms.

Last but not least the Basic System: It is a special deviation of a Car-to-Car Communication System that includes only functions and components obligatory in the car. These functions and components are required to forward and route messages as it will be specified in the standard and to make the car feasible to create and to send warning messages and traffic flow information messages.

The reason for equipping cars just with the Basic System is to reach the required market penetration and to make warnings and traffic flow applications running for the consumers that purchased these applications as an option. These applications will use the Basic System, but additional hard- and software not part of the Basic System might be necessary. In a car only equipped with the Basic System there is no application visible for the driver, the passengers or the owner.

The necessary components are not finally fixed, but it is sure that the Basic System must include an access to the in-car network, Wireless LAN and GPS.

5. Summary

The Car-to-Car Communication (C2CC) technology enables the autonomous exchange of data between vehicles and provides a platform for a multitude of applications from the areas safety, traffic information, comfort and fun.

To overcome the market introduction barrier of a minimum market penetration needed before the C2CC applications can be used, it is suggested to enable additional functions that do not rely on the equipment rates of vehicles. There are two possibilities: a) to equip traffic related infrastructure with communication units (Car-to-Infrastructure) and offer the respective applications to the customers and/or b) to exploit the synergies between the C2CC technology (IEEE 802.11p) and the IEEE 802.11a/b/g standards and to enable Car-to-WLAN (C2WLAN) applications. The resulting Car-to-X technology represents a perfect medium for making vehicles play an important role in the connected world.

There are two vital success factors to this approach. First, the car manufacturers have to commit themselves to equipping a certain percentage of their vehicles with C2CC units. They can meet their commitment by offering C2WLAN and C2I applications to the customers and by advancing (the remaining) C2CC units until the initial penetration is reached. Second, the manufacturers have to specify a “basic C2CC unit” and ensure its interoperability by a strict certification process.

References

[ADAC-p4.04] ADAC; “ADAC Prognose zu Navigationsgeräten 2004 – elektronische Lotsen kommen in Fahrt”; press release; April 2004

[AMS-n1.04] Auto Motor und Sport; „*VW entwickelt vorausschauendes Auto*“; news of January 20, 2004

[Ben-a3.02] Thomas Benz; „*Fahrzeug-Funkwarnsystem – Studie Wirksamkeitssimulation*“; BMW AG, Robert Bosch GmbH, Adam Opel AG, PTV AG, Karlsruhe; March 2002

[BMBF-p12.04] Bundesministerium für Bildung und Forschung; „*Autos sollen sich vor Verkehrshindernissen selbst warnen können*“; Pressemitteilung; 16.12.2004

[CKKW-a5.03] A.Chatterjee, H.Kaas, T.Kumaresh, P.Wojcik; „*A roadmap for telematics*“, automotive world; May 5, 2003

[DSKMZ-a5.03] Katharina Dahmen-Zimmer, Carsten Schneider, Markus Kostka, Claus Marberger, Alf Zimmer; „*Sicherheitsgewinn durch funkgestützte Unfallwarnungen im KFZ: Entwicklung und Evaluation eines MMI (Man-*

Machine-Interface) für funkgestützte Unfallwarnungen.“, 1. Dresdner Tagung “Verkehrssicherheit interdisziplinär”; June, 2003

[EC-e01] European Communities; ”*White Paper: European Transport Policy for 2010, time to decide*”, official publication of the European Communities; 2001

[FN-w2.05] FleeNet; official web site, http://www.fleetnet.de

[Hor-a9.04] Paul Horrell; „*The Future of the Car*“; September 8, 2004; http://www.popsci.com/popsci/futurecar/article/0,20642,679165-1,00.html

[KBA-r99] Kraftfahrt-Bundesamt; “*Haltegewohnheiten in Deutschland, ermittelt an den Besitzumschreibungen von Kraftfahrzeugen und Kraftfahrzeuganhängern im Jahre 1998*”; Statistische Mitteilungen, Reihe 1, Heft 11; 1999

[KBA-w04] Kraftfahrt-Bundesamt; official website; http://www.kba.de

[KT-a3.03] Peter M. Knoll, Gerd Teepe; “*Das sensitive Auto, mit Sensorik zum unfallvermeidenden Auto*”; auto & elektronik; 2-3/2003

[Min-s9.04] Fabrizio Minarini; „*The European Framework for the Development of Intelligent Vehicles*“; presentation slides; PEIT final review meeting, Stuttgart; September 2004

[NOW-e10.03] BMW, DaimlerChrysler, Fhl Fokus, NEC Europe, Siemens, Volkswagen; „*NOW: Network on Wheels*“; project description; October 30, 2003

[Pan-s11.03] Jeffrey F. Paniati; “*Intelligent Safety Efforts in America*”; presentation slides; 10th ITS World Congress Madrid; November 17, 2003

[PBM-a3.00] C. Passmann, C. Brenzel, R. Meschenmoser; „*Wireless vehicle to vehicle warning system*“; SAE 2000 World Congress, Detroit; March 2000

[WER-a4.03] Lars Wischhof, André Ebner, Hermann Rohling; „*SOTIS - A Self-Organizing Traffic Information System*“; 57th IEEE Semiannual Vehicular Technology Conference VTC 2003-Spring, Jeju, South Korea; April 2003