Internet on the Road via Inter-Vehicle Communications

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Abstract

Driving means constantly changing location. This, in turn, means a constant demand for information on the current location and specifically for data on the surrounding traffic. In particular, there is a demand for sensor data from other cars such as data on braking sent from a preceding car, for data on the traffic flow on a route, and for information about sites located along a route. Although need for information pertaining to the close environment of the car is obvious, so far no inter-vehicle communications system for data exchange between vehicles and between roadside and vehicles has been put into operation.

To promote the development of such an inter-vehicle communication system, the project "FleetNet – Internet on the Road" was set up by a consortium of six companies and three universities: DaimlerChrysler AG, GMD FOKUS, NEC Europe Ltd., Robert Bosch GmbH, Siemens AG, TEMIC TELEFUNKEN microelectronic GmbH, Universities of Mannheim and Hannover, and Technische Universität Hamburg-Harburg. The project is partly funded by the German Ministry of Education and Research. FleetNet started on September 1, 2000 and will end on December 31, 2003.

FleetNet aims at the development and demonstration of a wireless ad hoc network for inter-vehicle communications. Key design requirements for FleetNet are the capability to distribute locally relevant data where generated and needed and to satisfy the vehicle drivers' and passengers' needs for location-dependent information and services. Location awareness and position data play a crucial role not only for FleetNet applications but also for the communication protocols deployed. This paper provides an overview of the FleetNet project: we describe FleetNet applications and services as well as Fleetnet's technical challenges together with our current design choices.

1. Introduction

The objective of the FleetNet project is to develop an inter-vehicle communication platform that enables quick and cost-efficient distribution of data for the benefit of the vehicle passenger's safety and comfort. Speed of transmissions and cost-efficiency will be realized by a fully decentralized, ad hoc networking approach. The FleetNet platform is constituted by an arbitrary number of nodes capable of communicating in an ad-hoc manner. This includes cruising cars as well as temporarily immobile members such as a car at a parking lot, and permanently immobile members such as fixed roadside stations. Some of these will be able to provide additional functions such as a gateway to some remote network.

The project tasks range from selection of a suitable radio hardware and design of appropriate communication protocols to implementation of demonstrator applications, development of promising market introduction strategies, and standardization of the solutions. Since ad hoc networks are based on the principle of mutual assistance, many of the potential applications of FleetNet will only yield best benefits to drivers and passengers if the market penetration is high. Therefore, a major concern is to create conditions that allow inter-vehicle communication systems to be installed in cars independent of their makes and brands. Thus, the project results will be opened and standardized at appropriate international standardization bodies.

The development of communication protocols for large and highly dynamic ad hoc networks as well as the integration of such networks into the Internet represent the main technical challenges of the FleetNet project. In particular, development of adaptive and scalable routing algorithms that enable multi-hop data exchange and forwarding between cars and between car and stationary gateways are studied. Since vehicles will not necessarily be addressed only by an IP address, but also via their geographic position, the employed routing protocol should naturally support geographic addressing. Other topics of study are channel access mechanisms for the FleetNet radio subsystem that take into account quality of service requirements such as delay and packet errors. Moreover, efficient protocols for hot-spot communications have to be specified in order to allow reliable communications between e.g. mobile nodes and fixed gateways (Figure 1).

The radio communication protocols developed in FleetNet will be implemented on existing radio hardware. An appropriate FleetNet radio subsystem must perform robust in case of a high cruising speed, must operate in an unlicensed radio band, and a suitable hardware has to provide access to interfaces that allow link layer protocol implementation. Our current focus is on UTRA-TDD as a target system.

The structure of the paper is as follows. First of all, we outline applications and services that motivate the need for an inter-vehicle communication platform. Then, we present our design choices for the FleetNet radio system and discuss channel access schemes, routing issues as well as aspects of Internet integration. Finally, we conclude with an outlook to testbeds and standardization.

2. Applications and Services

FleetNet services and applications are divided into three categories: *i)* cooperative driver-assistance applications (safety-related applications), *ii)* Decentralized floating car data applications, and *iii)* user communication and information services. The applications belonging to each class pose their own particular requirements on the communication system in terms of delay, communication range, reliability, positioning accuracy, and bandwidth.

2.1 Cooperative Driver-Assistance Applications

Cooperative driver-assistance systems exploit the exchange of sensor data between cars, e.g. exchange of road condition data. One of the first applications to be implemented will be emergency braking. In case of an accident or if the brakes are pressed hard or floored, a notification is sent to following cars. Information of accidents can even be transported by cars driving in the opposite direction and, in this way, be conveyed to vehicles that might run into the accident [1]. Other sub-areas of driver assistance are passing assistance, security distance warning, and coordination of cars entering a lane. All these applications require position awareness of the vehicles, addressing of vehicles on the basis of their current positions, short transmission delay, and high reliability of data exchange. The average bit rate needed to realize these applications is low. Cooperative driver-assistance applications provide an excellent example of the need for exchange of data that is of local relevance.

2.2 Decentralized Floating Car Data Applications

Current floating car data services are based on service centers which collect and combine data from cars and broadcast the conclusions drawn back to the service members. For example, from several ‘no movement’ messages of cars on a highway, a traffic jam can be recognized, and a traffic jam warning message can be sent to service subscribers [2]. However, such a service can be realized without any centralized information processing in a local inter-vehicle communication system which exploits position-awareness for data distribution, thus avoiding the use of service centers and expensive transmissions via cellular radio systems. Data relevant to

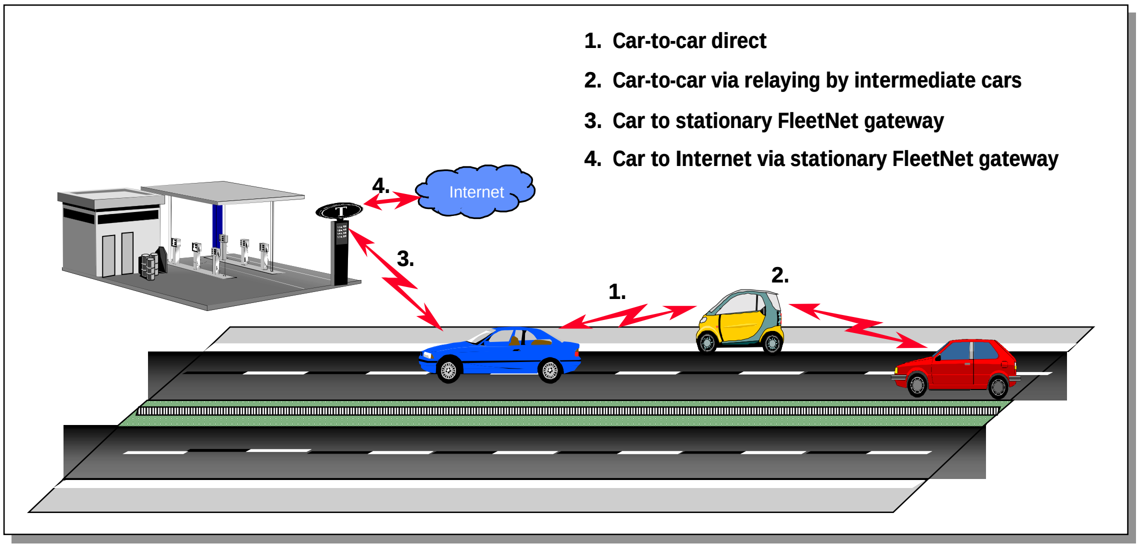

Figure 1. FleetNet Communication Scenario

cars on the same route can easily be transmitted in the opposite direction of the traffic flow, so that following cars receive data about the traffic situation ahead. Assuming that cars are equipped with digital maps and are therefore aware of the route to travel, messages can be sent along the route to query other vehicles about traffic flow, weather conditions, and other relevant data. Alternative routes can be assessed quickly. The requirements placed on the communications system are medium bandwidth, low position accuracy, low data transmission reliability, and medium priority. However it is expected that data transmission will occur periodically, so that periodical time slots are to be reserved by the channel access scheme as explained later in this work.

2.3 User Communication and Information Services

FleetNet applications deal not only with the passengers' safety and with traffic flow but also with the aspect of comfort and marketing. For example, passengers in the backseats can chat or play online games with passengers in other cars traveling on the same highway. Further applications include transmissions of data from commercial vehicles about their businesses. In contrast to the static presentation of business information prevalent today, i.e. the telephone numbers and logos printed on commercial vehicles, future electronic presentations will be dynamic and can be queried from and transmitted to interested passengers in other cars. With its concept of stationary FleetNet gateways on the roadside, FleetNet also provides a means for marketing along the road. Enterprises can set up stationary FleetNet gateways to provide marketing information to potential customers driving by [3]. Shopping malls or fast food chains can inform customers entering their premises about their offers – and can even take orders or assist drivers in finding an convenient parking lot. It is up to the operator of a certain stationary FleetNet node to include gateway functions into his service offerings — possibly restricted to a given area or to certain potential customers. On the one hand this will open up Internet access to clients. On the other, Internet-based offerings of the operating enterprise can be brought easily to the FleetNet.

Most of these applications will make use of the Internet protocols. Thus, quality of service requirements are reduced to best-effort service as experienced in the Internet. However, bandwidth requirements of these services are high.

3. Technical Challenges in FleetNet

The previous section outlined possible application areas for the FleetNet communication platform. In this section we address the technical issues to make these application scenarios happen.

Before proceeding to the various design choices of the FleetNet system, let us focus on some technological advances of the last decade that build the basis of FleetNet. Previously, some components crucial to our design were not available widely. The most important of such components are positioning systems. Yet, we can assume that in the mid-term cars will know their positions with an accuracy of less than 10 m by using GPS or digital maps. FleetNet will benefit of this advance in technology by using this information for the organization of the ad hoc radio network. First, routing protocols, which are typically based on flooding algorithms for route detection [4], will make use of the knowledge of the position of other cars within communications range. Second, means of addressing cars based on their current positions will be developed, which will enable applications for example to send messages to neighboring cars or cars running in front or rear probably using multi-hop relaying.

Another crucial component is the radio technology. FleetNet will not require development of a new radio hardware. Instead, we show below that some existing radio technologies meet Fleetnet's requirements and that radio protocols can be developed on top of the chosen solution.

In addition, advances in man-machine interfaces will be deployed. In particular, with the increase of available and presented information, drivers have to be supported through smart and effective speech recognition systems. Project partner TEMIC TELEFUNKEN microelectronic GmbH will work out new strategies for FleetNet applications which aim at distracting the driver as little as possible.

3.1 FleetNet Radio Communications System

As set out above, FleetNet will use existing radio hardware. The communications protocols developed will be implemented on top of the hardware system selected. The crucial requirements for the radio hardware are a bit rate of at least 1 Mbps, a communication range of at least 500 m, usage of unlicensed frequency bands, and accessible interfaces for protocol implementation. Several promising candidates for the radio hardware have been identified: WLAN technologies like IEEE 802.11 [5] and HIPERLAN type 2 ([6], [7]), UMTS radio hardware operating in time division duplex modes (UTRA-TDD, Siemens AG, [8]), and a proprietary system from Robert

Bosch GmbH called *Funkwarner* (a radio broadcast warning system [9]).

After investigating the alternatives mentioned above, an enhanced ad-hoc capable version of UTRA-TDD was identified as the most promising candidate. Thus we decided to concentrate on the UTRA-TDD hardware developed by Siemens AG. In order to cover different potential development paths, we will also investigate radar technologies on their options to additionally provide a means for data communications. Since it is assumed that radar systems will be integrated into car models on a large scale in the mid- to long-term, the use of such systems for inter-vehicle communications as well could help to solve the market introduction problem. Communication via radar systems is a very recent approach [10]. We are currently running a feasibility study, and a demonstration as a proof of concept is planned within the FleetNet project.

3.2 UTRA-TDD Radio Hardware

UTRA-TDD [11] offers high flexibility with respect to asymmetric data flows, allows communication over great distances, and supports high speeds. Another essential argument for the use of UTRA-TDD as a basis for FleetNet is the availability of an exclusive unlicensed frequency band in Europe (2010–2020 MHz), which offers two completely separate operating channels. Furthermore, the system allows high granularity for data transmission due to its CDMA component. However, because of the original cellular design of UTRA-TDD, a new ad hoc mode will have to be developed within the FleetNet project. The UTRA-TDD radio hardware provides a communications range of approximately 1 km and bit rates up to 384 kbps and 2 Mbps, depending on the absolute and relative speeds of communicating cars. Using UTRA-TDD not only results in technological benefits but also means that a high economy of scale can rapidly be achieved, because a mass market for UTRA-TDD systems and components is expected to emerge as soon as UMTS services are provided.

4 Communication Protocols

As mentioned in the previous chapters, communication protocols which enable ad hoc operation of FleetNet will be developed in the FleetNet project. These include protocols for *i)* channel access, *ii)* error control (ARQ) *iii)* position-aware routing and forwarding, *iv)* dynamic channel allocation (DCA), and *v)* protocols for Internet integration via FleetNet gateways.

Figure 2 shows the current state of discussion on the FleetNet protocol architecture. The Physical, DLC and Network layers decribe the FleetNet radio system. The layers above of them are standard Transport and Session Management layers and applications belonging to the three FleetNet service classes. Currently, we discuss the question if an extended version of the Internet Protocol can be used as FleetNet network layer, or if the FleetNet network layer will be a separate entity located below the common Internet Protocol as illustrated in Figure 2.

In the case of an IP-based FleetNet Network Layer, some mechanism for ‘header compaction’ will be needed for bandwidth efficiency reasons.

From particular interest are the FleetNet control layers, which essentially consist of:

FleetNet Network Layer Control: i.) Beacon generation (for exchanging information on the node itself and its neigbors), ii.) Postion table (for the position dependent routing scheme) iii.) Address mapping (if necessary)

FleetNet Link Layer Control: i.) Radio Ressource Management (for example power control), ii.) Dynamic Channel Allocation (time and frequency)

Since channel access mechanisms, routing algorithms, and Internet integration strategies seem to pose the most challenging problems, the principle solutions in FleetNet are discussed in the following.

4.1 Radio Channel Access Scheme

The challenges for a FleetNet MAC protocol are manifold, since the MAC protocol has to take application-driven parameters into account such as priority or maximum delay of a data packet. Additionally three major constraints of the radio hardware have to be considered [12].

i) Frequent topology changes and frame synchronization. The speed of vehicles can reach over 200 km/h. The resulting high network dynamics make it hard to achieve a frame and slot synchronization. Unfortunately, the UTRA-TDD radio hardware requires such a synchronization. Possible solutions currently under investigation rely on a common time-base of the cars, which is derived from GPS signals.

ii) Hidden-node problem. The hidden-node problem is known as a severe impairment which can decrease channel throughput to well below 30% of the achievable throughput without hidden nodes [13]. Well-known solutions for hidden nodes are the request-to-send (RTS) and clear-to-send (CTS) schemes and busy-tone solutions. By distributing the slot status information to all neighbors, slots that are reserved can be detected and hidden stations thus avoided for ongoing transmissions

iii.) Near-far problem. As set out above, the favored candidate for the air interface is UTRA-TDD, using a direct sequence CDMA scheme. Such an approach is sensitive to the near-far problem and, therefore, challenging if a distributed MAC scheme is to be developed.

So far some basic decisions concerning extensions of the UTRA-TDD MAC layer for operation in ad hoc mode have been derived. And working directions within FleetNet have been defined as follows: the basic UTRA-TDD frame and time-slot structure as defined in [11] as well as the spreading code tree used to support an orthogonal variable spreading factor (OVSF) as defined in [14] shall be maintained. It is further planned to reserve a number of slots in a frame for high priority services, e.g. cooperative driver-assistance systems. The remaining part of the frame can be dynamically assigned and temporarily reserved by different stations for services with lower priority. Periodic data transmissions, e.g., for decentralized FCD services or to perform routing data exchange, access this part of the frame as do transmissions of Internet data. The boundary between the two parts can be flexible. The number of spreading codes that can be used simultaneously by different stations has to be reduced in order to cope with the near-far problem. Investigations are ongoing regarding the number of stations simultaneously transmitting and are expected to lead to well-suited spreading code constellations. One early approach for MAC and radio resource management is based on a concept where only one station is allowed to transmit in one slot at a time. With such an approach, the near-far problem is avoided entirely. Yet, unfortunately, some flexibility in assigning transmission capacity to FleetNet nodes is lost. For dynamic reservation of transmission capacity, random access protocols are under investigation.

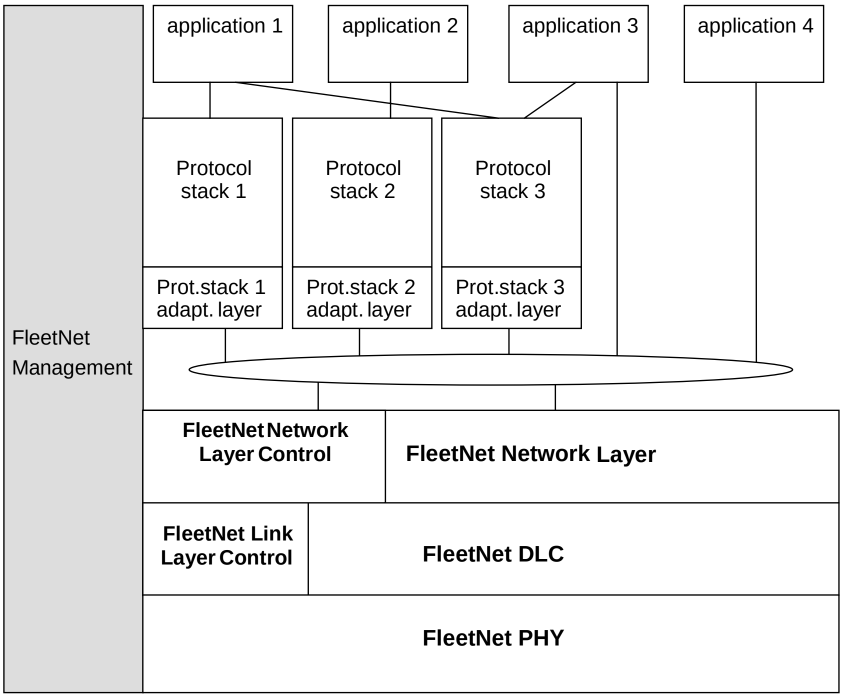

Figure 2. Current state of discussion on the FleetNet protocol architecture

4.2 Routing within FleetNet

Routing in a mobile ad hoc network is a challenging issue because of the network's frequent topological changes. A routing approach for a mobile ad hoc network should, therefore, show a high degree of *adaptability* with respect to the dynamics of the network. On the other hand, routing algorithms have to cope with *scalability*. These two competing aspects provide a key challenge for FleetNet due to the high relative speeds and large number of nodes involved. Since it is a valid assumption that the cars of the future will be equipped with an on-board positioning system like a GPS receiver, routing in FleetNet will be achieved using a *position-based approach*. This approach shows advantages over purely topology-based methods, i.e. proactive methods based on distance vector or link state and reactive methods like dynamic source routing [4], with respect to adaptability and scalability. In position-based routing strategies, a node is addressed by a unique identifier, i.e. its IP address, and its current position, i.e. its GPS coordinates. In order to forward a packet that contains the destination position, a router only has to be aware of its own position plus the positions of a number of its one-hop neighbors. The router simply forwards the packet to a node closer to the destination than itself. Several strategies have been proposed in the literature ([15], [16]). If there is no neighboring node that is closer to the destination, the router has to employ some *recovery* strategy to route around such a 'gap'. The key feature of position-based routing is that neither route setup nor route maintenance as in the case of topology-based routing approaches are required. In contrast to topology-based routing, the decision for a route is made on a per-packet basis on the fly – no hop-by-hop chain of routers has to be fixed before the packet is sent. However, the benefits sketched above do not come for free: a prerequisite for position-based routing is a system for dissemination and management of position information so that a node can learn the current position of its prospective communication partners.

4.3 Internet Integration

As mentioned before, FleetNet should not provide a 'stand alone' ad-hoc network for inter-vehicle communications but should be integrated into the Internet. That is, providing Internet access is mandatory to support acceptance of FleetNet and is required for a number of applications that rely on merging local data and information obtained from the World Wide Web. Nevertheless, providing Internet access *to* a vehicle's passengers as for example in mobile office scenarios is not the whole story. Within a network of cars where each node is generating information and is collecting information from its neighboring nodes and its geographical surroundings, each car becomes a server capable to provide up-to-date information, e.g., on traffic flow, as a service to FleetNet clients as well as to Internet clients. A variety of applications will benefit from the huge amount of data generated and processed by such a wide spread network of sensors.

Internet integration of FleetNet is based on a gateway architecture currently under development. We follow the approach not to use a managed infrastructure of some specific type of access points but to allow a gateway function to be provided by an arbitrary FleetNet node as a service to another FleetNet node within reach. Thus, a gateway node within FleetNet can be either a roadside station, e.g., located at a car service station offering Internet access among other (peer-to-peer / drive-by) services (Figure 3), or a mobile node providing access to a PLMN such as GPRS/UMTS. The latter case is for further study for regulatory reasons and since new business models need to be developed in order to allow for billing such a service.

Assuming a sparse density of gateway nodes in an early stage of FleetNet deployment or, e.g., in rural regions later on, connectivity to the Internet will be rather short living. That is, it can not be assumed that a sufficient number of FleetNet gateway nodes will be in reach even when using multi-hop techniques in order to establish a connection to some distant gateway while on the move. Thus, FleetNet Internet integration will rely basically on efficient caching, hot-spot communication techniques, protocols optimized for bulk data transfer, and agent-based approaches.

Caching. Caching information within FleetNet allows to distribute information to neighboring nodes that a single node recently obtained via the Internet. This scheme will support the re-use of public information of local relevance within a geographically limited region of Fleetnet.

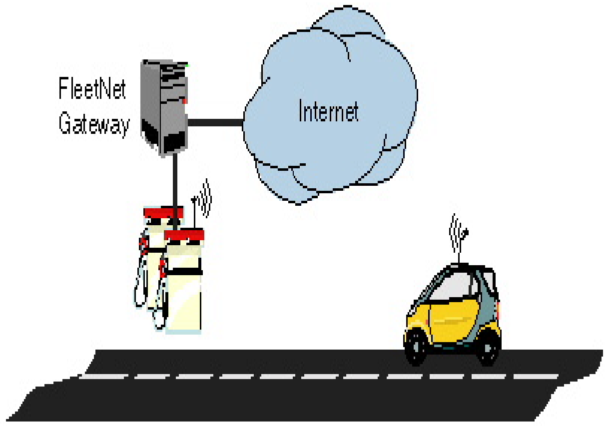

Figure 3. FleetNet gateway

Hot-spot communications. Applications and services relying on Internet access will be optimized for spontaneous connectivity rather than demanding always-on access to the Internet.

Optimization for bulk transfer. For user communications FleetNet will make use of standard protocols of the IP suite optimized for ad-hoc networks with a fast changing topology and rather unreliable connectivity. Since protocols used in the Internet are not to be modified in the first place, FleetNet gateways probably need to perform some type of protocol, or protocol parameter conversion. This includes PDU multiplexing to make the best out of a limited time window when a gateway is in range. The latter is applicable only for the first hop i.e. between gateway and first forwarding node. Furthermore, adaptive receive window size control is needed, in order to behave correctly in case of a network congestion or a temporary link failure.

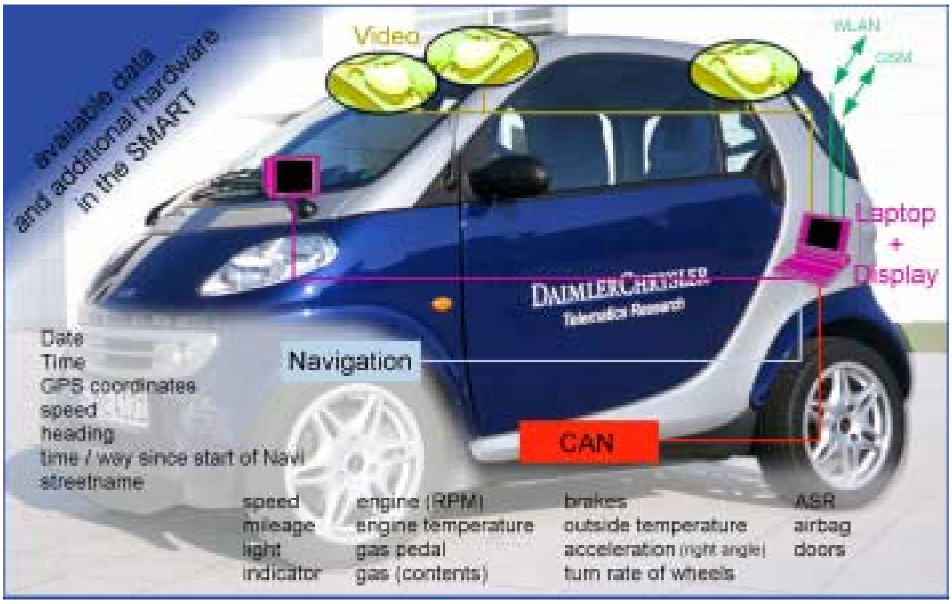

Figure 4. Smart used in the FleetNet testbed.

Agent-based approach. An agent based approach allows for communications with Internet servers that do not tolerate a disruption of active connections or, to a limited degree, for interactive applications such as Web browsing despite the fact that a FleetNet node might be without range of a gateway for quite a long time. In this case, a user or application agent is placed on a gateway when driving by. This agent acts as a user proxy until it is contacted again. When contacted, the agent transfers itself, including any collected data and state information, back to the requesting FleetNet node. In case of interconnected gateways, respectively gateway clusters, this requesting node might very well be a different gateway than the one where the agent has been 'dropped'.

5. Standardization & Testbed

The project results will fall into two categories: standardized ad hoc network protocols and a project demonstrator. Standardization of the protocols is necessary since most of the applications, especially those related to traffic safety and flow, work best when the penetration is high. Therefore, one target is to open the project results to all car manufacturers for standardization.

Second project objective is to prove the concept by field trials. For that, basic features of the developed ad hoc protocols will be implemented and integrated into a fleet of up to ten DaimlerChrysler Smarts. These cars - already in use for trials- are equipped with telematic and computer systems. Figure 4 shows one of the prototype cars and some of the telematic systems already installed. Project partner Temic microsystems GmbH will provide speech recognition systems for the man machine interface.

6. Summary

The project *FleetNet – Internet on the Road* is an innovative German activity undertaken by six companies and several German research institutes. The objectives are to develop an inter-vehicle communication platform for cooperative driver-assistance systems, decentralized floating car data applications, and Internet communication services. Multihop communications between cars and between cars and stationary FleetNet nodes will be provided in an ad hoc network. The project tasks include the specification of protocols for mobile position-aware ad hoc networks. The protocols developed will be implemented on top of existing radio hardware. Several promising candidates have been identified. UTRA-TDD radio hardware originally developped for the UMTS has been selected as first choice. In addition to the standardization of the developed solutions, the prototype implementation to demonstrate proof of concept and to illustrate the benefits of such a system is planned.

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