TOWARD INTERNET–BASED CAR COMMUNICATIONS: ON SOME SYSTEM ARCHITECTURE AND PROTOCOL ASPECTS

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Abstract

Internet–based personal wireless communications to/from cars would greatly enhance driving. New car–specific services and applications could help drivers and passengers to navigate and to obtain relevant information. This paper discusses some aspects for a future Internet system architecture and protocols that are relevant for this scenario. In particular, we bring up some questions and ideas regarding the IP addressing concept and domain name to IP address resolution in such an environment. Moreover, we briefly discuss relevant protocols and mechanisms for IP host autoconfiguration, service discovery, and mobility.

Keywords: Mobile Internet, Internet in the car; IP addressing, IP autoconfiguration, domain name to IP address resolution, service discovery, IP mobility.

1 INTRODUCTION AND MOTIVATION

The Internet has created new ways for personal communication and offers quick and worldwide access to relevant information. Within the last few years, it has dramatically changed the way we live, work, and do business. Today, people use the Internet mainly in the office or at home, but during the next years, with the deployment of new wireless network technologies and new terminals, the Internet will "go mobile." In addition to services known from today's Internet, completely new services and business ideas for a mobile Internet will be developed or are already on the way to start.

In Japan, for example, NTT DoCoMo offers a very successful cellular packet data service, called iMode. IMode subscribers can use several very interesting wireless services: Besides Web browsing (with volume based billing), email, and mobile banking, also several entertainment services are offered, such as network games and fortune telling. In fact, more than eight million Japanese people have become iMode subscribers since its launch in February 1999, and this number is expected to reach 20 million by the end of 2001 (Current numbers can be obtained from *http://www.nttdocomo.com/num.htm.*). In Europe, the recently introduced Wireless Application Protocol (WAP) enables mobile GSM users to access Web–like pages. New wireless services include mobile stock broking, movie reservations, or hotel guides. The next step in the migration from GSM toward a mobile Internet will be the introduction of the General Packet Radio Service (GPRS) [1], which will allow faster and more efficient wireless access to the Internet. From 2001 on, UMTS/IMT–2000 networks will enable true wireless multimedia services.

The convergence of cellular networks and the Internet will make information instantly available anywhere and anytime. Users will have their wireless terminals ready for accessing the Web, reading/writing emails, and doing mobile e–commerce.

Following this trend, Internet–based personal wireless communications to/from cars would greatly enhance driving. New car–specific services could help the driver and passengers to navigate and get informed. Possible new services to be of-

Figure 1: The parking space locator (Source: Cadence, 1998)

fered for drivers include relevant traffic and parking information, which are combined with route guidance systems (see Figure 1). Table 1 shows some more examples how wireless data communications could enhance driving comfort and safety as well as traffic management. In particular, location–based services are of great importance, such as location–aware information services (e.g.: "Where is the closest gas station," "What is this building on the left side?") and location–aware emergency calls. Services for backseat passengers may also include in–vehicle entertainment, such as music and video–on–demand (steaming and MPEG download) and multi–player network games.

2 RESEARCH FIELDS FOR IP–ENABLED CARS

2.1 General Aspects

It still requires considerable R&D and system integration efforts until our vision of Internet–based car communication will become reality. In our opinion, the following technical fields are of great importance for the success of Internet–enabled cars:

- A high–rate, packet–based wireless access technology,
- the IP (Internet Protocol) system architecture and new protocols,
- a very strong security concept,
- innovative services, in particular
  - location–aware services and
  - context–aware services,
- the application platform, and
- the user interface.

This paper focuses on some aspects of a future *IP system architecture and protocols* for the car environment.

2.2 IP system architecture and protocols

In order to enable Internet–based communications with cars, we must bring Internet functionality inside the electronic devices and communications infrastructure of cars. Each device that wants to participate in IP communications must have an IP stack implemented.

It is not a simple task to map the existing IP suite and the Internet architecture to the car environment. Several aspects that are clearly defined in the "classical IP world" are not clear in our scenario. Furthermore, today's IP suite does not yet offer all functionality we wish to have for an IP–enabled car.

Let us give some examples: In the classical Internet, it is assumed that there are administrators who manage the local network. They configure hosts, servers, and resources. In contrast, a car–based network puts heavy constraints on administration. It is not desirable that the user or a garage must have the knowledge to handle the network configuration of the car. Therefore it is an initial aim in our scenario to achieve an autoconfiguration environment.

Furthermore, the hierarchical structure of the Internet determines IP addressing and routing. Local networks are defined by subnets of the Internet, and administrators of those local networks assign IP addresses to hosts. How is this done in a car environment?

Moreover, today's Internet has been designed with the assumption that hosts are stationary. Mobility of IP hosts is not yet supported.

This paper does not aim to discuss solutions to these topics, but intends to bring up some questions and ideas and stimulate further research in this field. It gives references to existing work on these problems and shows in which fields solutions are on the way to come, and in which fields there is more research to do.

In our opinion, the following research topics are of great importance for an IP system architecture for cars:

- A concept for IP host addressing,

Area	Specific Service/Application
Car–related mobility services	- route guidance information - traffic information - parking information
Information	- local news - location weather report - location–based information - secure electronic commerce
Entertainment and infotainment (mainly for backseat passengers)	- audio/video streaming and download - WWW access - interactive multi–player games
Mobile office	- secure e–commerce - Intranet access, corporate database access
Personal communications	- email - voice over IP - video conferencing
Remote control and monitoring	- remote diagnostics - remote software update - emergency calls (with location information) - vehicle fleet management - traffic fleet management - traffic light monitoring - traffic movement measurements - electronic traffic signs

Table 1: Some in–vehicle wireless IP applications

- IP host (auto)configuration,
- domain name to IP address resolution,
- IP service discovery, and
- IP mobility.

In all of these fields, much work is currently under way to develop new protocols. The Internet Engineering Task Force (IETF) has several working groups related to these topics, such as the DHC, SvrLoc, ZeroConf, and Mobile IP working groups.

The general goal of dynamic host configuration (DHC), IP host autoconfiguration, and service discovery (SvrLoc group) is to turn today's static networks into much more flexible networks that require no configuration. The recently formed ZeroConf working group considers IP environments "where administration is impractical or impossible." They also name the automobile as a good example of such a network environment. The goal of this working group is to define requirements for Internet protocols in such a scenario.

The Mobile IP working group has defined a standard for mobility support in IP networks. The IPv4 version of Mobile IP has already been standardized [2], while Mobile IPv6 is a stable Internet draft [3]. Currently, the group works on protocol extensions to address deficiencies and shortcomings. Cellular network providers gained great interest in Mobile IP as one technique for IP mobility in future wireless data services (such as in GPRS and UMTS). The group therefore cooperates with standardization bodies that are trying to adopt and deploy Mobile IP in this context.

Before going into more details, let us sum up this analysis. In order to achieve an Internet architecture that is suitable for the car environment, there are mainly two types of work to do: The first is to develop a system integration concept, i.e., to map the IP system and protocol architecture to the car environment. The second is to actively contribute to ongoing research and development effort in fields in which today's Internet Protocol suite still has major drawbacks.

The remainder of this paper is as follows: First, we discuss the question whether the current Internet Protocol, IPv4, or/and the next generation IP, IPv6, should be the choice for IP–based car communications (Section 3). We continue by bringing up some questions and ideas related to IP host addressing for a car scenario (Section 4.1). In Section 4.2, we briefly discuss IP host autoconfiguration, which is an essential feature to enable "plug and play" functionality. We then ask (Section 5): How could domain name to IP resolution in such networks work, and which problems arise that are not present in the classical Internet? Next, we deal with IP service discovery approaches, which will enable passengers to bring mobile devices into the car and to automatically detect services and devices that are installed within the car network (Section 6). In Section 7, we discuss current research activities on IP mobility support. Finally, Section 8 concludes this paper.

3 IPV4 OR IPV6?

The current version of the Internet Protocol, IPv4, uses addresses that are 32 bits long. In theory, a 32–bit address space would be enough to address over $4 \cdot 10^9$ hosts. Due to the two–level structure of an IP address (IP address = network identifier + host number), however, a much smaller number of IP addresses is available. In the late 1980s it has been realized that there will be a problem if IP usage continues to grow the way it did. The indicated lack of IP addresses has thus been the main motivation for the introduction of a new Internet Protocol, namely IPv6 [4], which uses an upgraded address space of 128 bit. Besides its expanded addressing capabilities, IPv6 also supports:

- addressing flexibility (e.g., multiple addresses on one port, addresses are leased),
- simplified structure of IP packet (e.g., improvements in the IP header: no checksum; extension headers),
- autoconfiguration mechanisms,
- mobility support (Mobile IP),
- security capabilities (IPsec),
- quality of service for real–time applications, and
- utilization of multicast instead of broadcast.

The possibility to have multiple IP addresses per interface in combination with long IPv6 addresses enables improved routing efficiency compared to IPv4. The simplified packet structure is expected to compensate the network bandwidth cost of the longer IPv6 address field. IPv6 also adds new autoconfiguration functionality, namely a "stateless" address autoconfiguration service [5]. Another feature of IPv6 is its mobility support using Mobile IPv6 [3]. Furthermore, IPv6 also has integrated security support, i.e., *all* IPv6 devices support authentication and encryption. Finally, better quality of service support and the use of multicast instead of broadcast (to save network bandwidth) are two more improvements.

Although IPv6 seams to be much more powerful than IPv4, the question whether IPv4 will migrate to IPv6 is still unanswered. The migration costs are very high, for both Internet Service Providers and users. From the provider's point of view, new routers and new servers (e.g., Web servers, E–commerce servers, Domain Name System) with new server software must be installed. Companies must also install new servers and acquire new system configuration and administration knowledge. Another argument against IPv6 is that some IPv6 functionality such as Mobile IP, IPsec, and autoconfiguration protocols (e.g., DHCP (Dynamic Host Configuration Protocol [6])), have now also been developed for IPv4.

A very good argument, however, for the migration from IPv4 to IPv6 results from the convergence of IP and cellular networks. If all mobile phones in future cellular networks must have an IP address, the current IP address space will not be sufficient anymore. The need for more IP addresses becomes even more clear if we think of IP–enabled devices such as PDAs, IP–based radio and television, wearable computers, and last but not least IP–enabled devices inside a car. Another argument for IPv6 in an automobile environment is its built–in autoconfiguration capability without the need for DHCP servers. We will discuss this issue in Section 4.2. Furthermore, IP security is of major importance in a car environment. The main advantage of IPsec in IPv6 compared to IPv4 is that an IPv6 application can assume that IPsec is present on *all* nodes running IPv6, whereas in IPv4 security is only optional. With IPsec, each node can use packets with encrypted payload, and can thus be assure about the correct identity of its corresponding host.

We believe that IPv6 will be needed for IP–enabled cars, mainly because of the fact that there will be too few IPv4 addresses to support many cars with an IP address, and second because of the heavy security constraints in a car environment.

4 IP ADDRESSING CONCEPT AND (AUTO) CONFIGURATION

4.1 IP Host Addressing

The basis for IP–based communication is an IP addressing concept. In the "classical IP world" this concept is quite clear: An IP address can be divided into two parts. A network identifier (or "network prefix") specifies the network at which the host resides. Usually this network is under one administrative control, such as a company or university network. The second part of an IP address is the host number, which specifies a certain interface of a host at this network. The routing of IP packets is in general based on the network identifier part of an IP address and not on the individual host number.

The design of an IP addressing concept for IP–enabled cars poses several questions, such as:

- Which devices inside the car should have an IP address?
- Who assigns the IP addresses? Is there an address pool of one vendor?
- Should we use static or dynamic IP address allocation (see Section 4.2)? Dynamic address allocation in IP is usually done by installing a DHCP server in the network. How is this done in our case? If DHCP is used, who would administer the DHCP server?
- Does one car define one or several IP subnets? Or: Are all cars of one vendor one IP subnet?
- Or: Is IP addressing solved by the wireless access provider? In GPRS, for example, the provider dynamically assigns an IP address to a mobile GPRS station using DHCP [7]. A GPRS network can be regarded as a subnet of the large Internet, and its gateways look like usual IP routers.
- Is Mobile IP used to provide each IP host with two IP addresses (see Section 7), one static address for identification and one dynamically assigned address for mobility?

Since the IP addressing concept has significant impact on IP routing and therefore on the traffic load within the network, it is of major importance to design a good concept.

4.2 IP Host (Auto) Configuration

To keep our vehicular Internet communications architecture flexible and modular, we would like to have the possibility to exchange network–enabled devices without much effort. Ideally, we would like to achieve "plug–and–play" functionality. New devices should automatically configure themselves and obtain all parameters that are necessary to enable IP communications via the car network. Furthermore, it would be favorable if passengers can bring their own mobile devices into the car (see Figure 2).

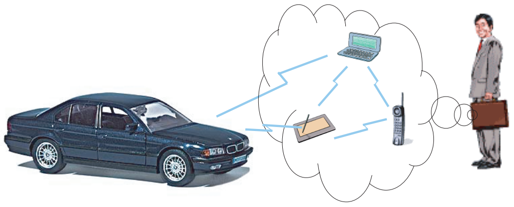

Figure 2: Autoconfiguration enables passengers to connect networked–enabled devices with the car network.

Each device that wants to participate in IP–based communication must be configured with an IP address (and a netmask and default router). This can be achieved in two different ways:

- static (manual) configuration and
- dynamic (auto) configuration.

In the first case, a host gets configured by a system administrator who assigns an available IP address from his/her address space. For dynamic configuration, i.e. autoconfiguration, the Dynamic Host Configuration Protocol (DHCP) has been developed [6]. Using DHCP, an IP host automatically obtains addresses and other configuration parameters from a DHCP server that has been installed in the network and dynamically manages the IP address space. Dynamic autoconfiguration using DHCP is called stateful autoconfiguration. Stateful autoconfiguration is also possible in IPv6 (using DHCPv6 [8]), but IPv6 also defines a more powerful autoconfiguration method, called stateless autoconfiguration [5].

Stateless autoconfiguration does not require a manually configured server but enables IPv6 hosts to configure their own addresses with the help of a local IPv6 router. Typically, the node combines its MAC address with a network prefix, which it learns from a neighboring router. In this way, every IPv6 device can create an IPv6 address that is globally unique. Note that there has also work been done to define a concept by which IPv4 hosts can automatically generate IP addresses that are valid on the local link (but not globally), without the need for a DHCP server [9].

For a car environment stateless autoconfiguration methods seem to be much easier deployable than administering DHCP servers.

5 DOMAIN NAME TO IP ADDRESS RESOLUTION

Many applications are only aware of domain names and not IP addresses. In the "conventional Internet" the mapping of domain names to IP addresses (and vice versa) is stored in a distributed database, called Domain Name System (DNS).

The IETF ZeroConf group is currently working on requirements for domain name to IP address resolution in autoconfiguration environments. They defined two types of domain names for such networks: fully qualified names and non–fully qualified names. The first type is a domain name that is globally unique. The second type is limited to a single autoconfiguration network, such as a single car or a network of cars. A DNS protocol for such networks must have the ability for a host to choose a name that is not already in use. The protocol must also become active when previously disconnected networks become connected [10]. The working group just started to write down the requirements for such a protocol, and it seams that there is still a lot of research work to do.

Moreover, the use of domain names in a car environment poses the following questions:

- Which IP devices in the car need a domain name?
- How is the structure of such a name? (For example: `radio.M-TU-206.bmw.de`)
- Do we need globally valid domain names, or are local valid names sufficient?

6 SERVICE DISCOVERY

In Section 4.2, we brought up the idea that passengers could bring their mobile devices into the car and connect them to the car network. These devices could use equipment and services that are installed inside the car. For example, in a "mobile office car" there would be a fax machine, a printer, a hard disc, and a color display. What is needed is a functionality that enables mobile devices to discover and use these services.

This task is addressed by newly emerging service discovery protocols, such as SLP (Service Location Protocol [11]), Jini [12], UPnP (Universal Plug and Play [13]), and Salutation [14]. In a service discovery environment, services advertise themselves, supplying details about their capabilities and information one must know to access the service (e.g., the IP address). Devices may locate a service by its service type (e.g., "I am searching for a printer") and may make an intelligent selection in case multiple services of the desired type are available (e.g., black/white laser printer, color ink printer, and photo printer).

Service discovery in a car environment would simplify the task of maintaining and updating the car network, especially introducing new services and new devices.

In [15] we treat this topic in much more detail. In particular, we compare several service discovery protocols currently under development and present our SLP beta implementation.

7 IP MOBILITY

Today's version of the Internet Protocol does not support any mobility of stations. This is because an IP address identifies the network on which the station resides (through its network prefix). If a station moves to a different network without changing its IP address, there is no information in its IP address about the new point of attachment. Existing IP routing protocols are therefore not able to deliver packets to the mobile station correctly, but always route them to its home link.

There is great effort under way in the IP research community to enhance the IP protocol suite with concepts that enable mobility.

The IETF has developed Mobile IP, which enables an IP station to roam in the Internet while still maintaining transport–layer connectivity. Mobile IPv4 has been standardized in [2], and Mobile IPv6 is currently an Internet draft [3]; it will be integrated into the standard IPv6 stack.

The basic functionality of Mobile IP is as follows: A station is always identified by its home address, regardless of its current point of attachment to the Internet. This address is the IP address that has been assigned to the station on its home network. When the station is away from its home network and attaches to a foreign network, it obtains a so–called care–of address. This is an additional temporary IP address that has the same network prefix as the visited foreign network and therefore provides information about the current location (the current network) of the mobile station. The mobile station registers its current care–of address at its home agent on its home network. The home agent stores the information about the current care–of address of the mobile station and acts as a proxy for the mobile station.

As usual, IP packets addressed to the home address of the mobile station are routed to its home network. When the station is away from home, the home agent intercepts these packets and transparently forwards them to the current location of the mobile station.

The exact role of IP mobility management in future mobile networks is still not quite clear, since cellular networks already offer inherent mobility management with central databases (home location register HLR and visited location register VLR) and handover mechanisms. Mobile IP is a "macro mobility" solution that is scalable globally, but it lacks support for fast handover control and real–time location tracking. On the other hand, cellular networks do not offer mobility support in the IP layer. IP addresses are assigned dynamically on an on–demand basis from an address pool. Thus, each mobile station keeps its IP address for at most one session (e.g., as proposed in the GPRS standard [7]). This results in two main drawbacks: First, IP packets will always be routed from the Internet to the gateway from which the mobile host obtained its IP address and not necessarily to its closest gateway. Second, there is no IP address for identification (as the home address in Mobile IP).

Combined GPRS/UMTS and IP mobility management is currently an important research issue (see, e.g., the 3GPP (3rd Generation Partnership Project) document [16]). This topic poses several questions such as protocol interworking, network architecture design, security, and evolution from GPRS. There is also some ongoing research about the interoperation of Mobile IP with other IP protocols (see, e.g., our work in [17]).

Recently, additional approaches for IP mobility have emerged. Cellular IP [18] intends to provide local mobility ("micro mobility") and handover support. It is based on some cellular system design principles, such as the storage of location information in distributed databases. The second new approach, called HAWAII [19], is a "micro mobility" solution as well. Both protocols interwork with Mobile IP to provide wide area mobility support.

8 CONCLUSIONS AND FURTHER WORK

Let us conclude this paper with a guideline for our future activities in this field. Our goal is to build an Internet–enabled car. We discussed some aspects for a future Internet system architecture and protocols that are relevant for this scenario. We listed our requirements such as autoconfiguration, service discovery, and IP mobility. In particular, we brought up some problems about an IP addressing concept and domain name to IP address resolution in such an environment.

IP host addressing concept This area is quite essential for the design of an IP architecture for cars. One of the first tasks will be to develop an IP addressing concept for a vendor's car community.

IP host autoconfiguration We must decide which configuration should be supported. Static (manual) configuration is not desirable. Using stateful auto configuration (e.g., DHCP), we must design a system architecture for this (e.g.: Where are the DHCP servers? Who administers them?). Stateless autoconfiguration seams to be much easier to implement, since it is included in IPv6.

Domain name to IP address resolution The IETF ZeroConf working groups is currently defining the requirements for domain name to IP address resolution for general autoconfiguration networks. We should adopt these results for the car environment. Questions to be answered at the beginning are: Which IP devices in the car need a domain name, and how is the structure of such a name? Who manages the domain name server for the car devices? Do we need globally valid domain names?

Service discovery There are several service discovery protocols and products. Which of these protocols is best suited for our environment? Most probably not only one but several service discovery protocols will exist in future terminals — how can we support various discovery mechanisms? Will there be bridges and harmonization between different approaches? Do we need an architecture that is built on a directory service, e.g., the directory agent in SLP, or do we need a peer–to–peer service discovery method?

The IETF approach SLP is a very promising candidate for our environment. It has a flexible and scalable architecture that allows service discovery by storing all services in a directory but works without a directory as well. Thus, SLP can be employed in various environments, ranging from small up to large enterprise networks. Furthermore, its service template concept [20] opens the way to standardize car–specific services.

IP mobility A lot of work still needs to be done in the IP mobility field as well. Current research topics include protocol refinement of Cellular IP, performance issues in general, and combined cellular and IP mobility management. In addition, more prototype implementations of the presented protocols are needed to test their functionality in practice. Furthermore, the system architecture related to the car environment is not clear yet (For example, who will provide the home agent? Who will assign addresses?). Or: Will IP mobility support be included in future cellular networks and will thus be transparent to our car network?

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