CONNECTING AUTOMOBILES TO THE INTERNET

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***Abstract*— In order to meet the requirements of the ITS applications, vehicles must be connected to the Internet, permanently, without disruption of service. The networking means to achieve this must be based on the TCP/IP protocol suite since it governs communications in the Internet. After detailing the functional networking needs of ITS applications, we evaluate how this could be achieved using TCP/IP. We advocate that IPv6 must be deployed everywhere, i.e. every in-vehicle communication device should be IPv6-compliant. We also advocate that an entire IPv6 network is likely to be deployed within vehicles, which is seen as a mobile network from the IP's perspective. This raises a number of issues which are currently being investigated at the Internet Engineering Task Force (IETF), the organization in charge of the standardization of the TCP/IP protocols. We therefrom outline ongoing IETF work of prior interest to meet the ITS networking needs. A new IETF working group (NEMO) is indeed very likely to be set up to tackle most of the specific network mobility issues for distinct cases of mobile network, particularly those found in vehicles such as trains, aircrafts, or automobiles. We therefore recommend the ITS community to monitor and to participate in this work in order to make sure ITS requirements are well taken into consideration by the IETF community so that the ITS community could benefit from this work.**

I. INTRODUCTION

The Internet is a collection of networks and is most known from the public as a medium for exchanging digital information. It allows to transfer various kind of information between any two computers in the world in the quickest and most efficient manner provided computers are connected to the network. With recent advances in computer miniaturization and wireless technology, and the thereafter declining manufacturing costs of devices, there is a tremendous need to connect anything to the Internet (not only computers) from a simple fridge to Internet devices per se such as a PDA, a laptop or more popularly, cellular phones. Automobiles, and all intelligent devices embedded in them, are no exception to this trend. Connecting automobiles to the Internet allows to achieve ubiquitous computing as desired from people: whether at office, home, in the street, or while displacing between those places with their car, people wish to be continuously connected to the Internet. Reasons range from professional to leisure. More and more people see their car as a workplace (not only people who actually work in their vehicle like taxi or lorry drivers) or as an annex of their house while on the move. This includes consulting emails, playing games, browsing the web, but also watching TV and listening to radio when those media become digital and get conveyed on the Internet.

On another hand, some governments or ITS organizations, such as the Japan government or the European ERTICO [7] have already published a number of documents with the intend to embed automobiles with information technology and communication features. This includes documents that define a system architecture for ITS applications [10],[6]. Some of the numerous applications need telecommunications (which is usually referred to as *telematics*) while other need Internet communications. Telematics does not seek to meet the ubiquitous computing wish of customers. It indeed faces two kind of expectations, one from the automobile industry, and one from the information technology industry. From the automobile industry, telematics is expected to improve the functions of vehicles, like driving assistance, traffic jam prevention, etc. From the information technology industry, telematics is expected to help connect all appliances which support our life in order to offer augmented reality.

In order to achieve telematics and ubiquitous computing, this paper demonstrates what are the ITS needs in terms of networking capabilities, and what are the protocol requirements. The ITS community is currently defining standards for this but there are similar efforts conducted by the Internet Engineering Task Force (IETF), the organization in charge of standardization of the protocols that govern Internet communications. ITS needs in term of networking span a large number of IETF working groups that range from the working group specifying the base protocol, i.e. IPv6, to working groups dealing with mobility support, access control, and security. However, there seems to be a lack of communication between the community in charge of defining ITS requirements, and the community in charge of specifying standards for communications in the Internet. The purpose of this paper is thus to provide insight to the ITS community in order to share a common understanding of the ITS requirements and IETF means to achieve them in terms of standardization.

The structure of this paper is as follows. In section II we describe the Internet and we outline the TCP/IP protocol suite on which the Internet relies on to connect computers to one another. In section III, we demonstrate that networking is a major issue for ITS and in section IV we give our point of view on the desired network architecture for connecting automobiles to the Internet. In section V, we outline the organization of the IETF and then we describe activities that we think are particularly relevant to ITS networking needs outlined in the precedent sections. This section will focus on the mobility aspects and particularly on NEMO, a new working group under the process of creation. NEMO is of prior interest for ITS as it considers mobility within the Internet topology of entire networks such as these deployed in vehicles. NEMO will be detailed less briefly than other IETF activities since it is a relatively new activity for which not much information may be available yet. Following this, we will have a word about existing studies conducted by the Internet community and aiming at connecting vehicles to the Internet. Finally, we conclude this paper with a number of recommendations to the ITS community.

II. Internet and TCP/IP

A. The Internet

The Internet is a collection of heterogeneous networks hierarchically organized and running under distinct administrative policies. Typically, the Internet is partitioned into different administrative *domains*. A domain shall usually correspond to a large organization operating an internal corporate network or an Internet Service Provider (ISP) (e.g. UUNET, MCI, Wanadoo, AOL). A domain is simply speaking a *network* made of *nodes* and *links*. The Internet terminology distinguishes two kinds of nodes: a *router* is a node that forwards packets not explicitly addressed to itself, whereas a *host* is any node that is not a router. Nodes connected on the same communication link form a *subnetwork* (typically, an Ethernet link, or a *802.11b WLAN*). Subnetworks are interconnected by means of routers. The node that initiates or terminates the transmission of a packet is referred to as the *end-node*, i.e. the source or the destination of the packet.

B. The TCP/IP reference model

Internetworking is performed by the TCP/IP reference model which defines the protocol suite used for data exchange between nodes in the Internet. TCP/IP is a *packet-switched* technology. Unlike *circuit-switched* technologies like telephone networks, TCP/IP relies on the *connectionless* concept: routers cooperate to determine the path toward the destination and carry packets between the two end-nodes. The forwarding decision called *routing* is made on a per-packet basis. The intelligence is put at the edge of the network (i.e. end-nodes), whereas the purpose of the network infrastructure is only to provide internetworking. This allows an easy deployment of new functionalities without need to upgrade the network infrastructure. As a result from this, the Internet is not specific network-technology-dependent, allowing a global network of unlimited scope and reach. This has largely accounted for its success.

TCP/IP is very similar to the OSI *reference model*, but does not map well into the seven layers as defined by ISO. It has fewer layers than its OSI counterpart as the use of intermediate abstraction layers between the *transport layer* and the *application layer* was not perceived. As its name stands for, it is named after its two main protocols, Transport Control Protocol (TCP) [29] and Internet Protocol (IP) [12], [28]. IP corresponds to OSI's network layer. Its role is to interconnect all the subnetworks so that any two nodes can communicate with each other. It defines a number of rules, a packet header format, and an addressing scheme which aims at identifying nodes and determining their position in the network hierarchy. It is assisted by a number of other protocols like routing protocols that determine the path a packet has to take between the source and the destination. There presently exists two versions of IP, the getting old IPv4, and the new generation IPv6 [12]. IPv6 is meant to replace IPv4 and to address its shortcomings. IPv6 has built-in features that allow to support the new services requested by recent applications. This includes embedded security and support for mobility, extension headers to specify additional information, native multicast, provisions for traffic reservation, etc. IPv6 also offers a generous number of addresses compared to IPv4. IPv6 addresses are 128-bits large. In theory, this would allow to allocate an address to billions of nodes on every square meter on Earth. In practice, it is much less due to allocation rules but still enough to embed an IPv6 stack in every computer, camera, phone, watch, sensor, etc, ever produced on Earth. For the novice reader, we advice [20], [26].

III. ITS Functional Networking Needs

Automobiles are globally distributed objects that are providing mobile and ubiquitous environment for human activities. The conventional technologies have been providing information toward people in a car via signboards, radio system, mobile phones and more sophisticated technologies relating to the automobile communication. The Internet technologies can integrate these systems into a general digital communication infrastructure. Once automobiles are connected to the Internet, sensors deployed in vehicles can provide valuable information. Automobiles on the Internet are not only for people accessing information from the Internet, but also for people on the Internet to monitor automobiles and to access to various environmental information generated from the in-vehicle sensors. In order to achieve the expectations of both the automobile and the information technology industries, we need the following networking features [32]:

a) In-vehicle communication system: Next generation vehicles produced by car manufacturers will embed a wide range of computers. Those computers need to be interconnected in order to exchange various types of information. This means a communication medium must be deployed in the car. Basically, there may be more than one communication medium, because applications have different needs. Some are more critical than the other, thus their communication medium may be isolated one from the other for security or efficiency reasons. For instance, driving assistance data has real-time and no-fault requirements essential to prevent accidents whereas electric windows control data has no trouble to suffer from higher delays.

b) Permanent Internet access: An access to the Internet is required by a number of applications. Among them, multimedia and navigation system applications are able to cope with a disruption of connectivity, but other applications are more sensitive. The Internet access must be *permanent* without disruption of service.

c) Wireless Communication and fast handovers: As automobiles move, the communication system necessarily has to deal with wireless communications and with handovers from one access point to another. Because automobiles move rapidly, the system may have to cope with fast handovers, depending on the radio or infrared communication range. We note that movements are usually not predictable for automobiles, unless driving on a highway. It is then very hard to predict when it could occur.

d) Vertical Handover: In order to achieve a permanent access to the Internet, one cannot assume only one medium of communication. *Multiple access* to the Internet is needed, not only as a backup to prevent one system's failure, but also because a single system cannot be deployed everywhere for various reasons ranging from financial to politics such as local arrangements in national park, universities campus, and lack of presence of a provider in some areas. For instance, IEEE 802.11b access may be offered on heavily frequented roads such as highways, Bluetooth access in parking lots, Personal Handy-Phone System access in cities, and Personal Digital Cellular access in less urbanized areas and also as an overlay network.

e) Scalability and flexibility: The system must be able to support a few billion vehicles. There are about 700 millions automobiles currently in the word. Their lifetime is turning around 10 years, which means the system architecture must be flexible enough to accommodate with technology progress, i.e. to extend the vehicle with new devices and new communication medias

IV. ITS TCP/IP REQUIREMENTS

In section III, we have advocated the need to connect automobiles to the Internet and the need to interconnect in-vehicle devices. The architecture currently being investigated by ISO TC204 (transport information and control systems) WG16 (wide area communications/protocols and interfaces) attempts to specify a number of networking mechanisms to allow in-vehicle devices to communicate. ISO is defining CAN (Control Area Network), a network devoted for both conveying sensitive control data (driving and transportation systems) and data controlling electronic devices (window, etc). It is specified as ISO 11898 (High-speed network)[2],[4] and ISO 11519-2 (Low-speed network)[3]. Another work, MOST (Media Oriented System Transport) aims at conveying multimedia in automobiles[5] and is being standardized by the MOST Cooperation, an organization run by more than 60 automobile related manufacturers.

None of CAN and MOST is based on TCP/IP although TCP/IP offers a versatile and complete networking stack and has proved its benefit over the years. We argue that specifying new networking standards is only desirable at places where the TCP/IP model is unable to fulfill the needs of ITS. There are probably missing features in the TCP/IP model, but this does not mean it cannot be enhanced. At first, needs must be specified, and thereafter TCP/IP's ability to meet those should be evaluated and therefrom requirements specified to the IETF community. In the following sections, we thus examine why ITS needs TCP/IP and how it could fit into the TCP/IP protocol suite.

A. IP Everywhere

This may not be put to light enough, but IP offers the tremendous advantage, once TCP/IP is widely deployed in vehicles, to bring any IP device out of the shop and plug it in a car or anywhere else. This includes devices not designed for ITS and sold in common stores. On the other hand, a communication architecture not based on TCP/IP and targeted to ITS would prevent from deploying existing IP devices into automobiles. This means devices that have not been designed for ITS could not be embedded in vehicles, or cannot be connected to the in-vehicle communication medium. This includes for instance sensors that would have been developed by companies selling fridges, wireless devices developed by telecommunication manufacturers, and so on. This also prevents existing Internet applications to be brought to ITS and requires to design applications for ITS specifically. This also questions how devices (e.g. a laptop) that don't have their own or an efficient Internet connectivity could get access to the Internet while brought in the car.

Using an open and versatile international standard such as TCP/IP allows for a lot of flexibility as devices could be interexchanged and replaced at will by the car owner. This is a particularly important advantage given the lifetime of vehicles and the tremendous growth of the electronic technology. Also, producing and selling IP devices enhances flexibility for both car manufacturers and customers, diminishes costs, and facilitates innovation.

To conclude, we argue that a TCP/IP-based communication system should be used whenever possible. When not possible, a TCP/IP architecture should nevertheless be deployed in parallel with whatever other architecture, at least for multimedia applications and for connecting IP devices to the Internet through the vehicle.

B. IPv4 vs IPv6

Given the fact that the number of cars is expected to reach 700 millions in the world, and that each car may contain tens of IP devices, the car industry needs a large number of IP addresses. Also, the ability to carry real-time traffic advocates for Quality-of-Service and security, while mobility of the vehicles implies mobility support. In order to carry critical information, the system must be secured. By secure we mean that the system cannot be corrupted by a third party other than the system administrator of the vehicle or the access network where the vehicle connects.

All those reasons means that the emerging IPv6 must be preferred over the aging IPv4. Not to say, new technologies should implement IPv6 natively because it will avoid the transition from IPv4 to IPv6. We advocate that it's not very wise to deploy and bring new functionalities to a protocol that has exhibited its limits. ITS applications have stronger needs that cannot be fulfilled by IPv4, and IPv6 needs new applications that will ease the shift from IPv4 to IPv6. It's time now to focus the effort on IPv6 and to bring to IPv6 the applications it deserves.

C. Network Mobility

In-vehicle devices implementing a TCP/IP stack are connected to one another by means of one or more subnetworks.

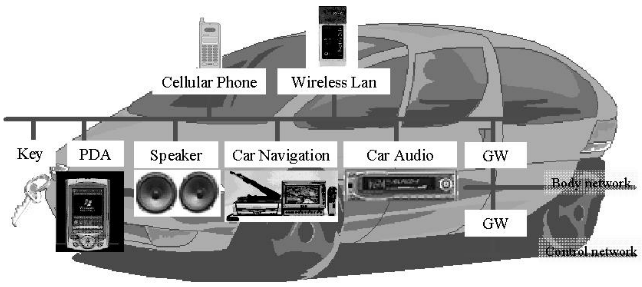

Fig. 1. InternetCAR: in-vehicle embedded network

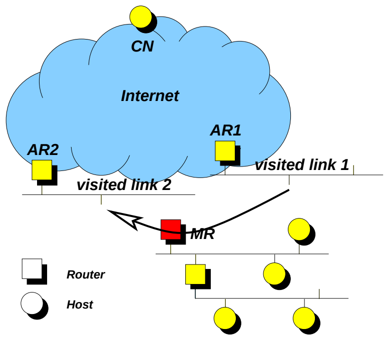

Fig. 2. Network Mobility

From the TCP/IP's perspective, we have a network deployed in a vehicle, something like what we usually refer to as a Local Area Network (LAN). This network is connected to the global Internet via one or more communication medium. The overall picture is somewhat illustrated on fig.1 which shows an in-vehicle network, composed by 3 distinct subnetworks, and multiple access technologies to the Internet, as investigated in the InternetCAR project[8],[33] (see section VI).

The gateway where the in-vehicle network gets connected to the Internet is usually referred to as a point of attachment, or an access router (AR). Because we want to guarantee a permanent connection to the Internet regardless of its location and speed, we have several of such mediums, connected to distinct ISPs, thus the in-vehicle network is *multihomed*.

Since the vehicle is moving, the in-vehicle network is changing its point of attachment to the Internet. We therefore have what we call a *mobile network* and the routers connecting the mobile network to the global Internet via the AR are mobile routers (MRs). This is illustrated on fig.2 where we show a mobile network moving between two ARs. The cloud represents the Internet and CN a correspondent node that may be communicating with a node in the mobile network.

The problem we have with this is that each time the network changes its point of attachment we loose active connections between the CN and nodes in the vehicle. In the Internet, each node has an IP address which reflects its topological location in the network. There is typically a change of this IP address each time the node changes its point of attachment. This results in losing packets in transit and breaking transport protocols connections if no specific services are added to handle mobility, what is usually referred to as *mobility support*. Mobility support is therefore to give the ability to cross networks in the midst of data transfers without breaking the communication session and without increasing the network load and delays.

V. How the IETF can help

A. Overview of the IETF

The TCP/IP protocol suite is specified by the IETF [1], a large open international community. There is no formal membership. Members include people with different background (network designers, operators, vendors, and researchers) and meetings are held three times in a year. Work in progress documents and standard specifications are available on the web site free of charge.

The actual technical work of the IETF is done in its working groups, which are organized by topic into several areas managed by the IESG (Internet Engineering Steering Group). A new working group may be created at anytime when enough people are gathering together to work on a given problem, pending definition of a charter and its approval by the IESG. To assess interest in forming a new working group, a first meeting (called a BOF) usually takes place. A few BOFs are held at each meeting, only a few actually leading to a working group, usually because the problem is not well understood, not mature enough for standardization (i.e. too research-oriented), or simply because a single meeting was enough to bring the answer. The working group charter is defined by the initial group members and approved by the IESG. It could then be appended whenever a need arises. There is no explicit lifetime for a working group; it could range from a sole meeting to a few years. It closes when the problem expressed by the charter has found its ultimate solution.

The output of working groups are Request for Comments (RFCs), which range from informational to standard specifications. The full standard stack is explained in RFC 2026. Much of the work is handled via mailing lists and work in progress is conducted by means of internet-drafts, i.e. draft documents that could either be work in progress from the working group or from individuals. Internet-drafts range from beta version of a specification before it becomes a RFC to less technical contributions which could simply express someone's point of view on a particular problem or solution to address the problem. It is thus easy for anyone to submit ideas and questions by means of an internet-draft, or a simple email.

The philosophy behind the IETF is *running code* and *rough consensus* meaning a standard is actually filed when at least a few implementations have been reported. The IETF is usually not specifying how to implement a protocol under some particular architecture, but only the flow of information and packet formats of the protocol.

B. Activities relevant to ITS networking needs

The base protocol of IPv6 is specified in the IPv6 working group. Specifications are on the standard track and have been filed for a long time already. This includes the specification of IPv6 itself [12], the addressing architecture [18] and the address format actually in use [19] and numerous other specifications.

However, the base protocol of IPv6 doesn't provide for mobility support. The MobileIP working group is discussing this issue and should publish the Mobile IPv6 [22] specification this year. Mobile IPv6 solves the question of mobility without changing the mobile node's IP address. It introduces *two-tier addressing* as the solution to the addressing problem depicted in section IV. *Two-tier addressing* associates a mobile node with two distinct addresses, a permanent home address in the initial subnetwork, and a temporary careof address in the currently visited subnetwork. An address translation mechanism offers migration transparency and prevents disruption of the connections.

Despite this work, there is currently no means to provide continuous Internet access to nodes located in a mobile network. Mobile IPv6 provides continuous connectivity for a single computer only, i.e. *host mobility support*, but not *network mobility support*. Indeed, the question of networks that frequently change their point of attachment in the Internet had rarely gained the deserved attention from the IETF until recently. The first version of internet-draft [17] was submitted to the Mobile IP working group and presented at the 48th IETF meeting, July 2000, as an effort to highlight Mobile IPv6 shortcomings in face of network mobility. It demonstrated that Mobile IPv6 is unable to keep open the connections between a CN in the fixed Internet and nodes behind the MR.

This work served as a basis to launch the discussion on this topic on a separate mailing list and was followed by a number of internet-drafts [16], [15], [14], [30], [25], [24] submitted as an attempt to clarify the difference between *host mobility* and *network mobility* and to exhibit some of the new challenging issues. This led to propose NEMO (*NEtwork MObility*) [11] as a new IETF working group specifically chartered to address network mobility. A BOF then took place to assess interest in forming a new group. The charter is currently under review of the IESG and NEMO should become a working group very soon. Minutes, presentation slides, the charter and internet-drafts can all be found on the NEMO web page [11].

As specified in the proposed NEMO charter, the purpose of *network mobility support* is to provide a continuous network access to all nodes located in a *mobile network* without disruption of sessions after displacement of the mobile network from an AR to another. NEMO also aims at routing packets from and to *mobile networks* optimally, efficiently, and transparently to upper layer protocols although this might cause a change of the IP address at the network layer. Other topics such as fast handoffs, multihoming, security, access control, scalability, and nested mobility will be considered by NEMO solutions. Nested mobility arises when the mobile network is used as an access network to other mobile devices like mobile phones, or even Personal Area Networks (PANs), which are themselves small mobile networks made of a number of devices (phone, digital camera, PDA) carried by humans.

The kind of applications concerned by *network mobility support* are mobile networks that may be deployed in the near future and for which there already exists a tremendous need. Those particularly include PANs, sensors networks deployed in vehicles, and public transportation vehicles that are willing to provide Internet access to their passengers, like trains, aircrafts, cars, buses. There is already a number of propositions, all based on Mobile IPv6, which attempt to support mobile networks [17], [23], [31]. Much of the initial work submitted to the IETF and other discussions can be found in [13].

There is a number of other working groups of particular interest to ITS and related to mobility or other matters. For instance, fast handover capabilities are discussed within the Seamoby working group; the Pilc working group is discussing performance of wireless communications and the IPsec working group is proposing means to provide network security by embedding security into the IP layer. As we see, most of the needs outlined in section III are indeed considered by existing or forthcoming working groups.

C. Missing pieces

The IETF can help to specify protocols related to Internet communications. However, as already mentioned, the IETF specifies protocols without particular scenarios in mind, not their use. When protocols are used for automobiles, address assignment procedures, access control methods, autoconfiguration mechanisms and so on, must also be specified, but by the community intending to use the protocols. However, some issues or missing pieces in the IETF protocols should better be discussed in cooperation between the automobile industry and the IETF community.

VI. Related work

Some studies that aim at connecting automobiles to the Internet have already been achieved by the Internet community. This includes the InternetCAR Project [8], [33]. This study investigates three different types of IPv6 models to connect vehicles to the Internet. In the single computer model, each computer has a direct access to the Internet. In the single router model, a number of in-vehicle computers are interconnected on a IPv6 subnetwork. Only one router has direct access to the Internet. A passenger can bring a laptop and connect it to the Internet via the router. In the multiple routers model, we assume more than one router with direct access to the Internet and one or more in-vehicle IPv6 subnetwork.

In the first quarter of 2002, the single computer model and the single router model were tested under the InternetITS Project [9], a large scale ITS trial in Japan. The single computer model was implemented based on Mobile IPv6 with two communication medium, a cellular phone and a Dedicated Short-Range Communication (DSRC). In this implementation, the in-vehicle-computer automatically switches the medium with regard to the DSRC communication area. When the automobile goes under the DSRC service area, it switches the active media to DSRC. Internet connection is ensured by a cellular phone outside the DSRC service area. The single router model was implemented based on Mobile IPv6 with NEMO extensions proposed in [17]. Only one prototype car was concerned in the testing. The prototype car had twelve computers connected to the IPv6 in-vehicle network.

Also worth to be mentioned, the work conducted at CMU [27], which tested inter-vehicle communications between five automobiles with the DSR[21] ad-hoc routing protocol.

As both studies show, there is on-going research and actual implementations of solutions needed by ITS applications. There is of course much more work to be done, but those studies are a good starting point to initiate collaboration between the ITS and the Internet communities.

VII. Conclusion

In this paper, we have reviewed ITS needs in terms of networking. An *in-vehicle communication system* and a *permanent and uninterrupted connectivity to the Internet* are absolutely required. We advocated the deployment of IPv6 for both communications between vehicles and the Internet and for internal communications within the vehicles. Most of the needs and requirements outlined in section III and IV are indeed considered by existing or forthcoming working groups. This includes NEMO, a new working group under the process of creation, which addresses issues related to mobility of networks like those deployed in vehicles. We therefore recommend the ITS community to monitor current IETF activities and specify their requirements to the IETF so that it is made sure the IETF knows about them before forthcoming standards are filed. Missing requirements must be claimed without waiting. If additional internetworking protocols are needed, it could only be specified by the IETF whereas the operation of those protocols with respect to ITS must still be specified by the ITS community.

We also observe that what the ITS community would like to achieve is not much different from what train companies or airlines companies would also like to achieve. Trains and aircrafts should be connected to the Internet by the same fashion as cars. By designing a model specifically targeted to ITS while ignoring other similar work would result in a duplication of effort, waste of time, waste of flexibility, and waste of money.

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