Mobile Internet Access in FleetNet

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Abstract. Inter-vehicle communication systems play an important role in future road communication scenarios like FleetNet. For such communication scenarios, ad hoc networks offer a promising approach due to their characteristics such as low latency and cost efficiency. While multi-hop ad hoc network communication among vehicles provides for many interesting and important applications (e.g., traveling safety, smoothed traffic flow), users also will be interested in accessing Internet services. This access can be achieved via roadside installed Internet gateways. However, the Internet integration of inter-vehicle communication systems entails several difficulties, such as mobility support, communication efficiency, or the discovery and handover of connections from one gateway to the next. In this paper, we propose a communication architecture that addresses these issues. Our communication architecture combines a proxy-based approach with Mobile IP. Additionally, the architecture integrates the passengers' mobile devices used within the vehicles, i.e. they are able to access the Internet using the inter-vehicle communication system.

1 Introduction

Future developments in the automobile domain are not limited to the field of automotive engineering. They also include the utilization of communication technologies focused on increasing automotive safety, providing passengers with information and entertainment, and achieving smooth traffic flow on the roads. In such a scenario, guaranteed delays and low communication costs play an important role. Hence, direct communication via inter-vehicle communication (IVC) systems presents one, probably even the most promising solution. Such systems base on radio ad hoc networks, i.e. they operate with no pre-installed infrastructure. This concept also comprises roadside installed gateways connected to the Internet. They provide the tunneling of data in case the communication distance between two cars is too large to send the data even over multiple radio hops. Moreover, the gateways enable the access to Internet services from vehicular IP-based applications, which opens up various types of new applications for the vehicular environment.

In this paper, the provisioning of Internet access for vehicles in ad hoc IVC networks is called *Internet integration*. Compared to the communication characteristics in fixed IP-based networks, future IVC system architectures will differ in many aspects. Examples of the issues to be addressed are the nodes' addressing and mobility, available bandwidth, and the temporary availability of Internet access. Besides accessing Internet services from the vehicles, the system architecture has to support the opposite direction of accessing services within the vehicles from Internet hosts. In order to face those challenges, we developed a communication architecture called MOCCA (MObile CommuniCation Architecture), an efficient Internet integration approach for future ad hoc IVC systems.

Before the architecture of MOCCA is described in section 3, section 2 gives an overview of communications in FleetNet. Section 4 covers the three essential aspects of MOCCA: mobility support, service discovery, and support of IP-based applications. Finally, section 5 concludes the paper and gives an outlook on future work for the Internet integration in the FleetNet project.

2 FleetNet: An Example for Future Road Communications

In 2000, the project "FleetNet – Internet on the Road" [1] was set up to promote the development of an inter-vehicle communication system. FleetNet aims at the development and demonstration of a wireless ad hoc network for inter-vehicle communications. Key design factors for FleetNet are the capability to distribute locally relevant data and to satisfy the needs of car drivers and passengers for location-dependent information and services. Potential applications comprise a broad range of safety increasing applications, but also infotainment services for the convenience of cars' passengers. Safety related applications are commonly time sensitive and therefore not implemented on an IP-based communication system. However, infotainment applications will likely use IP protocols.

Communications in future road scenarios like FleetNet will be different from current communication systems. Fig. 1 illustrates such a future road scenario, which generally includes both vehicle-to-vehicle and vehicle-to-infrastructure communications via so-called Internet gateways (IGWs). For inter-vehicle communications in FleetNet, ad hoc communication protocols for routing and forwarding of data are developed. Since many of the applications supported by the FleetNet communication system address the destinations not by Internet addresses but by the area in which the vehicles stay, position data plays an important role. Hence, the selected routing scheme forwards data packets based on the geographical addressing. As a result, vehicles will be able to communicate locally in decentralized ad hoc networks. Those networks not only allow the exchange of local information directly between adjacent vehicles within transmission range (single hop). Where applicable, data will be forwarded over several hops (multi hop) if a vehicle's communication partner is not in the immediate transmission range. For example, in Fig. 1 vehicle V_c communicates with vehicle V_b using V_a as a relaying station. A description of the routing aspects in FleetNet can be found in [2].

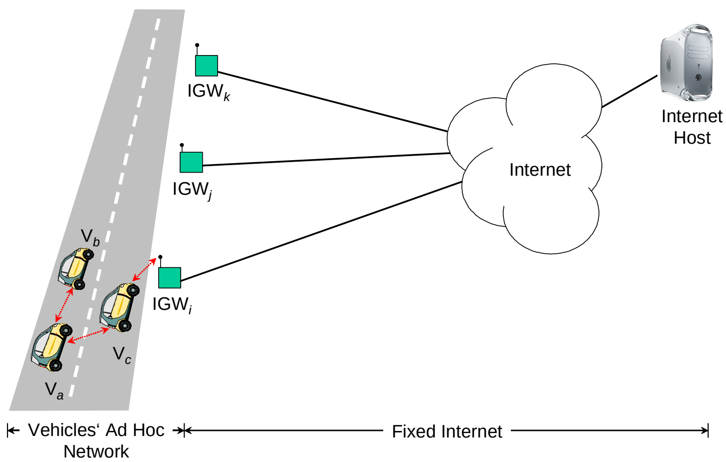

Fig. 1. Future Road Scenario

The Internet integration plays an important role in FleetNet. So-called Internet gateways (IGWs in Fig. 1) will provide access to the Internet from the vehicles by using the ad hoc network to connect the gateways to the vehicles. Since on the ad hoc network side the same communication system is employed as installed in the vehicles, the Internet gateways can be regarded as FleetNet radio nodes. In contrast to the vehicles, the gateways have a second network interface which connects them to the Internet. In combination with the position-based ad hoc routing, an IGW provides temporary access to Internet services for passing vehicles. Additionally, the multi-hop capability of the ad hoc routing protocol significantly increases the communication range. For example, in Fig. 1 vehicle V_a communicates with IGW_i using V_c as a relaying node. Although a FleetNet-enabled vehicle with a cellular radio modem can also be regarded as a gateway and could provide a similar service, we do no discuss this case further since it requires complicated billing and charging issues.

In order to connect FleetNet nodes to the Internet via IGWs, an IP-based addressing scheme is required to address the vehicles. Since vehicles may also provide Internet services, they have to be accessible from hosts in the Internet, which prohibits the use of private addresses using a network address translation scheme. Additionally, FleetNet has to support a tremendous number of potential vehicles, which will exceed the available IPv4 addresses. For example, an IPv4 class A subnet supports max. 2^{24}=16.777.216 vehicles, whereas 53.305.930 vehicles were registered in Germany in the beginning of 2002[1]. As a result, IP version 6 is deployed in FleetNet since its 128 bit address space provides sufficient capacity. The mapping from IPv6 addresses to the addresses used in FleetNet is straight forward, as the FleetNet addresses will be part of the vehicles' IPv6 addresses. From a conceptual point of view, the FleetNet communication system appears as a complex IPv6 subnet (with a global "FleetNet prefix") that has to be integrated into the Internet.

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[1] http://www.kba.de

3 Internet Integration

The outlined scenario has a strong impact on the performance of a communication system. Standard Internet communication protocols, mainly TCP/IP, require a fixed network topology and reliable communication links for efficient communication. The protocols do not handle mobility aspects of vehicles sufficiently: Classical Internet protocols neither support temporary connections nor the discovery and handover of connections from one Internet gateway to the next. As a result, TCP connections will terminate due to timeouts, if a communication partner is temporarily not available or if the IGW changes. In order to avoid those drawbacks, we designed an IPv6-based communication architecture called MOCCA (MObile CommuniCation Architecture) that allows both mobility support and efficient communication. MOCCA covers both network layer and transport layer protocols, and addresses the following aspects:

- Interoperability and efficient communication between Internet and FleetNet.
- Support of vehicles' mobility: Vehicles should be able to communicate independent of their location and IGW by using predefined global addresses.
- Discovery of Internet gateways: Vehicles must be able to identify (suitable) IGWs they can use for accessing the Internet.
- Within the vehicle, IP-based applications running on passengers' mobile devices should be able to use FleetNet for Internet-working.

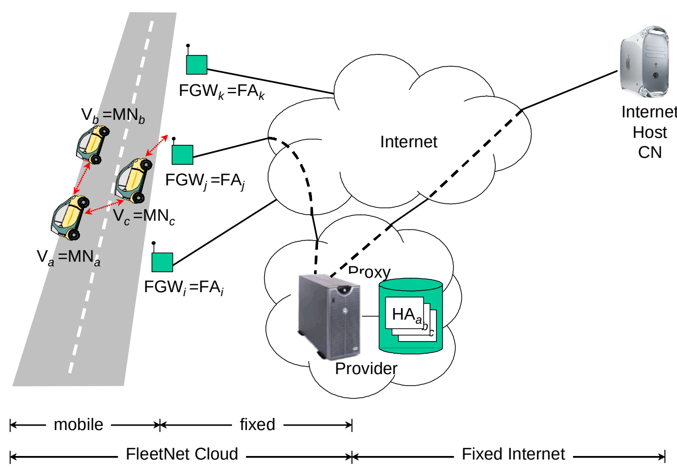

Fig. 2. MOCCA's Proxy-Based Communication Architecture

For the integration of the FleetNet's inter-vehicle communication system into the Internet, we combined a proxy-based communication architecture with a modified Mobile IP in MOCCA. Fig. 2 illustrates this basic idea. The central element in MOCCA is a Proxy located at the transition point between the Internet and the FleetNet cloud. The Proxy may be hosted by an arbitrary Internet provider, e.g. under private operation. The FleetNet cloud not only covers the inter-vehicle networks but also the paths from the Internet gateways to the Proxy. As described previously, FleetNet's communication protocols and addressing scheme are different from the protocols in the present Internet. Hence, one of the Proxy's tasks is to ensure interoperability between the FleetNet cloud and the Internet. In MOCCA, the required protocol translations occur on both the network layer and the transport layer. On the network layer, the Proxy has to handle the different addressing schemes and the mobility support of the vehicles. Whereas communication in the Internet bases on IPv4, FleetNet uses an IPv6 addressing scheme. In MOCCA, we use NAT-PT (Network Address Translation – Protocol Translation, RFC 2766), which provides for our case the most flexible solution for IPv4-IPv6 interworking (cf., Fig. 3). Using NAT-PT, the vehicles are able to access IPv4-based Internet services transparently. However, the opposite direction of accessing the vehicles from the Internet will be only possible by using IPv6-based applications in the Internet. The mobility aspect of MOCCA's network layer is described in section 4.1 in detail.

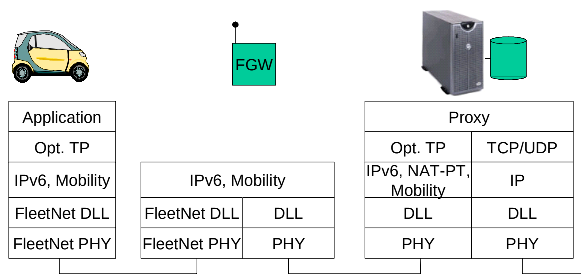

Fig. 3. Protocol Overview in MOCCA

On the transport layer, the use of TCP in the FleetNet cloud is not very useful as the TCP is very unsatisfactory in wireless and mobile networks [3]. Especially in FleetNet, the characteristics of communication links vary heavily over time, and connections to the Internet are only temporarily. As a result, continuous TCP connections from Internet hosts to vehicles will time out frequently. In order to improve communication efficiency, the Proxy in MOCCA additionally separates the end-to-end connection. Hence, TCP and UDP connections from the Internet terminate at the Proxy. Due to this separation, we are able to deploy efficient communication protocols in MOCCA in the FleetNet cloud (cf. Fig. 3). Currently, we are examining two promising approaches. As a first solution, we decided to use communication protocols from the Wireless Application Protocol (WAP) suite[2], as its protocols reflect our ideas of optimized communications in wireless networks. WAP 2.0 specifies two alternatives: The first is WTP (Wireless Transaction Protocol), a transaction-oriented protocol that avoids the overhead for connection establishment. Alternatively, the Wireless profiled TCP in WAP 2.0 combines several TCP enhancements that seem promising for an improved communication in wireless networks. Those enhancements concern a large (initial) window size (RFC 2414), a window scale option (RFC 1323), selective Acknowledgements (RFC 2018), or Explicit Congestion Notification (ECN, RFC 2481). Besides WAP, we also investigate the Stream Control Transmission Protocol (SCTP, RFC 2960) for its deployment in FleetNet. First evaluations of SCTP show an ade-

[2] http://www.wapforum.org

quate performance in mobile networks [4]. Based on those examinations, we will further optimize the developed transport protocol by utilizing information from the underlying FleetNet communication layers via a management plane. Examples are the current utilization of bandwidth or the current packet loss rate. Based on this information, upper layer communication protocols are able to optimize their configuration to the current communication characteristics.

The following example demonstrates the usefulness of the Proxy (see Fig. 2). If vehicle V_c requests a web page from an Internet host using IGW_j and looses the connection afterwards, the requested data already might have arrived at the Proxy when V_c connects to IGW_k. Then, the Proxy is able to transmit the outstanding data to the vehicle very efficiently using the optimized communication protocols listed above. In MOCCA, we locate the Proxy at a provider in the Internet. An alternative would be the deployment of proxies in the Internet gateways, i.e. closer to the vehicles. However, in this case the proxies have to become mobile and to "travel" with the vehicles. If a handoff occurs from one IGW to the next, the complete context of the proxy has to be transferred to the new gateway. In contrast to Mobile IP, which is our choice for MOCCA, a completely new and heavy-weighted signaling protocol would be necessary to realize mobile proxies. Since the transmission delay between Proxy and IGW is low compared to delays in the vehicular ad hoc network, Proxies on the IGWs promise no further benefits. The MOCCA architecture also provides better flexibility and less complexity:

- It is easier to manage and administrate the Proxy in the provider's network.
- Combinations with provider-specific services (e.g., a Web cache) are possible.
- Improved scalability by using powerful proxy farms and load balancing.
- Improved security because it is harder to infiltrate an Internet gateway than our Proxy in the provider's network.
- The Internet gateways require less hardware resources and are, thus, cheaper and more resistant to hardware failures.

4 Detailed Aspects of MOCCA

In the following sections, we depict the essential aspects of our communication architecture in more detail, namely the mobility support of the vehicles, the discovery of Internet gateways, and the integration of passengers' mobile devices within the vehicles.

4.1 Mobility Support

In order to enable mobility support for the vehicles traveling along the road, the Mobile IP we use in MOCCA has to be modified. The Proxy thereby plays an important role as it maintains the vehicles' home agents (HA). From a logical point of view, the IGWs function as foreign agents (FA), and the vehicles themselves represent the mobile nodes (MN, cf. Fig. 2). If a correspondent node (CN) in the Internet wants to communicate with a mobile node, it sends its data packets to the MN's home address

(Fig. 4). Thus, the packets arrive at the HA in the Proxy, which tunnels them to the (current) foreign agent using IP-in-IP encapsulation. Finally, the FA unpacks the data packets and forwards them to the MN. Fig. 4 illustrates this process.

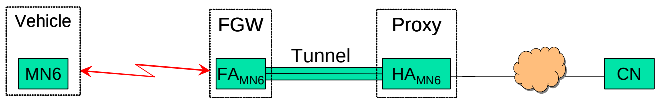

Fig. 4. Mobile IP Communication Path

Our primary goal for mobility support was to minimize signaling overhead within the vehicles' wireless ad hoc networks. This goal could be achieved either by avoiding unnecessary signaling overhead, or by shifting tunneling from the ad hoc network into the fixed network. As FleetNet uses IPv6-based addressing, this suggests the use of Mobile IPv6 [5]. However, Mobile IPv6 has some features that are in contrast to our goal of minimizing overhead in the vehicles' ad hoc networks. The following examples illustrate those circumstances in detail:

1. Mobile IPv6 assumes the use of co-located care-of addresses (CCoAs). CCoAs are addresses that are assigned to a MN by the access router (i.e. an IGW) using the auto-configuration mechanisms of IPv6. The original idea of CCoAs was that each node automatically obtains a valid IPv6 address if it enters a network. However, this configuration mechanism is of no use in FleetNet, because vehicles are addressed by their (pre-defined) global IPv6 addresses. CCoAs also impress a hierarchical structure to the nodes in the ad hoc network that can be hardly maintained due to the high mobility of the vehicles' ad hoc networks. Finally, the binding updates to correspondents due to handoffs must be prevented as the correspondent's TCP session terminates at the proxy. As a result, CCoAs would cause additional overhead in the inter-vehicle network for their assignment and for the required binding updates after a handoff occurs.
2. In Mobile IPv6, the MN itself implements the foreign agent functionality. This means that the MN acts as the tunnel endpoint, causing tunneling overhead in the FleetNet. Tunneling may occur in Mobile IPv6 if data packets are sent to previous CCoAs, which forward them to a MN's current CCoA.

In order to avoid those drawbacks, we developed a light-weighted Mobile IP for MOCCA, called Mobile IPv6*. Mobile IPv6* avoids any mechanisms for the automatic configuration of CCoAs and IGWs. Instead, only the vehicle's global IPv6 home address is used for addressing. In order to meet the other problems outlined above, we re-introduce the foreign agents in Mobile IPv6*. They are located on the IGWs, as shown in Fig. 4. Although this approach seems a step backward to Mobile IPv4 [6], it is necessary in the Internet integration scenario. The reason is that we shifted tunneling and signaling overhead from the vehicles' ad hoc networks into the fixed Internet. Additionally, FAs enable interoperability in the FleetNet cloud, because IGWs will be likely connected to the IPv4-based Internet. Hence, MOCCA tunnels the IPv6 traffic via IPv4 tunnels between HA and FA.

The functionality of Mobile IPv6* is closer to Mobile IPv4 than to Mobile IPv6. Hence, we chose not to use a Mobile IPv6 implementation for our prototype. Instead, we modified the DYNAMICS Mobile IPv4 implementation[3] to work with IPv6. However, using Mobile IP for handling mobility in ad hoc networks is generally not possible. In Mobile IP, mobile nodes always require immediate links to the foreign agents. For example, Mobile IPv6 uses link local IPv6 addresses for transmitting the router advertisements. However, in ad hoc networks each node acts as a router. Hence, a MN would select an arbitrary adjacent MN for its default gateway instead of an IGW. The following section describes how we accomplished this problem in MOCCA.

4.2 Service Discovery in the Vehicles' Ad Hoc Networks

As stated previously, Mobile IP is not able to support mobility in mobile ad hoc networks. Both Mobile IPv4 and Mobile IPv6 require an immediate link between a mobile node and the foreign agent/access router. Hence, a major issue in FleetNet is the discovery of Internet gateways, which function as foreign agents. In MOCCA, we use a *service discovery protocol* (SDP) for this task. As stated by the name, SDPs enable mobile devices to discover services in a network. Currently, various SDPs are available, such as the Service Location Protocol (SLP) [7, 8], Universal Plug and Play (UPnP), or Salutation [9]. Although those protocols are very different, their basic functionality is identical; thus we illustrate their procedure on the example of SLP. As illustrated in Fig. 5, three parties are involved in the process of service discovery in SLP: a user agent (UA) that is looking for a service, a service agent (SA) that provides a service, and a directory agent (DA) that manages the available services in a network. The first defined interaction scheme (Fig. 5 (a)) requires no DA but queries the available SAs using a Multicast request. Afterwards, each SA replies to the query in the second step. The second protocol interaction, shown in Fig. 5 (b), deploys a DA. Each SA registers its service at the DA (step 1). A user agent requests a service immediately from a DA (step 2), which replies with the registered services in step 3. Either the addresses of the DAs have to be either configured statically, or the DAs need to be discovered by using a pre-defined Multicast address each DA is assigned to.

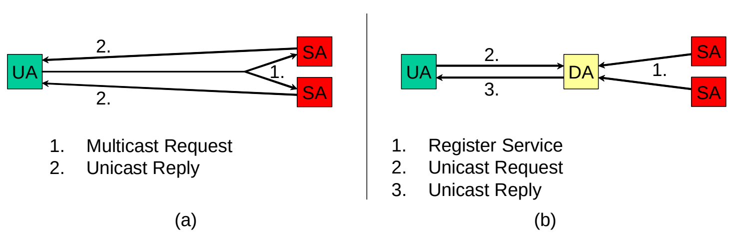

Fig. 5. Protocol Interaction of SLP

However, existing service discovery protocols are not suitable in the FleetNet scenario for several reasons. First, current SDPs do not utilize the geocasting capabilities FleetNet is optimized for. Second, current SDPs do not scale with an increasing penetration of vehicles participating in the inter-vehicle communication system. Due to the high dynamics of these ad hoc networks, vehicles permanently have to discover bet-

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[3] http://www.cs.hut.fi/Research/Dynamics

ter-suited IGWs while traveling. As illustrated in Fig. 6 (a), the permanent discovery of IGWs cause much overhead in the inter-vehicle communication system, even if no IGW is available. This overhead also occurs if no Internet gateway is in sight. Alternatively, a Multicast-based solution might be conceivable, where all IGWs form a pre-defined Multicast group. The vehicles will use this Multicast address as their default gateway. However, this approach also causes much overhead for maintaining the multicast group in the highly dynamical vehicle-based ad hoc networks. Additionally, it needs a multicast-based routing algorithm in the inter-vehicle communication system.

Due to those profound drawbacks, we developed and implemented an IPv6-based SDP for MOCCA using SLP as a starting point. Our service agent is divided into two distributed functional units. The first unit is situated on the Internet gateways and announces its service provision of Internet access periodically (Fig. 6 (b)). The service announcements are broadcasted in a geographically restricted area using FleetNet's geocasting capabilities. Note that it is up to the location-based routing algorithm to distribute the service announcements among the vehicles efficiently in the specified geocast region. The second functional unit resides locally in the vehicles. This in-vehicle SA component extracts the information from the service announcements and caches it locally in a database. If the service announcements of an IGW fail to appear, the corresponding IGW entry will be removed from the local database. In order to discover Internet gateways, a user agent within a vehicle queries the in-vehicle SA component and receives back a list of currently available IGWs. Finally, the user agent is able to configure Mobile IPv6* to use one of the IGWs as its foreign agent.

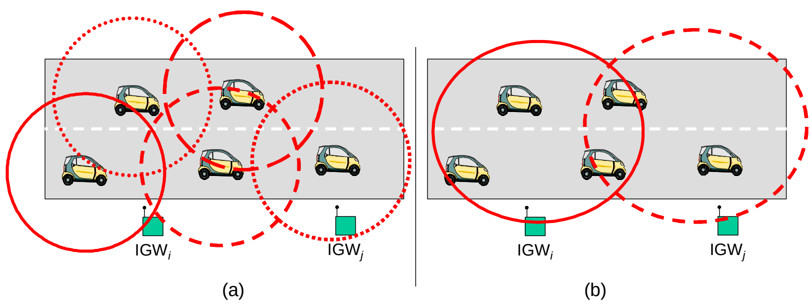

Fig. 6. Comparison of SLP vs. MOCCA SDP

A first evaluation of the MOCCA SDP with existing service discovery protocols shows that our approach is well suited for the FleetNet scenario. In a typical scenario with a transmission period of 1 s for the service announcements, the MOCCA SDP requires a bandwidth of about 12 kbit/s. In contrast, the bandwidth requirements of the original SLP increase linear with the number of vehicles. In this case, 25 vehicles per lane and per kilometer cause an overhead of about 3 Mbit/s, which is about 250 times higher compared to our approach. Refer [10] for further results.

Using the service information announced by the IGWs, it is up to the user agent within the vehicles to choose the available IGW for Internet access. In contrast to typical IPv6 scenarios with typically one router to the Internet, several IGWs might be available at the same time in FleetNet. For example, if the two circles in Fig. 6 (b) mark the geocast region covered by the corresponding gateway, the two vehicles in the middle will have Internet access via both gateways IGW_i and IGW_j. In this case, the communication system has to decide which IGW currently fits best to the requirements of the applications. For this decision, several parameters play an important role. Hence, the service announcements provide additional information in their attribute list, such as

– current number of clients using a IGW,
– current/statistical utilization of a IGW's available bandwidth (necessary for the requirements of the applications),
– geographical position (which allows an estimation of the connection's duration)
– optionally, the IGW's coverage,
– optionally, a maximum lease time (before the service will become unavailable),
– marketing information (which allows the IGW operators to send local advertisements to the vehicles).

Note that this parameter set is not complete. Further parameters will be also relevant for the decision, which depends on future applications deployed in FleetNet. The integration of those parameters is very easy by adding new parameters in the service announcements. However, the decisions about the most suitable IGW always will be in an area of conflict between a maximum duration of the connection to an IGW, and a minimum number of hops to this IGW.

For the choice of the most appropriate gateway, we deployed a fuzzy-based approach in MOCCA. We defined four abstract application classes: best effort, interactive, AV streaming, and real time applications. Based on the information announced by the Internet gateways (see above), the fuzzy system predicts future 'quality' parameters, such as expected delay, dropouts, or the probability for a disconnection. With those predictions, the MOCCA's user agent is able to decide which of the available gateway will be the best one for the specified application class. Further details on the fuzzy-based approach and the deployed rules for prediction are described in [10]

4.3 Support of Legacy Applications

Besides specific applications for future road scenarios, travelers will be likely interested in using their mobile devices (laptops, PDAs, etc.) inside the vehicles. However, the IP-based ("legacy") applications running on those devices are not able to use the optimized communication protocols deployed in FleetNet. A modification of each application to support MOCCA is practically unrealistic. In order to ensure interoperability of legacy applications in FleetNet, the MOCCA concept contains a second proxy located within the vehicle, the so-called *Vehicle Proxy*. This way, the vehicle acts as a proxy for (legacy) applications running on mobile devices within the vehicle. Fig. 7 illustrates this idea, when applications on a laptop communicate via FleetNet. The Vehicle Proxy (again) separates the end-to-end connection. On the one side, it communicates in the FleetNet cloud using FleetNet's optimized transport protocol (Opt. TP). On the other side, it uses TCP for communications with the mobile device. The proxy (supported by an optional cache) thereby translates between the different communication protocols. Additionally, NAT-PT performs the transparent translation between IPv4 and IPv6. As a result, MOCCA enables communication with the legacy applications using standard TCP/IP, and with the FleetNet cloud using the optimized communication protocols.

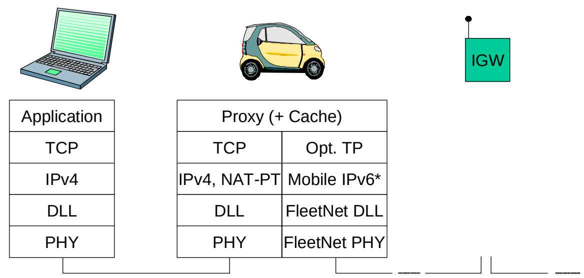

Fig. 7. Integration of Legacy Applications in FleetNet

Note that the Vehicle Proxy only supports the vehicles' mobility, not the mobility of the mobile devices. In this scenario (Fig. 7) the mobile device will obtain a private IPv4 address that is valid within the vehicle. Hence, the proxy hides this mobile device so it cannot be accessed from hosts in the Internet; it is only possible in this scenario that the mobile node accesses Internet services. In order to ensure overall mobility, the mobile devices have to support Mobile IPv4 additionally (not shown in Fig. 7). However, we do not discuss this feature in more detail as the support of "legacy servers" on mobile devices within vehicles plays an ancillary role in the FleetNet context.

5 Conclusion

In future road communication scenarios like FleetNet, the integration of inter-vehicle communication systems into the Internet plays an important role. For the Internet integration, several problems arise such as interoperability of communication protocols, discovery of gateways providing temporary Internet access, and the characteristics of vehicular communication systems. In order to meet those challenges, we developed MOCCA, a communication architecture for the Internet integration of inter-vehicle ad hoc networks. MOCCA deploys an IPv6-based proxy architecture in combination with Mobile IP for handling the vehicles' mobility. The Proxy enables interoperability with common Internet protocols by separating end-to-end connections. Additionally, we use optimized communication protocols in MOCCA for efficient communication between the Proxy and the vehicles. The Mobile IP deployed in MOCCA also requires some modifications as Mobile IP cannot be used in multi-hop ad hoc networking in general. Hence, we developed and implemented a scalable service discovery protocol that is highly optimized for scenarios like FleetNet. Using this protocol, vehicles are able to identify their foreign agents even via multiple hops in ad hoc networks. Finally, a second proxy located within the vehicle enables the use of common IP-based applications running on the passengers mobile devices.
The first results of our evaluation seem promising. One example is our service discovery protocol, which reduces the overhead significantly compared to existing ser-

vice discovery protocols. In order to evaluate our communication architecture, we currently set up a testbed that emulates such a future road scenario. In this testbed, we will integrate MOCCA for further evaluation. Moreover, the implementation of MOCCA will be deployed in the FleetNet demonstrator that is currently under development. Future work will comprise additional optimizations of the communication protocols we use in MOCCA. Currently we are working on the implementation and evaluation of the optimized transport protocol. An essential aspect will be the utilization of management information provided by lower communication layers for improved communications.

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