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Flexible Connectivity Management in Vehicular Communication Networks

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Abstract— **Vehicular communication, providing vehicle-to-vehicle and vehicle-to-roadside communication, can considerably improve traffic safety and comfort of driving and traveling. For communication in vehicular ad hoc networks, position-based routing has emerged as a promising candidate. For Internet access, Mobile IPv6 is a widely accepted solution to provide session continuity and reachability to the Internet for mobile nodes. While integrated solutions for usage of Mobile IPv6 in (non-vehicular) mobile ad hoc networks exist, we propose a solution that, built upon on a Mobile IPv6 proxy-based architecture, selects the optimal communication mode (direct in-vehicle, vehicle-to-vehicle, and vehicle-to-roadside communication) and provides dynamic switching between vehicle-to-vehicle and vehicle-to-roadside communication mode during a communication session in case that more than one communication mode is simultaneously available.**

Index Terms— **Vehicular communication, ad hoc routing, Mobile IPv6, mode switching.**

I. INTRODUCTION

Communication capabilities in vehicles are the basis of an envisioned Intelligent Transportation Systems (ITS). Vehicles are enabled to communicate among themselves (vehicle-to-vehicle, V2V) and via roadside access points (vehicle-to-roadside, V2R). Vehicular communication is expected to contribute to safer and more efficient roads by providing timely information to drivers, and also to make travel more convenient. The integration of V2V and V2R communication is beneficial due to the fact that V2R provides better service sparse networks and long distance communication, whereas V2V enables direct communication for small to medium distances/areas and at locations where roadside access points are not available. Additionally, in scenarios where V2V and V2R communication are available simultaneously, a communication service could be chosen that is optimal in terms of end-to-end delay, losses, consumption of wireless bandwidth or other metrics.

For both, mobile ad hoc and infrastructure-based communication with mobile nodes, solutions exist and are applied to vehicular environments. For ad hoc routing, position-based routing has emerged as a promising candidate [4]. Likewise, for infrastructure-based communication with mobile hosts, such as cellular networks, Mobile IPv6 [5] represents a well-known solution for mobility support based on IP addressing and packet forwarding. For integration of Mobile IPv6 and ad hoc routing a number of technical problems need to be solved, including the efficient distribution of router advertisements, selection of Internet gateways, and movement detection of the mobile node.

The specific features of VANETs require a novel solution for integration of ad hoc routing and Mobile IPv6. In [9] we propose an architecture with a Mobile IPv6 proxy executed in a vehicle's on-board unit that integrates Mobile IPv6 and ad hoc routing in vehicular networks. Based on the same architecture, this paper presents a solution for flexible connectivity management utilizing the Mobile IPv6 proxy. Essentially, the solution provides different communication modes. In case that more than one communication mode is simultaneously feasible (i.e., V2V and V2R), the optimal mode is chosen. A vehicle can dynamically switch between modes during a communication session.

This paper is structured as follows: After related work in Sec. II, Sec. III describes the system architecture and gives technical background on position-based ad hoc routing and Mobile IPv6. The proposed scheme for flexible connectivity management is presented in Sec. IV. Sec. V analyses the proposed solution and Sec. VI concludes the paper.

II. RELATED WORK

The integration of mobile networks with ad hoc routing protocols and occasional access to the infrastructure is becoming a world wide research topic. MANEMO, a candidate IETF working group with the aim to integrate NEMO [3] in ad hoc networks, is in the scope definition phase. In [12] Wakikawa et al. propose an extension to NEMO for V2V mode, which is not integrated with the VANET routing protocol and doesn't define a mode management algorithm.

Many other approaches target the integration of Mobile IP and MANET, focusing on gateway selection but without taking into consideration mobile networks nor node discovery [2], [6], [8], [11].

III. VEHICULAR AD HOC NETWORKS WITH INTERNET CONNECTIVITY

A. Architecture

The assumed VANET architecture is depicted in Fig. 1. The network consists of three distinct domains: *in-vehicle*, *ad hoc*, and *infra-structure domain*.

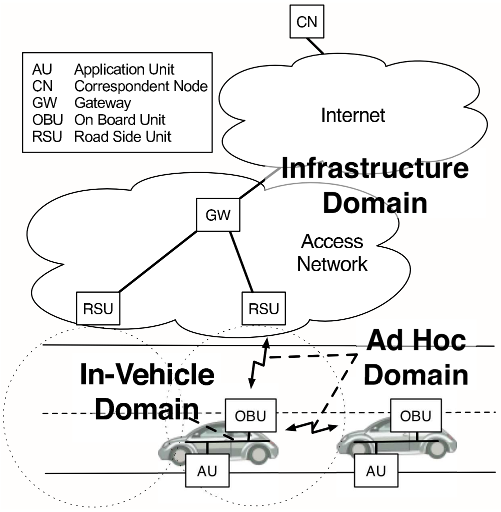

Fig. 1. System Architecture View

The *in-vehicle domain* is a network composed of an *on-board unit* (OBU) and (potentially multiple) *application units* (AUs). AUs are typically portable devices such as laptops, PDAs or game pads attached to an OBU and normally connected via a wired connection. We assume that AUs are not directly connected to the ad hoc domain.

The *ad hoc domain* is composed of vehicles equipped with OBUs and stationary nodes along the road, termed *road-side units* (RSUs). The units (OBUs and RSUs) can directly communicate if direct wireless connectivity exists. In the case that no direct connectivity exists, multi-hop communication is used, where data is forwarded from one OBU to another, potentially via RSUs, until the destination is reached.

RSUs interconnect ad hoc and infrastructure domains. They make it possible for AUs registered with an OBU to communicate with *correspondent nodes* (CNs) in the Internet.

B. Communication Modes

We define three basic types of communication:

- **DIV** (Direct In-Vehicle) AUs in the same vehicle communicate with each other using the in-vehicle network;
- **V2V** (Vehicle to Vehicle) AUs in different vehicles communicate with each other using OBU to OBU communication. The data packets are routed inside the ad hoc domain;
- **V2R** (Vehicle to roadside) AUs communicate either with a CN located in the infrastructure domain or with an AU not accessible via V2V communication.

C. Position-Based Routing for Vehicular Ad Hoc Communication

The referred protocol architecture adopts a position-based scheme as a multi-hop routing protocol in the ad hoc domain, which is termed PBRV. Compared to other ad hoc routing protocols, this approach has demonstrated better performances in highly dynamic scenarios as VANET [4], [10].

The two main advantages of PBRV are as follows: first, packets are routed *on the fly*, i.e. there is no need to maintain pre-established routes and the decision about the next hop is performed when needed, instead of when the route is created. Second, PBRV naturally enables the addressing of nodes located in a geographical area and the geographically-scoped distribution of packets. This is referred to as *geographical broadcast (Geocast)*.

A position resolution service is part of the PBRV protocol and, through a flooding mechanism, allows a source node to determine the location of the destination (discovery service).

D. IPv6 Support for PBRV

As the adopted position-based approach provides routing and forwarding functionalities, it enables integration of the Internet Protocol (IP) into the protocol architecture, allowing it to ignore the multi-hop nature of the ad hoc domain. In particular, IPv6 appears more suitable for this purpose compared with IPv4, essentially because it offers stateless address autoconfiguration and the IPv6 to PBRV address resolution can be simplier achieved.

In the presented solution, a RSU connected to the infrastructure domain acts as an Access Router (AR), announcing an IPv6 prefix through Router Advertisement messages which are delivered in restricted geographic areas using the above mentioned GeoCast mechanism. This allows an OBU to configure an IPv6 address and to exchange packets with nodes located in the infrastructure domain.

E. MIPv6 Proxy

An OBU interconnects the in-vehicle network with the vehicular ad hoc network. In order to provide IPv6 and mobility support to the AUs, the OBU can adopt one of the several approaches:

- Behaving similarly to a bridge, the OBU distributes packets from the ad hoc domain to the AUs, in such a way that the two domains are part of the same IPv6 network;
- Behaving as a router, the OBU forwards the packets between two different IPv6 subnets and is responsible for announcing the in-vehicle prefix;
- Behaving as an enhanced router, the OBU could potentially interact with the Mobile IPv6 instance running in the AUs. This guarantees reachability of the AUs even when no access to the infrastructure domain is available, which is the most frequent scenario for VANETs.

The MIPv6 Proxy solution illustrated in [9] and adopted here as part of the protocol architecture, belongs to the last category. Its main design principle is to perform MIPv6 signaling on behalf of the AU when a point of attachment to the infrastructure is available, and to act as a surrogate Home Agent (HA) when the infrastructure is not accessible. More specifically, the MIPv6 Proxy takes advantage of managing the AU's Home Address (HoA), choosing whether to forward the data packets via the HA or directly to other AUs through the ad hoc domain. The resulting protocol architecture is depicted in Fig.2.

The MIPv6 Proxy, in order to make use of V2V communication mode, needs to know to which OBU it should forward the data packets. This is achieved by extending the discovery service of the position based routing protocol: when the Proxy detects a packet from an attached AU, it sends a query to determine whether or not the target node is an AU and the OBU it is attached to. The query is flooded in the VANET and, in case a reply is sent, it contains also the geographical position of the OBU. We refer to this mechanism as *Application Unit Discovery Service*. Since this service is important for the algorithm explained in the following section and may influence the overall performance of the VANET, some possible improvements of its are described in Sec. IV-D.

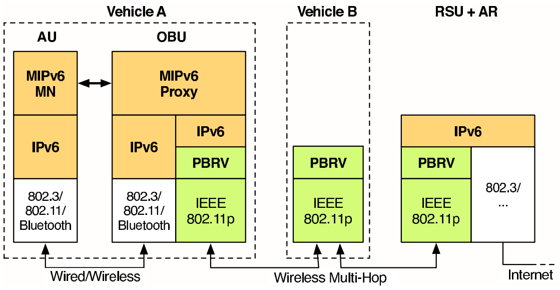

Fig. 2. Protocol Stacks of the Integrated Solution

IV. DYNAMIC MODE SELECTION

In Sec. III-B we define the three communication modes that are possible in the considered architecture. In scenarios where more than one communication mode is available, the proposed protocol architecture offers the possibility to dynamically select a mode. The most interesting case occurs when AUs of two vehicles are communicating with each other. The selection of the mode, between V2R and V2V, can have a strong impact on the quality of the communication, e.g. in terms of packet delay, bandwidth consumption, and packet loss. This fact, together with the need to achieve a good scalability, suggests to adopt a criterion based on the optimal path.

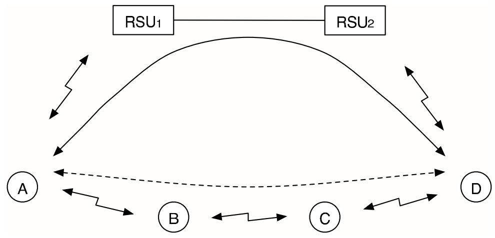

Fig. 3. Optimal Paths for V2V and V2R Mode

In Fig. 3, we depict how routing can be optimal if the correct communication mode is selected: For vehicles A and D to communicate, a packet traverses two wireless hops when communicating via V2V and no intermediate wireless hop via V2R, meaning that V2R should be the preferred method of communication. We identify two main factors that influence the decision about mode switching:

- **Hop Count**: The number of wireless hops between two PBRV nodes. This metric gives information about the current topology of the ad hoc network;
- **Distance**: The geographical distance between two PBRV nodes.

A. Metric Definition

When developing an appropriate metric for mode selection, we consider the following prerequisites:

- Both geographical distances and hop count should be regarded as input for a metric. They should be weighted with a factor that normalizes the different scales of the units involved.
- The metric calculation should be adjustable for different scenarios by changing the weight of hop count and distance contributions.
- Switching between V2V and V2R mode should not be very frequent if both modes have approximate metric values.

With this in mind, we propose the metric **Weighted Distance & Hop Count** (*WDHC*). *WDHC* is calculated as follows:

$$WDHC = (hc \times w_{hc}) + \left(\frac{d \times (1 - w_{hc})}{f} \right) \tag{1}$$

The terms hc and d represent hop count and distance, w_{hc} and $(1 - w_{hc})$ are the corresponding weights, f is the factor to normalize the distance to hops.

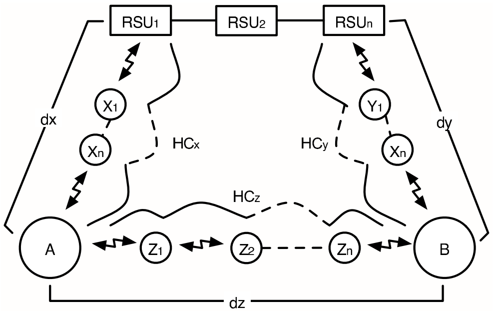

Fig. 4. Distance and Hop Count Calculation

It is worth noting that Eq. 1 includes only wireless hops and ignores any hops in the wired network for V2R communication. In Fig. 4 it is depicted how *WDHC* is calculated in both communication modes. For communication from A to B, the metrics are as follows:

$$\begin{aligned} hc_{V2R} &= hc_x + hc_y \\ hc_{V2V} &= hc_z \\ d_{V2R} &= d_x + d_y \\ d_{V2V} &= d_z \end{aligned}$$

In the proposed protocol architecture, the position-based ad hoc routing protocol PBRV provides values for hop count hc and distance d of Eq. 1 through the Application Unit Discovery Service described in Sec. III-E. The factor f can be pre-calculated for some typical scenarios or derived from the topology known to the node.

For mode selection we distinguish between two basic decisions: The *initial mode selection* and the *refresh mode-selection*. The initial mode selection is made at the beginning of a communication session between two communication peers.

Once a communication session has been established, the optimal path may change, possibly resulting in a different mode being selected. This is referred to as *refresh mode selection*. Reasons for switching the mode during a session could be the movement of both, a communicating node and intermediate nodes.

We propose differentiated strategies for initial and refresh mode selection that are described in Sec. IV-B and Sec. IV-C.

B. Initial Mode Selection

The initial mode selection is triggered when data arrives from the in-vehicle network, which has to be forwarded to a node that is unknown to the MIPv6 Proxy. In this case, the OBU issues an initial discovery request for the target node and, at the same time, selects the V2R as default mode. If no RSU is available, packets are silently dropped. When a discovery reply is received the appropriate mode is selected according to the metric of Eq. 1.

The pseudo code below describes the algorithm for initial mode selection. The variables a_{V2V} and a_{V2R} are boolean that indicate mode availability. $WDHC_{V2V}$ and $WDHC_{V2R}$ represent the metric values for V2V and V2R communication.

C. Refresh Mode Selection

After establishing a connection as described above, in the case that both sender and receiver are AUs located in the VANET, the OBUs make regular use of the AU discovery service to obtain up-to-date topological and geographical information. Using these parameters, OBUs calculate and compare the $WDHC_{V2V}$ and $WDHC_{V2R}$ metric values.

In scenarios where the values of $WDHC_{V2V}$ and $WDHC_{V2R}$ are similar, it is likely that the OBU could constantly switch back and forth between modes. To solve this erroneous behavior, we introduce an hysteresis mechanism based on the variation $\Delta WDHC = |WDHC_{V2V} - WDHC_{V2R}|$. The

Algorithm 1 Algorithm for Initial Mode Selection

```
Receive a packet destined to a CN not known
if DEST_ADDR is locally registered then
    $mode \leftarrow DIV$
else if $a_{V2R}$ then
    $mode \leftarrow V2R$
else
    Drop packets
end if
start AU Discovery Service
if Reply then
    Calculate $WDHC_{V2V}$ and $WDHC_{V2R}$
    if $(a_{V2V}/WDHC_{V2V}) > (a_{V2R}/WDHC_{V2R})$ then
        $mode \leftarrow V2V$
    else
        $mode \leftarrow V2R$
    end if
end if
```

switch is performed only if $\Delta WDHC > Th$, where Th is a predefined threshold that provides stability, in the sense that the algorithm keeps the current mode over a small (and possibly temporary) change in the metric's value.

Algorithm 2 Algorithm for Refresh Mode Selection

```
Send discovery request
if Reply then
    Calculate $WDHC_{V2V}$, $WDHC_{V2V}$, and $\Delta WDHC$
    if ($a_{V2V}$ and $a_{V2R}$) and $(\Delta WDHC > Th)$ then
        if $WDHC_{V2V} > WDHC_{V2R}$ then
            $mode \leftarrow V2V$
        else
            $mode \leftarrow V2R$
        end if
    else
        do not change mode
    end if
end if
```

D. Improving AU Discovery Service

The mode selection algorithm described above relies on the AU Discovery Service defined in Sec.III-E. Such a service, which generates flooding in the ad hoc network, is unavoidable due to the fact that a VANET with in-car devices represents a self-organizing dynamic network, and might have no access to an infrastructure network. Nevertheless, the scalability of such a system strongly depends on how the flooding affects the available access medium.

For this reason, the interval for re-submitting pending queries is important. In the proposed algorithms, this interval, defined as I_{LU}, is based on the geographical distance between the AUs (d) and is calculated as follows:

$$I_{LU} = \begin{cases} I_{Max} \\ \frac{I_{Max}}{d_{Thres}-d_{Max}}(d - d_{Thres}) + I_{Max} \end{cases}$$

where the first upper bound, I_{Max}, is chosen for $0 < d < d_{Thres}$ and the second term is chosen for $d_{Thres} \leq d < d_{Max}$. d_{Max} is the maximum communication distance that should be provided and d_{Thres} represents a distance threshold.

Furthermore, the position information could be exchanged between the two OBUs that host the communicating AUs through various piggyback mechanism. For example, a discovery request/reply mechanism could be achieved using a new IPv6 extension header appended to the data packets. Optionally, in order to avoid flooding, the request and reply messages could go from one OBU to the other through the Home Agent, which maintains the registration of the OBUs' Care-of Addresses, according to the MIPv6 Proxy functioning explained in Sec. III-E. An additional improvement for the location service is proposed in [7].

V. ANALYSIS OF THE PROPOSED SOLUTION

In this section, we analyze the presented solution with respect to i) system and implementation complexity, ii) overhead caused by signaling operations, iii) impact on latency of message transfer and 4) network security issues.

1) System and Implementation Complexity: Comparing the integrated solution with basic Mobile IPv6, an additional network element – the MIPv6 Proxy – has been introduced. The discussed discovery service is closely related to the MIPv6 Proxy. Both, the MIPv6 Proxy and the discovery service, clearly increase the system complexity. However, the MIPv6 Proxy essentially unifies operations of a Mobile IPv6 mobile node, access router and home agent for which existing functions (and software code from Mobile IP) can be highly reused. Similarly, the proposed discovery service represents a generalization of a service in Mobile IPv6 (address assignment and discovery) and ad hoc routing (location discovery). The integration of both services simplifies the system rather than making it more complex.

2) Overhead for Signaling Operations: The signaling operations used to determine the availability of V2V and V2R mode as well as calculate the WDHC metric can significantly contribute to data overhead. In particular, frequent flooding of signaling messages through the network can consume a considerable portion of the overall wireless bandwidth. However, as discussed in IV-D, a flooding mechanism is necessary and the suggested improvements strongly limit its impact, specially if we consider that PBRV offers the possibility to restrict the flooding to a certain geographical area.

3) Latency of Message Transfer: When a communication session between two nodes is established, the packets are cached and the discovery service is triggered. The forwarding of the first packets is delayed until the discovery service has delivered the information. In the worst case, establishment of communication is delayed until a timeout occurs. In order to decrease the delay introduced by the discovery service, we allow that a packet is forwarded as soon as the reply for one mode is available, though this mode might not be the optimal one (see Sec. IV-B).

4) Network Security Issues: The proposed protocol architecture assumes that the MIPv6 Proxy provides V2R and V2V modes, by handling the AU's home registration or acting itself as surrogate Home Agent, respectively. This requires the presence of a trust relationship between the OBU (installed in the car) and the AU (owned by the driver or passengers), since they need to share a Security Association with the real Home Agent. Hence, according to [1], the signaling between MN and HA should be protected by IPsec, which prevents a third node to modify the messages. IPsec support for MIPv6 Proxy is part of ongoing research. Nevertheless, it's worth noting that the concept of AU is not restricted to passenger devices: It is possible to imagine AUs permanently installed in the car, in which case AU and OBU reciprocally trust each other.

VI. CONCLUSIONS

We have proposed a solution that provides dynamic connectivity management for vehicular communication. The solution is based on an architecture that enables IP communication among vehicles as well as among vehicles and nodes in the Internet via access points along the road. We use Mobile IPv6 for global IP mobility and position-based routing (PBRV) for efficient and scalable wireless multi-hop communication in the ad hoc domain. The integrated solution of both Mobile IPv6 and PBRV, introduces a Mobile IPv6 Proxy for support of network mobility that shields the mobile node attached to the in-vehicles network from the ad hoc network characteristics.

We provide three different modes for IP communication: In-vehicle (IVC), vehicle-to-vehicle (V2V), and vehicle-to-roadside communication (V2R). A specific challenging issue is the optimal selection between V2V and V2R in the case that both modes are simultaneously available. We define a metric WDHC that allows the comparison of possible V2V and V2R by means of the geographical distance and number of wireless hops. In addition, two communicating nodes can switch from V2V to V2R communication (and vice versa) during a communication session in case the metric changes. When analyzing the integrated solution and comparing it with Mobile IP and position-based routing for vehicular ad hoc networks as separate solutions, we can claim that our solution only slightly increases system and implementation complexity.

VII. ACKNOWLEDGEMENTS

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