Survey on IP-based Vehicular Networking for Intelligent Transportation Systems

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Introduction to Vehicular Networking

- Objective of this Draft
  - To survey the research activities of IP-based vehicular networks for Intelligent Transportation Systems (ITS).
- Assumptions for Vehicular Networks
  - **IEEE 802.11p** is considered as MAC protocol.
  - **IPv6** is considered as a Network-layer protocol.
  - **Road-Side Unit (RSU)** is connected to the Internet as an access point for vehicles.
  - **Traffic Control Center (TCC)** is a central node for managing vehicular networks as vehicular cloud.

Categories for Vehicular Networking

1. IP Address Autoconfiguration

2. Vehicular Network Architecture

3. Vehicular Network Routing

4. Mobility Management in Vehicular Networks

IP Address Autoconfiguration (1/2)

- Automatic IP Address Configuration in VANETs [1]
  - A **distributed dynamic host configuration (DHCP)** with a cluster leader as a DHCP server.

- Routing and Address Assignment using Lane/Position Information in a VANET [2]
  - **Each lane of a road segment** has a **unique IPv6 prefix** for IPv6 SLAAC.
  - A connected VANET is constructed per lane as a cluster.

- GeoSAC: Scalable Address Autoconfiguration for VANET Using Geographic Net Concepts [3]
  - A **link** is defined as a **geographic area** having a connected VANET for multicast.
  - Ad Hoc routing is performed to support such a multicast link for IPv6 SLAAC for an RA from an RSU.

IP Address Autoconfiguration (2/2)

- Key Observations
  - **High-speed mobility** should be considered for a light-overhead address autoconfiguration.
    - **A cluster leader** can have an IPv6 prefix [1].
    - **Each lane in a road segment** can have an IPv6 prefix [2].
    - **A geographic region** under the communication range of an RSU can have an IPv6 prefix [3].
  - **IPv6 Neighbor Discovery (ND)** should be extended to support the concept of a link for an IPv6 prefix in terms of multicast.
    - Ad Hoc routing is required for the multicast in a connected VANET with the same IPv6 prefix [3].
    - **A rapid Duplicate Address Detection (DAD)** should be supported to <u>prevent or reduce</u> **IPv6 address conflicts**.

Vehicular Network Architecture (1/3)

- VIP-WAVE: On the Feasibility of IP Communications in 802.11p Vehicular Networks [4]
  - VIP-WAVE provides three schemes:
    - An efficient mechanism for the IPv6 address assignment and DAD,
    - On-demand IP mobility based on Proxy Mobile IPv6 (PMIPv6), and
    - one-hop and two-hop communications for I2V and V2I networking.

- IPv6 Operation for WAVE - Wireless Access in Vehicular Environments [5]
  - IEEE 1609.3 minimizes IPv6 operation over WAVE.
    - IPv6 Neighbor Discovery is not recommended.

  - IPv6 link model does not hold in WAVE.
    - Unidirectional links in WAVE may exist due to interference and different Tx power levels.
    - Interfaces with the same prefix may not on the same IP link due to node mobility and highly dynamic topology.

Vehicular Network Architecture (2/3)

- A Framework for IP and non-IP Multicast Services for Vehicular Networks [6]
  - Distributed mechanism allowing to configure a common multicast address: Geographic Multicast Address Autoconfiguration (GMAA), without signaling.
- Joint IP Networking and Radio Architecture for Vehicular Networks [7]
  - Three classes of nodes may define all required IP ITS topologies corresponding to direct V2V communication, range extension V2V (REV), and V2I communications.
  - VANET ITS interference may be controlled by separating each WiFi/ITS-G5 channel as IP subnetworks and advertising them through range extension nodes using REV.
- Mobile Internet Access in FleetNet [8]
  - Re-introduction of a foreign agent (FA) in MIP located at the IGW, so that the IP-tunneling can remain in the back-end, not on the air.
- A Layered Architecture for Vehicular Delay-Tolerant Networks [9]
  - DTN Bundle Layer between L2 and L3 to keep it transparent to IP.

Vehicular Network Architecture (3/3)

- Key Observations
  - **Unidirectional links** exist and must be considered.
  - **Control Plane** must be separated from **Data Plane.**
  - **ID/Pseudonym change** requires a **lightweight DAD.**
  - **IP tunneling** should be **avoided.**
  - **Vehicles** do **not** have a **Home Network.**
  - **Protocol-based mobility** must be **kept hidden** to both the vehicle and the correspondent node (CN).
  - **An ITS architecture** may be composed of **three types of nodes**: Leaf Nodes, Range Extension, and Internet Vehicle.

Vehicular Network Routing (1/3)

- Different routing protocols categories in VANET.
  - Geocast/position/broadcast/cluster-based ad hoc routing.
- An IP Passing Protocol for Vehicular Ad Hoc Networks with Network Fragmentation [10]
  - It tackled the issue of network fragmentation in VANET environments.
  - It can postpone the time to release IP addresses to the DHCP server and select a faster way to get the vehicle's new IP address.

Vehicular Network Routing (2/3)

- Experimental Evaluation for IPv6 over VANET Geographic Routing [11].
  - It proposes **a combination** of **IPv6 networking** and a **Car-to-Car Network routing protocol (C2C Net)** of the Car2Car Communication Consortium.
  - C2CNet is an architecture using a **geographic routing**.
  - The combination of **IPv6 multicast** and **GeoBroadcast** was implemented.
  - The test results show that **IPv6 over C2CNet** does not have too much delay (less than 4ms with a single hop) and is feasible for vehicular communication.
  - In the outdoor testbed, they developed **AnaVANET** to enable hop-by-hop performance measurement and position trace of the vehicles.

Vehicular Network Routing (3/3)

- Key Observations
  - **IP address autoconfiguration** should be manipulated to support the efficient networking.
  - Due to **network fragmentation**, vehicles cannot communicate with each other temporarily.
  - **IPv6 Neighbor Discovery (ND)** should consider the temporary network fragmentation.
  - **IPv6 link concept** can be supported by **Geographic routing** to connect vehicles with the same IPv6 prefix.

Mobility Management in Vehicular Net (1/3)

- A Hybrid Centralized-Distributed Mobility Management [12][13]
  - Hybrid centralized-distributed mobility management (DMM + PMIPv6)
  - A vehicle obtains a prefix from the mobile access router through DMM and another prefix from the PMIPv6 domain.
- NEMO-Enabled Localized Mobility Support for Internet Access in Automotive Scenarios [14]
  - It enables IP mobility for moving networks in a network-based mobility scheme based on PMIPv6.
  - The functionality of the MAG is extended to the mobile router.
- Network Mobility Protocol for Vehicular Ad Hoc Networks [15]
  - Using a NEMO-Based protocol, vehicles acquire IP addresses from other vehicles through V2V communications in highway scenarios.
  - Cars on the same or opposite lane are entitled to assist the vehicle to perform a pre-handoff.

Mobility Management in Vehicular Net (2/3)

- Performance Analysis of PMIPv6-Based Network MObility for Intelligent Transportation Systems [16]
  - It adapts PMIPv6 to enable IP mobility for the moving network, instead of a single node as in the standard PMIPv6.
  - It adopts the fast handover approach standardized for PMIPv6 in [RFC5949].

- A Novel Mobility Management Scheme for Integration of Vehicular Ad Hoc Networks and Fixed IP Networks [17]
  - It uses information provided by vehicular networks to reduce mobility management overhead.

- SDN-based Distributed Mobility Management for 5G Networks [18]
  - Hybrid PMIP-DMM is used, where mobility functions are located in Open Flow Switches (data plane).
  - One or more SDN controllers handle the Control plane.

Mobility Management in Vehicular Net (3/3)

- Key Observations
  - Mobility Management (MM) solution design varies, depending on scenarios: highway vs. urban
  - Hybrid schemes (NEMO + PMIP, PMIP + DMM, etc.) usually show better performance than pure schemes.
  - Most schemes assume that IP address configuration is already set up.
  - Most schemes have been tested only at either simulation or analytical level.
  - SDN can be considered as a player in the MM solution.

Summary and Analysis (1/3)

- Fitness of IPv6 over WAVE
  - IPv6-based vehicular networking can be well-aligned with IEEE WAVE standards for various vehicular network applications,
    - such as driving safety, efficient driving, and infotainment.

- IPv6 ND Adaption
  - The IEEE WAVE standards do not recommend to use the IPv6 neighbor discovery (ND) protocol for the communication efficiency under high-speed mobility.
  - It is necessary to adapt the ND for vehicular networks with such high-speed mobility such that ND can operate rapidly with little overhead.

Summary and Analysis (2/3)

- Support of IPv6 Link Concept
  - The concept of a link in IPv6 does not match that of a link in VANET.
  - This is caused by the physical separation of communication range in a connected VANET.
  - The IPv6 ND should be extended to support this multi-link subnet of a connected VANET through either ND proxy or VANET routing.
- IP Address Autoconfiguration
  - In mobility management, a vehicle's IP address should be updated/configured proactively along its movement via the vehicular cloud.
  - DAD for unique IP addresses can be performed by the infrastructure rather than a vehicle.

Summary and Analysis (3/3)

- Routing and Mobility Management using Vehicle Trajectory
  - Most of vehicles are equipped with a GPS navigator as a dedicated navigation system or a smartphone App.
  - With this GPS navigator, vehicles can share their current position and trajectory (i.e., navigation path) with TCC.
    - TCC can predict the future positions of the vehicles with their mobility information (i.e., the current position, speed, direction, and trajectory).
  - With the prediction of the vehicle mobility, TCC supports RSUs to perform data packet routing and handover proactively.

Next Steps for Survey Draft

- Enhancement of Security and Privacy Considerations
  - The use of TLS certificates for vehicle communications
  - Privacy considerations by a new ETSI activity (e.g., in-vehicle device’s identifier generation)
- Inclusion of More Relevant Papers
- Inclusion of Industry Activities for Vehicular Networking

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