Survey on IP-based Vehicular Networking for Intelligent Transportation Systems

(draft-ietf-ipwave-vehicular-networking-survey-00)

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Updates from the Previous Version

- The previous version was:
  - draft-jeong-ipwave-vehicular-networking-survey-02

- Changes from the previous versions
  - Use Cases for Vehicular Networking are added as Section 10:
    - Use Cases for V2I Networking
    - Use Cases for V2V Networking

Introduction to Vehicular Networking

- Objective of this Draft
  - To survey the activities of academia, SDOs, and industry of IP-based vehicular networks for Intelligent Transportation Systems (ITS) along with use cases.
- Assumptions for Vehicular Networks
  - **IEEE 802.11 Series** (a, b, g, n / OCB) or **Cellular Links** (3G-UMTS, WCDMA, 4G-LTE, 5G-New Radio (NR)) are considered as main link types.
  - **IPv6** is considered as the 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.

Vehicular Networking Topics

1. IP Address Autoconfiguration
2. Vehicular Network Architecture
3. Vehicular Network Routing
4. Mobility Management in Vehicular Networks
5. Vehicular Network Security
6. Standard Activities for Vehicular Networks
7. Use Cases for Vehicular Networking

Use Cases for Vehicular Networking (1/2)

- Use Cases for V2I Networking
  - Navigation Systems
    - SAINT: Self-Adaptive Interactive Navigation Tool for Cloud-Based Vehicular Traffic Optimization [33]
    - SAINT+: Self-Adaptive Interactive Navigation Tool+ for Emergency Service Delivery Optimization [34]
  - Intersection Management
    - Cooperative Vehicle Intersection Control Algorithm for Connected Vehicles (CVIC) [40]
  - Emergency Network System
    - First Responder Network Authority (FirstNet) [35]
  - Pedestrian Protection System
    - SANA: Safety-Aware Navigation Application for Pedestrian Protection in Vehicular Networks [36]

Use Cases for Vehicular Networking (2/2)

- Use Cases for V2V Networking
  - Driving Safety Systems
    - CASD: A Framework of Context-Awareness Safety Driving in Vehicular Networks [37]
  - Automated Driving Systems
    - Cooperative Adaptive Cruise Control [38]
    - Automated Truck Platooning [39]
  - Vehicle-to-Vehicle Warning System
    - Coyote marketed black-boxes warning about speed limits and traffic hazards, in community, over GPRS with IP [41]
    - Waze [42] and TOMTOM Live Services [43]

Summary and Analysis (1/3)

- Suitability 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 entertainment.

- IPv6 ND Adaptation for Vehicular Networking
  - 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 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 vehicular networks.
  - DAD for unique IP addresses can be performed by the infrastructure (e.g., RSU) 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 (e.g., a dedicated navigation system or 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 permits RSUs to perform data packet routing and handover proactively.

Next Steps

- Inclusion of More Papers, Use Cases, and Industry Activities along with
  - Automotive Companies (e.g., GM, Toyota, Honda, and BMW)
  - CAR 2 CAR Communication Consortium (C2C-CC)
  - 5G Automotive Association (5GAA)
  - European Automotive-Telecom Alliance
  - Use Cases from ETSI Intelligent Transport Systems (ITS)
    - Basic Set of Applications (ETSI TR 102 638)

- Inclusion of Taxonomy Tables
  - Each technology section will have a taxonomy table to categorize the protocols and schemes with their characteristics and features.

- **Plan for WGLC in IETF 100**.

- Welcome Comments from IPWAVE WG.

Appendix: Document Summary

IP Address Autoconfiguration (1/3)

- 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 (2/3)

- Cross-layer Identities Management in ITS Stations [32]
  - Cross-layer Identity Management in Vehicular Networks using Multiple Access Network Technologies
    - An ITS station (e.g., vehicle) should be correctly identified even with multiple identities for its multiple network interfaces.
  - Consideration in ETSI GeoNetworking
    - For security and privacy constraints, the IPv6 address of a vehicle should be derived from a pseudonym-based MAC address and renewed correspondingly.

IP Address Autoconfiguration (3/3)

- 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 prevent or reduce **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 be 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 are defined for all required IP ITS topologies: Leaf Vehicle (LV), Range Extending Vehicle (REV), and Internet Vehicle (IV)
  - VANET ITS interference may be controlled by separating each WiFi/ITS-G5 channel as IP subnetworks and advertising them through REVs.
- 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 Vehicle (LV), Range Extending Vehicle (REV), and Internet Vehicle (IV)

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.

Vehicular Network Security (1/2)

- Securing Vehicular IPv6 Communications [21]
  - A secure vehicular IPv6 communication scheme is proposed using
    - Internet Key Exchange version 2 (IKEv2) and
    - Internet Protocol Security (IPsec).
  - The aim of the proposed scheme is
    - To support the security of IPv6 Network Mobility (NEMO) for in-vehicle devices inside a vehicle, and
    - To use a Mobile Router (MR) in a vehicle, which has multiple wireless interfaces (i.e., IEEE 802.11p, WiFi, and WiMAX).

- Providing Authentication and Access Control in Vehicular Network Environment [22]
  - A security scheme for vehicular networks is proposed using
    - Authentication, authorization, and accounting (AAA) services
  - The support of confidential data transfer between communicating parties by using IEEE 802.11i (i.e., WPA2)

Vehicular Network Security (2/2)

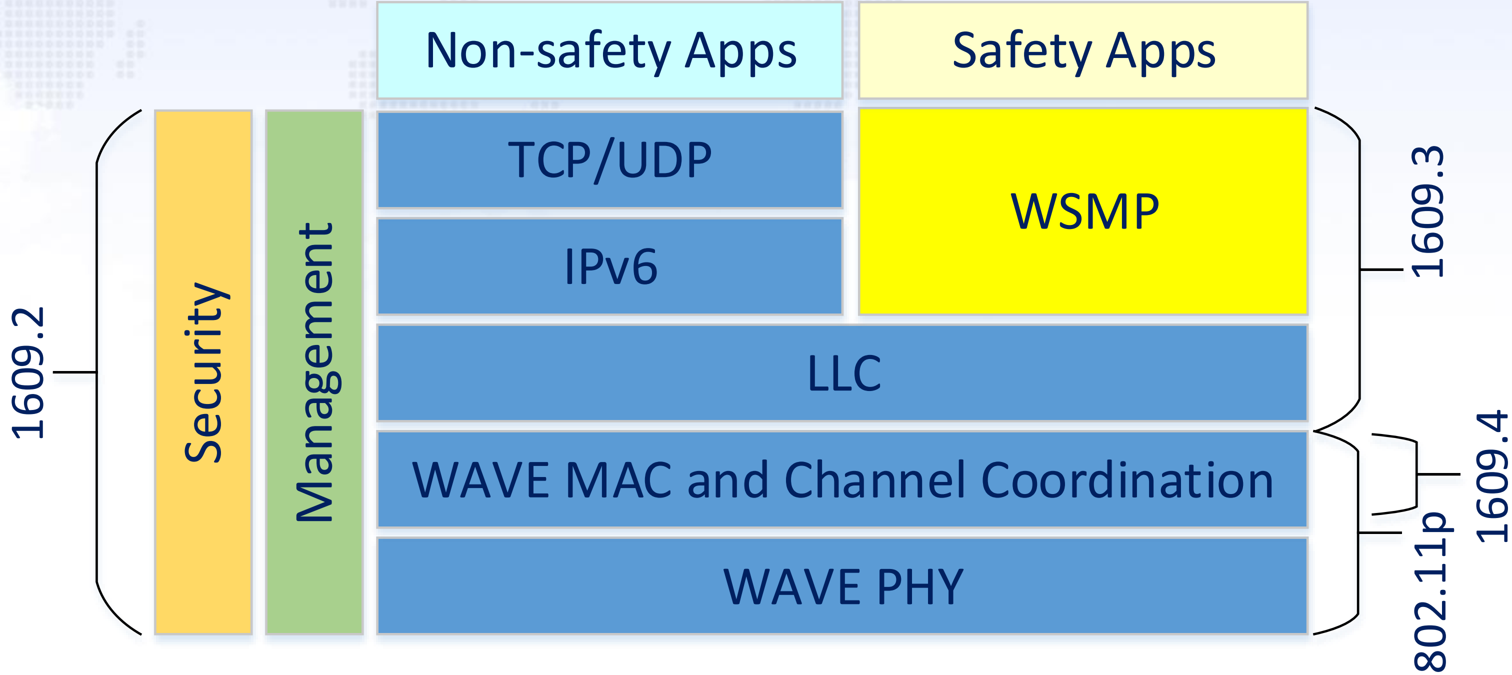
- Key Observations
  - The security for vehicular networks should provide vehicles with AAA services in an efficient way.
  - It should consider not only horizontal handover, but also vertical handover since vehicles have multiple wireless interfaces.

Standardization Activities (1/7)

- **IEEE Guide for Wireless Access in Vehicular Environments (WAVE) - Architecture (1/2)**
  - IEEE 1609 [25] is a suite of standards for WAVE developed in the IEEE, which define
    - An architecture and a complementary standardized set of services and interfaces for V2V and V2I communications.
  - IEEE 1609.0 [25] provides a description of the WAVE system architecture and operations.
    - Two data plane protocol stacks, such as IPv6 and WAVE Short Message Protocol (WSMP)

Standardization Activities (2/7)

- **IEEE Guide for Wireless Access in Vehicular Environments (WAVE) - Architecture (2/2)**



IEEE 1609.1: Core Systems

IEEE 1609.2: Security

IEEE 1609.3: Network Services

IEEE 1609.4: Channel Management

Standardization Activities (3/7)

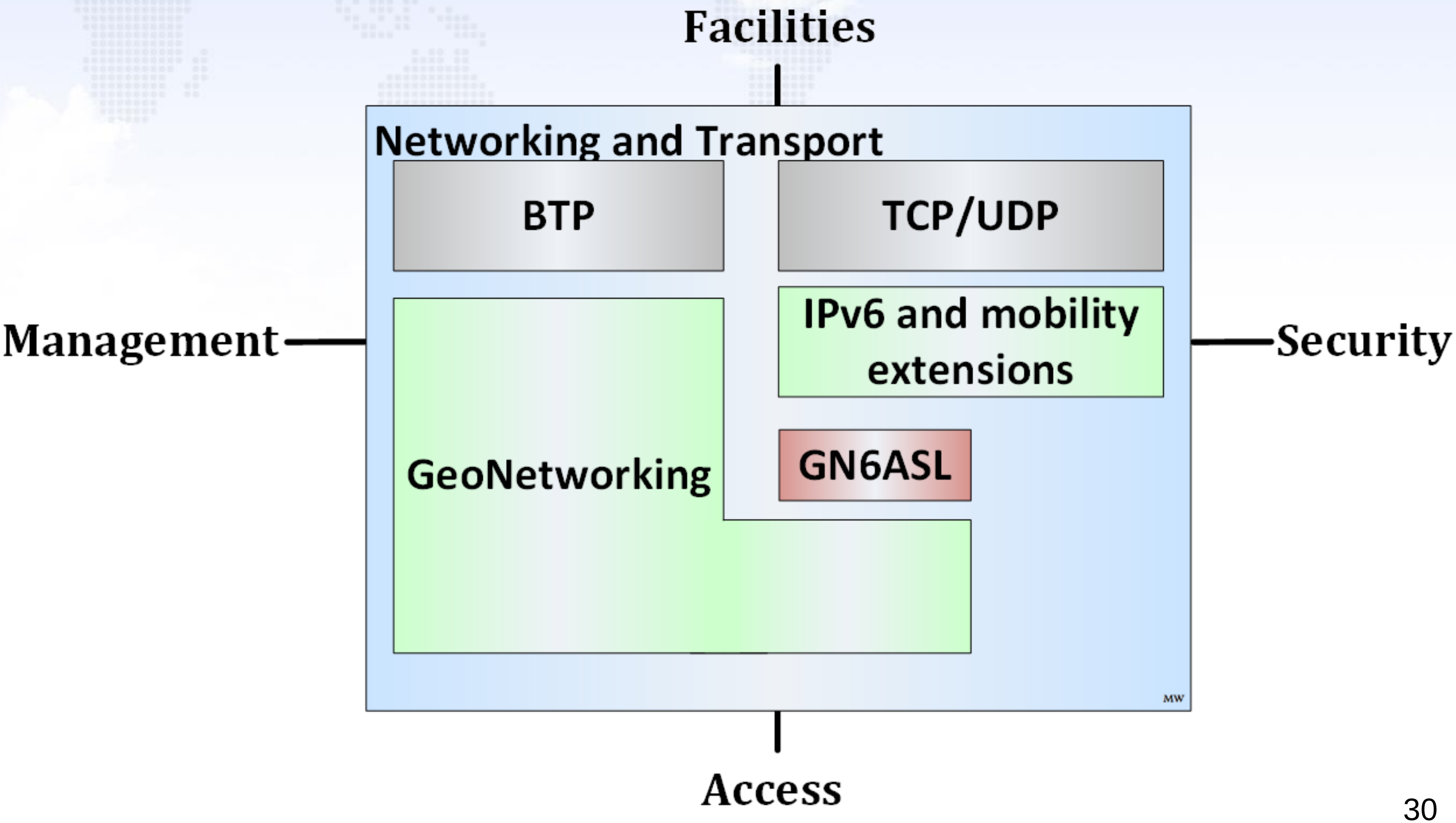
- **IEEE Guide for Wireless Access in Vehicular Environments (WAVE) - Networking Services**
  - IEEE 1609.3 [27] defines networking services operating at the network and transport layers in WAVE.
    - It specifies addressing and routing services at the network layer and transport layer in WAVE for the application layer (e.g., safety and navigation applications).
  - It provides requirements for IPv6 configuration, such as address setting.
    - WAVE Routing Advertisement (WRA) provides information about infrastructure internetwork connectivity.
    - WRA removes the need for an IPv6 Router Advertisement (RA) message in IPv6 Neighbor Discovery (ND).

Standardization Activities (4/7)

- **ETSI ITS: Transmission of IPv6 Packets over GeoNetworking Protocols (1/3)**
  - ETSI specified the transmission of IPv6 packets over the ETSI GeoNetworking (GN) protocol.
    - GN is defined in **ETSI EN 302 636-4-1 [29]**.
    - IPv6 packet transmission over GN is defined in **ETSI EN 302 636-6-1 [30]** using a protocol adaptation sub-layer called GeoNetworking to IPv6 Adaptation Sub-Layer (GN6ASL).
  - The GN6ASL enables the following:
    - IPv6 on V2X communications,
    - Global IPv6 address acquisition (or configuration), and
    - Operating as a mobile router.

Standardization Activities (5/7)

- **ETSI ITS: Transmission of IPv6 Packets over GeoNetworking Protocols (2/3)**



Standardization Activities (6/7)

- **ETSI ITS: Transmission of IPv6 Packets over GeoNetworking Protocols (3/3)**
  - IPv6 over GN protocol introduces three types of virtual links for
    - Symmetric reachability by means of stable geographically scoped boundaries,
    - The support of Neighbor Discovery (ND) protocol including Stateless Address Autoconfiguration (SLAAC),
    - The dynamic definition of a broadcast domain, and
    - The support of the change of pseudonym, i.e., changing IPv6 addresses when the GN address is changed.

Standardization Activities (7/7)

- **ISO ITS: Communications Access for Land Mobiles (CALM) Using IPv6 Networking**
  - ISO specified a standard to support the following IPv6 networking [31]:
    - The global reachability of ITS stations (ITS-S),
    - The continuous Internet connectivity for ITS-S, and
    - The handover functionality required to maintain such a connectivity.
  - The standard defines the following IPv6 functional modules that are necessary in an IPv6 ITS-S
    - IPv6 forwarding,
    - Interface between IPv6 and lower layers (e.g., LAN, WLAN interfaces),
    - IPv6 address configuration of static nodes and mobile nodes,
    - Mobility management, and
    - IPv6 security.

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