Advanced Architectures and Control Technologies in Internet of Vehicles

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- **Acknowledgement**
  - This overview and analysis is compiled and structured, based on several public documents, conferences material, studies, research papers, standards, projects, overviews, tutorials, etc. (see specific references in the text and Reference list).
  - The selection and structuring of the material belongs to the author.
  - Given the extension of the topics, this presentation is limited to a high level overview only, mainly on architectural aspects.

Advanced Architectures and Control Technologies in Internet of Vehicles

- **Motivation of this talk**
- ***Intelligent Transport System (ITS) – mature set of standards and implementations***
  - includes vehicular communication **(VC)**

- **Vehicular ad-hoc Networks (VANET)**
  - special class of ***Mobile ad-hoc Network -MANET***)
  - (VANET) – is a part of the ITS ; V2V, V2R, V2I communications
  - **VANET limitations: technical and business-related => not very large scale deployment in the world**

- **Recent approach: IoV –significant extension of the VANET capabilities**
  - global network of vehicles – enabled by ***Wireless Access Technologies (WAT)***
  - involves Internet and includes heterogeneous access networks
  - IoV – can be seen a special case of ***Internet of Things (IoT)***
  - **IoV Target domains:**
    - Vehicles driving and safety (basic function – in VANET)
    - Novel domains:
      - traffic management, automobile production repair and vehicle insurance, road infrastructure construction and repair, logistics and transportation, etc.

  - IoV challenges : still open issues related to architectures and implementations

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1. Introduction

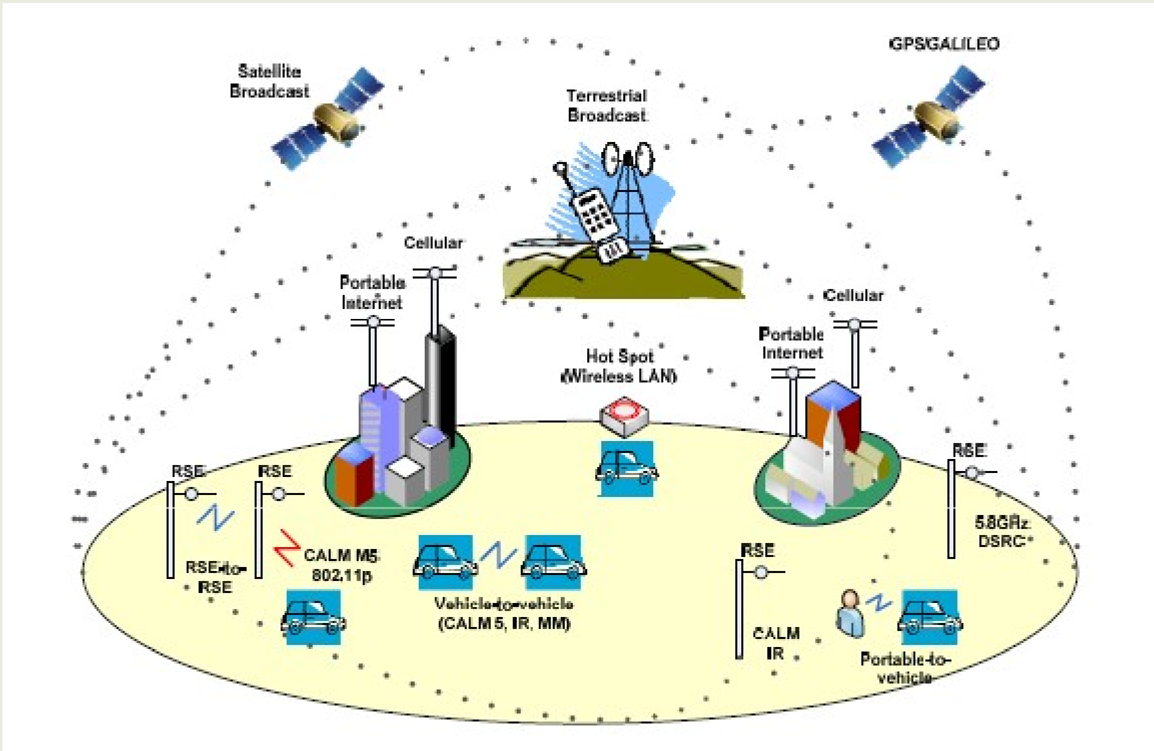
1.1 Intelligent Transport System (ITS)

- Comprises **advanced technologies using IT&C,** to serve **transportation systems**
- Operation of vehicles, manage vehicle traffic, assist drivers with safety and other information, provision of applications for passengers
- high interest for companies, operators, government, academia, research; many countries have public and private sector bodies working on ITS
- **Typical use cases and services/applications**
  - **Active road safety** applications
    - Warnings, notifications, assistance
  - **Traffic efficiency** and management applications
  - **Infotainment** applications

1.Introduction

1.1 Intelligent Transportation System

- Elements of ITS are standardized : on int'l level at e.g., ISO TC204, and on regional levels, e.g., in Europe at ETSI TC ITS and at CEN TC278



ITS Scenario illustration

Source : ETSI EN 302 665 V1.1.1 (2010-09, European Standard (Telecommunications series) Intelligent Transport Systems (ITS); Communications Architecture

Source : G.Karagiannis,et.al.,"Vehicular Networking:A Survey and Tutorial on Requirements,Architectures, Challenges, Standards and Solutions", IEEE Comm. Surveys and Tutorials, 2011

1. Introduction

1.1 Intelligent Transportation System (cont'd)

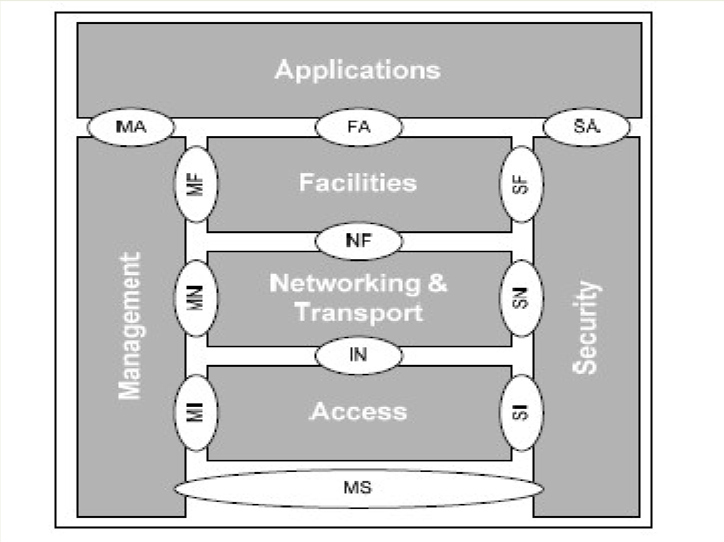
- **Application categories – target usage**
  - Infrastructure oriented applications
  - Vehicle oriented applications
  - Driver oriented services
  - Passengers oriented applications

- **Networks involved in the ITS architecture**
  - **Ad-hoc network**
    - Essentially is an ad-hoc V2V, connecting also roadside and personal ITS stations; Wireless technologies, (limited range)
  - **Access Networks**
    - provides access to specific ITS services and apps.
    - can be operated by a road operator or other operators
    - interconnect roadside ITS stations and provides communication between entities
  - **Core networks**

1. Introduction

1.1 Intelligent Transportation System (cont'd)

- **ITS station reference architecture** [2 - ETSI EN 302 665 V1.1.1]
  - **"Access" - ITSC's, L1-2**
  - **"Networking & Transport" - ITSC's, L3-4**
  - **"Facilities" - ITSC's, L5-7**
  - ITS sub-systems:
    - personal ITS - in hand-held devices
    - central ITS - part of an ITS central system
    - vehicle ITS - in cars, trucks, etc., in motion or parked
    - roadside ITS - on gantries, poles, etc.



Interfaces

FA facilities layer - ITS-S applications
NF networking & transport layer facilities layer
IN access layer - networking & transport layer
Management entity to
  MF -facilities layer
  MI -access layer
  MS - security entity
Security entity to
  SF - facilities layer
  SI - access layer
  SN - networking & transport layer

1. Introduction

1.1 Intelligent Transportation System and CALM

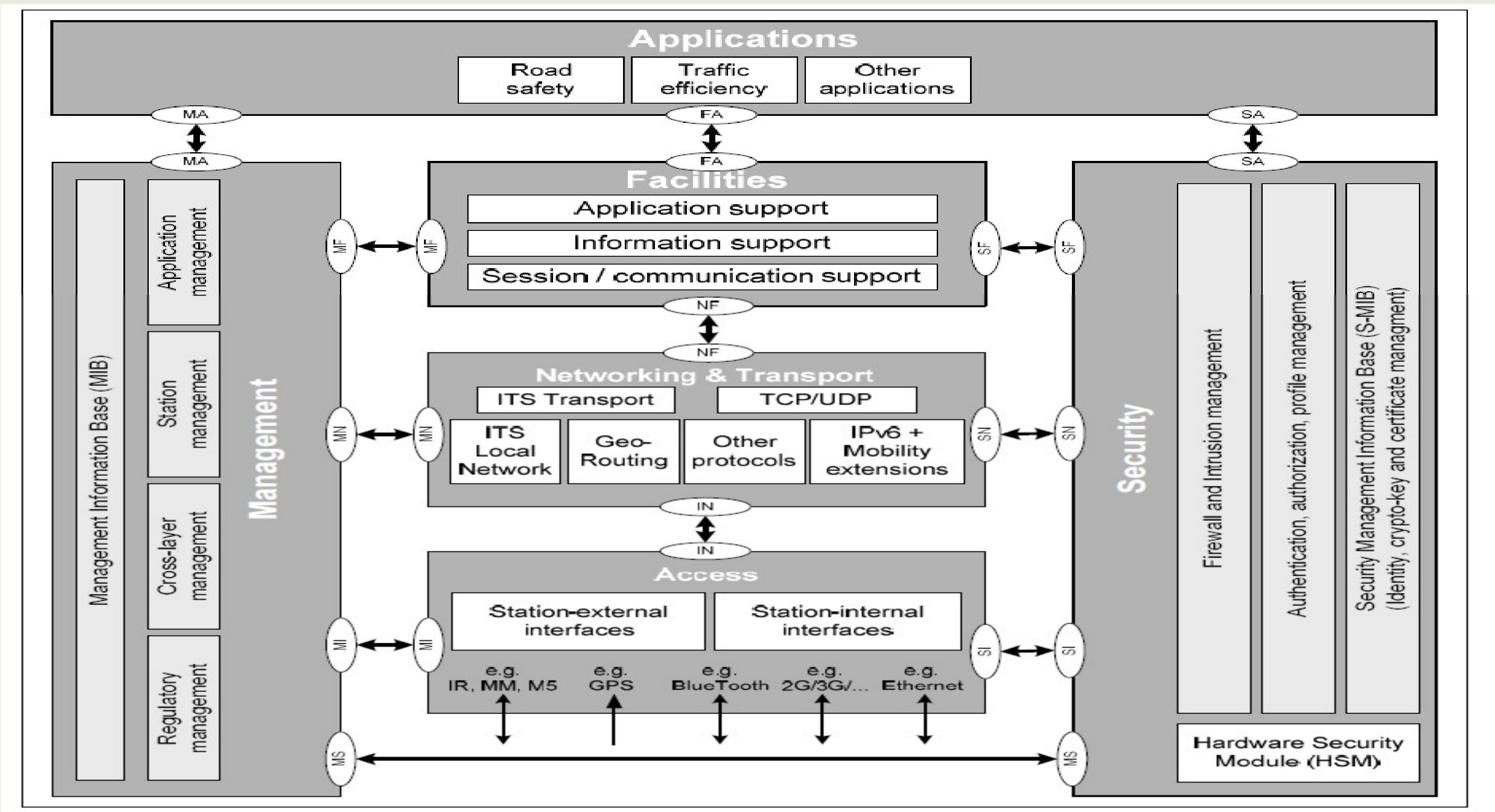
- **ISO Technical Committee 204**:
  - http://www.sae.org/technicalcommittees/tc204wg16.htm
- WG 16: Wide Area Communications
  - **CALM: Communication Architecture for Land Mobile**
  - SWG 16.0-: SWG 16.6-: Architecture; Media; Network; Probe Data; Application Management; Emergency notifications (eCall); CALM ad-hoc subsystem
- CALM allows V2V, V2I and Internet access through multiple RATs
  - (potentially used simultaneously)

- **Media:**
  - Cellular (CALM 2G/3G) – cf CD 21212 & CD 21213, ...
  - Infrared light (IR) – cf CD 21214
  - Microwave (CALM M5) – cf CD 21215
  - **IEEE 802.11 a/b/g (WIFI)**
  - **IEEE 802.11p (mobile WIFI)**
  - Millimeter waves (CALM MM) – cf CD 21216
  - Microwaves CEN DSRC
- Network protocol : IPv6

1.Introduction

1.1 Intelligent Transportation System (cont'd)

- **ITS station reference architecture –typical instantiation- developed for CALM**



1. Introduction

1.1 Intelligent Transportation System (cont'd)

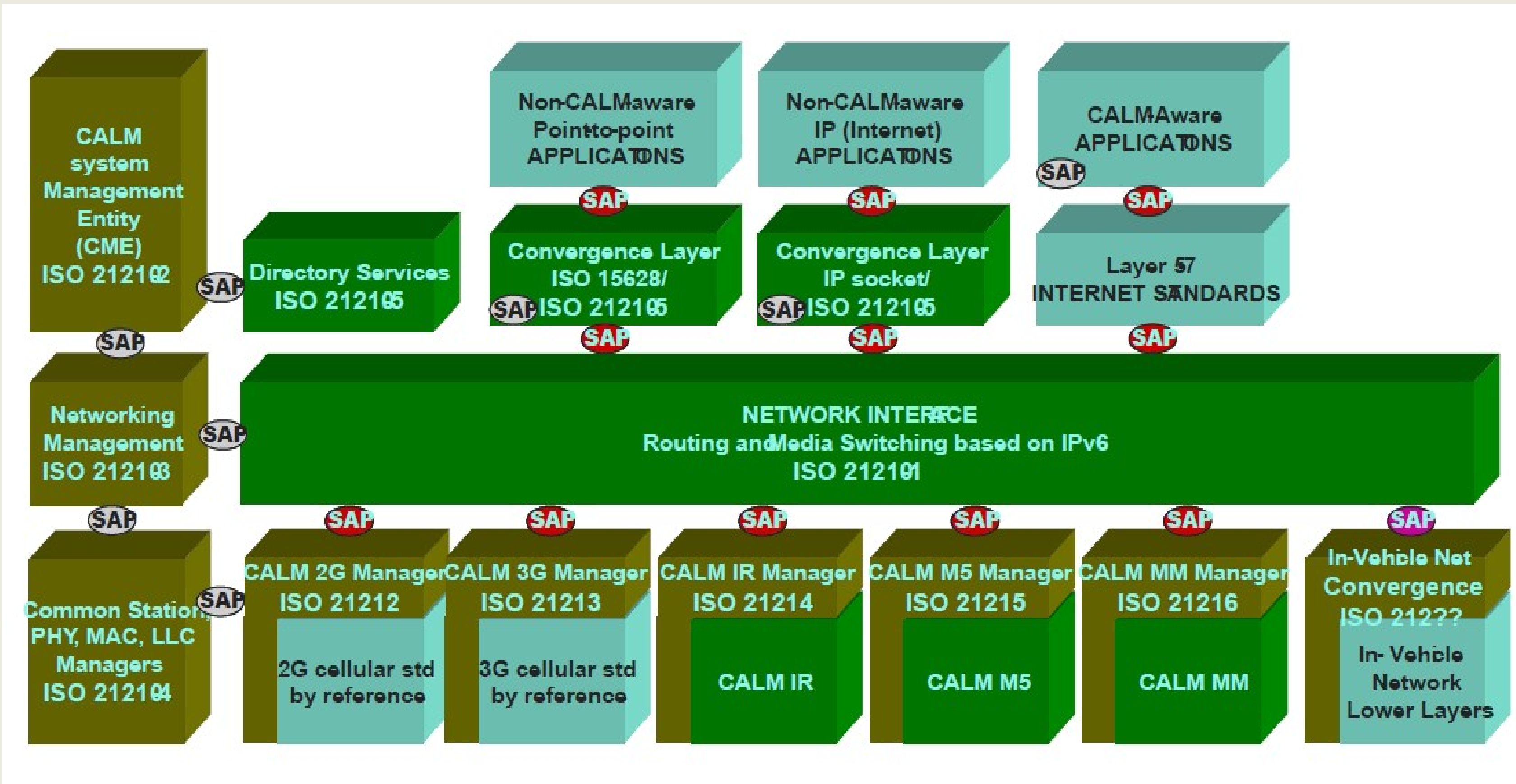
- **Functional components of an ITS/CALM station**
  - **ITS-S host-** ITS-S applications and the functionality of the ITS-S ref. architecture
  - **ITS-S gateway-** interconnects two different OSI protocol stacks at layers 5 to 7.
    - It shall be capable to convert protocols
  - **ITS-S router-** It interconnects two different ITS protocol stacks at layer 3
    - It may be capable to convert protocols.
  - **ITS-S border router –** functions similar to a traditional border router

- **ITS sub-systems**
  - ***personal ITS***
  - ***central ITS****;* part of an ITS central system- cooperates with the Central System
    - ITS-S gateway, ITS-S host, ITS-S border router
  - ***vehicle ITS;*** in cars, trucks, etc., in motion or parked
    - ITS-S gateway, ITS-S host, ITS-S router
    - Cooperates with vehicle network (containing Electronic Control Units)
  - ***roadside ITS*;** on gantries, poles, etc.
    - Roadside ITS-S gateway, ITS-S host, ITS-S router, ITS-S border router
    - roadside ITS-S gateway connects the components of the roadside system, e.g. inductive loops, variable message signs (VMS)

1. Introduction

1.2 CALM Architecture – basic standards

- Standards that are outside CALM scope

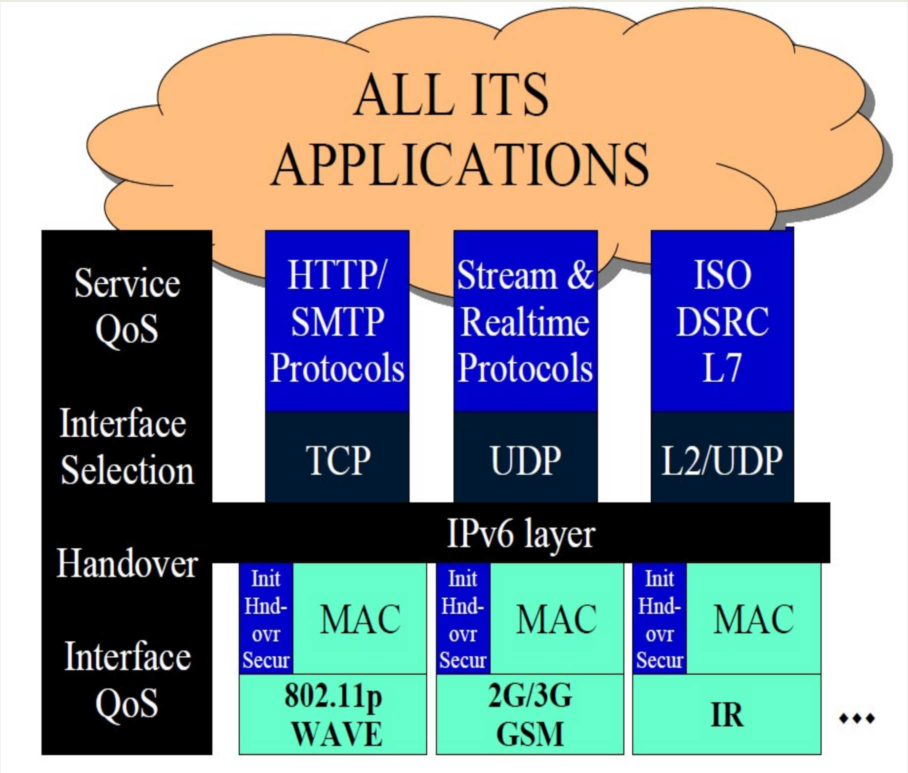


Source : E. Thierry, „ISO TC204 WG 16: The CALM Architecture", IMARA project- INRIA, 2008, http://www.lara.prd.fr

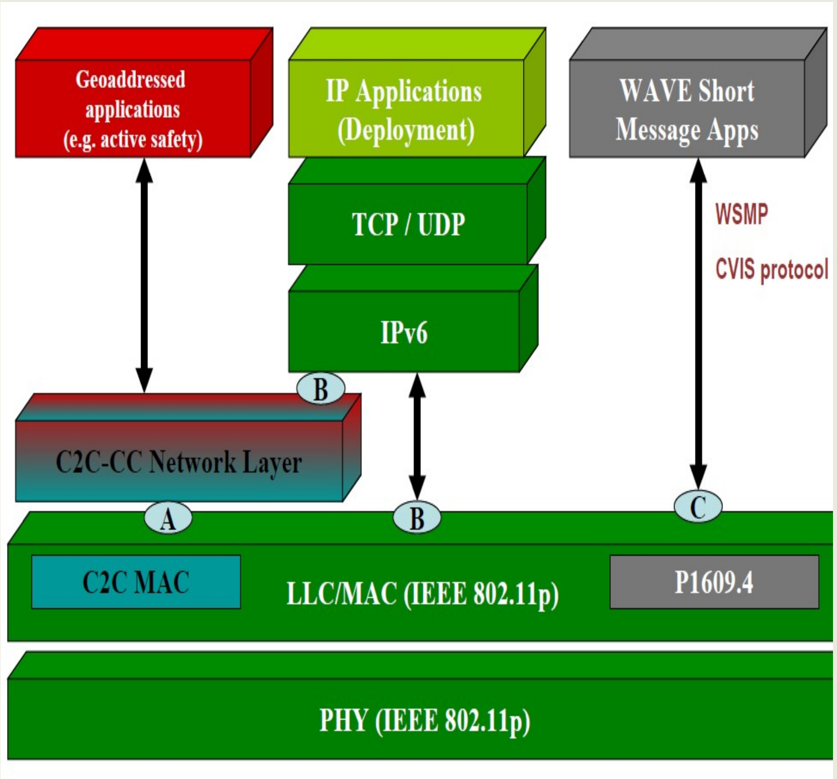
1. Introduction

1.2 ITS and CALM Architecture

ISO TC204 WG16: CALM Architecture



CALM M5: C2C-CC & WAVE



Source : E. Thierry, „ISO TC204 WG 16: The CALM Architecture", IMARA project- INRIA, 2008, http://www.lara.prd.fr

1. Introduction

1.3 Vehicular communication technologies- examples

- ***DSRC (Dedicated Short Range Communication):***
  - spectrum dedicated for comm. of ITS components (vehicles, infrastructure)
  - US *Federal Communications Commission* (FCC) allocated 75 MHz of spectrum in the 5.9 GHz band for ITS - 1999
  - ETSI allocated 30 MHz of spectrum in the 5.9 GHz band for ITS- 2008
  - **Issue:** DSRC systems in Europe, Japan and U.S. are not fully compatible
- ***WAVE (Wireless Access in Vehicular Environment):***
  - MAC/PHY and higher layers standards used for VC
  - higher layers, such as IEEE 1609.1-4, are also considered as part of WAVE
  - **WAVE : IEEE 802.11p + IEEE 1609.1-4 + SAE 2735** (*Society of Automotive Engineers*)

1. Introduction

1.3 Vehicular communication technologies (cont'd)

- **VANET**
  - V2V and V2I communications based on WLANs

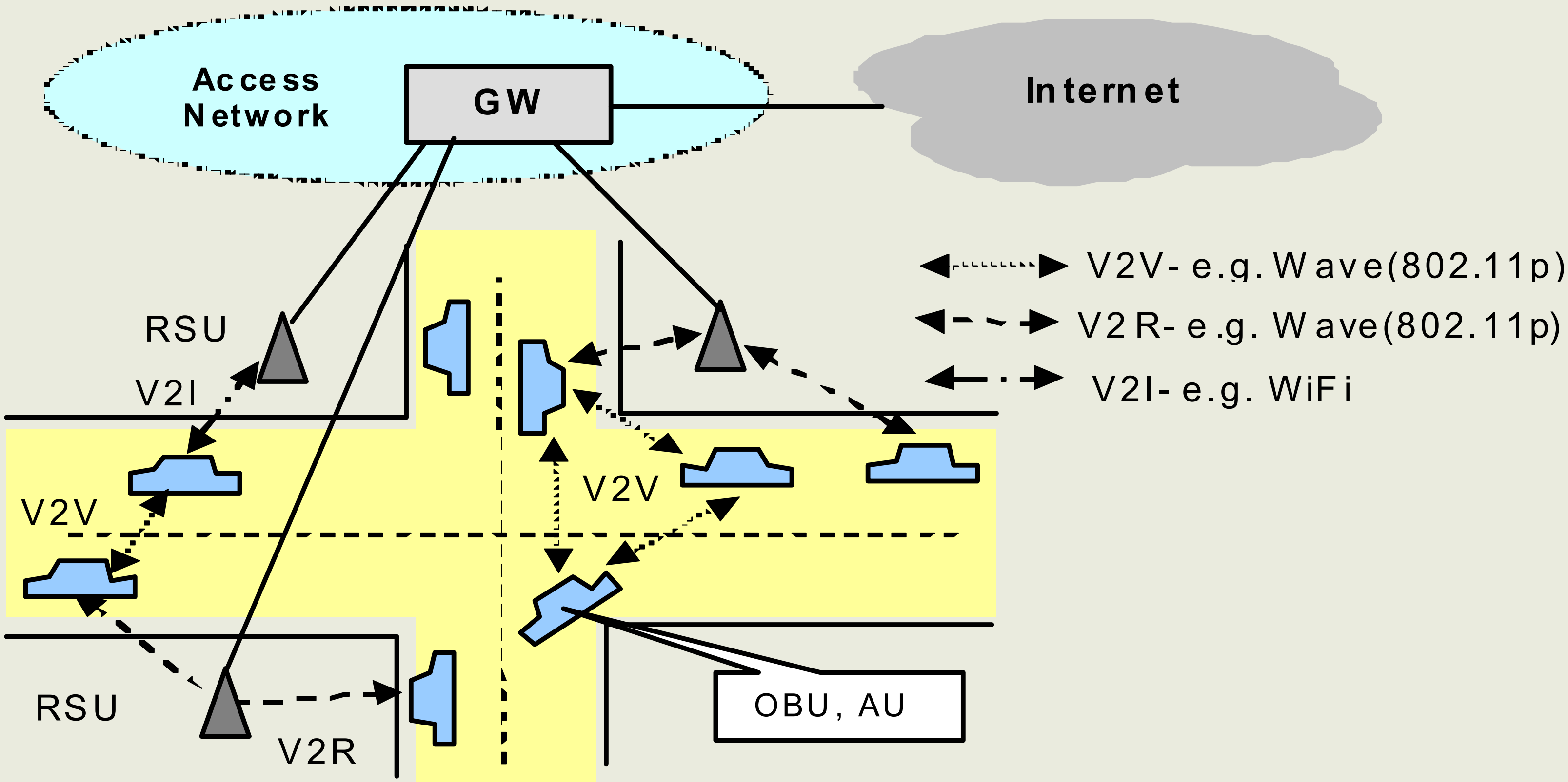
  - **Applications examples**
    - **Safety**
      - Purpose: avoid collisions and accidents
      - Severe delay tolerance (~100ms)

    - **Non safety**
      - **Efficiency/traffic management:**
        Latency – few seconds; Purpose: save time and money
      - **Comfort**
        Relaxed latency constraints; Purpose: info on facilities- restaurants, hotels, parking, etc.
      - **Entertainment**
        Real-time or non-real time constraints (depending on apps.)
        Multimedia sharing, general Internet access, etc.

1. Introduction

1.3 VANET

- VANET communication types
  - **V2V, V2R, V2I**



1. Introduction

1.3 VANET (as ITS subsystem)

- **Main VANET characteristics**

Characteristic	VANET
Participating nodes	Vehicles (OBU) , Roadside unit (RSU) static and/or mobile nodes
Communication type	V2V, V2R/V2I, single or multi-hop
Available bandwidth	e.g. 75MHz band available for VANET in US
Energy constraint	No
Topology	Variable: nodes (vehicles) frequently join and leave the network Vehicle movements – may be correlated
Node mobility speed	0 – 40 m per second
Signal reception quality	Poor signal reception due to the radio: obstacles, (roadside buildings) interferences
Connection life	Short- depending on road conditions, traffic lights, jams, etc.
Physical Channel	Fast time varying (blocked transmission by buildings, vehicles)
Connectivity	End-to-end connectivity not guaranteed
Additional sensors	High-quality GPS and digital maps
Infrastructure	RSUs work as gateways to the Internet

1. Introduction

1.3 VANET

- **Basic VANET system components**

  - **RSU- Road Side Unit typically**
    - hosts applications that provides services
    - connection to the Internet of several AUs

  - **OBU On-board Unit-** device that uses the services
    - set of sensors *to collect* and *process* the information
    - sending information as messages to other Vs or RSUs

  - **AU - Application Unit**
    - Vehicle: may host n≥1 AUs that use the applications offered by the provider, supported by OBU connection capabilities

- The applications may also reside in the RSU or in the OBU (provider/user model)

1. Introduction

1.3 VANET (cont'd)

- **Basic VANET system components**

- **On-Board Unit (OBU)** *(Ref [12] Saini)*
  - HW device mounted on the vehicle
  - It communicates with other OBUs and RSUs (~router)

  - **Typical structure**:
    - transceiver ,RF antenna
    - processor , read/write memory
    - user interface.

    - A *Vehicle Control Unit (VCU)* coordinates with the OBU to collect/disseminate vehicular statistics.
    - Other OBU I/Fs: (e.g. USB and Bluetooth), to connect to other devices on the vehicle, for example: laptops, smartphones and PDAs
    - GPS sensor

  - A **network stack** runs on the processor to provide the abstraction of VANET
  - Communication standards: IEEE 802.11p, IEEE1609.1, 2, 3 and 4

1. Introduction

1.3 VANET (cont'd)

- **Basic VANET system components**
- **On-Board Unit (OBU)** (cont'd)
- **OBU basic requirements and responsibilities :**
  - A RF antenna + wireless channel (communication -other OBUs and RSUs)
  - Software to run a specific VANET network stack
  - Data forwarding on behalf of other OBUs

  - **Control functions**:
    - routing, network congestion, control, data security, and IP mobility
  - A user I/F to exchange information with the end user, or a connection with a device that has a user I/F
  - A mechanism to generate safety messages to be shared with other OBUs and RSUs
    - these messages can come
      - directly from the user
      - or from automatic processing of sensory data

1. Introduction

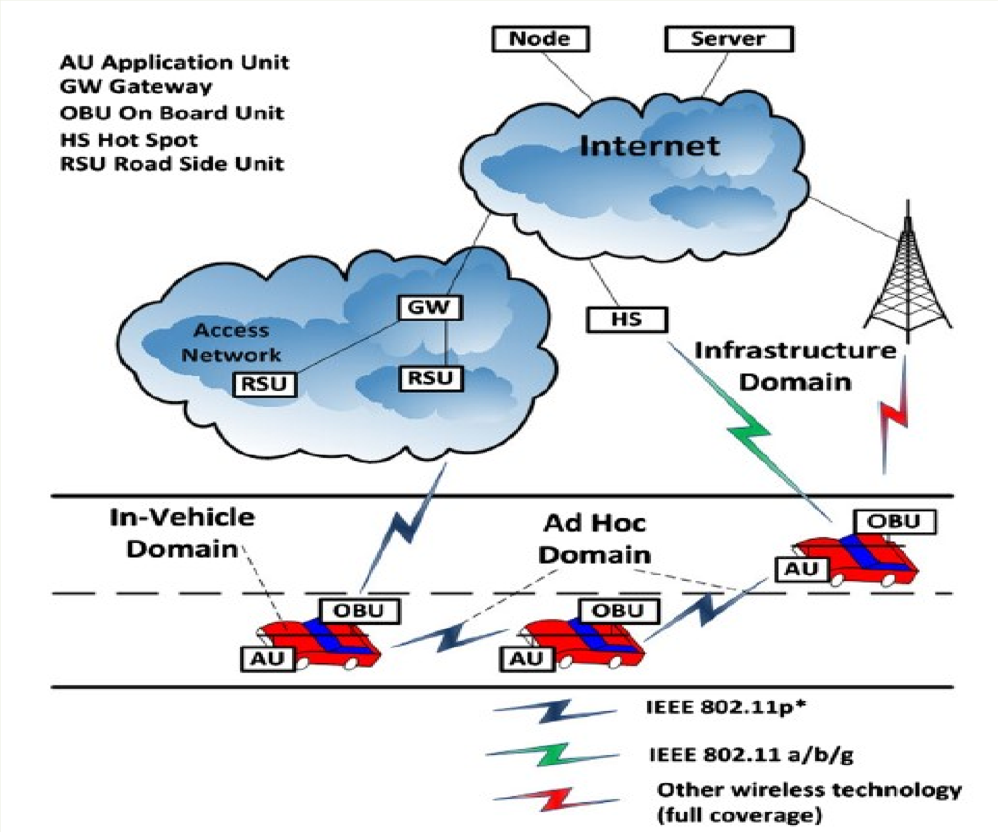
1.3 VANET (cont'd)

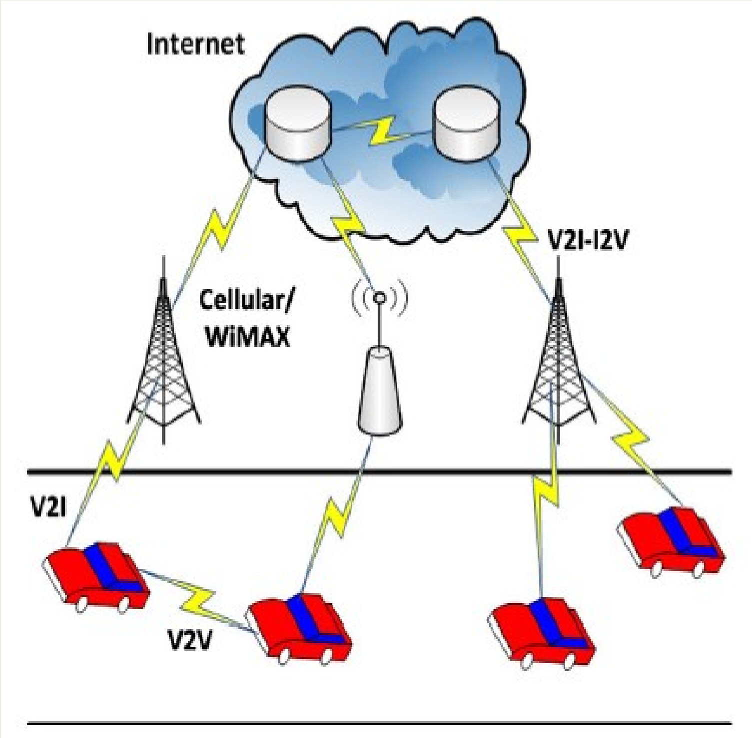
- **Basic VANET system components (cont'd)**
- **RSU- Road Side Unit**
  - antenna, processor, and R/W memory
  - wireless and wired I/Fs to communicate with OBUs, other RSUs and the Internet
  - extends the coverage area of OBUs through data forwarding
  - **RSUs are installed** (optimization multi-criteria problem!)
    - along the roads, mainly near intersections and gas stations
    - locations of high vehicle density
  - **RSU Main functionalities**
    - RF, high power, and long-range antenna
    - access to wired channels, (coax, cable or OF cable, with Eth-like protocols)
    - Network stack (L1- L3) protocols
    - Forwarding data packets to OBUs in its range and other RSUs
    - Aggregation of safety information from OBUs through safety apps. and alarming incoming OBUs
    - GW to provide Internet connectivity to OBUs
  - **Standards to be supported:** IEEE 802.11p, and all four IEEE 1609 protocols.

1. Introduction

1.3 VANET (cont'd)

- **VANET – communication domains**





Combined DSRC, Cellular, Wi-Fi and WiMAX

Source: S. Sultan, M. Moath Al-Doori, A.H. Al-Bayatti, and H.Zedan "A comprehensive survey on vehicular Ad Hoc Network", J.of Network and Computer Applications, Jan. 2014

1. Introduction

1.4 Radio Access Technologies (RAT)

- **Spectrum Allocation in US , Europe, and Japan**

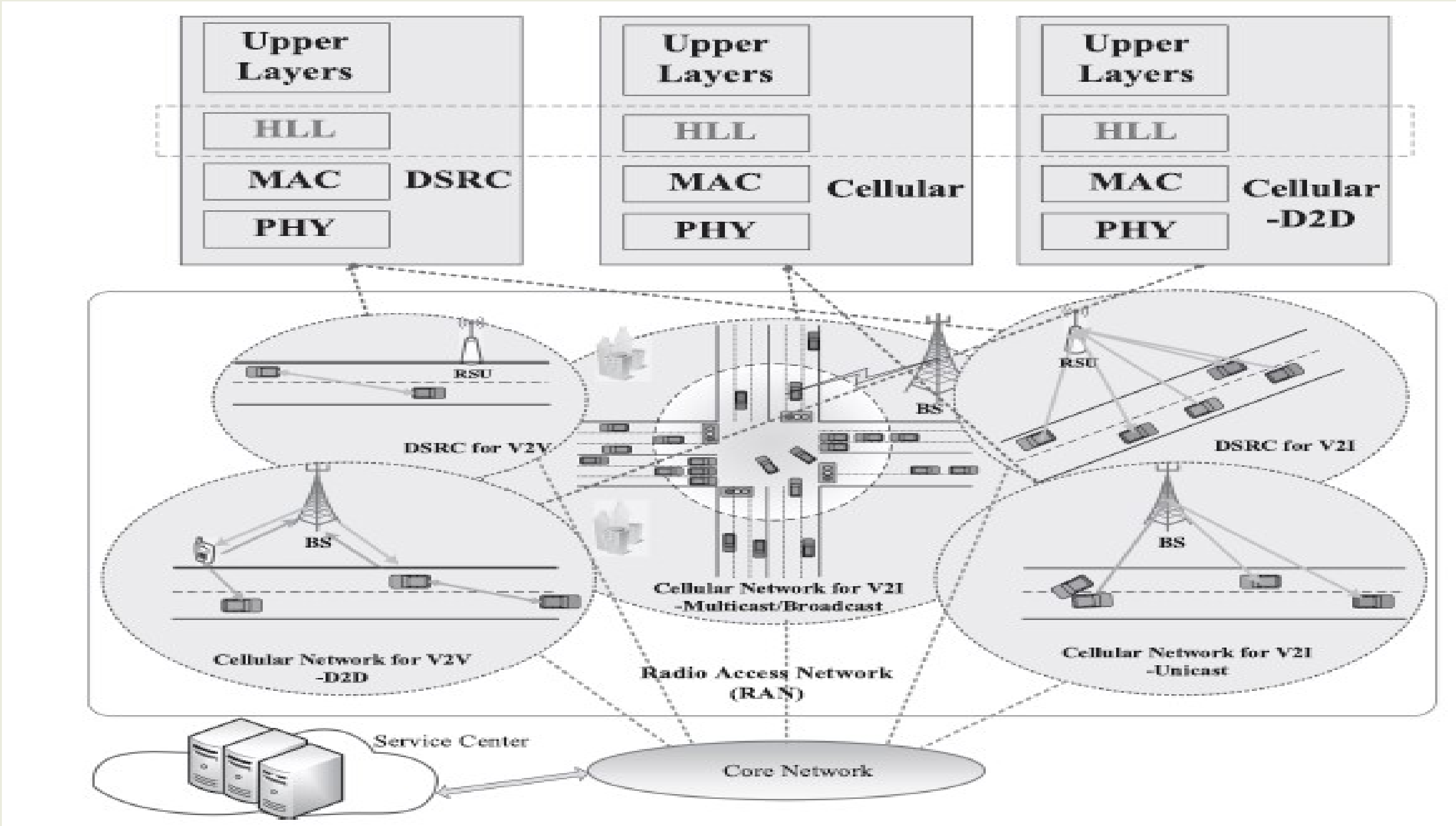
	North America	Europe	Japan
Bandwidth	75MHz (30MHz for safety and 40MHz for general purpose)	50MHz (30MHz for safety and 20MHz for general purpose)	80MHz
Frequency range	5850-5925MHz	5855-5905MHz	5770-5850MHz
Channel classification	Control channel (1), service channel (6)	Control channel (1), service channel (4)	Uplink (7), downlink (7)
Channel bandwidth	10MHz (can be up to 20MHz for general purpose channels)	10MHz	4.4MHz
Bandwidth allocation	30MHz safety, 40MHz general purpose	30MHz safety, 20MHz general purpose	Not specified
Coverage	30m	15 to 20m	1000m
Data transmission rate	3-27Mbps	Uplink/500Kbps, Downlink/250Kbps	1 or 4Mbps
Main standardization bodies	IEEE, SAE International, FCC	ETSI, ISO/CEN, CEPT	ARIB, NPA, MITI, MPT

SAE: Society of Automotive Engineers
FCC: Federal Communications Commission
ARIB: Association of Radio Industries and Businesses
ASTM: American Society for Testing and Materials
CEPT: European Conf. of Postal and Telecom Administrations
CEN: European Committee for Standardization
NPA: National Police Agency
MITI: Ministry of International Trade and Industry
MPT: Ministry of Posts and Telecommunications
ETSI: European Telecommunications Standards Institute
ISO: International Organization for Standardization

1. Introduction

1.4 Radio Access Technologies (RAT)

- *Heterogeneous Vehicular Networks*



Source : K.Zheng, et.al., "Architecture of Heterogeneous Vehicular Networks", Springer 2016, www.springer.com/cda/.../9783319256207-c1.pdf

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2.IoV objectives, use cases and challenges

2.1 VANET limitations -> VANET evolution to IoV

- **Note: The IoV advanced features can be seen as well as challenges**

- ***Factors***
- ***Commercial , objectives, architecture***
  - **VANET**: specific apps. only (safety, traffic efficiency)
    - Internet access is not fully available (due to specific architecture)
  - **IoV:** IoV-business oriented architecture → more rich set of apps. (safety, traffic optimization and efficiency, infotainment, etc.)

- ***Collaboration capabilities:***
  - **VANET**: specific arch. non-collaborative (no Internet collaboration)
  - **IoV:** collaboration between heterogeneous nets, reliable Internet service

- ***Communication types:***
  - **VANET**: basically - V2V, V2R only

  - **(IoV) additionals:**
    - infrastructure of cellular networks and Internet (V2I)
      - personal devices (human) (V2D/V2P)
      - sensors (V2S)

2. IoV objectives, use cases and challenges

2.1 VANET to IoV (cont'd)

- ***Processing power and decision capabilities:***
  - **VANET**: limited (local simple decisions), low volume data
  - **IoV:** high capabilities – (cloud based), big data, data mining, ..
- ***Compatibility with personal devices***: VANET: limited; IoV : any PD
- ***Scalability:***
  - **VANET**: non-scalable (consequence of its architecture)
  - **IoV:** scalable (and it integrates various access: VANET, WiFi, 4G/LTE, ..)

- ***Connectivity:***
  - **VANET:** vehicles can experience connection/disconnection- depending on network current availability
  - **IoV:** **"**always-connected" is possible, one can use the best network type
- ***Network/environment awareness:***
  - **VANET:** limited (basically on neighborhood of the vehicle)
  - **IoV:** global network awareness is possible (cloud-assisted)

- ***Cloud Computing (CC) compatibility***:
  - **VANET**: limited (possible, but currently not supported)
  - **IoV**: the main operations can be based on CC services

2. IoV objectives, use cases and challenges

2.2 IoV main objectives

- IoV **– distributed transport fabric –takes** its own decisions about driving customers to their destinations
- IoV should have **communications, processing, storage, intelligence, learning and strong security** capabilities
- To be **integrated in IoT** framework and smart cities technologies
- To **cooperate with and support advanced ITS systems**
- **Extended business models and the range of applications** (including media- oriented) w.r.t current vehicular networks
- Incorporate **heterogeneous networking and peripheral devices access**

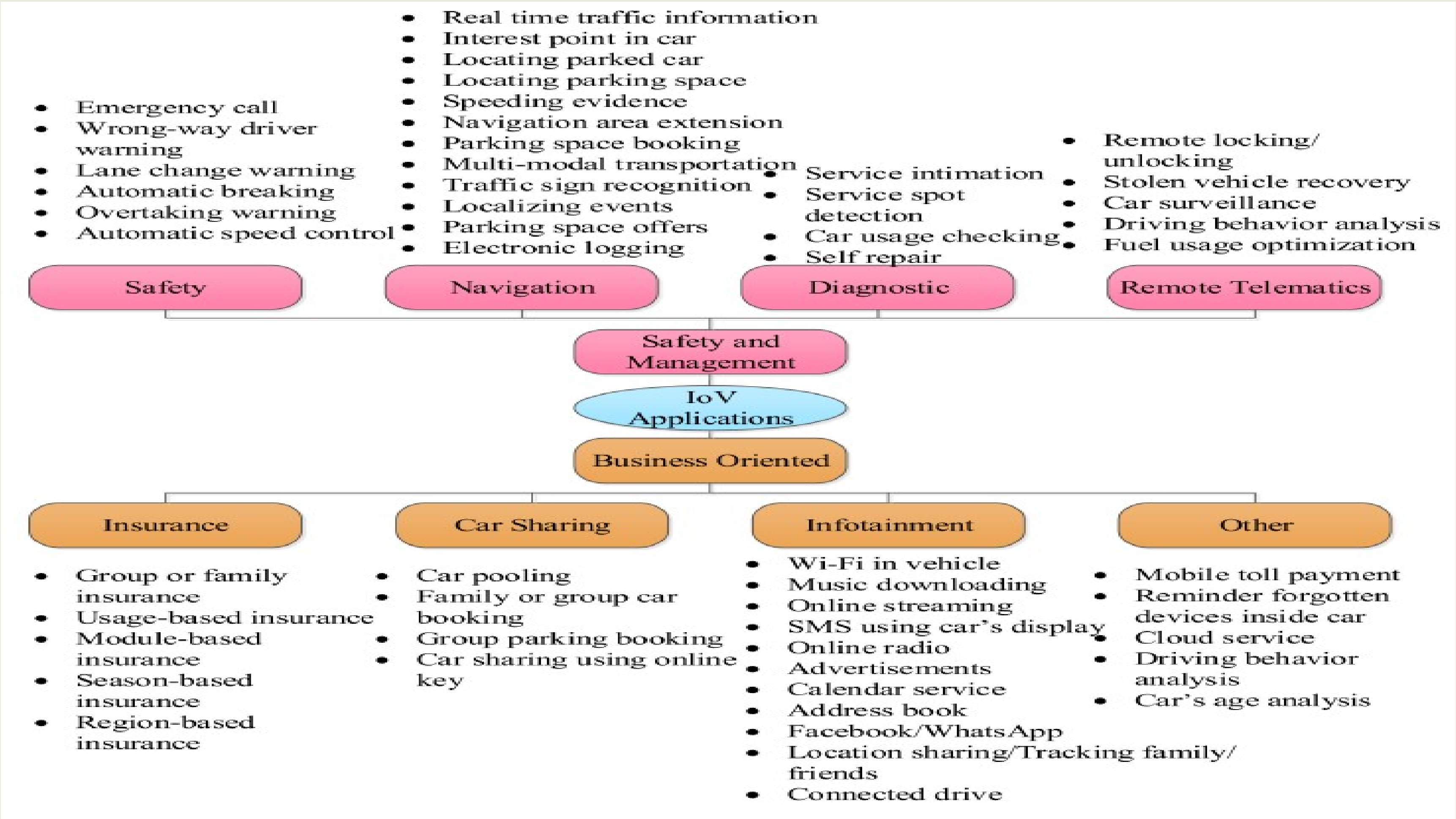
2. IoV objectives, use cases and challenges

2.2 IoV main objectives (cont'd)

- IoV should make profit of recent technologies and approaches
  - **Cloud Computing, Vehicular Cloud Computing**
  - **Mobile Edge computing and Fog Computing**
  - **Software Defined Networking**
  - **Virtualization technologies + Network Function Virtualization (NFV)**
  - **Big Data technologies**
  - **Complex Cyber-Physical Systems (CPS) technologies**
- Interaction with humans (pedestrians and drivers) and with infrastructure (built or self-organizing) should be supported
- Allow, large-scale and seamless deployments/approaches

2. IoV objectives, use cases and challenges

2.3 IoV – large range of target applications



Source: O. Kaiwartya, A.H Abdullah, Y.Cao, et. al., "Internet of Vehicles: Motivation, Layered Architecture, Network Model, Challenges, and Future Aspects" IEEE Access, SPECIAL SECTION ON FUTURE NETWORKS: ARCHITECTURES, PROTOCOLS, AND APPLICATIONS, September 2016

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3. IoV general functional architecture

- **Different approaches for architectures**

- **Objectives of architectural definitions**

  - **Open and flexible architecture** – capable to include technologies like
    - cloud computing, vehicular cloud computing, fog computing, mobile edge computing
    - heterogeneous network technologies
    - novel management, control and data plane capabilities like
      - Software Defined Networking
      - Network Function Virtualization

  - Accommodate a **large set of business models** and large range and services and applications

  - Allow **inclusion of the current ITS and VANET** systems

  - **Compatibility** with emergent **IoT** framework

3. IoV general funtional architectures

- **Different approaches for architectures (cont'd)**

- **Objectives of architectural definitions (cont'd)**

  - **Layered architecture** of IoV
    - Vertical split - considering functionalities and representations of the layers as to allow mapping of the ITS and TCP/IP like architectures to IoV

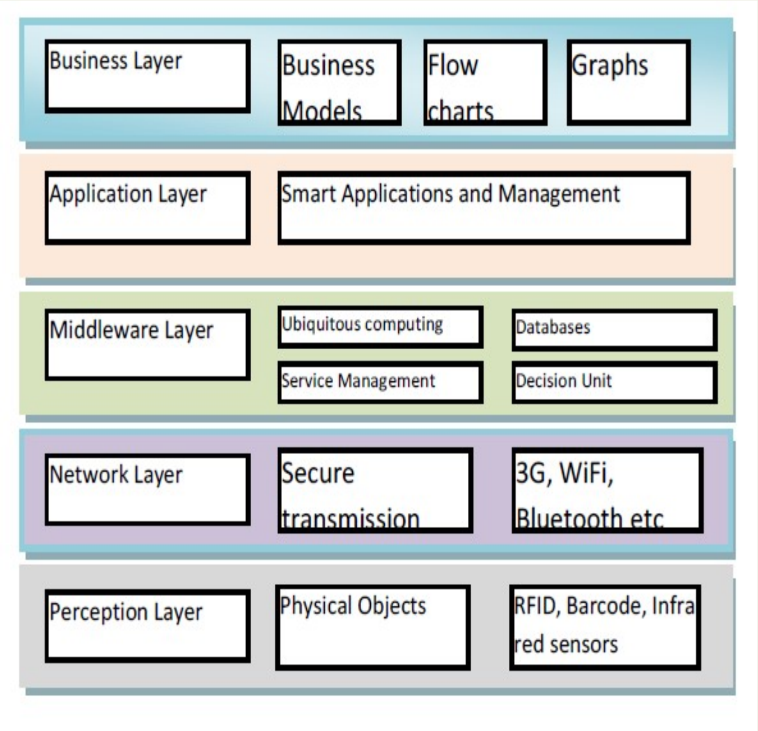
  - **Multiple plane approach**
    - Horizontal split - to allow distribution of functions in macro-sets (each plane could be composed at its turn, by several layers)
    - Example: management, operational and security planes

  - Identification of a network model for IoV
    - e.g. one composed of: *cloud, connection* and *client*

3. IoV general functional architectures

- **IoV – can be seen as a special case of IoT**

- **IoT layered typical architectures (5-layers):** different w.r.t. TCP/IP architectures; however the layering principles are still preserved
  - ***Business (BL) (highest)***
    - manages all IoT system activities and services
  - ***Application (AL)***
    - provides to the customers the requested services (with appropriate quality)
  - ***Middleware layer (ML)***
    - Service management, data bases, ubiquitous computing, decisions
  - ***Object Abstraction (OAL)***
    - transfers data to the SML through secure channels
    - L2 functions are included here, - for RFID, GSM, 3G, 4G, UMTS, WiFi, Bluetooth Low Energy
  - ***Objects (perception) (OL) (lowest)***
    - functions :querying location, temperature, weight, motion, vibration, acceleration, humidity, etc



Equivalent view of 5-layer IoT architecture

Source: A. Al-Fuqaha, et.al., "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications", IEEE Communications Surveys & Tutorials Vol. 17, No. 4, pp.2347-2376, 2015.

4. IoV general functional architectures

- **Example 1**: **Five layer IoV functional architecture**
  - similar to IoT architecture- high level view
  - **Architectural planes: Operational, Management, Security**
  - Five layers

Business : Graphs, Tables, Diagrams, Flowcharts

Application : Applications for vehicles and vehicular dynamics

Artificial Intelligence: Cloud computing, big data analysis, expert systems

Coordination: Heterogeneous networks-WAVE, WiFi, LTE, etc.

Perception: Sensors and actuators of vehicles, RSU, personal devices

Source: O. Kaiwartya, et.al., "Internet of Vehicles: Motivation, Layered Architecture, Network Model, Challenges, and Future Aspects" IEEE Access, Special Section on Future Networks, Architectures, Protocols and Applications, Vol. 4, pp.5536-5372, September 2016

3. IoV general functional architectures

- **Example 1** (cont'd)
- **IoV 5-layer architecture**
- **Operational plane**
  - **PERCEPTION LAYER**
    - Generally it corresponds to **PHY layer** in terms of its **functions**
    - It is represented by the *sensors* and *actuators* attached to vehicles, RSUs, smartphones and other personal devices
    - **Role:** to gather information on vehicle, traffic environment and devices (including movement –related parameters)

  - **COORDINATION LAYER**
    - **virtual universal network coordination** module for het-nets
      - (WAVE, Wi-Fi, 4G/LTE, satellite networks etc.)
    - **Role:**
      - transport tasks
      - processing tasks : information received from het-nets -> need to create an unified structure with identification capabilities for each type of network
    - Still there is a lack of standards → challenges:
      - interoperability and cooperation among different types of networks
      - need for reliable network connectivity

3. IoV general functional architectures

- **Example 1** (cont'd)
- **IoV generic 5-layer architecture-** (cont'd)
- **Operational Plane**
  - **ARTIFICIAL INTELLIGENCE (AI) LAYER**
    - represented by the **virtual cloud infrastructure**; it is the main IoV intelligent layer
    - **Role:**
      - storing, processing and analysing the information received from lower layer
      - decision making
    - It works as information management centre; major components are:
      - *Vehicular Cloud Computing (VCC), Big Data Analysis (BDA), Expert System*
    - It meets the requirements of applications serviced by this layer

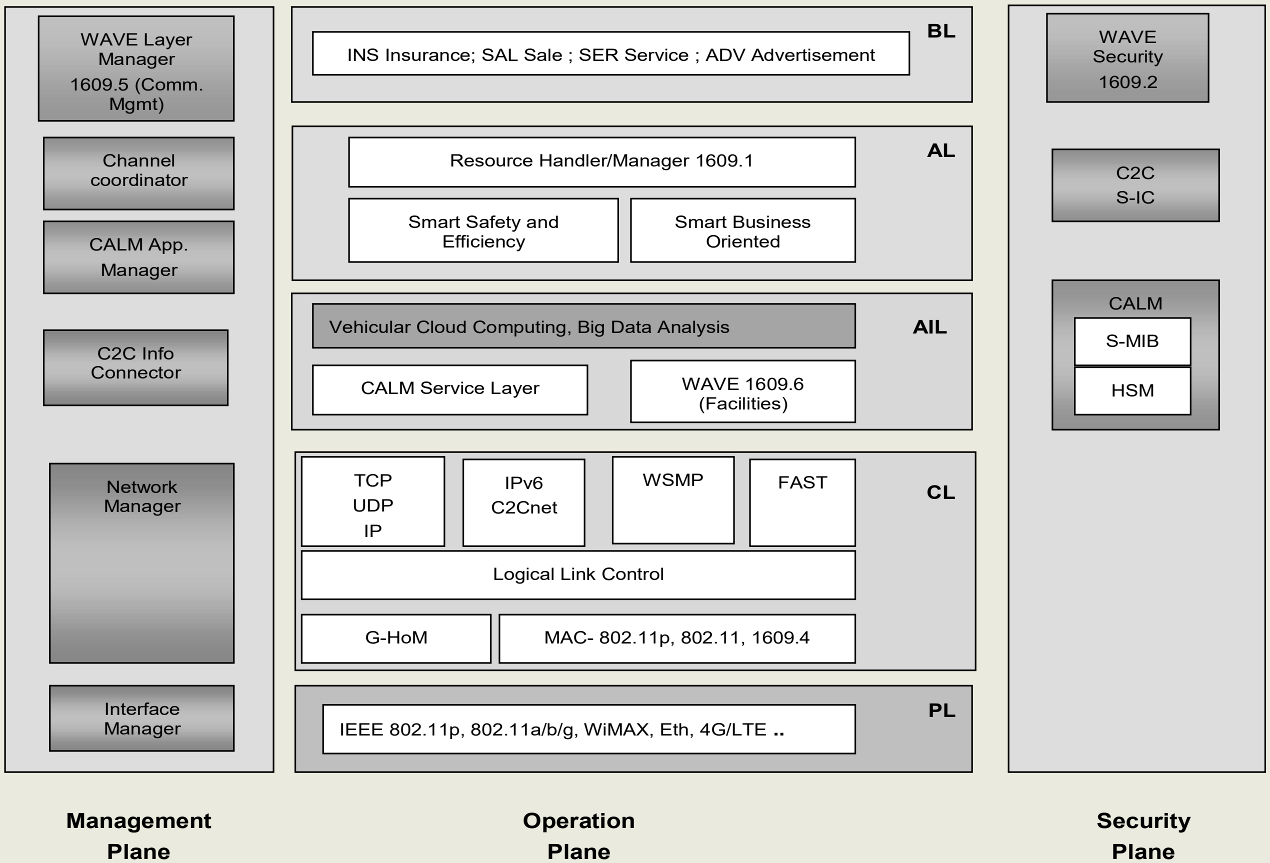
  - **APPLICATION LAYER**
    - represented by **smart applications. traffic safety, efficiency, multimedia based infotainment and web based** utility applications.
    - **Role:**
      - to provide smart services to EUs (based on intelligent analysis done by AI
      - safety and efficiency apps (legacy of VANET)
      - provides EU application usage data to the business layer.
    - Need: procedure for discovery of services provided by AI layer and their combination ; these smart applications: the driving force to further develop IoV

3. IoV general functional architectures

- **Example 1** (cont'd)
- **IoV 5-layer architecture**
- **Operational plane**
  - **BUSINESS LAYER**
    - IoV operational management module
    - **Role** (business aspects)
      - to foresight strategies for the development of business models based on the application usage data and statistical analysis of the data
      - analysis tools including graphs, flowcharts, comparison tables, use case diagrams, etc.
      - decision making related to economic investment and usage of resources
      - pricing, overall budget preparation for operation and management
      - aggregate data management
- **Security Plane**
  - Open research challenge (unavailability of clear definitions of layer-wise security protocols)
  - Currently, security protocols (coming from WAVE, C2C and CALM) can be used:
    - IEEE 1609.2, Security Information Connector (S-IC), Security Management Information Base (S-MIB) and Hardware Security Module (HSM)

3. IoV general functional architectures

- **Example 1: 5 layer IoV architecture mapped on particular protocols**



Layers

BL Business

AL Application

AIL Artificial Intelligence

CL Coordination

PL Perception

Source: O. Kaiwartya, et.al., "Internet of Vehicles: Motivation, Layered Architecture, Network Model, Challenges, and Future Aspects" IEEE Access, Special Section on Future Networks, Architectures, Protocols and Applications, Vol. 4, pp.5536-5372, September 2016

3. IoV general functional architectures

- **Example 1: Five layer IoV architecture (cont'd)**
- **Notations**
  - **General**
    - **C2C** Car to Car; **CALM** Communication Architecture for Land Mobile
    - **DSRC** Dedicated Short Range Communication
    - **WAVE** Wireless Access in Vehicular Environment
  - **Coordination layer**
    - **FAST** Fast Application and Communication Enabler
    - **LLC** Logical Link Control; **WSMP** WAVE Short Messages Protocol
  - **Artificial Intelligence layer**
    - **BDA** Big Data Analysis; **VCC** Vehicular Cloud Computing
  - **Application layer**
    - **SSE** Smart Safety and Efficiency
    - **SBO** Smart Business Oriented
  - **Business layer**
    - **INS** Insurance; **SAL** Sale ; **SER** Service ; **ADV** Advertisement
  - **Security**
    - **HSM** Hardware Security Manager; S-IC Security Information Connector
    - **S-MIB** Security Management Information Base
  - Notes:
    - 1. AI layer protocols are open research challenges in IoV, due to the current unavailability of suitable protocols for VCC and BDA.
    - 2. The VANETs projects generally do not have clear definitions of the upper sub-layer, while some IoT projects are working towards these

3. IoV general functional architectures

- **Example 2: IoV 7- layers architecture**
  - **Network model** (cont'd)
    - Intra vehicular model: V2P, V2S
    - Environmental model (outside vehicle): V2V, V2I, V2R, R2R, V2P, R2P
  - **Layered architecture**
    - **User interaction layer; Data acquisition layer**
    - **Data filtering and pre-processing layer**
    - **Communication layer**
    - **Control and management layer**
    - **Business layer; Security layer**
  - *Source: J.C. Contreras-Castillo, et al., "A seven-layered model architecture for Internet of Vehicles",Journal of Information and Telecommunications , Vol. 1, No. 1, pp. 4–22, 2017.*

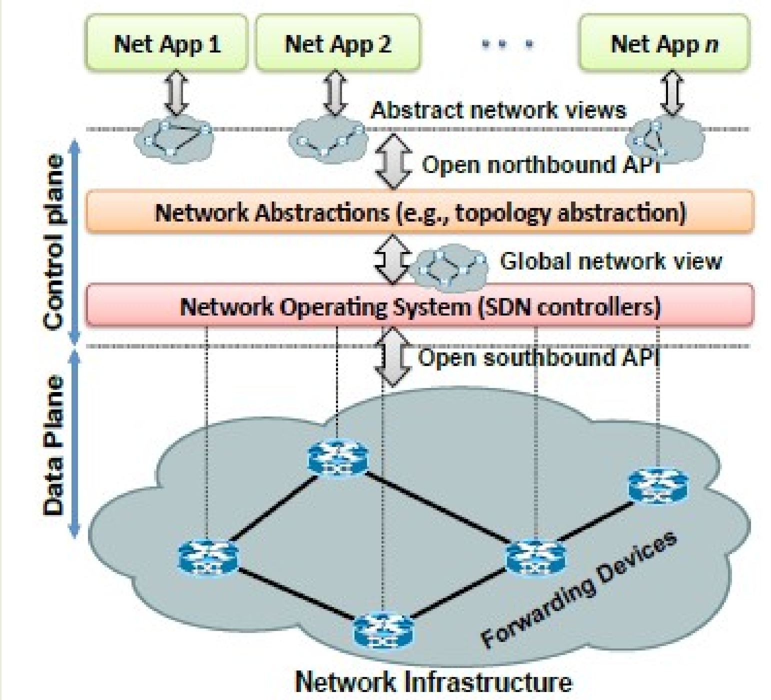
- **Comments**
  - apparently, this stack does not respect the principles of a layered architecture
  - E.g. : "Control and management layer" and "Security layer" seem to be rather architectural "planes "and not "layers"
  - No notion of a "plane" is explicitly defined in the proposal

CONTENTS

4. SDN-Cloud-Fog based architectures of IoV

- **SDN architecture – summary**
- **Principles:**
  - **Decoupling** of traffic forwarding and processing from control
  - Logically **centralized control**
  - **Programmability** of network services
- The major **SDN components** (ONF vision)
  - **resources**
  - **controllers**
- SDN controllers mediate between clients and resources to deliver services.
- Most resources are related to traffic, but support resources are also recognized, (e.g. security credentials and notification subscriptions)
- The **primary roles** in an SDN
  - **Administrator**
  - **Service requestor and provider**
  - **Resource user.**
  - Others: may be defined

SDN architecture and its basic abstractions

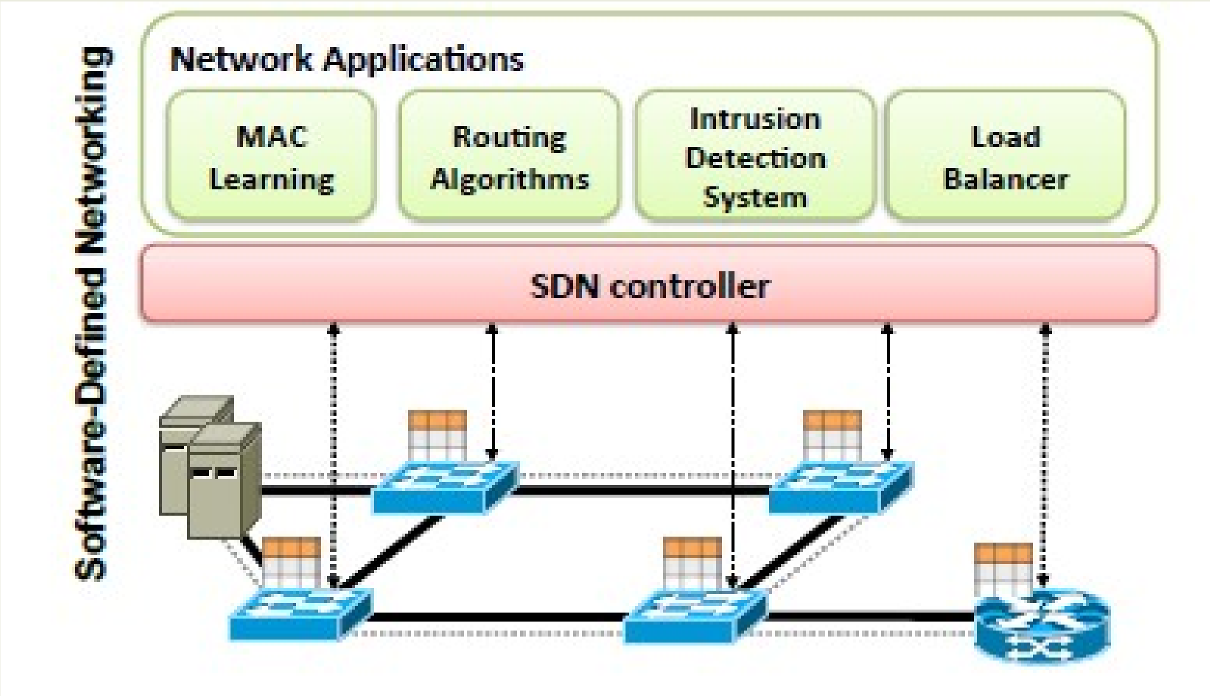


Source: Diego Kreutz et.al., Software-Defined Networking: A Comprehensive Survey, PROCEEDINGS OF THE IEEE, VOLUME 103, ISSUE 1. HTTP://TINY.CC/PIEEE, 2014

4. SDN-Cloud-Fog based architectures of IoV

- **SDN architecture - summary**

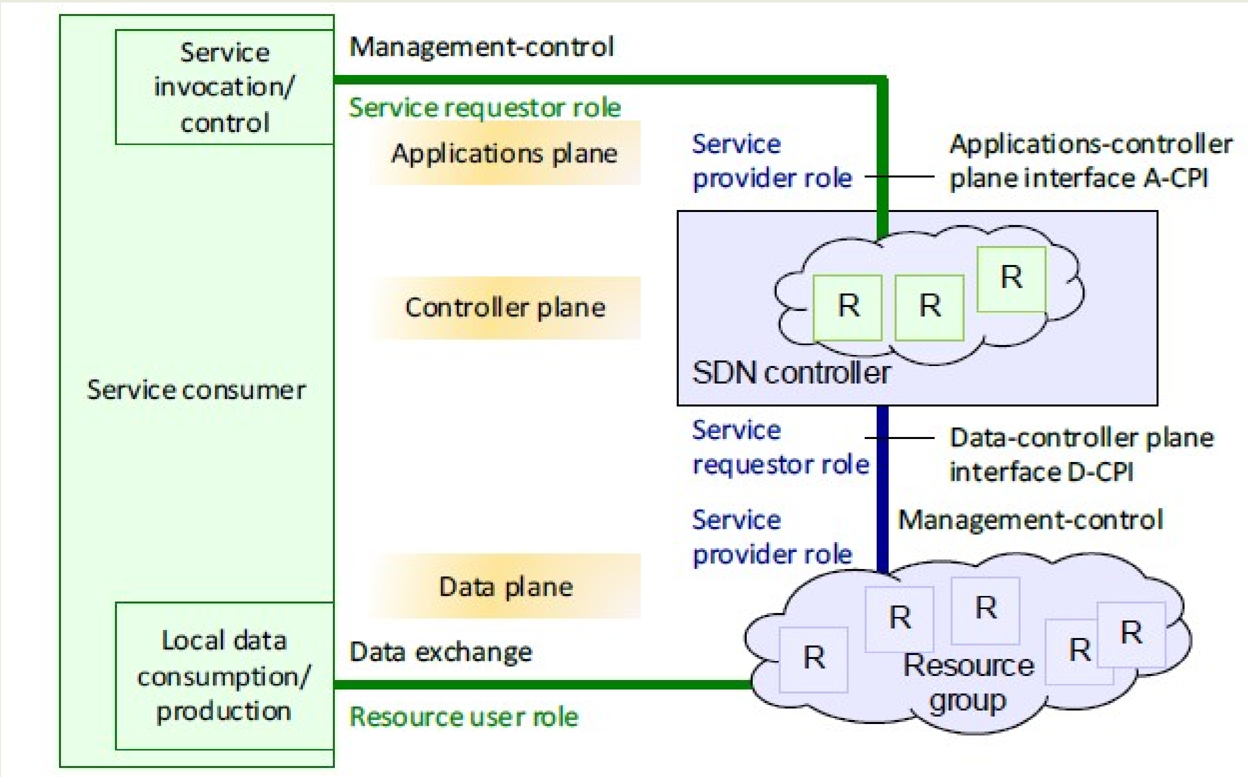
Example of SDN networking applications



Source: Diego Kreutz et.al., Software-Defined Networking: A Comprehensive Survey, PROCEEDINGS OF THE IEEE, VOLUME 103, ISSUE 1. HTTP://TINY.CC/PIEEE, 2014

4. SDN-Cloud-Fog based architectures of IoV

- **SDN architecture – summary** (cont'd)
- **Open Networking Foundation (ONF) vision**
  - -more complete view - from business model point of view
  - ONF-defined basic model of SDN (**Service provider – Service consumer** vision)



Service consumer (SDN-C) (client, user, customer) (green)

SDN server or provider (SDN-P) (blue) – owner of resources (R)

SDN-C <--> SDN-P exchanges of data and M&C operations

Source: SDN Architecture Issue 1.1 2016 ONF TR-521, 2016

4. SDN-Cloud-Fog based architectures of IoV

- **SDN architecture – summary** (cont'd)

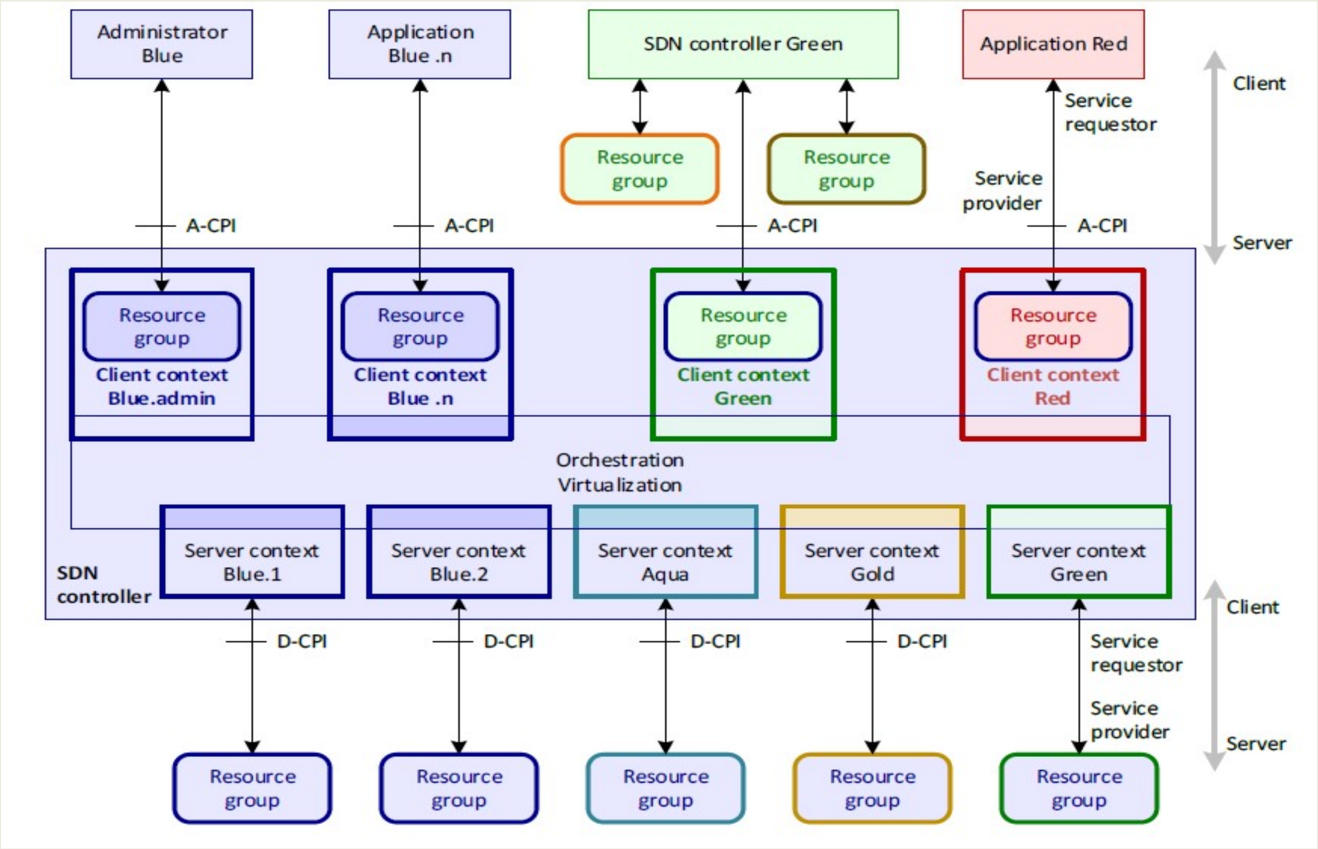
- **Open Networking Foundation vision**
  - Basic ONF model of SDN (cont'd)
    - SDN-C controls its service via a session contained in a M&C association
      - It **invokes actions on a set of virtual resources (R**) perceived as its own
      - SDN controller **virtualizes** and orchestrates the (Green) **resource and service** view **onto its own underlying (Blue) resources** and services.

  - **The concepts of resources and services are intentionally unbounded**

- **The ONF SDN architecture extends the basic SDN model**
  - **include sharing resources** a) among multiple clients, b) dynamically, c) in an optimum way.
  - **include management** in the classical sense, both of network resources and of services.
  - usually portrays client and server as existing in separate business domains (separate colors)
  - emphasize the need for traffic isolation, information hiding, security and policy enforcement at interface points

4. SDN-Cloud-Fog based architectures of IoV

- **SDN architecture – summary** (cont'd)
- **Open Networking Foundation vision**
  - Core SDN architecture



Source: SDN Architecture Issue 1.1 2016 ONF TR-521, 2016

4. SDN-Cloud-Fog based architectures of IoV

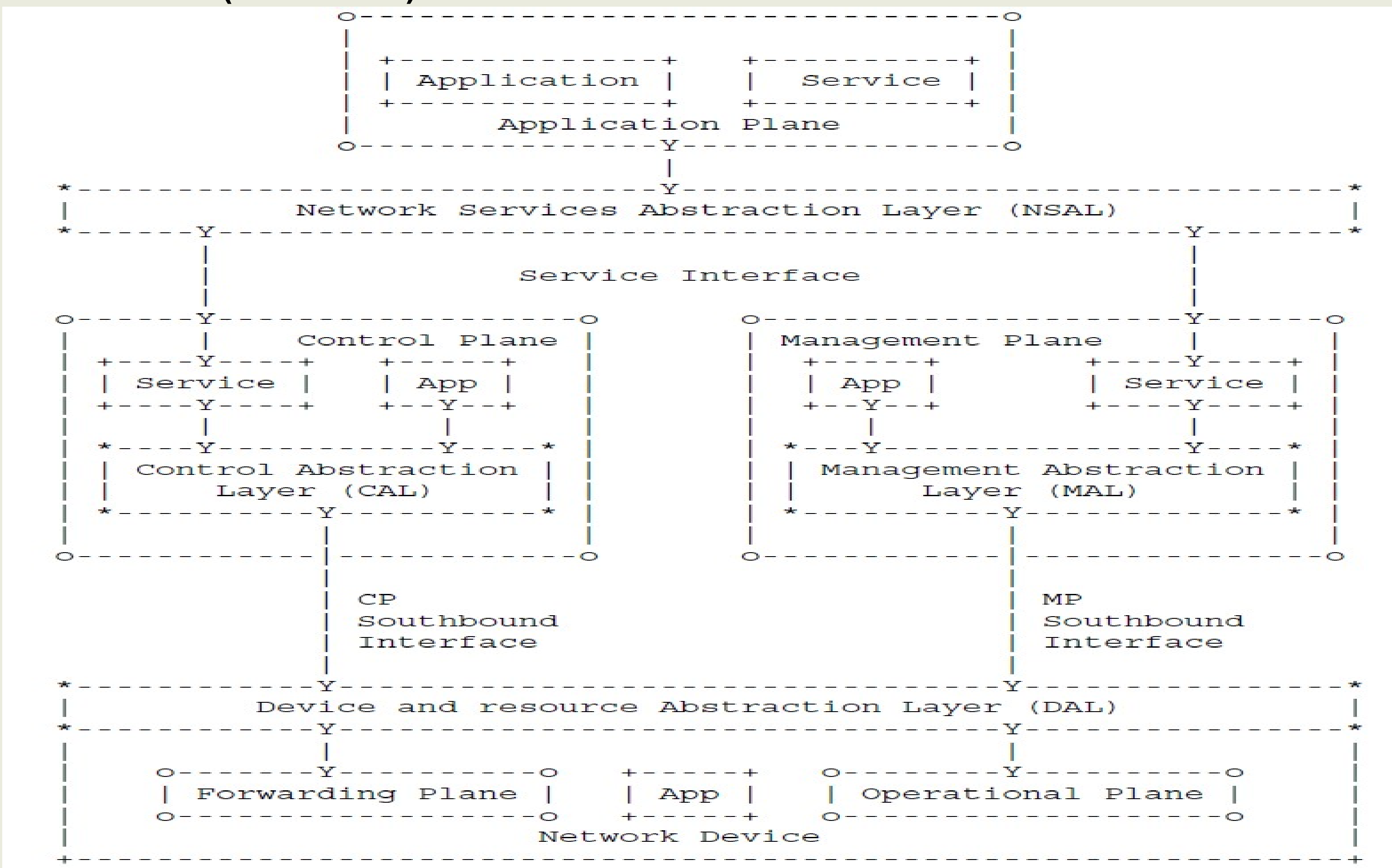
- **SDN architecture – summary** (cont'd)
- **Open Networking Foundation vision**
  - The SDN architecture
    - modelled as a **set of C-S relationships** between SDN controllers and other entities that may themselves be SDN controllers
    - is **recursive: repeated service requestor and service provider roles**
    - **SDN controller**
      - may play a **server role** as, offering services to any number of clients
      - or, may act as **client**, to invoke services from any number of servers
    - the internal details of entities that are **not** SDN controllers are beyond the scope of the architecture as long as they exhibit appropriate interface behavior
- The architecture offers **two complementary perspectives** on the nature of Customer-Provider (Cs-Pr) interfaces.
  - **Services perspective** : top-down or Cs-Pr viewpoint.
  - **Resources perspective** bottom-up viewpoint of a **resource owner**, especially an internal administrator.
  - The construction of views and mappings on a common underlying information model **helps tie these perspectives together**.

4. SDN-Cloud-Fog based architectures of IoV

- **SDN architecture – summary** (cont'd)
- **Open Networking Foundation vision (cont'd)**
- **SDN controller**
  - satisfies client requests by **virtualizing and orchestrating** its underlying resources
  - Network environment or client demands **changes** → the SDN controller continuously **updates network and service state** toward a policy-based optimum configuration
  - **exposes services and resources** to clients via A-CPIs I/Fs
  - **consumes underlying services and resources** via D-CPI I/Fs
  - Each I/F: is a reference point for information hiding, traffic and namespace isolation, and policy enforcement
  - M&C viewed as a continuum, in which an administrator role differs from that of ordinary apps. only by having greater scope and privilege
  - The administrator has authority to configure the SDN controller itself, along with client and server contexts

4. SDN-Cloud-Fog based architectures of IoV

- **SDN architecture – summary** (cont'd)
- **IETF vision (RFC 7426)**



4. SDN-Cloud-Fog based architectures of IoV

- **SDN architecture – summary** (cont'd)
- **IETF vision (cont'd)- definitions valid in SDN context**
  - **Application (App)** - standalone SW piece that utilizes underlying services to perform a function
    - Application operation can be parameterized, by passing certain arguments at call time
    - An Application does not offer any interfaces to other applications or services
  - **Service**
    - A SW piece performing one or more functions
    - **provides one or more APIs to applications or other services** of the same or different layers to make use of said functions and returns one or more results.
    - Services can be combined with other services, or called in a certain serialized manner, to create a new service

4. SDN-Cloud-Fog based architectures of IoV

- **SDN architecture – summary** (cont'd)
- **IETF vision (cont'd)- definitions valid in SDN context**

  - **Forwarding/Data Plane (FP) –** set of resources across all network devices responsible for forwarding traffic based on the instructions received from CP
    - FP is usually the termination point for CP services and applications

  - **Operational Plane (OP) –** set of resources responsible for managing the overall operation of individual network devices

  - **Control Plane (CP)** - functions for controlling network devices (instructs them how to process and forward packets)
    - CP interacts primarily with FP and, to a lesser extent, with OP

  - **Management Plane (MP)** - functions responsible for monitoring, configuring, and maintaining one or more network devices or parts of network devices.
    - MP is mostly related to the OP (it is related less to the FP)

  - **Application Plane** - The collection of applications and services that program network behavior

4. SDN-Cloud-Fog based architectures of IoV

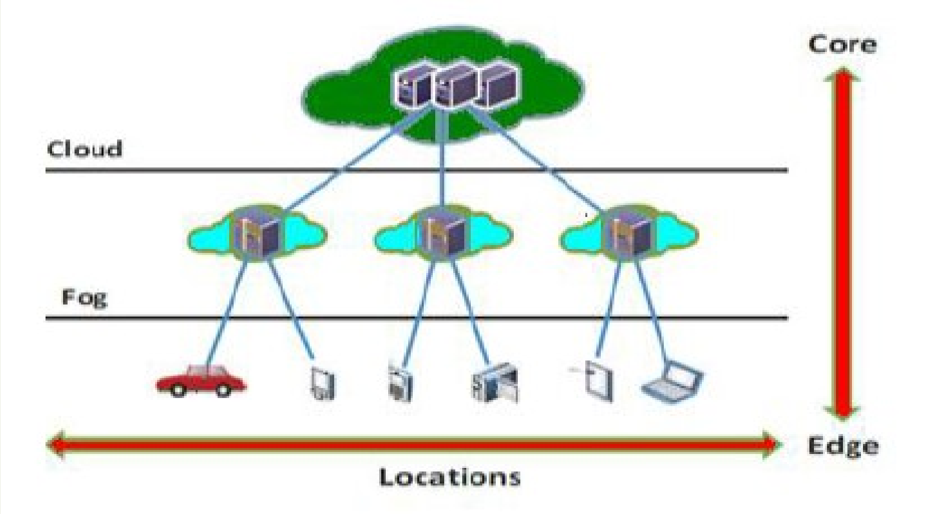
- **Fog architecture – summary**
  - **Initial (FC) – term coined by Cisco** to make the data transfer more easy in wireless and distributed environment
    - Rationale : ***„fog” means that „cloud” is closer to the ground*** →
      - **FC = Cloud Computing (CC)** carried out closer to the end users' networks
    - FC = virtualized platform, located between cloud data centers (hosted within the Internet) and end user devices
    - **FC offers strong support for Internet of Things**
    - **FC is not intended to replace CC; they are complementary**

    - *Source : F.Bonomi, R.Milito, J.Zhu, and S.Addepalli, "Fog computing and its role in the Internet of Things," in ACM SIGCOMM Workshop on Mobile cloud Computing, Helsinki, Finland, 2012, pp. 13--16.*
- **Fog computing and networking**
  - **Fog:** decentralized computing infrastructure
  - computing resources and appl. services are distributed in the most logical, efficient places, **at any point along the continuum from the data source to the cloud**

  - Higher efficiency: lower amount of data to be transported to the cloud for data processing, analysis and storage
    - Reasons: efficiency, security and compliance

4. SDN-Cloud-Fog based architectures of IoV

- **Fog architecture – summary** (cont'd)
- FC performs/offers significant amount of
  - *storage at or near the end-user (avoid* primarily to store in large-scale data centers)
  - *communication at or near the end-user (avoid* routing through the backbone network)
  - *management, including network* measurement, control and configuration - are performed at or near the end-user premises



Deployment of IoT applications in a 2-tiered way (Cloud- things) does not meet the requirements related to low latency, mobility of the "things" and location awareness

Solution : a multi-tiered architecture (at least 3 tiers) → Fog computing

Source : I.Stojmenovic, S.Wen," The Fog Computing Paradigm: Scenarios and Security Issues", Proc. of the 2014 Federated Conf. on Computer Science and Information Systems, pp. 1–8

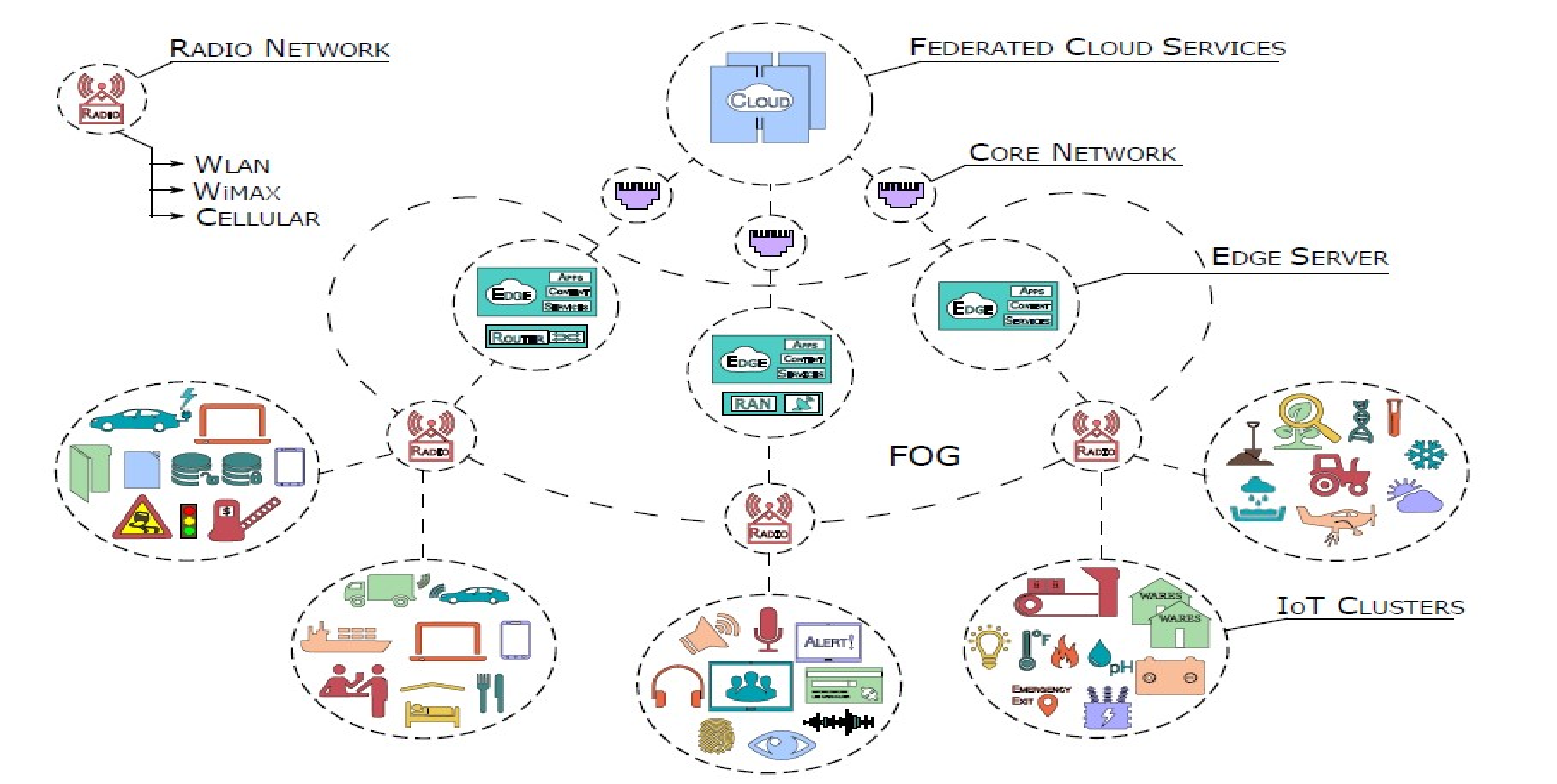
4. SDN-Cloud-Fog based architectures of IoV

- **Fog architecture – summary**
- **Comparison : Cloud Computing versus Fog Computing**
- **FC provides**
  - **light-weight cloud-like facility** close of mobile users
  - users with a **direct short-fat** connection versus traditional long-thin mobile cloud connection
  - customized and engaged **location-aware** services
- **FC - still lack of a standardized definition**

	Fog Computing	Cloud Computing
Target User	Mobile users	General Internet users.
Service Type	Limited localized information services related to specific deployment locations	Global information collected from worldwide
Hardware	Limited storage, compute power and wireless interface	Ample and scalable storage space and compute power
Distance to Users	In the physical proximity and communicate through single-hop wireless connection	Faraway from users and communicate through IP networks
Working Environment	Outdoor (streets, parklands, *etc.*) or indoor (restaurants, shopping malls, *etc.*)	Warehouse-size building with air conditioning systems
Deployment	Centralized or distributed in reginal areas by local business (local telecommunication vendor, shopping mall retailer, *etc.*)	Centralized and maintained by Amazon, Google, *etc.*

4. SDN-Cloud-Fog based architectures of IoV

- **Fog architecture – summary**



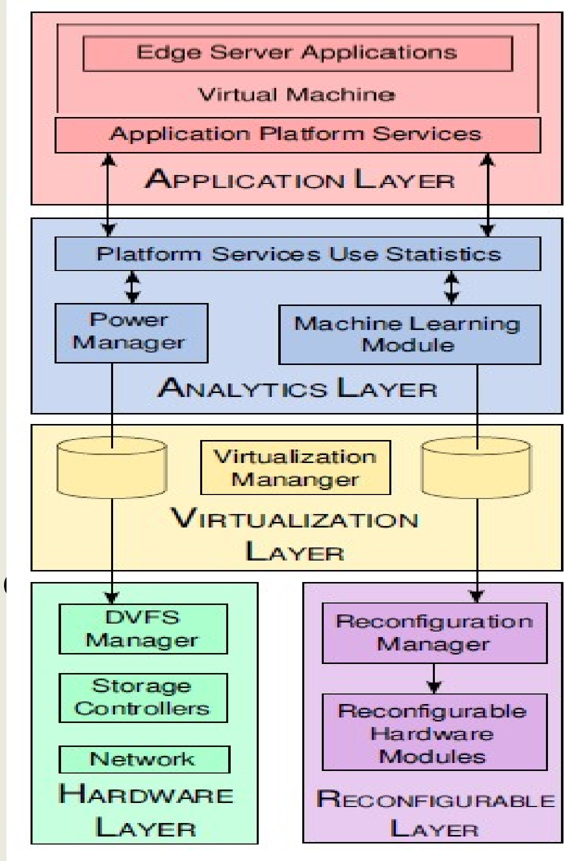
Source: A.Munir, et.al., "IFCIoT: Integrated Fog Cloud IoT Architectural Paradigm for Future Internet of Things", arXiv:1701.08474v1 [cs.DC] 30 Jan 2017

4. SDN-Cloud-Fog based architectures of IoV

- **Fog architecture – summary** (cont'd)

- **OpenFog Consortium** : fog nodes are seen as a fluid system of connectivity
  - RAN is a part of the fog architecture (F-RAN)
- Reconfigurable and adaptive Fog Node/Edge Server architecture is needed
- **Example of architecture** – see Figure
  - layers: **application, analytics, virtualization, reconfiguration, hardware layer**
- **Layers:**
  - **Application:** includes **app. platform services** that the edge server provide to various apps. hosted on the edge server
  - services : *computation offloading, content aggregation, databases and backup, network information, etc.*
  - **Analytics Layer:** modules: statistics on platform services use, machine learning (predict HW resources reqs), and power manager.

Layered fog node architecture (IoT)



Source: A.Munir, et.al., "IFCIoT: Integrated Fog Cloud IoT Architectural Paradigm for Future Internet of Things", arXiv:1701.08474v1 [cs.DC] 30 Jan 2017

4. SDN-Cloud-Fog based architectures of IoV

- **Fog architecture – summary** (cont'd)

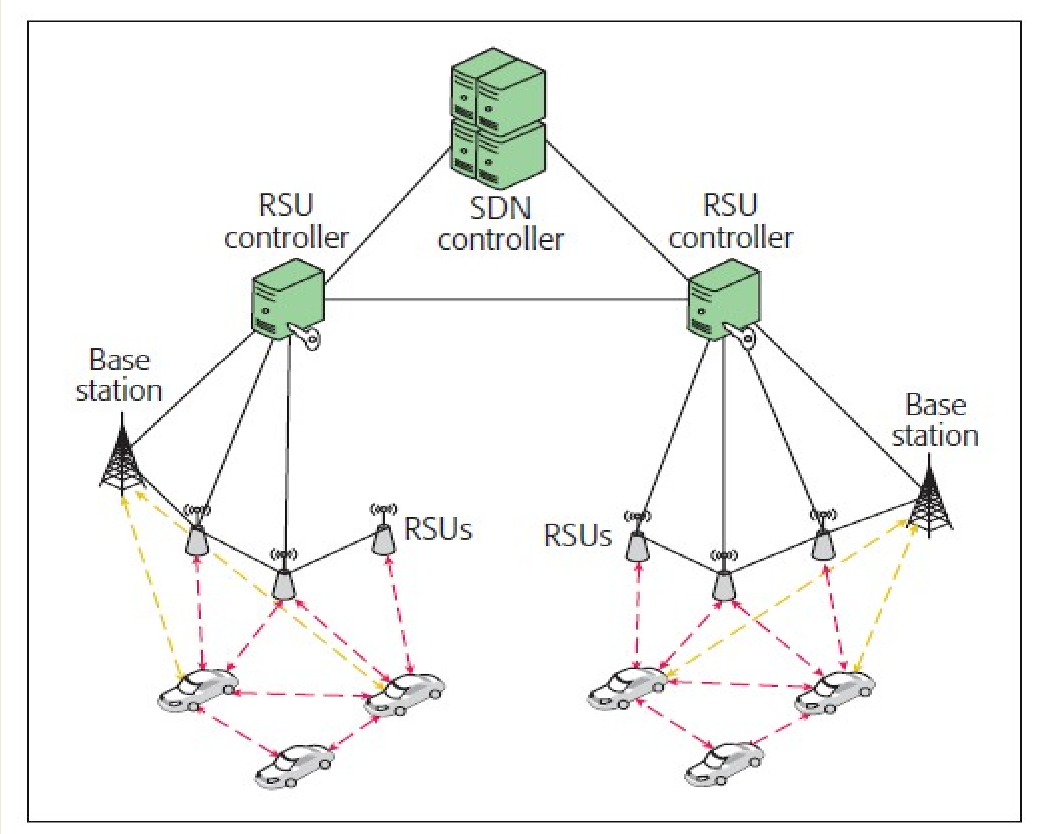
- **Layers** (cont'd):
  - **Virtualization Layer** acting as IaaS provider: abstracts the underlying HW resources (can be from different vendors) to provide a common interface for applications

  - **Reconfigurable Layer:** a *reconfiguration manager* and a set of *reconfigurable modules*
    - The reconfiguration manager (novel feature) takes input from the machine learning module and reconfigures the architectural resources to dynamically meet the requirements of the peak workload application

  - **Hardware Layer:** dynamic voltage and frequency scaling (DVFS) manager, storage controllers, and network resources

4. SDN-Cloud-Fog based architectures of IoV

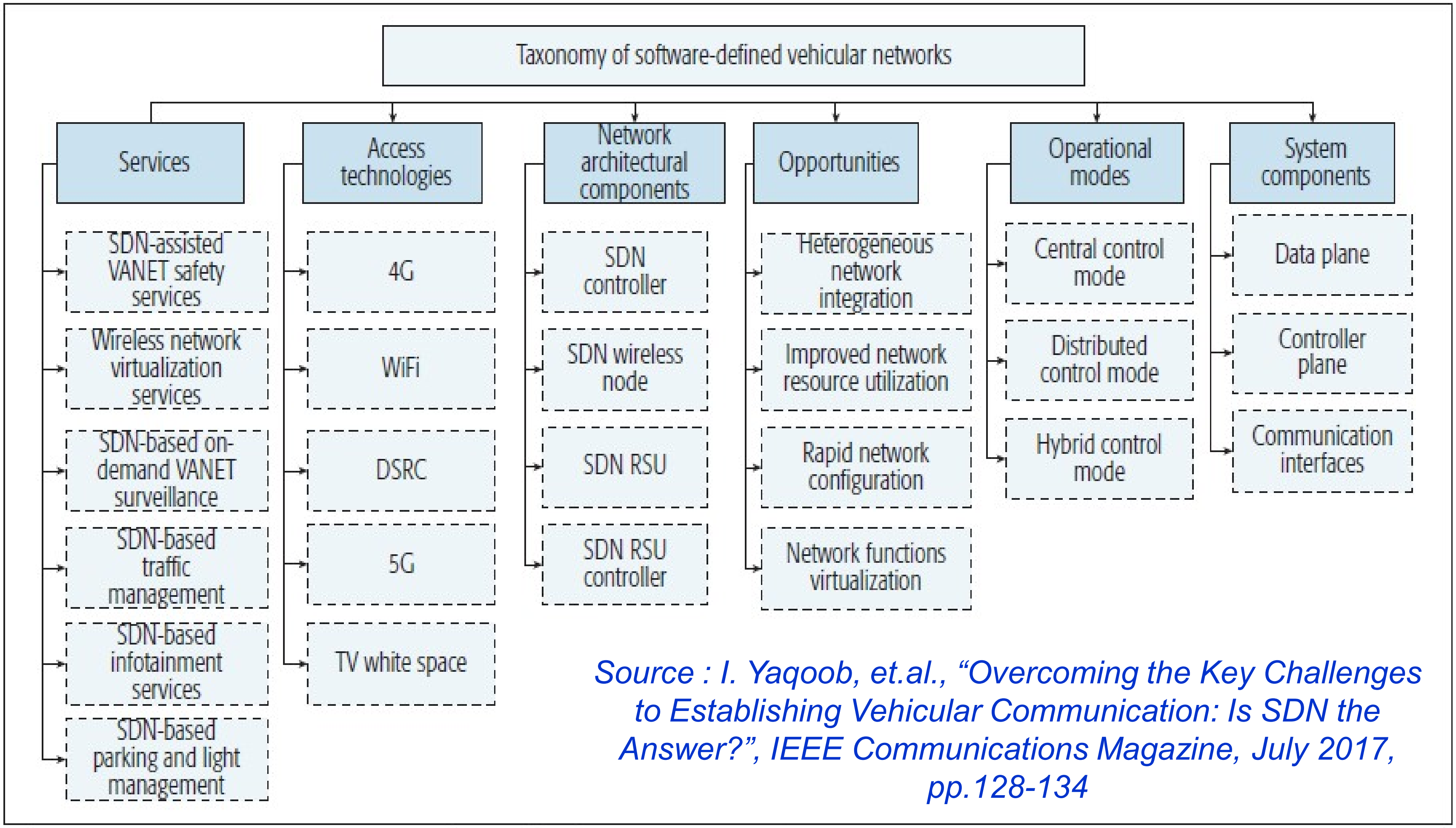
- Several studies propose SDN control of the IoV
- Example of generic SD- vehicular network (SDVN)



Source: I. Yaqoob, et.al., Overcoming the Key Challenges to Establishing Vehicular Communication: Is SDN the Answer?", IEEE Communications Magazine, July 2017, pp.128-134

4. SDN-Cloud-Fog based architectures of IoV

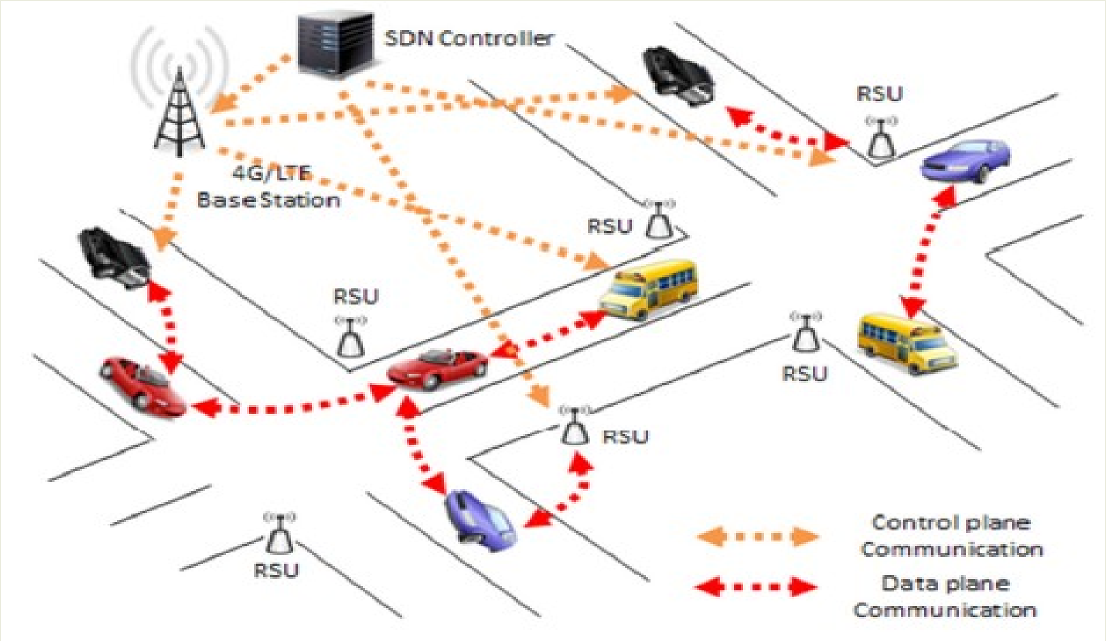
- **Example of taxonomy for SD- vehicular networks**



Source : I. Yaqoob, et.al., "Overcoming the Key Challenges to Establishing Vehicular Communication: Is SDN the Answer?", IEEE Communications Magazine, July 2017, pp.128-134

4. SDN-Cloud-Fog based architectures of IoV

- **Example 1: Software defined VANET**
  - SDN components: **SDN controller, SDN wireless (forwarding) nodes and SDN-enabled RSUs**.
    - **SDN controller** (single entity) ; OpenFlow control protocol at its South I/F
    - **SDN wireless nodes**: vehicles, seen as data plane elements
    - **SDN enabled RSUs** - stationary data plane elements
  - **a complete layered functional IoV architecture is not discussed**



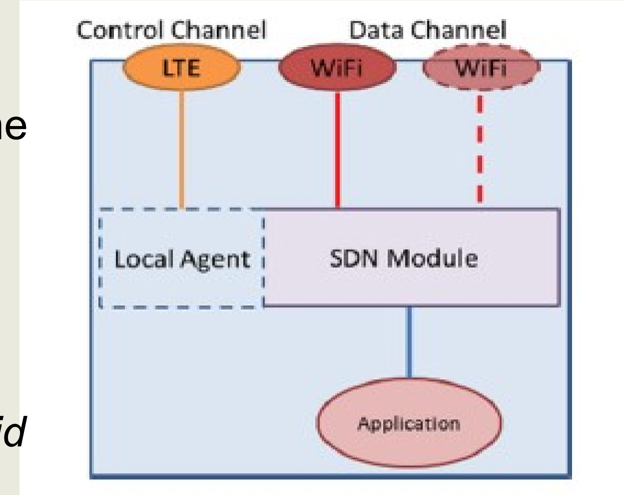
Issues: scalability of control

Source: Y.Lu, M.Gerla, R. Gomes, and E. Cerqueira, "Towards software-defined VANET: Architecture and services", MedHocNet.2014.6849111

4. SDN-Cloud-Fog based architectures of IoV

- **Example 1: Software defined VANET (cont'd)**
- **Network (wireless connection):**
  - CPI: Long range e.g., LTE/Wimax
  - DPI: high bandwidth e.g., Wi-Fi
- **SDN wireless node**
  - OpenFlow-enabled switch + intelligence for different VANET modes of operation
  - It is both an SDN *DPI forwarding element* and an *end-point for data*

- **SDN module** : packet processing (user traffic) + I/F to accepts input from a separated CPI
- **local SDN agent**: functions depending on features of the SDN wireless node
  - can either be the backup controller if necessary
  - traditional Ad hoc routing protocols (e.g., GPSR, AODV, DSDV, OLSR, etc.) are supported as fallback mechanisms
- **Possible control modes**: *centralized, distributed, hybrid*
  - Hybrid:
    - SDN controller does not hold complete control; it delegates control of packet processing details to local agents; It sends out policy rules



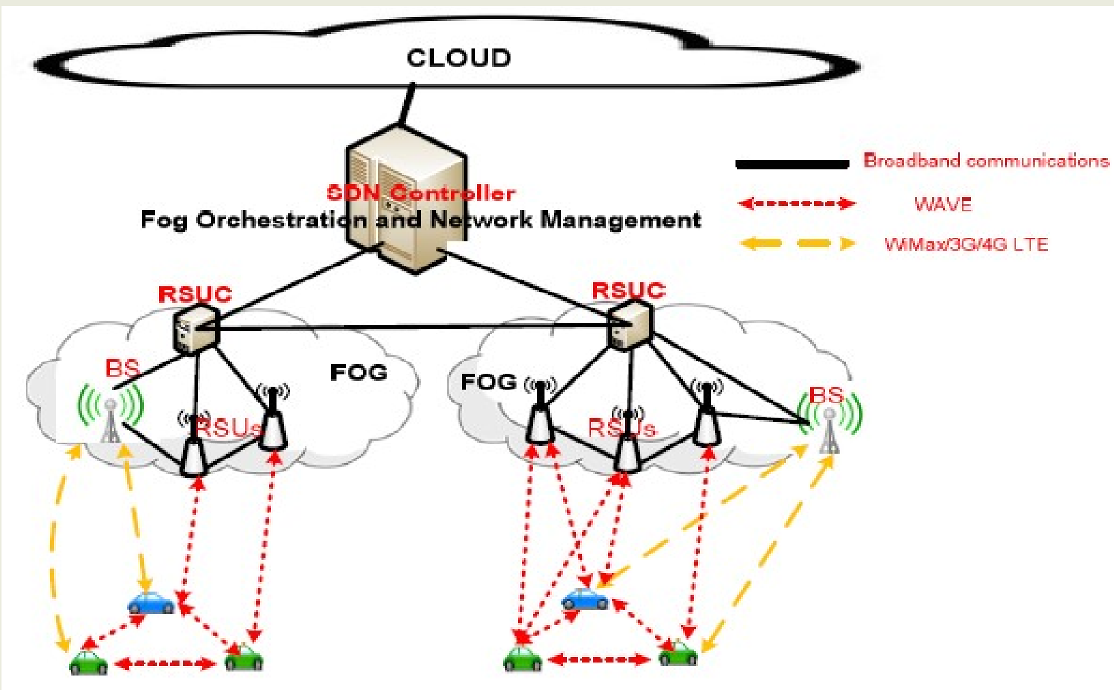
SDN wireless node

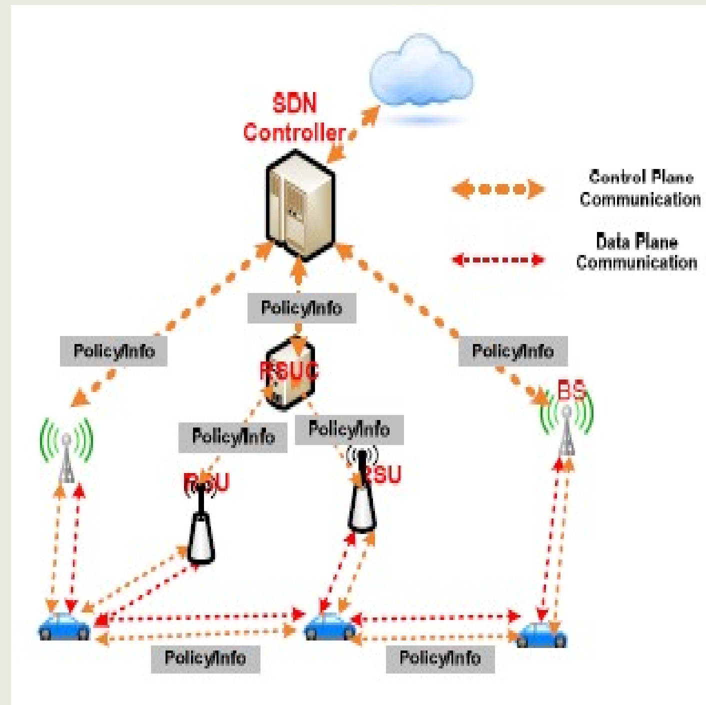
4. SDN-Cloud-Fog based architectures of IoV

- **Example 2: Fog-SDN architecture (FSDN)** - for advanced VANET for V2V, V2I and Vehicle-to-Base Station communications.
  - *Source: N.N.Truong et.al., , "Software defined networking-based vehicular ad hoc network with fog Computing", Proceedings of the 2015 IFIP/IEEE International Symposium on Integrated Network Management (IM'15), May 2015*
  - Advantage: Fog operates at the network edge, offering special services which require network context information, location awareness, and ultra-low latency
  - **SDN components** :
    - ***SDN Controller***
      - Overall network control
      - Orchestration and Resource Management for the Fog);
    - ***SDN Wireless Nodes*** (vehicles - end-users and forwarding elements, equipped with OBU)
    - ***SDN RSU*** (it is also a Fog device)
    - ***SDN RSU Controller* (RSUC)** (controlled by the central SDN controller
      - each RSUC controls a cluster of RSUs
      - it can forward data, and store local road system information or perform emergency services
      - from Fog perspective RSUCs are fog devices
  - **CPI:** flow rules or policy rules**; DPI:** data transfer

4. SDN-Cloud-Fog based architectures of IoV

- **Example 2: Fog-SDN architecture (FSDN)** –(cont'd)
- **Basic operation: *Hybrid Control Mode* *variant***
  - SDN Controller : no full system control ; it shares the work with BSs and RSUCs
    - It sends no specific flow rules, but an abstract policy (policy rules)
    - specific behaviour: decided by RSUCs or BSs based on local knowledge





Source: N.N.Truong et.al., , "Software defined networking-based vehicular ad hoc network with fog Computing", Proceedings of the 2015 IFIP/IEEE International Symposium on Integrated Network Management (IM'15), May 2015

4. SDN-Cloud-Fog based architectures of IoV

- **Example 2: Fog-SDN architecture (FSDN)** –(cont'd)
- **Basic operation**
  - **Updating the network topology**
    - L2 mechanism in each vehicle periodically broadcast beacon messages for learning neighbor's information
    - This information is sent along with traffic data of the vehicle such as route map, position, speed, and sensor data - to RSU or BS
    - **SDN controller can build a global connectivity graph of the SDN wireless nodes** and other necessary knowledge for various services
  - RSUC and BSs also receive information of vehicles and/or traffic data from a cluster of RSUs,
    - thus, they are **able to process some surveillance services without entire knowledge as in SDN Controller**
  - RSUC and BSs **offer local, distributed intelligence with low latency and location awareness characteristics**
  - The RSUCs and BSs are co-ordinated with each other by a **Fog orchestration layer located at SDN Controller.**

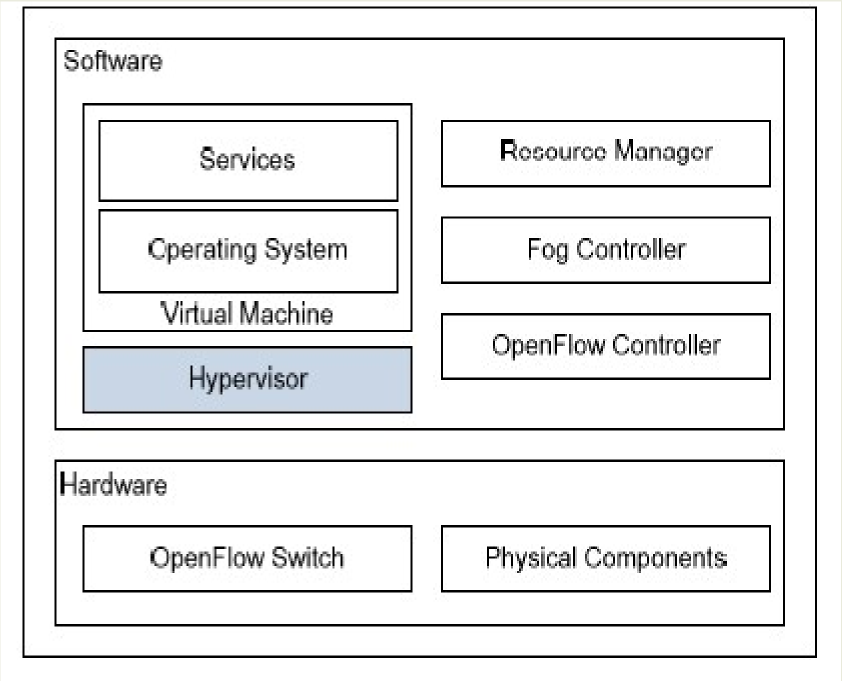
4. SDN-Cloud-Fog based architectures of IoV

- **Example 2: Fog-SDN architecture (FSDN)** –(cont'd)
- **Basic operation (cont'd)**
  - In Fog computing concepts central **data centers** and pervasive **edge devices** share their heterogeneous resources and support services
  - Here : RSUCs and BS, as the Fog devices, incorporate with the Cloud through SDN Controller and share their resources for controlling vehicles
  - To enable Fog computing framework for the SDN-based VANET system,
    - **SDN Controller, RSUCs and BSs**
      - are equipped with SDN-capability ,and
      - also offer **virtualization** for enabling Cloud (Fog) services
  - a **Hypervisor**, (low-level middleware), is **implemented** at these physical devices to support abstraction of **Virtual Machines (VMs)**
    - **Services are hosted at VMs** allowing service migration and replication.
    - improved portability, resource utilization and fault tolerance

4. SDN-Cloud-Fog based architectures of IoV

- **Example 2: Fog-SDN architecture (FSDN)** –(cont'd)
- **SDN Controller architecture**
  - **Functions**
    - SDN controller core functions
      - OpenFlow enabled
    - Fog orchestration
    - Resource management

- **Resource management**
  - *Service-Oriented Resource Sharing* arch. and math. models are applied for SDN Controller, BSs and RSUCs
  - SDN Controller, BSs and RSUCs host services, through application installed in them.
  - They request resources service by service
  - A service is composed of multiple tasks
    - processed using the node resources
    - or, using resources from other nodes (outsourced tasks)



SDN Controller hardware and software components

4. SDN-Cloud-Fog based architectures of IoV

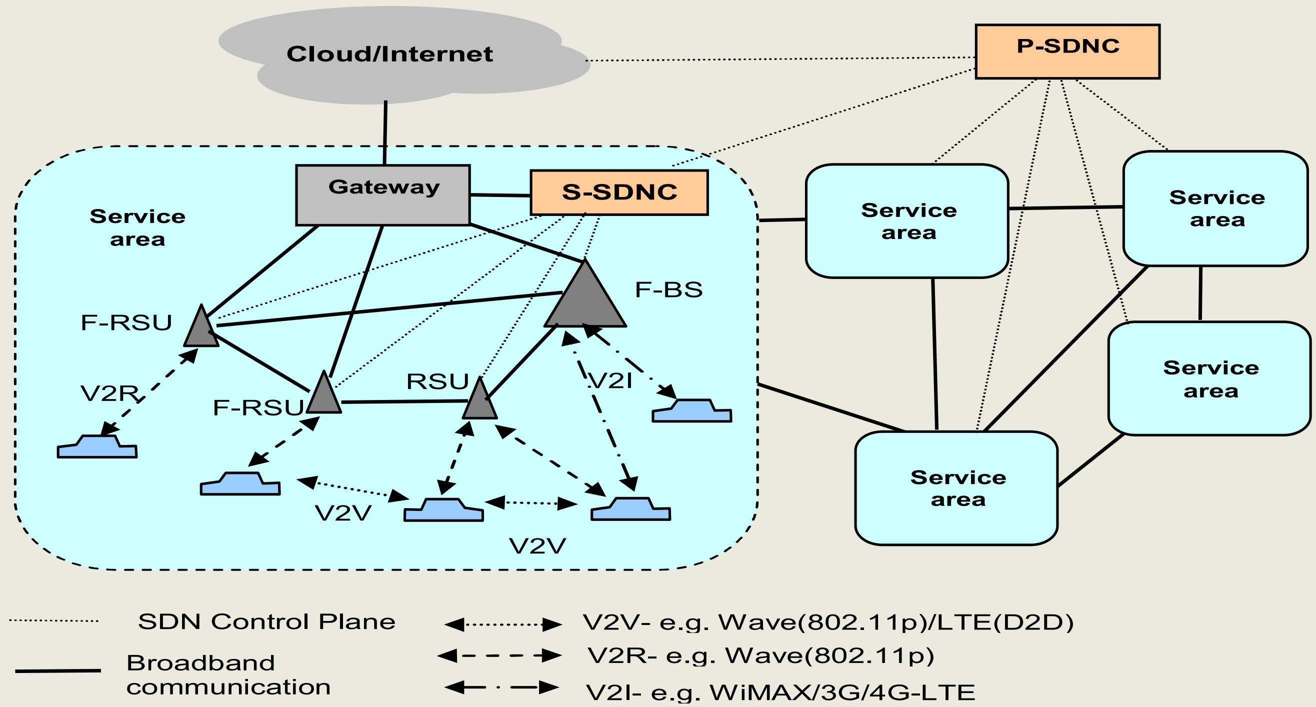
- **Example 2: Fog-SDN architecture (FSDN)** –(cont'd)
- **SDN Controller architecture**
- ***Fog Controller - component***
  - Services implemented at VMs in SDN Controller, BSs and RSUCs need an orchestration mechanism
    - to disseminate information of data forwarding rules changes and service hosting
  - The orchestration also works on service instantiation, replication and migration
  - **Example:** a service operating along road system may require different number of BSs or RSUCs hosting the service
    - need for physically migrating VMs in these RSUCs or BSs.
    - This can be done by a Fog Controller incorporating with SDN Controller for automatically updating service hosting and data forwarding rules.
    - That is the benefit of integrating SDN in the Fog architecture
- Issues to be further analysed:
  - the reconfiguration to service hosting, instantiation, migration, replication and data flow rules
    - is costly
    - can result in increased latency and deteriorating Quality of Experience (QoE)

4. SDN-Cloud-Fog based architectures of IoV

- **Example 3: SDN-FOG architecture- mapping example to generic functional architecture**
- **Main characteristics**
  - An access IoV geo zone is divided into several non-overlapping service areas (SA)
  - Each SA region is covered by forwarders (RSUs and/or BSs) placed in fixed locations
  - forwarding nodes in a SA - > abstract overlay graph
  - **two level hierarchy of SDN controllers is proposed: one Primary-SDNC and several Secondary-SDNCs (P-SDNC, S-SDNC)**
  - one SA can be controlled by n ≥ 1 S-SDN controller(s)
  - S-SDNCs may be co-located with some of the forwarders
  - SDNC implementation variants:
    - 1-to-1 associated with a physical machine/node, or
    - several virtual SDN controllers (NFV based) can exist in the same physical node
      - (the equivalent abstract graph will have groups of nodes close together)

4. SDN-Cloud-Fog based architectures of IoV

- **Example 3: SDN-FOG architecture- mapping example to generic functional architecture** (cont'd)

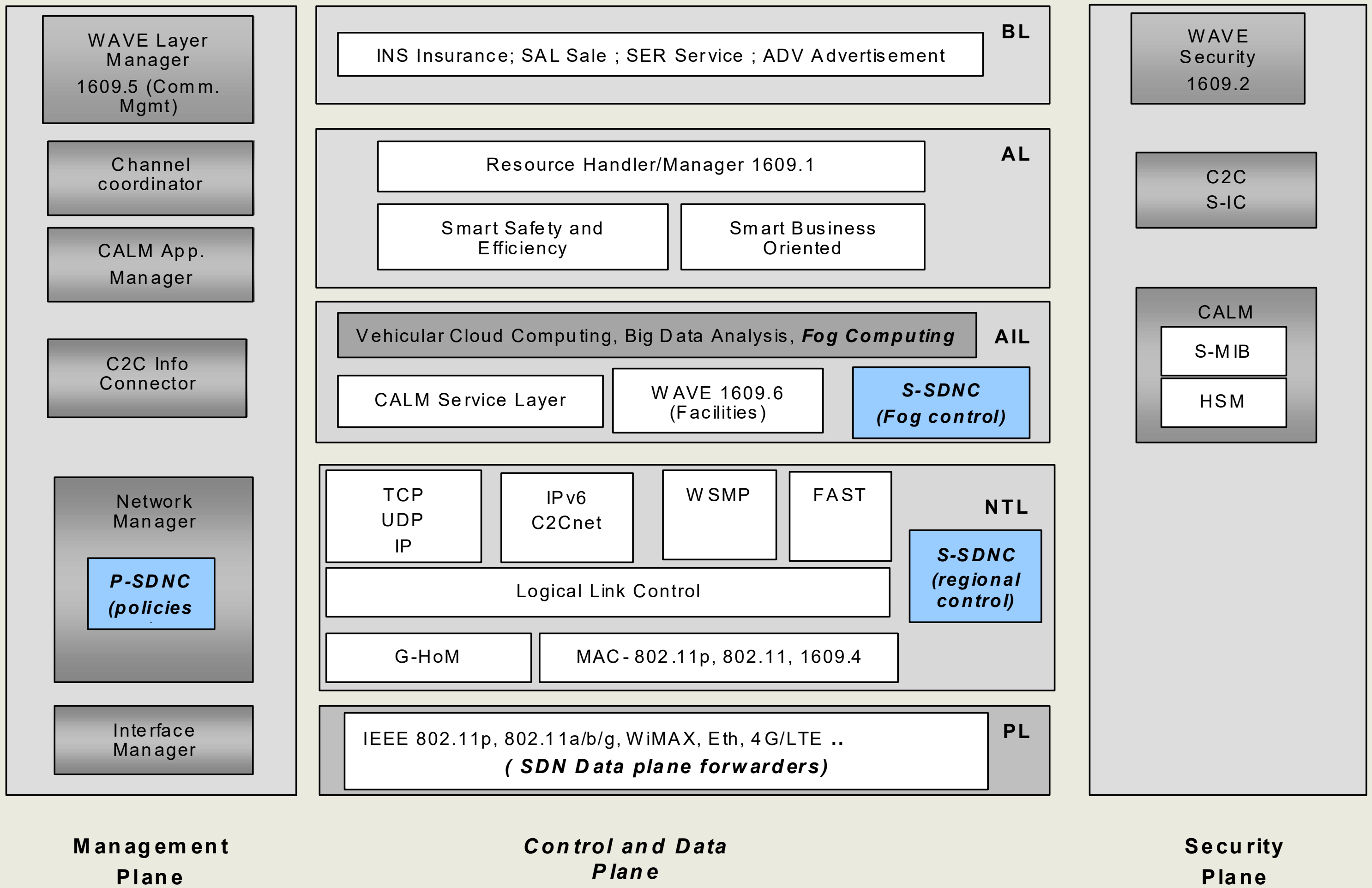


F-BS - Fog-capable Base Station; F-RSU Fog-capable Road Side Unit; P-SDNC- Primary SDN Controller; S-SDNC Secondary-SDN Controller; D2D- device to device communication

Source: E.Borcoci, et.al., "Internet of Vehicles Functional Architectures - Comparative Critical Study", AFIN 2017, The Ninth International Conference on Advances in Future Internet, http://www.iaria.org/conferences2017/ProgramAFIN17.html

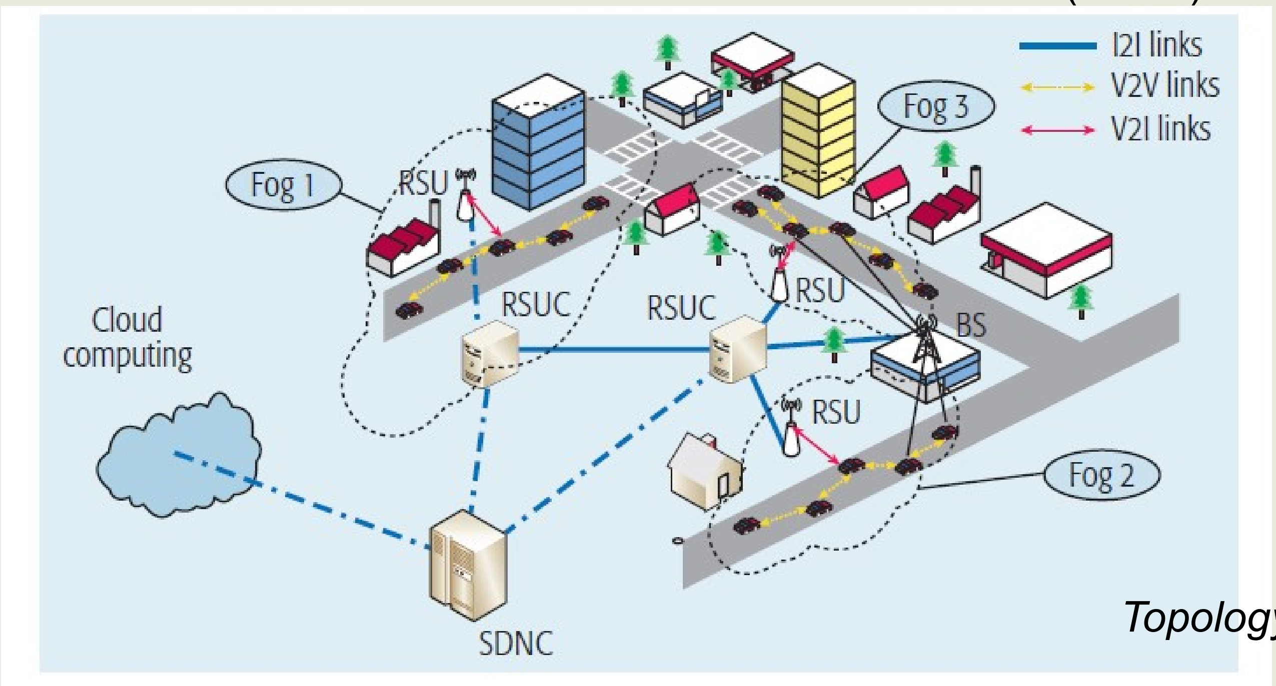
4. SDN-Cloud-Fog based architectures of IoV

- **Example 3: SDN-FOG architecture- mapping example to generic functional architecture** (cont'd)



4. SDN-Cloud-Fog based architectures of IoV

- **Example 4 5G Software Defined Vehicular Networks (SDVN)**
- IoV architecture based on 5G technology
  - partially - similar to that of Example 2 and 3
  - **fog cells** have been proposed to flexibly cover vehicles and avoid frequently handover between vehicles and road side units (RSUs)



Topology

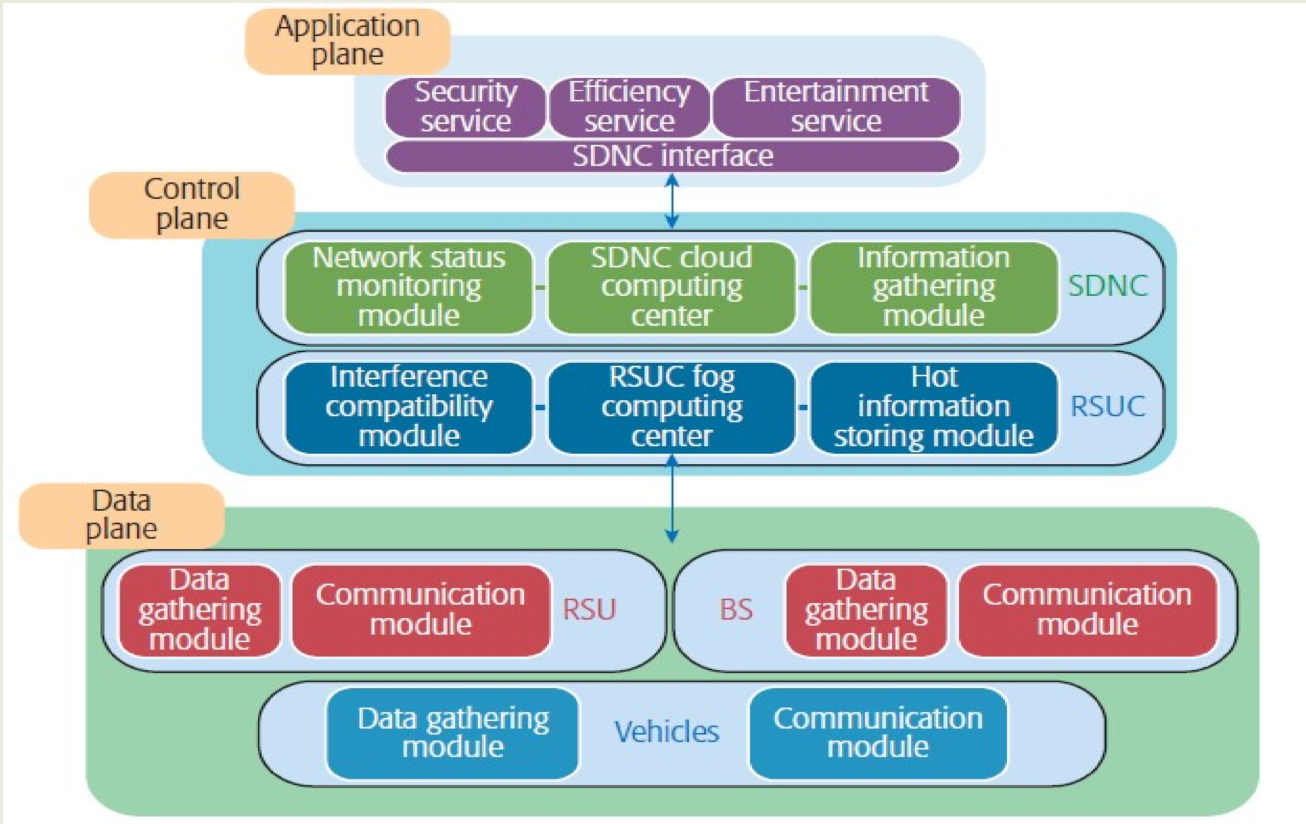
Fog computing clusters are configured at the edge of 5G SDVN

Most data in the edge of 5G SDVN is saved and processed by fog computing clusters, (including RSUC, RSUs, BSs, vehicles, and users)

Source: Xiaohu Ge1, et.al., 5G Software Defined Vehicular Networks, IEEE Communications Magazine, July 2017, http://ieeexplore.ieee.org/document/7981531/

4. SDN-Cloud-Fog based architectures of IoV

- **Example 4 5G Software Defined Vehicular Networks (SDVN)** (cont'd)
  - **Functional architecture**



Source: Xiaohu Ge1, et.al., 5G Software Defined Vehicular Networks, IEEE Communications Magazine, July 2017, http://ieeexplore.ieee.org/document/7981531/

4. SDN-Cloud-Fog based architectures IoV

- **Example 4 5G Software Defined Vehicular Networks** (cont'd)
- **Architectural Planes**
  - **Data plane** : **vehicles, BSs, and RSUs**
    - data collection, quantization, and then fwd. data horizontally or into the CPI
    - Vehicles (module types):
      - Information collection (data gathering); E.g. position information
      - Communications : V2I and V2V
    - RSU/BS (module types)
      - Information collection : e.g. sensors (e.g., cameras and speed measurement)
      - Comm. of RSUs; link types: RSUs - RSUC; RSUs - vehicles
  - **Control plane** : RSUCs, SDNC
    - **RSUC**
    - is the control center of a fog cell; allocate resources in the cell
    - fog cell : several vehicles and one RSU
    - why such Fog cell ? : to avoid frequent handover between the RSU and vehicles
      - one vehicle in a vehicle group connects with the RSU => the whole group in the fog cell could be connected with the RSU

4. SDN-Cloud-Fog based architectures of IoV

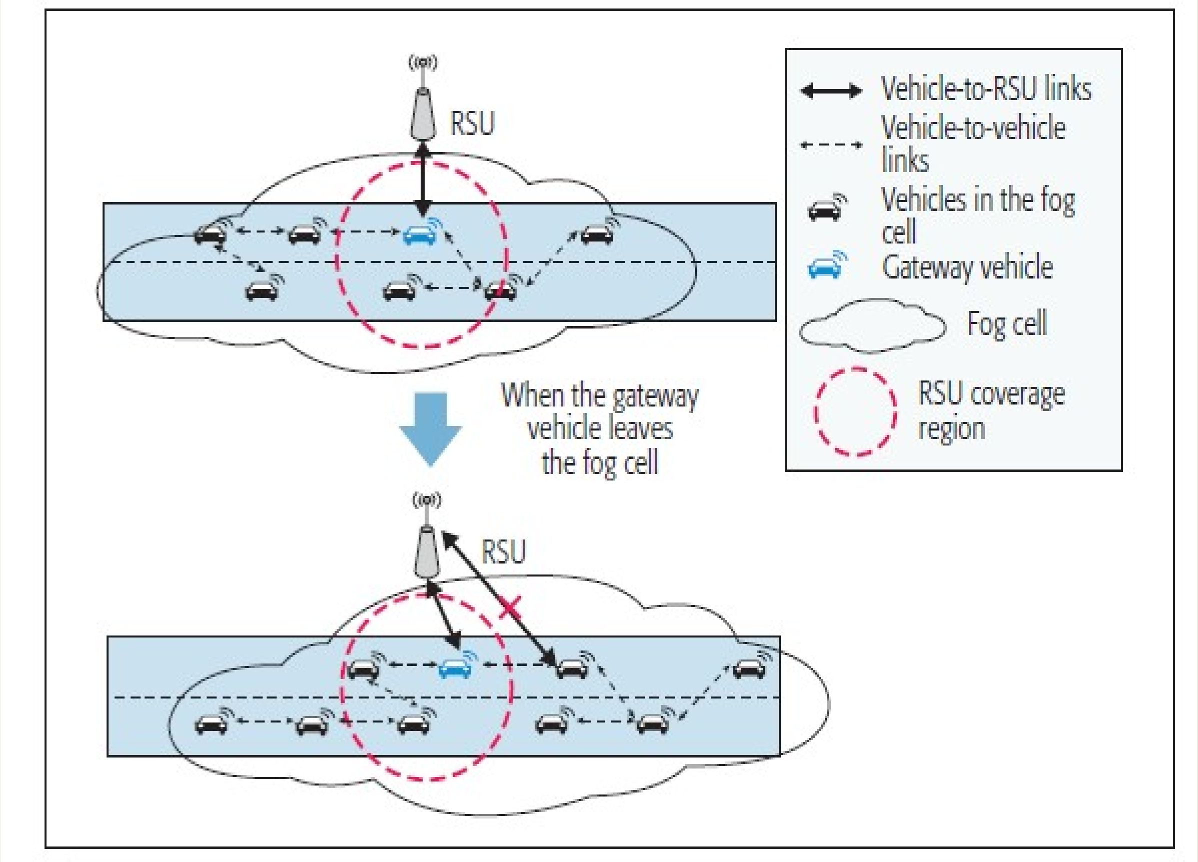
- **Example 4 5G Software Defined Vehicular Networks** (cont'd)

  - **Control Plane (CPl) (cont'd)**
    - **SDNC**
      - Highest control center of the SDVN
      - CPl allocate resources among cells
    - **Modules of RSUC and SDNC**
      - RSUC and SDNC: Information collection , Computing
      - SDNC: Networking status and monitoring
      - RSUC: Caching, Interference compatibility

  - **Application Plane (Apl)**
    - different application requirements from users and vehicles.
    - application requirements (from users, vehicles) -> rules and strategies of 5G SDVN are generated (API→ CPI)
    - Typical service modules : security, efficiency, entertainment

4. SDN-Cloud-Fog based architectures of IoV

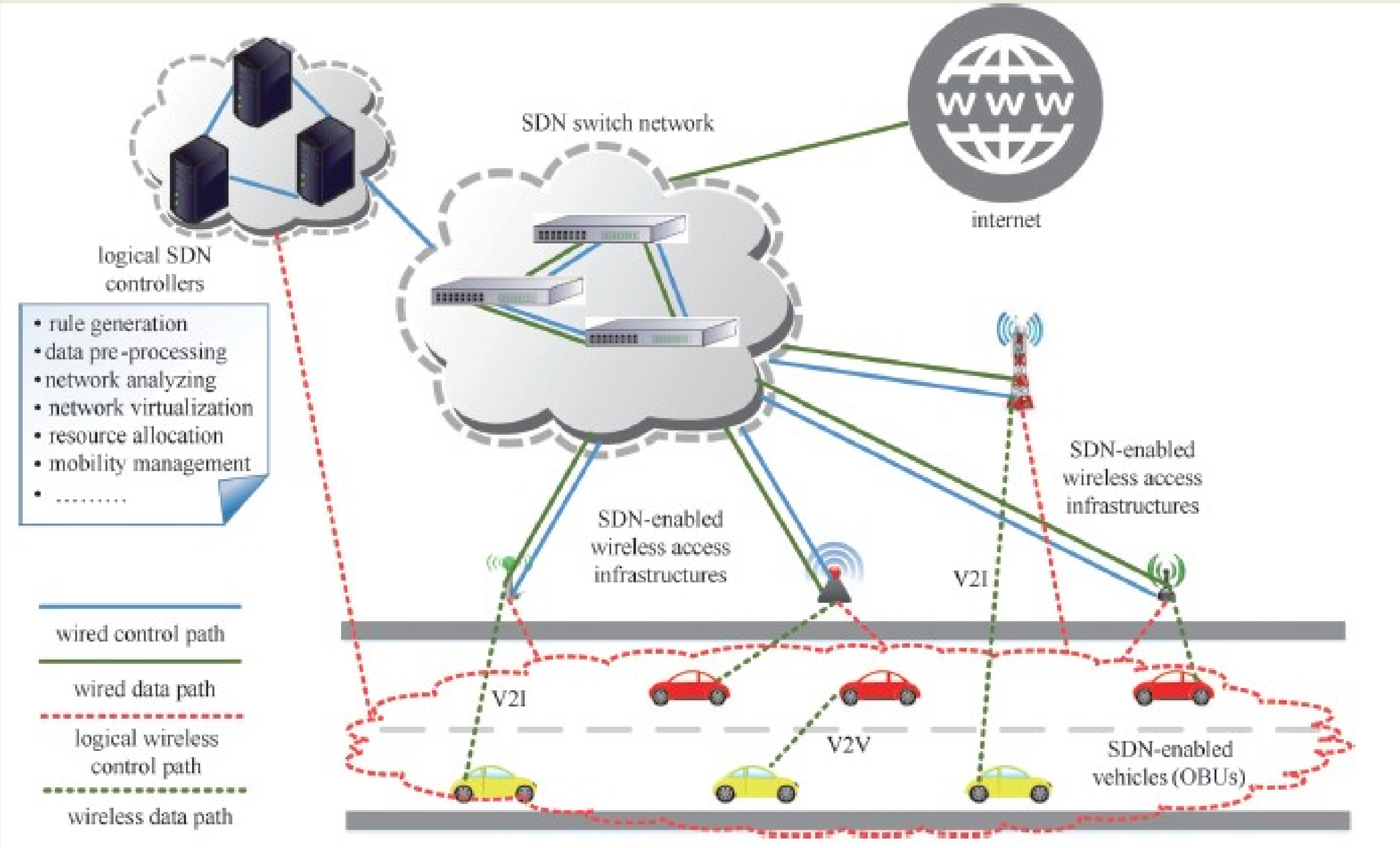
- **Example 4 5G Software Defined Vehicular Networks** (cont'd)
  - Examples of Vehicle communications in a typical fog cell



Source: Xiaohu Ge1, et.al., 5G Software Defined Vehicular Networks, IEEE Communications Magazine, July 2017, http://ieeexplore.ieee.org/document/7981531/

4. SDN-Cloud-Fog based architectures

- **Example 5: Software defined IoV generalized architecture**



Source: Chen Jiacheng et.al., Software defined Internet of vehicles: architecture, challenges and solutions, Journal of Communications and Information Networks, Vol. 1, Iss. 1, Jun. 2016 JCIN

4. SDN-Cloud-Fog based architectures

- **Example 5: Software defined IoV generalized architecture (cont'd)**
- **Components**

- **Logical SDN controllers**
  - have a global view of all the other components in the SD-IoV system

  - network management and operation (e.g., rule generation, network virtualization, client association, resource allocation, and mobility management)
  - and also advanced functionalities (e.g., data pre-processing, network analysis and learning)
  - "logical" → they may be **physically placed in cloud**, **and/or in the local areas** (for scalability and delay-reduction purposes)
  - these functionalities can be distributed among different controllers in a hierarchical manner.

- **SDN switch network**.
  - is operated by the same independent SD-IoV operator
  - and is connected to the core Internet via high-speed links
  - not necessarily SDN switch network is localized or scale-limited

4. SDN-Cloud-Fog based architectures

- **Example 5: Software defined IoV generalized architecture (cont'd)**
- **Components (cont'd)**

- **SDN-enabled wireless access infrastructures(SE-WAI)**
  - **heterogeneous IoV**: Wi-Fi APs, cellular BSs, RSUs, or even DSA coordinators
  - the SDN controller can control their behavior, at least partially
  - general SDN functionalities : packet forwarding and transmitting, and also

  - operations specific to the infrastructures such as
    - power control for the BSs,
    - operation channel assignment for the APs,
    - and resource allocation for the DSA coordinators.

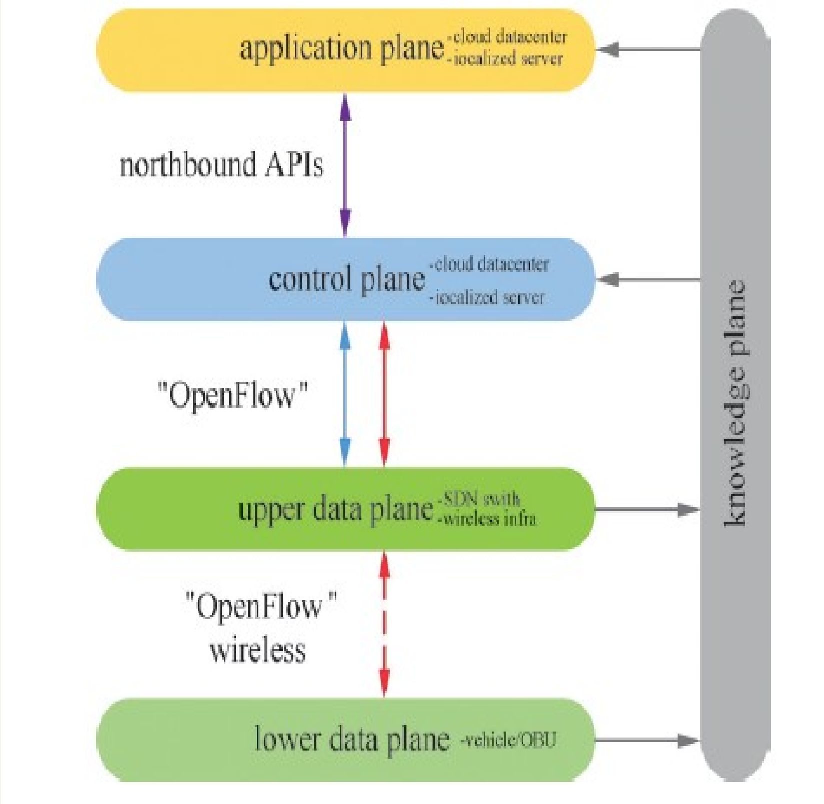
- **SDN-enabled vehicles (OBUs)**
  - Vehicles
    - end-users in the SD-IoV or, relays for V2V cases, they also act as
    - OBUs have multi-homing capabilities and may have partial of full SDN support

    - Examples of potential SDN-enabled functions : *forwarding, power control, channel selection, interface selection, and transmission mode selection*

4. SDN-Cloud-Fog based architectures

- **Example 5: Software defined IoV generalized architecture (cont'd)**
- **Data paths:** wired and wireless links
  - Wired : data transport between the Internet, SDN switch networks, and SEWAI
  - Wireless : data exchange for the SDN-enabled vehicles

- **Control paths**
  - Transport control information
  - guarantee real-time state feedbacks from other components.
  - wired : among SDN controllers, SDN switch networks, and SE-WAI
  - wireless : various, w.r.t. control channels, protocols and HW support



SD-IoV multiple plane architecture

4. SDN-Cloud-Fog based architectures

- **Example 5: Software defined IoV generalized architecture (cont'd)**
- **SD-IoV multiple plane architecture** (cont'd)

  - **Application plane (API) and Control plane** (CPI)
  - both reside in cloud datacenters and localized servers
    - API: network services on the top of CPI; offers APIs to realize the services *and translate services into rule*
    - The relationship API-CPI ~ relationship between app. SW and OS in computers.

  - **Data Plane (DPl)**
    - **Upper (wired) data plane**
      - **SDN switches and SDN-enabled wireless access infrastructures**
      - The fwd. rules are set by the CPI through an "enhanced" OpenFlow (OF) protocol.
      - extension of OF realize more advanced functionalities than simple packet forwarding (e.g. *power control of cellular BSs, power-saving mode of Wi-Fi APs*, etc.)

4. SDN-Cloud-Fog based architectures

- **Example 5: Software defined IoV generalized architecture (cont'd)**

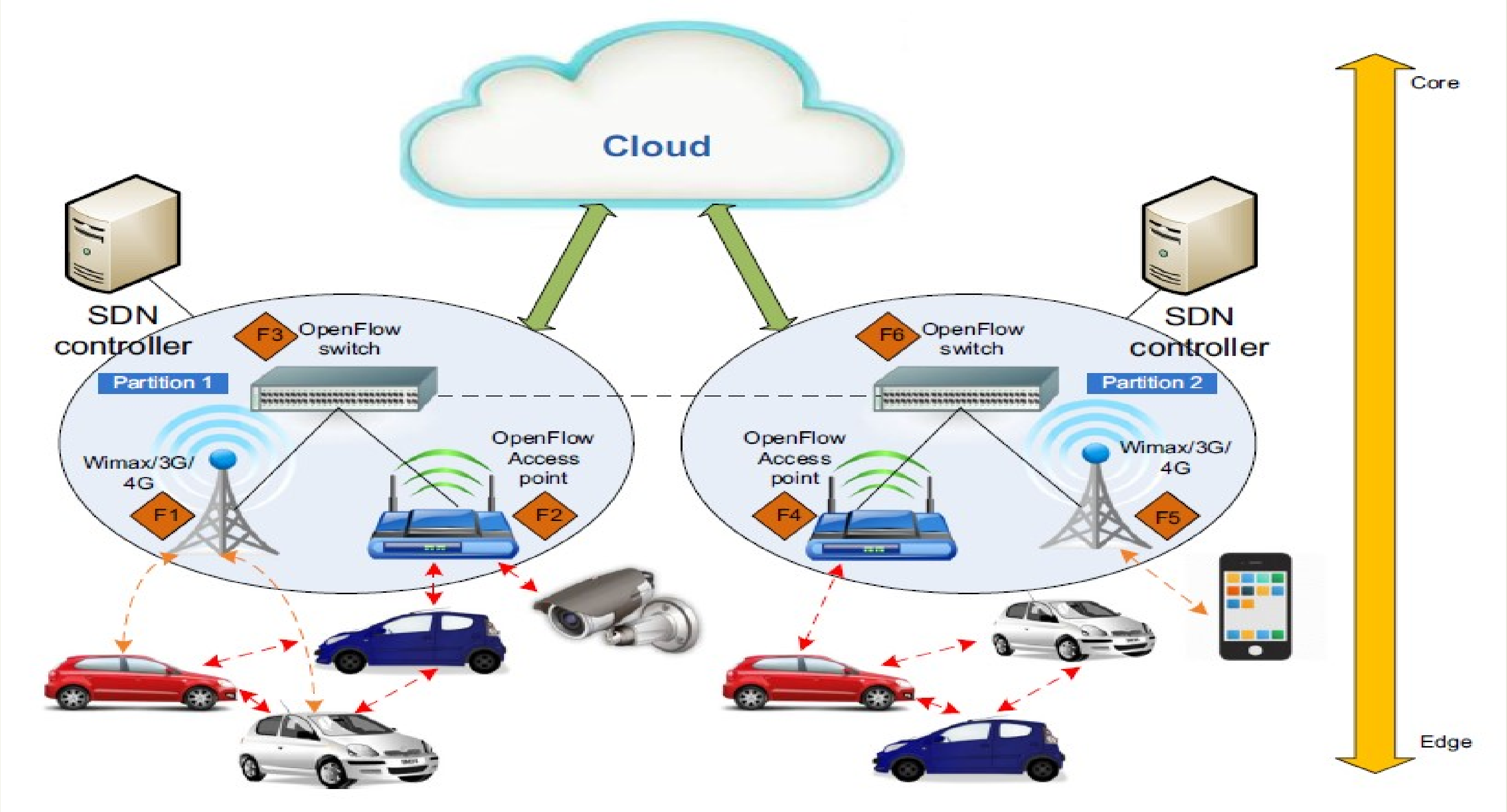
- **SD-IoV multiple plane architecture** (cont'd)
-
  - **Lower data plane (wireless)**
    - **SDN-enabled vehicles**, (**end-users and/or relays for V2V**)
    - A wireless extension of OF protocol is required
      - (e.g., configuration of OBUs, vertical handoff among different wireless interfaces)

  - **Knowledge plane (KPI)**
    - In order to generate appropriate rules, the API and CPI need information about the current states of data planes

    - KPI provides this info as an abstraction of the network state feedback functionalities

4. SDN-Cloud-Fog based architectures of IoV

- **Example 6: Software-Defined Fog Network Architecture for IoT**
- **System architecture**



Source: S.Tomovic, et al., "Software-Defined Fog Network Architecture for IoT", Springer, Wireless Personal Communications, DOI 10.1007/s11277-016-3845-0, 2016

4. SDN-Cloud-Fog based architectures of IoV

- **Example 6: Software-Defined Fog Network Architecture for IoT** (cont'd)

- **The system structure**
  - end devices with multiple RATs , SDN controllers, heterogeneous Fog infrastructure (virtualized servers, routers, access points, etc.) and Cloud in the network core.

- **Hierarchical deployment** of Fog network
- Fog nodes expose a set of APIs for app. deployment and development, resource management and control
  - These APIs
    - allow seamless access to hypervisors, various OSes and service containers on a physical machine
    - enable remote monitoring and management of Phy resources (CPU, mem., network interfaces)
- The **applications** : multiple processes that perform different tasks with respect to the device capabilities and position in the network hierarchy.

- Fog concept needs **service orchestration**.
  - Orchestration : *automated instantiation, replication and migration of service instances* on different Fog nodes with a wide range of capabilities

4. SDN-Cloud-Fog based architectures of IoV

- **Example 6: Software-Defined Fog Network Architecture for IoT** (cont'd)

- **System arhitecture** (cont'd)
  - **Possible solution for Fog Orchestration: SDN controller**
  - SDN Controller functions
    - Fog orchestration
    - Injection of routing logic into SDN-enabled network elements.
    - Selection of optimal Aps for IoT devices (i.e. RAN management)
  - Information necessary for SDN controller
    - **Features of Fog nodes** in the controlled domain
    - **Capabilities, state and interconnectivity** of the network elements
    - **Characteristics of the connected smart devices**
  - The Fog orchestration is performed according to business polices defined by application service providers.

  - **Policies**
    - are stored in SDN controllers and the Fog nodes hosting the provider's application
    - **examples** : reqs. for computing and memory resources, bandwidth and delays for different classes of subscribers, thresholds for load balancing, privacy rules etc.

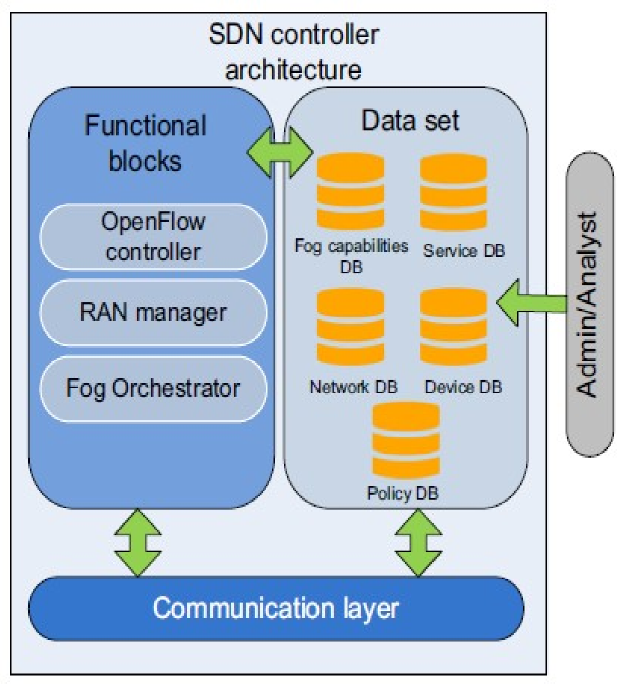
4. SDN-Cloud-Fog based architectures of IoV

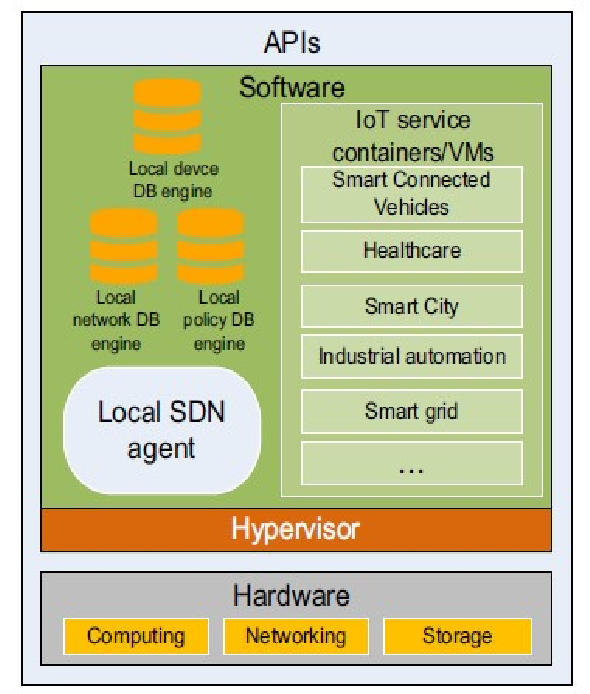
- **Example 6: Software-Defined Fog Network Architecture for IoT** (cont'd)
- **System arhitecture** (cont'd)

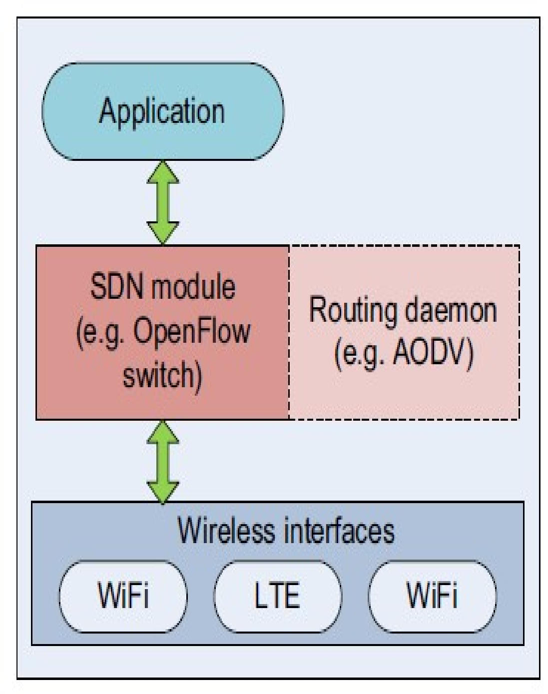
SDN controller

Fog node Structure

Wireless end device







Source: S.Tomovic, et al., "Software-Defined Fog Network Architecture for IoT", Springer, Wireless Personal Communications, DOI 10.1007/s11277-016-3845-0, 2016

4. SDN-Cloud-Fog based architectures

- **Example 7: IoV software-defined heterogeneous vehicular network (SERVICE), based on Cloud-RAN technology**

  - *Source :K. Zeng, et.al., "Soft-Defined Heterogeneous Vehicular Network: Architecture and Challenges", IEEE Network, vol. 30, pp.72-79, July/August 2016.*

  - **Main characteristics**

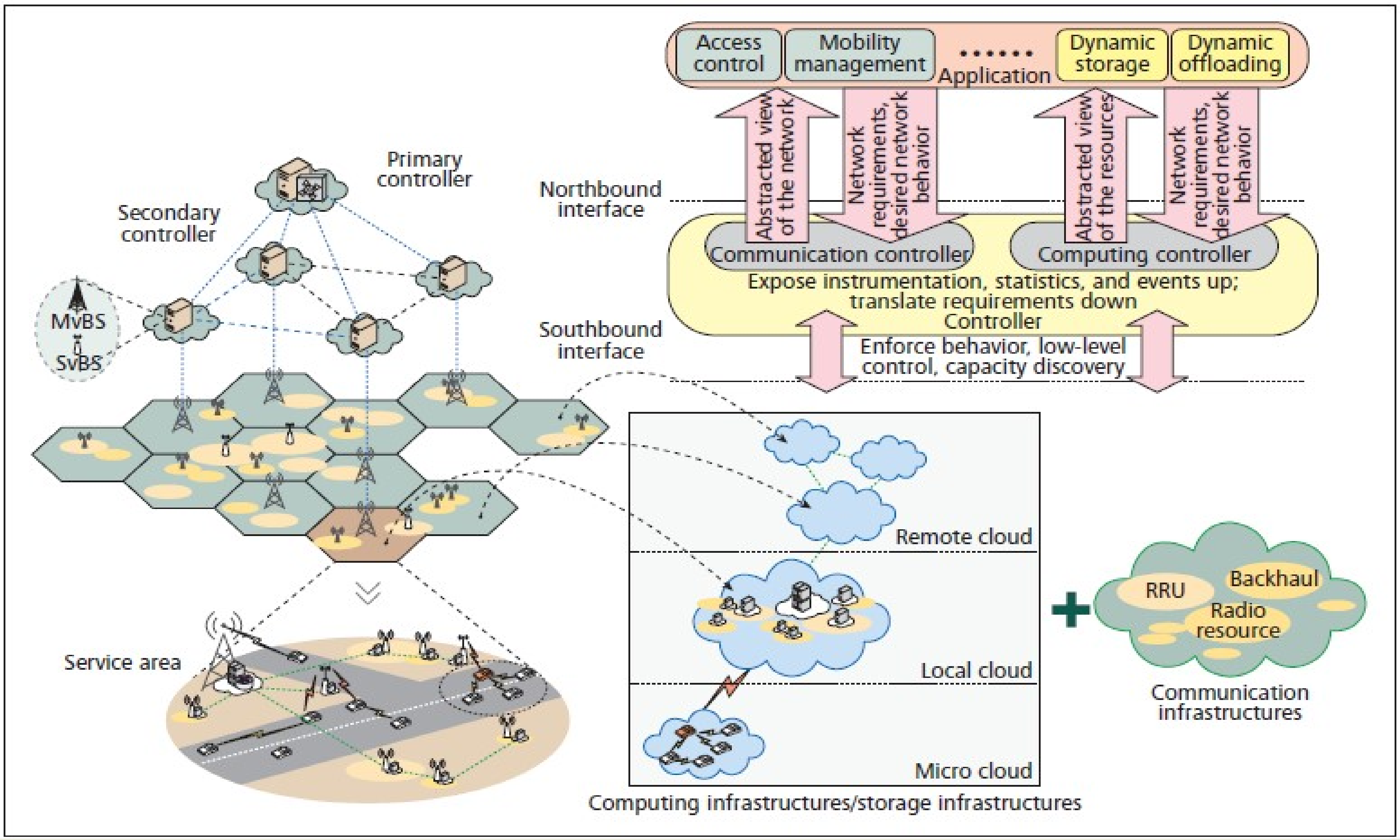
    - A multi-layer, multi-domain, Cloud-RAN is proposed

    - hierarchical organization (***remote, local and micro clouds***) and **virtualization** (for flexibility)

    - **two levels SDN control**
      - one primary controller and
      - several secondary controllers; each one of the latter controls a given service area

4. SDN-Cloud-Fog based architectures

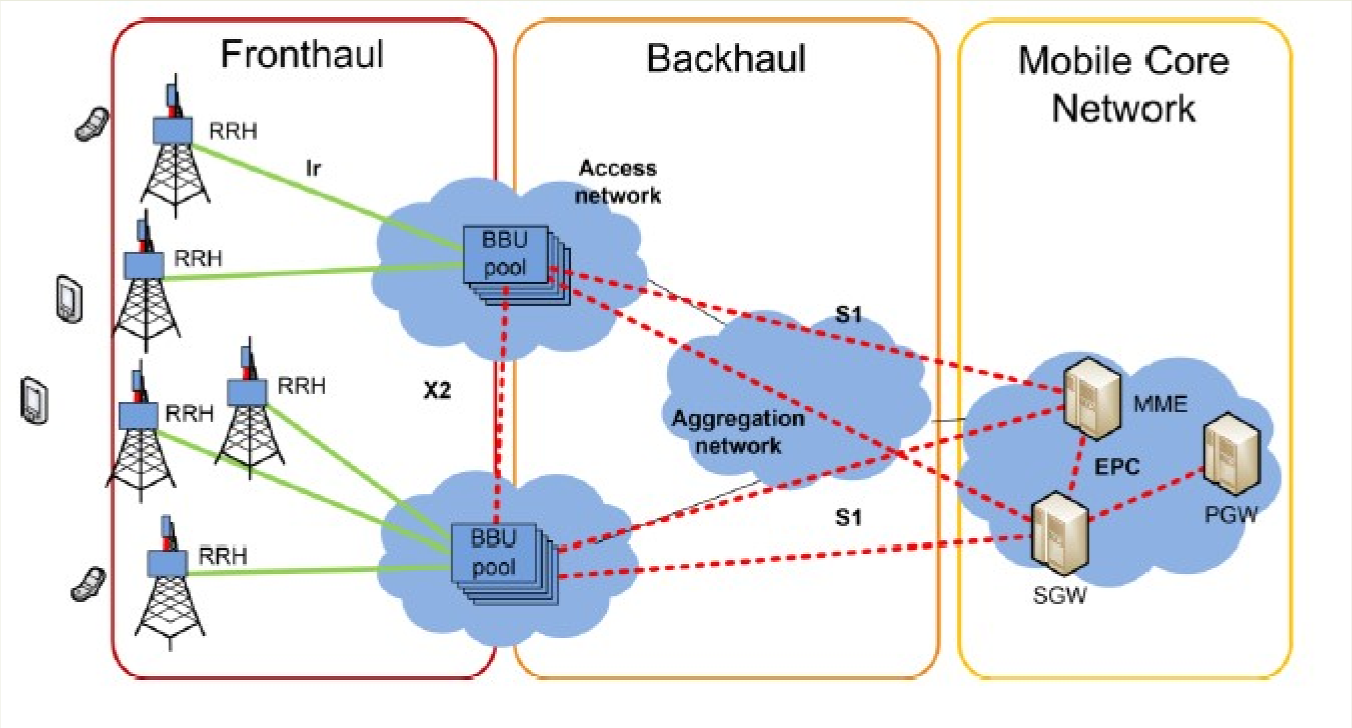
- **Example 7: IoV software-defined het-net vehicular (SERVICE)** (cont'd)



Source :K. Zeng, et.al., "Soft-Defined Heterogeneous Vehicular Network: Architecture and Challenges", IEEE Network, vol. 30, pp.72-79, July/August 2016.

4. SDN-Cloud-Fog based architectures

- **Example 7: IoV software-defined het-net vehicular (SERVICE)** (cont'd)
  - **CRAN architecture**



Source:A.Checko, "Cloud RAN fronthaul ", iJOINWinter School "5G Cloud Technologies: Benefits and Challenges„ Bremen, 2015-02-23

4. SDN-Cloud-Fog based architectures

- **Example 7: IoV software-defined het-net vehicular (SERVICE)** (cont'd)

- **Micro Cloud (MC)**
  - **Vehicles equipped with onboard computer,** storage, a radio transceiver, and various sensing devices realizes the bottom tier (MC) in SERVICE system.
  - The **MC controller** coordinates computing, sensing, communication, and storage resources, providing services only to authorized users.

- **Local Cloud (LC)**
  - Service area (SA) is defined and used as a basic geographical unit,
  - SAs = N ≥ 1 coverage of macrocells
  - **Each SA has its own LC** with the management entity, controlling the local communication and computing infrastructures
  - The resources of LC can be deployed inside the SA (e.g., macrocell BS sites)
  - A vehicle entering the SA coverage area connects to the LC and use the services

4. SDN-Cloud-Fog based architectures

- **Example 7: IoV software-defined het-net vehicular (SERVICE)** (cont'd)

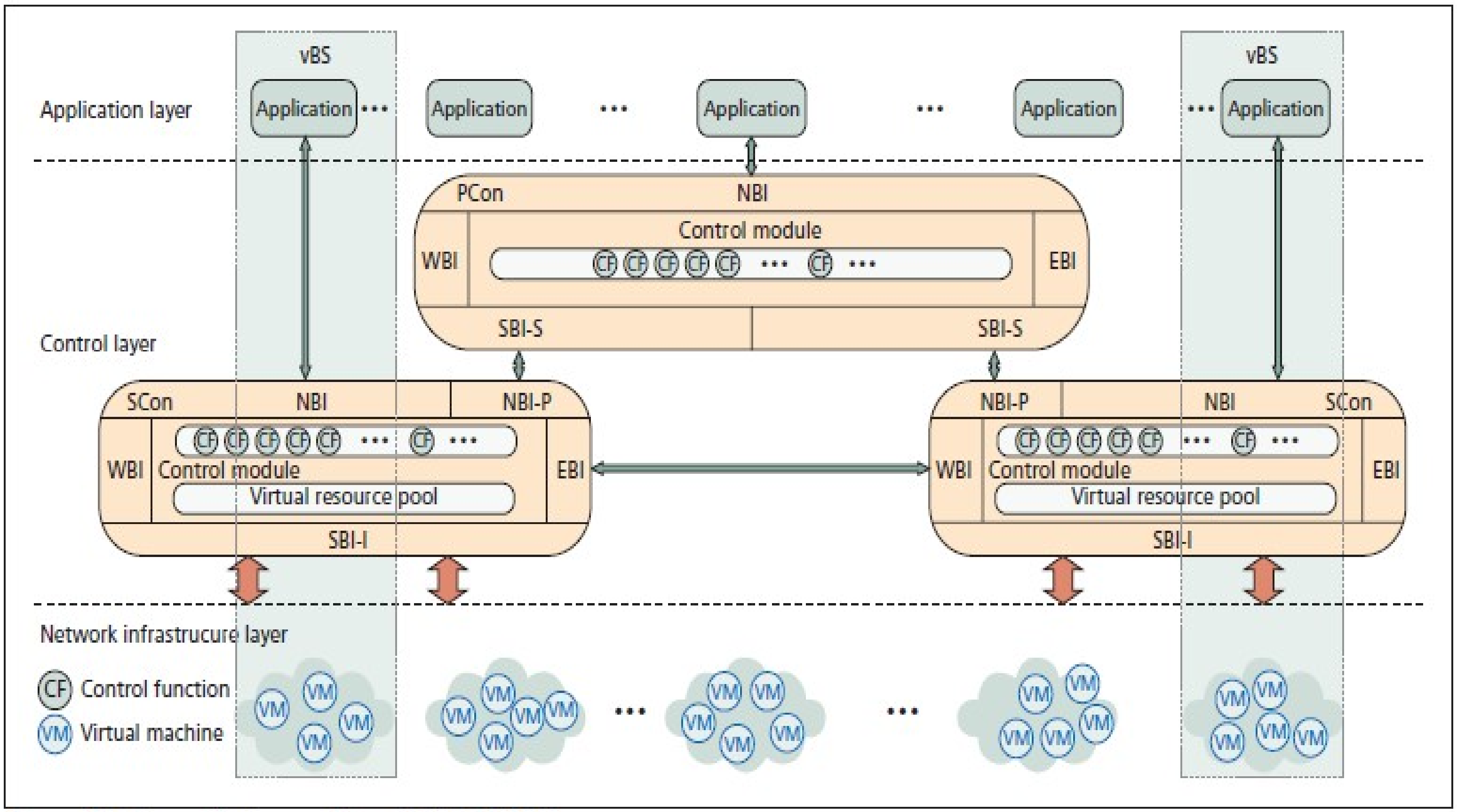
- **Local Cloud**
  - It can be accessed directly through a wireless connection→ lower latency and avoidance of wired transmission to the core networks (better QoE)
  - Some cloud services may involve resources in more than one layer. In such a case, the LC can act as a cache or a service proxy.

- **Remote Cloud**
  - For a vehicle user in a certain SA, remote resource can be called in the remote cloud (RC)
  - RC has powerful processing and storage capacities.
  - Access to RC: wireless and wired links

  - Offloading services (if necessary) to the RC involves coordination between SAs → which may create "east-west" data traffic in the wired domain.
    - Additional signaling overhead is needed.

4. SDN-Cloud-Fog based architectures

- **Example 7: IoV software-defined het-net vehicular network (SERVICE)** (cont’d)
- S



Source : K. Zeng, et.al., “Soft-Defined Heterogeneous Vehicular Network: Architecture and Challenges”, IEEE Network, vol. 30, pp.72-79, July/August 2016.

4. SDN-Cloud-Fog based architectures

- **Example 7: IoV software-defined het-net vehicular network (SERVICE)** (cont'd)
- **SDN Logical Architecture**

- **Network Infrastructure Layer:**
  - It corresponds to the data plane of the standard SDN architecture
  - Resources : communication (BBUs in clouds, RRHs, and high rate backhaul links), computing, storage

- **Control Layer:**

  - ***Hierarchical Control Layer (CL)***
  - The control layer acts as a service proxy translating the users' requirements
  - It controls the behaviors on the virtualized resources and provide relevant information to the applications
  - A centralized controller is inefficient in the context of dynamic topology of vehicle network
  - Controller horizontal scalability is also an issue for large networks

  - **SERVICE system: hierarchical CL: primary controller (PCon) and secondary controllers (SCon).**

4. SDN-Cloud-Fog based architectures

- **Example 7: IoV software-defined het-net vehicular network (SERVICE)** (cont'd)
- **SDN Logical Architecture** (cont'd)

- **Control layer (cont'd)**
- **Primary Controllers (PCon)**
  - control the global SERVICE network and takes decisions
  - include wide area or n.r.t. control functions, such as inter-SA handoff and cloud resource allocation.
  - PCons assemble global network information (control layer topology, SA states, resource states)
  - PCons I/Fs: with SCons and directly with the network infrastructures

- **Secondary controllers (Scon):**
  - SCons are located logically below PCons
  - SCon: regional control entity - usually for a SA
  - ensure the QoS requirements of low-latency safety applications (e.g., V2V)
  - control the intra-SA resources through managing a virtual resource pool

- **Control Layer Functions:** Communication control, Computing control, Storage control

4. SDN-Cloud-Fog based architectures

- **Example 7: IoV software-defined het-net vehicular network (SERVICE)** (cont'd)

- **SDN Logical Architecture** (cont'd)

- **Application Layer:** by this, the operators can configure and control the system via designing different applications

  - **Examples of functions**
    - **Access management**
      - the SCons monitor the network load and radio link status
      - if the network load in a given virtual BS (vBS)is too high, then SCons performs handover
      - it send new vehicle access requests to another vBS (load balance and meeting the QoS reqs)

    - **Dynamic resource allocation**
      - SCons collect information of different resources into its virtual resource pool

      - dynamic resource allocation application is run based on network status

CONTENTS

5. Conclusions

- IoV- powerful development in the IoT framework, following ITS, VANET
- IoV has many promises but also these constitute, as well, challenges

- **IoV layered architecture is based on**
  - Legacy developments ITS, WAVE, VANET
  - IoT architectures
  - Cloud Computing and Fog computing (decentralised cloud-like capabilities and better service for the mobile environment)
  - Software Defined Networking (programmability and logical centralized control)
  - Network Function Virtualization (flexibility)

- Combined SDN, NFV, Fog architectures and developments are intensively studied
- Hierarchical control for large scale environments

- Thank you !
- Questions?

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Advanced Architectures and Control Technologies in Internet of Vehicles

- **List of Acronyms**
- ADV Advertisement
- AODV Ad hoc on Demand Distance Vector
- AI Artificial Intelligence
- BBU ` Baseband Unit
- BDA Big Data Analysis
- C2C-CC Car to Car – Communication Consortium
- CA Certificate Authority
- CALM Communication Architecture for Land Mobile
- CaaS Cooperation as a Service
- CC Cloud Computing
- CPl Control Plane
- CPS Complex Cyber-Physical Systems
- CRAN Cloud based Radio Access Network
- CRM Customer Relationship Management
- D2D- Device to Device communication
- DoS Denial of Services
- DPl Data Plane
- DSRC Dedicated Short Range Communication
- DSDV Destination-Sequenced Distance Vector routing
- ECU Electrical Control Unit
- ENaaS Entertainment as a Service
- FAST Fast Application and Communication Enabler
- FC Fog Computing
- F-RAN Fog RAN
- GIN Gateway of Internetworking
- GPS Global Positioning System
- HSM Hardware Security Manager
- HLL Hybrid Link Layer
- IaaS Infrastructure as a Service
- INaaS Information as a Service
- INS Insurance

Advanced Architectures and Control Technologies in Internet of Vehicles

List of Acronyms

IoT	Internet of Things
ITS	Intelligent Transportation Systems
IT&C	Information Technology and Communications
LLC	Logical Link Control
MANET	Mobile Ad hoc Network
MCC	Mobile Cloud Computing
NaaS	Network as a Service
NFV	Network Function Virtualisation
OBU	On Board Unit
ONF	Open Networking Foundation
PaaS	Platform as a Service
P-SDNC	Primary SDN Controller
PKI	Public Key Infrastructure
RRH	Remote Radio Head
RSU	Road Side Unit
RSUC	Road Side Unit Controller
SaaS	Software as a Service
SAL	Sale
SBO	Smart Business Oriented
SDN	Software Defined Networking
SER	Service
S-IC	Security Information Connector
SM	Service Management
S-MIB	Security Management Information Base
S-SDNC	Secondary-SDN Controller
SSE	Smart Safety and Efficiency
STaaS	Storage as a Service
TPNIO	Third Party Network Inter Operator

- List of Acronyms

V2I	Vehicle to Infrastructure of cellular networks and Internet
V2D/V2P	Vehicle to Personal devices (human)
V2R	Vehicle to Roadside
V2S	Vehicle to Sensors
V2V	Vehicle to Vehicle
V2X	Vehicle-to-everything
VANET	Vehicular Ad hoc Network
VC	Vehicular Cloud
VCC	Vehicular Cloud Computing
V-Cloud	Vehicular Cloud
VM	Virtual Machine
VPKI	Vehicular Public Key Infrastructure
WAT	Wireless Access Technologies
WSN	Wireless Sensor Network
WAVE	Wireless Access for Vehicular Environments