From Vehicular Ad-hoc Networks to Internet of Vehicles

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

From Vehicular Ad-hoc Networks to Internet of Vehicles

- **Motivation of this talk**
- The traditional ***Intelligent Transport System (ITS)*** has significantly evolved, including vehicular communication
  - Main communications: V2V, V2R, V2I→ *Vehicular ad-hoc Networks (VANET)*
  - VANET – is an important part of the ITS

- **VANET** (special class of ***Mobile ad-hoc Network - MANET***)
  - **has both technical and business-related limitations**
  - **still - 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)*
  - involving Internet and including heterogeneous access networks
  - IoV – special case of ***Internet of Things (IoT)***
  - **IoV Target domains:**
    - vehicles driving and safety (basic function – in VANET) and additionally:
      - urban traffic management, automobile production
      - repair and vehicle insurance, road infrastructure construction and repair, logistics and transportation, etc.

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1. Introduction

1.1 Intelligent Transport System (ITS)

- Advanced vehicles and associated transportation infrastructures that use IT&C technology to make driving safer, efficient and comfortable
- Operation of vehicles, manage vehicle traffic, assist drivers with safety and other information, provisioning of convenience applications for passengers
- ITS
  - high interest for companies, operators, government, academia, research; many countries have public and private sector bodies working on ITS
  - Important technologies - implementing many applications related to vehicles, vehicle traffic, drivers, passengers and pedestrians
- **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 Transport Systems (ITS) (cont'd)

- **Typical use cases and services/applications**
  - **Active road safety applications**
    - Collision warning: Intersection, Risk, Head on, Rear end, Co-operative forward, Pre-crash
    - Warning on: Overtaking vehicle, Wrong way driving, Stationary vehicle, Traffic condition, Signal violation, Control Loss, Emergency vehicle proximity, etc.
    - Lane change assistance
    - Emergency electronic brake lights
    - Hazardous location notification
    - Co-operative merging assistance

    - **Message types for safety apps**: time-triggered position messages and event-driven hazard warnings

  - **Traffic efficiency and management applications**
    - Speed management and Co-operative navigation
  - **Infotainment applications**
    - Co-operative local services
    - Global Internet services

1. Introduction

1.1 Intelligent Transport Systems (ITS) (cont'd)

- Many **projects and standards** - developed all over the world: USA, Europe, Asia, etc.
- Standardization made by US Federal Communications Communication (FCC)
  - allocation of 75MHz of ***Dedicated Short Range Communication (DSRC)*** spectrum
  - basically for V2V and V2I communications for safety apps.

- Numerous research works and standardization/projects have been performed
- **Examples:**
  - **DSRC** development by Vehicle Safety Communications Consortium (VSCC) (USA)
  - European automotive industry project dedicated to road safety development and demo - **PReVENT** project (Europe) 2004-2008
  - Internet intelligent transportation system (ITS) **Consortium and Advanced Safety Vehicle** project (Japan), 2011-2015
  - **Car-2-Car** Communications Consortium (C2C-CC), ETSI TC ITS
  - **Vehicle Infrastructure Integration** (VII) Program- USA 2009
  - Secure Vehicle Communication (**SeVeCOM**) - FP6 Europe, 2006-2008
  - **Network on Wheels** project (Germany), 2008, etc.

1. Introduction

1.2 Vehicular communication technologies- examples

- ***DSRC (Dedicated Short Range Communication):***
  - Related to the spectrum dedicated to vehicular communication and any type of communication among 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 and include some significant variations (5.8 GHz, 5.9 GHz or even infrared, different baud rates, and different protocols).

- ***WAVE (Wireless Access in Vehicular Environment):***
  - basically is related to all MAC/PHY protocols and standards used for vehicular communication (DSRC)
  - it mainly defines MAC/PHY protocols
  - however, the higher layers, such as IEEE 1609.1-4, are also considered in WAVE

  - **WAVE : IEEE 802.11p + IEEE 1609.1-4 + SAE 2735** (*Society of Automotive Engineers*)

1. Introduction

1.2 Vehicular communication technologies (cont'd)

- **VANET**
  - V2V and V2I communications based on WLANs
  - Features
    - Special applications (e.g., collision warning and local traffic information for drivers)
    - resources (licensed spectrum, rechargeable power source)
    - environment (e.g., vehicular traffic flow patterns, privacy concerns)

- **VANET Applications examples**
- **Safety**
  - Severe delay tolerance (~100ms); Purpose: avoid collisions and accidents
- **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 From VANET to IoV

- **Note: while IoV promises advanced features, all these can be considered as well as challenges**
- ***Commercial, objectives, architecture***
  - **VANET**: architecture supports specific apps. only (safety, traffic efficiency)
    - Internet access is not fully available (due to specific architecture)
  - **IoV:** business oriented architecture → high opportunities for various apps. (safety, traffic optimization and efficiency, infotainment, etc.)
- ***Collaboration capabilities:***
  - **VANET**: specific architecture, non-collaborative (i.e., Internet-wide)
  - **IoV:** collaboration between heterogeneous nets, reliable Internet service
- ***Communication types:***
  - **VANET**: basically - V2V, V2R, only partially V2I
  - **(IoV) includes different types of communications:**
    - vehicle-to-vehicle (V2V), roadside (V2R)
    - and additionally :
      - infrastructure of cellular networks and Internet (V2I)
      - personal devices (human) (V2D/V2P)
      - sensors (V2S)

1. Introduction

1.3 From 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 types: 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

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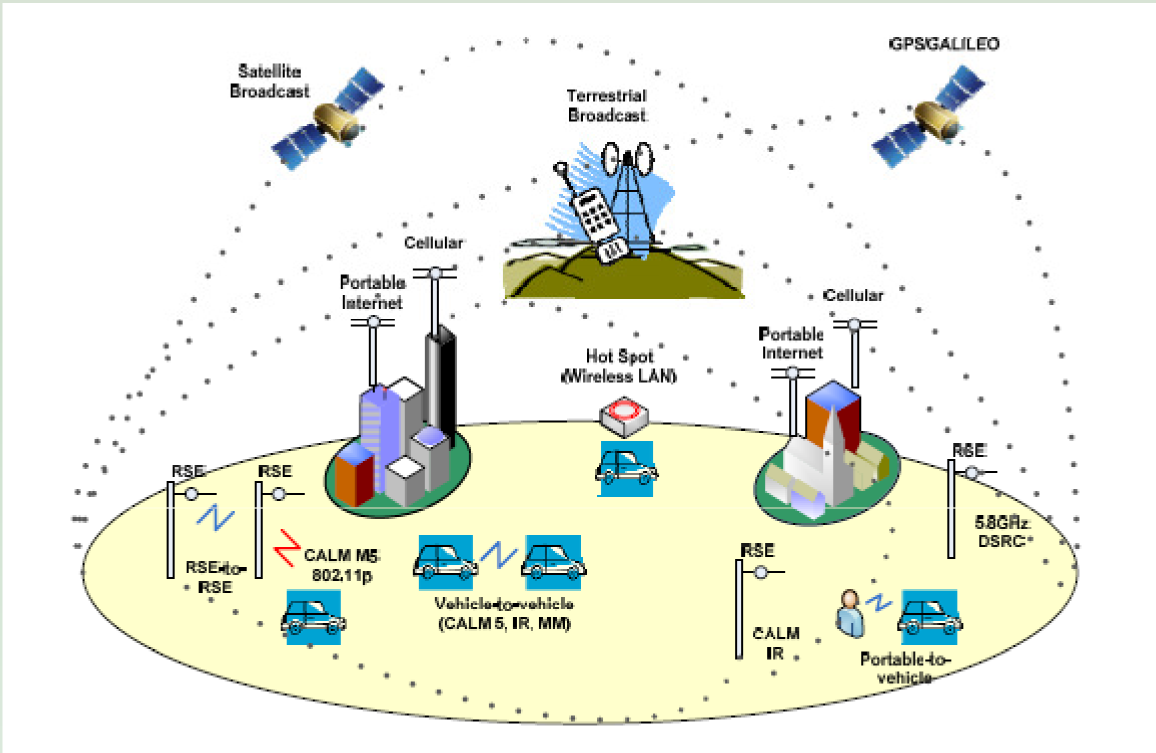
2.Vehicular networks - short overview

2.1 Intelligent Transportation System

- Elements of ITS are standardized in various organizations: 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 [1]: ETSI EN 302 665 V1.1.1 (2010-09, European Standard (Telecommunications series) Intelligent Transport Systems (ITS); Communications Architecture
Source [4]: G.Karagiannis,et.al.,"Vehicular Networking:A Survey and Tutorial on Requirements,Architectures, Challenges, Standards and Solutions", IEEE Comm. Surveys and Tutorials, 2011

2.Vehicular networks - short overview

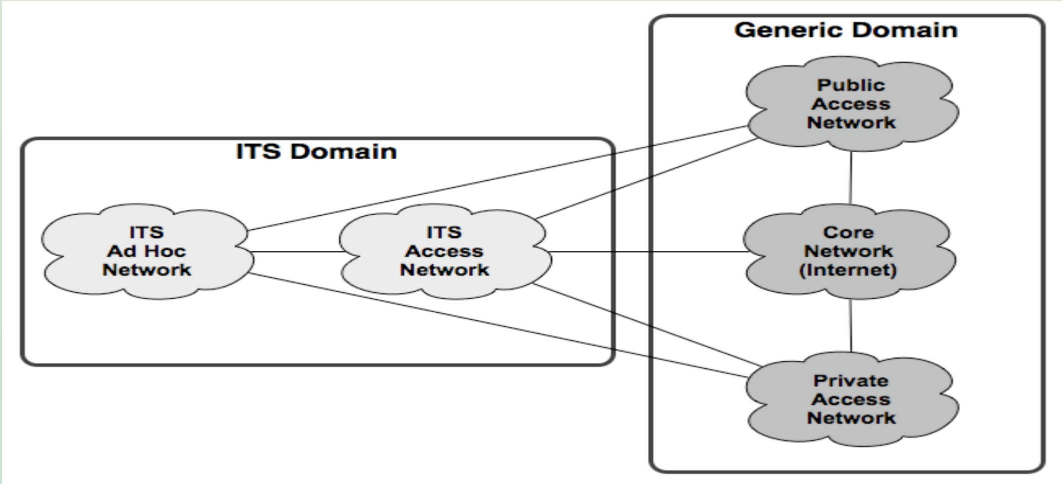
2.1 Intelligent Transportation System (cont'd)

- **Application categories – target usage**
  - **Infrastructure oriented applications**
    - management optimization: transit, freeway, intermodal freight
    - emergency organization...
  - **Vehicle oriented applications**
    - road safety
    - incident management, crash prevention, collision
    - avoidance, driver assistance...
    - automatic/adaptive settings
  - **Driver oriented services**
    - improving the road usage
    - traffic jam, road work information, traveller
    - payment, ride duration estimate...
  - **Passengers oriented applications**
    - for offering new services on board
    - Internet access, distributed games, chats, tourist information
    - city leisure information, movies announces downloads

2.Vehicular networks - short overview

2.1 Intelligent Transportation System (cont'd)

- Networks involved in the ITS architecture



ITS domains

- ***ITS ad-hoc network***
  - Essentially is an ad-hoc V2V, connecting also roadside and personal ITS stations
  - Wireless technologies (limited range)
  - Stations mobility → arbitrary network topologies, without the need for a coordinating communication infrastructure
  - Example: network of vehicle, roadside and personal ITS stations interconnected

2.Vehicular networks - short overview

2.1 Intelligent Transportation System (cont'd)

- **Networks involved in the ITS architecture**
  - ***ITS access network***
    - provides access to specific ITS services and applications
    - can be operated by a road operator or other operators
    - interconnects roadside ITS stations and provides communication
      - between these ITS stations
      - among vehicle ITS stations via the roadside ITS stations
      - (enable the Vs to communicate via a roadside infrastructure instead directly in ad hoc mode)
    - Example: ***access network -***it can connect roadside ITS stations along a highway, with a central ITS station (e.g. a road traffic management centre)
  - ***Public access network***
    - provides access to general purpose networks that are publicly accessible (e.g. IMT-2000)

2.Vehicular networks - short overview

2.1 Intelligent Transportation System (cont'd)

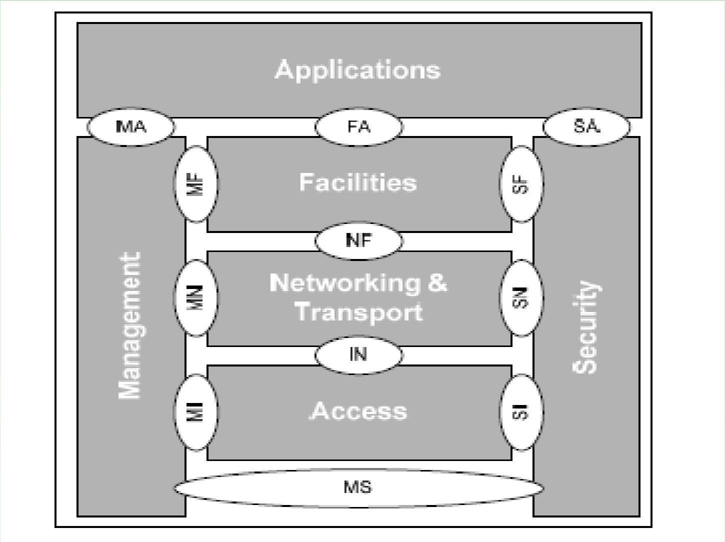
- **Networks involved in the ITS architecture**
  - ***Private access network***
    - provides data services to a closed user group for a secured access to another network
    - Example: a private access network can connect vehicle ITS stations to a company's intranet
  - The **access networks** and the **core network** provide access to various services:
    - legacy services, such as WWW, email, etc.
    - ITS services provided by road traffic management centres and backend services
    - ITS operational support services e.g., security services

  - **Core component of the architecture** : **ITS station**
  - ITS station two main roles
    - 1. network node and acts as a communication source, sink, or forwarder of data, e.g. in the *ITS ad hoc network.*
    - *2.* ITS station is placed at the network edge and connect the different networks via an ITS station internal network

2.Vehicular networks - short overview

2.1 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 others
- MF -facilities layer
- MN – network layer; MI -access layer
- MS - security entity

Security entity to others
- SF - facilities layer
- SI - access layer
- SN - networking & transport layer

2.Vehicular networks - short overview

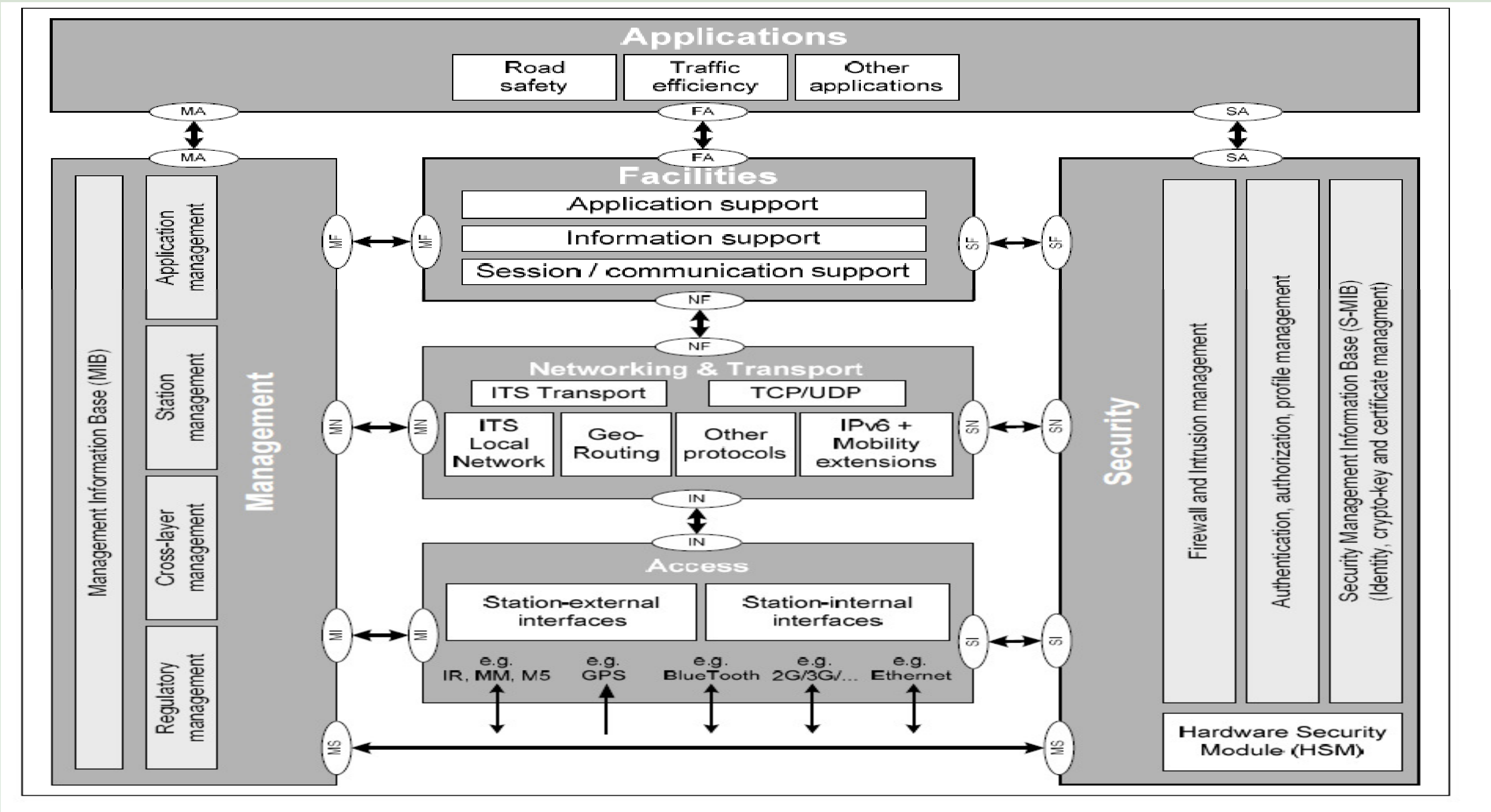
2.1 Intelligent Transportation System and CALM (cont'd)

- **ISO Technical Committee 204**:
  - http://www.sae.org/technicalcommittees/tc204wg16.htm
- WG 16: Wide Area Communications
  - **CALM: Communication Architecture for Land Mobile**
  - (renamed from Communications Air-interface, Long and Medium range)
  - 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

2.Vehicular networks - short overview

2.1 Intelligent Transportation System (cont'd)

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



2.Vehicular networks - short overview

2.1 Intelligent Transportation System (cont'd)

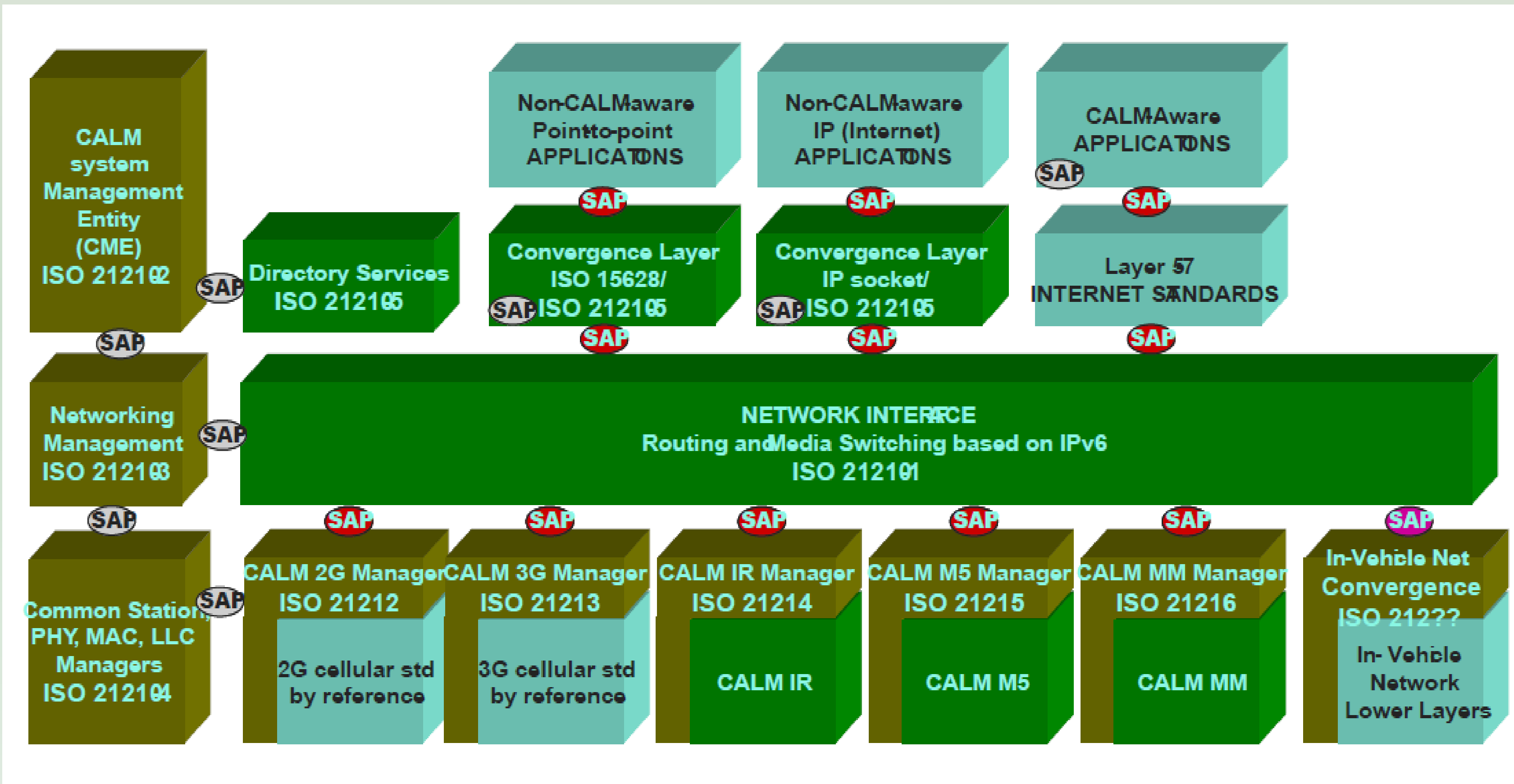
- **Functional components of an ITS/CALM station**
  - **ITS-S host-** contains as a minimum the ITS-S applications and the functionality of the ITS-S reference architecture
  - **ITS-S gateway-** interconnects two different OSI protocol stacks at layers 5 to 7
    - It shall be capable to convert protocols
  - **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)

2.Vehicular networks - short overview

2.1 CALM Architecture – basic standards

- Standards that are outside CALM scope

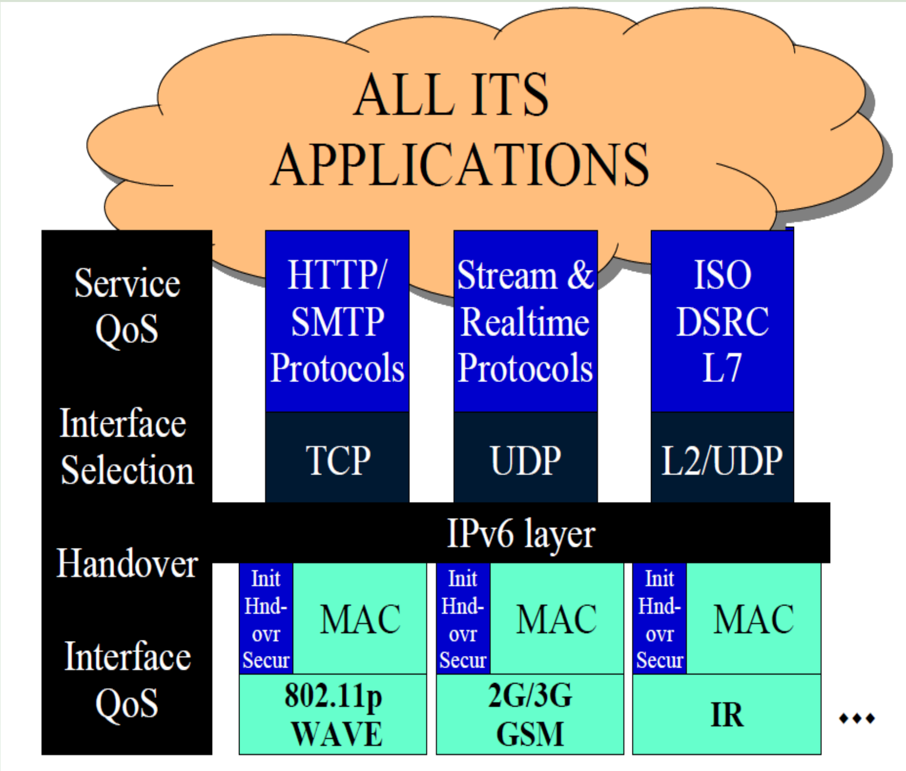


Source [11]: E. Thierry, „ISO TC204 WG 16: The CALM Architecture", IMARA project- INRIA, 2008, http://www.lara.prd.fr

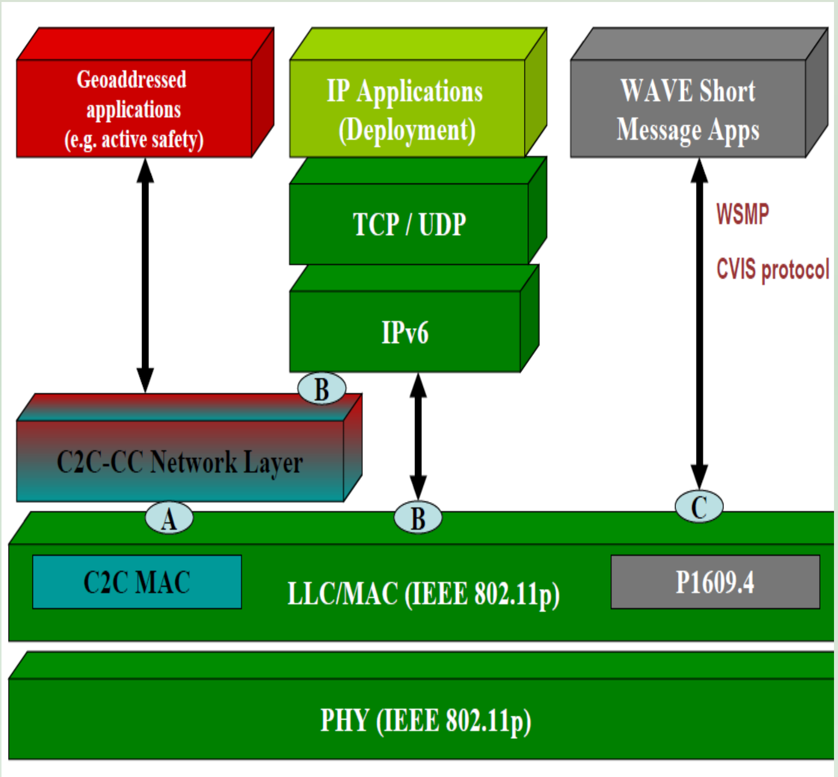
2.Vehicular networks - short overview

2.1 ITS and CALM Architecture

ISO TC204 WG16: CALM Architecture



CALM M5: C2C-CC & WAVE



Source [11]: E. Thierry, „ISO TC204 WG 16: The CALM Architecture", IMARA project- INRIA, 2008, http://www.lara.prd.fr

2.Vehicular networks - short overview

2.2 VANET (seen as an 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

2.Vehicular networks - short overview

2.2 VANET (cont'd)

- **Basic VANET system components**
  - **RSU- Road Side Unit**
  - **OBU On-board Unit**
  - **AU - Application Unit**
- Typically
  - RSU hosts applications that provides services
  - OBU is a peer device that uses the services
- The applications may reside in the RSU or in the OBU (provider/user model)
  - OBU
    - set of sensors *to collect* and *process* the information
    - sending information as messages to other Vs or RSUs
  - Vehicle: may host n≥1 AUs that use the applications offered by the provider, supported by OBU connection capabilities
- The RSU can also connect to the Internet or to another server which allows AU's from multiple vehicles to connect to the Internet

2.Vehicular networks - short overview

2.2 VANET

- **Basic VANET system components (cont'd)**
- **On-Board Unit (OBU)** *(Ref [13] 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

2.Vehicular networks - short overview

2.2 VANET

- **Basic VANET system components (cont'd)**

- **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

2.Vehicular networks - short overview

2.2 VANET

- **Basic VANET system components (cont'd)**
- **RSU- Road Side Unit**
  - antenna, processor, and read/write memory
  - wireless and wired I/Fs to communicate with OBUs, other RSUs and the Internet
  - It can 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

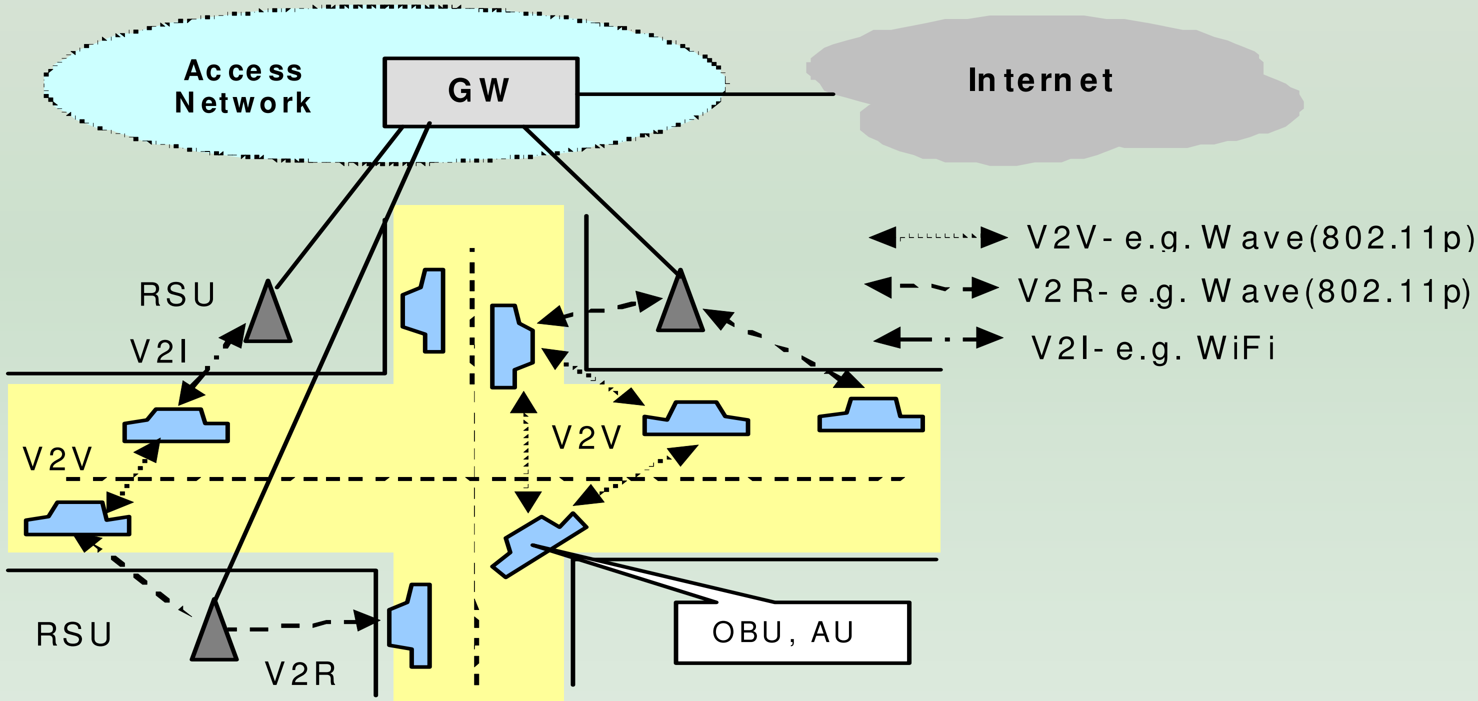
  - **Main functionalities of an RSU**
    - RF , high power, and long-range antenna
    - Support access to wired channels, (coax, cable or optical fiber cable, with Ethernet-like protocols)
    - Network stack to run a VANET specific network, link and L1 protocols
    - Forwarding data packets to OBUs in its range and other RSUs
    - Aggregation of safety information from OBUs through safety applications and alarming incoming OBUs
    - GW to provide Internet connectivity to OBUs

  - **Standards to be supported:** IEEE 802.11p, and all four IEEE 1609 protocols

2.Vehicular networks - short overview

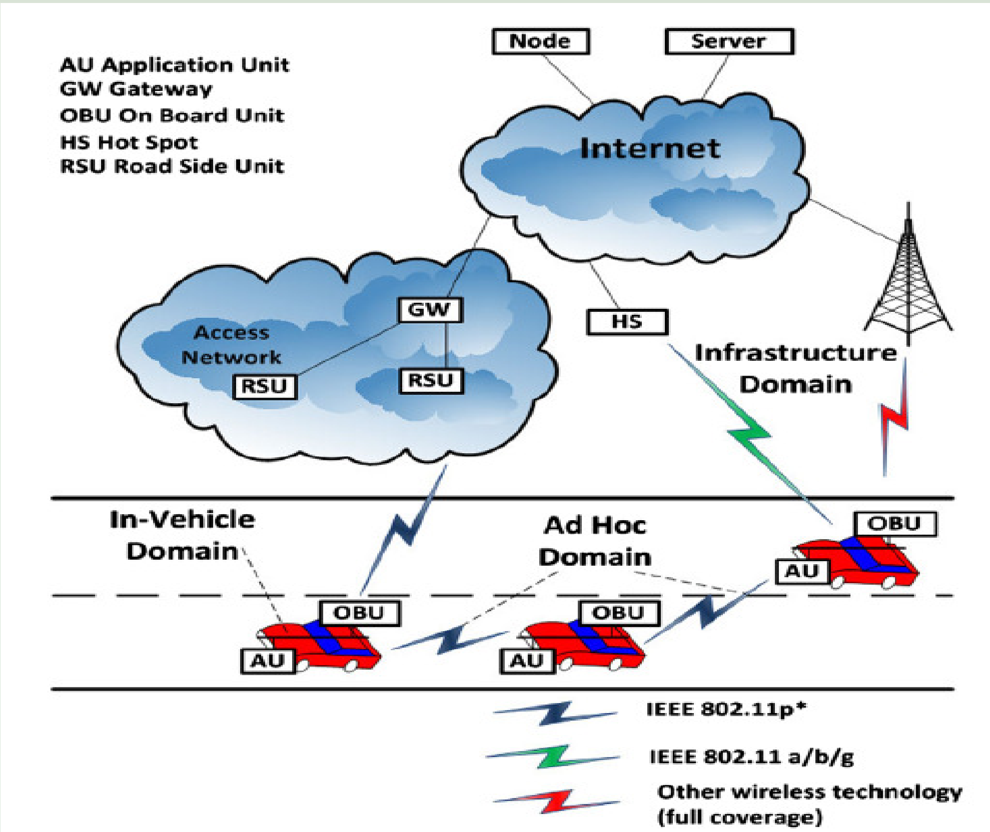
2.2 VANET (cont'd)

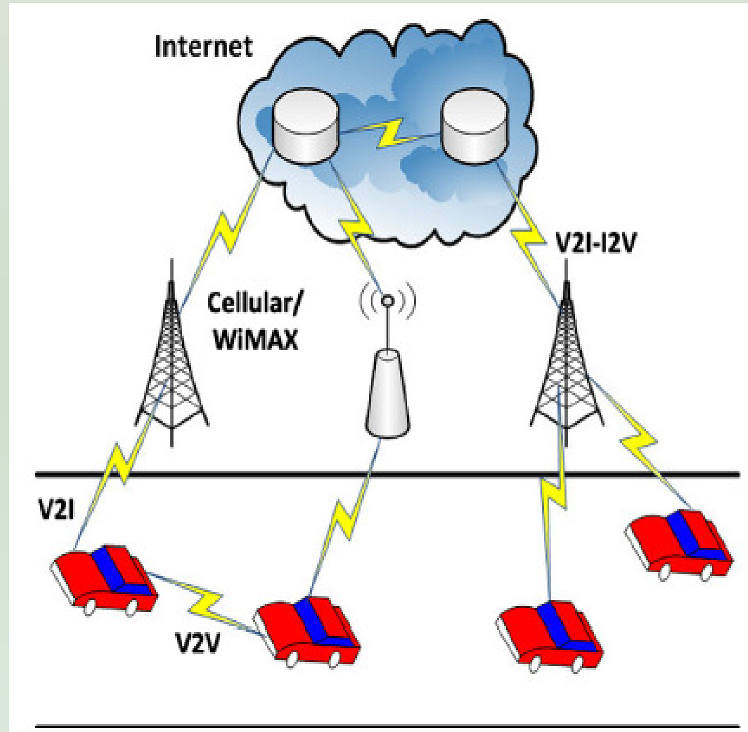
- VANET communication types
  - **V2V, V2R, V2I**



2.2 VANET (cont'd)

- **VANET – communication domains**





Combined DSRC, Cellular, Wi-Fi and WiMAX

Source: [6] 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,

2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT)

- **Comparison of wireless technologies for vehicular communication** [3]

Characteristic	Bluetooth	Wi-Fi	WAVE	UMTS[1]	LTE[2]	LTE-A[3]
Channel width	1MHz	20MHZ	10MHz	5MHz	1-4-20MHz	Up to 100MHz
Frequency Bands	2.4GHz	2.4GHz, 5.2GHz	5.86-5.92GHz	700-2600MHz	700-2690MHz	0.45-4.99GHz
Bit rate	800Kbps	6-54Mbps	3-27Mbps	2Mbps	Up to 300Mbps	Up to 1Gbps
Range	up to 30m	Up to 100m	Up to 1km	Up to 10km	Up to 30km	Up to 30km
Coverage	Intermittent	Intermittent	Intermittent	Ubiquitous	Ubiquitous	Ubiquitous
Mobility support	Low	Low	Medium	High	Very high (up to 350km/h)	Very high (up to 350km/h)
Broadcast/ multicast support	Limited support	Native broadcast	Native broadcast	Through MBMS	Through eMBMS	Through eMBMS
Vehicle to vehicle support	Limited, through ad-hoc	Native (ad-hoc)	Native (ad-hoc)	No	No	No

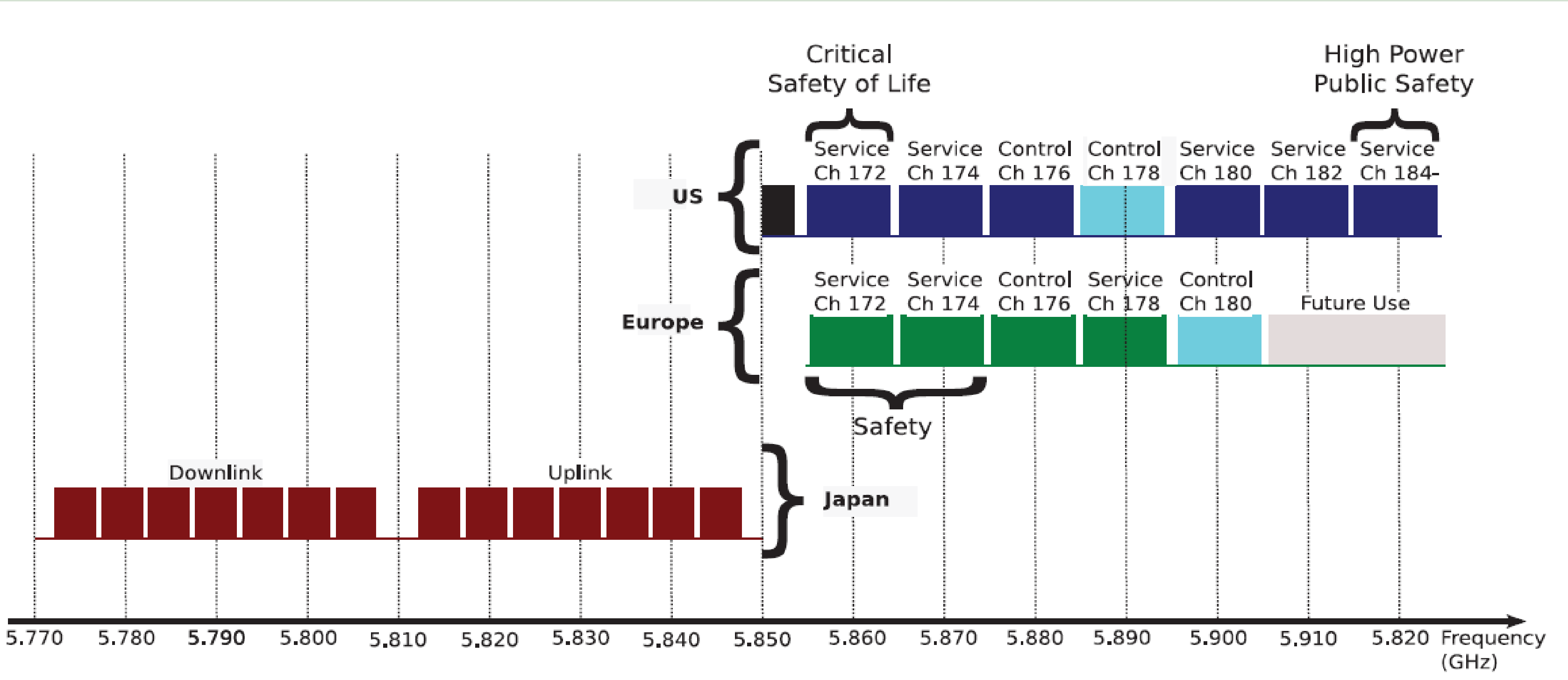
MBMS – Media Broadcast and Multicast System

Recent: D2D

2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

- **Spectrum allocation for ITS**
  - US and Europe: the spectrum is divided between service and control channels of 10MHz size
  - Japan: downlink and uplink channels, (5MHz in size)



2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

- **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

2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

- DSRC – IEEE 802.11p -WAVE

- **DSRC** (Dedicated Short Range Communications)- short range wireless technology
  - ASTM Standard E2213-03, based on IEEE 802.11a
  - name of the 5.9 GHz Band allocated for the ITS communications
  - DSRC standards suite is based on multiple cooperating IEEE standards
- **IEEE 802.11p -** includes DSRC
  - based on ASTM Standard E2213-03- developed for vehicular communications

- **WAVE** (Wireless Access in Vehicular Environments)
  - mode of operation used by IEEE 802.11 devices to operate in the DSRC band
  - the core design aspects of DSRC is Wireless Access in Vehicular Networks (WAVE) corresponding to IEEE 1609.1/.2/.3/.4
- **DSRC Devices**
  - IEEE 802.11 systems using the WAVE mode of operation in the DSRC band

- **IEEE P1556**
  - WAVE – IEEE P1609 – Layer 3-7 (OSI)
  - DSRC: EEE 802.11p, ASTM 2213

2.Vehicular networks - short overview

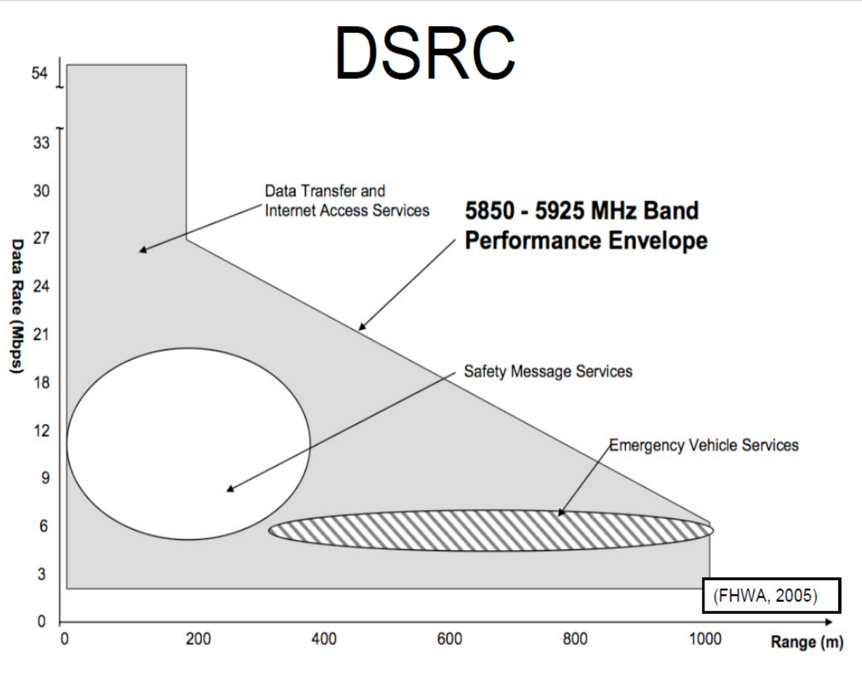
2.3 Radio Access Technologies (RAT) (cont'd)

- DSRC - IEEE 802.11p - WAVE
- **IEEE 802.11p/DSRC**
  - dedicated 5.9 GHz ITS bwdth. in the US, EU, and in the 5.8 GHz in Japan.
  - primarily for V2V safety apps. but possible extensions for -V2R, V2I, V2P and possible general Internet access
  - extended range and non-line of site awareness over and above current advanced driver assistance systems (ADAS)
  - is likely to become mandated in the US for all light vehicles starting in the 2020 model year
    - However, probably -not mandatory everywhere (EU, Japan, S.K, China)
  - Uses open off-the-shelf chip set & software

  - 5.850-5.925 GHz range :7 licensed channels (each 10 MHz)
    - 2 small and 2 medium zone service channels - for extended data transfer
    - 2 service channels for special safety critical applications
    - Public safety applications and messages have priority in all channels
  - Short range radio ~300m (1000m max)
  - Data rate : 6-27 Mbps, Half-duplex
  - Fast - 2 ms over the air latency, command-response & peer to peer modes

2.3 Radio Access Technologies (RAT) (cont'd)

- DSRC – WAVE - IEEE 802.11p
- **DSRC**
- **Basic -working example**:
  - **RSU:** announces to OBUs n times (e.g. n= 10) per sec.
    - the applications it supports
    - on which channels
  - **OBU**
    - listens on channel 172
    - authenticates RSU digital signature
    - executes safety apps first
    - then, switches channels
    - executes non-safety apps
    - returns to channel 172 and listens



2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

- **DSRC – WAVE - IEEE 802.11p**
- **IEEE 802.11p**
  - defines link (MAC) layer
  - Supports two different stacks:
    - IPv6- only on service channels (not control channel)
    - WAVE Short Message Protocol (WSMP)can be sent on any channel
    - allows apps to directly control PHY characteristics (channel number and transmitter power)
  - **Priority**
    - applications have a communication priority level
    - MAC transmission priority (based on IEEE 802.11e EDCA)
  - **Security in 802.11p**
    - Authenticate messages
    - Encrypt confidential data
    - Messages must be short and transactions fast
    - Special compact certificate format and a public key algorithm with short keys- for broadcast, high-priority messages

2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

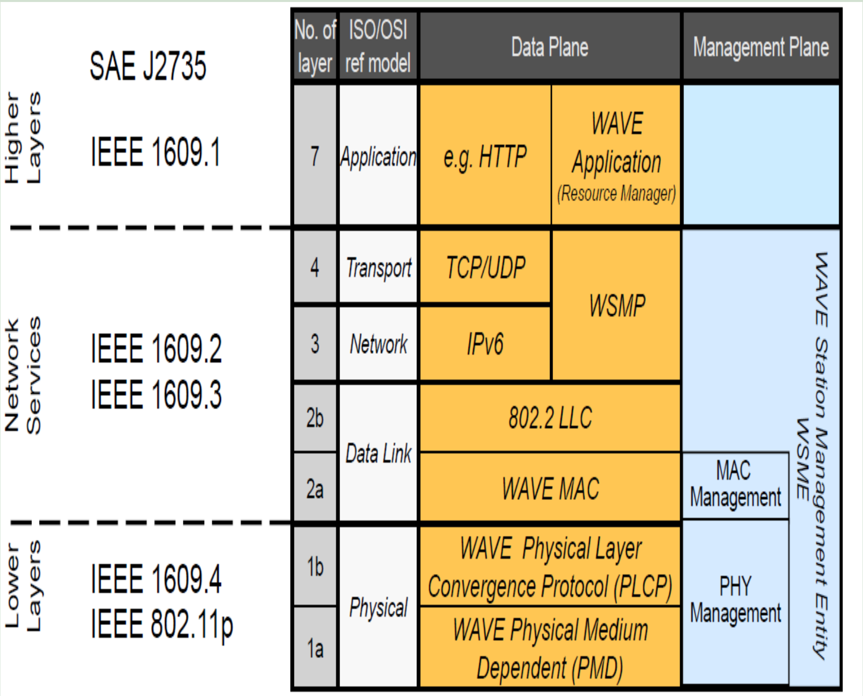
- **DSRC – WAVE - IEEE 802.11p**
- **IEEE 802.11p (cont'd)**
- 802.11p and Trust
  - Vehicle safety: operator is untrusted, applications should be isolated from operator
  - Public safety: operator is trusted

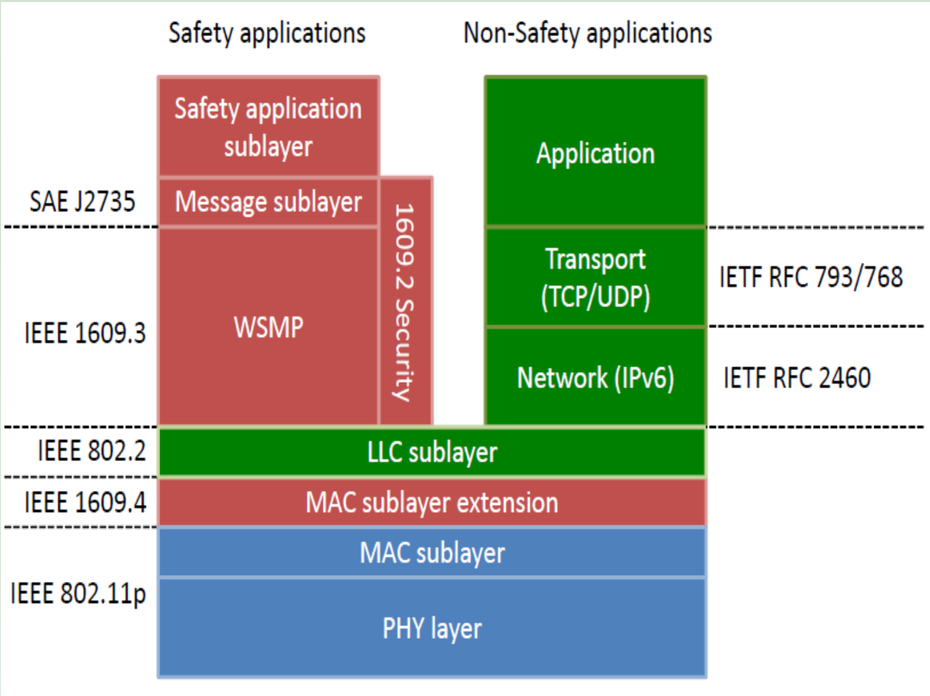
- 802.11p and Anonymity
  - Identifiers: Certificate, IP address, MAC address
  - Anonymous Certificates
  - Broadcast messages from OBU
    - must be authenticated but not be traceable to a specific OBU
    - Method: group signatures, OBU having large number of certificates, must be compatible with revocation
- MAC addresses
  - RSUs have a fixed 48-bit MAC address
  - OBUs generate a random MAC address upon start-up of the device
  - If a MAC address collision occurs the OBU automatically changes its MAC address

2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

- DSRC – WAVE - IEEE 802.11p (cont'd) WAVE
- WAVE- IEEE 1609 defines architecture, communications model, management structure, security and physical access
  - **Architectural layers**





Source[10]: T.Strang,M.Röckl, "Vehicle Networks: V2X communication protocols", http://www.sti-innsbruck.at/sites/default/files/courses/fileadmin/documents/vn-ws0809/11-VN-WAVE.pdf

2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

- **DSRC – WAVE - IEEE 802.11p**
- IEEE WAVE Family Standards Description

WAVE Standard	Usage	Describes/defines
IEEE P1609.0	Architecture	Architecture and service for multi-channel WAVE devices
IEEE P1609.2	Security Services for Applications and Management Messages	Methods for securing WAVE management and application messages, It also describes admin. functions to support the core security functions
IEEE 1609.3–2010	Networking Service	Standard messages that support higher layer communication stacks, including TCP/IP
IEEE 1609.4–2010	Multi-Channel Operation	Various standard message formats for DSRC applications at 5.9 GHz
IEEE P1609.5	Communication Manager	Communication management services in support of wireless connectivity among vehicle-based devices, and between fixed RSUs and vehicle-based devices
IEEE 1609.11–2010	Over-the-Air Electronic Payment Data Exchange Protocol	Basic level of technical interoperability for electronic payment equipment, i.e. (OBU) and roadside equipment (RSE) using DSRC
IEEE P1609.12	Identifier Allocations	Specifies allocations of WAVE identifiers defined in the IEEE 1609 series of standards

2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

- **WAVE (cont'd)**

- **P1609.1 Resource Manager**
  - describes key components of WAVE architecture,
  - defines data flows and resources, formats for command message and data storage
  - specifies the types of devices that may by supported by OBU

- **P1609.2 Security Services for Applications and Management Messages**
  - defines secure message formats and processing
  - circumstances for using secure message exchanges

- **P1609.3 Networking Services**
  - defines network and transport layer services, (addressing and routing, in support of secure data exchange)

  - WAVE Short Messages (WSM), - efficient WAVE-specific alternative to IP that can be directly supported by applications
  - defines MIB for WAVE protocol stack

2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

- **WAVE (cont'd)**
- **P1609.4 Multi-Channel Operations** enhancements to 802.11 MAC
- **New: 1609.4-2016 - IEEE Standard for Wireless Access in Vehicular Environments (WAVE) -- Multi-Channel Operation**
  - Revision of IEEE Std 1609.4-2010 (Revision of IEEE Std 1609.4-2006)
  - **Abstract:** Multi-channel wireless radio operations, WAVE mode, MAC and PHY including parameters for priority access, channel switching and routing, management services, and primitives designed for multi-channel operations
  - **Scope:** MAC sublayer functions and services that support multi-channel wireless connectivity between IEEE 802.11 WAVE devices
  - **Purpose:**
  - to enable effective mechanisms that control the operation of upper layer data transfers across multiple channels, without requiring knowledge of PHY parameters
  - and describe the multi-channel operation channel routing and switching for different scenarios.

2.3 Radio Access Technologies (RAT) (cont'd)

- **WAVE (cont'd)**
- **Security and Privacy**
  - OBU address randomized: prevents tracking vehicles
  - Authenticated RSU application announcements: prevents bogus message to V
  - Link level encryption for all messages prevents eavesdropping
  -
  - Authentication: PKI; US Government is CA

2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

- **Cellular alternative to IEEE 802.11p/DSRC**
  - C-V2X is a part of the overall 3GPP process to advance cellular systems from 4G to 5G technologies.
  - Standardization
    - LTE Broadcast (3GPP Rel. 9)
    - LTE Direct (3GPP Rel.12)
    - 3GPP Release 14
  - LTE Direct : enable direct V2V communications at distances up to hundreds of meters with low alert latency (about one ms)
  - both in-coverage and out-of-coverage (of standard cellular infrastructure)
  - LTE Broadcast facilitates V2I and V2N, within traditional cellular infrastructure
    - The V2X servers can broadcast messages to groups while individual vehicles can unicast messages back to the server
      - Vehicle can

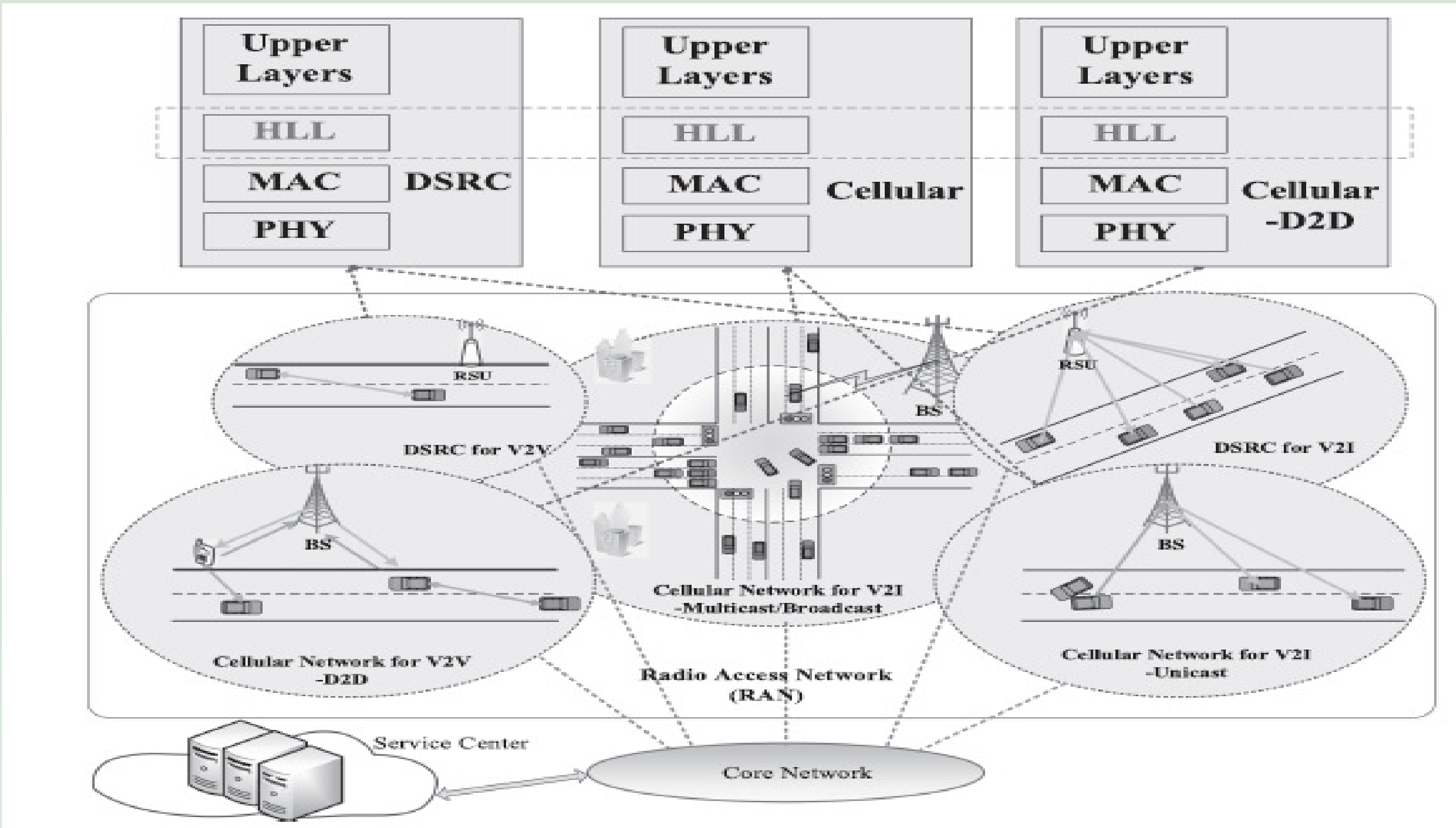
        receive alerts about accidents a few miles ahead up the road

        connect to smart parking systems to find open available parking spaces

2.Vehicular networks - short overview

2.3 Radio Access Technologies (RAT) (cont'd)

- *Heterogeneous Vehicular Networks*



Source [3] : K.Zheng, et.al., "Architecture of Heterogeneous Vehicular Networks", Springer 2016, www.springer.com/cda/.../9783319256207-c1.pdf

CONTENTS

3. IoV objectives, use cases and challenges

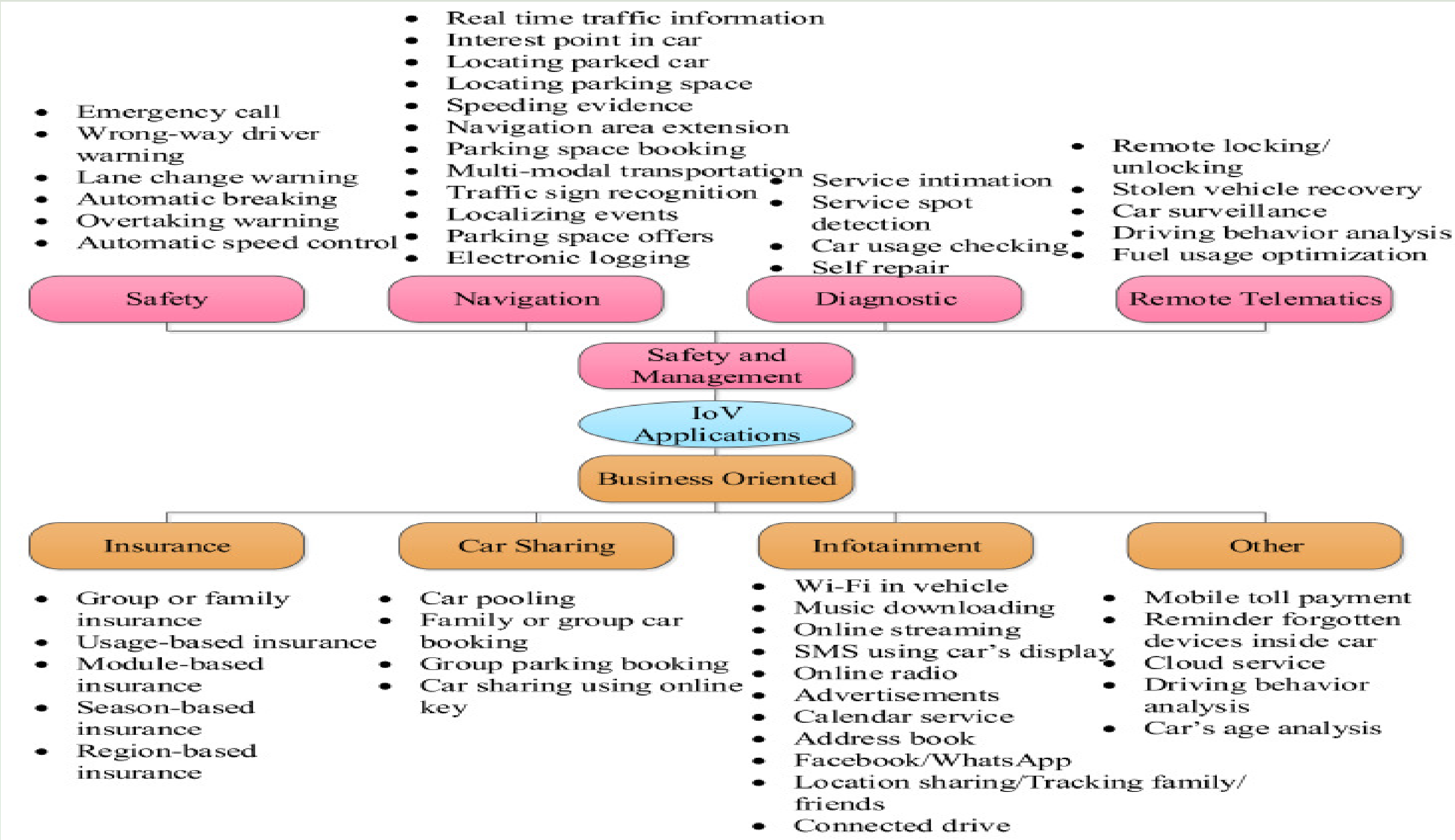
- **IoV main objectives**
  - IoV **– distributed transport fabric** capable of making its own decisions about driving customers to their destinations
  - IoV should have **communications, processing, storage, intelligence, learning and strong security** capabilities
  - To be **integrated in IoT** framework 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 access** technologies to provide universal Internet access (integrate multiple users, multiple vehicles, multiple things and multiple networks)

3. IoV objectives, use cases and challenges

- **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
    - Big Data technologies
    - Virtualization 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 seemles deployments/approaches

3. IoV objectives, use cases and challenges

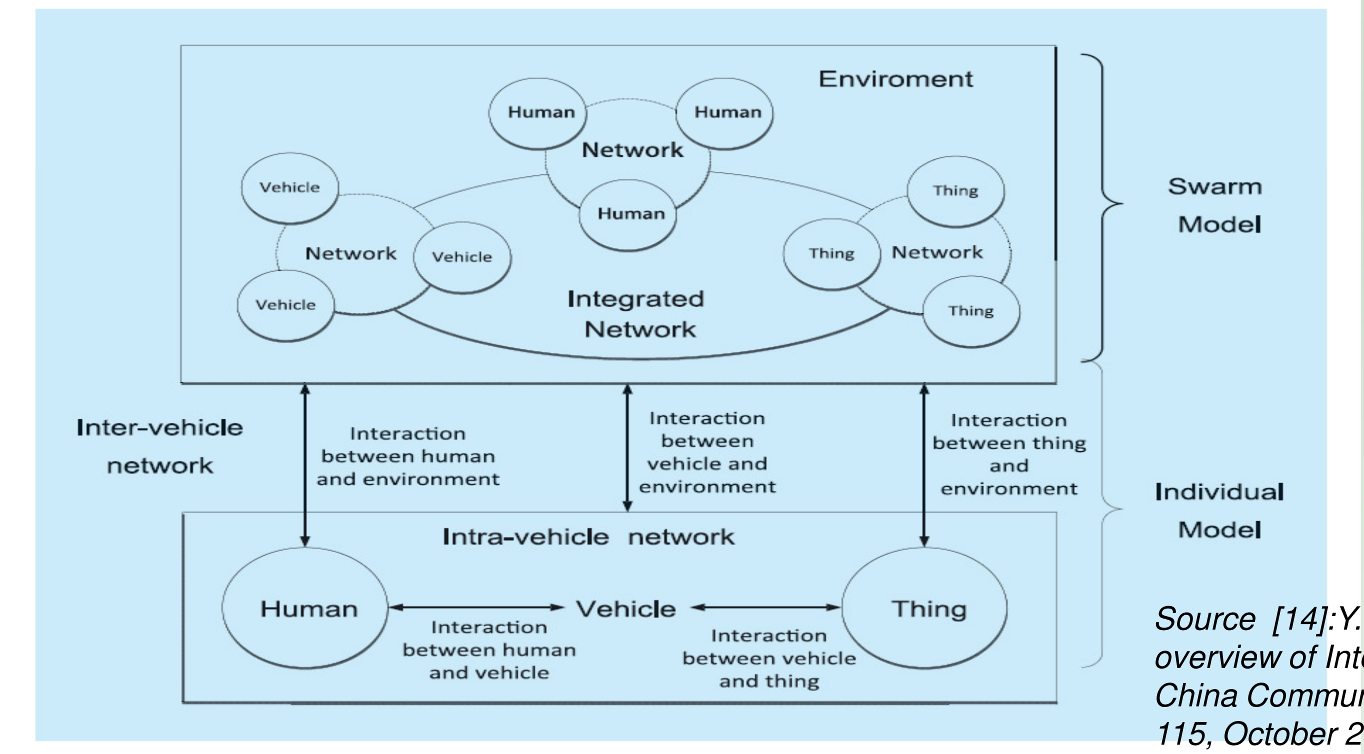
- **IoV – large range of target applications**



Source: [15]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

3. IoV objectives, use cases and challenges

- **IoV general challenges – examples**
  - To develop advanced network model and service model of human-vehicle in IoV
  - Enhance communication ability in IoV
  - Cooperation among Autobots
  - Assurance of the sustainability of service providing in IoV?
- **Network model – example- identifies interactions between entities**



Source [14]:Y. Fangchun, et.al., ``An overview of Internet of Vehicles," China Commun., vol. 11, no. 10, pp. 115, October 2014

3. IoV objectives, use cases and challenges

- **Examples of IoV specific technical challenges**
  - **Localization accuracy**
    - Should be better than for GPS, solve the GPS temporary unavailability
    - ~5m (GPS) → ~50 cm (IoV)
  - **Localization privacy**
    - not yet fully solved problems
  - **Location verification of neighboring vehicle**
    - Issues: cost of infrastructure – if directional antennas are used; overload of the beaconing approach; un-thrusty neighbour in cooperative approach
  - **Radio propagation problems and related models**
    - LOS, NLOS issues
  - **Operational and management – related problems**
    - Collaborative work issues
    - Computational complexities (tasks splitting among the entities of the network model)
    - Disruption reduction - need
    - …

CONTENTS

4. IoV architecture and main protocols

- **Different approaches for architectures**
  - **no single solution agreed yet…**

- **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 Networking and 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

4. IoV architecture and main protocols

- **Different approaches for architectures**
- **Objectives of architectural definitions**
  - 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 those of 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*

4. IoV architecture and main protocols

- **Example 1**
- **IoV generic 5- layer architecture -** proposed in [15]- as a VANET evolution
  - five types of vehicular communications: V2V, V2R, V2I, V2P, V2S
  - IoV Network model elements: *client, connection, cloud*
  - 3 architectural planes: *operation, management, security plane*

Layers	Representation	Functionalities
Business	Graphs, Flowchart, Table, Diagram	• Business model and investment designs • Resource usage and application pricing • Budget preparation, data aggregation
Application	Smart applications for vehicles and vehicular dynamics	• Smart, intelligent services to end users • Service discovery and integration • Application usage data and statistics
Artificial Intelligence	Cloud computing, big data analysis, expert systems	• Storing, processing, analysis of data • Analysis based decision making • Service management based on profit
Coordination	Heterogeneous Networks: WAVE, WiFi, LTE	• Unified structure transformation • Interoperability provisions • Secure transportation of information
Perception	Sensor and actuator of vehicles, RSU, personal devices	• Data gathering: vehicle, traffic, devices • Digitization and transmission • Energy optimization at lower layers

Source: [15]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

4. IoV architecture and main protocols

- **Example 1** (cont'd)
- **IoV generic 5-layer architecture**

  - **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, smart-phones and other personal devices
    - Mission: to gather information on vehicle, traffic environment and devices (including movement –related parameters)

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

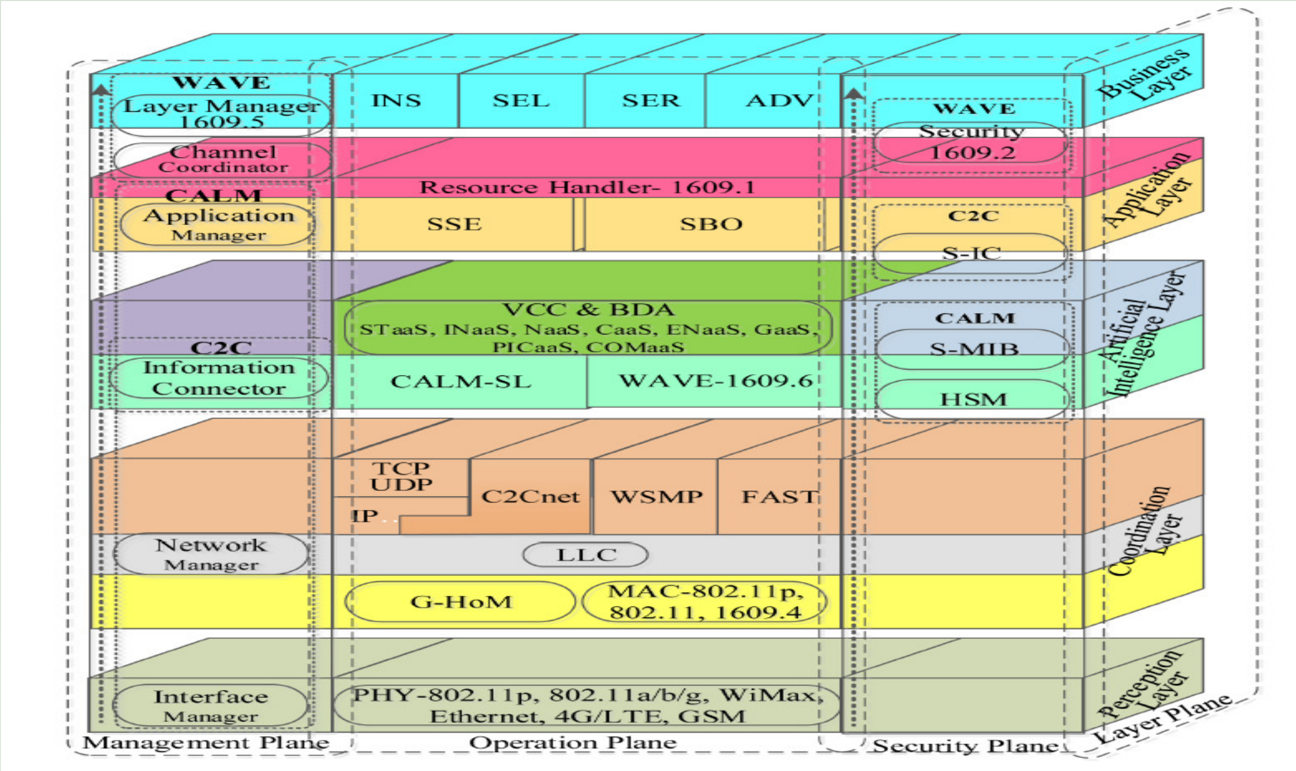
4. IoV architecture and main protocols

- **Example 1** (cont'd)
- **IoV generic 5-layer architecture-** (cont'd)
  - **ARTIFICIAL INTELLIGENCE (AI) LAYER**
    - represented by the **virtual cloud infrastructure**; it is the main IoV intelligent layer
    - Mission:
      - 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 requirement of applications serviced by this layer
  - **APPLICATION LAYER**
    - represented by **smart applications. traffic safety, efficiency, multimedia based infotainment and web based** utility applications.
    - Mission:
      - to provide smart services to EUs (based on intelligent analysis done by AI
      - safety and efficiency apps (legacy of VANET)
    - Efficient discovery of services provided by AI layer and their combination
    - It also provides EU application usage data to the business layer.
    - these smart applications: the driving force to further develop IoV

4. IoV architecture and main protocols

- **Example 1** (cont'd)
- **IoV generic 5-layer architecture-** (cont'd)
  - **BUSINESS LAYER**
    - IoV operational management module
    - Mission (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

4. IoV architecture and main protocols

- **Example 1** (cont'd)
- **IoV generic 5-layer architecture: protocol stack**
  - **Objective: to implement the 5-layer previous generic architecture**
  - The generic layers are mapped to the actual architectural protocol stack:
  - 

Source: [15] 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

4. IoV architecture and main protocols

- **Example 1: IoV generic 5-layer architecture: protocol stack** (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

4. IoV architecture and main protocols

- **Example 1** (cont'd)
- **IoV generic 5-layer architecture: protocol stack (cont'd)**
- **Main characteristics and components**
  - 3 architectural planes**: operation, management, security plane**
  - Components at different layers

- **Operation Plane**
  - **Perception Layer (~L1-L2)**
    - Different types of sensors and actuators attached to vehicles, RSUs, smartphones, personal devices, etc.
    - Wireless /wireline access technologies
      - 802.11p of WAVE, 802.11a/b/g of WLAN
      - Worldwide Interoperability for Microwave (WiMax)
      - 2G-GSM, 3G, 4G/Long Term Evolution (LTE)
      - (GSM) and satellite communications
      - Ethernet
    - **Coordination Layer (~L2-L4)**
      - *Lower sub-layers: L2- MAC protocols*:
        - IEEE 802.11p, 802.11 (a/b/g/n)
        - 1609.4 along with a Global Handoff Manager (GHM-open research)
        - Logical Link Control (LLC)- abstraction role

4. IoV architecture and main protocols

- **Example 1** (cont'd)
- **IoV generic 5-layer architecture : protocol stack (cont'd)**

- **Operation Plane (cont'd)**

  - **Coordination Layer (~L2-L4) (cont'd)**
    - Upper sub-layers/protocols:
      - IP, UDP, TCP
      - or other solutions (~L3-L4)

        Protocols proposed at network layer in projects like CALM, C2C, WAVE

        WSMP - Short Message Protocol

        FAST -Fast Application and Communication Enabler (No IP usage)

        The WSMP and FAST do not utilize IP whereas C2C-net uses IPv6

    - Example: CALM M5 and IEEE 802.11p
      - IEEE 802.11p (part of Wave, 1km, 10MHz channel in the 5.9 GHz band
      - CALM M5

        Framework for packet-switched communication in mobile environments

        It defines the medium range part based on IEEE 802.11p

4. IoV architecture and main protocols

- **Example 1** (cont'd)
- **IoV generic- 5 layer protocol stack (cont'd)**

- **Operation Plane (cont'd)**
  - **Artificial Intelligence (AI) Layer**
    - lower sub-layer: CALM Service Layer (CALM-SL) and WAVE-1609.6 service related protocols
    - upper sub-layer :Vehicular Cloud Computing (VCC) and Big Data Analysis (BDA) related protocols - including cloud services "**X as a Service**":
      - Storage (**STaaS**), Infrastructure (**INaaS**), Network (**NaaS**),
      - Cooperation (**CaaS**), Entertainment (**ENaaS**), Gateway (**GaaS**)
      - Picture (**PICaaS**), Computing (**COMaaS**).
  - 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

4. IoV architecture and main protocols

- **Example 1** (cont'd)
- **IoV generic 5-layer architecture: protocol stack (cont'd)**
- **Operation Plane (cont'd)**
  - **Application Layer**
  - Includes two sets of applications
    - Smart Safety and Efficiency (SSE)
    - Smart Business Oriented (SBO).
  - The WAVE resource handler protocol 1609.1 can be used on the top of these applications, for managing resources among smart applications
  - **Business Layer**
    - Open research challenge
    - Various business models can be defined: Insurance (INS), Sale (SAL), Service (SER) and Advertisement (ADV)

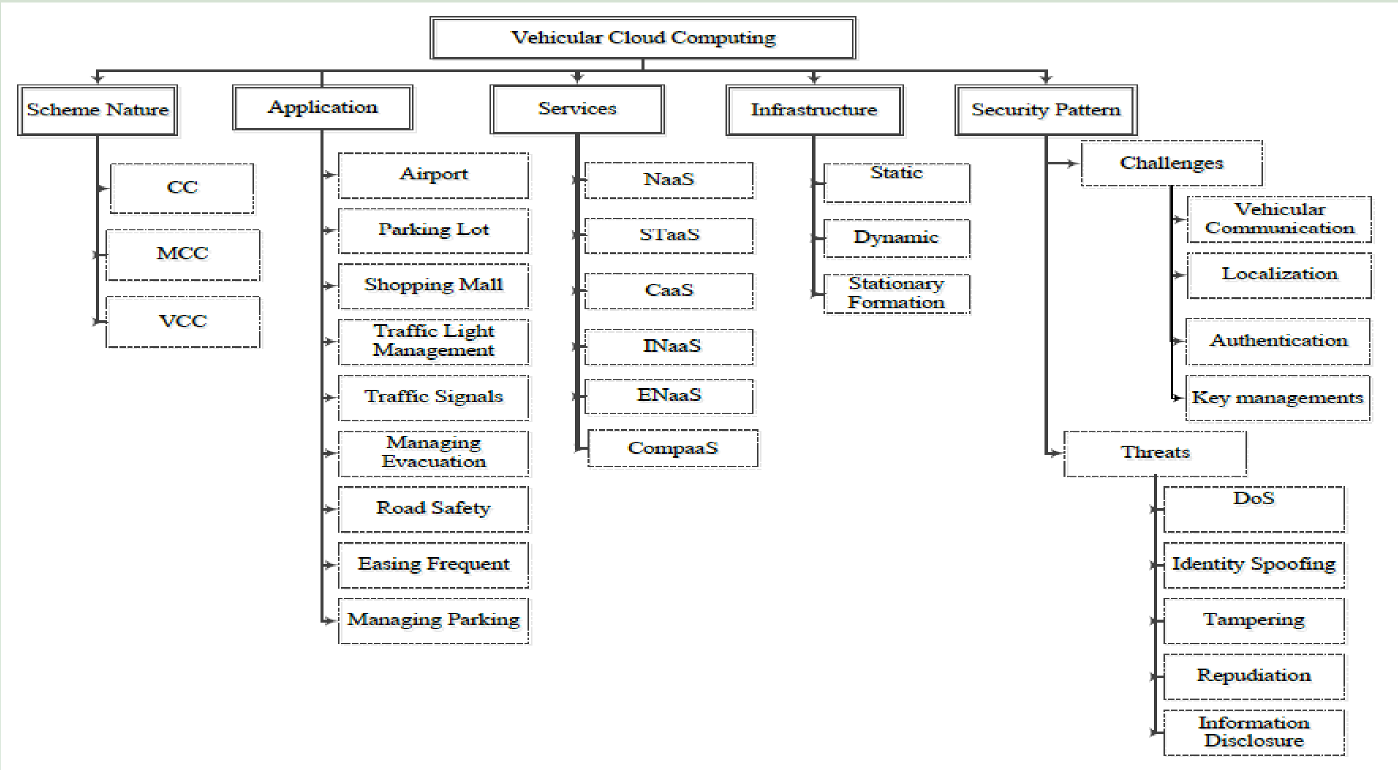
- **Security Plane**
  - Open research challenge (unavailability of clear definitions of layer-wise security protocols)
  - Currently, security protocols (coming from WAVE, C2C and CALM) can be used:
    - IEEE 1609.2, Security Information Connector (S-IC), Security Management Information Base (S-MIB) and Hardware Security Module (HSM)

4. IoV architecture and main protocols

- **Example 1 IoV generic 5-layer architecture (cont'd)**
- **IoV proposed network model [15]: Cloud + connection + clients**
- **Cloud:**
  - basic CC services, Smart ITS applications, Information consumer and producer
- **Connection**
  - Two major components of a connection:
    - **Third Party Network Inter Operator (TPNIO)** -management of the connection
    - **Gateway of Internetworking (GIN).** - represents the connection itself
  - **TPNIO**
    - Components : Global Handoff Manager (GHM), Global Authentication, Authorization and Billing (GAAB), Service Management (SM), Network Database (NDB) and Operator Database (ODB)
  - **GIN**
    - Mobility Management (MM)
    - Local Authentication Authorization and Billing (LAAB)
    - Traffic Management (TM)
- **Client**
  - **Safety and Management Client:** safety, navigation, diagnostic and remote telematics
  - **Business Oriented Client:** insurance, car sharing, infotainment and other applications

4. IoV architecture and main protocols

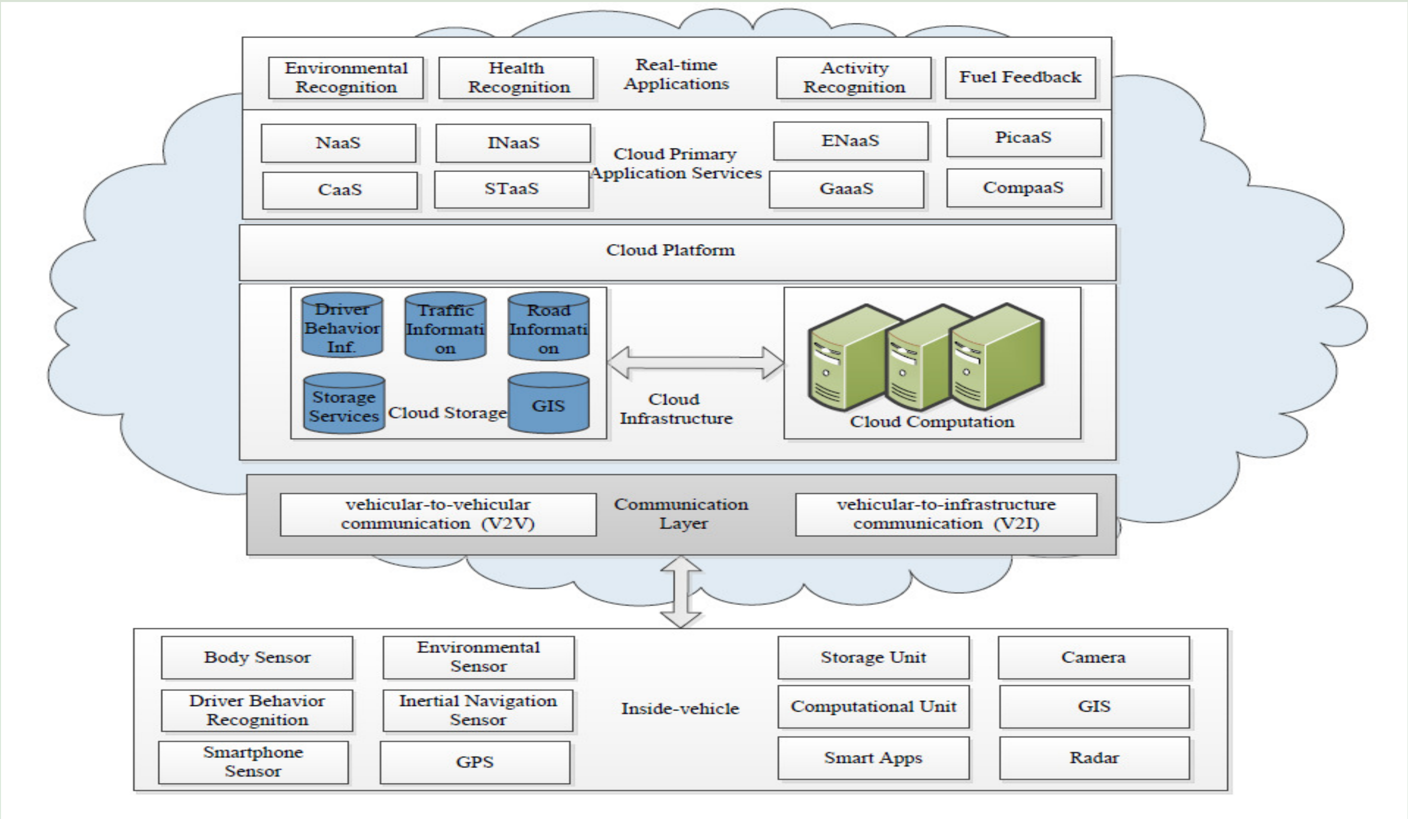
- **Example 2: Vehicular Cloud Computing (VCC)**
  - **VCC : new recent hybrid technology** ; it can enhance traffic management and road safety by **using cloud-like vehicular** resources, such as computing, storage and internet for decision making
  - **VCC taxonomy**



Source [22]: Md. Whaiduzzaman, et.al., "A survey on vehicular cloud computing", J.of Network and Computer Applications, November 2013, https://www.researchgate.net/publication/260407696

4. IoV architecture and main protocols

- **Example 2** (cont'd)
- **Vehicular Cloud Computing**



Source [22]: Md. Whaiduzzaman, et.al., "A survey on vehicular cloud computing", J.of Network and Computer Applications, November 2013, https://www.researchgate.net/publication/260407696

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture** [16]
  - It supports the functionalities, interactions, representations and information exchanges among all the devices inside an IoV ecosystem
  - The authors in [16] **propose seven layers** (more than in other proposals), claiming to reduce the complexity of each layer and better standardize the interfaces and protocols used in each layer

- **Interaction model :** V2V, V2R, V2I, V2D, V2P, V2S, D2D, S&A2S&A
  - **Network model**
    - **Multi-level collaboration** between different entities:
      - multi-users (drivers, passengers and pedestrians),
      - multi-vehicles (vehicles, motorcycle, bicycles),
      - multi-devices (sensors, actuators, mobile devices, access points)
      - multi-communication models (point to point, multi-point, broadcast, geocast)
      - multi-networks (wireless or wire networks)
      - And different technologies and characteristics
        multiple technologies (WiFi, Bluetooth, WiMAX, 3G, 4G/LTE, etc.)
        multiple characteristics (latency , throughput, packet loss)

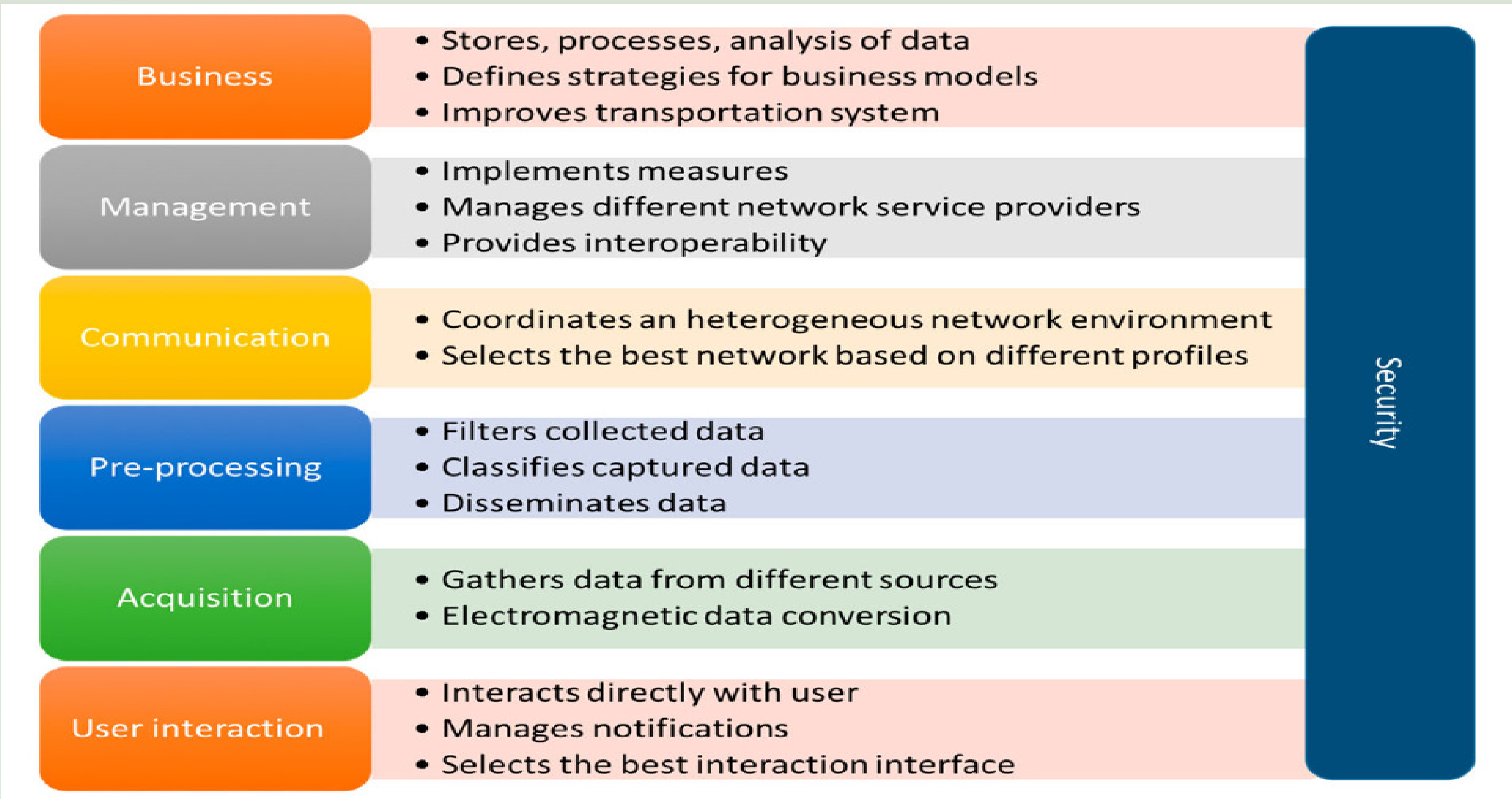
Source [16]: J.C. Contreras-Castillo, et.al., "A seven-layered model architecture for Internet of Vehicles", JOURNAL OF INFORMATION AND TELECOMMUNICATION, 2017, VOL. 1, NO. 1, 4–22

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture(cont'd)**
  - **Network model** (cont'd)
    - Intra vehicular model
      - V2P, V2S
    - Environmental model (outside the 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**
- **Comments on this architecture**
  - While the above functionalities are all defined as "layers", apparently, this stack does not respect the principles of a layered architecture (each layer traditionally offers some services to the above one)
  - 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

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture (cont'd)**



Source [16]: J.C. Contreras-Castillo, et.al., "A seven-layered model architecture for Internet of Vehicles", JOURNAL OF INFORMATION AND TELECOMMUNICATION, 2017, VOL. 1, NO. 1, 4–22

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture** (cont'd)

- **Layered architecture (cont'd)**

  - **User interaction layer**
    - In-vehicle computing systems including
    - **a. information-based systems**
      - They provide relevant information (e.g., route information, traffic conditions, car parking availability and warning/advice regarding risks)
      - to components of the driving environment, the vehicle or the driver.
      - Some recent solutions are referenced in [16].
    - **b. control-based systems**
      - They monitor changes in driving habits and experiences that affect the routine, operational elements of the driving task such as adaptive cruise control, speed control, lane keeping and collision avoidance.
      - Designing user interfaces for in-vehicle systems is seen still as posing many new research challenges

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture** (cont'd)

- **Layered architecture (cont'd)**

- **Data acquisition layer**
  - As defined in [16], this layer has tasks covering all three traditional planes (data , control and management).
    - Apparently it corresponds to a kind of "networking" layer

  - **It gathers data (for safety, traffic information, Infotainment), from a given area of interest**, from all the sources (vehicle's internal sensors, GPS, inter-vehicle communication, WSN, or devices such as cellular phones, sensors and actuators, traffic lights and road signals) located on streets and highways

  - Division of the roads into groups of contiguous clusters
    - use of a cluster-head and D2D technologies are mentioned

  - **Intra- and inter vehicular interactions** are within the scope of this layer.

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture** (cont'd)
- **Layered architecture (cont'd)**
  - **Data acquisition layer (cont'd)**

  - **Intra-vehicle** technologies envisaged for are : Bluetooth (2.4 GHz) , ZigBee(868 MHz, 915 MHz and 2.4 GHz) Wi-Fi HaLow (900 MHz) Ultra-wideband (3.1–10.6 GHz), with data rates up to 480 Mbps and coverage distances up 1000m

  - **Inter vehicle**: for V2V, V2R, V2I the most predominant access technologies are
    - IEEE WAVE/DSRC with IEEE 802.11p for PHY and MAC layers and the IEEE 1609 family for upper layers

    - **Dynamic Spectrum Access (DSA)** is used as a complementary technology to DSRC(enabling vehicular communication over unused spectrum of other communication technologies such as TV spectrum)

    - 4G/LTE (1700 and 2100 MHz) and supports data speeds up to130 Mbps and high mobility through soft handoff and seamless switching

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture** (cont'd)
- **Layered architecture (cont'd)**

  - **Data filtering and pre-processing layer**
    - IoV, may generate huge amounts of data, but much of them might not be relevant
    - ***Data collection, data filtering and data dissemination*** are important processes
    - This layer analyses and filters the collected information to avoid the dissemination of irrelevant information and reduce the network traffic
    - Several data filtering approaches are referenced in [16], but novel intelligent and efficient data mining techniques are considered to be necessary
    - Some techniques information dissemination are also referenced in [16]

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture** (cont'd)
- **Layered architecture (cont'd)**
  - **Communication layer**
    - ***Note: apparently this "layer" performs actually a control function***
    - **selects the best network to send the information based on several selection parameters** , e.g.: congestion and QoS level over the different available networks, information relevance, privacy and security, etc.
    - challenge: intelligent selection of a suitable network using the relevant information and measurements.
      - One should consider several criteria and needs to use Multiple Attributes Decision Making (MADM) algorithms
      - Several MADM solutions are shortly discussed and referenced in [16]

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture** (cont'd)

- **Layered architecture (cont'd)**

  - **Control and management layer**
    - global coordinator for managing the different network service providers within the IoV environment

    - Functions:
      - to manage the data exchange among the various services

      - to manage the information generated by devices: in-vehicle or around sensors, roadside infrastructure and user devices in the environment

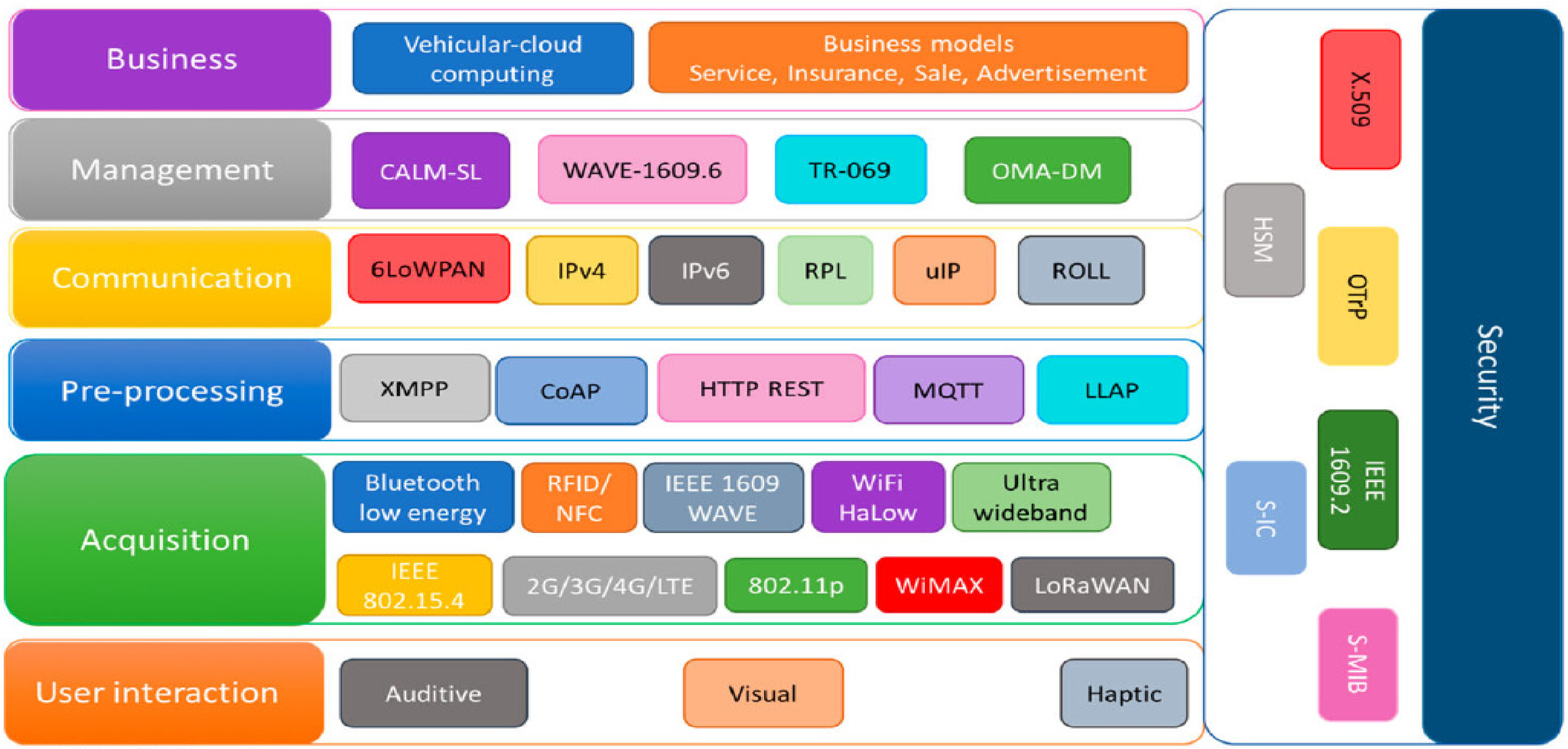
      - different policies (traffic management and engineering, packet inspection, etc.) can be applied

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture (cont'd)**
- **Layered architecture**
  - **Business layer**
    - processes information using various types of cloud computing infrastructures locally and remotely.
    - Functions:
      - storing, processing and analysing info received from the other layers,
      - making decisions based on data statistical analysis and identifying strategies
      - that help in applying business models based on the usage of data in applications and the statistical analysis.
      - statistical analysis uses tools such as graphs, flowchart, critical analysis, etc.
  - **Security layer**
    - communicates directly with the rest of the layers
    - implements security functions (data authentication, integrity, non-repudiation and confidentiality, access control, availability, etc.) to exchange data among sensors, actuators, user's devices through secure networks and service providers

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture** (cont'd) protocol stack *(Source [16])*

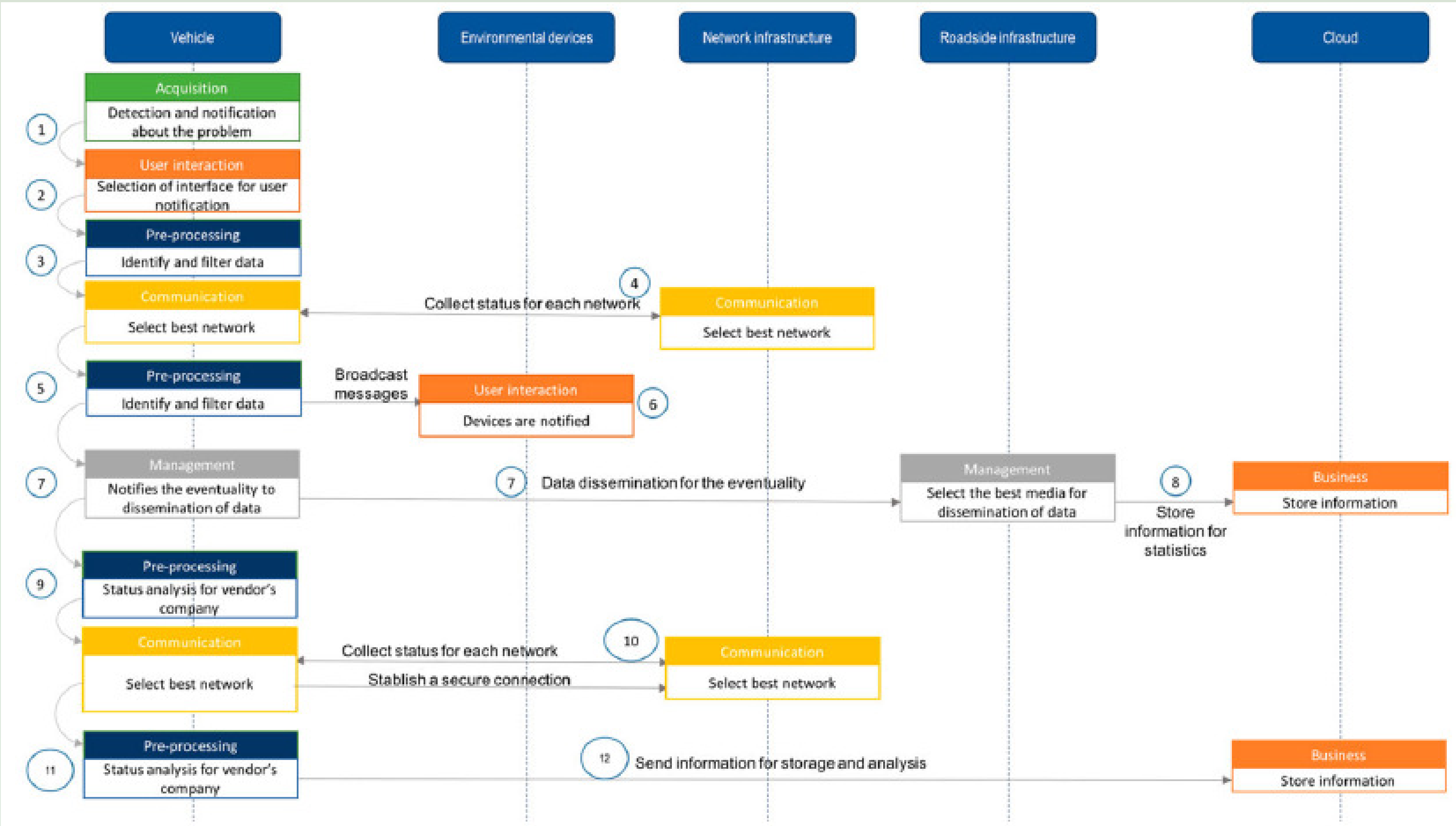


CALM-SL = CALM service layer
OMA-DM = Open Mobile Alliance Device Management
6LoWPAN = IPv6 over Low Power Wireless Personal Area Network
RPL = Routing Protocol for Low Power and Lossy Networks
uIP = micro Internet Protocol
ROLL = Routing Overlow Power and Lossy Networks
XMPP = Xtensinble Messaging and Presents Protocol
CoAP = Constrain Application Protocol

HTTP REST = HypeText Transfer Protocol Representational State Transfer
MQTT = Message Queuing Telemetric Transport
LLAP = Lightweight Local Automation Protocol
LoRaWAN = Low Power Wide Area Network
OTrP = Open Trust Protocol
S-MIB = Security Management Information Base
HSM = Hardware Security Management
S-IC = Security Information Connector

4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture** (cont'd) Source [16]
- **Use case scenario example**



4. IoV architecture and main protocols

- **Example 3 IoV 7- layer architecture** (cont'd) Source [16]
- **Use case scenario example (cont'd)**
  - **Comments on the above use-case scenario- versus the 7-layer architecture**
    - The diagram is still very high level
    - The entities represented are rather differently located in space: vehicle, environment devices (i.e. others), network infrastructure, road infrastructure, cloud
    - The mapping of architectural layers previously defined on this use case scenario is not explicit in the picture and no orthogonality is emphasized
    - Instantiation of the architectural layers stack on different components would be necessary
    - Security related operations are still not visible

CONTENTS

5. Conclusions

- IoV- powerful development in the IoT framework, following ITS, VANET
- IoV has many promises but also these constitute, as well, challenges:
  - Commercial, objectives, architecture
  - Collaboration capabilities
  - Communication types
  - Security and privacy
  - Processing power and decision capabilities:
  - Compatibility with personal devices
  - Scalability
  - Connectivity aspects
  - Network/environment awareness
  - Cloud Computing (CC) compatibility
- Layered architecture: based on current developments in ITS, WAVE, VANET
  - More open architecture than in VANET
  - Full Internet connectivity
  - Collaboration possibility among heterogeneous access technologies

5. Conclusions

- **Some other research topics of interest in IoV area – (only summarised or not discussed in depth in this overview)- to be continued in a second part of this tutorial**
  - **Cloud Computing** and **Vehicular Cloud Computing** as powerful set of capabilities in IoV [21]
  - **Edge (Fog) computing** – in order to de-centralise the cloud-like capabilities and better serve the mobile environment [18]
  - **Optimal function distribution** between centralized, edge and terminal components
  - **Integration issues of IoV** in the general IoT and smart cities environment [17,18]
  - Usage of virtualization, **Software Defined Networking** and **Network Function Virtualization** in IoV [19, 20, 22, 23, 24]
  - Specific aspects of using 4G, 5G, D2D in IoV environment
  - **Applications and services** including content and media- related
  - **Security and privacy**
  - **Seamless deployment and scalability issues**

- Thank you !
- Questions?

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- **Backup slides**

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- **List of Acronyms**

ADV	Advertisement
AI	Artificial Intelligence
AVS	Autonomous Vehicular Cloud
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
CRM	Customer Relationship Management
DoS	Denial of Services
DSRC	Dedicated Short Range Communication
ECU	Electrical Control Unit
ENaaS	Entertainment as a Service
FAST	Fast Application and Communication Enabler
GIN	Gateway of Internetworking
GPS	Global Positioning System
HSM	Hardware Security Manager
IaaS	Infrastructure as a Service
INaaS	Information as a Service
INS	Insurance
ITS	Intelligent Transportation Systems
LLC	Logical Link Control
MANET	Mobile Ad hoc Network
MCC	Mobile Cloud Computing

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List of Acronyms

NaaS	Network as a Service
OBU	On Board Unit
PaaS	Platform as a Service
PKI	Public Key Infrastructure
RSU	Road Side Unit
SaaS	Software as a Service
SAL	Sale
SBO	Smart Business Oriented
SER	Service
S-IC	Security Information Connector
SM	Service Management
S-MIB	Security Management Information Base
SSE	Smart Safety and Efficiency
STaaS	Storage as a Service
TPNIO	Third Party Network Inter Operator
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

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List of Acronyms

VM	Virtual Machine
VPKI	Vehicular Public Key Infrastructure
WSN	Wireless Sensor Network
WAVE	Wireless Access for Vehicular Environments