LEC 2

American vision: government actions

- ITS development in the USA: evolution process which in in most aspects overlaps with the European and Japanese ones
- In the same period of the launch of the first European ITS projects (namely Drive and **Prometheus**) and the second wave of Japan projects (i.e., RACS), a number of initiatives started all around the USA, under the initiative of **private companies, universities, State Government and the Federal Government**
- Just to name a few, we recall Smart Corridor, Pathfinder, GuideStar, and the Partners for Advanced Transportation TecHnology (PATH) projects
- In first years, in the USA the amount of **public fu**nds dedicated to ITS projects was **significantly smaller** than in Japan an Europe

American vision: government actions

- The main body of the Federal Government involved in ITS development has always been the **United States Department of Transportation (USDOT)**, which has often operated through one of their agencies, such as Federal Highway Administration (FHWA), National Highway Traffic Safety Administration (NHTSA), and the Research and Innovative Technology Administration (RITA), which was created in 2005 with the mission to advance transportation science, technology, and analysis and to improve the coordination of transportation research within the Department and throughout the transportation community
- Under the USDOT initiative, in **1991 the Intelligent Transportation Society of America (ITS America)**, the largest organization dedicated to advance the research, development and deployment of ITSs, was founded

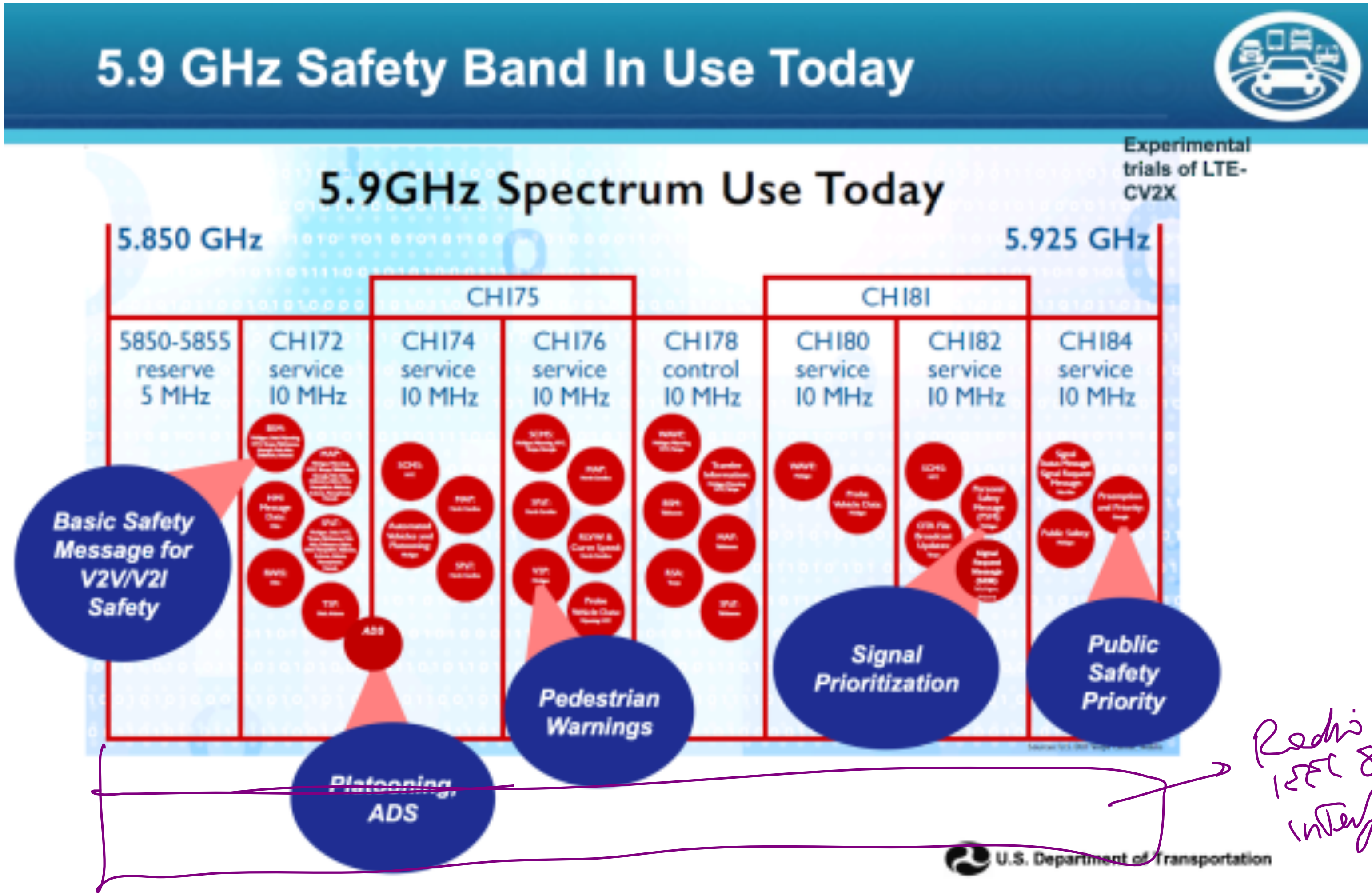
American vision: government actions

- ITS America has played a major role in laying the groundwork at the Federal Communications Commission (FCC) and other agencies, for the use of the **electromagnetic spectrum and other telecommunication infrastructures** as the foundation for almost all ITSs

- Thanks to such an effort, in **1999**, a 75 MHz spectrum in the **5.9 GHz bandwidth** was set aside by the FCC. The idea was to allocate a spectrum that could be used for the development of Vehicle-to-X (V2X) communications, without fearing potential signal interference from non-automotive users.

American vision: frequency utilization

- In **2020**, US Department of Transportation (USDOT) Federal Highway Administration (FHWA) broad agency announcement (BAA) to procure **prototype or commercially available, off-the-shelf, vehicle-to-everything (V2X) communications devices** to support USDOT 5.9 GHz Safety Band spectrum testing



Radio IEEE 802.11 interfaccia

American vision: ITS strategic research plan

- Since 2009, the strategic directions of USDOT's ITS are established in a 5-year long program, denoted as ITS Strategic Research Plan (2010-2014, 2015-2019, etc.)
- The vision of the **ITS Program for 2010 to 2014** was to provide USA with a **national, multimodal transportation system**, which delivers connectivity among vehicles of all types, the infrastructure, and portable devices, thus realizing an integrated connected vehicle environment
- The expected outcomes of such a research included
  - the determination of the potential benefits of connected vehicle technologies and evaluation of driver acceptance of vehicle-based safety systems, as well as the identification of research gaps and the ways to address them
  - Factual evidence needed to support a 2013 NHTSA agency decision on the deployment of these technologies for light vehicles
- The ITS strategic research plan involves several ITS research areas, including **connected vehicles**, mobility, environment, road weather management, integrated corridor management, ITS asset viewer and multimodal transportation systems

American vision: connected vehicle program

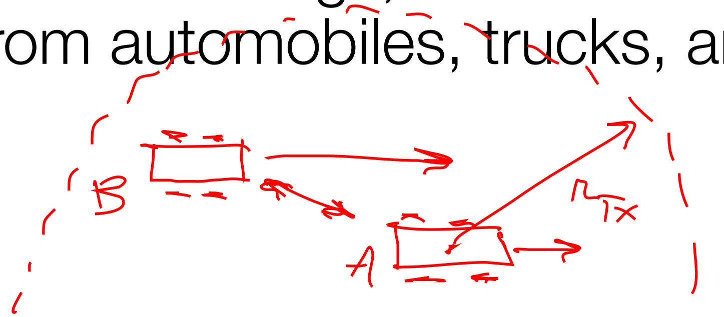
- The Connected Vehicle program is a pillar of current ITS plan
- **Connected Vehicle program**: large set of research activities related to vehicles equipped with communications and processing power, able to communicate with each other and with the surrounding infrastructure. V2V connections allow for crash prevention, while V2I connections enable safety, mobility, and environmental benefits
- Connections among vehicles, infrastructure, and wireless devices to provide continuous **real-time connectivity to all system users**

long-range connections (not necessarily cellular)

dedicated short-range connections

American vision: connected vehicle program

- Connected Vehicle project: both **non-DSRC** and **DSRC** technologies, but for all security-related applications it does strongly rely on DSRC, because of its high availability and very low latency characteristics. For this reason, USDOT has participated in the development of all DSRC-related standards that are critical to the connected transportation environment, including **IEEE 802.11p** (amendment to IEEE 802.11), the vehicle-centric **IEEE 1609 series** (known as IEEE 1609.x) and the **SAE J2735 DSRC** message set standard
- Connected vehicle **safety applications** are designed to increase situational awareness and reduce or eliminate crashes, by means of V2V and V2I data communications
- Connected vehicle **mobility applications** provide a data-rich travel environment. Such communications should support driver advisories, driver warnings, and vehicle and/or infrastructure controls, by capturing real-time data from automobiles, trucks, and buses, and within the transportation infrastructure



American vision: connected vehicle program

- **Data are transmitted wirelessly** and are used by transportation managers in a wide range of dynamic, multi-modal applications, to manage the transportation system for optimum performance
- As part of this, connected vehicle environmental applications both **generate and capture environmentally relevant real-time transportation dat**a, and use such data to support and facilitate green transportation choices, thus reducing the environmental impact of each trip
- In August 2012, the USDOT started the **Connected Vehicle Safety Pilot project**, a 1-year long trial involving over 2800 vehicles, in Ann Arbor (Michigan, USA). The goal of the trial is to assess the capacity of vehicular communication technology to improve safety. In detail, the pilot is not only testing the technical reliability of Dedicated Short-Range Communications (DSRC) devices in real-world conditions, but also how drivers adapt to the technology, and how they respond to in-vehicle warnings. The cost of the trial is 25 million dollars, 80% funded by the USDOT

Outline

- Principles and challenges
- Standardization and open issues
- ITS Architecture
- ITS Applications
- Autonomous driving

ITS Architecture: Global Standardization Effort

- In last decades governments and private companies involved in global ITS standardization and harmonization efforts, coordinated by a **large number of Standard Development Organizations (SDOs)** → general consensus about the ITS architecture and related communication protocols, but we are still far from having market-ready implementations
- In order to enable effective collaboration, by establishing a common vocabulary, experts from a number of SDOs developed the **concept of ITS station (ITS-S)**, which is described in standard ISO 21217 (CALM)
- At the highest level of abstraction, an ITS-S is a **set of functionalities** in a bounded, secured, managed domain, which provides communication services to resident applications (ITS-S applications)

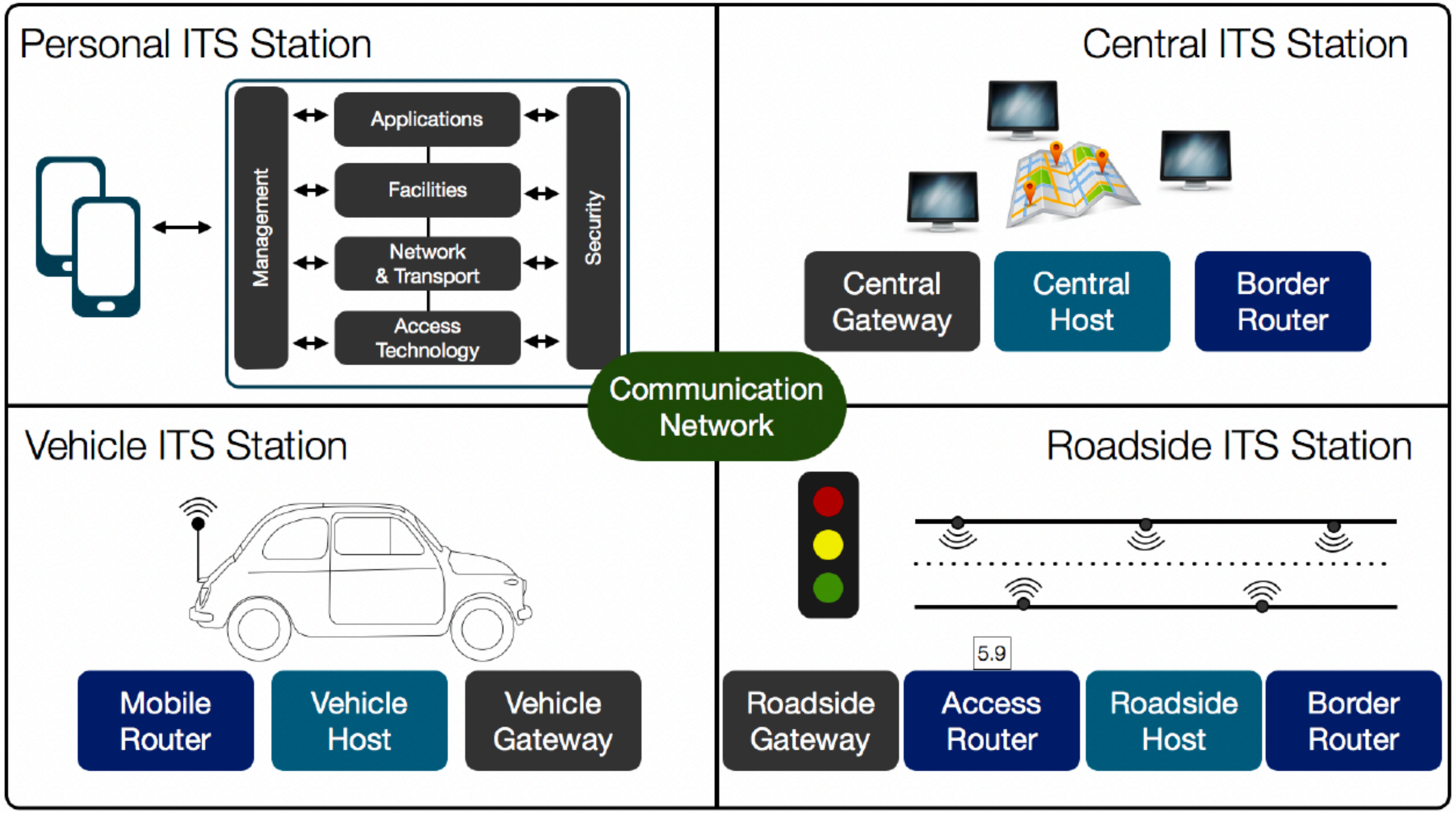
ITS Architecture: Global Standardization Effort

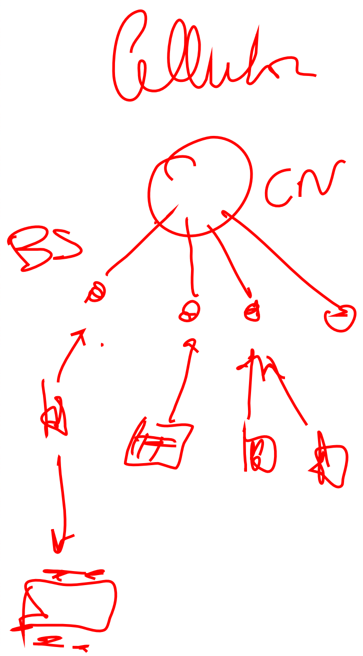
- From an architectural perspective, an ITS-S is a **set of functionalities in an Open Systems Interconnection (OSI)-like layered model** (from ISO/IEC 7498-1). Illustrative functionalities are those to securely manage applications and communication resources
- The ITS-S concept and its architecture have been adopted by CEN (Comité européen de normalisation, European Commitee for Standardization) TC278, by ETSI TC ITS and by ISO TC204
- A different approach is the WAVE one (see later)

ITS Architecture: ISO/ETSI ITS Station Architecture

- Starting points for the definition of a **common ITS Communication (ITSC) architecture** are the ETSI EN 302 665 standard, and the Communications Access for Land Mobiles (CALM) family of standards—in particular, ISO 21217:2013 and its predecessor ISO 21217:2010
- The ITSC architecture is designed around the concept of ITS station (ITS-S), a modular computing unit equipped with communication capabilities, which can be installed virtually anywhere

ITS Architecture: ISO/ETSI ITS Station Architecture





ITS Architecture: ISO/ETSI ITS Station Architecture

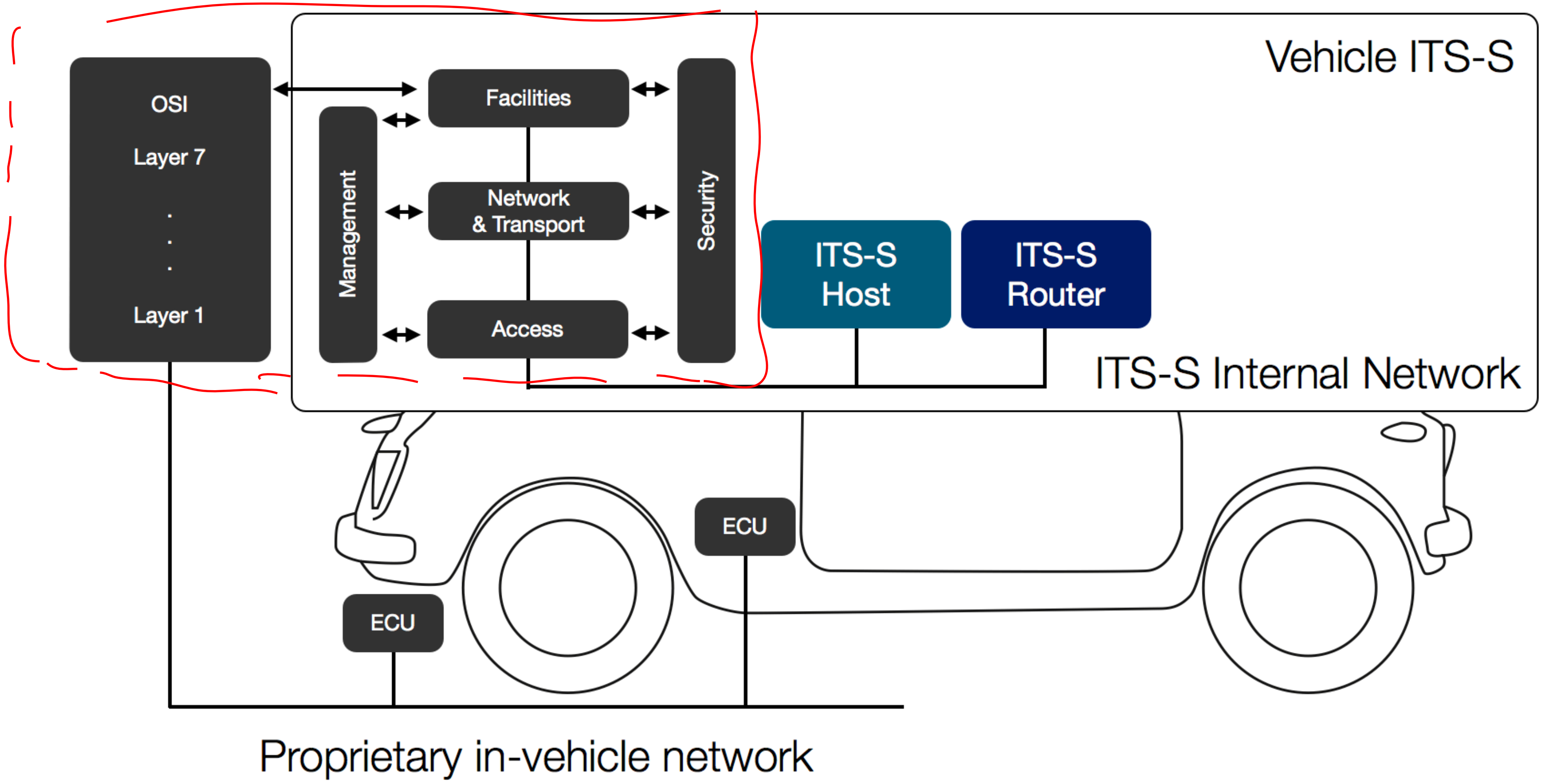
ETSI EN 302 665 standard ('Intelligent Transport Systems (ITS); Communications Architecture') defines four main ITS-S types:

- **Vehicle ITS Stations**: embedded or after-market devices in road-enabled vehicles (cars, trucks, bus, motorcycles), both in motion or parked
- **Roadside ITS Stations**: installed at the roadside, at road gateways, on traffic lights
- **Central ITS Remote Stations**: installed in back offices, it is a key component of the centralized ITS management/service systems, needed to coordinate the whole system and to collect, store, and process information
- **Personal ITS Stations**: handheld or nomadic devices such as smartphones and tablets

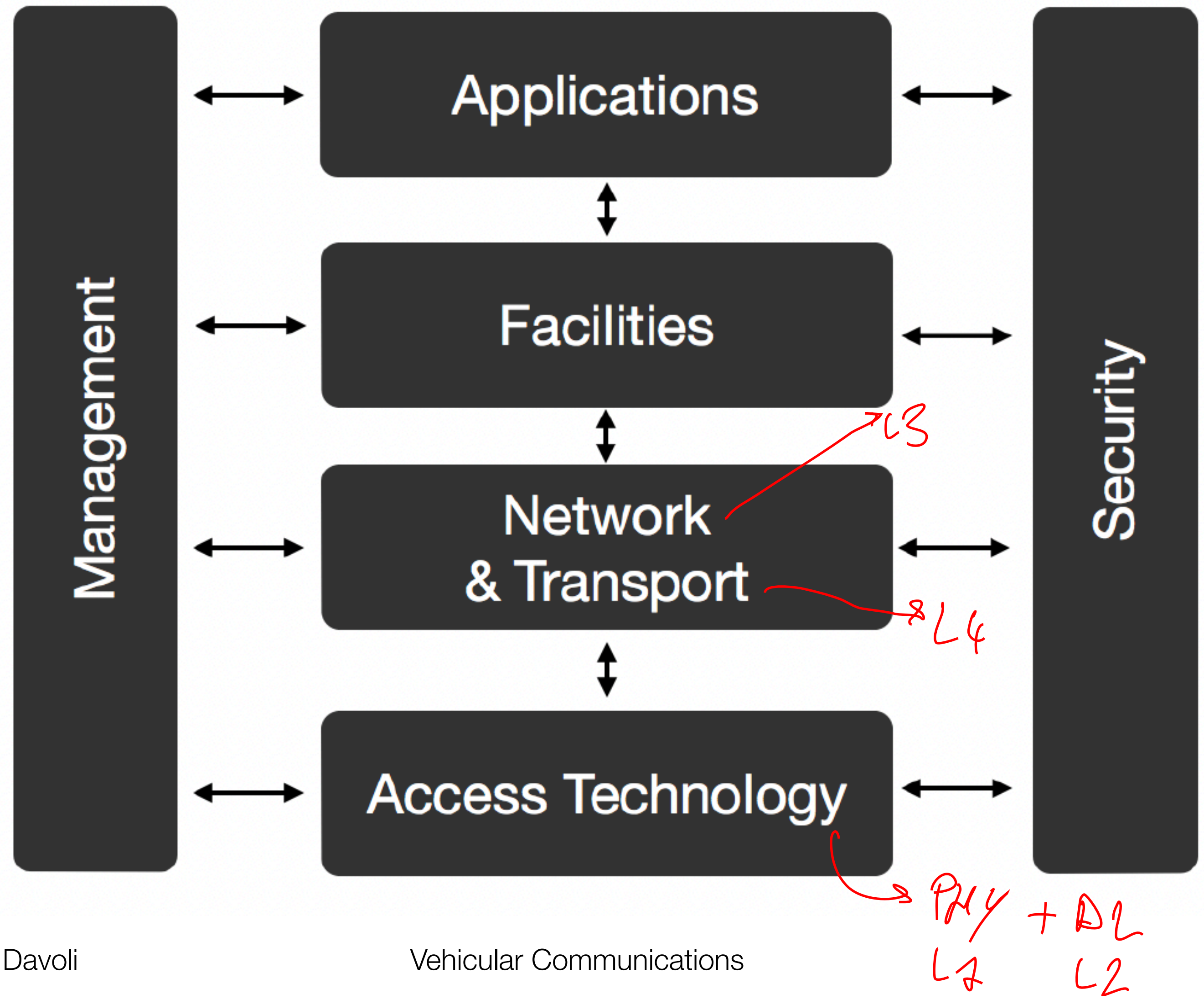
ITS Architecture: ISO/ETSI ITS Station Architecture

- With the exception of the Personal ITS-S, which is composed by a single ITS-S host entity, all stations are based on a number of independent entities, which can be classified as hosts, gateways, routers and border routers
- Hosts have both applicative and communication functionalities, while other entities have only specific communication functionalities, namely, protocol translation for the gateways, and routing for the routers
- Example: architecture of a vehicle ITS-S composed by a gateway, a host and a router
  - The **gateway** translates messages interchanged with the proprietary internal network of the vehicle
  - The **router** is charged of routing packets through a series of heterogeneous networks

ITS Architecture: ISO/ETSI ITS Station Architecture



ITS Architecture: ITS Host Architecture



ITS Architecture: ITS Host Architecture

- The ITS-S Host: 4 horizontal logical layers and 2 vertical layers
- Horizontal layers
  - **Access technologies** layer, which groups together the corresponding physical and link layers of the ISO/OSI stack
  - **Networking & Transport** can be straightforwardly mapped with the homonym layers of the ISO/OSI stack. The *transport layer* includes TCP, UDP and dedicated ITS transport protocols, such as the ETSI Basic Transport Protocol (BTP). The *networking layer* includes a large variety of protocols, such as GeoNetworking, IPv6 networking with mobility support, developed at IETF and ISO, IPv6 over GeoNetworking, CALM FAST protocol, also known as Fast Networking & Transport Layer protocol (FNTP), Fast Service Advertisement Protocol (FSAP), which follows closely the functionality of IEEE for WAVE Service Advertisement (WSA)

ITS Architecture: ITS Host Architecture

- Horizontal layers (ctd) L6 L7
  - L5 The ITSC **Facilities layer** contains functionalities from the OSI application layer, the OSI presentation layer (e.g., ASN.1 encoding, decoding and encryption) and the OSI session layer (e.g., inter-host communication), with amendments dedicated to ITSC. Within ITSC Facilities also lie some functionalities not directly related to communications, such as the Human Machine Interface functionality
  - The **Applications layer** is composed by all ITS-S applications, built on top of the previous three layers
- Vertical layers: **management** and **security** stacks, which are interrelated with all the previous horizontal layers

ITS Architecture: WAVE ITS Station Architecture

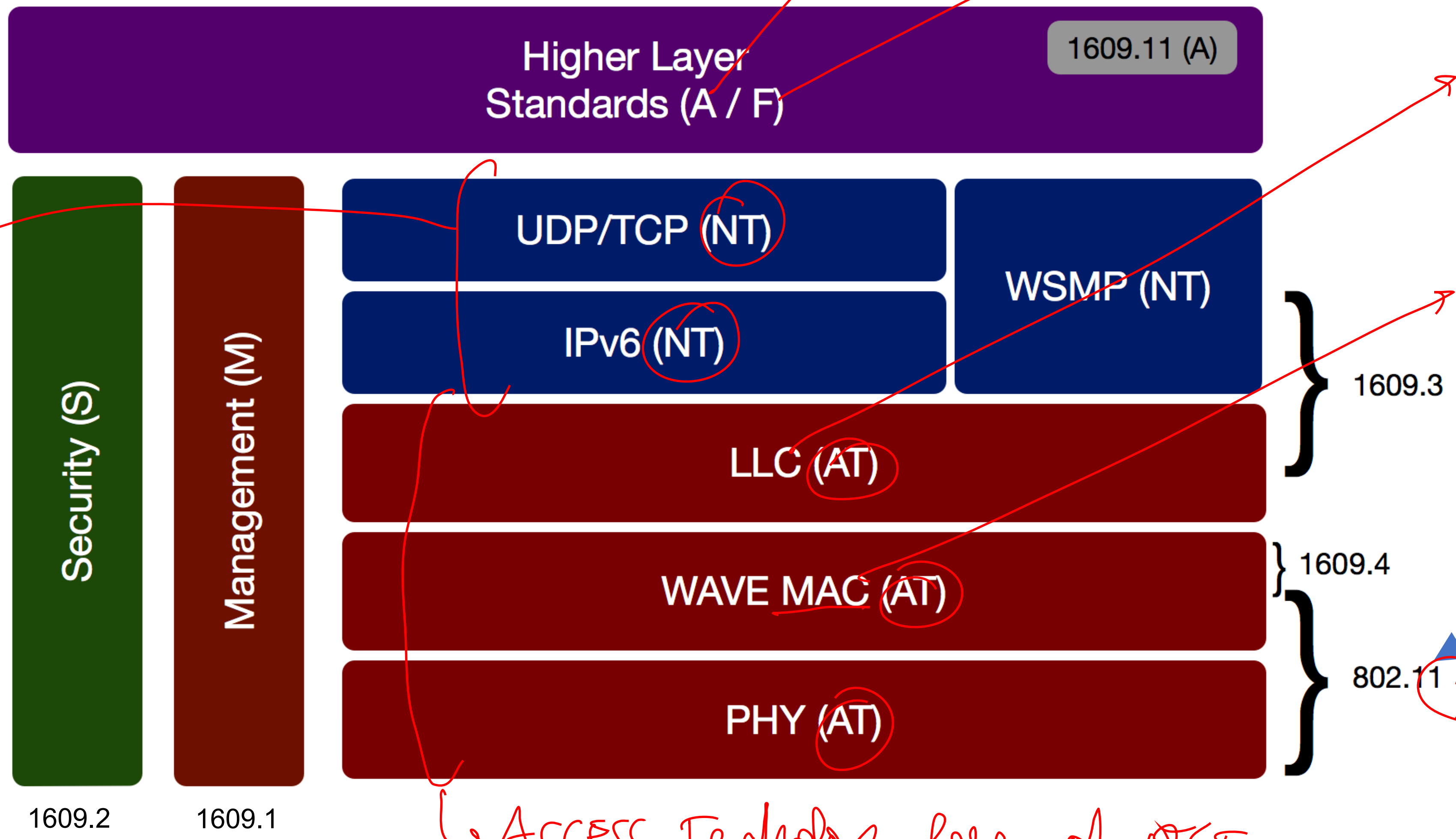
- Architecture adopted by the IEEE 1609 WG with a **subset of the functionalities shown in the CEN/ETSI/ISO ITS station** architecture
- IEEE WAVE reference architecture does **not explicitly include Facilities or Applications layer functions** (included in Higher Layer)
- The CEN/ETSI/ISO approach is intended to support (but does not require) multiple network stacks from the outset, while IEEE 1609 WG work is **focused on a 5.9 GHz radio interface**

ITS Architecture: WAVE ITS Station Architecture

Applications

Facilities

ISO-OSI



Network & Transport of ETSI

Logical Link Control + Medium Access Control

DL

Access Technology layer of ETSI

ITS Architecture: WAVE ITS Station Architecture

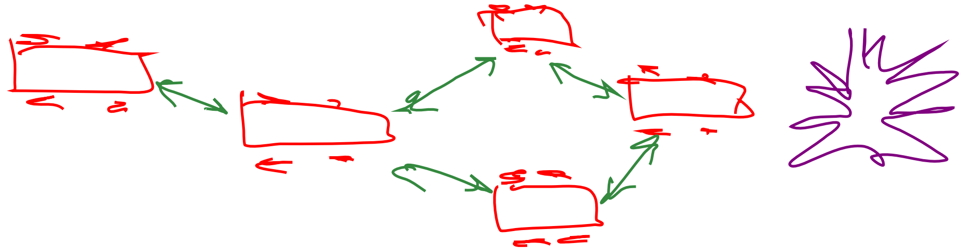
- IEEE 1609 is defined by 4 sub-protocols.
  - **IEEE 1609.1** defines a **resource manager** acting as an "outsourcing" manager. In other words, it allows to physically separate the applications from the physical radio interfaces, either Road Side Units (RSUs) or On-Board Units (OBUs). For example, an application can run on an external device, such as a smartphone or a Global Positioning System (GPS) navigator, without adding computational load and complexity to the OBU. This should allow to reduce the cost and increase the reliability of OBUs and RSUs
  - **IEEE 1609.2** defines **security services** for the WAVE networking stack and for applications that are intended to run over the stack, such as authentication of STAs and encryption of messages. IEEE 1609.2 provides mechanisms to **authenticate** WAVE management messages, to authenticate messages that do not require anonymity, and to **encrypt** messages to a known recipient

ECU

ITS Architecture: WAVE ITS Station Architecture

- IEEE 1609 is defined by 4 sub-protocols (ctd.).
  - **IEEE 1609.3: networking services** for Inter-Vehicle Communications (IVCs). The WAVE networking services can be divided into two sets:
    - (i) data-plane services, with data-bearing functions
    - (ii) management plane services, in charge of system configuration and maintenance
  - WAVE supports two network-layer protocols:
    - (i) the traditional IPv6 routing protocol, together with the transport protocols associated with it;
    - (ii) the WAVE Short Message Protocol (WSMP), expressly designed to accommodate high-priority, time-sensitive communications

Very similar to the approach of a cellular scheme



ITS Architecture: WAVE ITS Station Architecture

- IEEE 1609 is defined by 4 sub-protocols (ctd.).
  - **IEEE 1609.4: organization of multiple channels operations** and, therefore, it has a strong relation to the Enhanced Distributed Channel Access (EDCA) mechanism
    - IEEE 1609.4 envisions the presence of a *single Control CHannel (CCH)*, reserved for system control and safety messages, and *up to 6 Service CHannels (SCHs)* used to exchange non-safety data packets (e.g., IP traffic) and WAVE-mode Short Messages (WSM)
    - According to the multi-channel operation, all vehicular devices have to monitor the CCH during common time intervals (the CCH intervals), and to (optionally) switch to one SCH during the SCH intervals
    - The described operation allows the safety warning messages to be transmitted on CCH using the WSM protocol, while non-safety dat applications, either running over IP or WSM packets, use the SCHs

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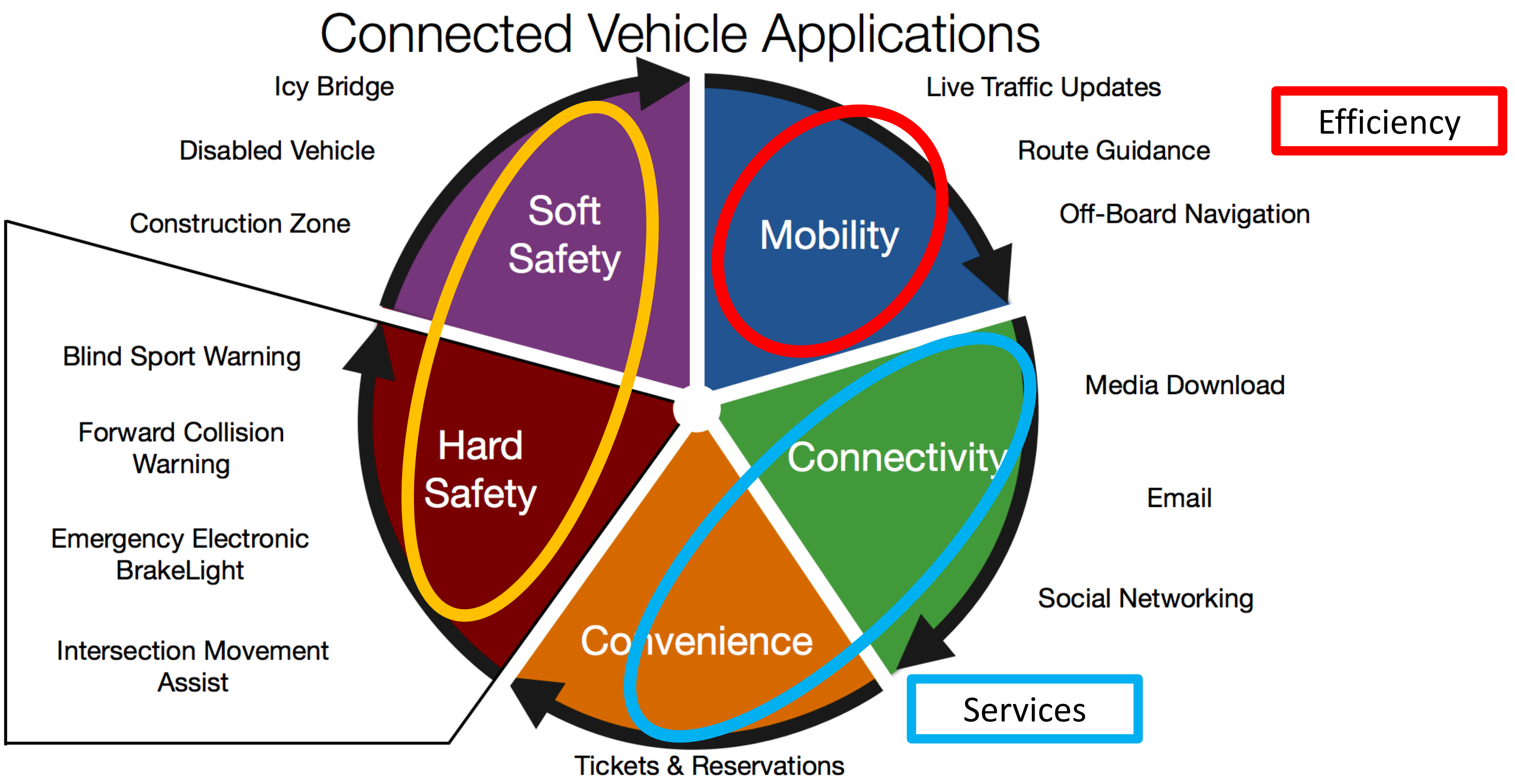
ITS Applications

- As vehicles become integrated in an ITS, their "**horizon of awareness**" **drastically increases** and an entirely new ecosystem of applications can be created, and even pre-existent applications can greatly enhance their efficiency
- New applications, especially which in the domain of **transportation safety and efficiency**, are the main drivers for the development of new systems
- These applications shall cope with **new challenges** created by high vehicle speeds and highly dynamic operating environments, and shall guarantee high packet delivery rates and low packet latency

ITS Applications

- ITS applications can be classified in three categories acting in three primary directions:
  - (i) transportation safety
  - (ii) transportation efficiency
  - (iii) user services delivered to the vehicles (typically in the field of connectivity and convenience)
- Due to their nature, **safety applications** require to be executed in dedicated reliable hardware, while the **remaining applications** can be delivered through consumer electronic devices such as smartphones or in-vehicle embedded devices (COTS)
- Obviously, a **better integration with the vehicle** can provide additional advantages. The vehicles display and sound system can offer a user interface designed to minimize driver distraction

ITS Applications



ITS Safety Applications

- **Hard safety applications** are targeted to avoiding imminent crashes and minimizing the damage when these crashes become unavoidable
  - These applications impose the most stringent requirements on the communication system
  - The communication latency has to be minimized in order to offer the driver sufficient time to take action and the communication system must provide high levels of reliability such a high message reception probabilities
- **Soft safety applications** have less time-critical requirements, increase driver safety but do not require immediate driver reaction, because the hazards are not imminent
  - Examples include warning the driver of weather, road, traffic, icy roads, construction zones, reduced visibility, pot holes, and traffic jams
  - Typical actions in response to soft safety application alerts would be to proceed with caution or take alternate routes to avoid the dangerous conditions ahead

ITS Efficiency and Service Applications

- **Transportation efficiency applications** focus on improving traffic flow. Examples include navigation, road guidance, traffic information services, traffic assistance, and traffic coordination
- **Service (general purpose) applications** focus on making driving more enjoyable and providing greater convenience. Examples include point-of-interest notification, email, social networking, media download, and applications update
- All these applications can tolerate long delays but may occasionally demand high data throughput

ITS Traffic Information Services (TIS)

- **Traffic information Services (TIS)** combine historical, real-time, and predictive information, to enable optimized (re-)routing and reliable Estimated Time of Arrival computing
- Major navigation brands, such as Nokia (with HERE Drive) and Google (with Google Maps), leverage probe data from their customer base, to offer **free traffic updates**. Smaller vendors, like TomTom, shifted to lifetime traffic offers, bundled with the navigation device
- TIS rely on
  - **embedded On-board Infotainment Systems (OISs)**, which combine entertainment, multi-media and driver information functions in one module
  - **unintegrated information systems**, such as smartphones and tablets, which may extend the functionalities of OISs, or operate independently of them
  - **general-purpose communication infrastructures**, such as the cellular network
  - **dedicated communication infrastructures**, such as Road Side Units (RSUs) based on IEEE 802.11p; and on remote services (e.g., cloud-based) which provide/collect and process information collected by RSUs and/or vehicles

ITS Traffic Information Services (TIS)

- **OISs**, also known as In-Vehicle Communications and Entertainment System (IVCES), **combine entertainment, multi-media and driver information functions in one module.** They offer AM/FM or satellite radio, DC/DVD player for music and video, navigation system, data and multi media ports (USB, Bluetooth, line in, line out, video in) as well as general and vehicle status information
- **OISs may also be networked**, e.g., by means of 802.11n, with multiple-input multiple-output (MIMO) antennas, operating at a maximum net data rate from 54 Mbit/s to 600 Mbit/s

ITS Traffic Information Services (TIS)

- An OIS is an **embedded hardware module**, powered by dedicated embedded operating systems and middleware, able to provide passengers with several services, including audio/video entertainment, navigation assistance, telephony, car setup and diagnostic, driver information, Internet connectivity, and smartphone integration
- To achieve these results, an OIS must **interact with the diagnostic and multimedia buses of the vehicle (CAN BUS, FlexRay, MOST)**, to offer a multimodal friendly HMI (including touch-screens, steering wheel buttons, vocal controls).
- On the basis of the desired level of functionality, an OIS could also be equipped with a **certain number of network interfaces** (Bluetooth, WiFi, 3G/4G, USB), auxiliary inputs and positioning systems (i.e., GPS)

Cellular

ITS Traffic Information Services (TIS)

- From a historical perspective, the **need for entertaining** car passengers was born with cars themselves
- The **first car radio**, developed by Motorola, appeared on the market during the 1930s
- During the whole 20th century, OISs have been devices able to offer a limited set of functionalities — mainly audio entertainment, diagnostics and navigation services (the latter, only in last decades) — without interoperability and connectivity capabilities

ITS Traffic Information Services (TIS)

- Since the appearance of the **Bluetooth technology**, in 2000, OISs became more and more influenced by mobile phone technologies
- Later, the Bluetooth technology triggered the development of a **new generation of OISs** able to offer integrated phone services, interoperating with mobile phones
- The smartphone revolution started with the **launch of the iPhone**, in 2007, and forced a further change of paradigm for OISs manufacturers
- **Smart devices**, such as smartphones and tablets, have quickly achieved a **pivotal role in vehicle infotainment**, thanks to their flat Internet connectivity, their application stores with thousands of apps, and their vertically integrated cloud services

Outline

- Principles and challenges
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Applications

Connection capabilities

Future Trends in Vehicular Communications

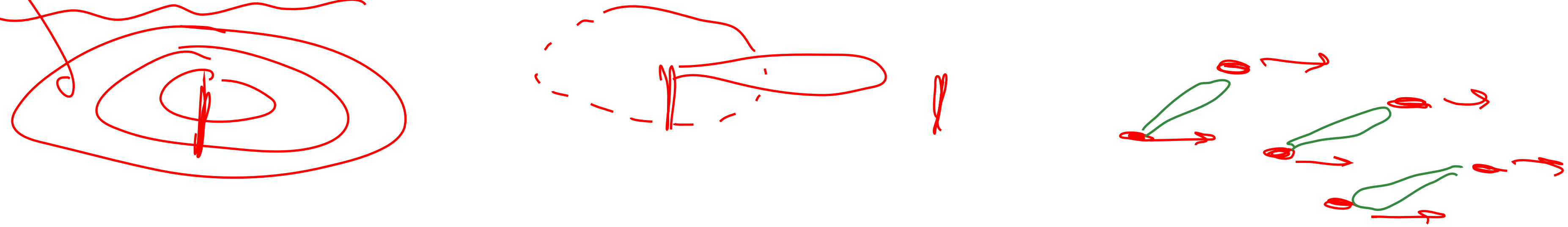
- Future vehicular applications in the mass market like infotainment, driver assistance systems and autonomous driving will create a **massive communication demand**, especially in urban areas
- Drivers and autonomous cars will also be supported by an **increasingly intelligent roadside infrastructure**, such as roadside wireless-enabled detection systems to avoid severe accidents resulting from wrong-way driving
- The **key requirements** in order to support future communication demands are peak data rate, cell edge data rate, spectral efficiency, mobility support, cost efficiency, number of simultaneous connections and latency

Machine-Type Communications

Future Trends in Vehicular Communications

- The **5G cellular communication standard** tries to address all these requirements, especially the support of massive MTC → likely to continue in 6G
- **Technical trends** in the development of communication networks are:
  - Device-to-Device (D2D) communication that enables a direct transmission of data between two devices (very interesting for V2V communication)
  - beam forming, to improve the channel quality (also with regard to mobility)
  - non-orthogonal multiple access, to allow future cellular massive radio access

- Save energy
- Minimizes interference



Autonomous Driving

- In general, **autonomous** means having the power for self-governance. There have been several research and development projects dedicated to vehicle autonomy. However, **most of them have in fact only been automated** (made to be automatic) due to a heavy reliance on artificial hints in their environment (such as magnetic strips) or perception systems (e.g., based on computer vision)
- **Autonomous control implies good performance under significant uncertainties** in the environment for **extended periods of time** and the ability to compensate for system failures without external intervention
- From many projects mentioned, it is often suggested to extend the capabilities of an autonomous car by implementing **communication networks both in the immediate vicinity (for collision avoidance) and far away (for congestion management)** → no longer autonomous? (bringing in outside influences in the decision process)

Autonomous Driving: NHTSA Levels

In the **United States**, the National Highway Traffic Safety Administration (NHTSA) has proposed a formal classification system

- **Level 0**: The driver completely controls the vehicle at all times
- **Level 1**: Individual vehicle controls are automated, such as electronic stability control or automatic braking
- **Level 2**: At least two controls can be automated in unison, such as adaptive cruise control in combination with lane keeping. Example: Tesla Model S
- **Level 3**: The driver can **fully cede control** of all safety-critical functions in certain conditions. The car senses when conditions require the driver to retake control and provides a "sufficiently comfortable transition time" for the driver to do so
- **Level 4**: The vehicle **performs all safety-critical functions for the entire trip**, with the driver not expected to control the vehicle at any time. As this vehicle would control all functions from start to stop, including all parking functions, it could include unoccupied cars

Autonomous Driving: SAE Levels

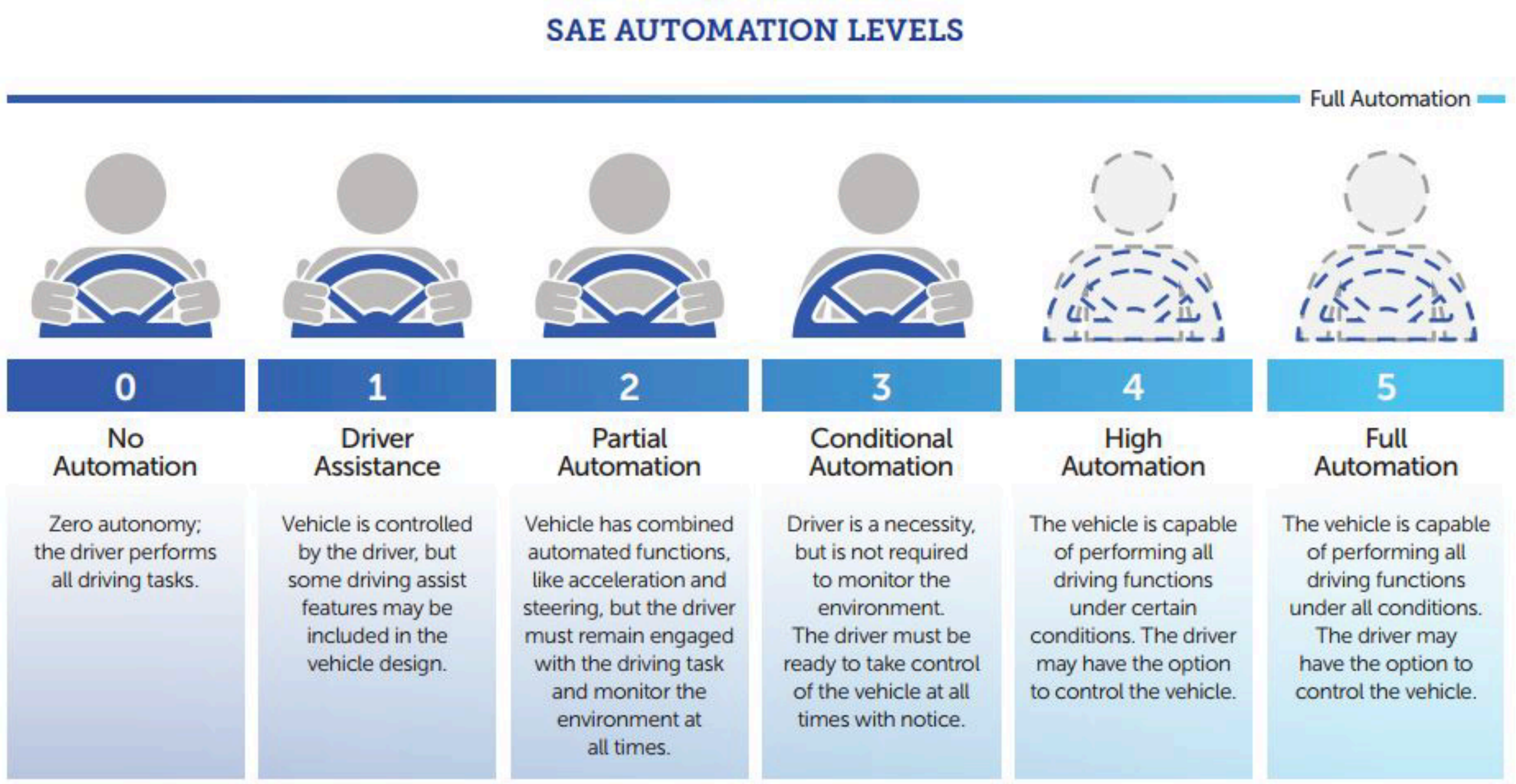
In SAE's autonomy level definitions, driving mode means "a type of driving scenario with characteristic dynamic driving task requirements (e.g., expressway merging, high speed cruising, low speed traffic jam, closed-campus operations, etc.)"

- **Level 0**: Automated system issues warnings and may momentarily intervene but has no sustained vehicle control
- **Level 1 (*hands on*)**: The driver and the automated system share control of the vehicle. Examples are
  - Adaptive Cruise Control (ACC), where the driver controls steering and the automated system controls speed
  - Parking Assistance, where steering is automated while speed is under manual control. The driver must be ready to retake full control at any time
  - Lane Keeping Assistance (LKA) Type II is a further example of level 1 self driving
- **Level 2 (*hands off*)**: The automated system takes full control of the vehicle (accelerating, braking, and steering). The driver must monitor the driving and be prepared to intervene immediately at any time if the automated system fails to respond properly. The shorthand "hands off" is not meant to be taken literally. In fact, contact between hand and wheel is often mandatory during SAE 2 driving, to confirm that the driver is ready to intervene

Autonomous Driving: SAE Levels

- Level 3 (*eyes off*): The driver can safely turn his/her attention away from the driving tasks, e.g. the driver can text or watch a movie. The vehicle will handle situations that call for an immediate response, like emergency braking. The driver must still be prepared to intervene within some limited time, specified by the manufacturer, when called upon by the vehicle to do so.
  - Example: the 2018 Audi A8 Luxury Sedan was the first commercial car to claim to be capable of level 3 self driving. This particular car has a so-called Traffic Jam Pilot. When activated by the human driver, the car takes full control of all aspects of driving in slow-moving traffic at up to 60 kilometres per hour (37 mph). The function works only on highways with a physical barrier separating one stream of traffic from oncoming traffic
- Level 4 (*mind off*): As level 3, but no driver attention is ever required for safety, i.e. the driver may safely go to sleep or leave the driver's seat. Self driving is supported only in limited spatial areas (geofenced) or under special circumstances, like traffic jams. Outside of these areas or circumstances, the vehicle must be able to safely abort the trip, i.e. park the car, if the driver does not retake control
- Level 5 (*steering wheel optional*): No human intervention is required at all. An example would be a robotic taxi

Autonomous Driving: SAE Levels

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謝謝
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Vehicular Communications

Prof. Gianluigi Ferrari, Prof. Luca Davoli

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Department of Engineering and Architecture

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Lecture 2

Telecommunication networks basics

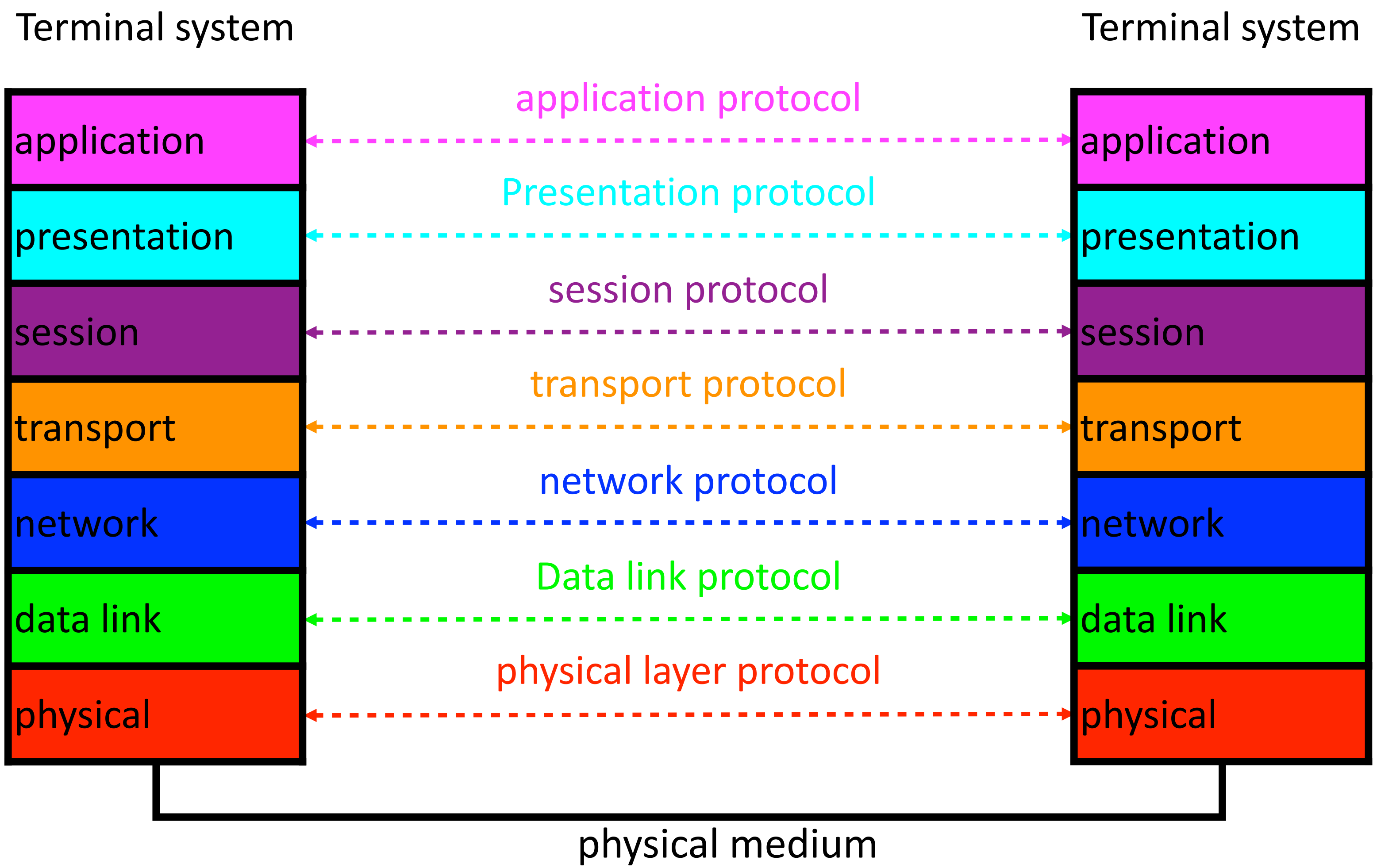
Outline

- The OSI and Internet models
- Communication models
- Delimitation
- Sequence control
- Error management

Outline

- The OSI and Internet models
- Communication models
- Delimitation
- Sequence control
- Error management

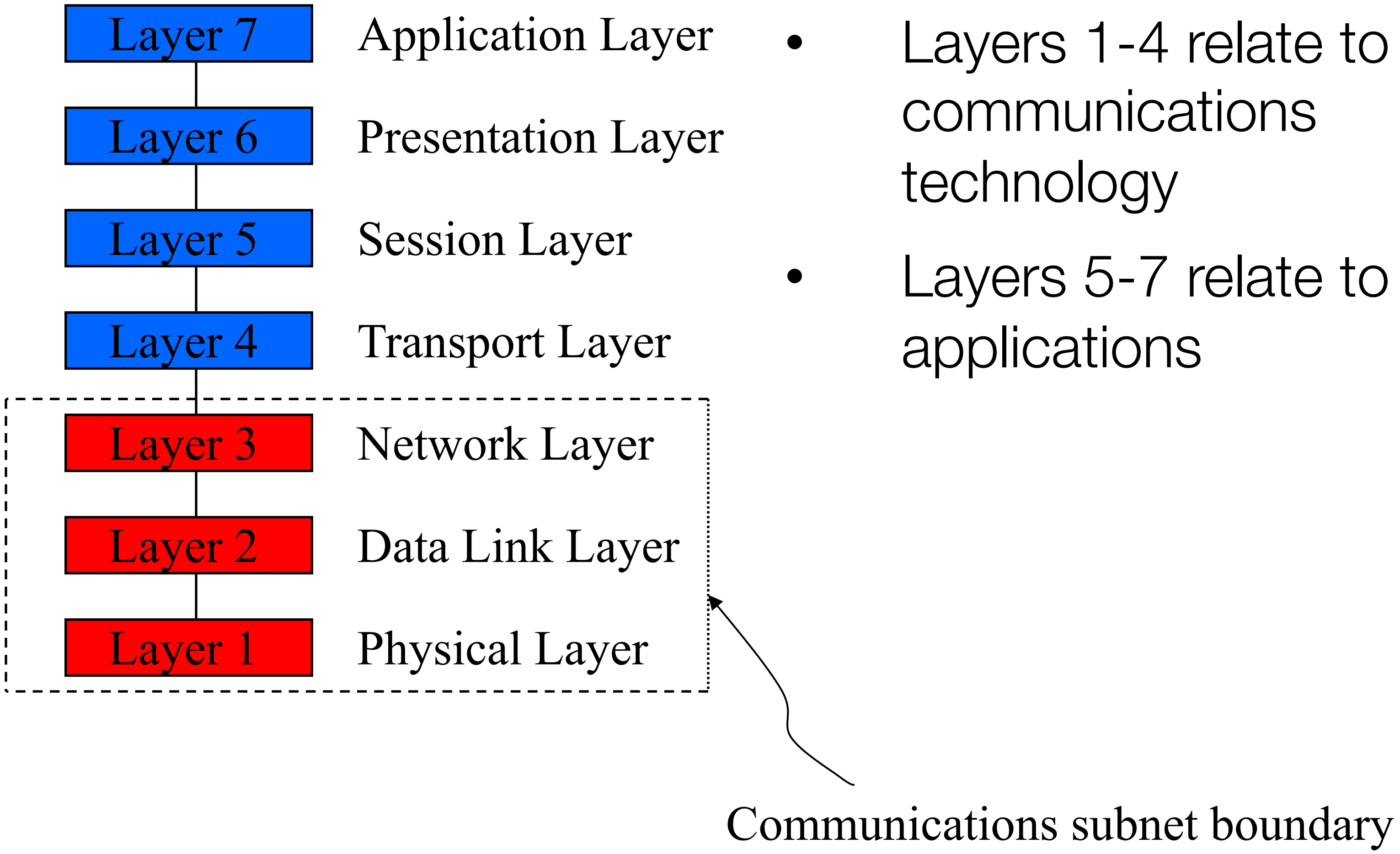
OSI Architectural model



OSI Reference Model

- OSI Reference Model - internationally standardised network architecture
- OSI = *Open Systems Interconnection*: deals with *open systems*, i.e. systems open for communications with other systems
- Specified in ISO 7498
- Model has 7 layers

7-Layer OSI Model



- Layers 1-4 relate to communications technology
- Layers 5-7 relate to user applications

Layer 7: Application Layer

- Level at which applications access network services
  - Represents services that directly support software applications for file transfers, database access, and electronic mail etc.

Layer 6: Presentation Layer

- Related to representation of transmitted data
  - Translates different data representations from the Application layer into uniform standard format
- Providing services for secure efficient data transmission
  - e.g., data encryption, and data compression

Layer 5: Session Layer

- Allows two applications on different computers to establish, use, and end a session
  - e.g., file transfer, remote login
- Establishes dialog control
  - Regulates which side transmits, plus when and how long it transmits
- Performs token management and synchronization

Layer 4: Transport Layer

- Manages transmission packets
    - Repackages long messages when necessary into small packets for transmission
    - Reassembles packets in correct order to get the original message
- Handles error recognition and recovery.
    - Transport layer at receiving acknowledges packet delivery
    - Resends missing packets

Layer 3: Network Layer

- Manages addressing/routing of data within the subnet
  - Addresses messages and translates logical addresses and names into physical addresses
  - Determines the route from the source to the destination computer
  - Manages traffic problems, such as switching, routing, and controlling the congestion of data packets
- Routing can be:
  - based on static tables
  - determined at start of each session
  - individually determined for each packet, reflecting the current network load

Layer 2: Data Link Layer

- Packages raw bits from the Physical layer into frames (logical, structured packets for data)
- Provides reliable transmission of frames
    - It waits for an acknowledgment from the receiving computer
    - Retransmits frames for which acknowledgement not received

Layer 1: Physical Layer

- Transmits bits from one computer to another
- Regulates the transmission of a stream of bits over a physical medium
- Defines how the cable is attached to the network adapter and what transmission technique is used to send data over the cable. Deals with issues like
  - The definition of 0 and 1, e.g. how many volts represents a 1, and how long a bit lasts?
  - Whether the channel is simplex or duplex?
  - How many pins a connector has, and what the function of each pin is?