V2X Communications and Edge Computing for Connected Vehicles

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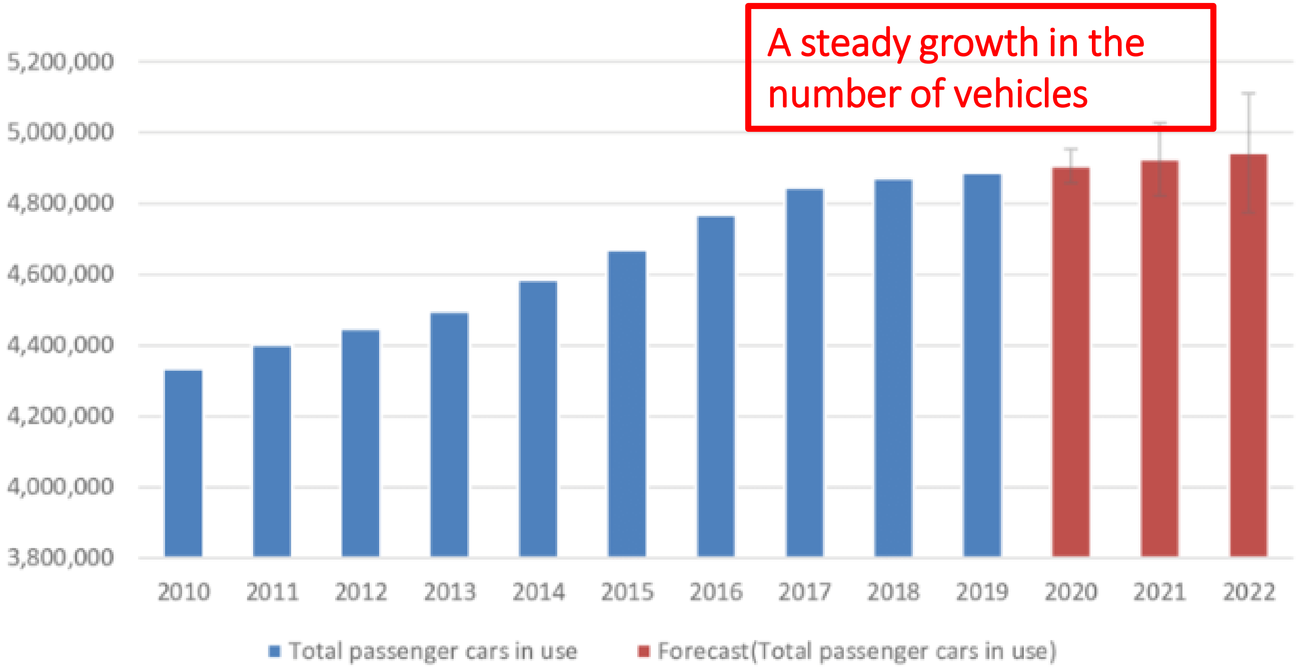
Outline

Background

- Quick growth in the global population living in urban (60% expected by 2030), leading to a steady growth in the total number of passenger cars.



Background

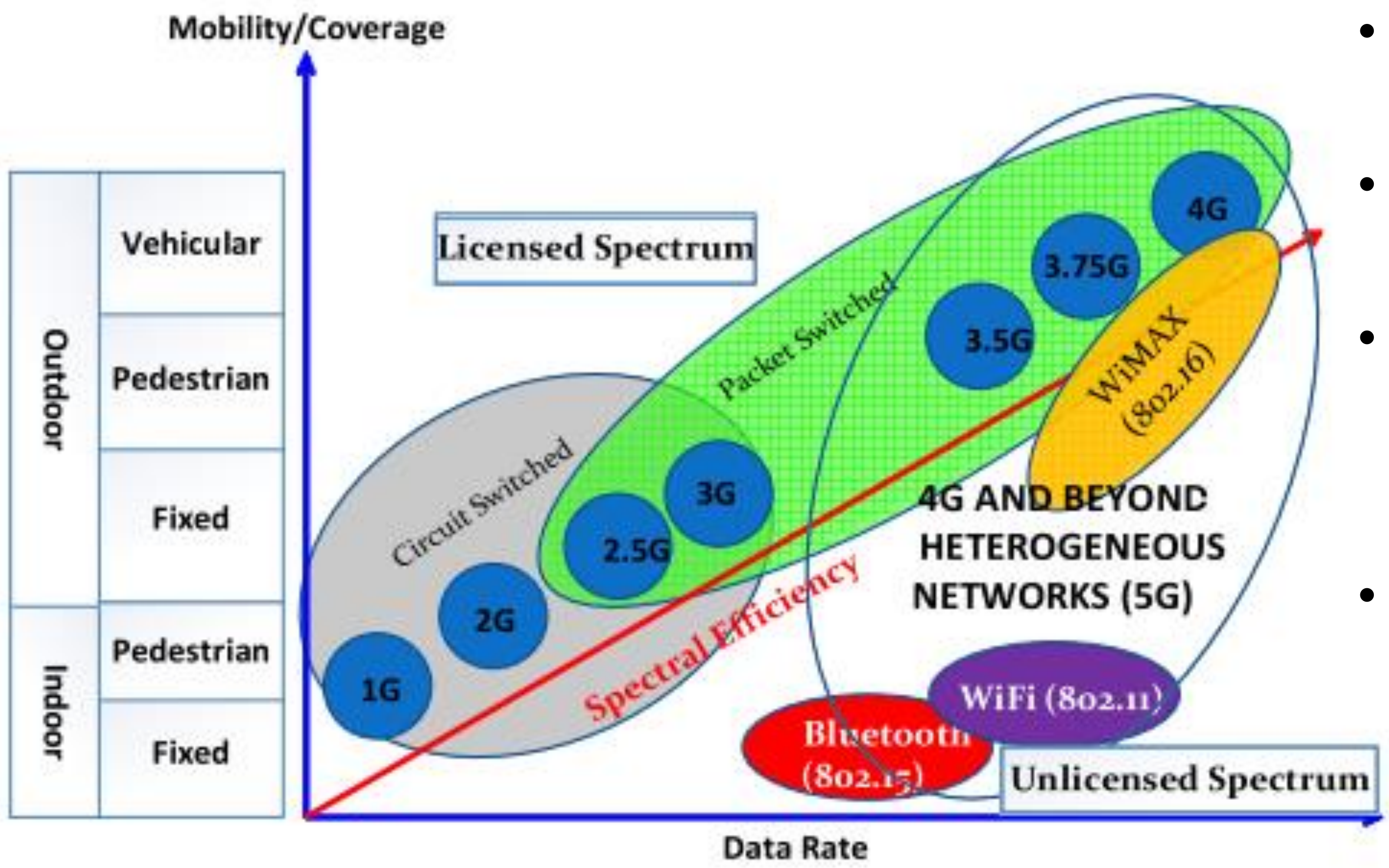
- Quick growth in the global population living in urban (60% expected by 2030), leading to a steady growth in the total number of passenger cars.
  - Global environmental issues
  - Energy resource consumptions
  - Socio-economic: accidents, and life quality

Environmental issues

Energy consumptions

Background

- Advanced Information and Communications Technologies (ICT) in past decades

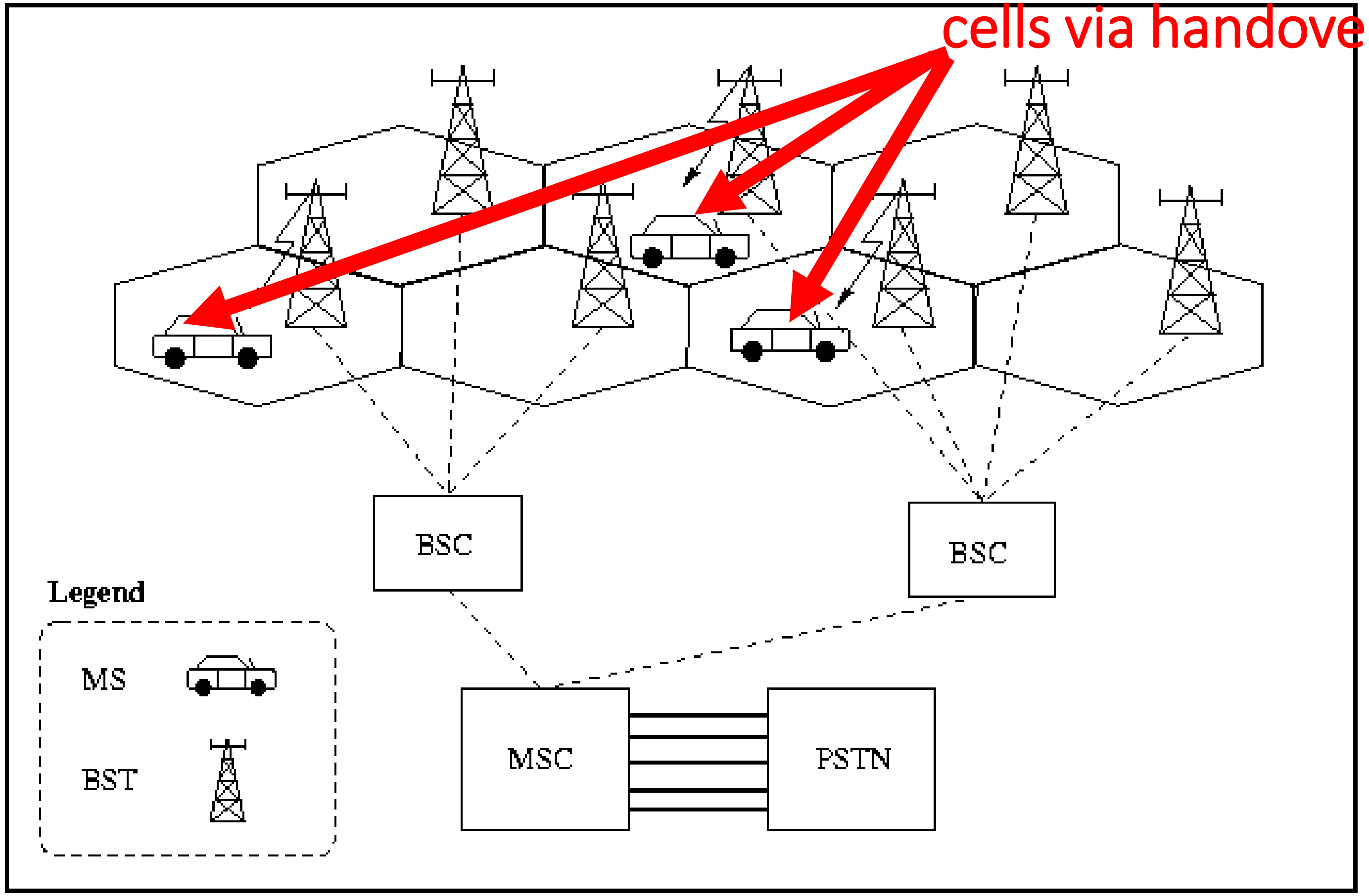


- 1G: Advanced Mobile Phone System (AMPS), 2.4kbps
- 2G: Global Systems for Mobile communications (GSM), 64kbps
- 3G: Code Division Multiple Access (CDMA) & WCDMA, 100kbps ~ <=10Mbps
- 4G: 3GPP Long Term Evolution (LTE), providing 10Mbps ~ 100Mbps

Background

- The multi-cell structure of cellular systems for providing seamless wireless connectivity to moving vehicles

Seamless connectivity across different cells via handover management



Background

- Evaluation from 4G to 5G/6G cellular systems

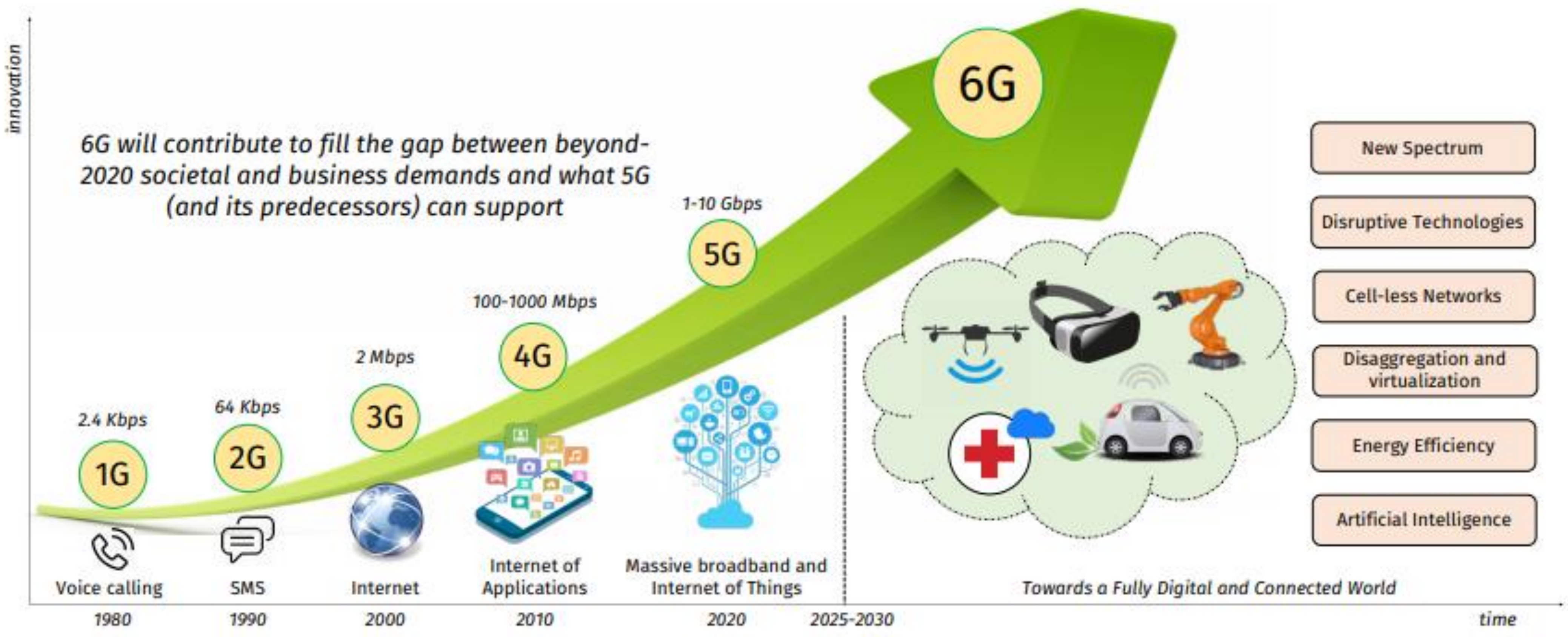


Fig. 1: Evolution of cellular networks, from 1G to 6G, with a representative application for each generation.

Background

- Essential goals of 5G systems
  - eMBB (enhanced broadband access): ultra-high throughput applications
  - uRLLC: low-latency and ultra-high reliable applications (e.g., mission-critical applications Industry 4.0)
  - eMTC: Massive machine-type (IoT) communications

E-health

Autonomous driving

Industry 4.0

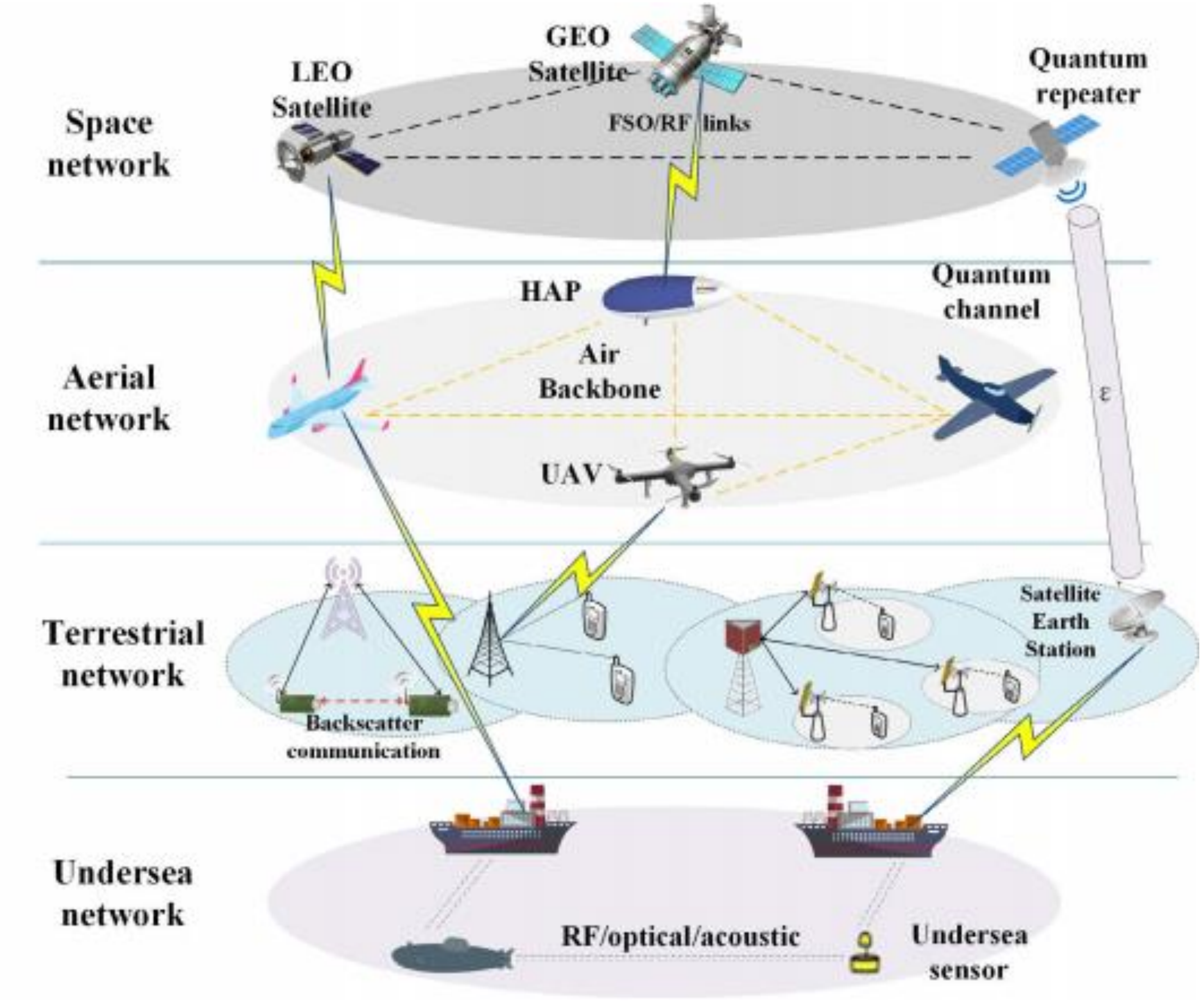
VR/AR

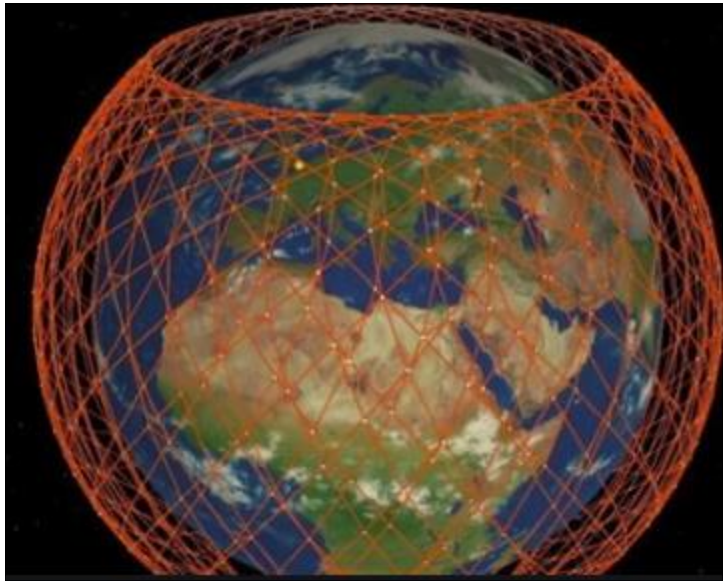
Background

- Enabling technologies for 5G
  - Ultra-dense Heterogeneous Networks (UDN)
  - Massive MIMO
  - millimeter Wave (mmWave) and Unlicensed spectrum
  - Device-to-Device (D2D) communications
  - Massive Machine-type Communications (MMC)
  - Advanced Multiple Access Scheme: PDMA, NOMA, and etc.
  - Clould Radio Access Network and Network slicing (function virtualization)
  - ....

Background

- 5G enabled Space-Air-Ground-Sea System: A global ultra-high throughput access

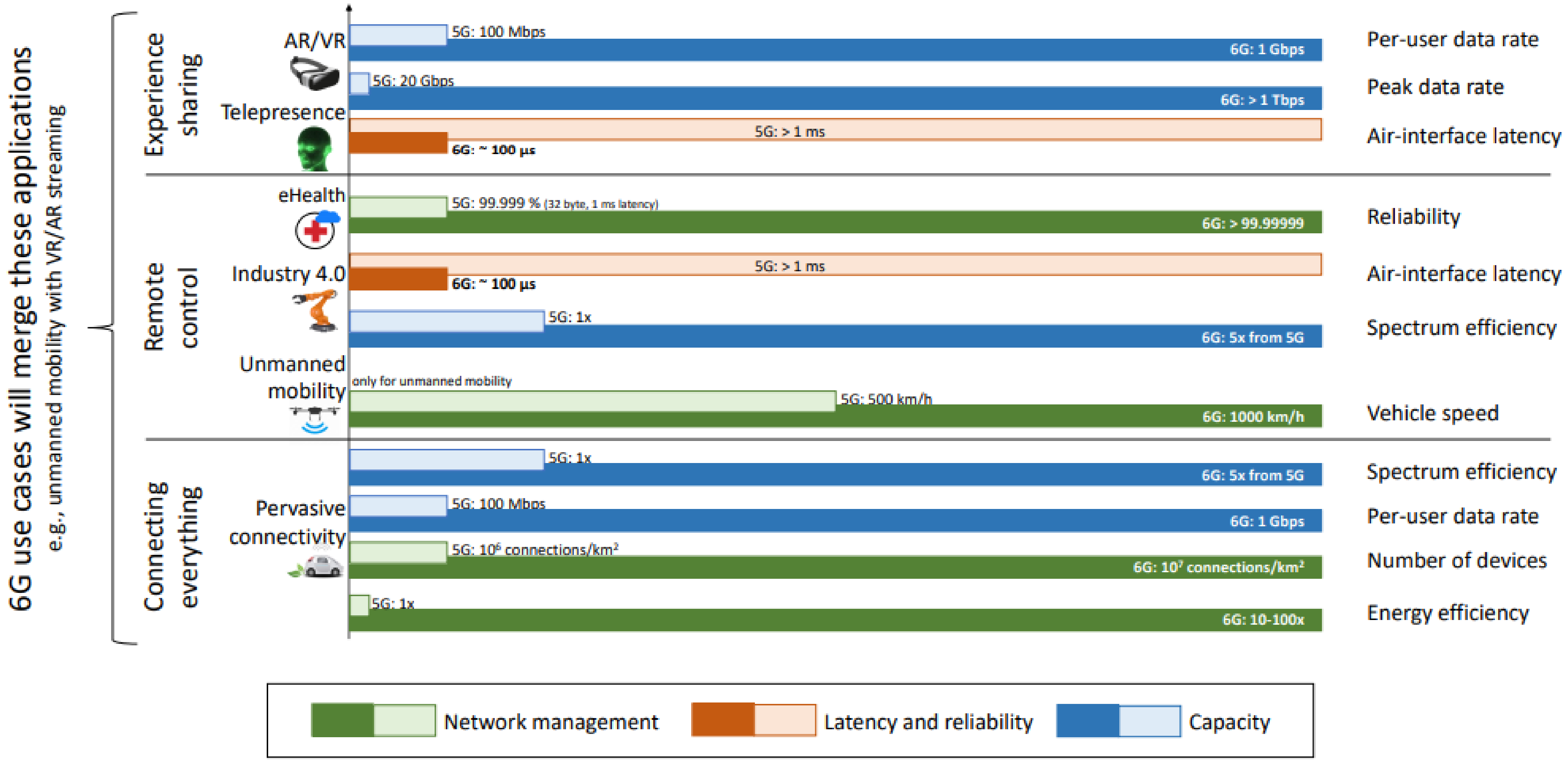




Starlink 星聯計畫

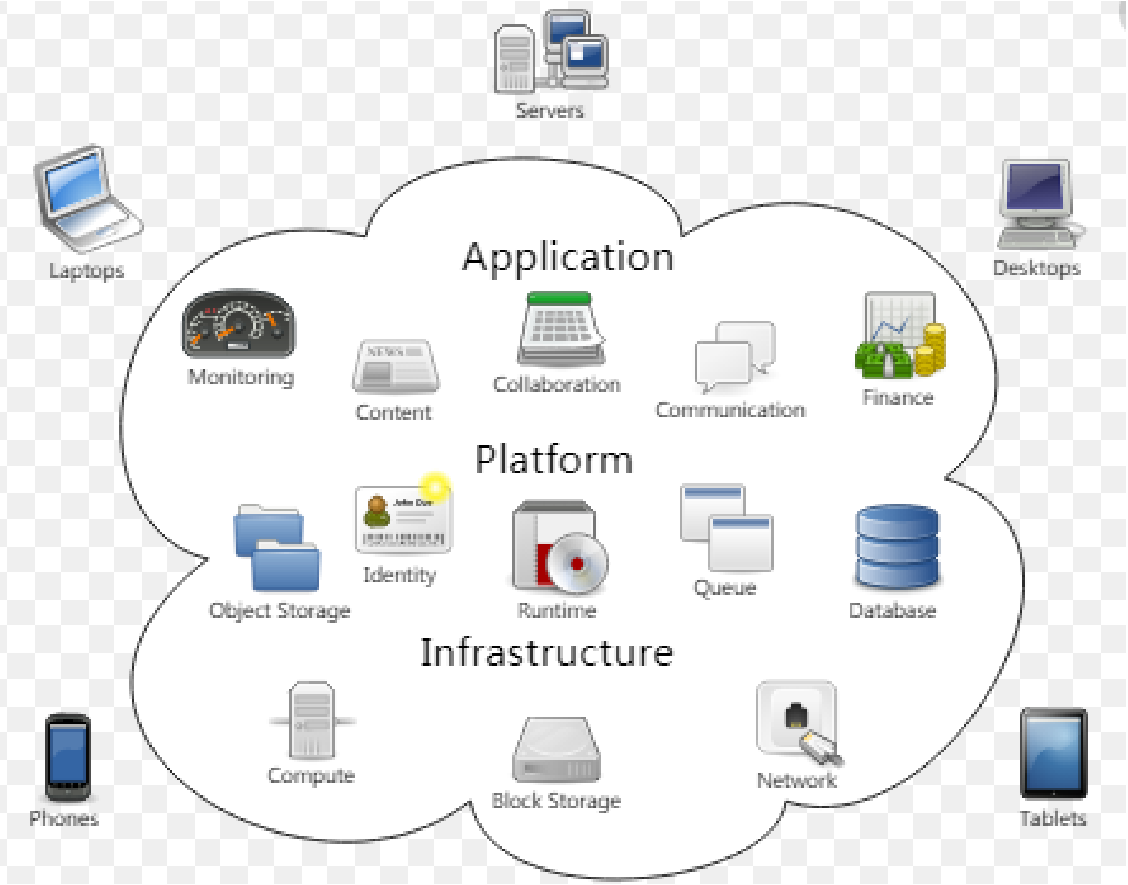
Background

- Vision of 6G: far beyond of 5G



Background

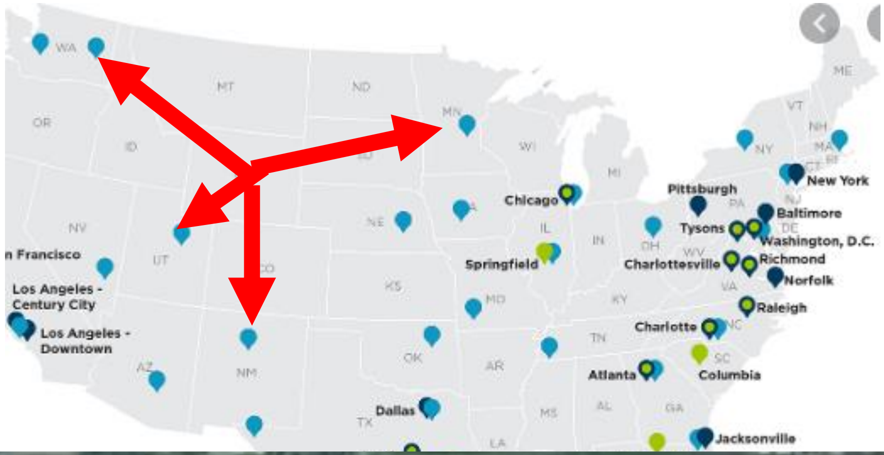
- Cloud computing
  - On-demand availability and provisioning of computer system resources, e.g., data storage and computing units without direct managed by the end-user
  - Conventional IaaS, PaaS, and SaaS
  - Cost-efficiency by reducing infrastructure cost



Background

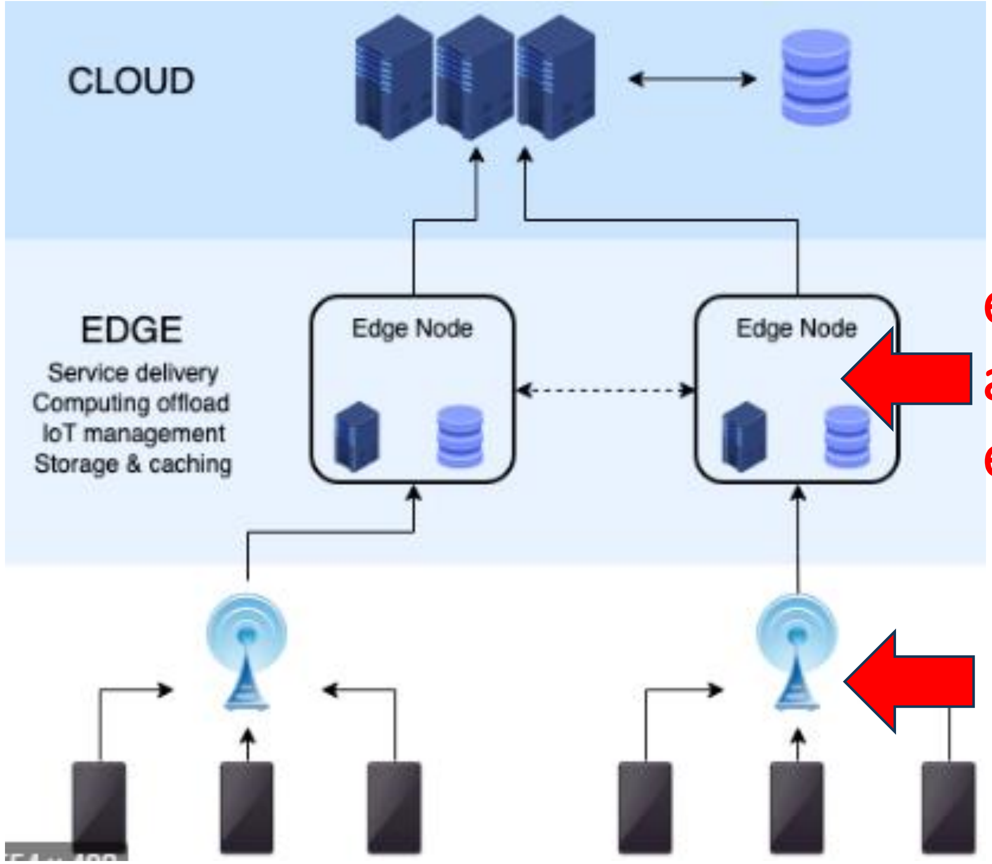
- Cloud computing
  - Large-scale data centers Geographically distributed across the nation and world wide
  - Deep inside Internet, strongly dependent on backbone networks (connections)
  - Uncontrollable congestion and latency

Latency-insensitive applications



Background

- Edge computing
  - Computation-resources at the edge of networks, e.g., at the cellular base station
  - User can actively offload computational tasks to the edge-servers via one-hop wireless transmission.
  - Efficiency by close-proximity between users and resources: enabling low-latency applications while improving the efficiency in resources (computation, storage, and radio resources) utilization

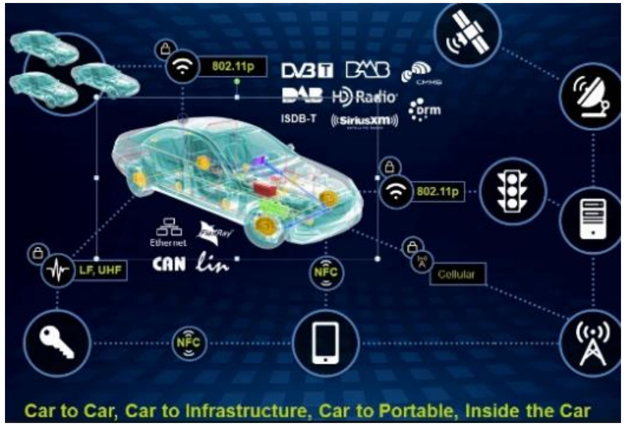


edge server at network edge

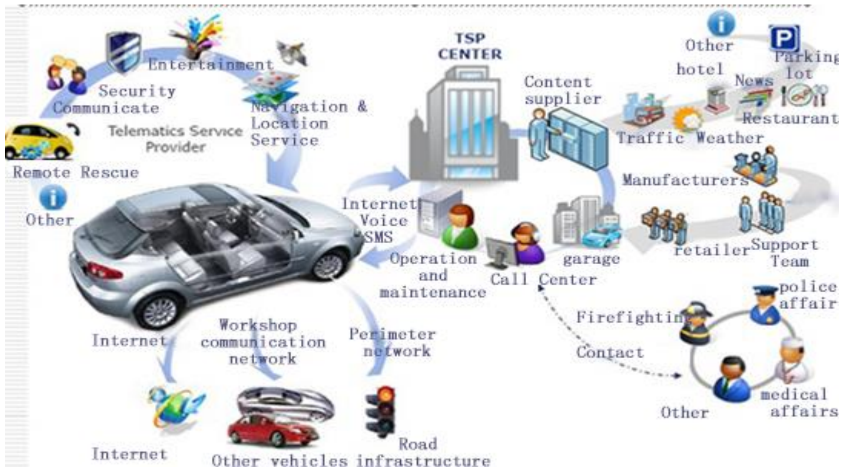
wireless access

Background

- Connected Vehicles by advanced ICT technologies for improving the efficiency of transportation systems, safety, and comfortness



Single-car intelligence (e.g., autonomous driving)



Connected cars via crowd intelligence

Intelligent transportation system (ITS)

Outline

1 Background

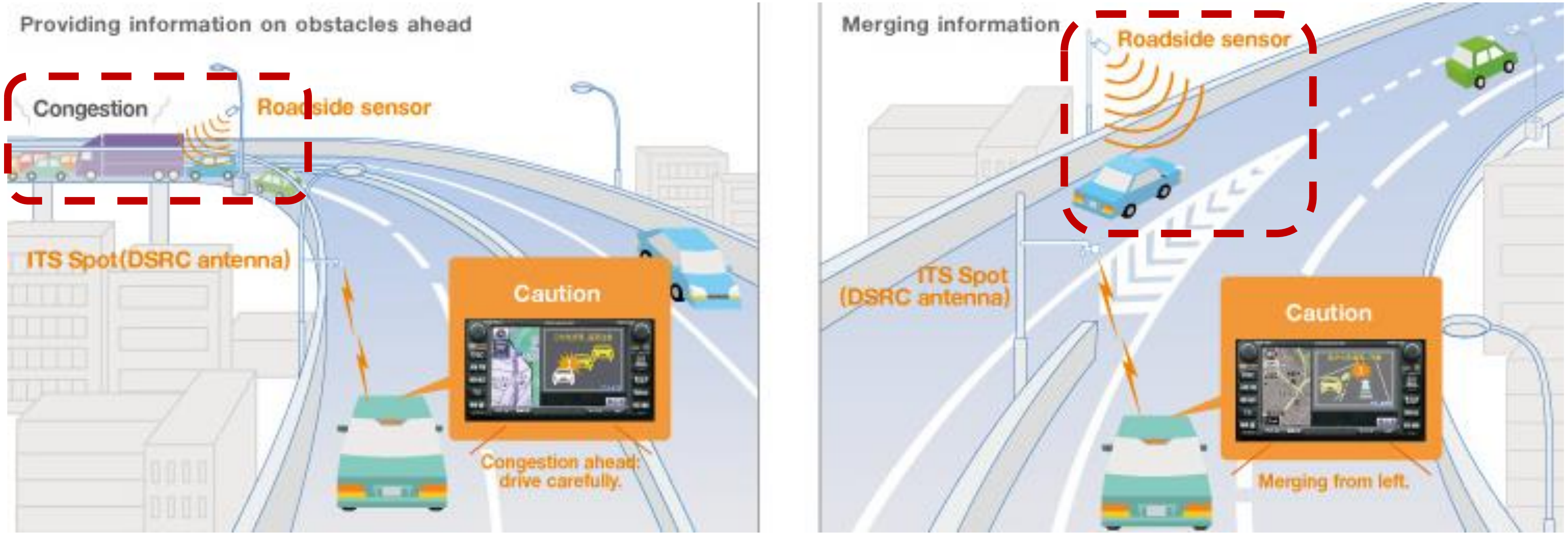
2 V2X Communications

3 Edge Computing and Applications

4 SDN and EV

V2X Communications

- Improving the safety and efficiency of vehicles by exploiting advanced information and communication technologies
- Connecting vehicles via Vehicular Ad-hoc Networks (VANET) represents an early attempt to support safety-related applications, such as accident warning, crash notification, and cooperative cruise control



V2X Communications

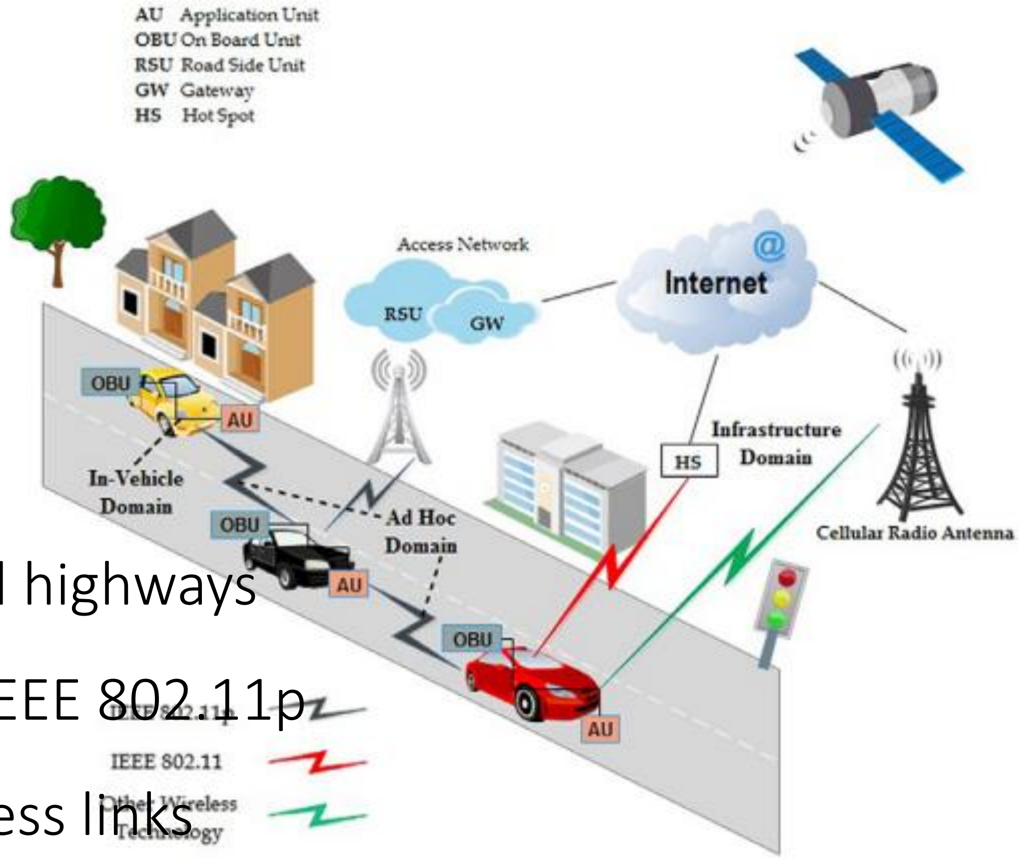
- Internet of Vehicles (IoV): wirelessly exchange information (e.g., speed, location, heading, and etc) through onboard communication devices.

- Key elements
  - Onboard Unit (OBU): a device attached on-board a vehicle used for exchanging information with RSUs or with other OBUs
  - Road Side Unit (RSU):

    * Situated at stationary positions along roads and highways

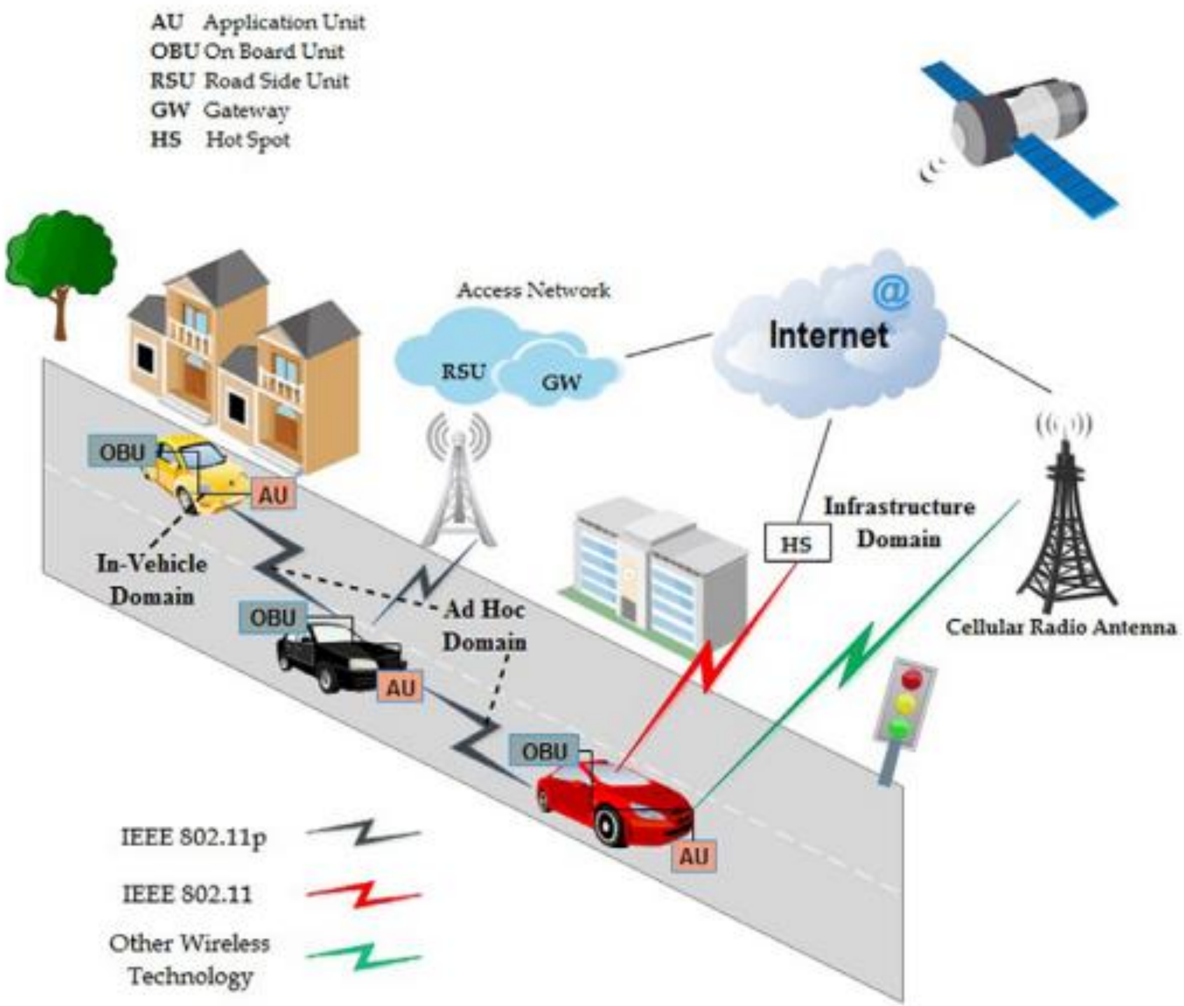
    * Provide Internet connectivity to OBU, e.g., via IEEE 802.11p

    * Vehicles with OBU sends data to RSUs via wireless links



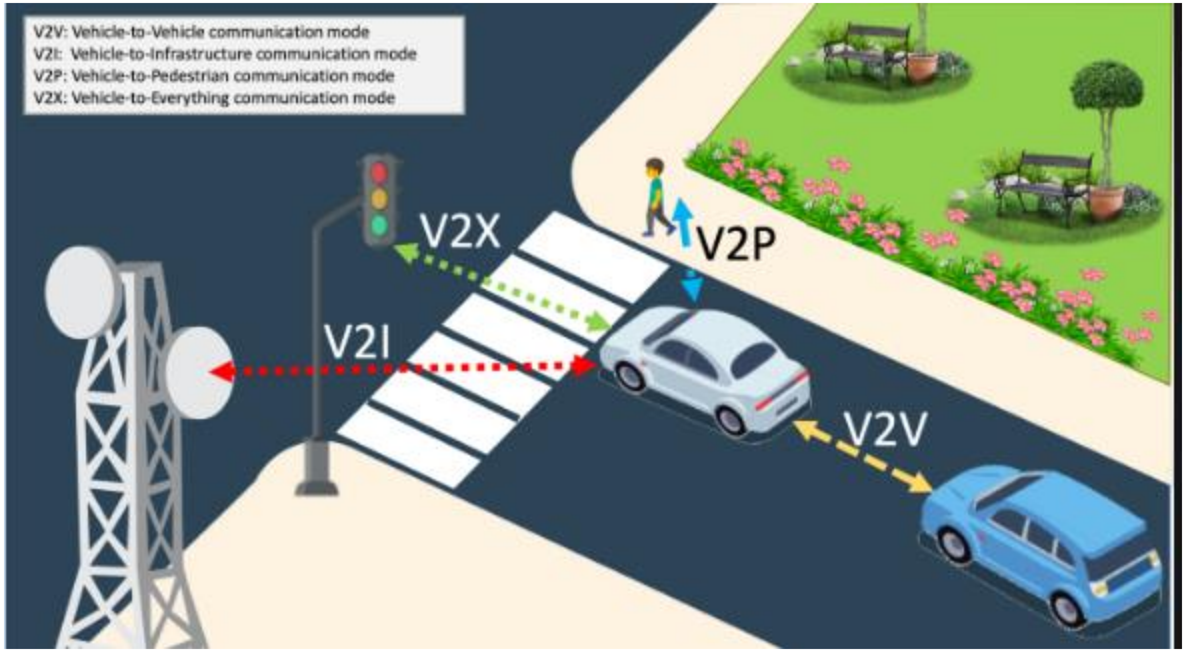
V2X Communications

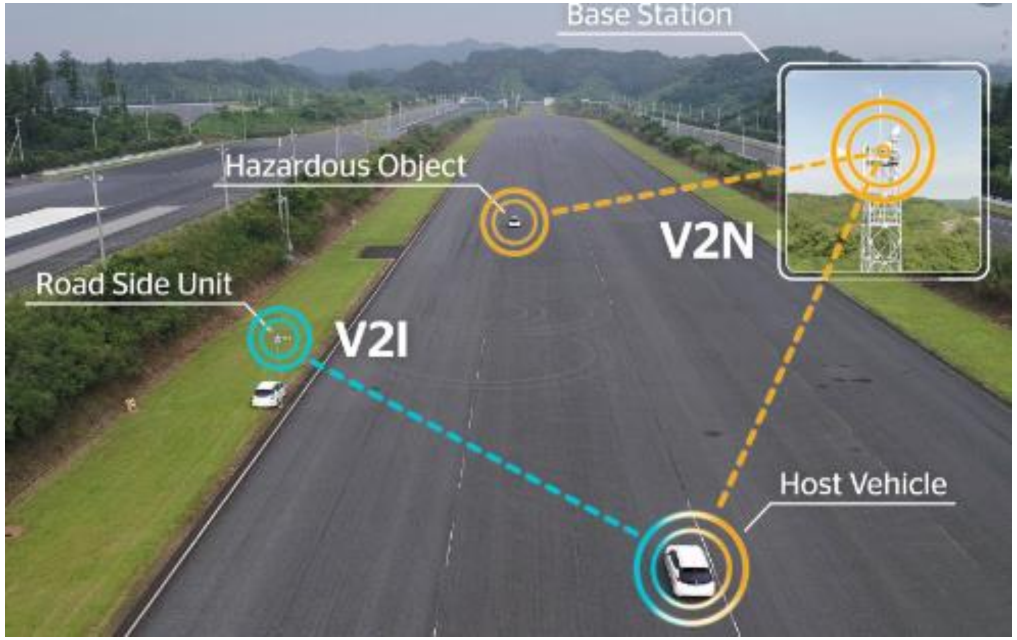
- More details about Road Side Unit (RSU):
  - Extending the communication range by re-distributing the information to other OBUs and by sending the information to other RSUs in order to forward it to other OBUs.
  - Running safety applications such as a low bridge warning, accident warning or work zone, using V2I communication and acting as an information source.
  - Providing internet connectivity to OBUs.



V2X Communications

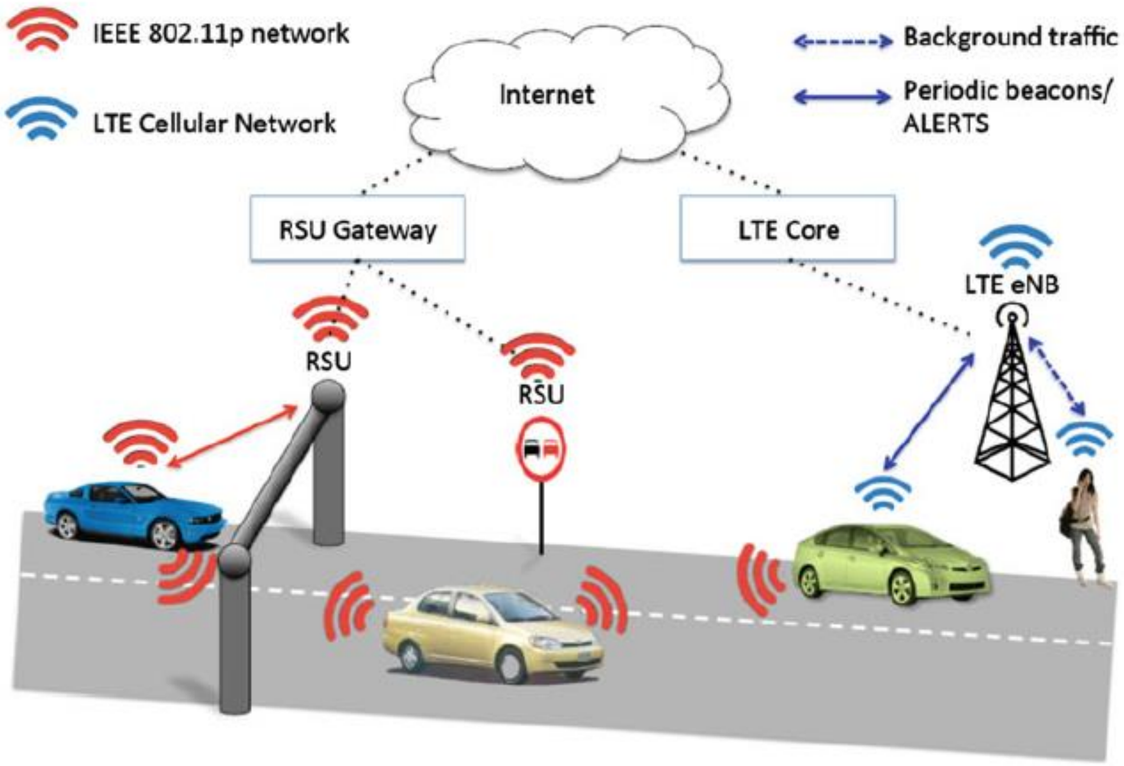
- Paradigm of V2X Communications
  - V2V: Vehicle to Vehicle
  - V2P: Vehicle to Pedestrian
  - V2I: Vehicle to Infrastructure (RSU)
  - V2C: Vehicle to Networks





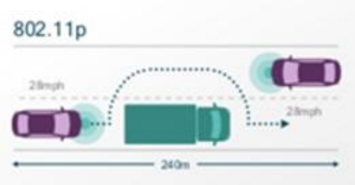
V2X Communications

- To enable V2X communications
  - V2X via infrastructure of advanced cellular networks: LTE for vehicles (LTE-V)
  - V2X via the matured technologies of wireless LAN access (random access in a relatively small coverage): Dedicated Short Range Communication (DSRC)



V2X Communications

- Milestone of LTE-V and DSRC



DSRC initiated
ASTM (America) introduced DSRC operated in 915 MHz band

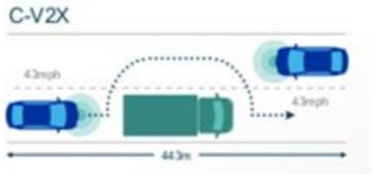
DSRC Japan
23 Japanese companies jointly draft DSRC in Japan

DSRC Europe
ETSI set 5.9GHz DSRC band and started framework project

DSRC standard finished
IEEE 802.11p was officially delivered for MAC/PHY of DSRC

1992 1994 1999 2008 2009 2010 2012 2014 2016 2017 2020

NR-V2X (5G) and 6G are coming !



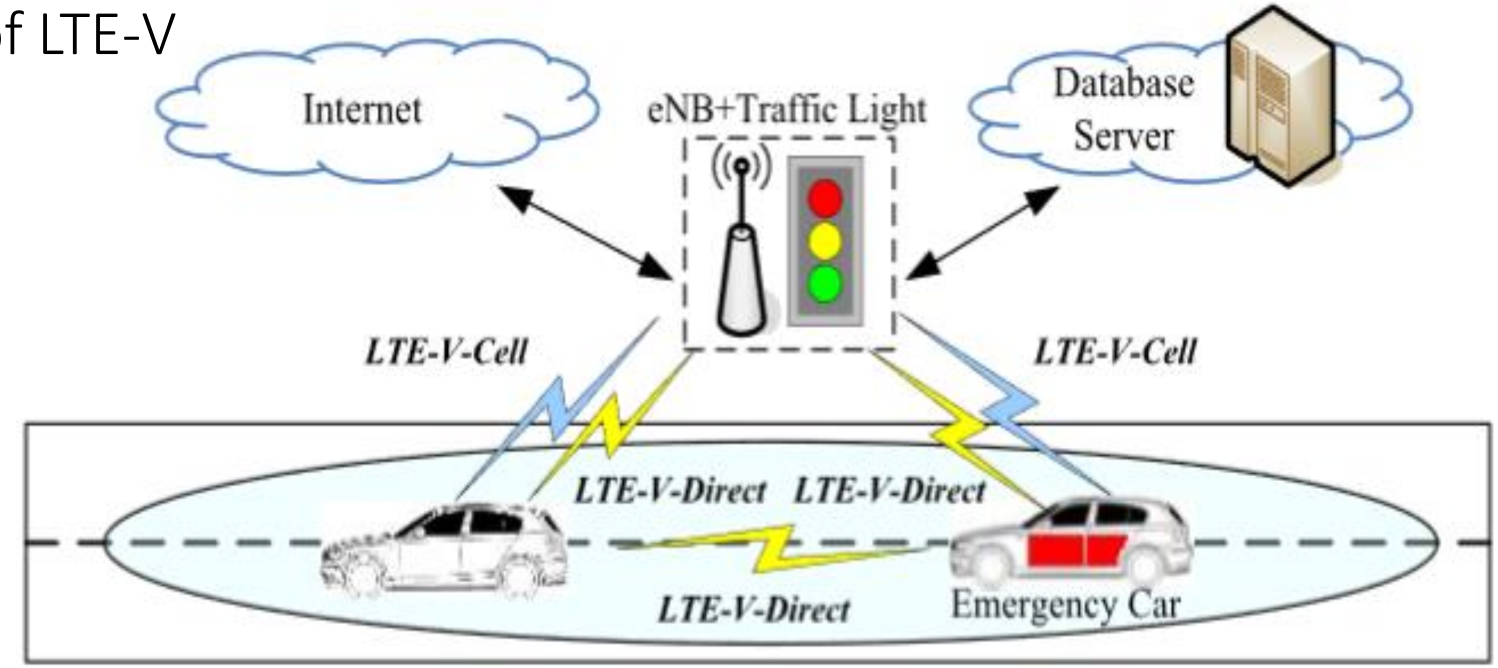
C-V2X initiated (3G based)
Ericsson, MAN Trucks, Vodafone, Volkswagen, BMW and Ford jointly start up the CoCarX project to utilize 3G cellular network for V2X communications.

LTE-V2X initiated
The European Union funded LTEBE-IT project to push forward LTE based V2X communications. Then, 3GPP initiated the related standards specification.

LTE-V2X standard finished
3GPP finished the LTE-V2X standards, including Release 14 and Release 15.

V2X via LTE-V

- Architecture of LTE-V

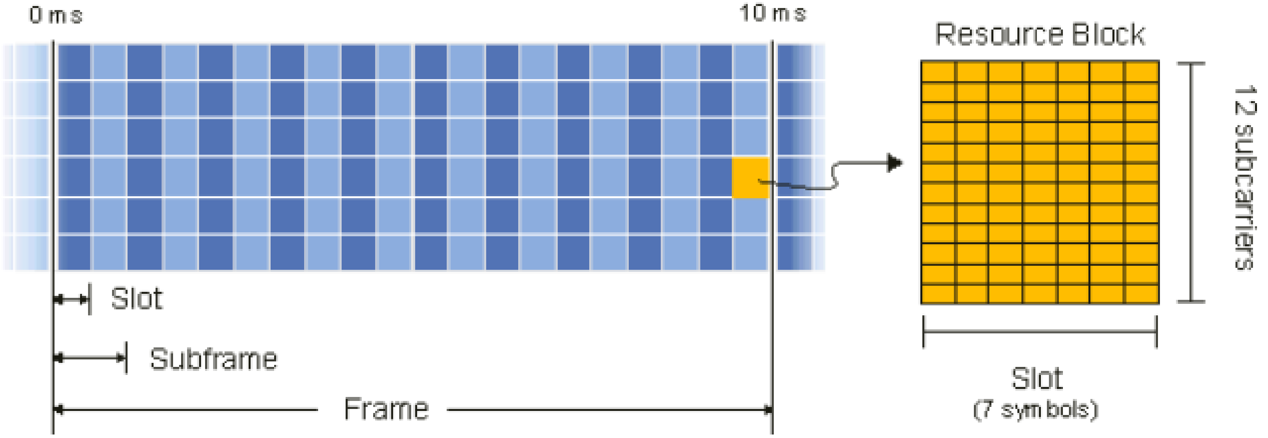


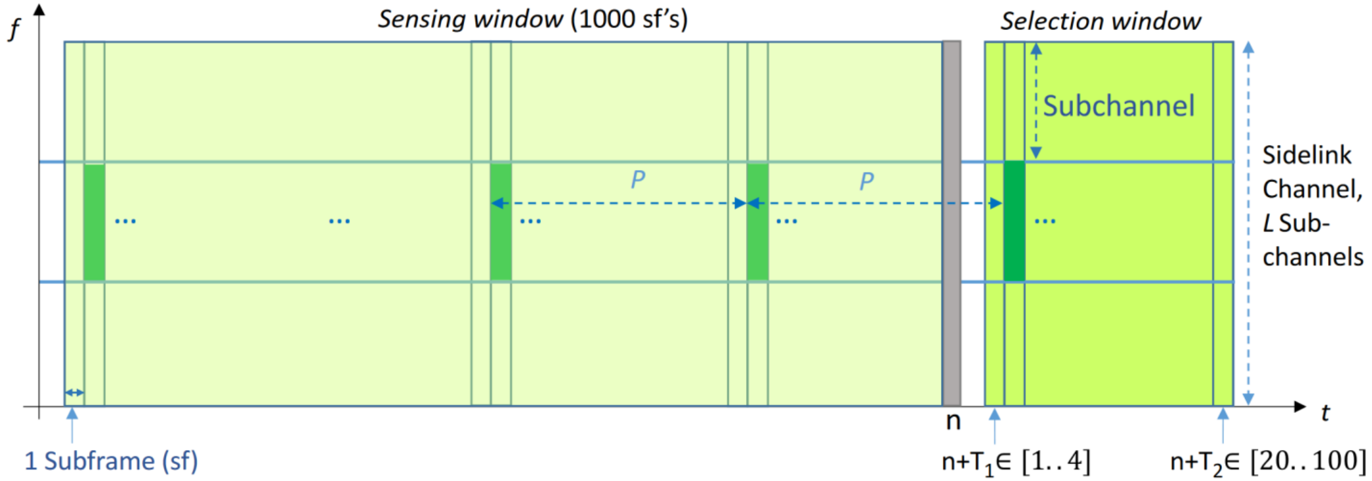
- LTE-V-Cell: vehicles communicate to the eNodeB (eNB).
- The communication is through the LTE-Uu interface.
- Uplink/downlink communication links.

- LTE-Direct: vehicles communicate directly to the other vehicles without passing through the eNB.
- The communication is through the PC5 interface.
- LTE-Direct-mode 3: resources are allocated by the cellular network.
- LTE-Direct-mode-mode 4: vehicles autonomously select their radio resources using a distributed scheduling scheme.

LTE-V2X

- MAC/PHY of LTE-V: Centralized scheduling with Orthogonal based resource block allocation and time-division based vehicular user scheduling



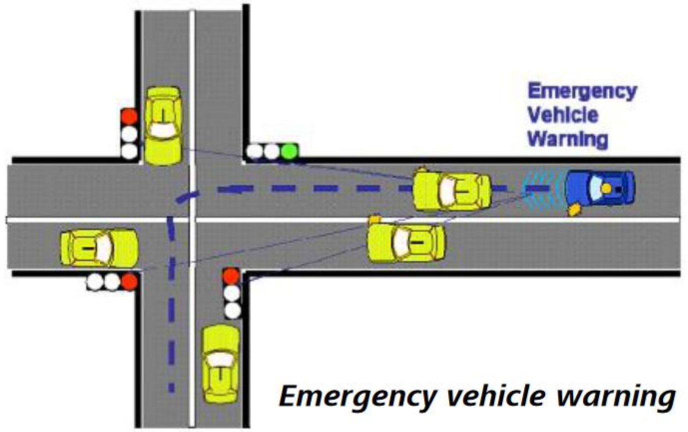


- At PHY Layer, Division of time/frequency resource into Resource Block (RB) with each BB of one slot (0.5 msec) in time domain and 12 subcarriers (180 kHz) in frequency domain.
- At MAC Layer, Centralized scheduling based Semi-persistent scheduling (SPS): UE-report based scheduling & resource reservation scheduling allowed.

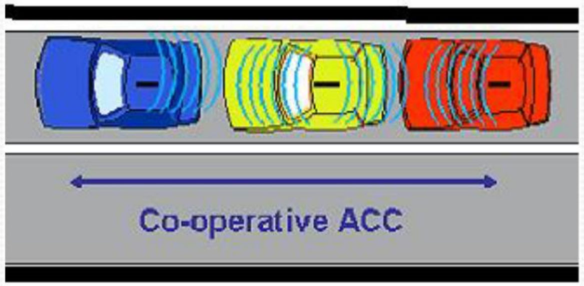
Better coverage and reliability

LTE-V2X

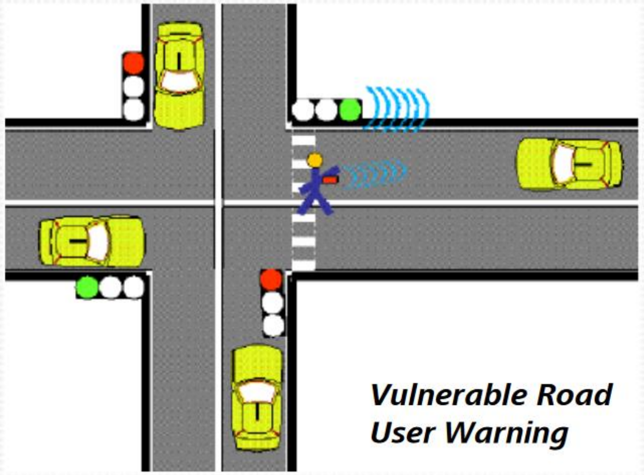
- Safety oriented services with latency-sensitive requirements



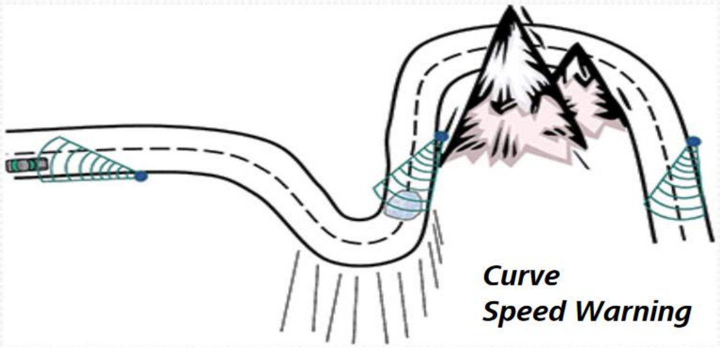
V2V Safety



V2V/V2I Traffic Efficiency



V2P Road Safety



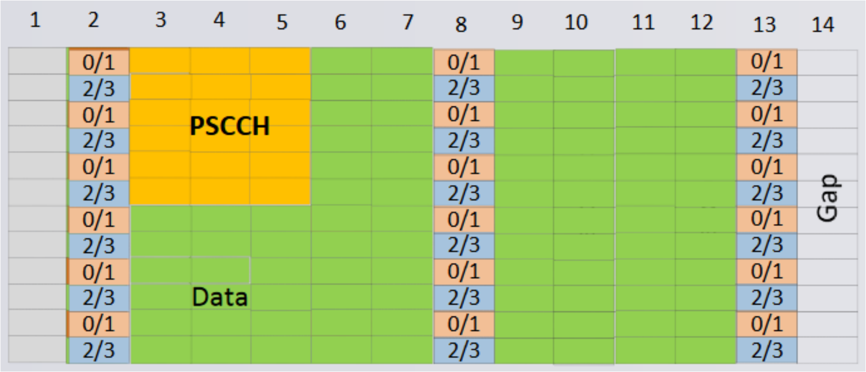
V2I Road Safety

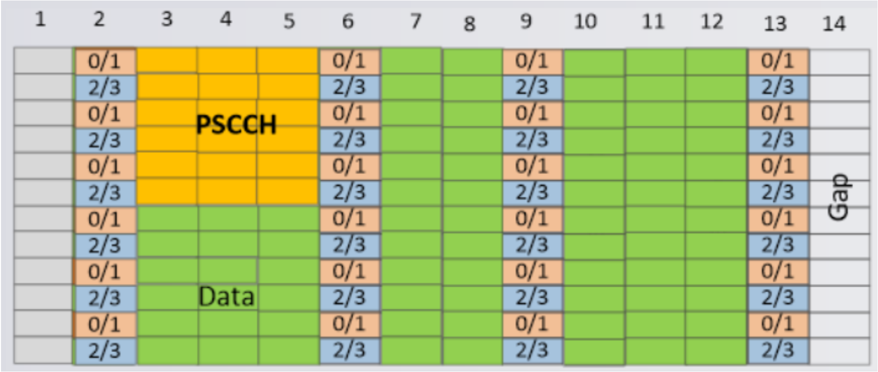
NR-V2X

- NR-V2X architecture: Evolving from LTE-V2X with the following features

  - Enabling flexible grouping of PHY resources
  - Variable sub-carrier spacing for better handling Doppler effect
  - Variable TTI for controlling latency
  - Variable reference signal design density to support multiple vehicle mobility

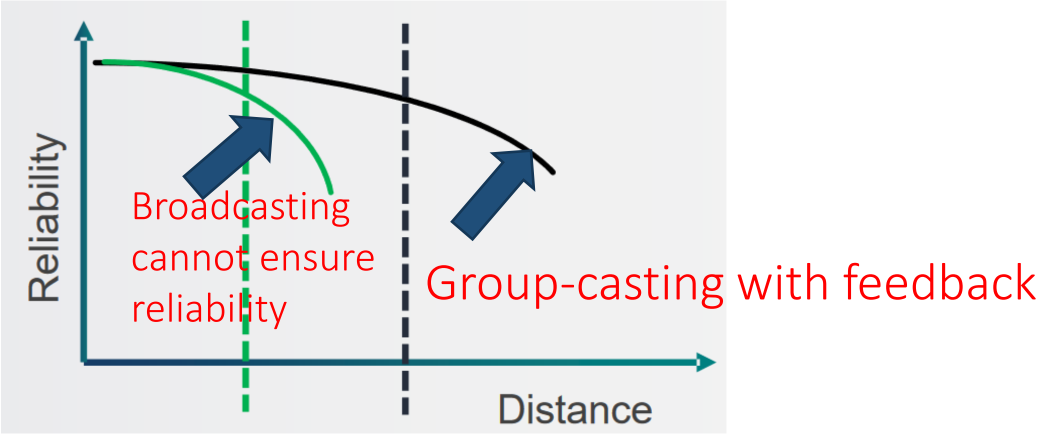
μ	Δf	Symbols per slot	TTI duration
0	15 kHz	14	1 ms
1	30 kHz	14	0.5 ms
2	60 kHz	14	0.25 ms
3	120 kHz	14	0.125 ms
4	240 kHz	14	62.5 μs
5	480 kHz	14	31.25 μs



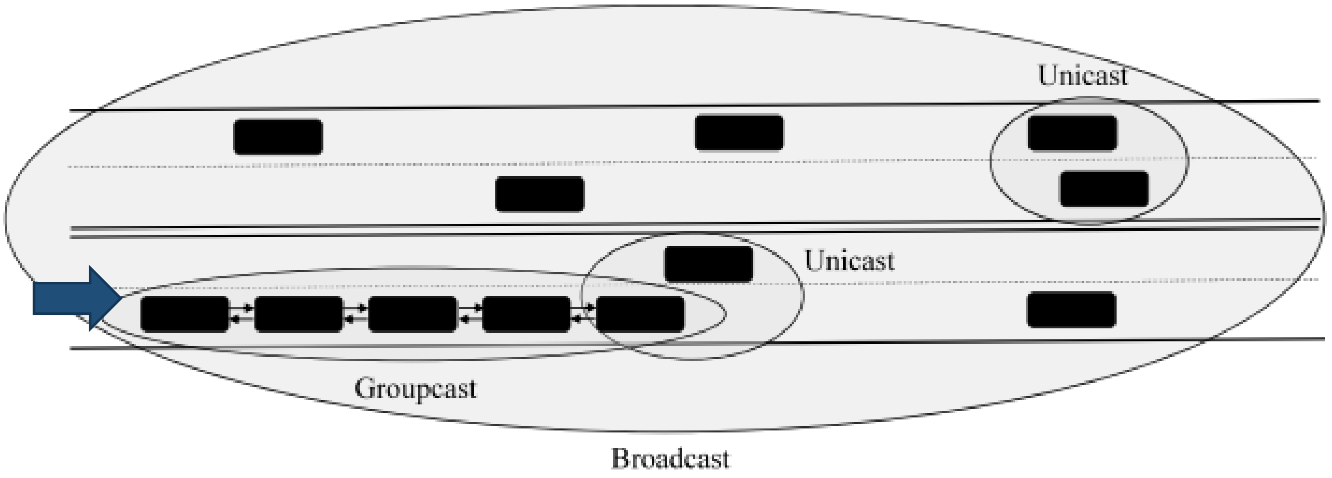


NR-V2X

- NR-V2X architecture: Evolving from LTE-V2X with the enhanced transmission modes
  - Three transmission modes: unicasting, broadcasting & group-casting
  - Group-casting with feedback introduced to get higher reliability, and Group-casting can support platoon scenarios

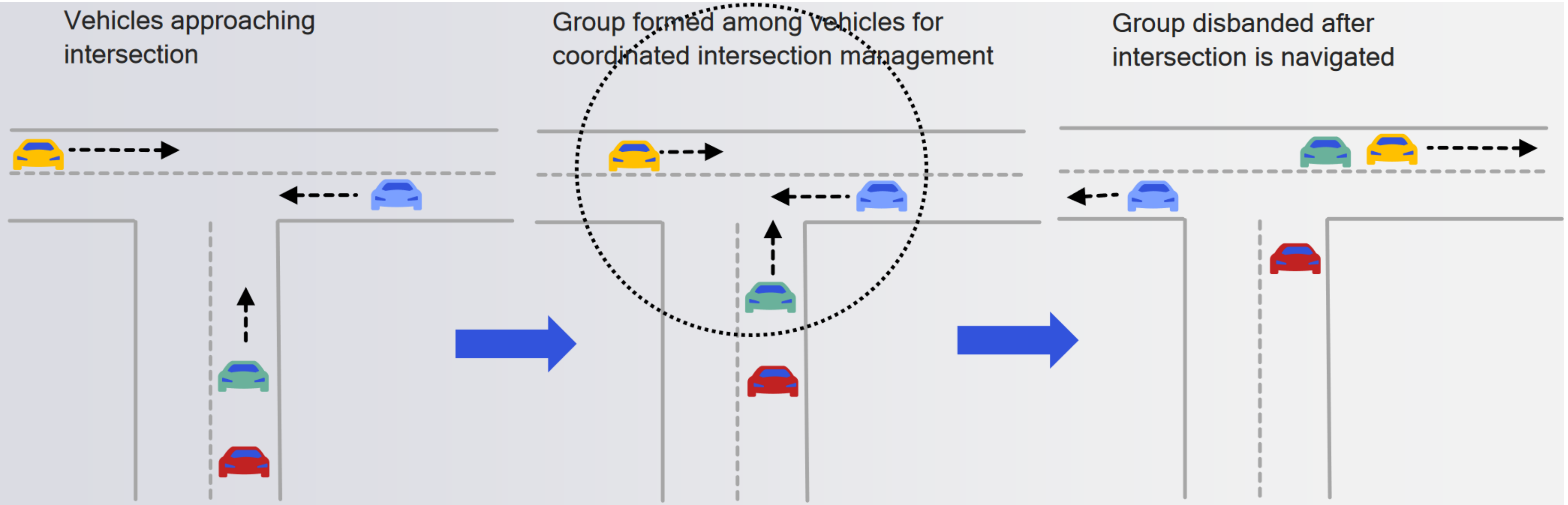


Platoon of vehicles enabled by group-casting



NR-V2X

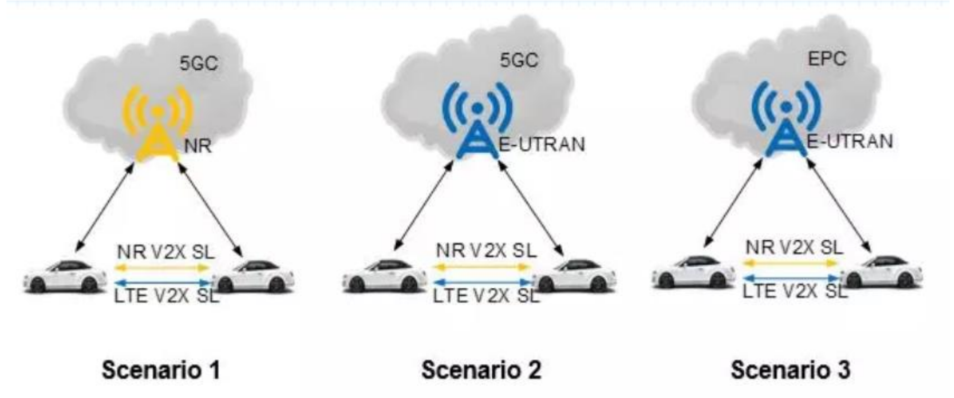
- The NR-V2X architecture: Evolves from LTE-V2X with the following features
  - ✓ Advanced scheduling/QoS management



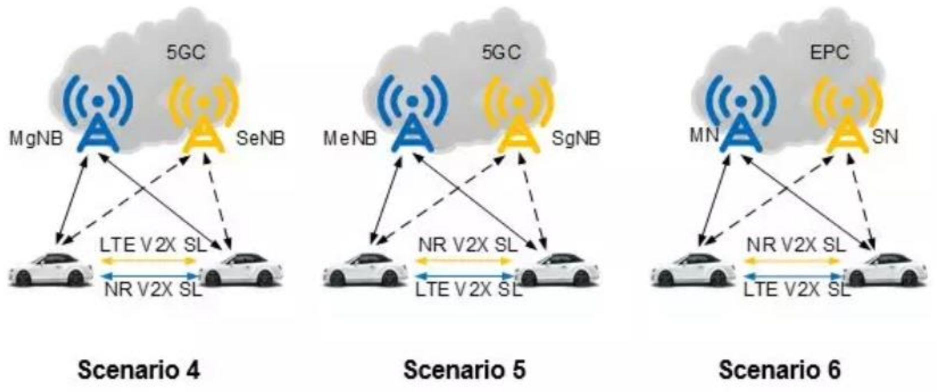
- Vehicles within a certain distance & interested in same services form a group/platoon
- The resources can be coordinated within the platoon with reduced complexity
- Safety is increased within the platoon

NR-V2X

- The NR-V2X architecture: Evolves from LTE-V2X with the following features
  - ✓ Co-existence with LTE-V
  - ✓ RAT/Interface selection: capability of identifying the best interface among LTE PC5, LTE Uu, NR PC5, NR Uu.



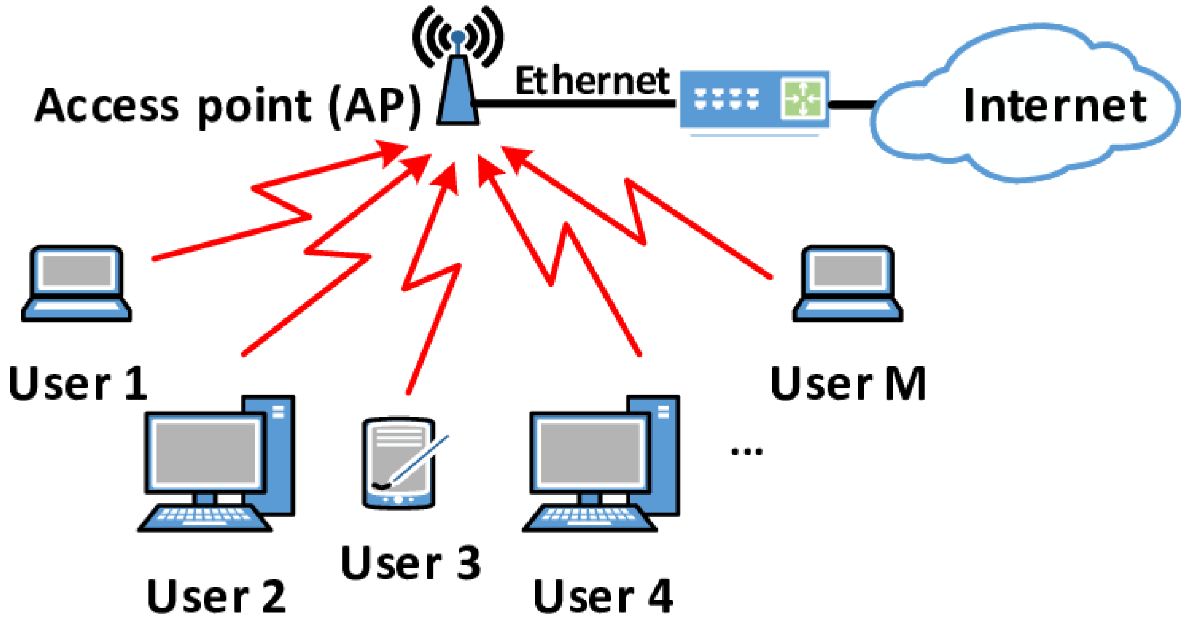
- Standalone mode: gNB (Scenario 1) , ng-eNB (Scenario 2) and eNB (Scenario 3) are responsible for the management and configuration of the LTE/NR V2X sidelink, respectively.



- MR-DC (Multi-RAT Dual Connectivity) mode: the Main Node (MN) is responsible for the management and configuration of the LTE/NR V2X sidelink. The Secondary Node (SN) can only provide communication functions.

DSRC

- Wireless Local Area Networks
  - Limited coverage but with high-throughput provisioning
  - IEEE 802.11 series



802.11 Protocol	Frequency (GHz)	Data Rate	Release
802.11a	3.7/5	Up to 54 Mbps.	1999
802.11b	2.4	Up to 11 Mbps.	1999
802.11g	2.4	Up to 54 Mbps.	2003
802.11n	2.4/5	Up to 150 Mbps.	2009
802.11ac	5	Up to 1.3 Gbps.	2012
802.11ad	60	Up to 6 Gbps.	2014

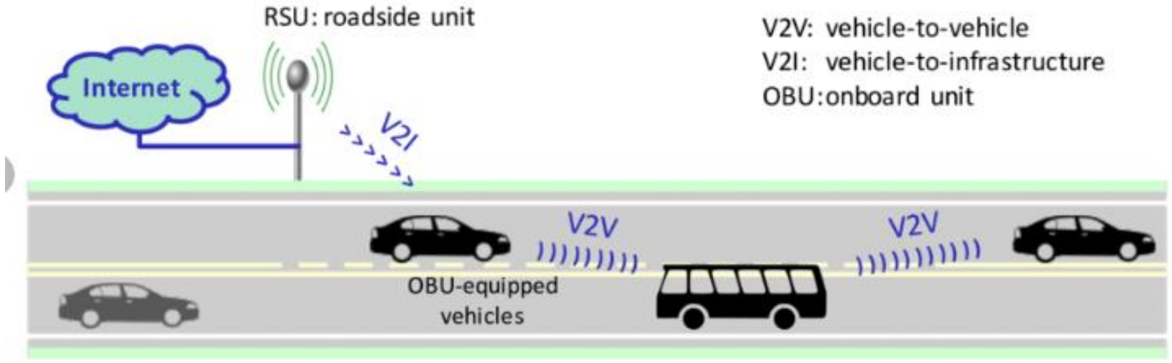
DSRC

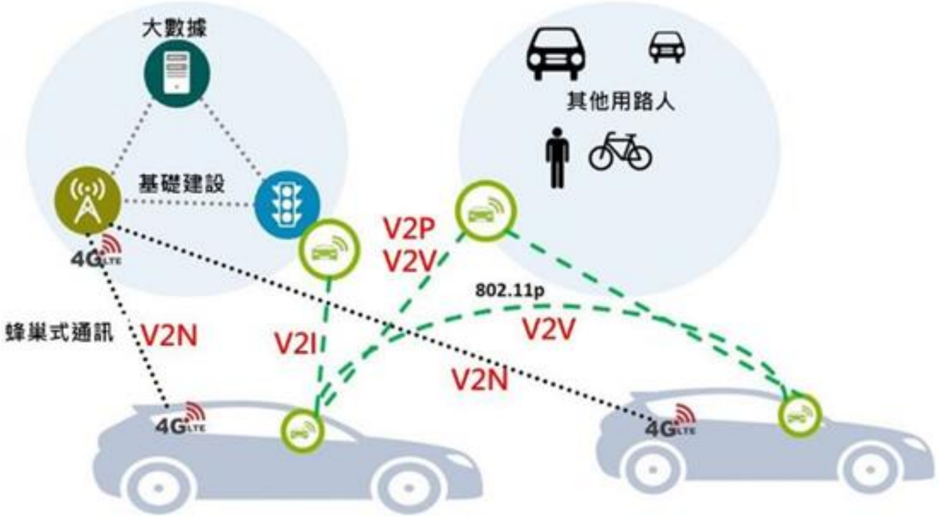
- Latest IEEE 802.11 standards for n
  - IEEE 802.11ac for 6+GHz band
  - IEEE 802.11ad for 60+GHz band
  - IEEE 802.11af for TW white space
- IEEE 802.11p: one of the IEEE 802.11 standards targeted for vehicular environments
- For supporting ITS applications: for data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure

	DSRC/WAVE	Wi-Fi
Data rate	3-27Mbps	6-54Mbps
Latency	< 50ms	Seconds
Range	< 1km	< 100m
Mobility	> 60 mph	< 5mph
Nominal Bandwidth	10MHz	20MHz
Operating Band	5.86-5.92GHz (ITS-RS)	2.4GHz, 5.2GHz (ISM)
IEEE std.	802.11p (WAVE)	802.11a

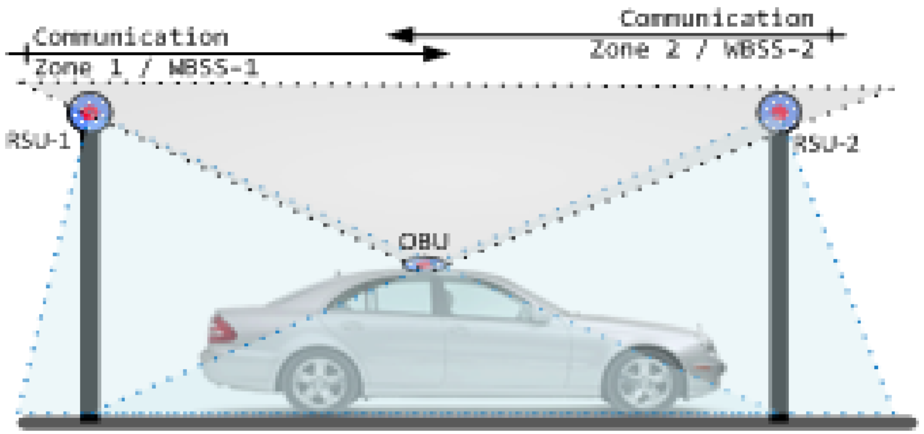
DSRC

- Dedicated Short Range Communication (DSRC): A wireless communication protocol for supporting vehicle-to-vehicle and vehicle-to-infrastructure communications.
- United States, Europe, and Japan are the main countries of research and application for DSRC.
- An 802.11p-based wireless communication technology, an amendment to the IEEE 802.11 standard that defines enhancements to support Intelligent Transportation Systems (ITS) applications.
- Features: flexible deployment, low complexity, low cost without cellular infrastructure.





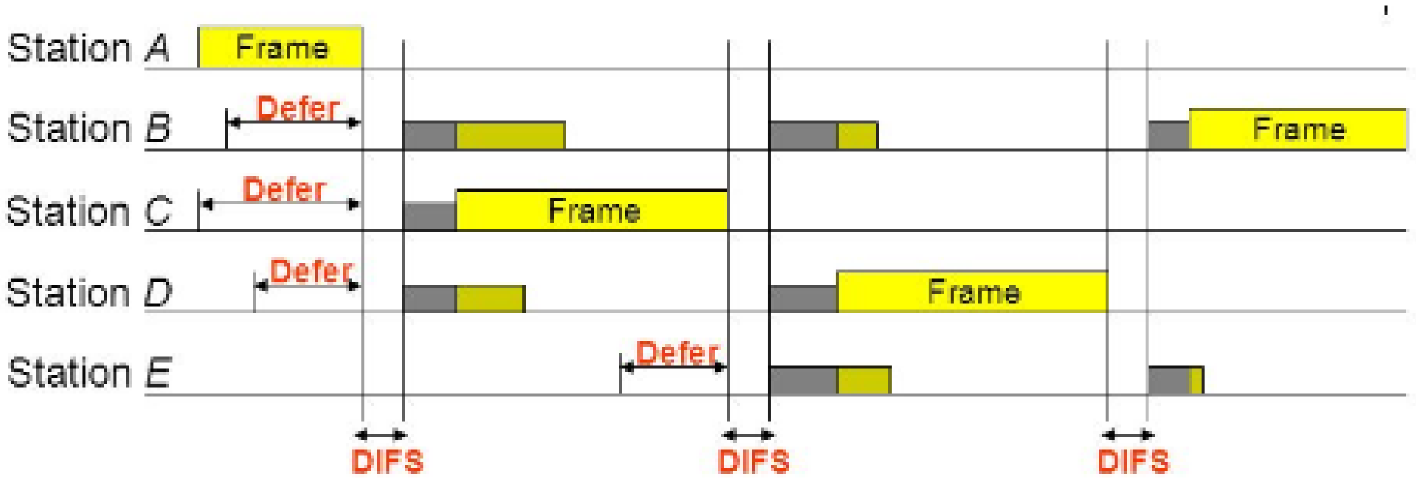
DSRC



- RSU: Road-Side Unit, a stationary unit that connects roaming vehicles to the access network.
- OBU: On-Board Unit, a network device fixed in a roaming vehicle.
- WBSS: Wireless Access in Vehicular Environment Basic Service Set is an alternative reference for the DSRC based OBU.

DSRC MAC

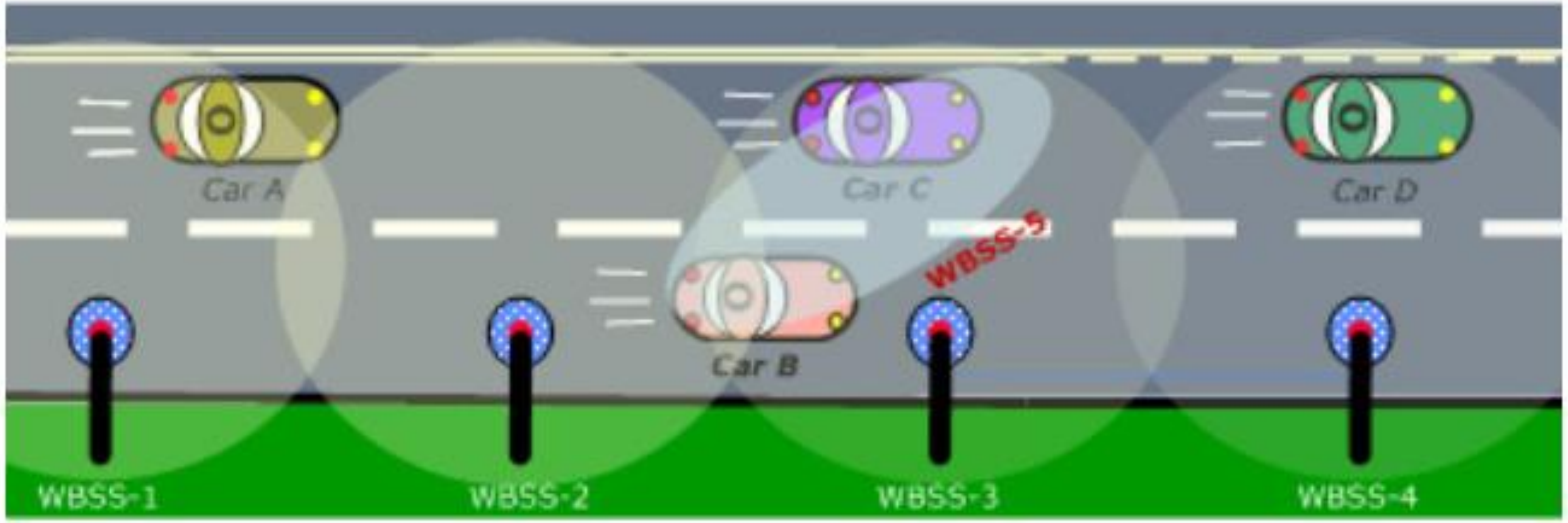
- CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance
  - A Random Access based MAC Protocol
  - DIFS: Distributed Inter-frame Spacing
  - SIFS: Short Interframe Space
  - CTS: Clear to send message
  - ACK: Acknowledge message



Sensing based random access with backfoff (collision avoidance)

DSRC

- Networking modes and PHY basics



- V2I mode: Each Car can be associated with one WBSS.
- V2V mode: Car-B and Car-C may have a V2V communications link.
- PHY-channel mode: Orthogonal Frequency Division Multiplexing (OFDM) based channel with 10 MHz bandwidth
- PHY-channel band: 75 MHz of bandwidth at 5.9 GHz (U.S.); 30 MHz of bandwidth at 5.875–5.905 GHz for safety applications and 20-MHz bandwidth at 5.855– 5.875 GHz for non-safety-related applications (Europe).

DSRC vs LTE-V

- Comparison between LTE-V and DSRC

	IEEE 802.11p	LTE-V2X (3GPP Rel-14/Rel-15)
Standardization Completion	Completed in Mar. 2012	Rel-14: Mar. 2017 Rel-15: Jun. 2018
Evolution path	Forward compatible to IEEE 802.11bd	Forward compatible to NR-V2X
Network coverage support	Limited, through AP to connect with network	Yes
Out of network operation	Yes	Yes
Latency	No deterministic delay	Rel-14: 20ms Rel-15: 10ms
Reliability	No guaranteed reliability	Rel-14: > 90% Rel-15: > 95%

	IEEE 802.11p	LTE-V2X (3GPP Rel-14/Rel-15)
Data rate	6 Mbps	30 Mbps
Synchronization	No	Yes
Waveform	OFDM	SC-FDM
Channel coding	Convolutional	Turbo
Resource mutiplexing	TDM only	TDM and FDM
HARQ	No	Yes, fixed two transmissions
Resource allocation	CSMA/CA	Sensing and SPS
Multi-antenna	UE implementation	Transmission diversity, 2Tx/2Rx
Modulation	64QAM	64QAM

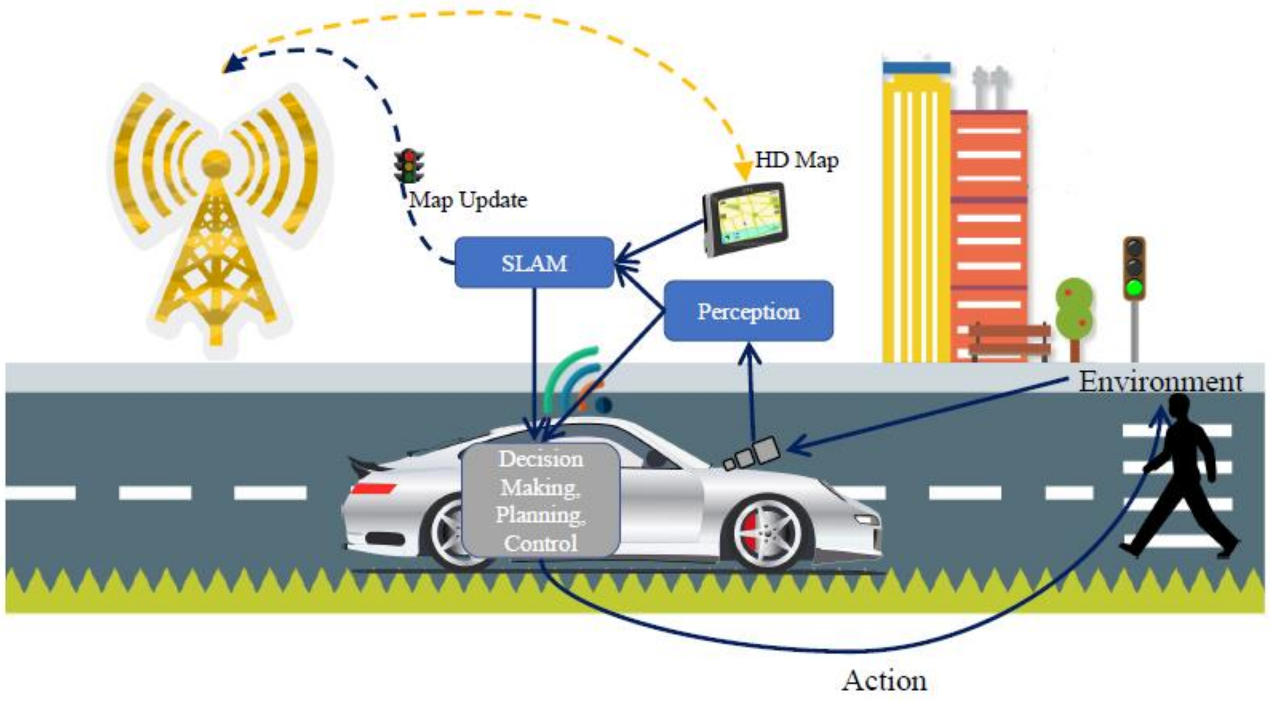
Outline

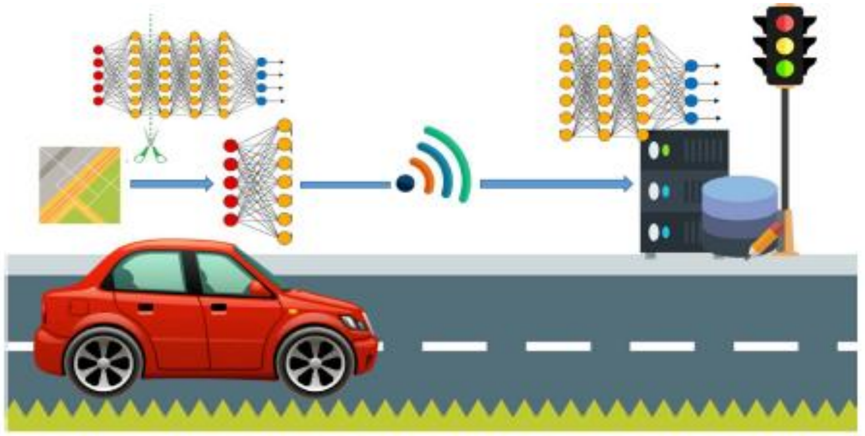
Edge Computing

- Data Processing and driver-assistance
  - Data-driven intelligent transportation systems: The advancements in information technologies, including communication, sensing, data processing, and control, are transforming the transportation system from conventional technology-driven systems into more powerful data-driven intelligent transportation systems
    - Cameras
    - Sensors
    - Radars
    - Light Detection And Ranging (LiDAR) sensors,
    - Global Navigation Satellite Systems (GNSS), and etc
  - Big data generated by intelligent vehicles places unprecedented pressure on communication, storage and computing infrastructures.

Edge Computing

- Real-time data analytics & recognition
  - Deep learning and federated (distributed) learning
  - Mobility of vehicles and pedestrian
  - Latency sensitive (safety-oriented applications)





Edge Computing

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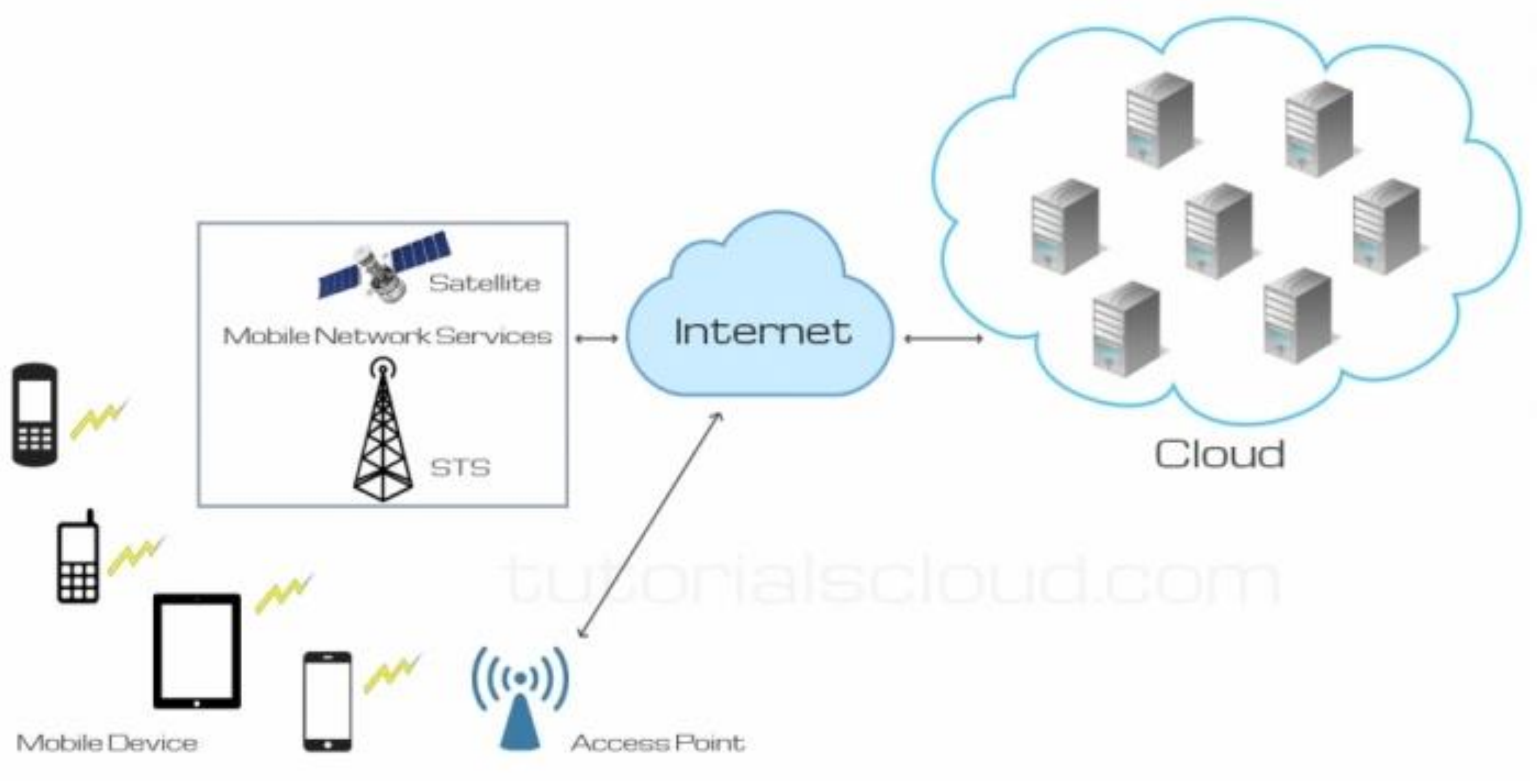
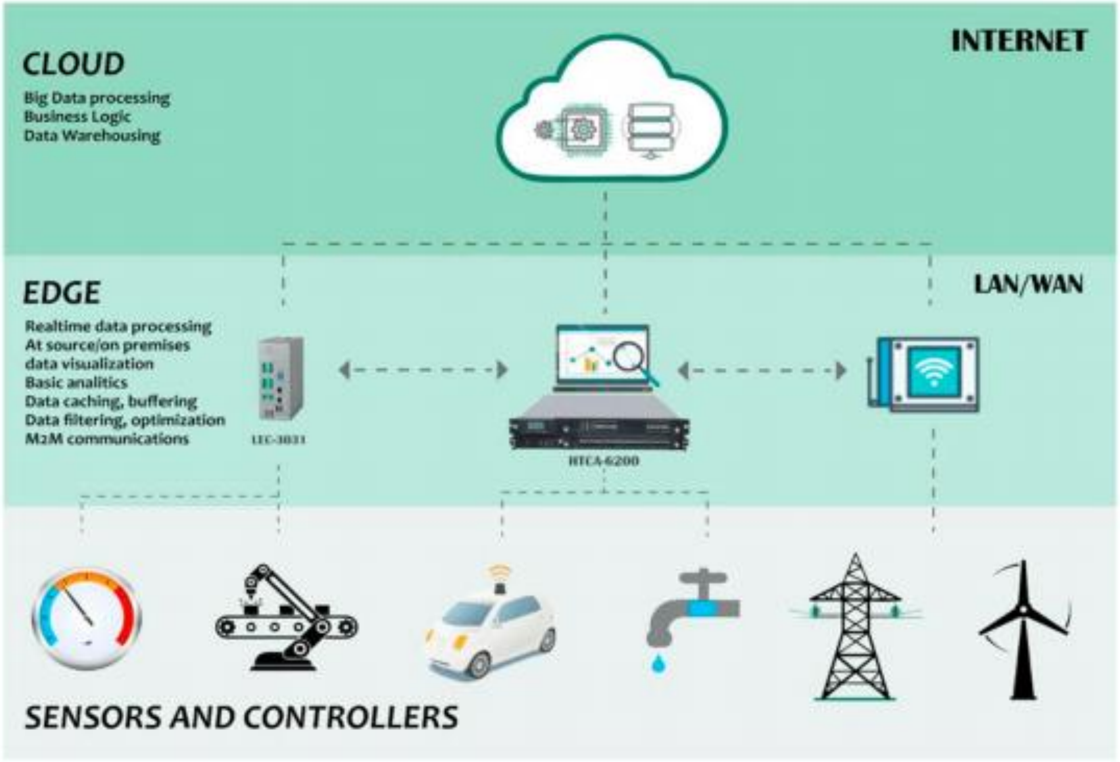
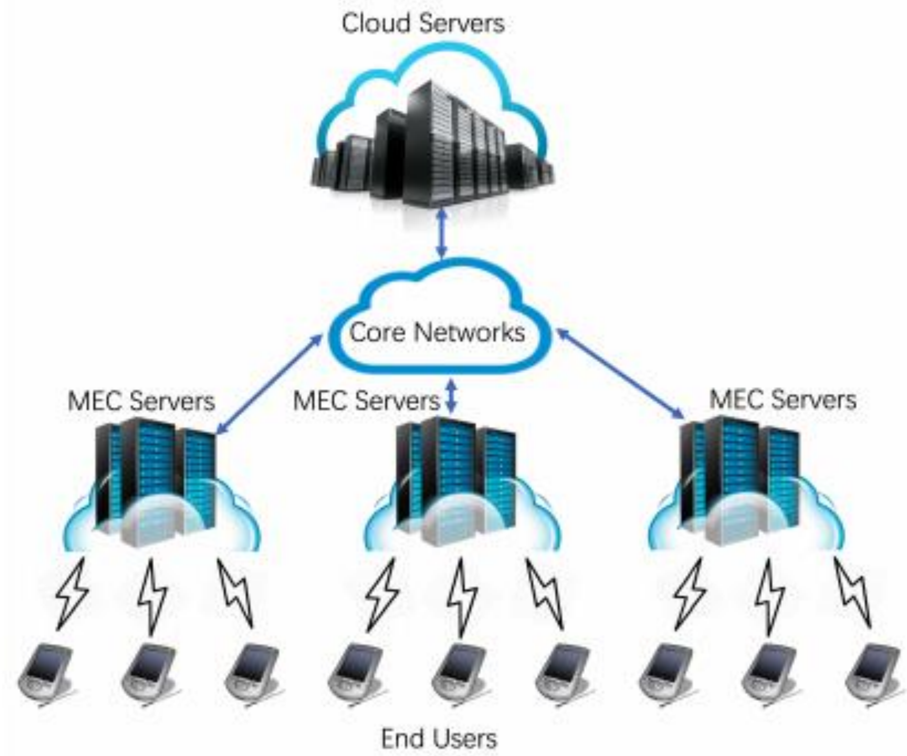
- Offloading computation tasks via Cloud Computing
  - Disadvantage: latency in delivering data in the Internet, unpredictable and controllable congestion and latency



Edge Computing

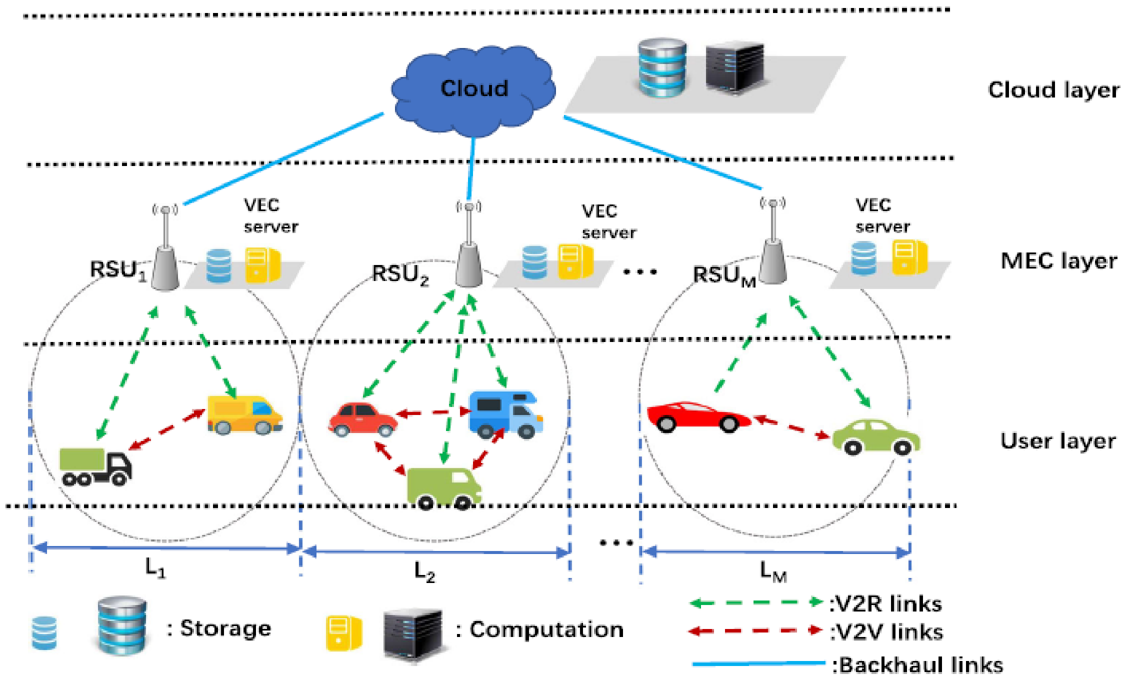
- Vehicular Edge/Cloud Computing
  - Deploying computation-resources at the edge of networks
  - Close-proximity: latency in offloading transmission of the tasks





Edge Computing

- Architecture
  - Vehicular terminals
    - Smart Vehicles
  - Edge Computing Server
    - RSUs often act as edge servers in
  - Could Server
    - Cloud services are deployed in a remote cloud



Edge Computing

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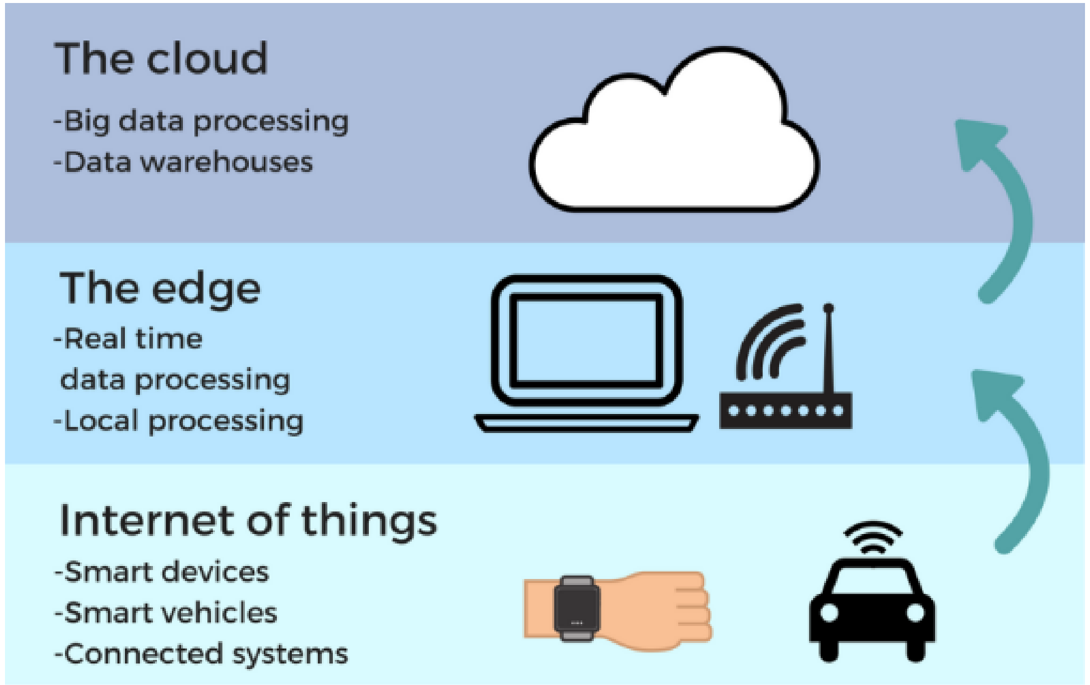
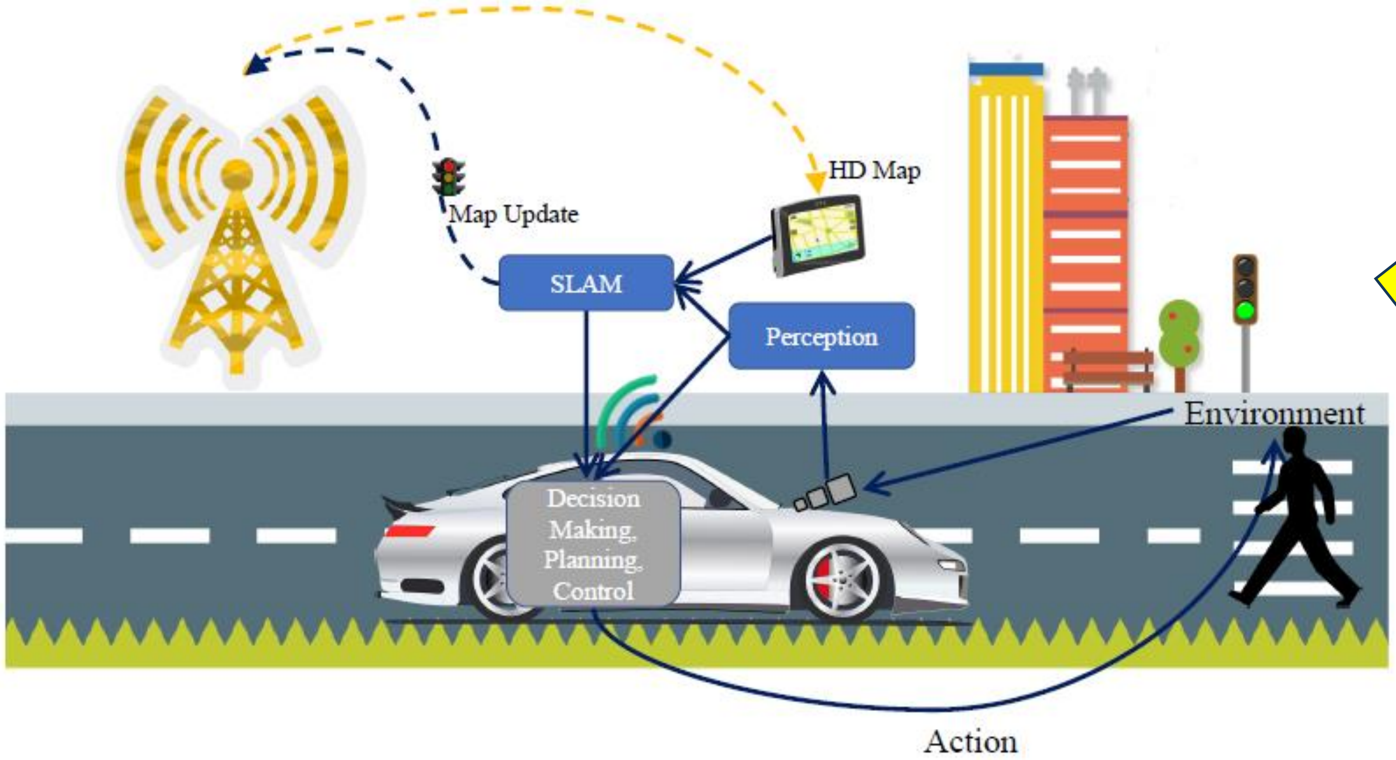
- Onboard processing for highly latency-sensitive tasks: such as real-time decision making for vehicle control, and for preprocessing sensing data to reduce communication bandwidth
- Edge severs for latency-sensitive and computation-intensive tasks: e.g., localization and mapping, and for aggregating and storing local information, such as the area's high-definition map
- Cloud computing for training powerful deep learning models with massive datasets, acts as a non-real-time aggregator for wide-area information, and stores valuable historic data for continuous learning.

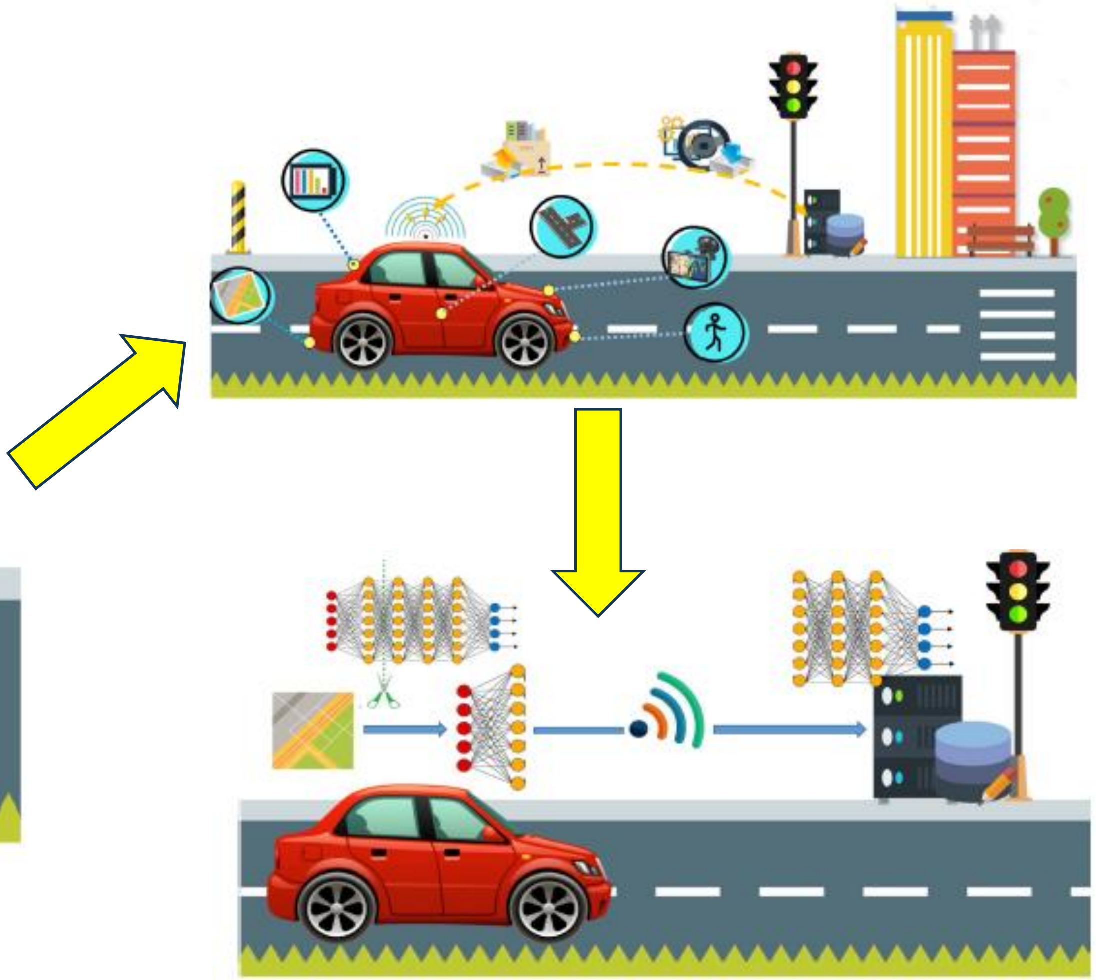
Edge Computing

- Cloud processing
- Edge severs processing
- Onboard processing



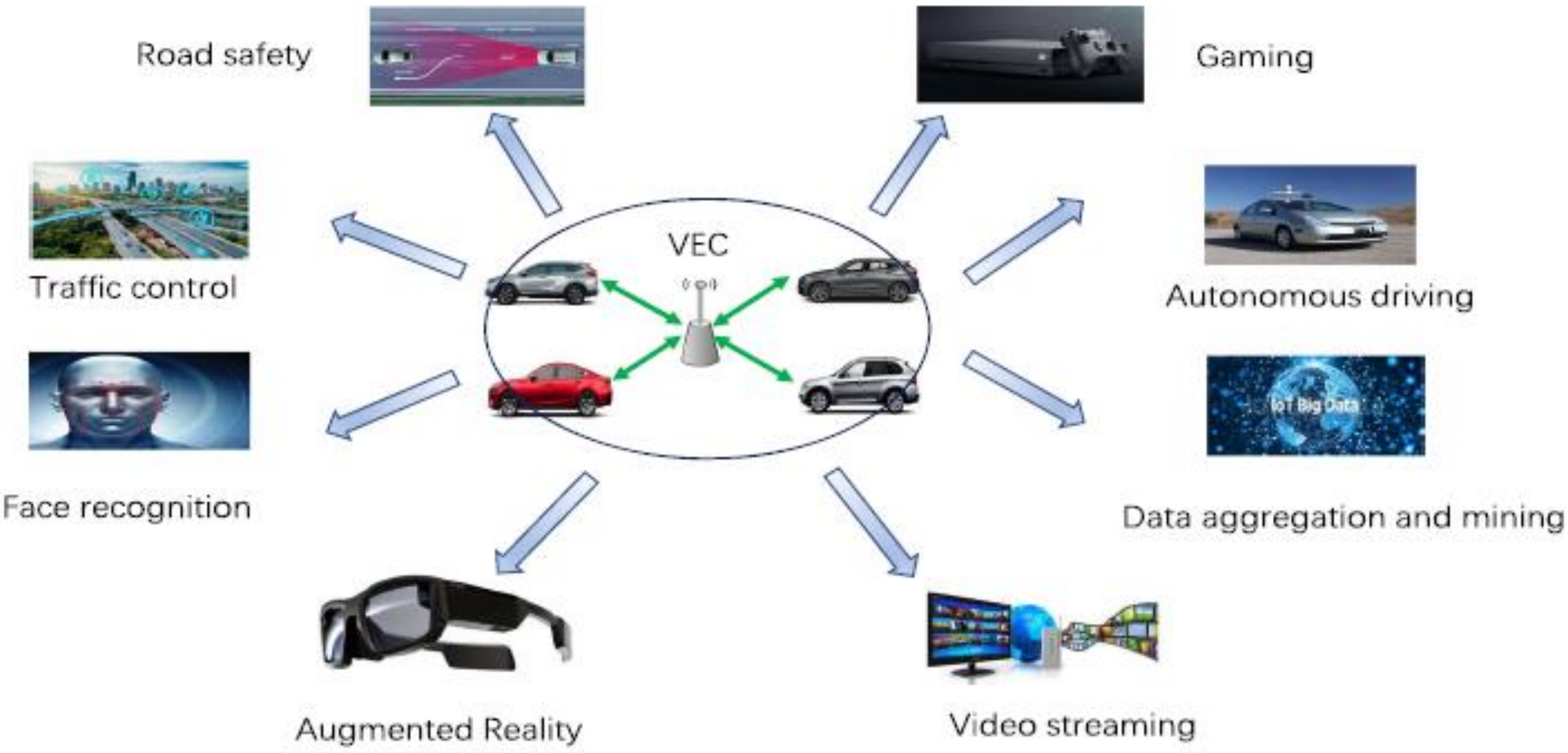
Edge Computing





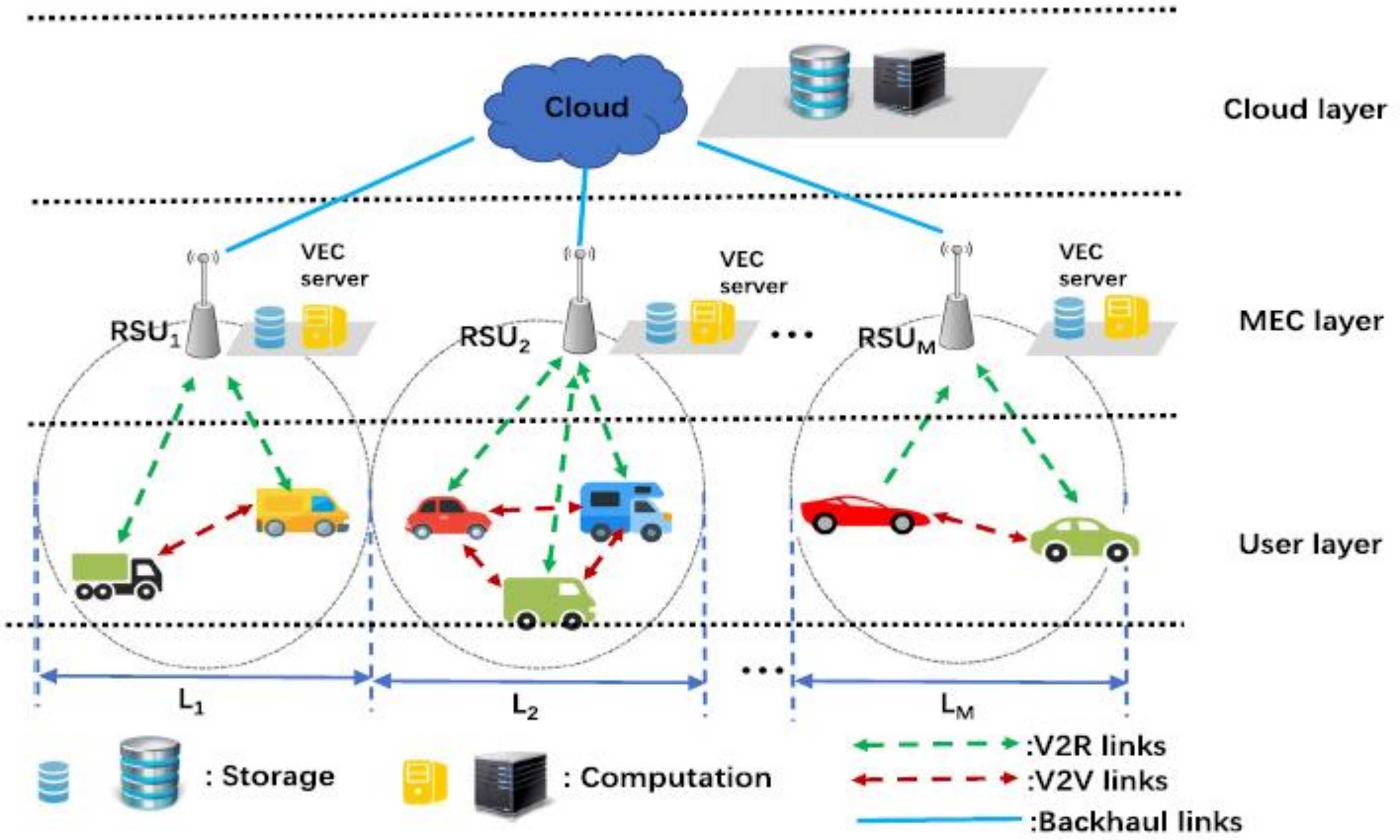
Edge Computing

- Applications of vehicular edge computing



Edge Computing

- Challenges of vehicular edge computing
  - High mobility of vehicles
  - Harsh channel environment
  - Resource management
  - Task migration
  - Security and privacy



Outline

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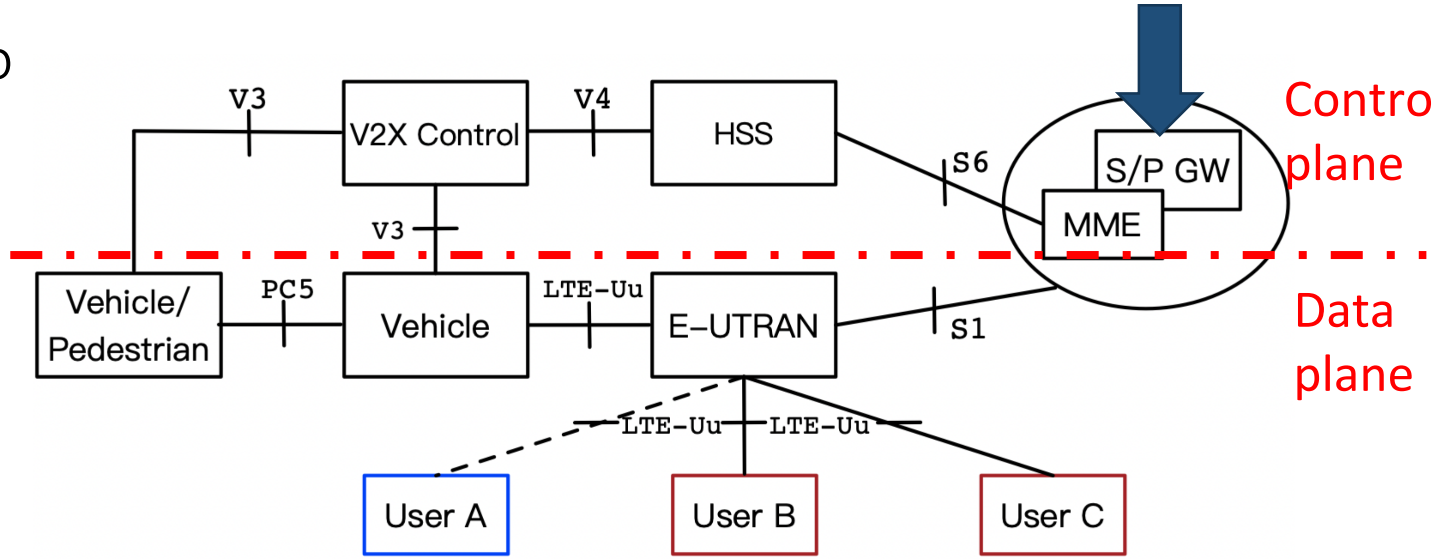
SDN for Efficient VEC

- Software defined networking (SDN): an architecture designed to make a network more flexible and easier to manage.
- SDN centralizes management by abstracting the control plane from the data forwarding function in the discrete networking devices.
- Efficient resource allocation for enabling computation offloading by vehicular users and resource allocation at the edge-computing servers

Virtualizing network resource here



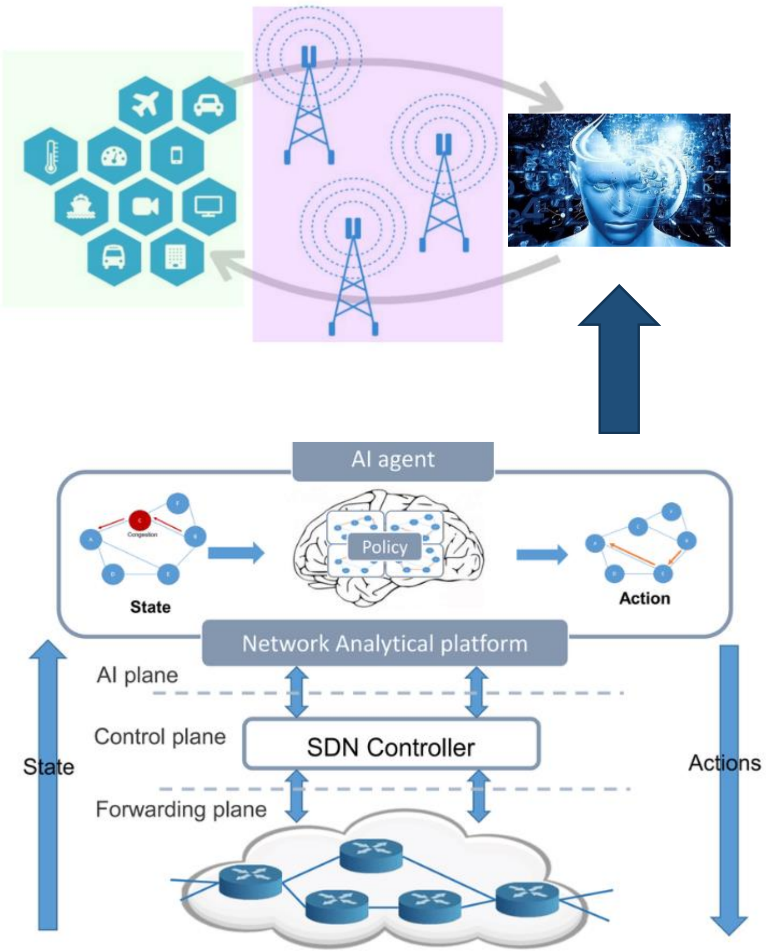
Control plane

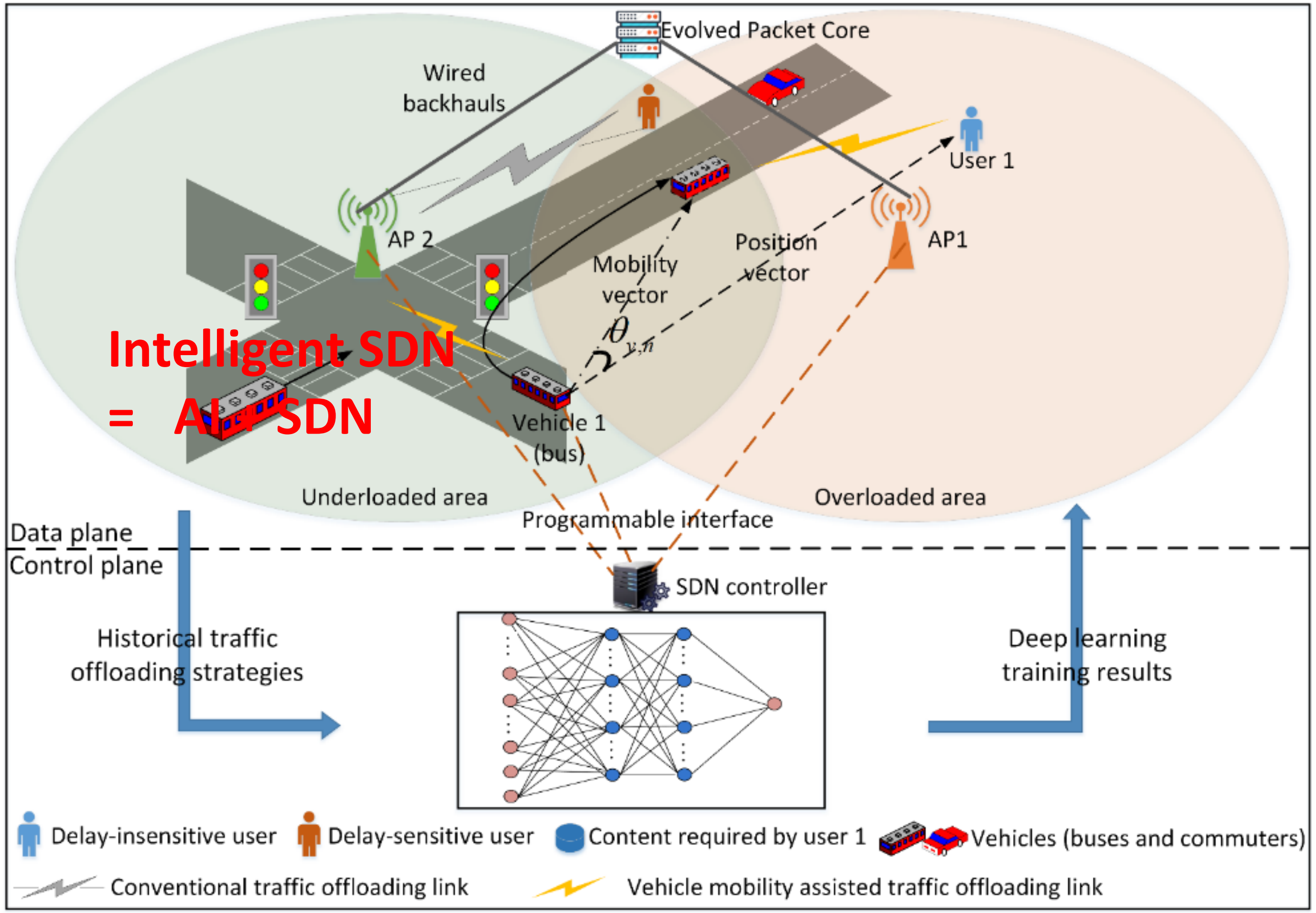
Data plane

Efficient resource allocation among vehicular users

Integrated AI and SDN

- Integrated AI and SDN for V2X Communications and Vehicular Edge Computing





Intelligent SDN

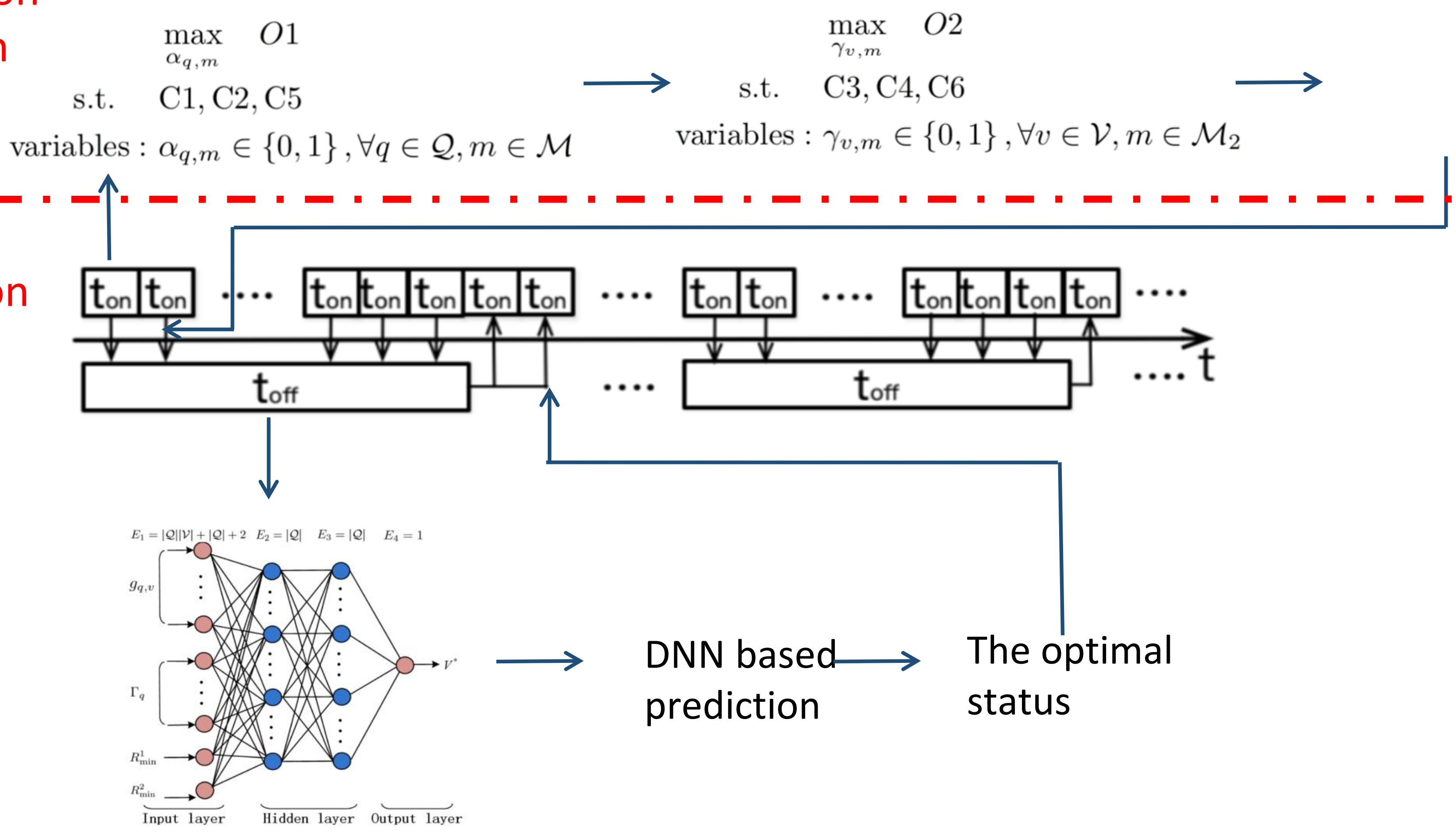
= AI + SDN

Integrated AI and SDN

- Online and offline optimizations

Online optimization for VU association and traffic scheduling

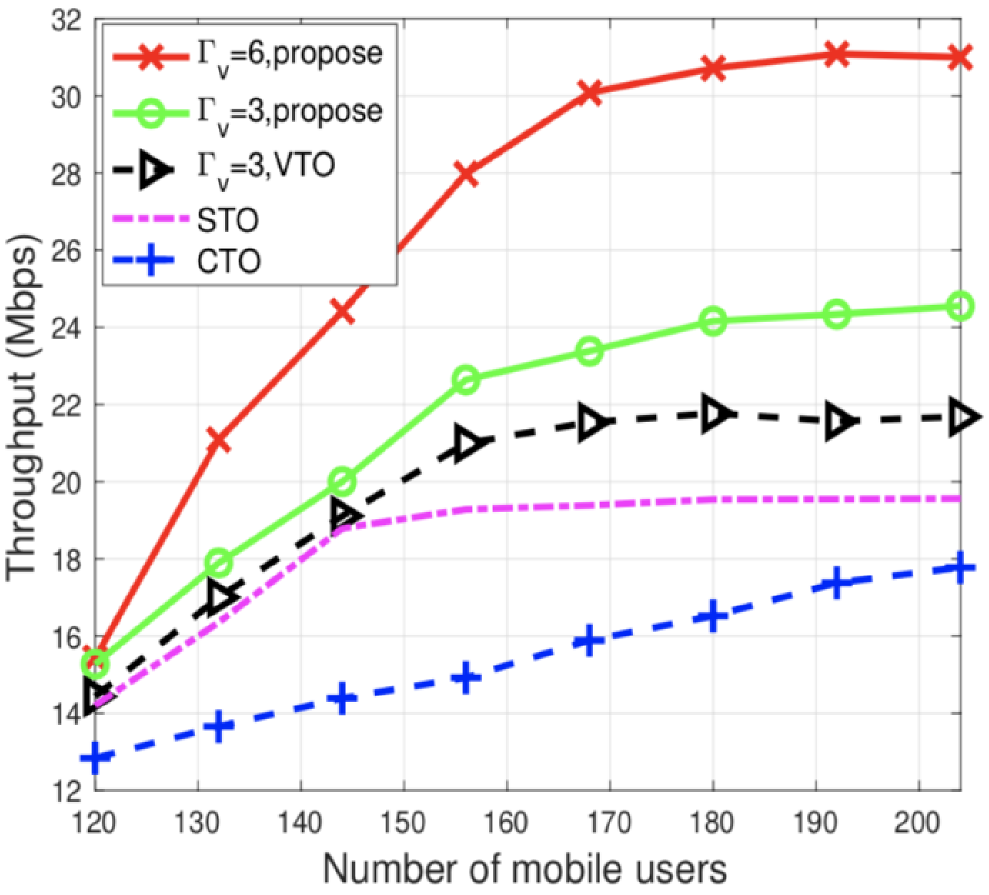
Offline optimization for RSU resource allocation based DNN predication



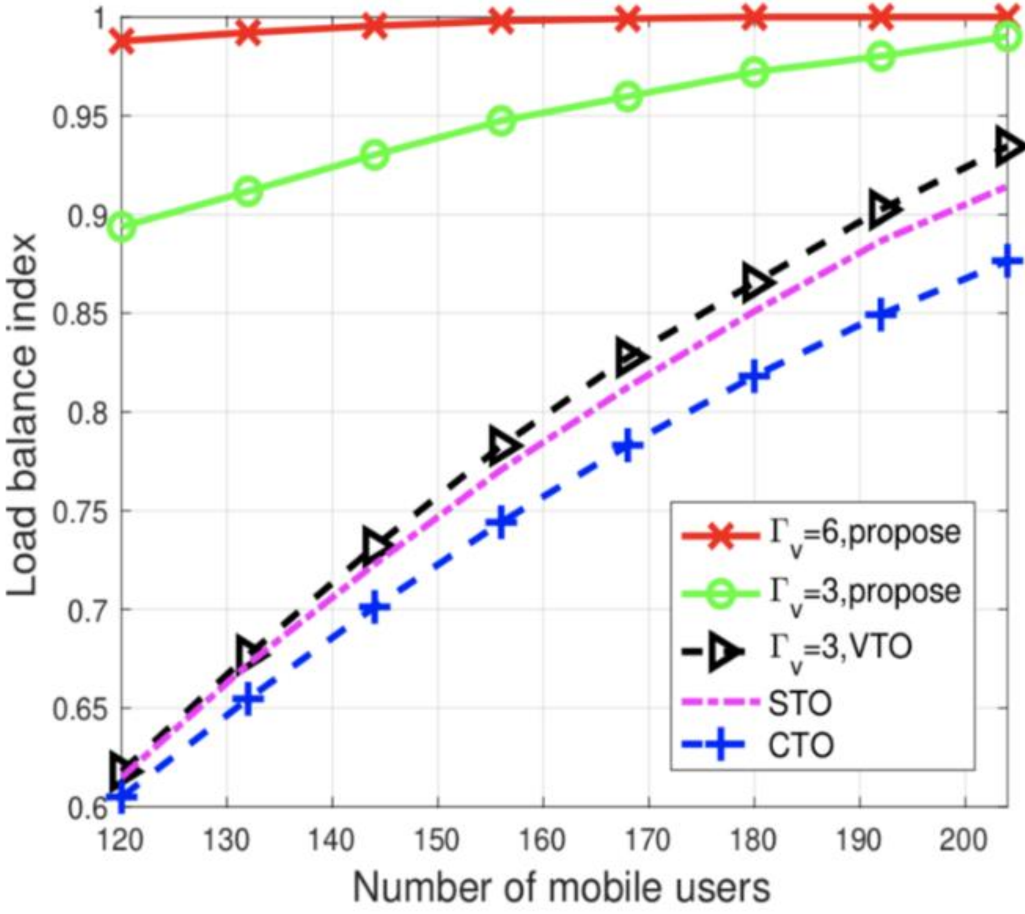
Integrated AI and SDN

Performance:

- Higher traffic offloading flexibility
- Increased resource efficiency
- Robustness under different configurations



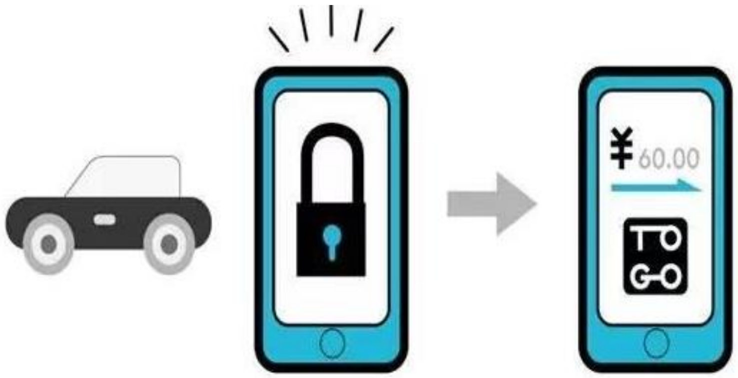
Network throughput versus the user number



Load balance versus the user number

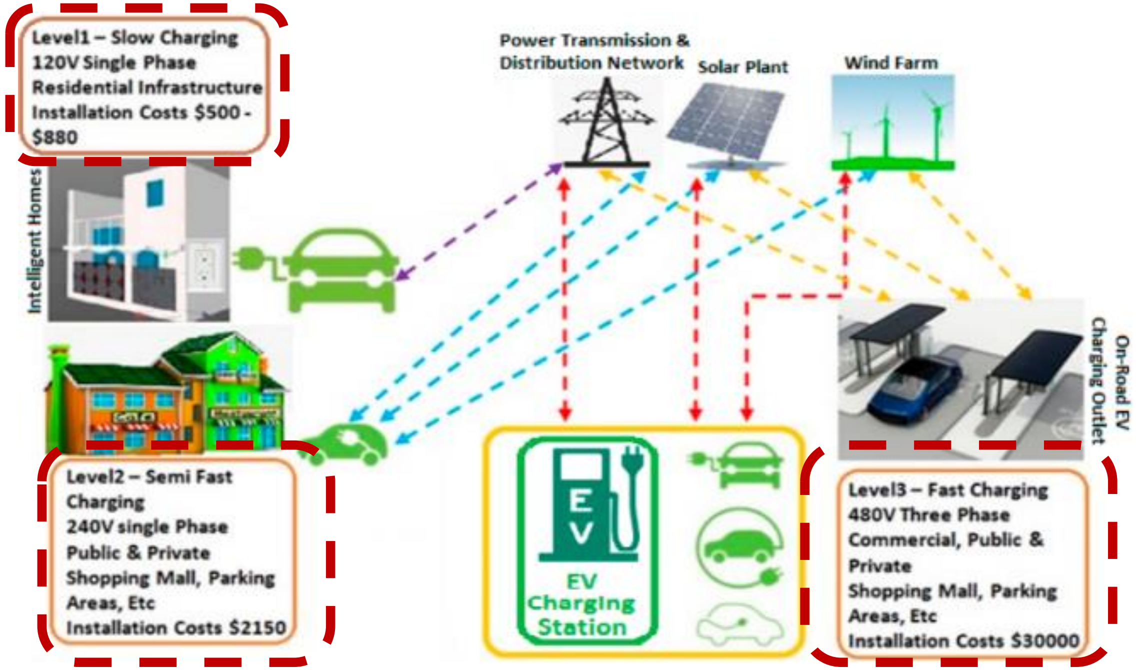
Sharing Vehicles

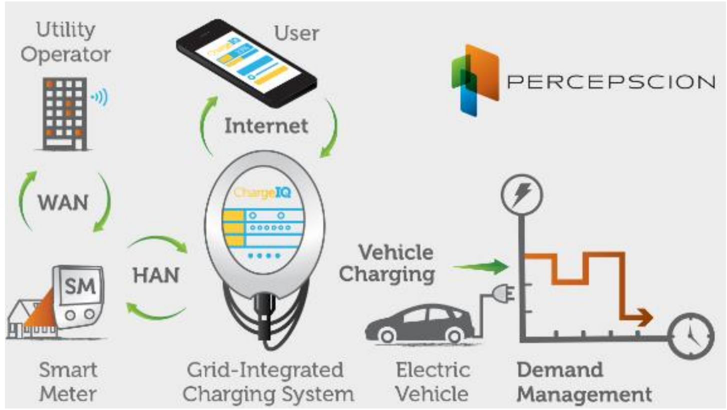
- “Internet Plus” enabling service: transportation and economics
- Internet of Vehicles: position, navigation, energy, payment
- Other social issues: security and safety

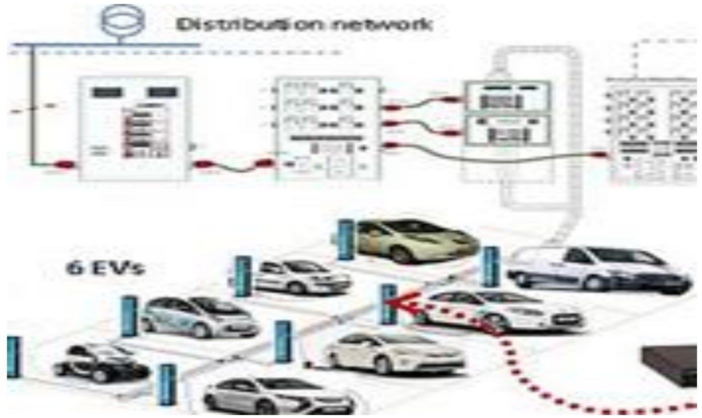


Emerging EV systems

- Joint Optimization of Navigation and Charging Service for Electric Vehicles
  - Routing optimization and comfortness for EVs
  - Energy service for Evs
  - Stability and efficiency of power supply

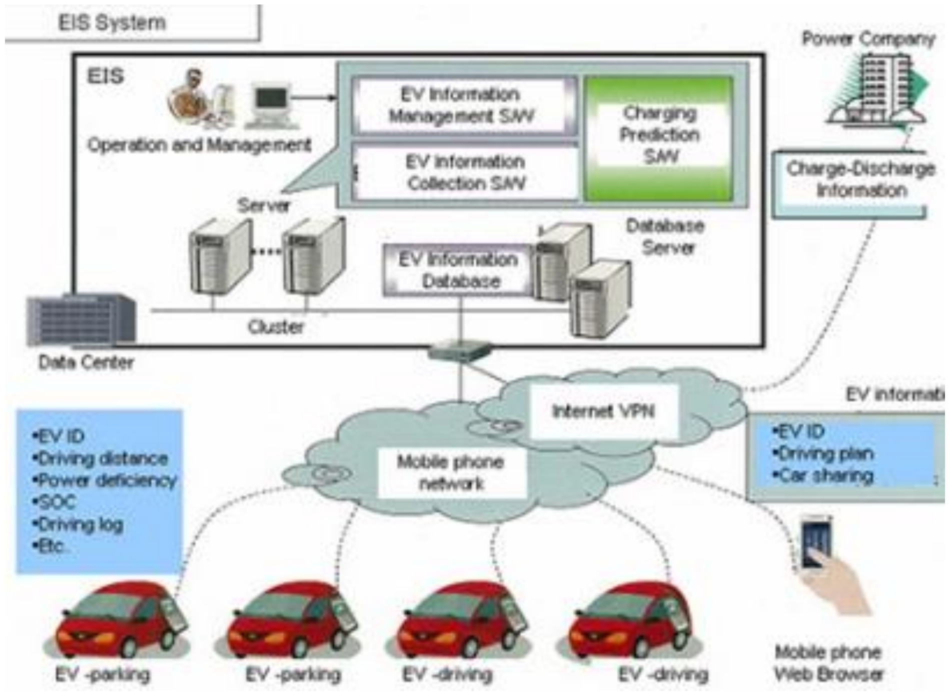


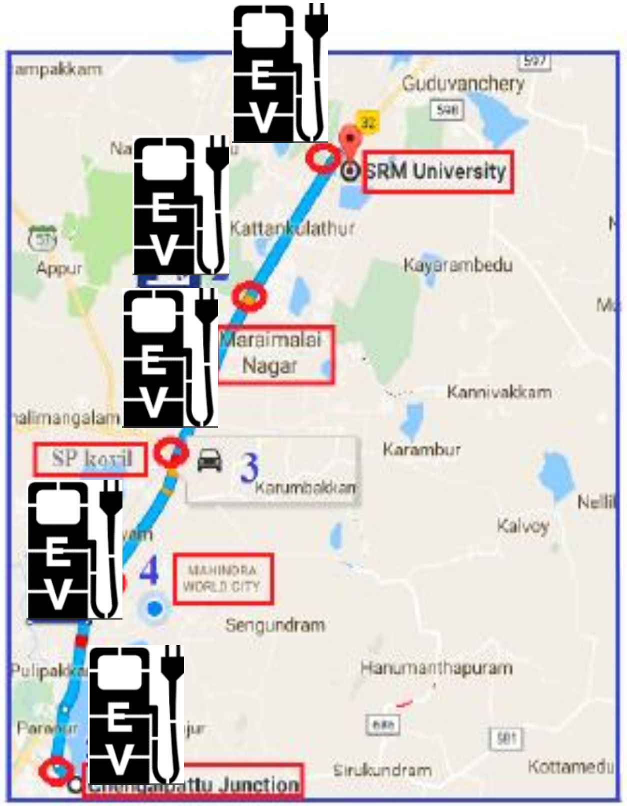




Emerging EV systems

- Management of charging station and energy provisioning
- Real-time navigation and routing optimization
- Driving behavior and learning for optimization





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Thanks!

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