TeamSoc21
The ICT Engineer of the 21st Century

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New capabilities of 5G network for connected vehicles - the way to totally connected world

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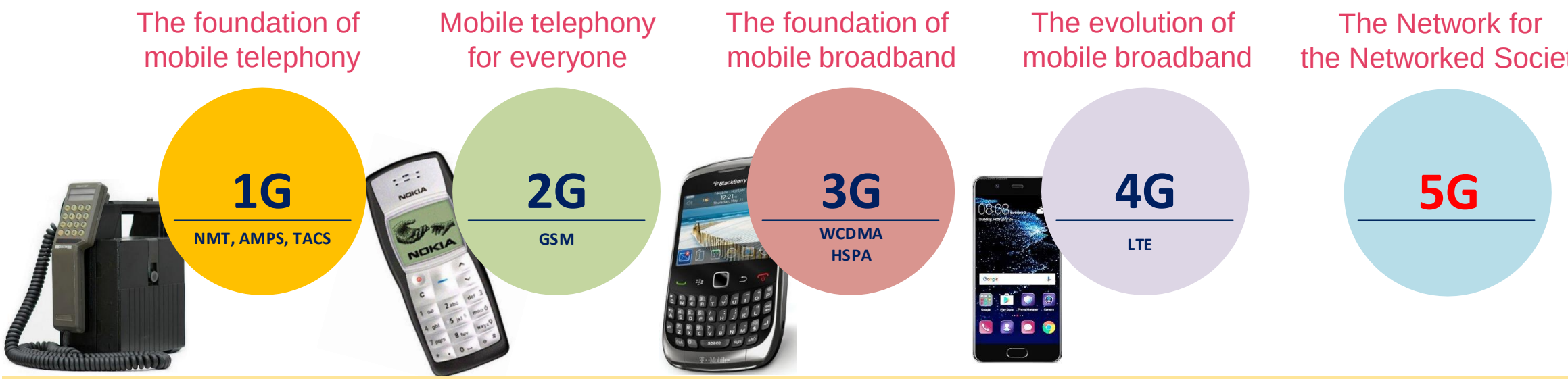
Lecture outline

- Introduction
- Characteristics of 5G
- 5G Challenges & Scenarios
- Intelligent Transport System (ITS)
- Vehicle to X (V2X) connectivity
- References
- Key takeaways

Introduction

Mobile generations across the time

- Higher peak data rates, denser infrastructure and more bandwidth have been the hallmark of each mobile technology generation!



Fifth generation network (5G)

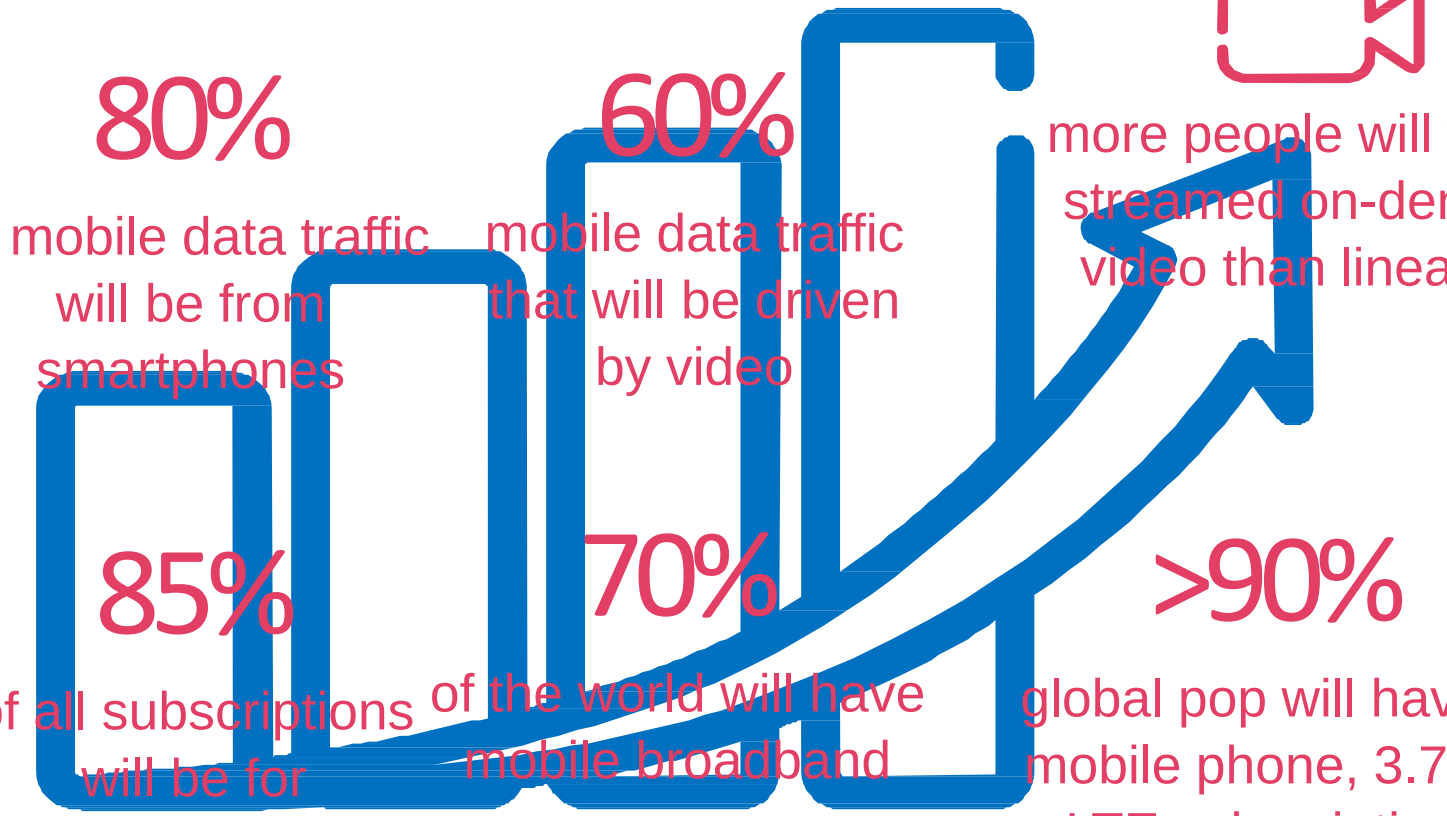
- LTE/LTE-Advanced standards lack the performance needed to keep up with market demand for higher data throughput, greater cell capacity and more reliability.
- New 5G cellular standards are being developed to achieve the desired performance goals and to co-exist with 4G technologies
- mmWave frequencies can incorporate wide-bandwidth transmissions and are being investigated for next generation cellular systems

Fifth generation network (5G)

- NGMN alliance defined 5G network requirements as:
  - Data rates of several tens of Mb/s should be supported for tens of thousands of users.
  - 1 Gb/s to be offered, simultaneously to tens of workers on the same office floor.
  - Up to several 100,000's simultaneous connections to be supported for massive sensor deployments.
  - Spectral efficiency should be significantly enhanced compared to 4G.
  - Device-to-Device and Car-to-Car Communications.

What is changing? In Numbers

- What to expect by 2020



11x growth in smartphone traffic

80% of mobile data traffic will be from smartphones

60% mobile data traffic that will be driven by video

more people will watch streamed on-demand video than linear TV

9.2B mobile subscriptions worldwide

85% of all subscriptions will be for mobile broadband

70% of the world will have mobile broadband coverage

>90% global pop will have a mobile phone, 3.7 Bn LTE subscriptions

Fifth generation network (5G)

- The advantages which will lead the network of Fifth generation are as follows:
  - Interoperability will become possible
  - Low battery consumption of smartphones
  - Better coverage and high-speed data transfer
  - Multiple ways for data transfer simultaneously
  - Secure & reliable network
  - Flexible architecture
  - Greater spectral efficiency
  - Better QoS

5G use cases

- With ultra-reliable, ultra-low latency communication links

5G performance requirements

- Power efficient
  - Multi-year battery life
- Low complexity
  - Low device and network cost
- Long range
  - Deep coverage
- High reliability
  - Extremely low loss rate
- Ultra-low latency
  - Down to 1ms e2e latency
- High availability
  - Multiple links for failure tolerance & mobility

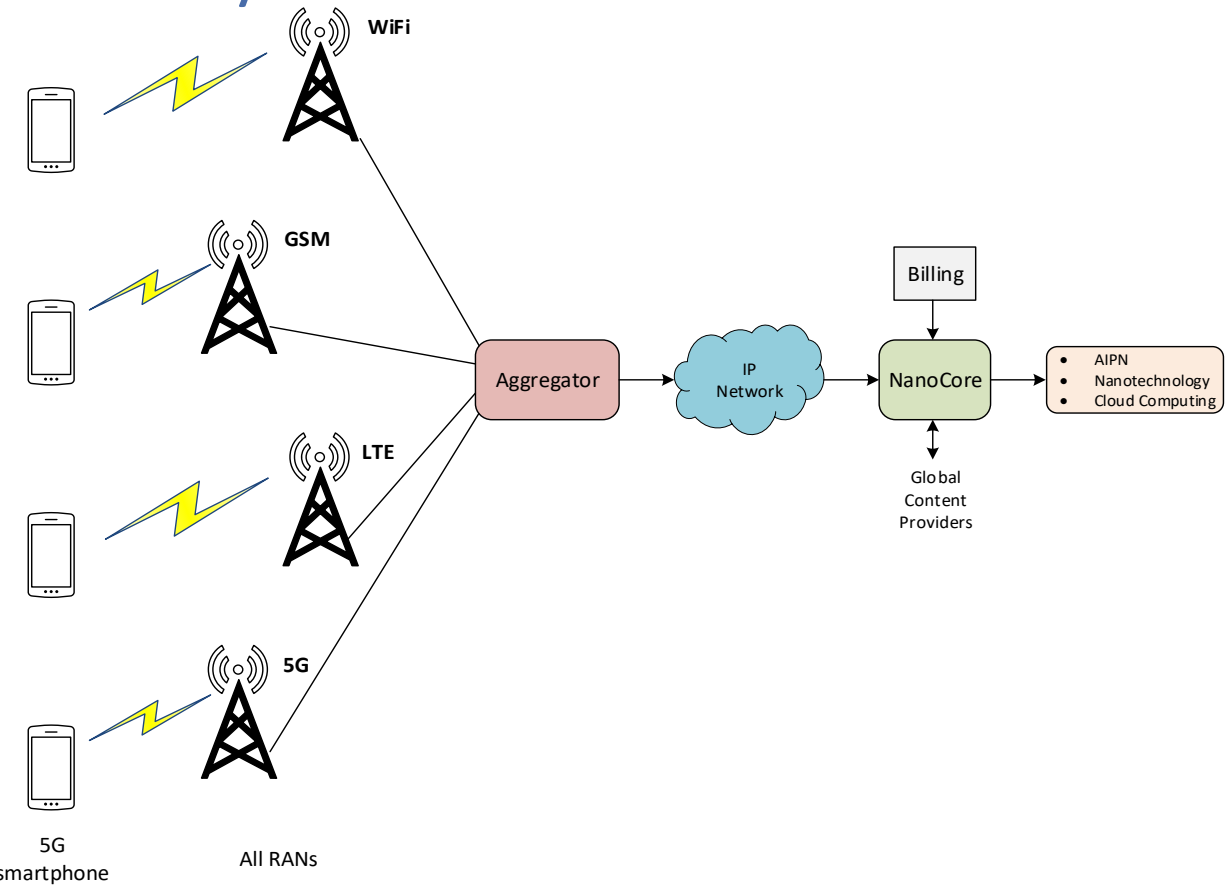
Characteristics of 5G

Characteristics of 5G

Specification	5G Support
Bandwidth	1Gbps or higher
Frequency range	3 to 300 GHz
Standard (access technologies)	CDMA/BDMA
Technologies	Unified IP, seamless integration of broadband, LAN/PAN/WAN/WLAN and 5G based technologies
Applications/Services	wearable devices, dynamic information access, HD streaming, smooth global roaming
Core network	flatter IP network, 5G network interfacing (5G-NI)
Handoff	vertical, horizontal
Peak Data Rate	Approx. 10 Gbps
Cell Edge Data Rate	100 Mbps
Latency	less than 1 ms

Characteristics of 5G

- Physical architecture of the network of 5G



OSI Stack

Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer

5G Network Stack

Application of Service
Open Transport Protocol
Upper Network Layer Lower Network Layer
Open Wireless Architecture

Key Enablers for 5G Communication Systems

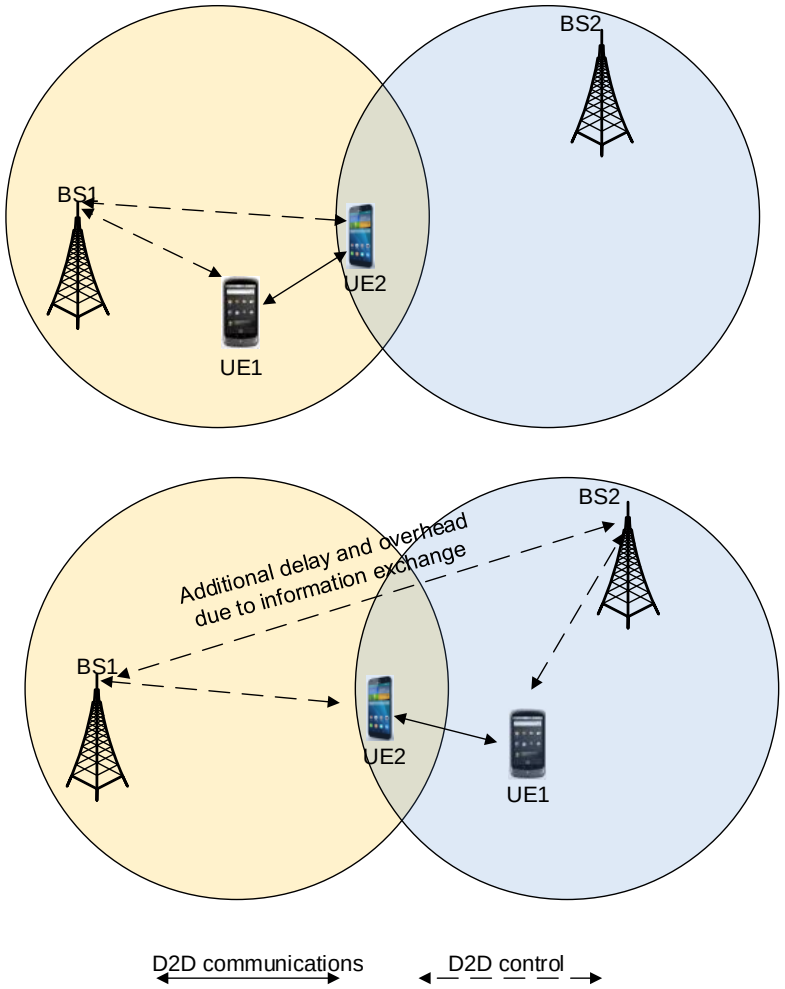
- Fifth-Generation (5G) mobile communication system that is currently under discussion will not only have to cope with an increasing demand of traffic volume, but also provide a wider range of applications:
  - Device-to-Device (D2D) communication;
  - Vehicle-to-Vehicle (V2V) communication;
  - Massive Machine Type Communications (MMC);
  - Moving Networks (MN);
  - Ultra-Reliable Communication (URC).

Device-to-device (D2D) Communication

- Key technology in LTE-Advanced networks:
  - Users with short distance and high signal-to-interference-plus-noise ratio (SINR) may directly communicate with each other without sending the information through base station (BS);
- D2D communications - met the growing requirements of 5G and must be ensured spectral and energy efficiency requirements
- Main technology component of D2D is mode selection (MS):
  - Selects the communication mode for a D2D pair based on issues such as the current resource condition, traffic load and level of the interference signals

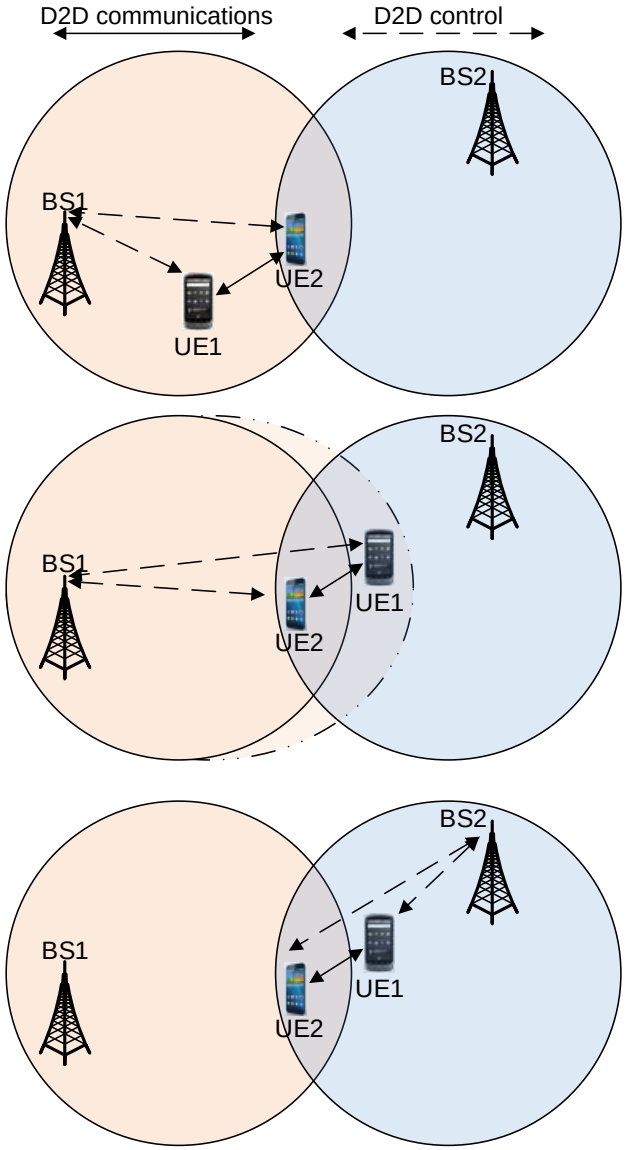
Smart Mobility Management for D2D

- We assume that the D2D resource usage and coordination are under the network's control:
  - This is due to the fact that in-band D2D operation, requires the network's control on D2D radio resources in order to provide optimized resource utilization, minimized interference among D2D links and from D2D links to cellular link;
  - We propose two smart mobility management solutions that can be used to minimize the negative impacts, reduce the network signaling overhead caused by the inter-BS information exchange.



D2D-Triggered Handover

- D2D control and communications during the device UE mobility between different sites:
  - UE1 and UE2 are controlled by BS1
  - UE1 handover to BS2 is postponed until D2D control condition is fulfilled for both UEs
  - Handover to BS2 is executed, when D2D control condition is fulfilled for both UEs



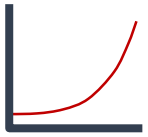
5G Challenges & Scenarios

5G Challenges

Avalanche of
Traffic Volume

Further expansion of mobile broadband

Additional traffic due to communicating machines



"1000x in ten years"

Massive growth in
Connected Devices
"Communicating machines"

"50 billion devices in 2020"

Large diversity of
Use cases & Requirements

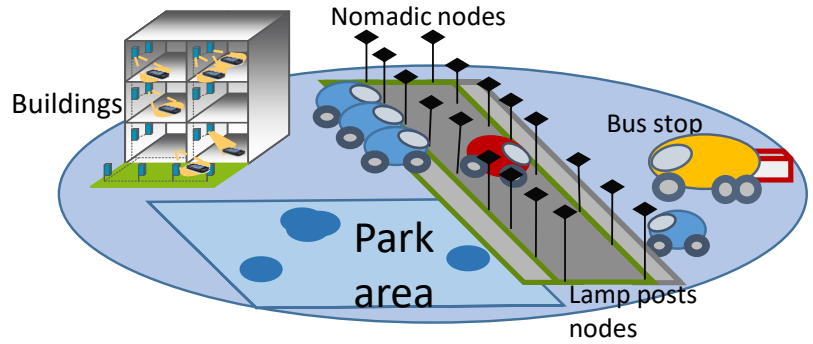
Device-to-Device Communications

Car-to-Car Comm.

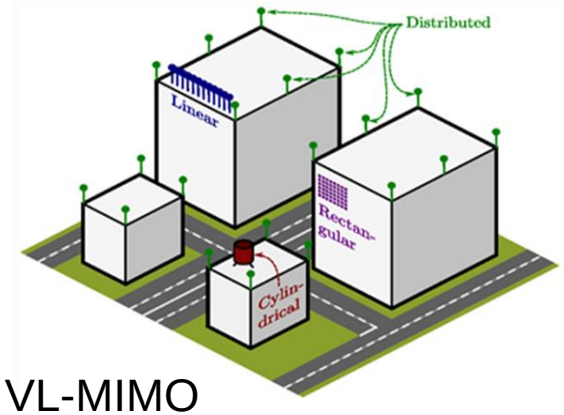
New requirements and characteristics due to communicating machines

5G Technology Components

New spectrum bands and access methods

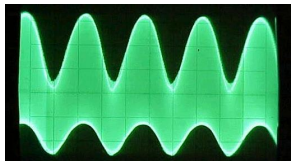


Dense and moving networks
Multi-hop wireless backhaul



VL-MIMO
Massive multi-antenna systems

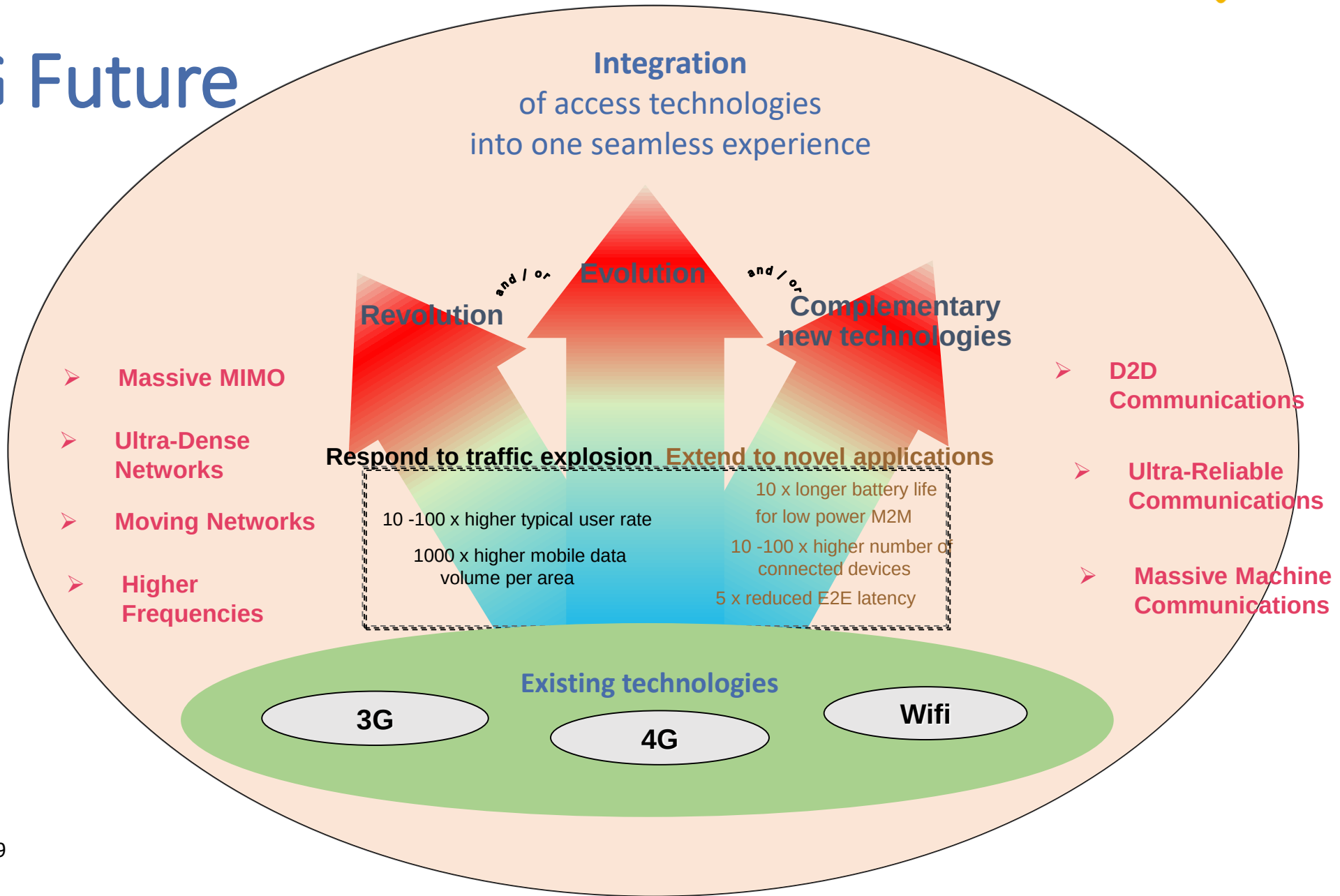
Context-aware interference and mobility management



Air interfaces for new applications and reduced signaling

Mobile
Device-to-device

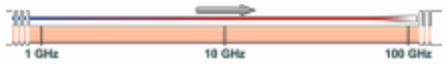
5G Future


Integration
of access technologies
into one seamless experience
Revolution
and / or
Evolution
and / or
Complementary
new technologies
Massive MIMO
Ultra-Dense Networks
Moving Networks
Higher Frequencies
Respond to traffic explosion
Extend to novel applications
10 -100 x higher typical user rate
1000 x higher mobile data volume per area
10 x longer battery life for low power M2M
10 -100 x higher number of connected devices
5 x reduced E2E latency
D2D Communications
Ultra-Reliable Communications
Massive Machine Communications
Existing technologies
3G
4G
Wifi

5G key radio technology areas

Extension to higher frequencies

Complementing lower frequencies for extreme capacity and data rates in dense areas



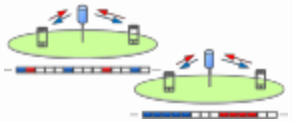
Spectrum flexibility

Spectrum sharing

- ***Unlicensed***
- ***Shared licensed***
- ***Network sharing***

Complementing dedicated licensed spectrum

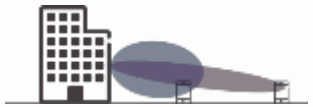
Duplex Flexibility



Multi-antenna technologies

For higher as well as lower frequencies

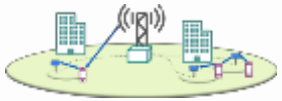
Beam-forming for coverage



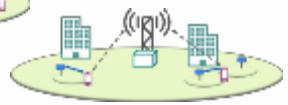
Multi-user MIMO for capacity

Multi-site coordination

Multi-site transmission/reception



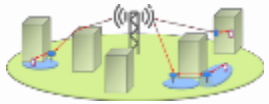
Multi-layer connectivity



Access/backhaul integration

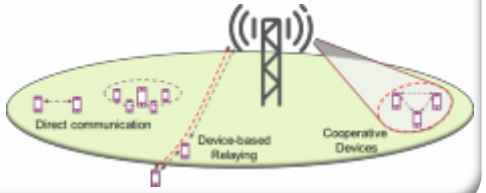
Same technology for access and backhaul

Same spectrum for access and backhaul



Device-to-device communication

Direct communication
Device-based relaying
Cooperative devices



Ultra-lean design

Minimize transmissions not related to user data
Separate delivery of user data and system information

Higher data rates and enhanced energy efficiency

...

Intelligent Transport System (ITS)

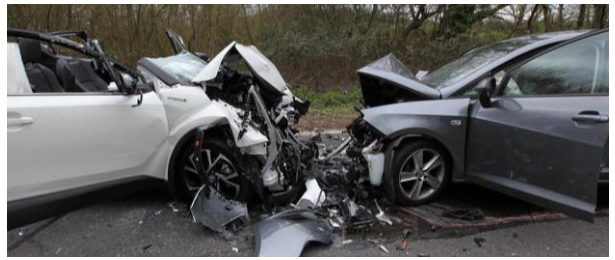
Identify the Connected Vehicle Environment

- Transportation Challenges in the EU

Safety
25 300 highway deaths in 2018
1 099 032 road accidents

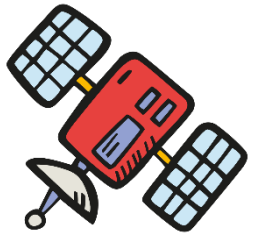
Mobility
5,5 billion hours of travel delay
€ 96 billion cost of urban congestion

Environment
2,2 billion liters of wasted fuel
49 billion kg of additional CO_2



Identify the Connected Vehicle Environment

- Vehicles
  - Have safety devices and sensors
  - Have a navigation device
  - Have a multimedia center

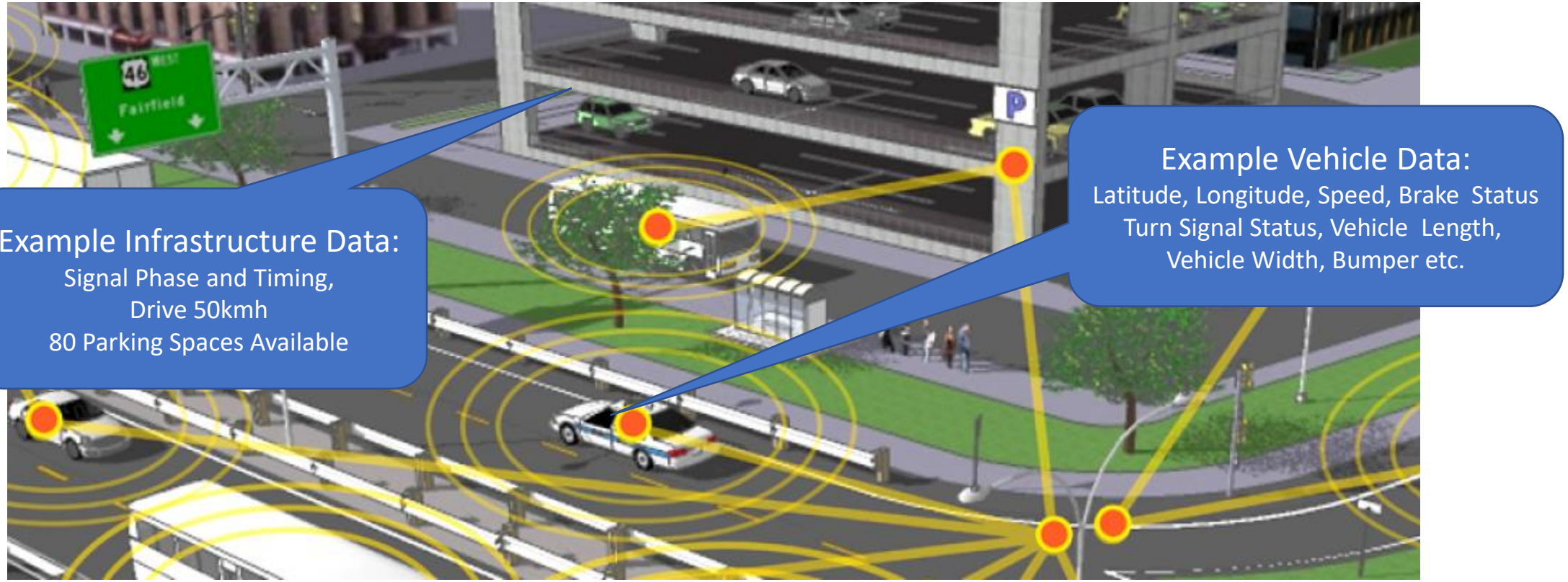


- Millions of people carry mobile devices today that have Global Positioning System (GPS) and can access data

Identify the Connected Vehicle Environment

- What if….
  - Vehicles shared their sensor data with other vehicles and the roadway
  - Vehicles shared their current position with other vehicles and the roadway
  - Vehicles can receive data from the roadway that can reduce the likelihood of incidents
  - Vehicles can receive data from the roadway to improve mobility (e.g., reduce delays)

Identify the Connected Vehicle Environment



Motivation

- From Vehicular Ad-hoc Networks to Internet of Vehicles
  - 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
- 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). Target domains:
    - vehicles driving and safety
    - urban traffic management, automobile production
    - repair and vehicle insurance, road infrastructure construction and repair, logistics and transportation, etc

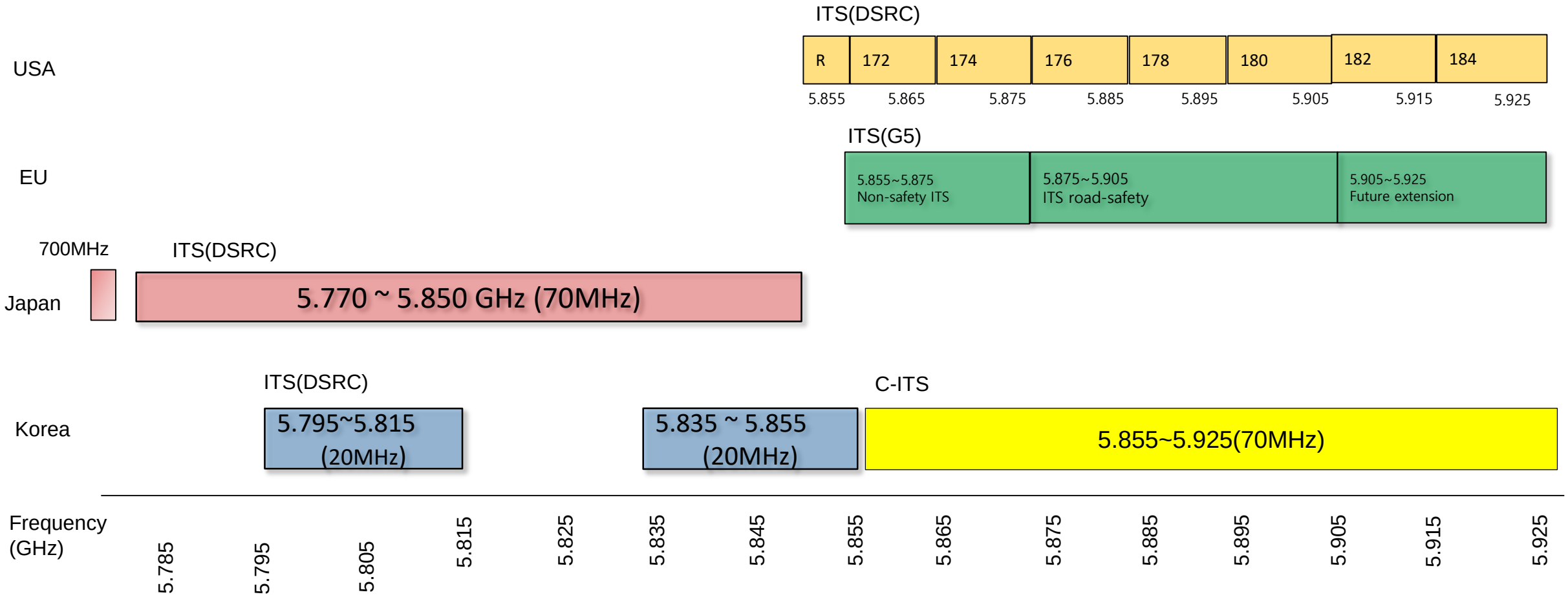
Intelligent Transport System (ITS)

- Advanced vehicles and associated transportation infrastructures that use ICT 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
- 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

7 Categories & 15 Applications

Service Categories	Applications
Vehicle Safety	• Vehicle Collision Warning • Road Hazard Warning • Road and Weather Condition Warning • Road work warning
Intersection Safety	• Intersection Collision Warning • Signal Phase/Timing Information
Protection for Disabled Person	• Yellow Bus Warning • School Zone Warning • Pedestrian Waning
Emergency Situation	• Emergency Warning • Emergency Preemption Warning
Cooperative Traffic Management	• Location based Position Information Gathering • Location based Traffic Information Provision
Smart Tolling	• Multi-lane Toll Charging
Public Transportation Management	• Public Transportation Management

Intelligent Transport Systems Frequency Band



Dedicated Short Range Communications

- Definition
  - The use of non-voice radio techniques to transfer data over short distances between roadside and mobile radio units, between mobile units, and between portable and mobile units to perform operations related to the improvement of traffic flow, traffic safety and other intelligent transportation service applications in a variety of public and commercial environments. Dedicated Short Range Communications (DSRC) systems may also transmit status and instructional messages related to the units involved.

Dedicated Short Range Communications

- Low latency
  - Information can be transmitted at a high rate
  - Critical for V2V safety applications
  - Data can be transmitted 10 times per second
- Short to medium range (< 300 meters reliably)
  - Advantage -only interested in messages from nearby vehicles
  - Higher power permitted for emergency response vehicles (range can be 1 km)

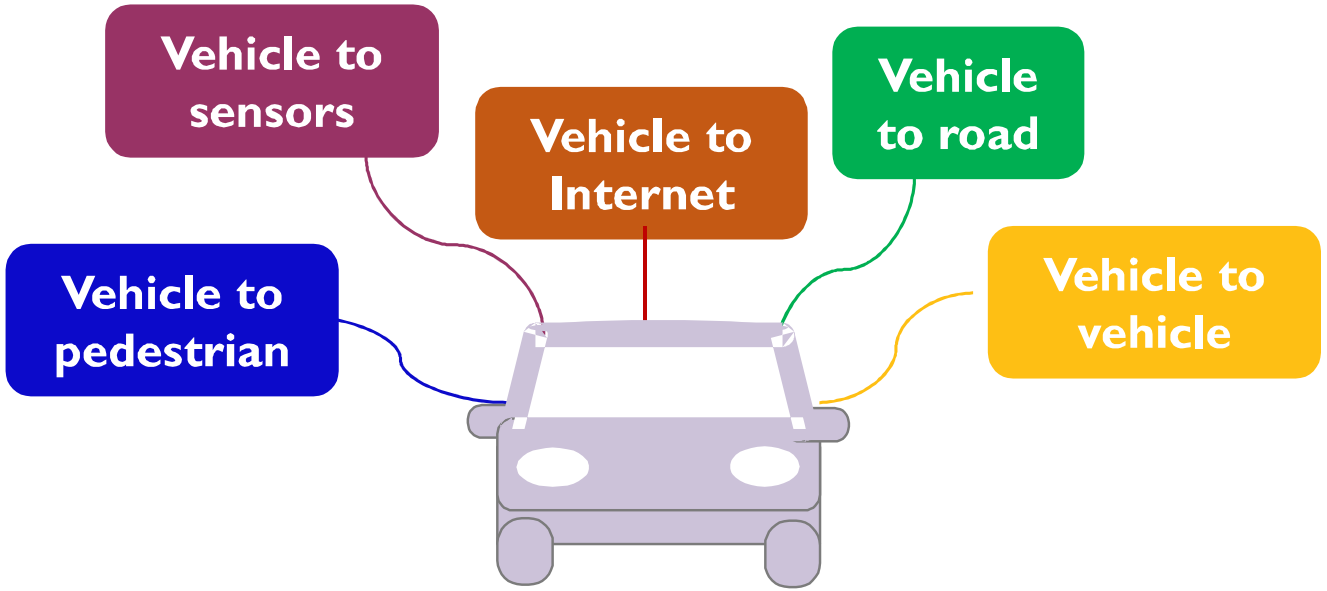
DSRC Technology Characteristics

Parameter	Characteristics
Frequency Band (GHz)	75 MHz (5.850 - 5.925 GHz)
Channel Bandwidth	10MHz (20MHz USA)
Modulation	OFDM (BPSK, QPSK, 16QAM,64QAM)
Channels	7 - 10 MHz channels (optional combinations of 10 and 20 MHz channels)
Data Rate	6, 9, 12, 18, 24, and 27 Mbps with 10 MHz Channels 6, 9, 12, 18, 24, 36, 48, and 54 Mbps with 20 MHz Channel option
Max Tx Power	28.8 dBm (at the antenna input)
C/I	4 - 6 dB (for QPSK @ 10^{-4} BER coded) 16 - 17 dB (for 64QAM @ 10^{-4} BER coded)
Road-side Unit (RSU) and On-board Unit (OBU) Sensitivity	- 82 dBm (QPSK) / - 65 dBm (64QAM)

Vehicle to X (V2X) connectivity

The era of connected vehicles

- Key element for the new generation Intelligent Transportation Systems



Vehicle to X (V2X) connectivity

What is the difference?

- May or not may be connected
- May or may not be self driving

CONNECTED

V2X communication capabilities

AUTOMATED

Some safety-critical control functions **without direct driver input**

AUTONOMOUS

Self driving capabilities **without connectivity**

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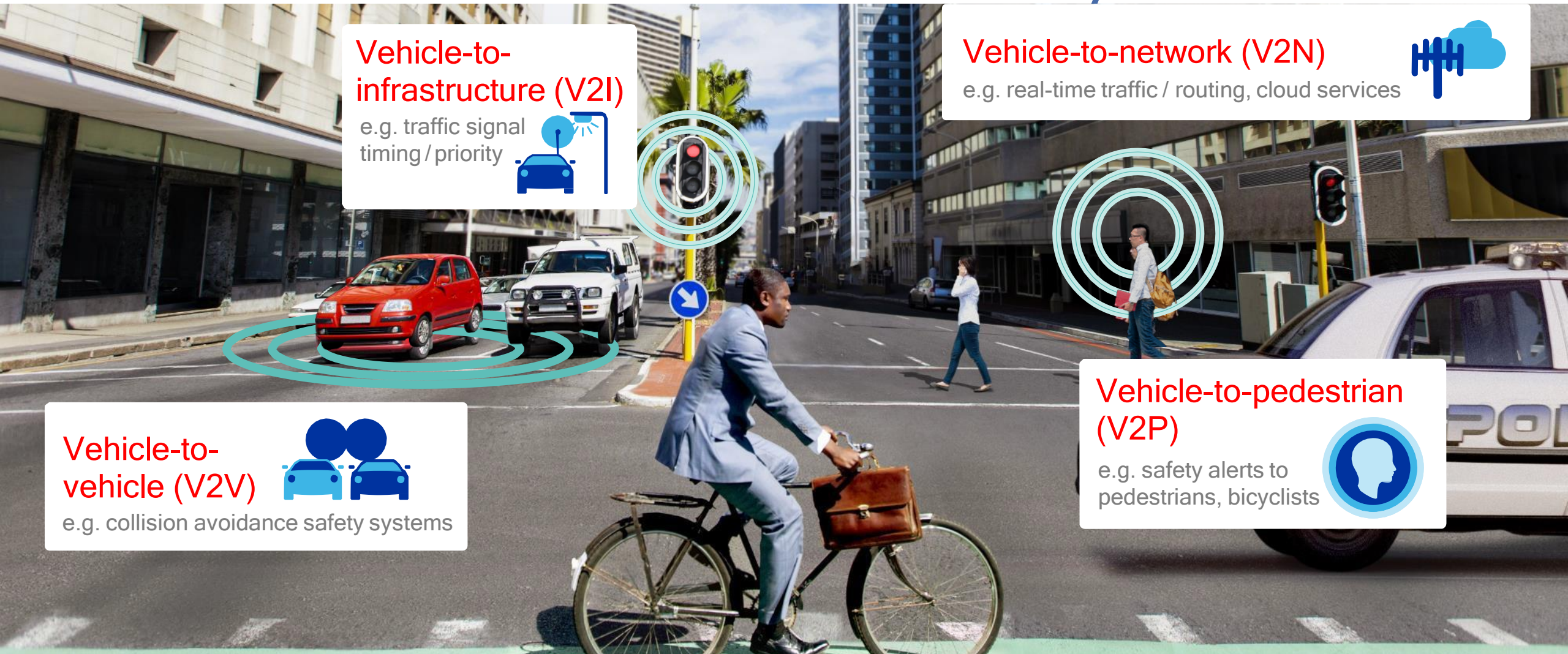
V2X is giving to the vehicles the ability to communicate with each other and beyond



Vehicle-to-infrastructure (V2I)
e.g. traffic signal timing / priority

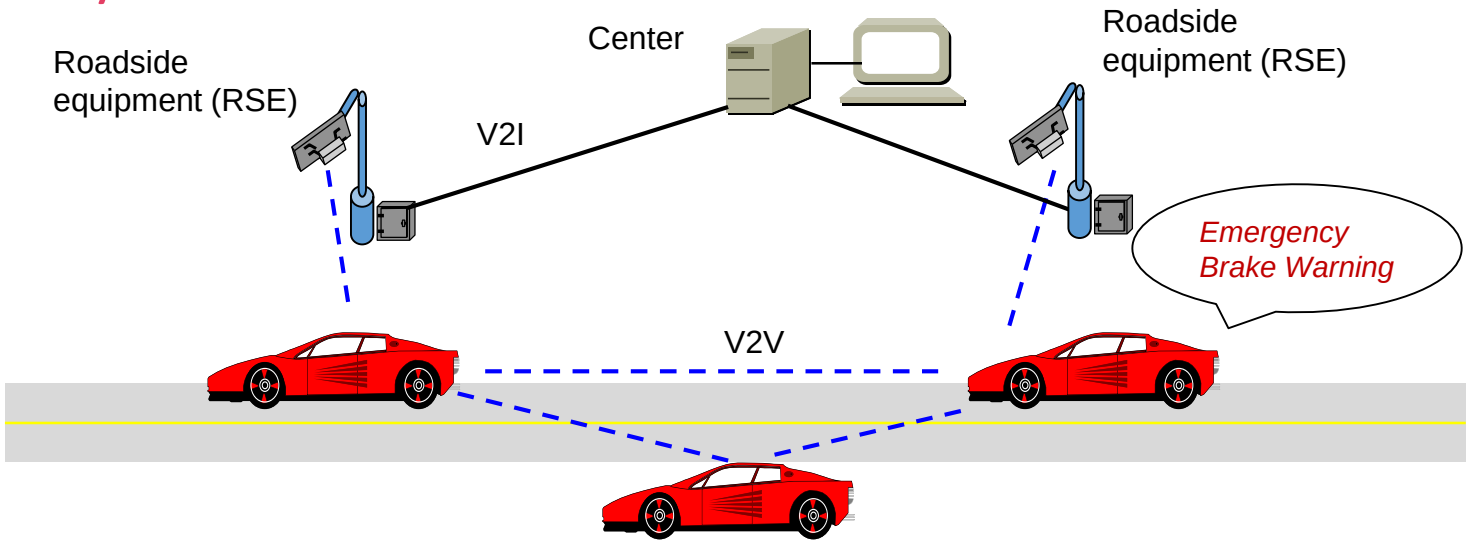
Vehicle-to-network (V2N)
e.g. real-time traffic / routing, cloud services

Vehicle-to-vehicle (V2V)
e.g. collision avoidance safety systems

Vehicle-to-pedestrian (V2P)
e.g. safety alerts to pedestrians, bicyclists

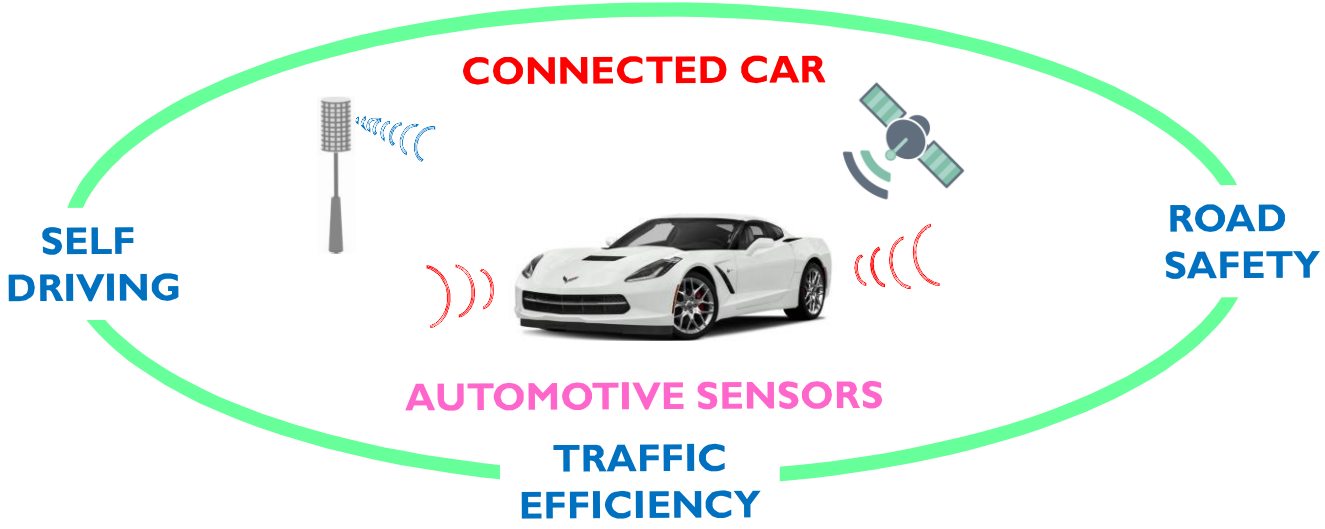
V2X Communication Technology

- Intelligent Transport Systems
  - V2V and V2I Wireless Networking for Vehicle Safety & C-ITS
  - WAVE (Wireless Access in Vehicular Environment) & EU ITS G5
  - Less than 100msec Latency and 1km Radio Coverage
  - Frequency Band : 5.855 ~ 5.925GHz.



Trends in the automotive sector

- To achieve higher automation levels, connectivity seems critical
- Vehicular communications to share sensing data and enhance sensing capability



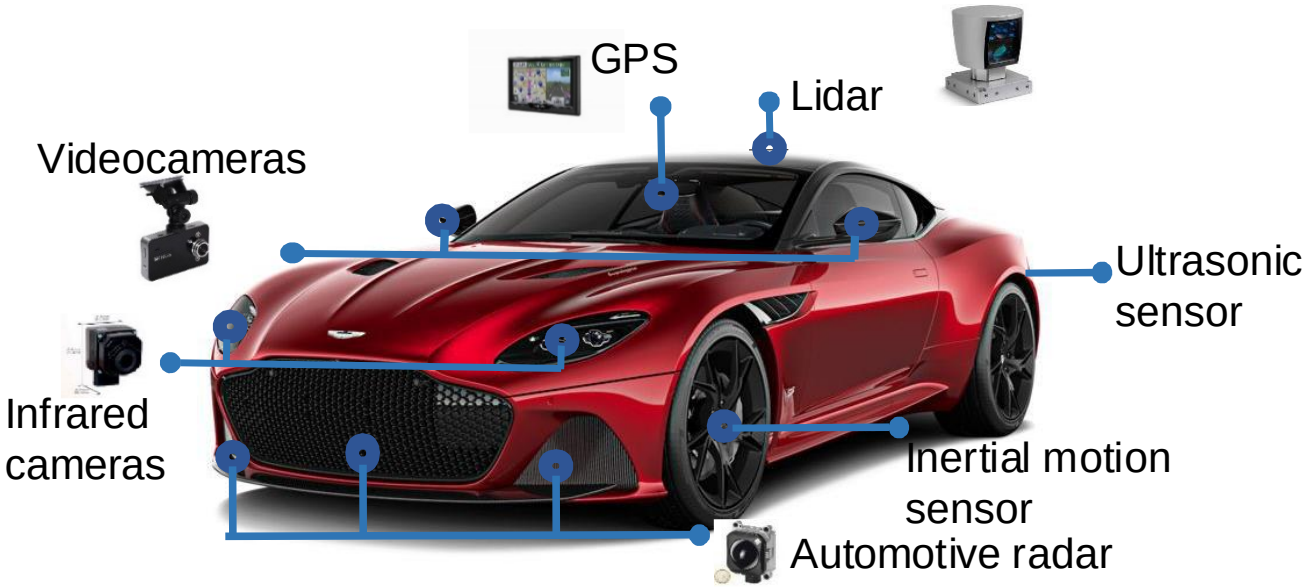
Summarizing automotive sensors

	Purpose	Drawback	Data rate
Radar	Target detection, velocity estimation	Hard to distinguish targets	Less than 1 Mbps
Camera	Virtual mirrors for drivers	Need computer vision techniques	100-700 Mbps for raw images, 10-90 Mbps for compressed image
LIDAR	Target detection and recognition, velocity estimation	High cost	10-100 Mbps

- Is it possible to exchange raw sensor data between vehicles?

Massive data rates from sensors

- Connected vehicle is expected to drive 1.5GB monthly mobile data
- Autonomous vehicles can generate up 1 TB per hour of driving
  - 4G and DSRC can not support these data rates



Each sensor generates data

+

Lots of sensors in a vehicle

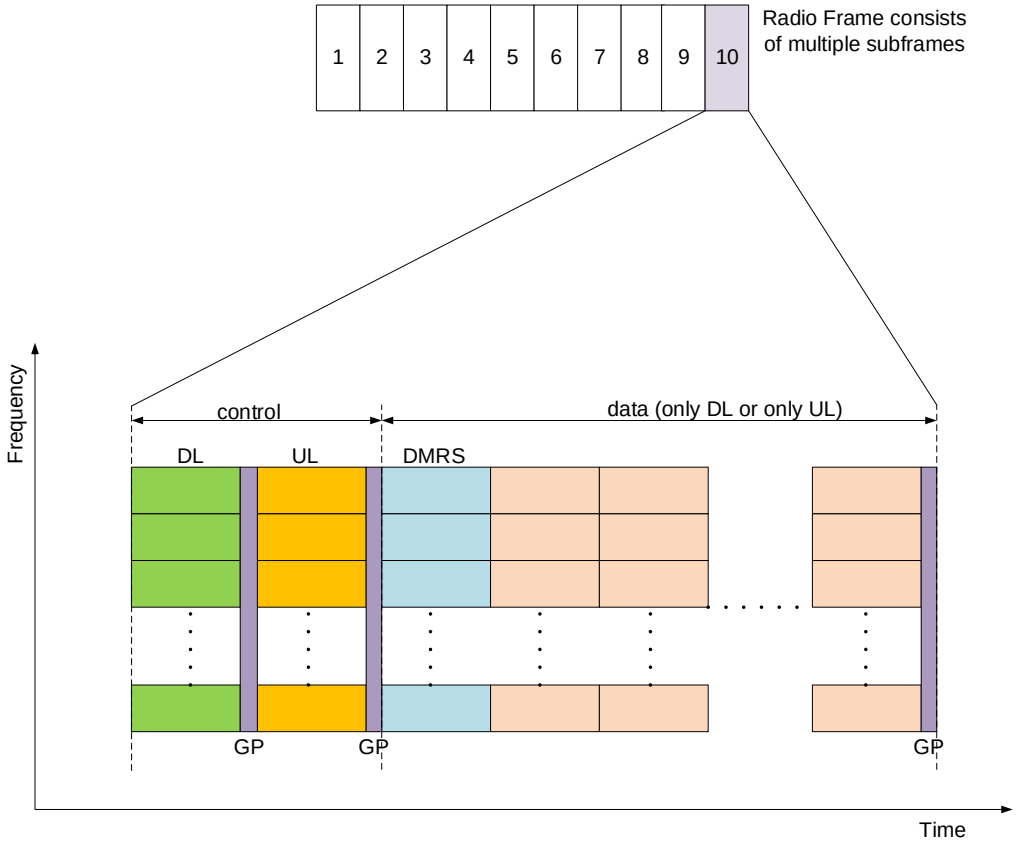
=

Massive amount of data per vehicle

New communication solution is needed for connected cars

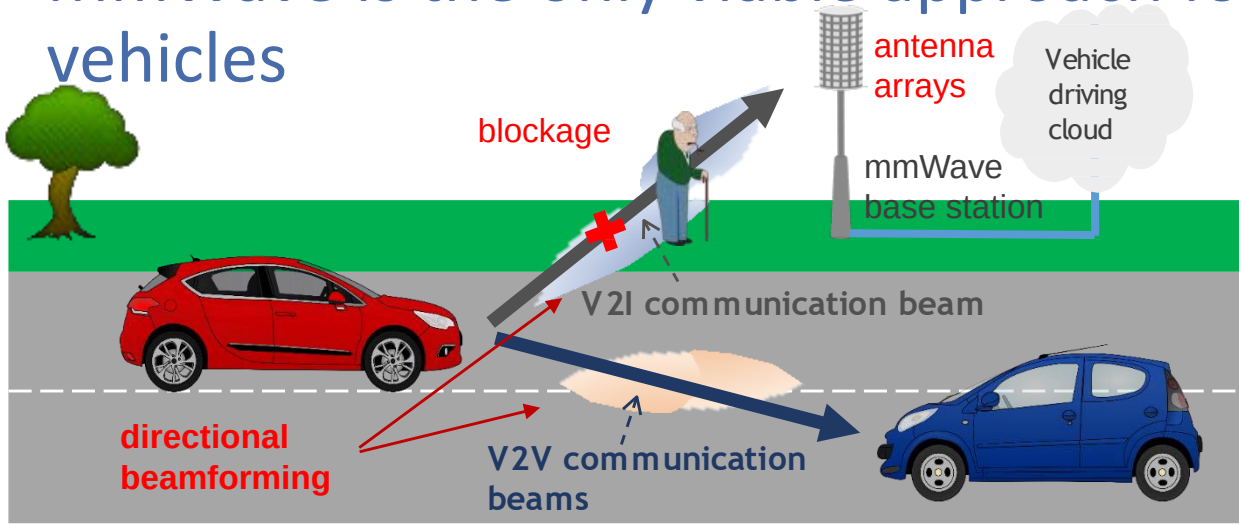
5G millimeter waves

- Advantages of 5G millimeter waves:
  - Provide a lot of traffic
  - More favorable placement of small cells
  - Channel sound
  - Size of the antennas is physically small
  - Dynamically generating waves
  - Supports multi-gigabit transfer rates
  - Suitable for mobile communications in 6GHz range

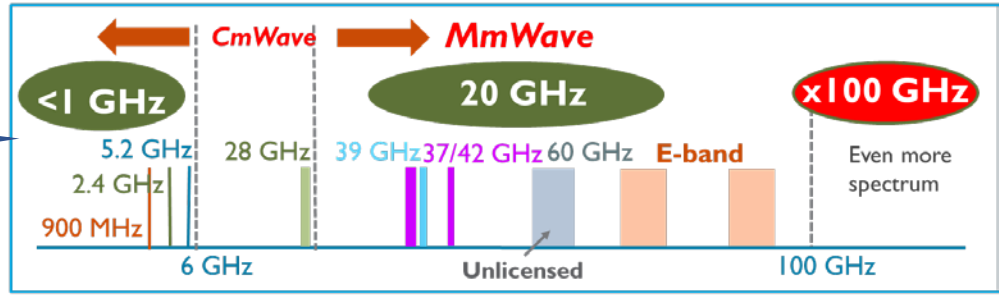


Millimeter wave for connected cars

- MmWave is the only viable approach for high bandwidth connected vehicles

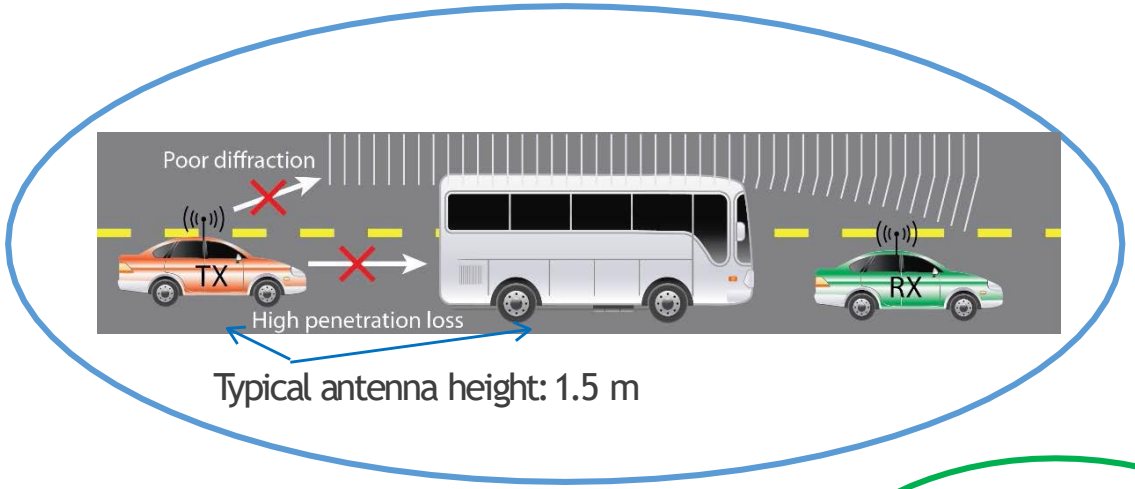


Spectrum available at mmWave bands

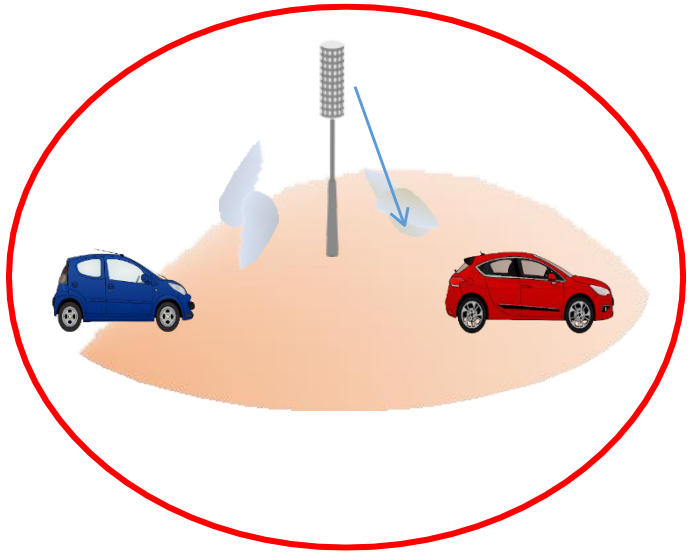


Challenges for mmWave

Lack of propagation channel models

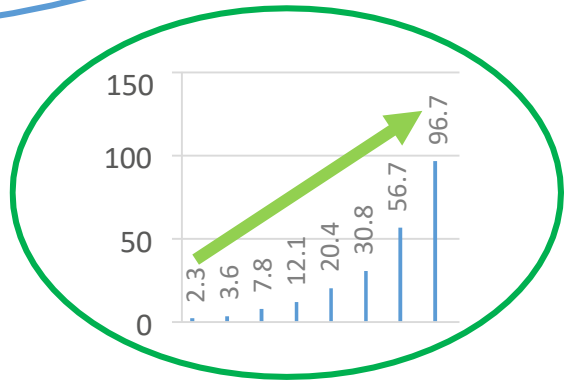


More infrastructure



Communication overhead

High penetration rate needed for most gains

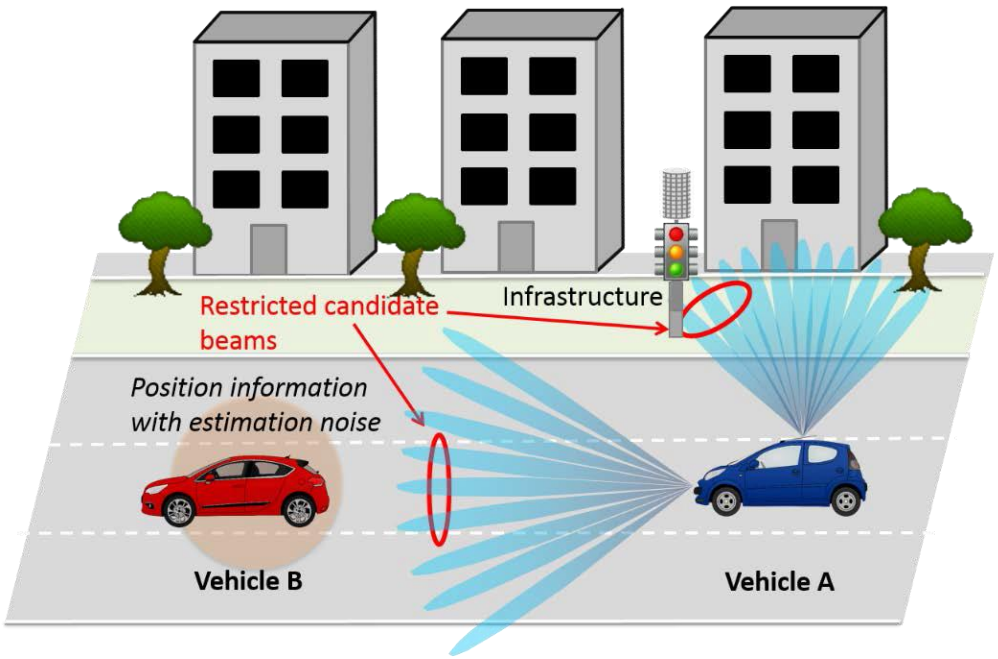


Challenges for mmWave

- Implications of using mmWave in automotive

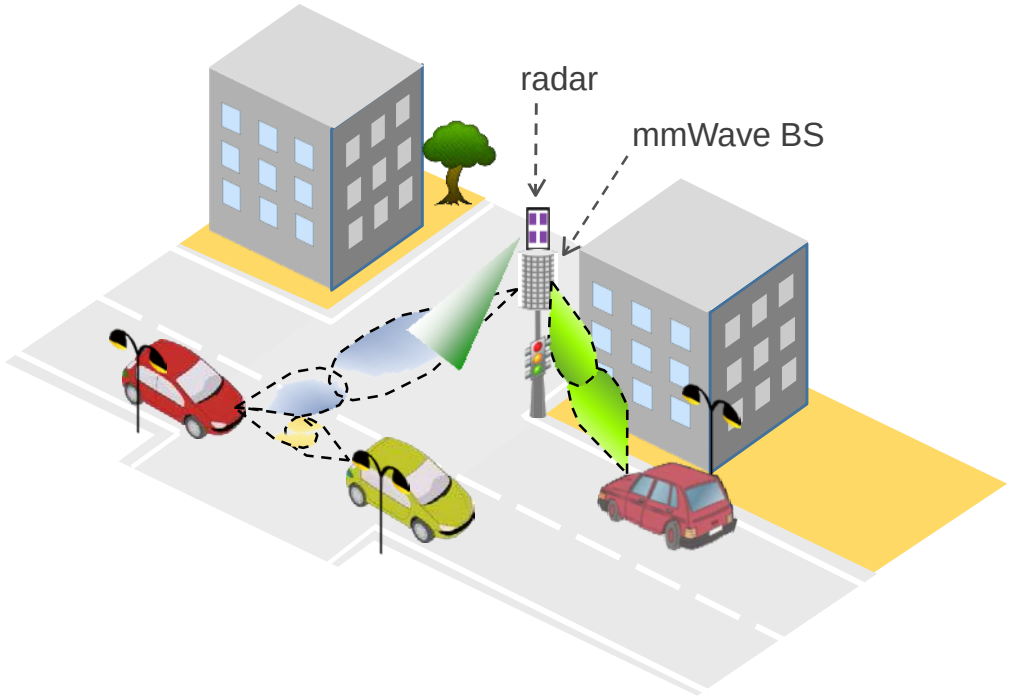
Challenges for mmWave

- Using position information to reduce beam alignment overhead in mmWave V2X
- Each vehicle decides candidate beams from other vehicles position and size info



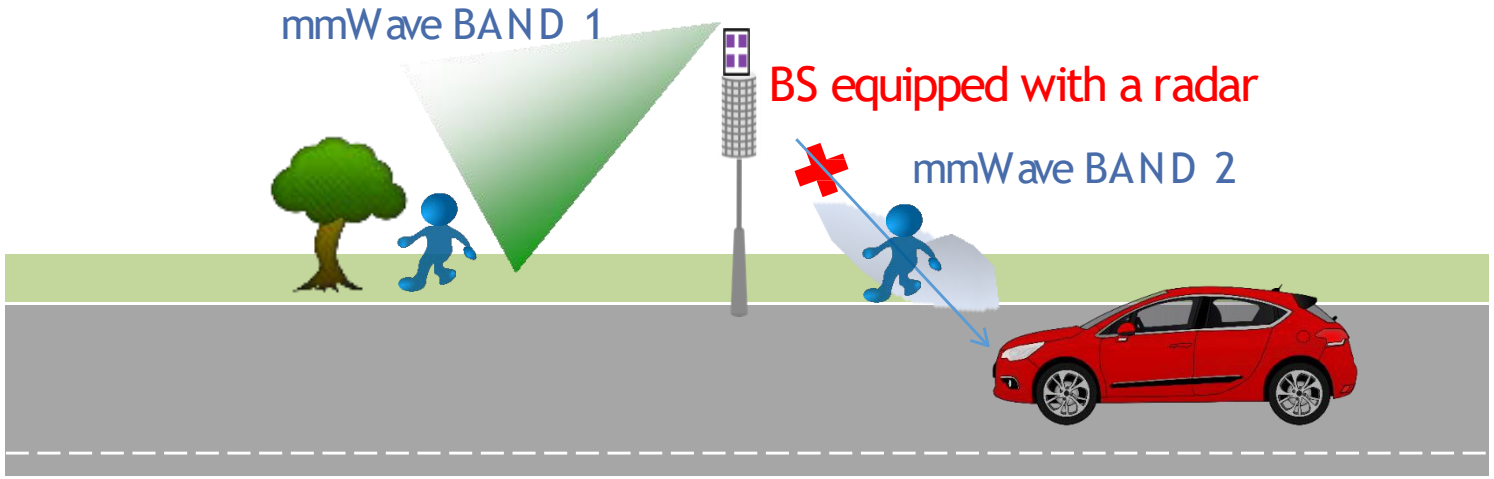
Challenges for mmWave

- Adding radar to the infrastructure
  - The radar can capture information of the scattering environment
  - Used to design multiuser beamforming, support remote car traffic control

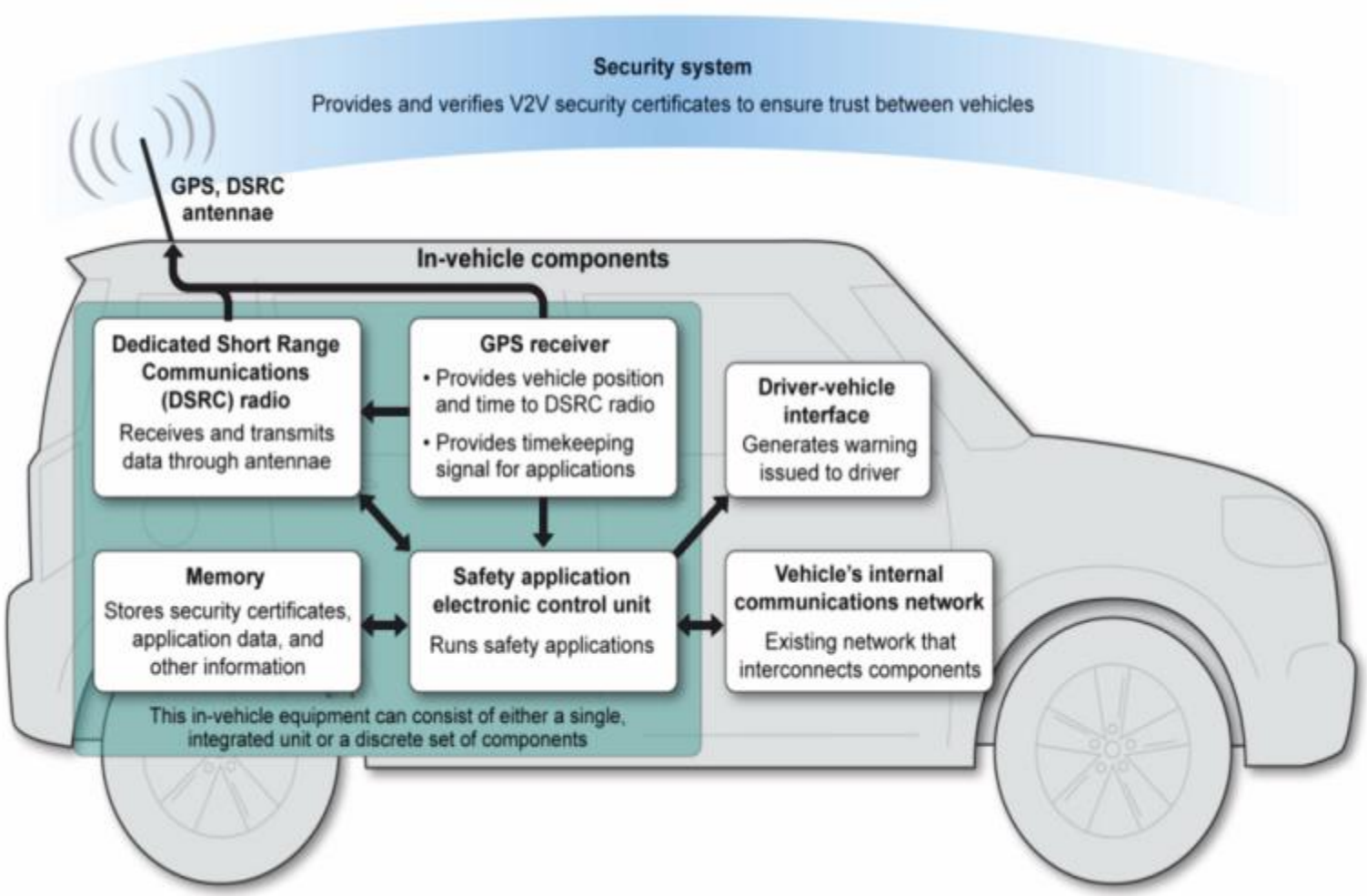


Challenges for mmWave

- Predicting blockage from out-of band sensing
  - Radar can detect potential obstacles and their associated mobility
  - Machine learning can classify particular radar responses as blockages



List the Components of a V2V Environment



List the Components of a V2V Environment

- On-Board Units (OBUs)
  - Represents the DSRC radio alone
- Integrated Safety Devices (ISDs)
  - Installed by the manufacturer, these devices integrate directly with the vehicle's computers, which can provide additional information
- Aftermarket Safety Devices (ASDs)
  - A portable unit with a driver interface, broadcasting basic safety information and receiving safety information from other vehicles
- Vehicle Awareness Devices (VADs)
  - Only broadcasts basic safety information. Cannot receive information from other devices

V2V Safety Applications

- Emergency Vehicle Alert (EVA)
  - Warns driver about nearby public safety vehicles responding to an incident
- Vehicle Emergency Response (VER)
  - Provides public safety vehicles with information from connected vehicles involved in a crash
- Transit Vehicle at Station/Stop Warnings
  - Warns driver about transit vehicles that may be pulling into or out of a transit station or stop
- Vehicle Turning Right in Front of a Transit Vehicle (VTRFTV)
  - Warns the transit vehicle driver of a nearby vehicle pulling in front of the transit vehicle to make a right turn

V2V Mobility Applications

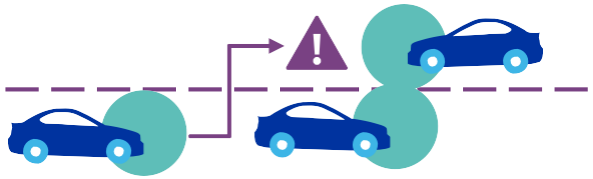
- Advanced Automatic Crash Notification Relay (AACNR)
  - Enables a vehicle to automatically transmit an emergency message when the vehicle is disabled. Also enables another connected vehicle to relay the emergency message to a public safety vehicle. Also a V2I application
- Cooperative Adaptive Cruise Control (CACC)
  - Advises driver of a recommended cruise speed based on information from other connected vehicles within a platoon
- Queue Warning (Q-WARN)
  - Advises drivers of an impending queue

V2V Environmental Applications

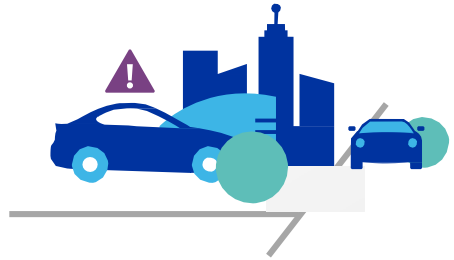
- Connected Eco-Driving
  - Advises driver to adjust their driving behavior to save fuel and reduce emissions
- Eco-Cooperative Adaptive Cruise Control (Eco-CACC)
  - Advises driver of a recommended cruise speed based on information from other connected vehicles within a platoon and eco-driving strategies. Also incorporates other information to determine the most environmentally efficient speed

V2V and V2X use cases

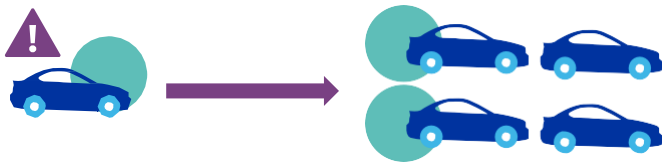
Forward collision warning



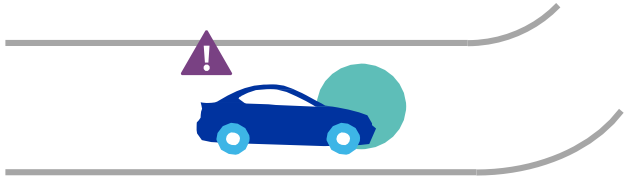
Do Not Pass Warning (DNPW)



Blind intersection



Queue warning



Curve speed warning

Cooperative adaptive cruise control & platooning

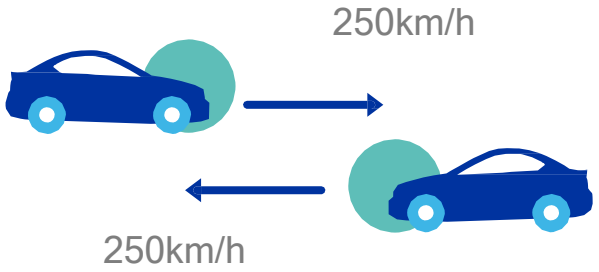
Vulnerable Road User (VRU) alerts

Discover parking and charging

Traffic signal priority and optimal speed advisory

Emergency vehicle alert

Overcoming the challenges of V2X communications



V2X Challenges

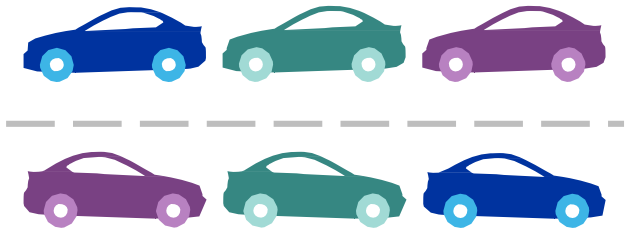
C-V2X Solutions

High relative speeds

Leads to significant Doppler shift / frequency offset

Enhanced signal design

E.g. increasing of ref. signal symbols to improve synchronization and channel estimation



High node densities

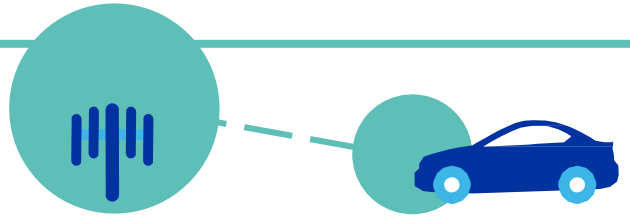
Random resource allocation results in excessive resource collisions

Enhanced transmission structure

Transmit control and data on the same sub-frame to reduce in-band emissions

More efficient resource allocation

New methods using sensing and semi-persistent resource selection



Time synchronization

Lack of synchronization source when out-of-coverage

Allow utilization of GPS timing

Enhancements to use satellite (e.g. GNSS) when out-of-coverage

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Key takeaways

Key takeaways – Technical aspect

- Upgrades of existing environments
  - Vehicle manufacturers would install the technology in all new vehicles
  - Full-scale deployment in both the vehicles and the roadside infrastructure
- MmWave and V2X communication introduce new challenges:
  - Lack of propagation channel models
  - New signal processing techniques need to be developed
  - Infrastructure and penetration rate
- New technologies
  - R&D
  - IoT & IoV
  - etc

Key takeaways – Societal aspect

- Growth of Intelligent Transport Systems:
  - Transport safety due to the reduction of human errors
  - Needs of highly qualified ICT professionals, such as software developers
  - Save fuel and reduce CO_2 emissions
- Benefits for drivers and passengers:
  - Reduction of car accidents
  - Increasing the incoming information from the surrounding environment
  - Less time loss in traffic jams and more time spending with family

Key takeaways – Business aspect

- Growth of the EU economy
  - New SMEs
  - New jobs
- Strategy
  - Advertising
  - Identify opportunities
  - Smart financial planning

Quiz

Question 1

- What does 5G stand for?
  - A. Five gigabytes
  - B. Fifth gateway
  - C. Five gigabit
  - D. Fifth generation wireless

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  - A. The time it takes to reboot a connection
  - B. The length of time devices will automatically connect to the network
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- To accommodate faster data transmission speeds, 5G has greater **bandwidth**. What other term is synonymous with **bandwidth**?
  - A. Capacity
  - B. Speed
  - C. Connection
  - D. Strength

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  - B. Lower-frequency spectrum
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  - A. RFID Communication
  - B. Dedicated Short Range Communication
  - C. Long Range Communication
  - D. Medium Range Communication

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Question 6

- Which of the following is **NOT** a component of the V2V environment?
  - A. Vehicle powertrain
  - B. Safety application electronic control unit
  - C. GNSS (GPS) receiver
  - D. Memory for security certificates or application data

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