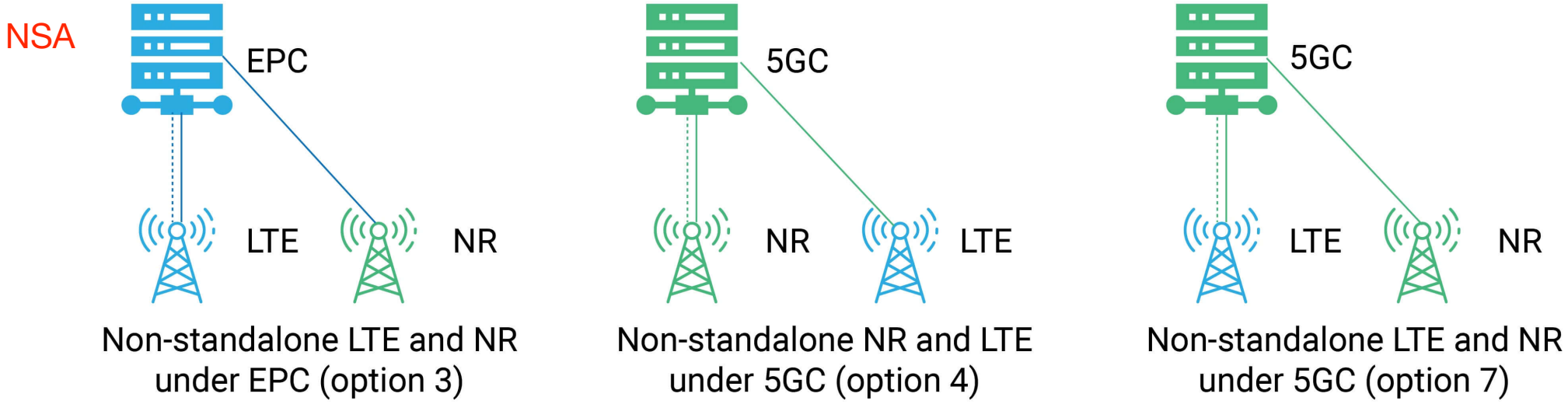
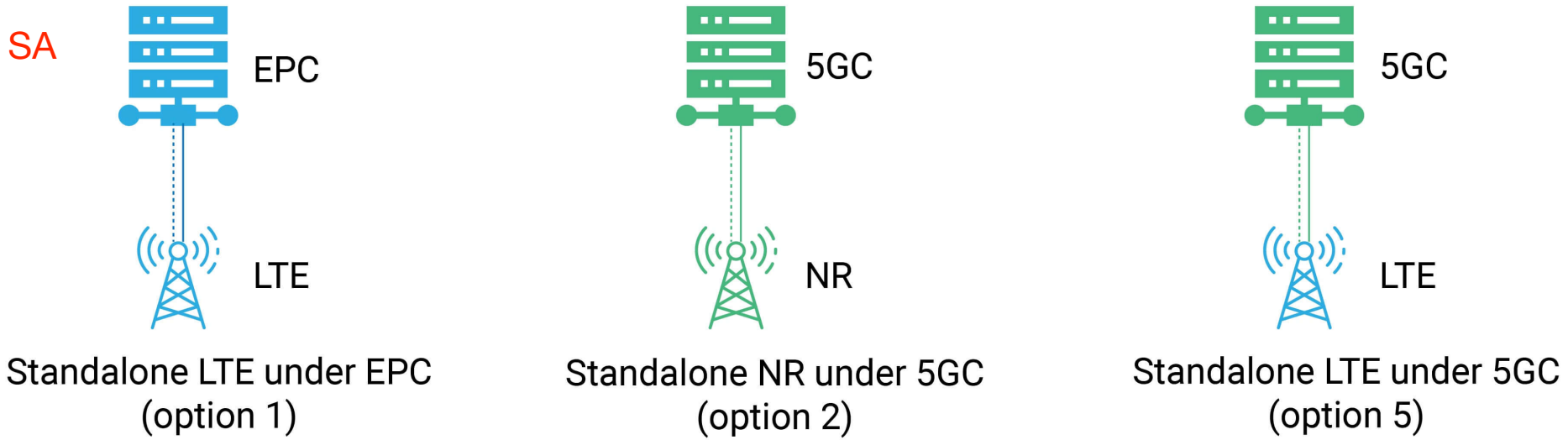
5G NR：NSA vs. SA mode

- **Non-Standalone (NSA) mode**
  - 5G NR in NSA mode relies on the control plane of an existing 4G LTE network for control functions
  - 5G NR is exclusively focused on the user plane in this mode
  - Speed up 5G adoption



- **Standalone (SA) mode**
  - SA mode uses 5G cells for both signalling and information transfer
  - Involves the new 5G Packet Core architecture and doesn't rely on the 4G Evolved Packet Core
  - Allows the deployment of 5G without the LTE network
  - Expected to have lower cost, better efficiency, and is crucial for the development of new use cases

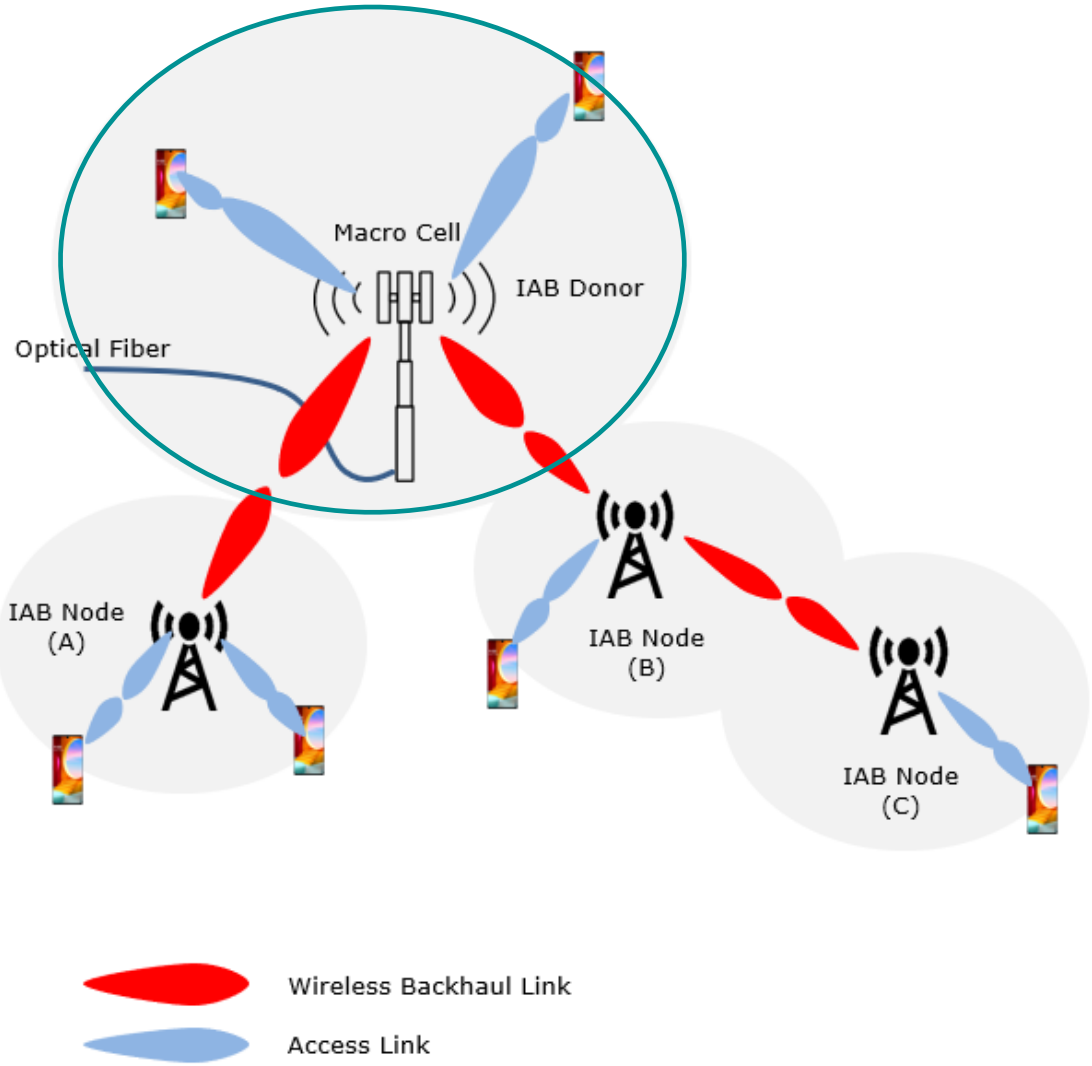


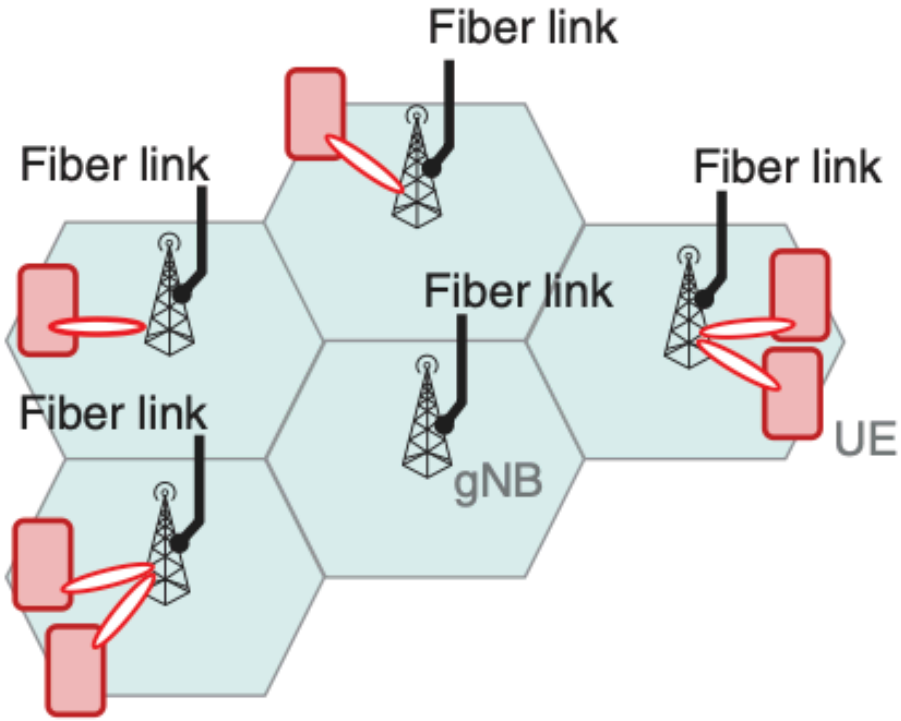
Standalone LTE under EPC (option 1)

Standalone NR under 5GC (option 2)

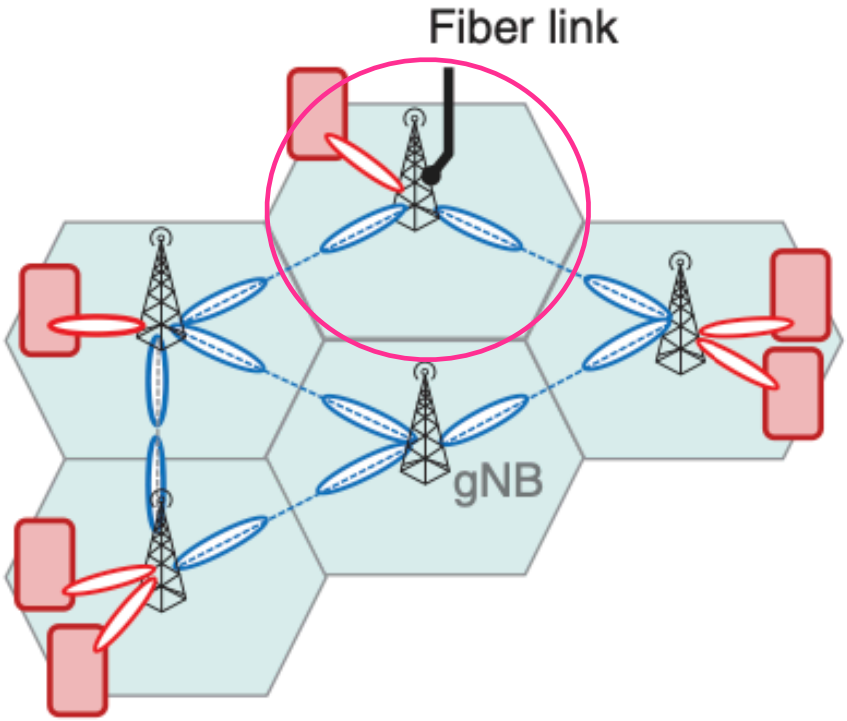
Standalone LTE under 5GC (option 5)

NR for Integrated Access and Backhaul (NR-IAB)



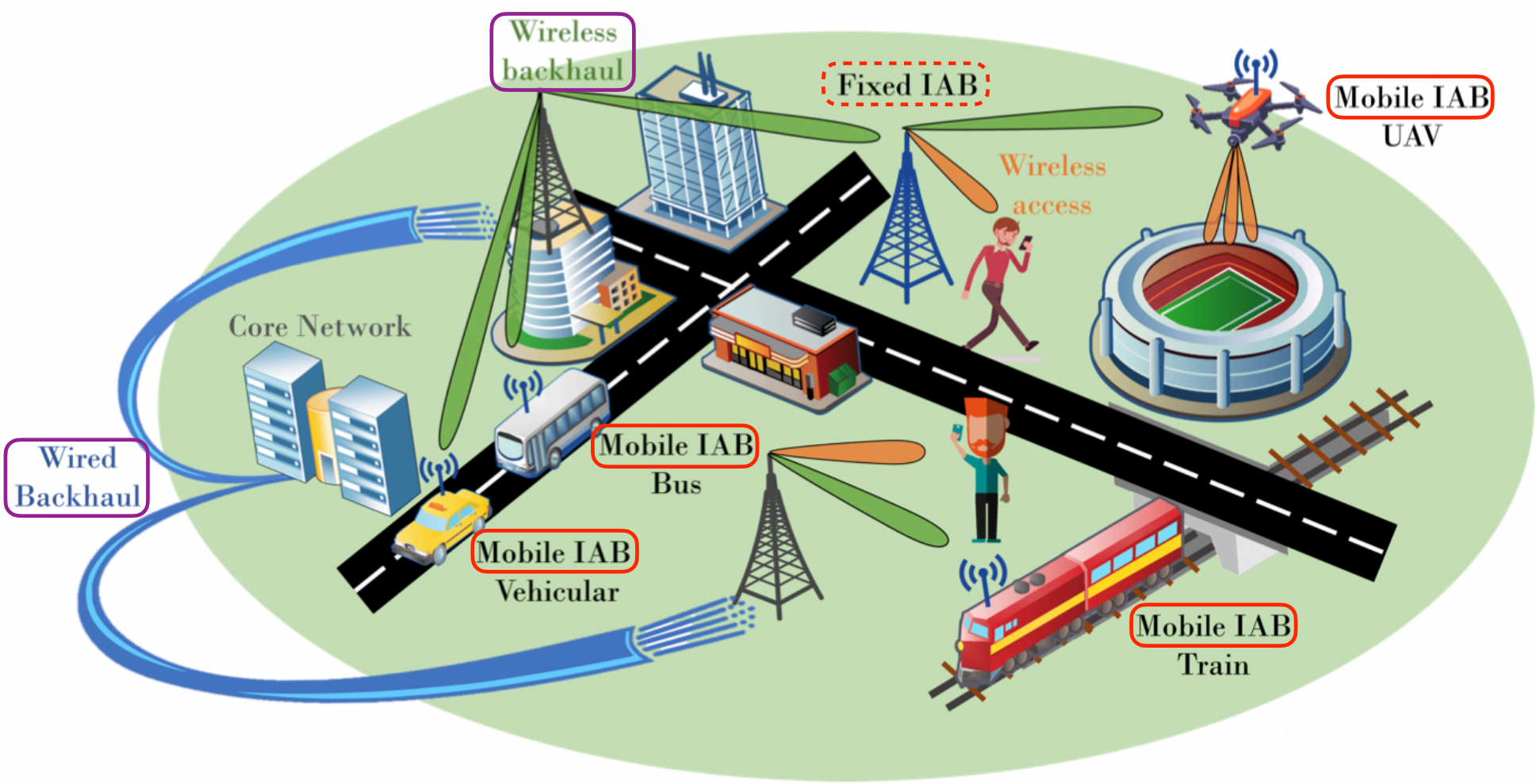


Without IAB: Separate fiber link needed for each cell

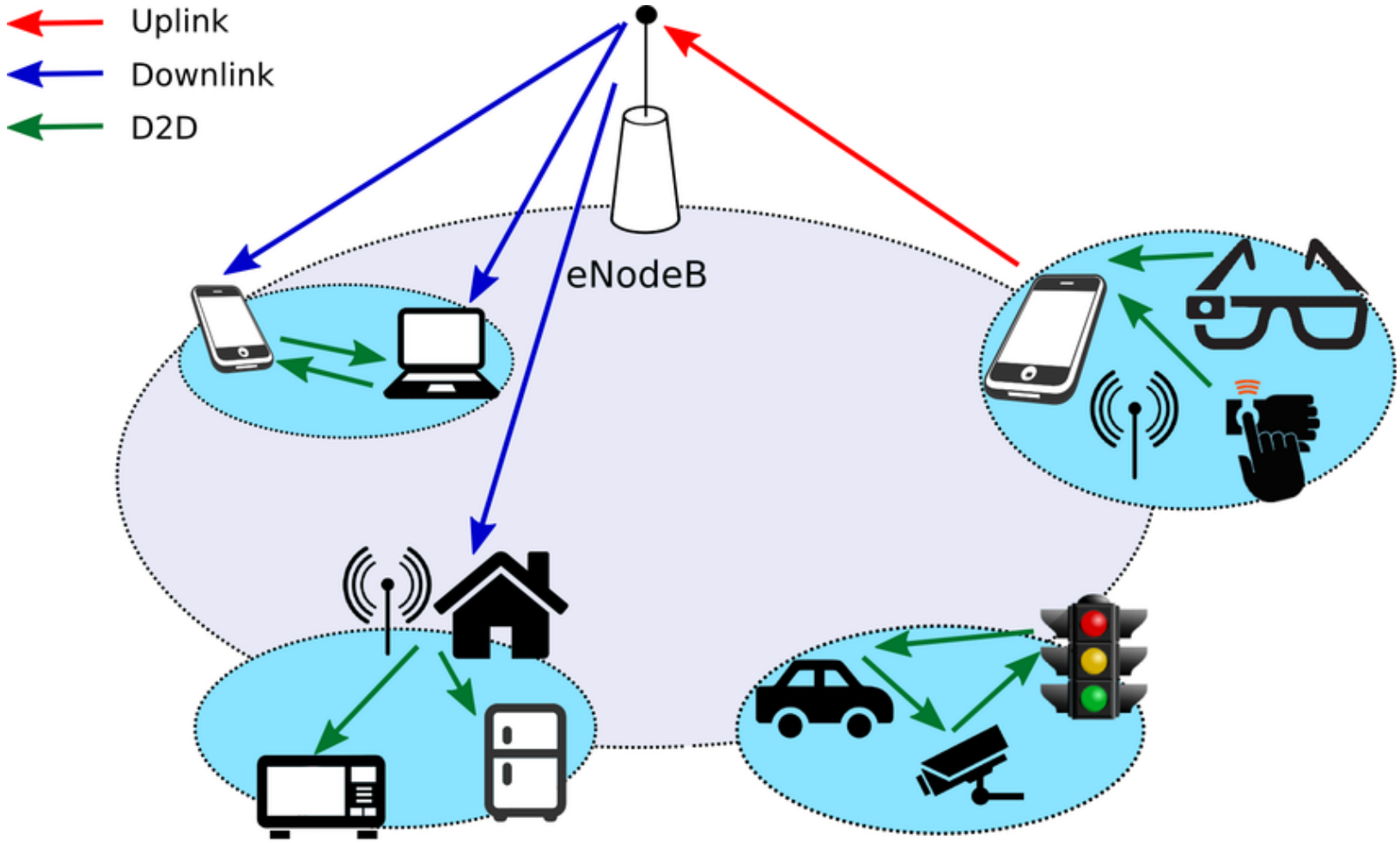


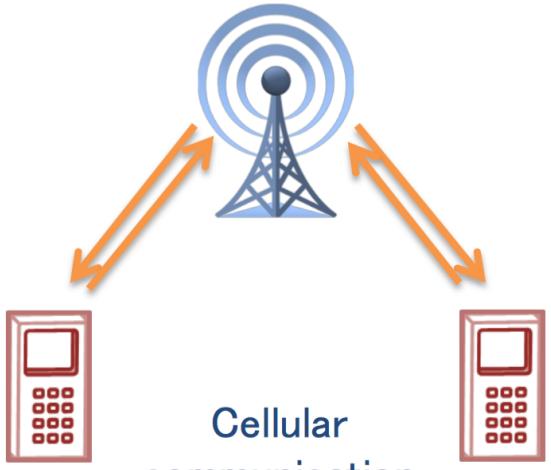
With IAB: One fiber link shared among multiple cells

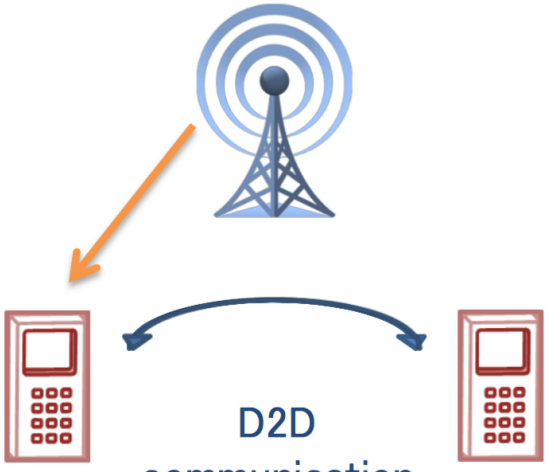
Mobile IAB (mIAB)



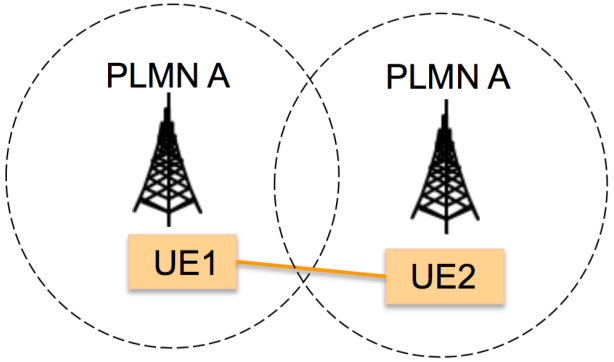
Proximity based Services in 5GS



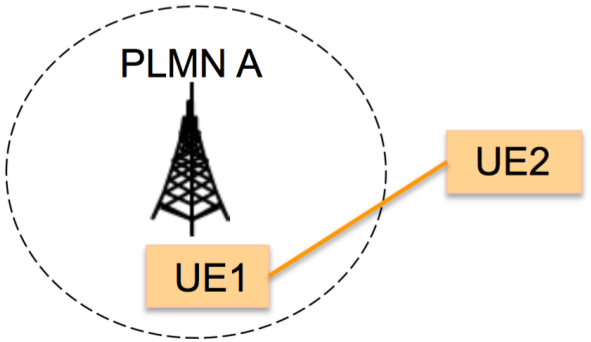




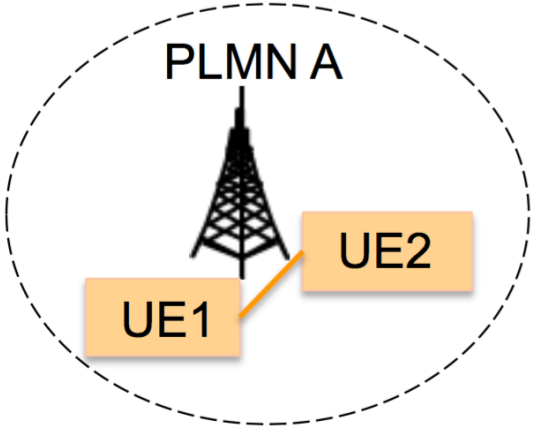
both out-of-coverage



both in-coverage:
same PLMN, different cells

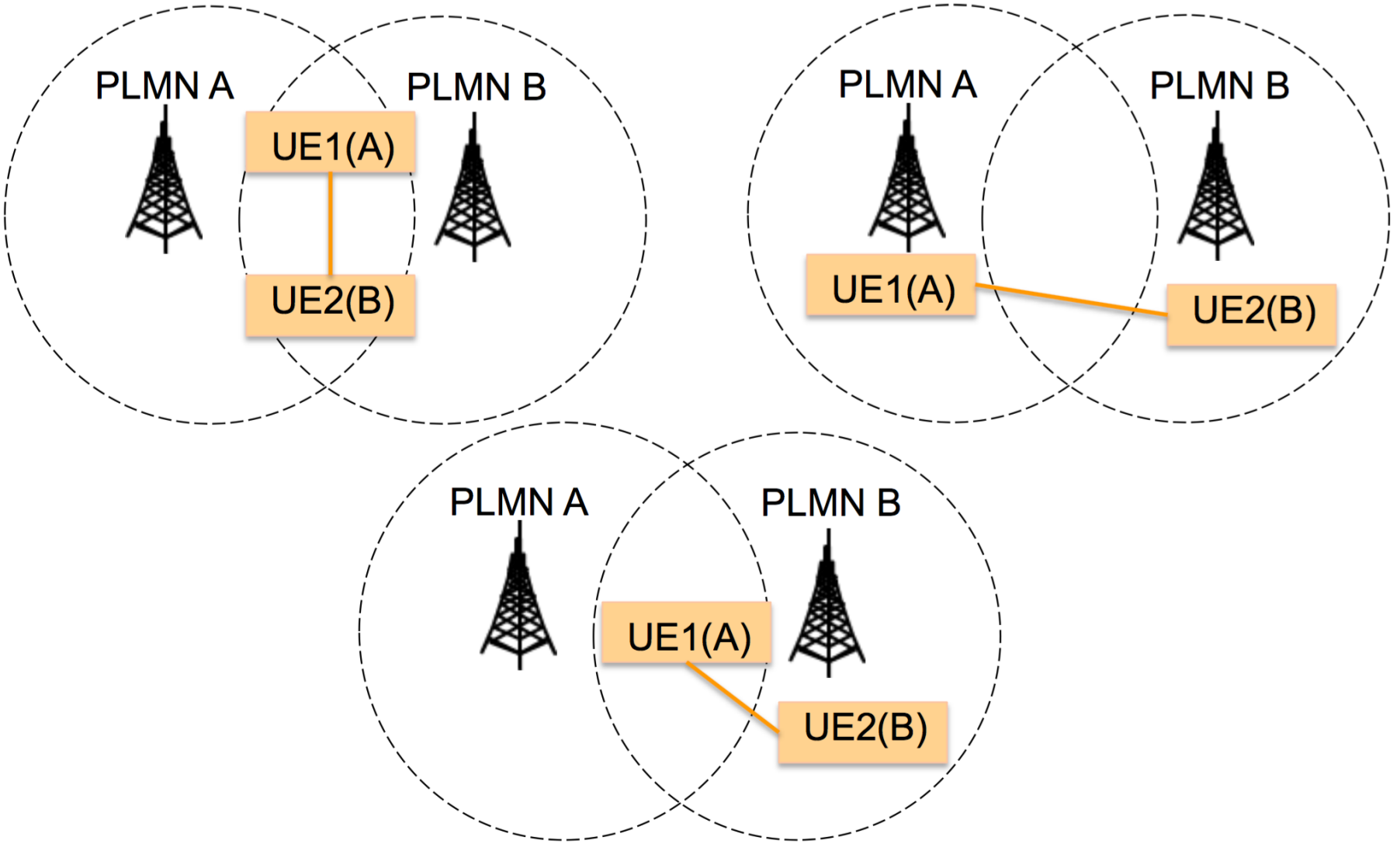


one in-coverage, one out-of-coverage

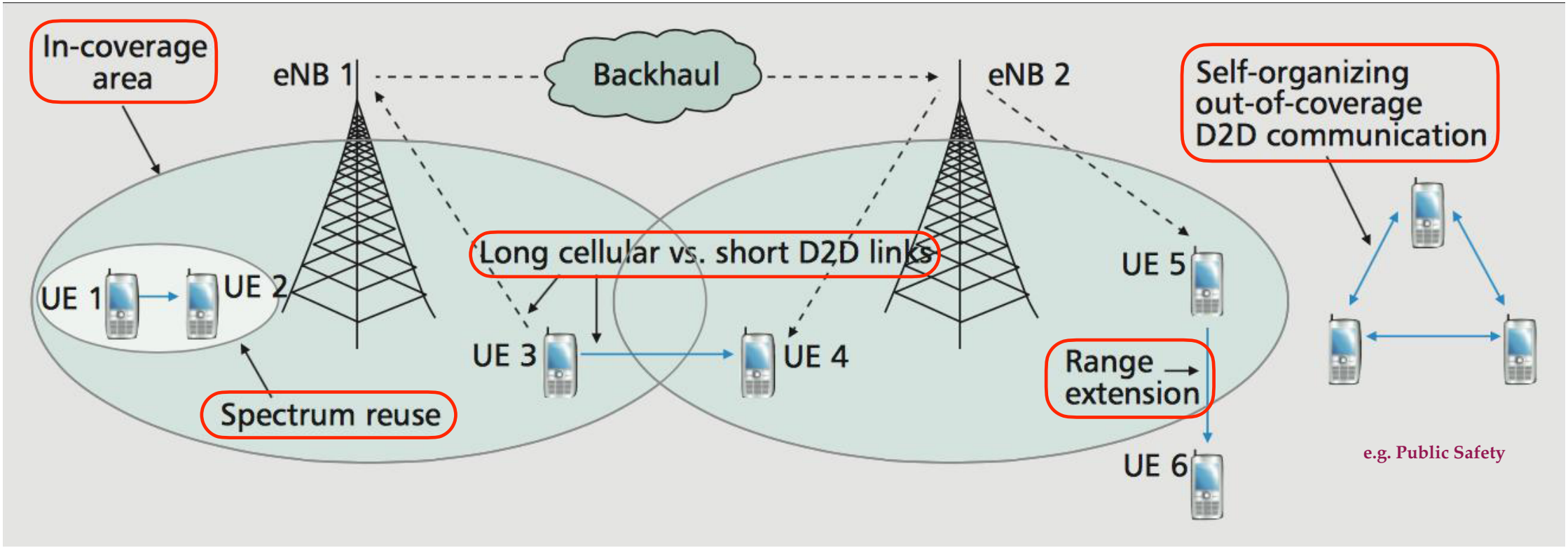


both in-coverage:
same PLMN, same cell

Source: TR 23.703

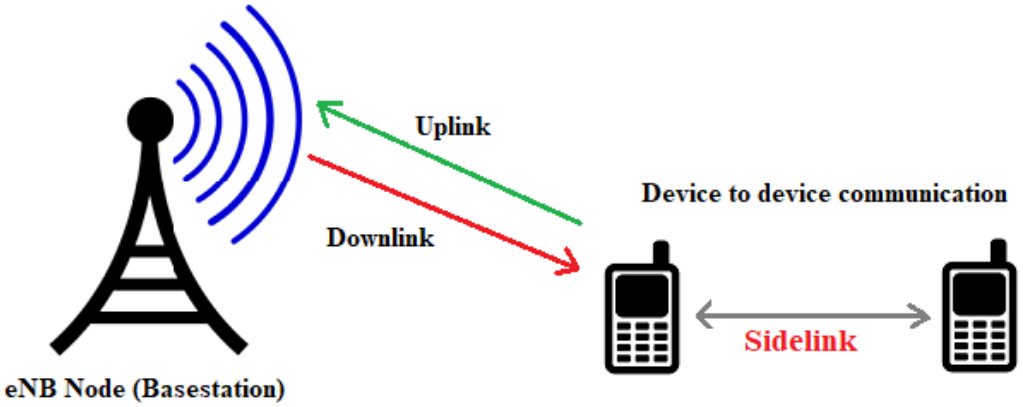


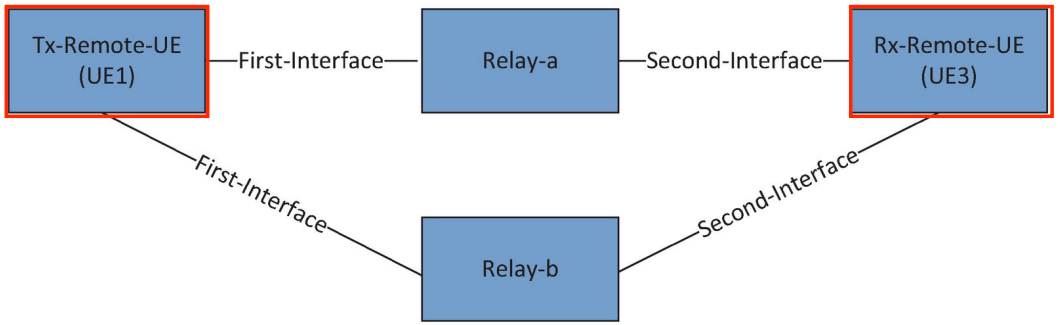
Source: TR 23.703

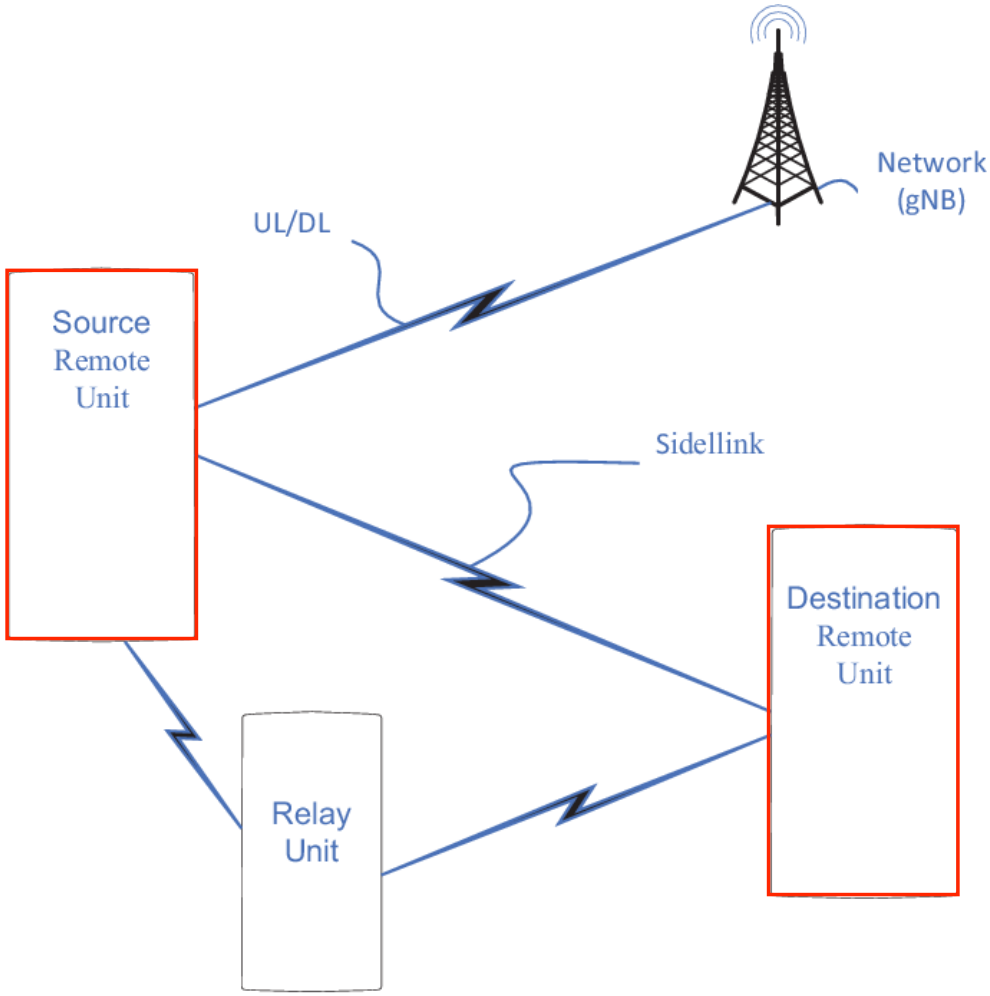


IEEE Communications Magazine, April 2014

NR Sidelink Enhancement







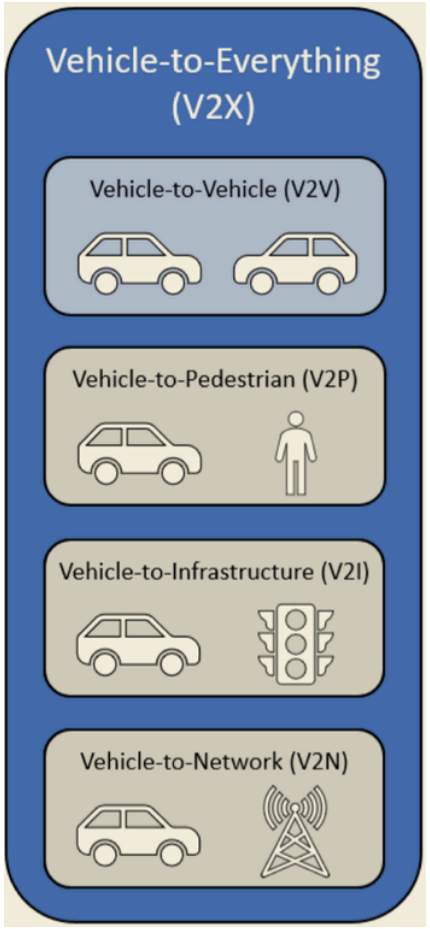
Sidelink Enhancements

- **Unlicensed spectrum**
  - Supporting optimized sidelink operations in unlicensed 5 and 6 GHz bands
- **Sidelink carrier aggregation**
  - Supporting enhanced use cases that can benefit from wider bandwidths
- **Multi-beam operation**
  - Supporting sidelink beam management by reusing and enhancing existing framework and concepts

Sidelink Relay Enhancements

- **Device-to-device relay**
  - Allowing single-hop operation for unicast with forward compatibility for more hops
- **Multipath relay & UE aggregation/switching**
  - Enhancing reliability and throughput for 1 direct (Uu) + 1 indirect (PC5 or ideal link) path within the same cell
- **Service continuity enhancements for UE-to-NW relay**
  - Supporting inter-gNodeB mobility and intra-gNodeB indirect-to-indirect path switching
- **Discontinued reception (DRX) for sidelink relay operations**

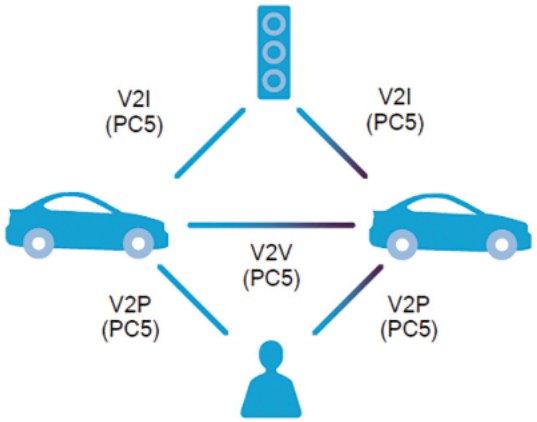
Vehicle to Everything (V2X)



C-V2X has two complementary communication modes

Direct (= Sidelink)

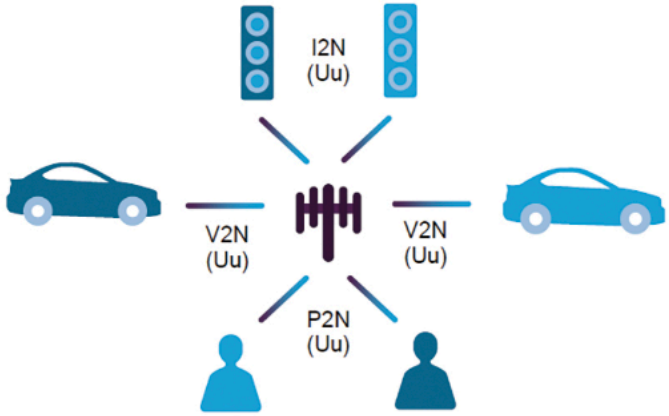
V2V, **V2I**, and **V2P** operating in ITS bands (e.g. ITS 5.9 GHz) independent of cellular network



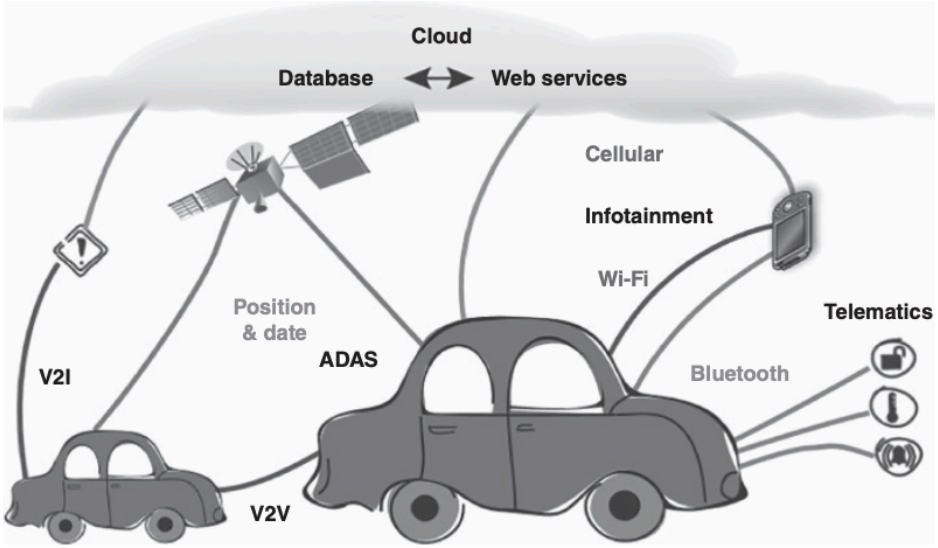
Short range (<1/2 mile), location, speed
Implemented over 3GPP's "PC5 interface"

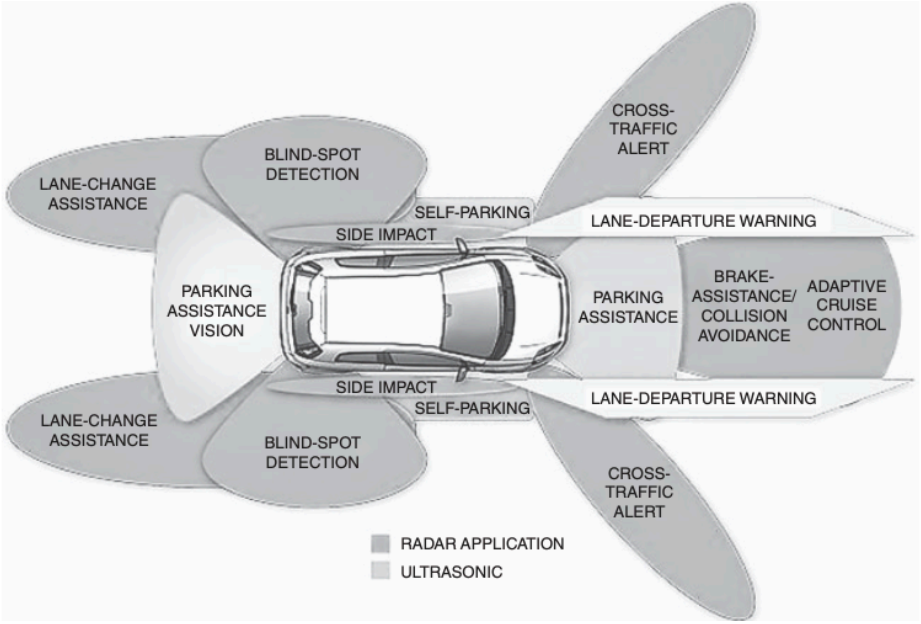
Network (= Up/Downlink)

V2N operates in traditional mobile broadband licensed spectrum



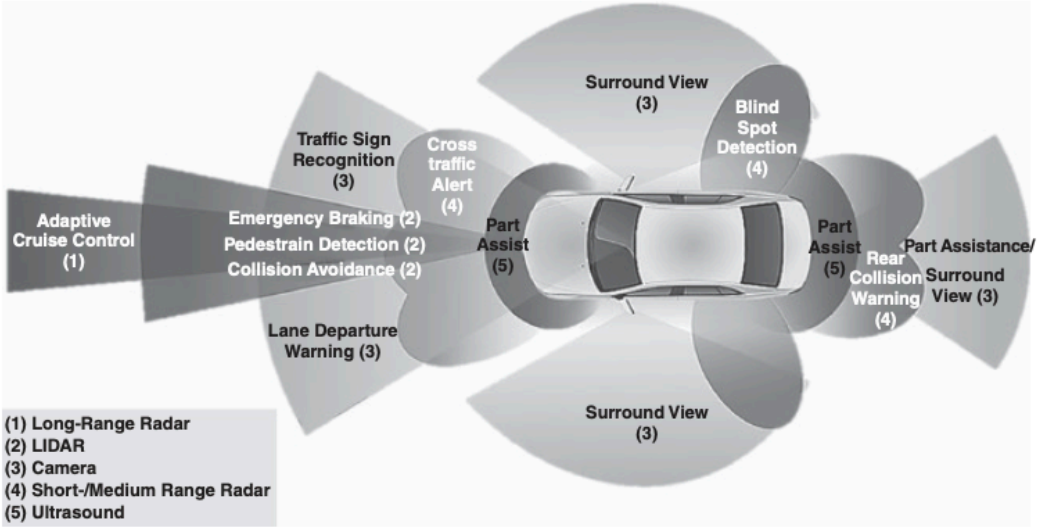
Long range (>1/2 mile), e.g. accident ahead
Implemented over "Uu interface"





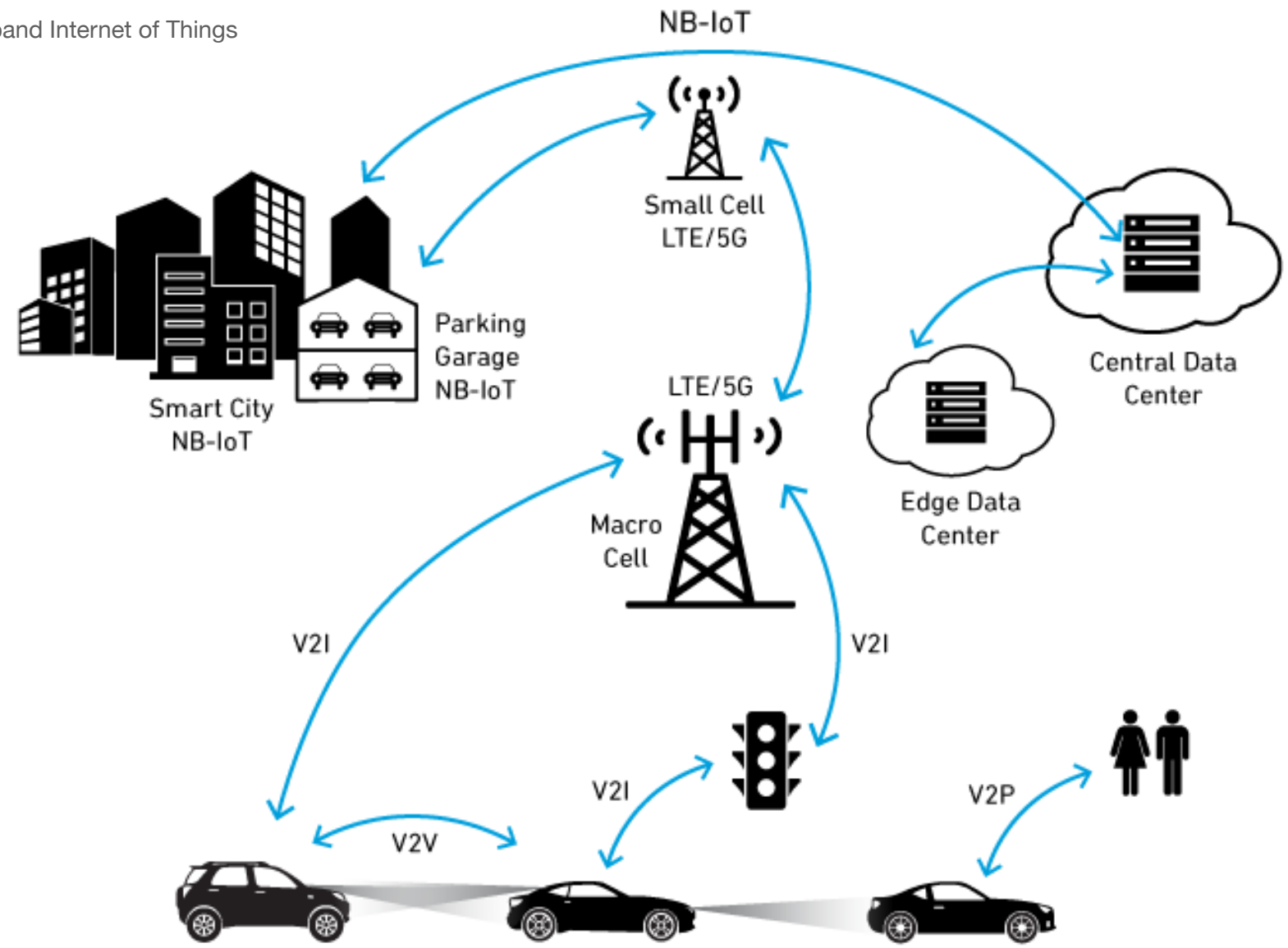
ADAS

- Adaptive Cruise Control (ACC)
- Automatic Emergency Braking (AEB)
- Blind Spot Detection (BSD)
- Lane Departure Warning (LDW) and Lane Keeping Assist (LKA)
- Traffic Sign Recognition (TSR)
- Cross Traffic Alert (CTA)
- Parking Assistance Systems
- Adaptive Headlights
- Driver Monitoring Systems (DMS)
- Night Vision Systems
- Connected ADAS
- Automated Highway Driving Assist (AHDA)

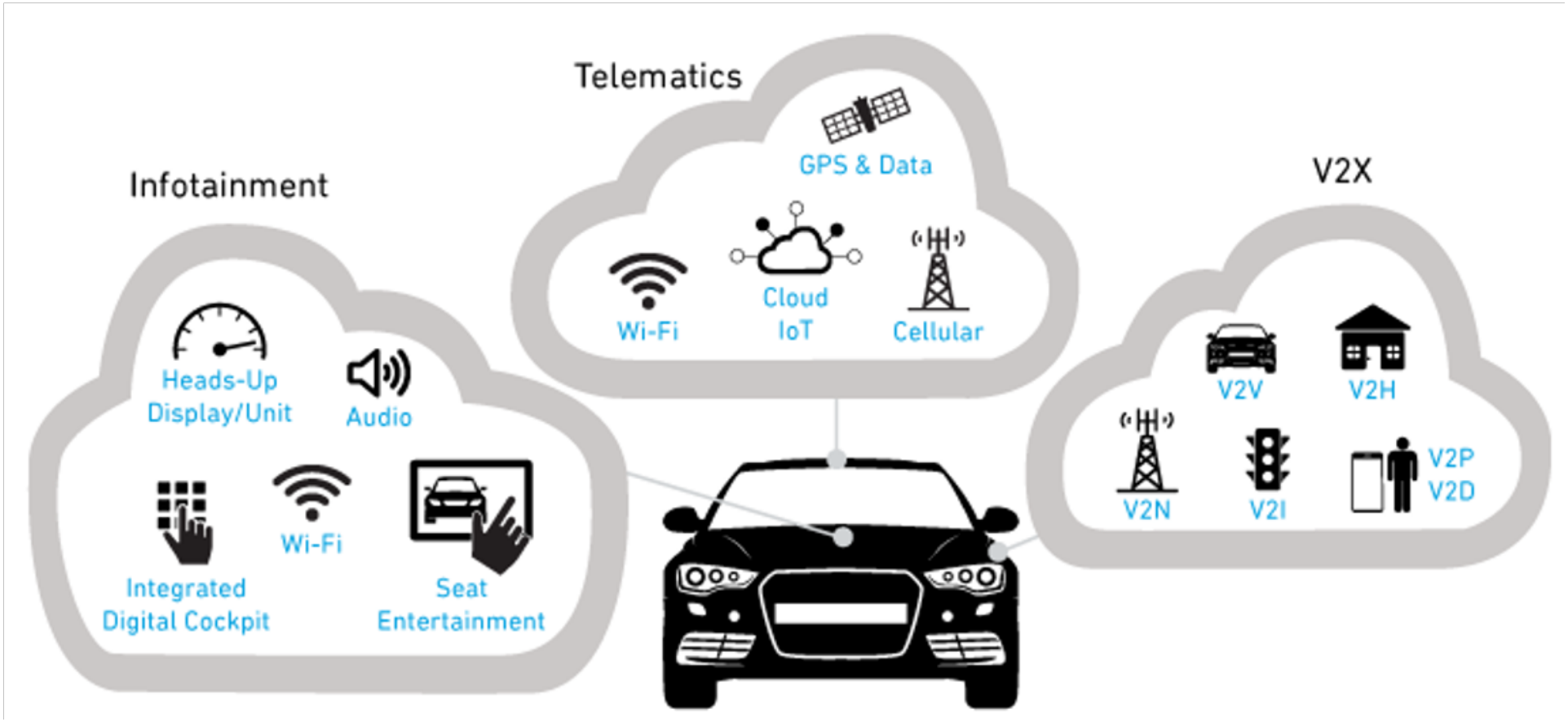


ADAS：Advanced Driver Assistance Systems　**LiDAR**：Light Detection and Ranging

NB-IoT：Narrowband Internet of Things

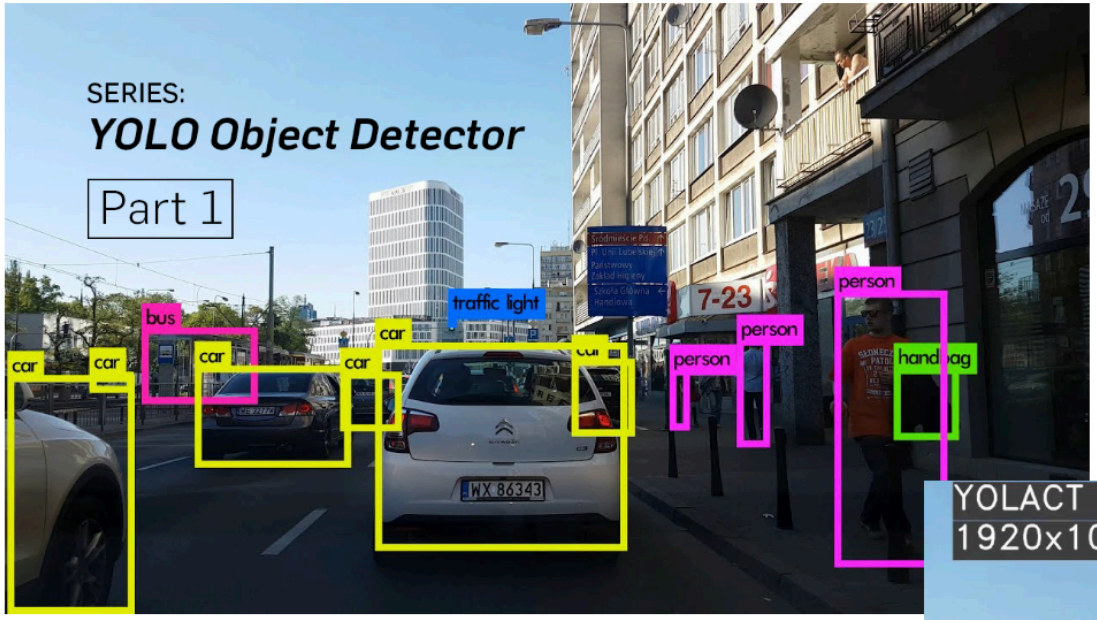


V2X: Connecting to Environment



ML Assisted V2X

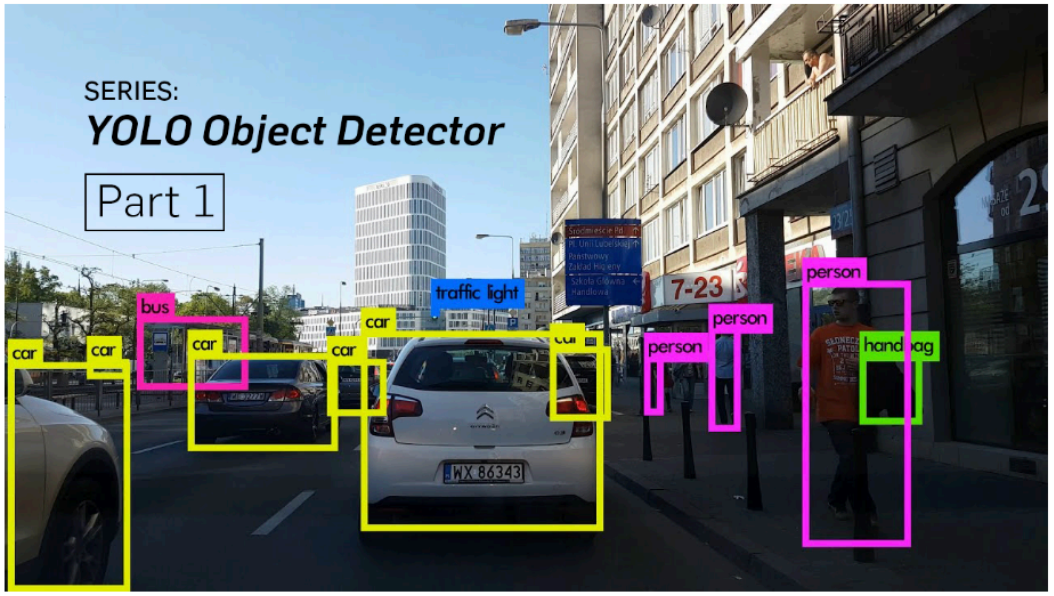
- Using ML coupled with data from sensors to observe and extract features of the environment around the vehicles
- Feature detection algorithms draw bounding boxes around objects in an image to identify them
- Semantic segmentation marks the pixels of an image as representing different objects
- AVs are outfitted with multiple cameras for varying view angles
- Still possible for a vehicle's view to be hidden if an important object is hidden behind some other obstacle



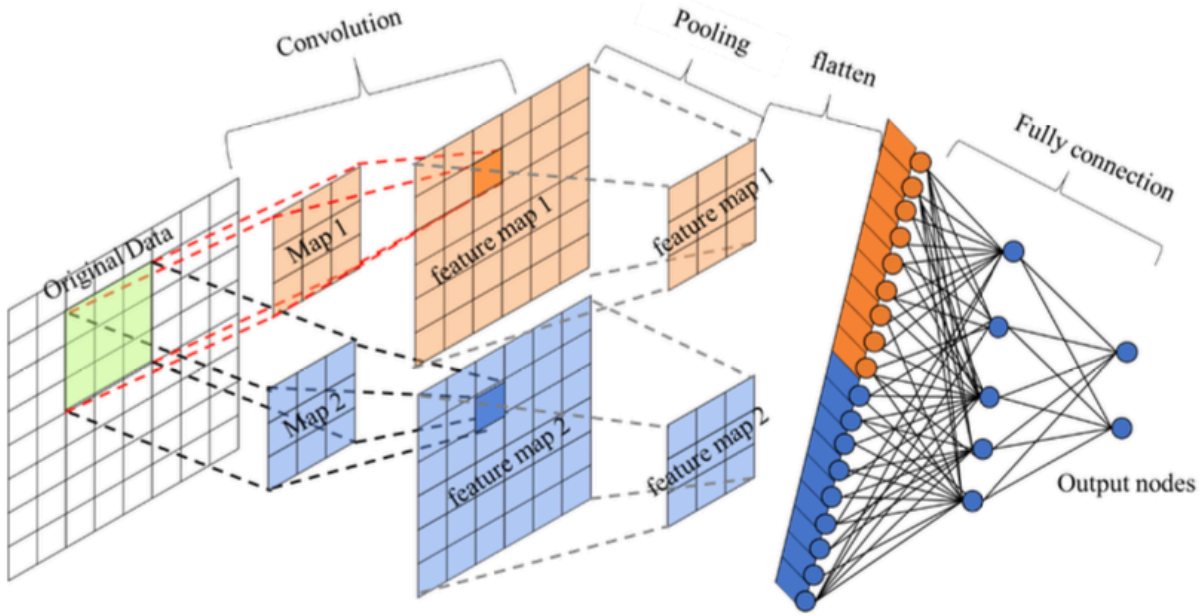
YOLO (You Only Look Once):
a popular object detection model
known for its speed and accuracy.

- **Data fusion**
  - The features of deep CNN models are shared between communicating vehicles to improve object detection in AVs
  - Packet loss and delay can cause significant negative impacts on data fusion performance in V2V networks
  - ML models for data fusion must be able to perform inference in real-time, which limits their complexity

- **Collaborative vision**
  - Instead of sharing raw data, objects are processed and locations are transmitted to other vehicles to reduce bandwidth requirements
  - Relies on YOLO for constructing bounding boxes, and DenseNet for object classification

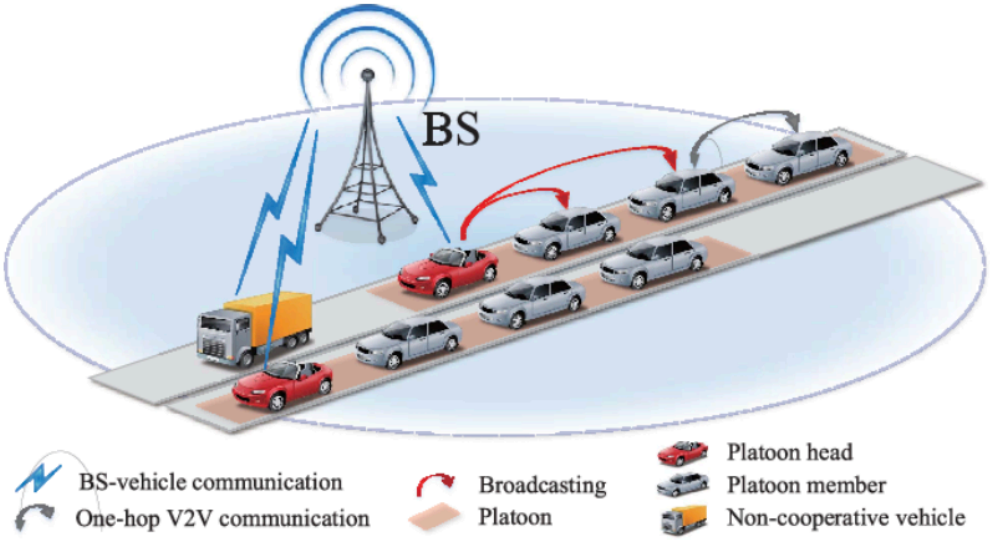


- **Selecting data to be transmitted**
  - Compresses feature maps using a CNN
  - If certain data has higher importance than others, it may optimal to give priority to more important transmissions by canceling or delaying others

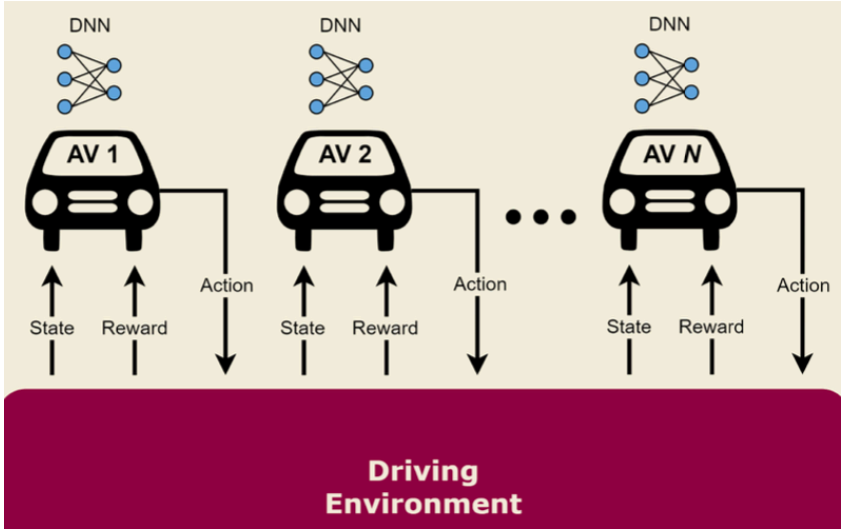


- **Safety and collision avoidance**
  - System data sharing
  - Environment data sharing
  - Detecting driver fatigue

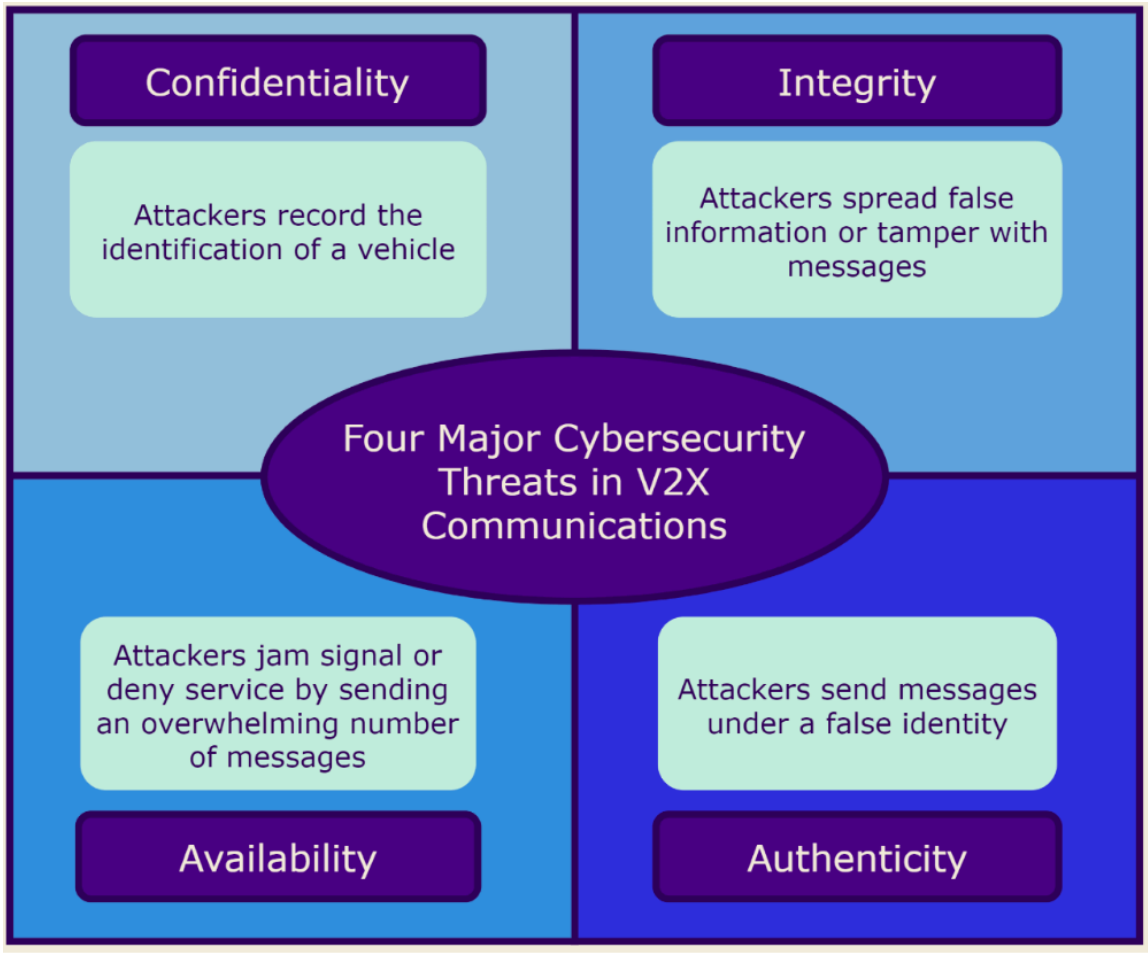
- **Collaborative traffic**
  - Urban traffic and highway
  - Optimal traffic control
  - Vehicle platooning
  - Higher road utilization, which reduces traffic
  - Less wind resistance, which reduces fuel consumption



- **Multi-agent learning**
  - Deep multi-agent reinforcement learning (DMARL)
  - In DMARL, each agent uses a DRL technique to optimize some function
  - Multiple agents collaborating to solve an optimization problem is also known as decentralized optimization, which cooperatively control each other's speeds using V2V communications



- **Common cybersecurity threats**
  - Integrity
  - Authenticity
  - Confidentiality
  - Availability



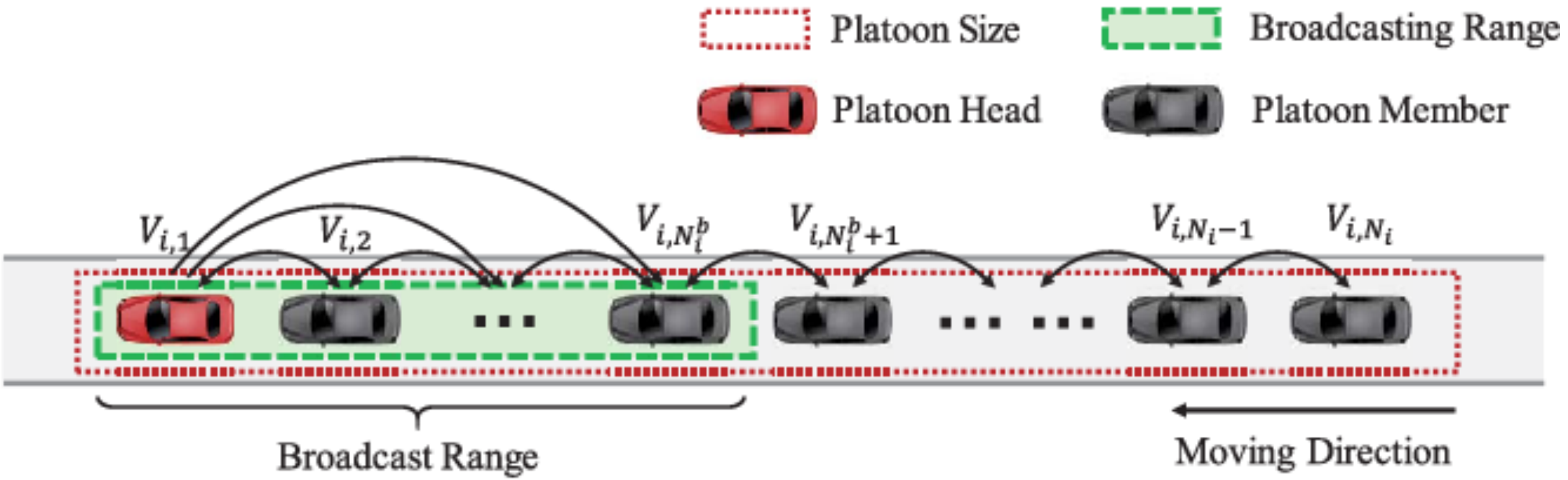
V2X Phases

- LTE sidelink
- V2N, V2V, V2P, V2I
- Multimedia service
- Initial 5G studies

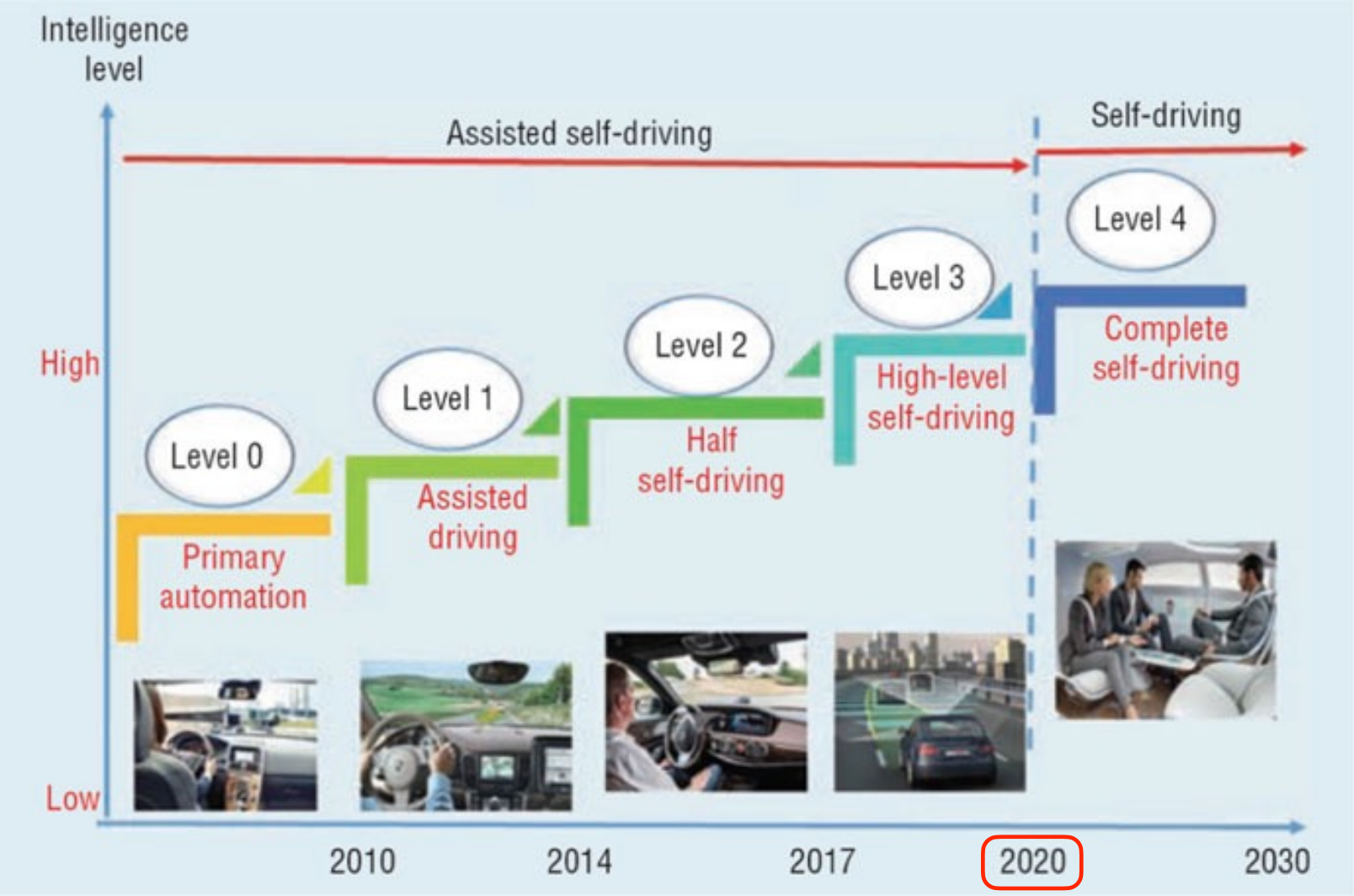
- eMBB & initial URLLC
- Flexible numerology
- Advanced coding
- 64-QAM modulation
- Short TTI (Transmission Time Interval)

- Enhanced URLLC
- Higher throughput
- NR sidelink
- 256-QAM modulation
- Network slicing

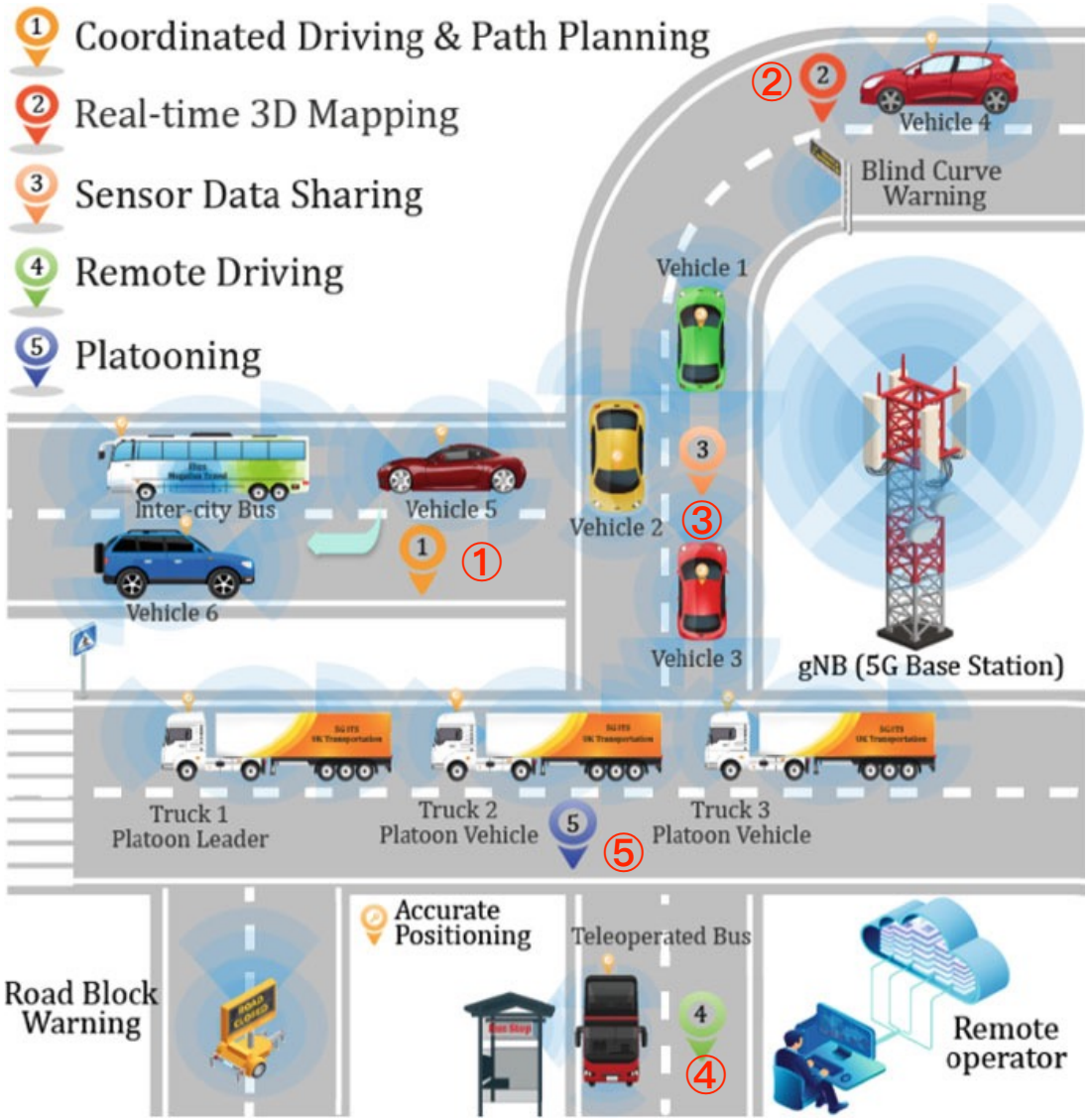
V2X Phase 3: Platooning Extended Sensors, Automated Driving, Remote Driving


Platoon Size
Broadcasting Range
Platoon Head
Platoon Member
$V_{i,1}$
$V_{i,2}$
V_{i,N_i^b}
V_{i,N_i^b+1}
V_{i,N_i-1}
V_{i,N_i}
Broadcast Range
Moving Direction

Evolutionary Roadmap of Autonomous Driving



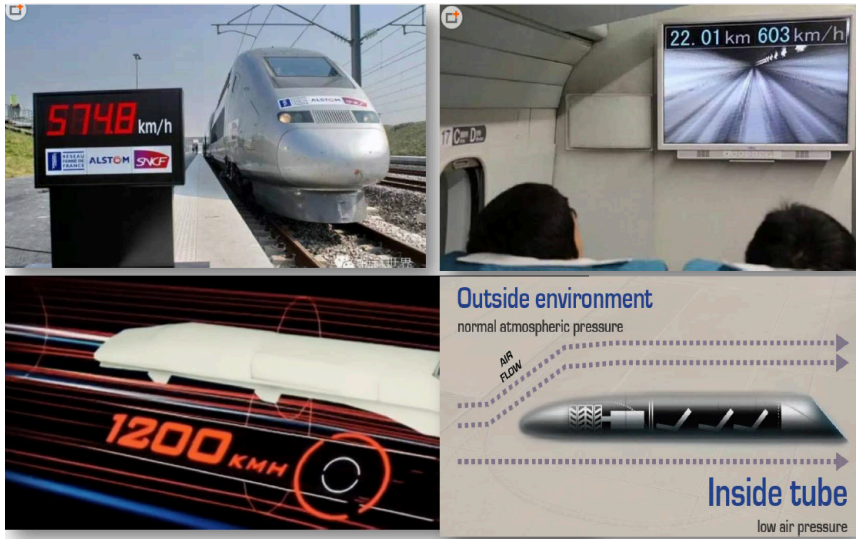
Advanced Use Cases and Services Envisioned in 5G-V2X

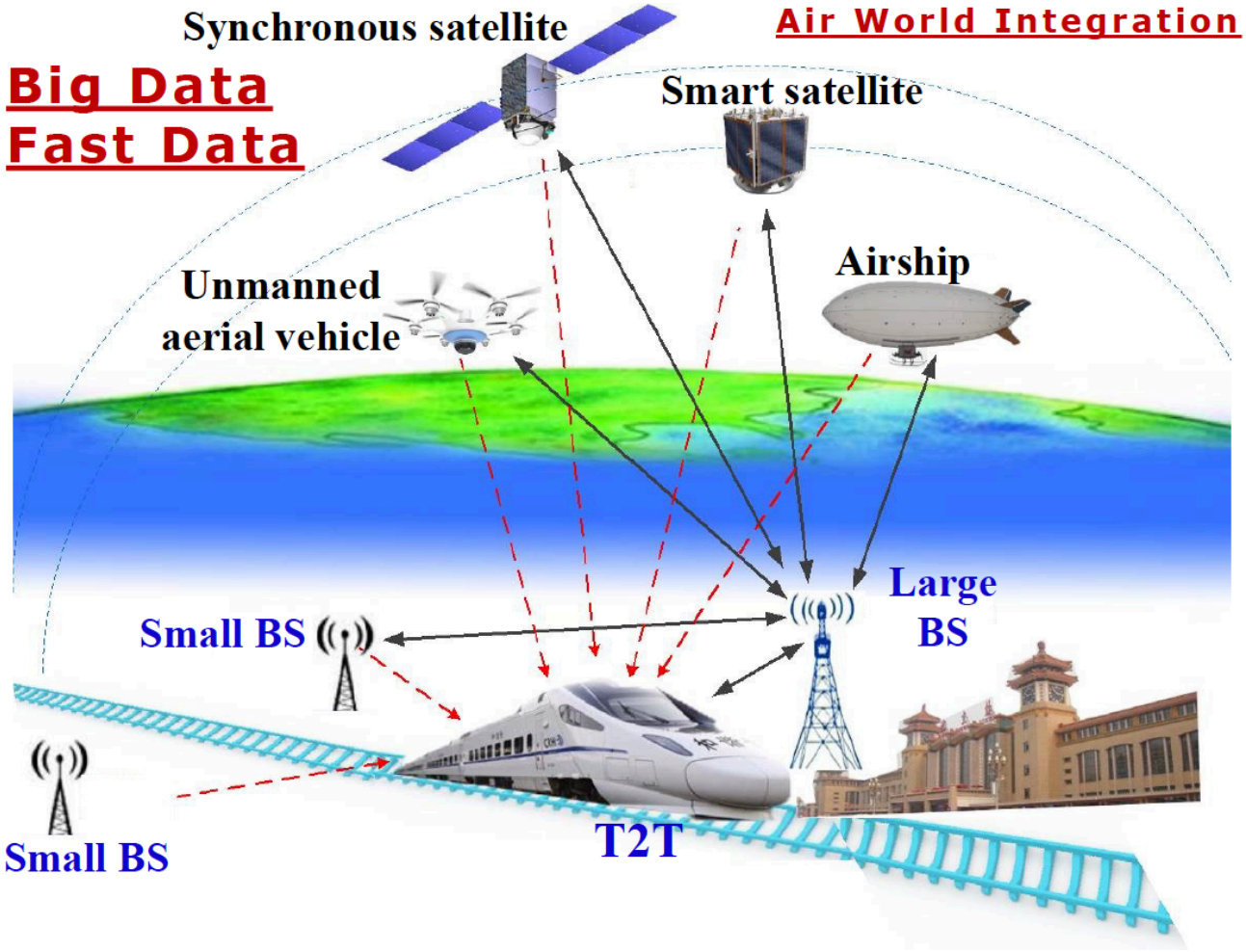


- **Machine learning**
  - Perform robust detection by processing large data streams
  - Classifying types of malware, simulating attacks
  - Defending against adversarial visual attacks on sensors such as cameras
  - Providing fallback solutions for safe driving in case an intrusion does occur

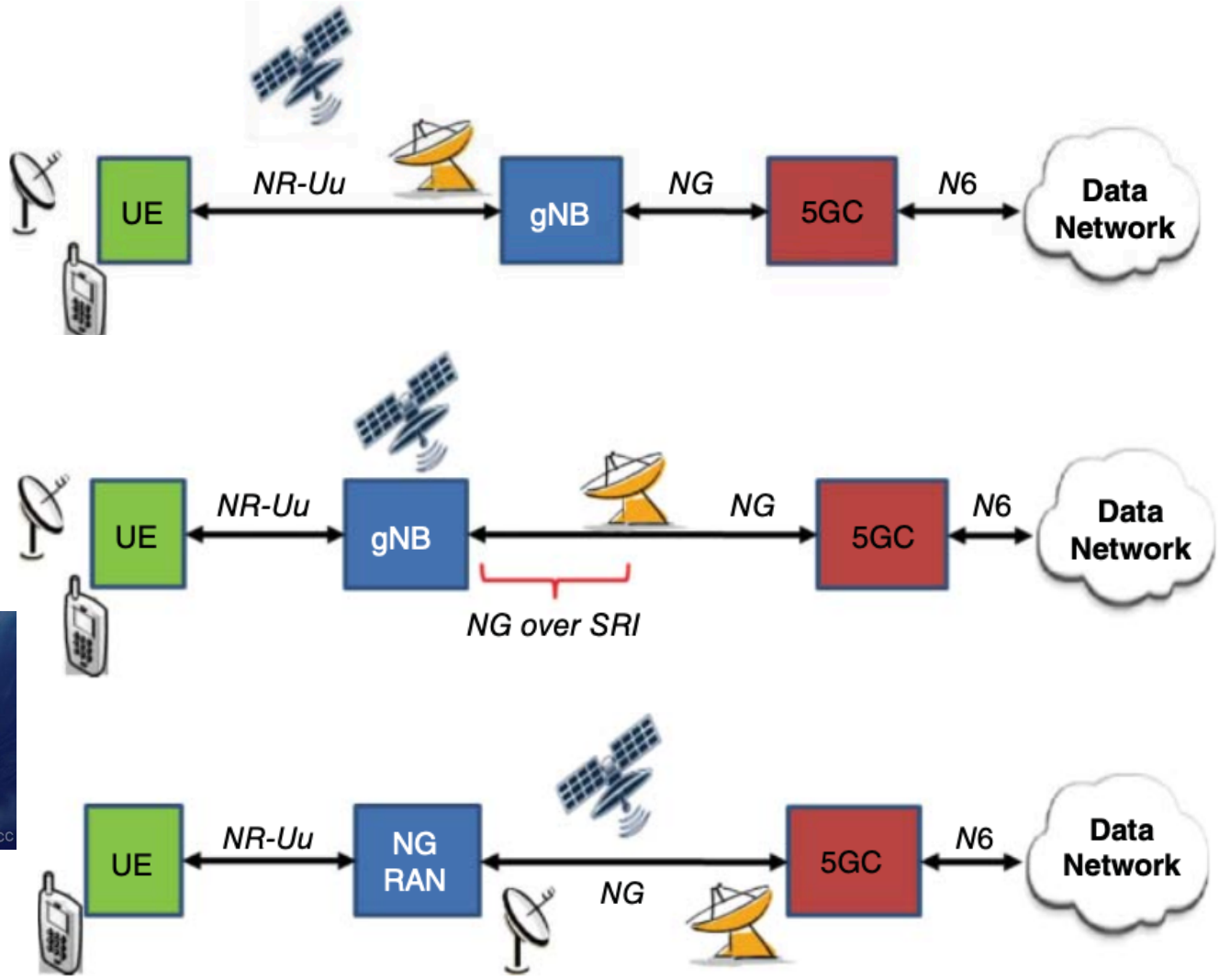
5G Railway

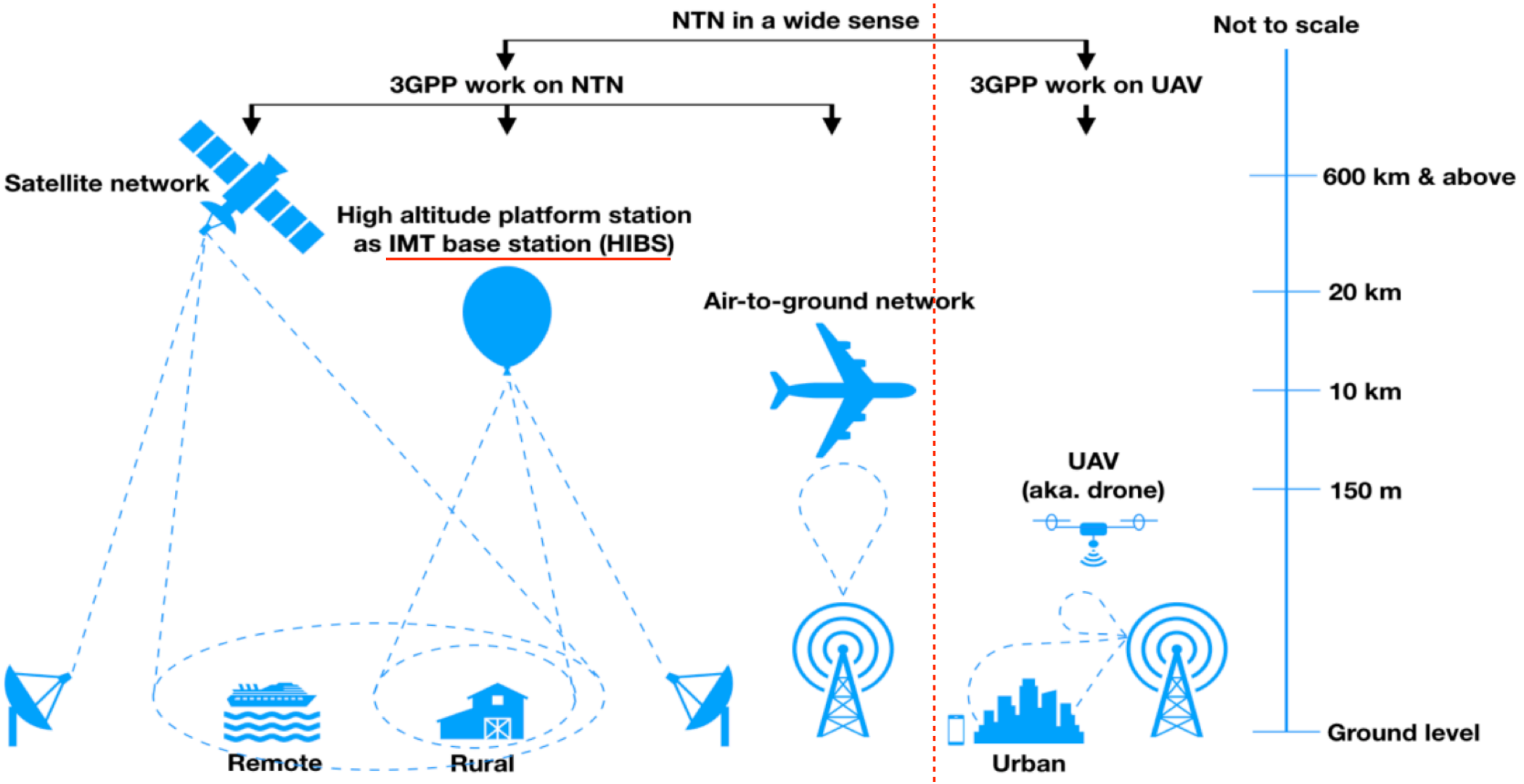
Services Category	Services Attribution	Use Case Category
Railway Safety-Critical Services	Train Control and Operation Services	Intelligent Transportation and Control System
		Onboard and Wayside HD Video Surveillance
		Distributed Emergency Communication
		Remote Monitoring and Diagnosis System
Railway Non-Safety Services	Train Comprehensive Services	Train Information Distribution System
		Customized Passenger Supplementary Business
		Train Multimedia Entertainment System
Passenger-Oriented Services	Onboard Broadband Communication	Onboard Cloud Office
		Onboard HD Multimedia Entertainment System
		Onboard Instant Messaging
		Onboard Online Game
		Social Network Services for Passengers
		Remote Medical Assistance System
Internet of Things for Railways	Internet of Things for Railways	Intelligent Train Marshalling System
		Dynamic Crew Scheduling System
		Railway Mobile Ticketing Dynamic
		Passenger Luggage Safeguarding System
		Freight Management Information System
		Intermodal Container Management System


5748 km/h
ALSTOM
SNCF
22. 01 km 603 km/h
1200 KMH
Outside environment
normal atmospheric pressure
AIR FLOW
Inside tube
low air pressure

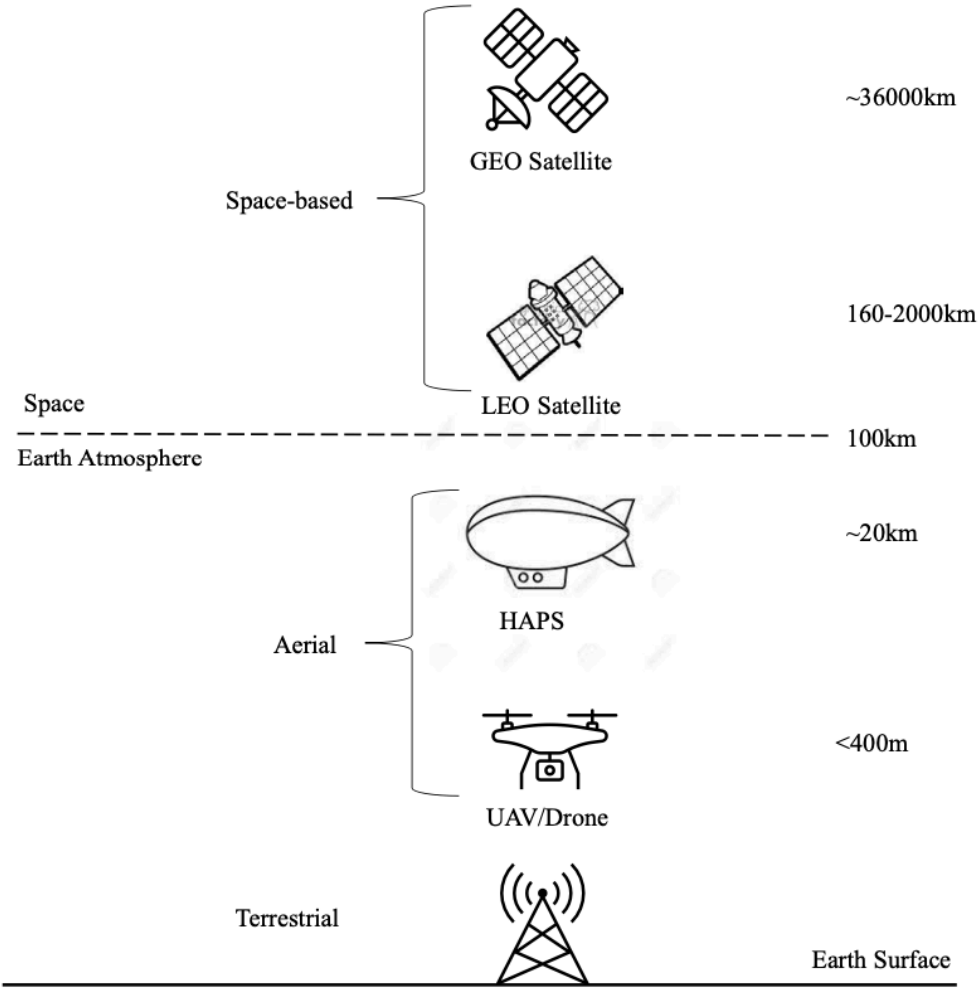

Synchronous satellite
Air World Integration
Big Data
Fast Data
Smart satellite
Airship
Unmanned
aerial vehicle
Large
BS
Small BS
Small BS
T2T

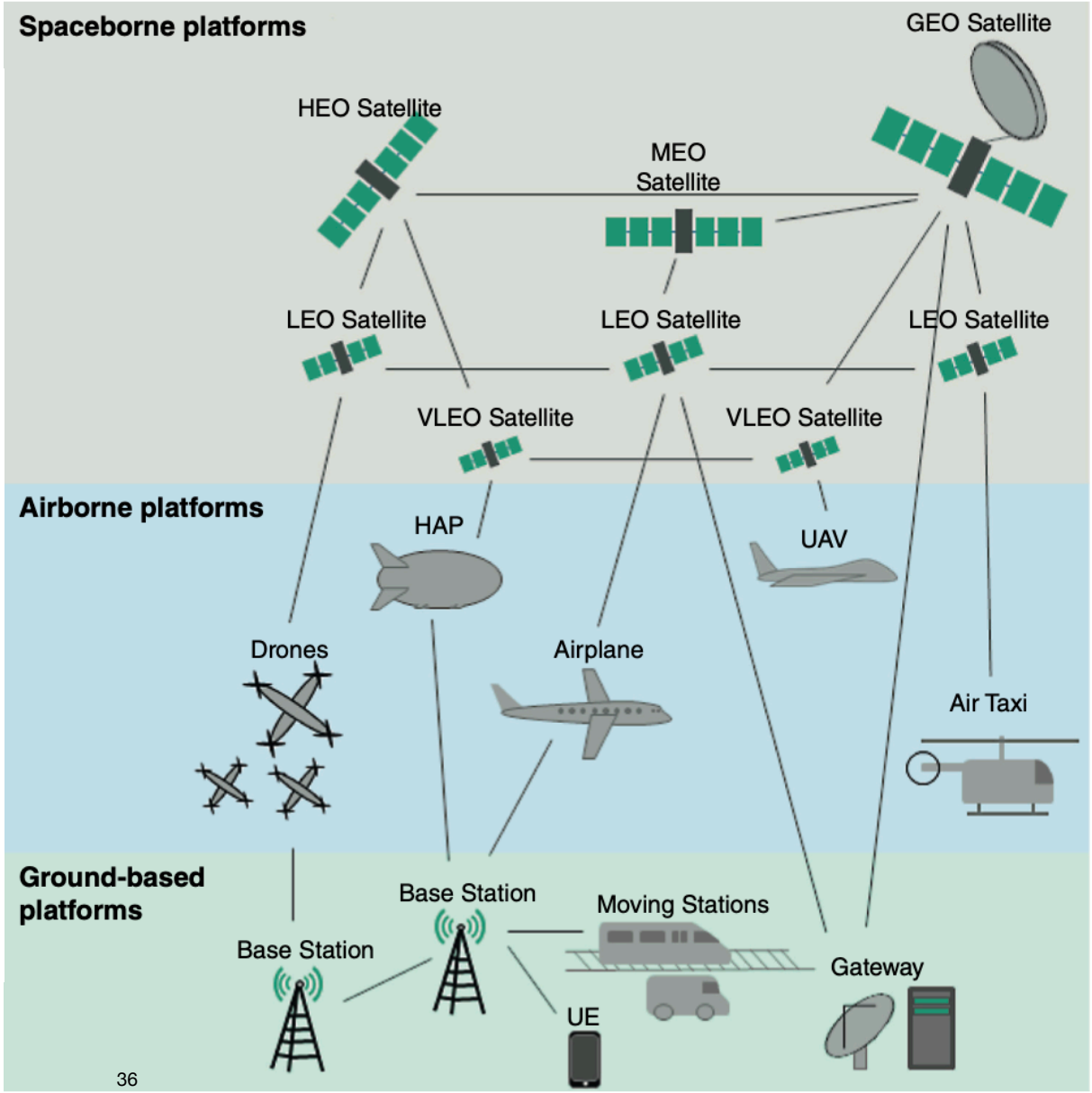
NR over Non-Terrestrial Networks (NTN)





HIBS：High altitude platform stations as IMT Base Stations

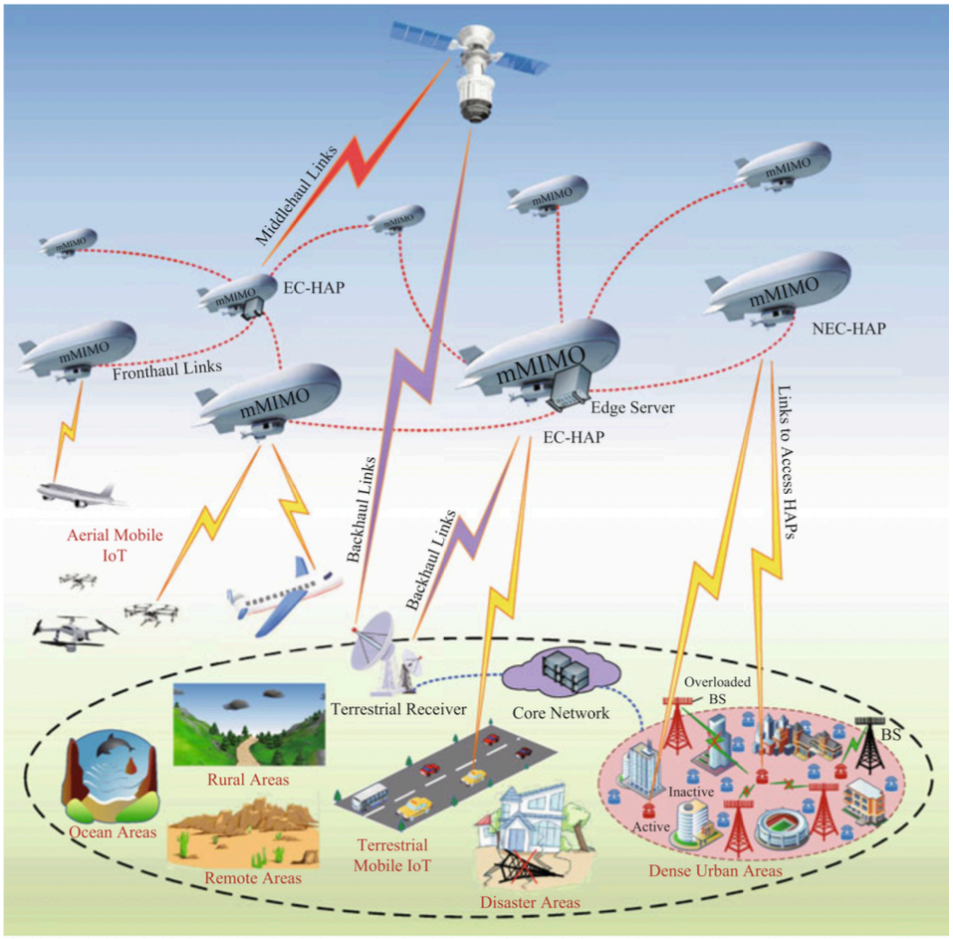




HAPS：High Altitude Platform Station

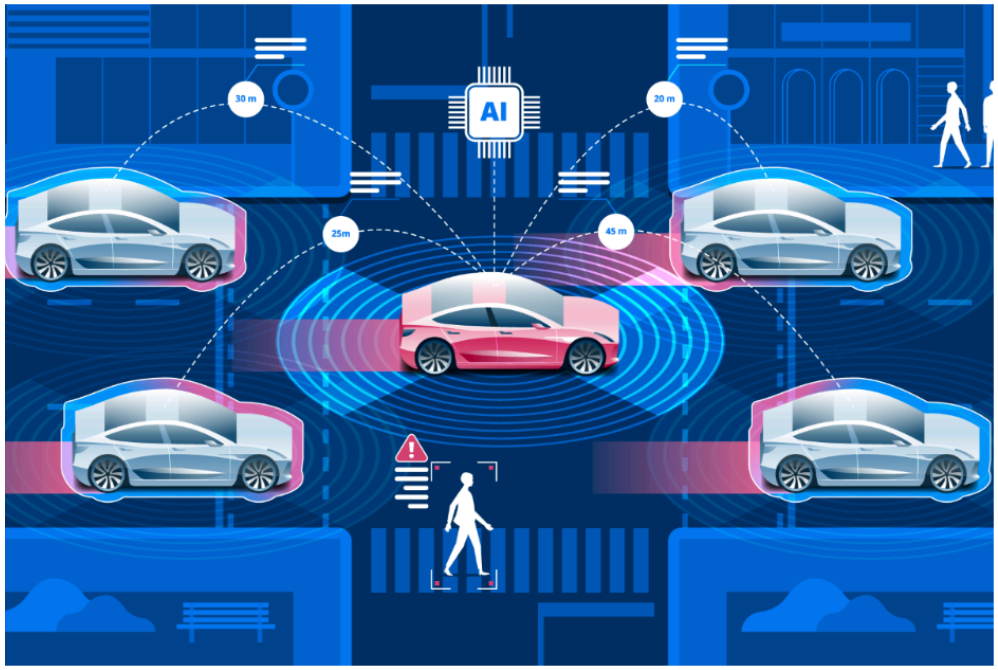
- Massive IoT access over High-Altitude Platform (HAP) networks
  - Improve the QoS for hotspot areas
  - Provide ubiquitous connectivity for remote areas
  - Emergency services for disaster areas
  - Support mobile IoT applications

- Improve the QoS for hotspot areas
  - Massive volume of data and computing tasks
  - IoT pose more strict signal processing requirements
  - HAP can assist the terrestrial systems for executing computing tasks



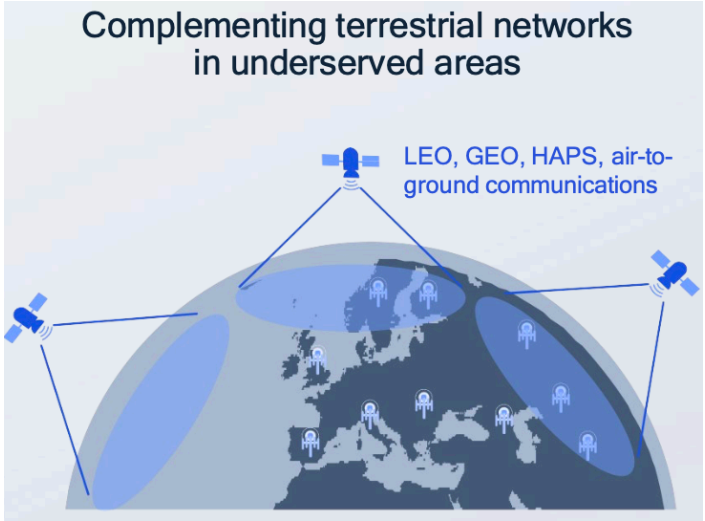
- Provide ubiquitous connectivity for remote areas
  - Roughly half the world population remains unconnected or poorly connected
  - Smart agriculture and environment protection
  - A low-cost solution providing a wide coverage is indispensable

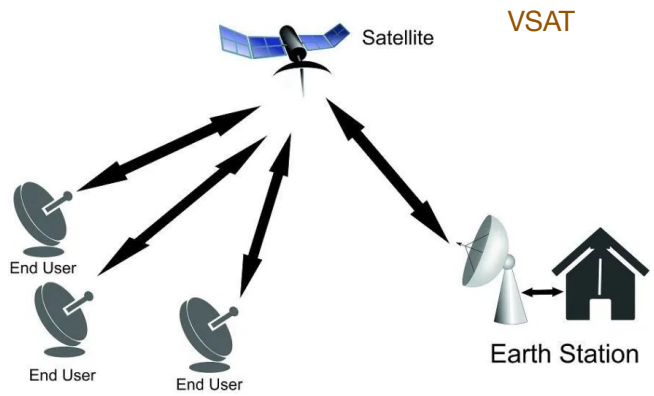
- Support mobile IoT applications
  - Autonomous driving and UAV communications
  - Terrestrial networks require a frequent BS handover
  - Improves reliability



5G NR for NTN

- Complementing terrestrial networks in underserved areas
  - Network verified device location based on satellites network
  - Coverage enhancements for voice and low-data rate services
  - Mobility enhancements for satellite and terrestrial networks
  - Deployment in 10+ GHz bands and support for VSAT/ESIM

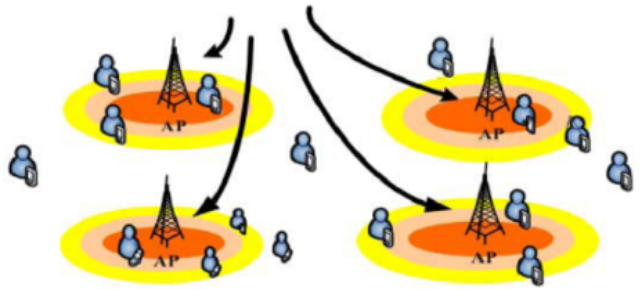




VSAT：Very Small Aperture Terminal　ESIM：Earth Stations in Motion

5G IoT for NTN

- Expanding addressable market for the 5G massive IoT
- Disabling HARQ feedback to mitigate impact of HARQ device data rate stalling
- Enhanced mobility such as neighbor cell measurements and extending to eMTC
- Enhanced GNSS operation for longer connections and reduced power consumption
- Enhancements discontinuous coverage



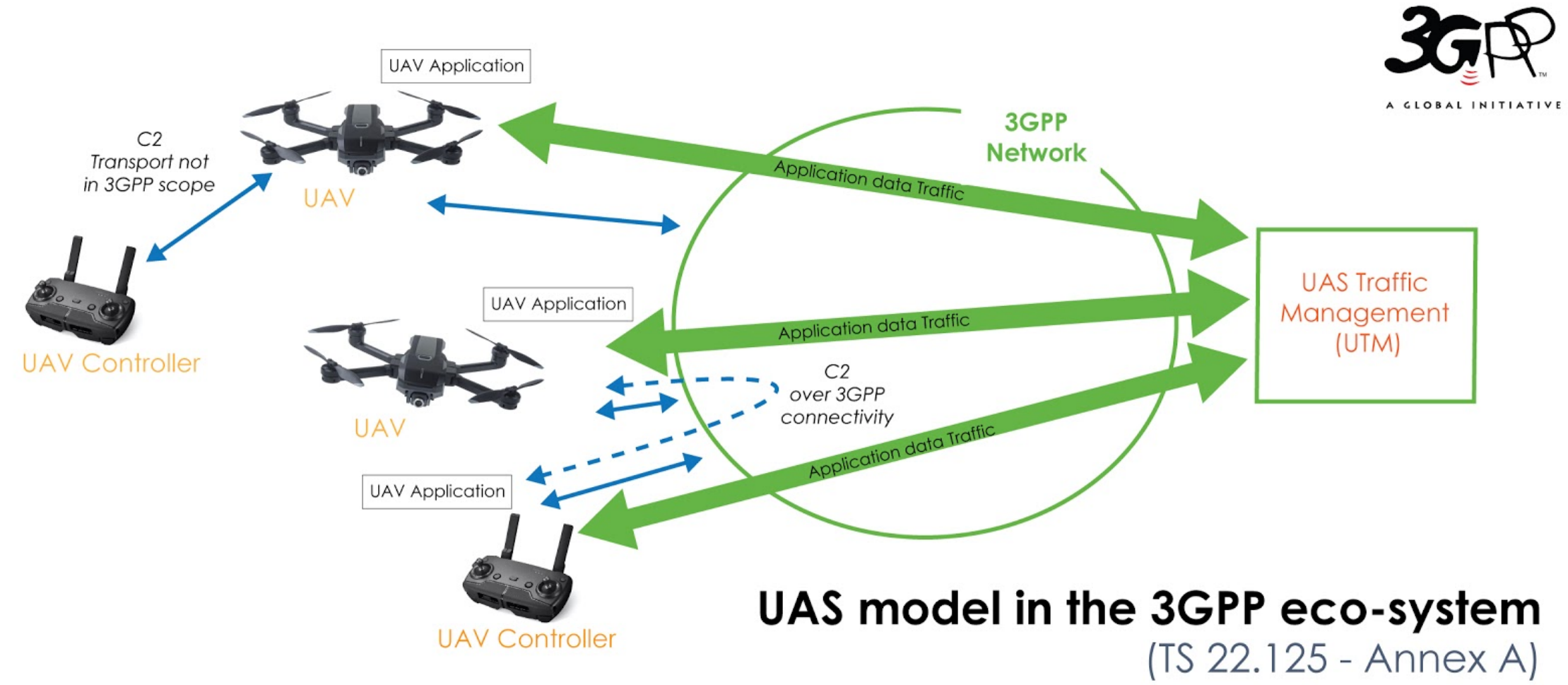
discontinuous coverage

5G NTN for Network Resilience

- **Provide backup communication channels**: NTN utilizes satellites or high altitude platforms that can provide backup communication channels when ground BSs fail, improving network resilience
- **Expand coverage**: satellites or high altitude platforms can cover long distances or remote areas, expanding network coverage and avoiding communication dead zones
- **Enhance load balancing**: dynamic load balancing can be achieved between satellites, high altitude platforms and ground BSs according to actual traffic demand
- **Support fast recovery**: NTN can be quickly deployed to restore interrupted ground communications in the event of a disaster
- **Provide network slicing**: dedicated network slices can be provided for critical communications to increase priority and resilience
- **Dual connectivity support**: support users connecting to both ground and NTNs simultaneously, enabling automatic failover

Unmanned Aerial Systems (UAS)

- **Unmanned Aerial Vehicles (UAV)**
  - Aircraft that operates without an onboard pilot and carries no passengers
  - Applications
    - Defence
    - Agriculture
    - Cinema
    - Tourism
    - Surveillance
- **Unmanned Aircraft Systems (UAS)**
  - A system, which incorporates various subsystems, e.g.
    - Aircraft
    - Ground control station
    - Launch and recovery system
    - Navigation system
    - Payload
    - Onboard computer



C2：Command-and-Control infrastructure

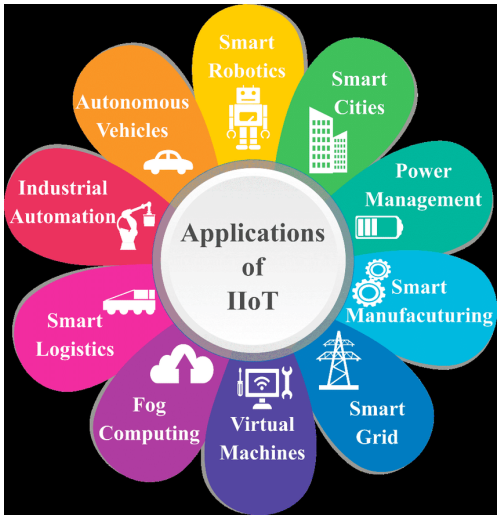
UAV (Drone) Support in 5G-Advanced

- Flight path reporting, height reporting etc. as in LTE
- Beamforming with UAVs to reduce interference they create
- Subscription based UAV identification
- UAV ID broadcast (ideally with unlicensed spectrum to avoid interference)

- Key benefits
  - UAV with HD-video stream transmission will create a lot of interference due to visibility to many BSs, thus use of 5G beamforming can greatly reduce the interference with the use of antenna directivity in UAVs
  - UAV identification important to secure responsible use of UAVs, avoiding interference for example to air traffic

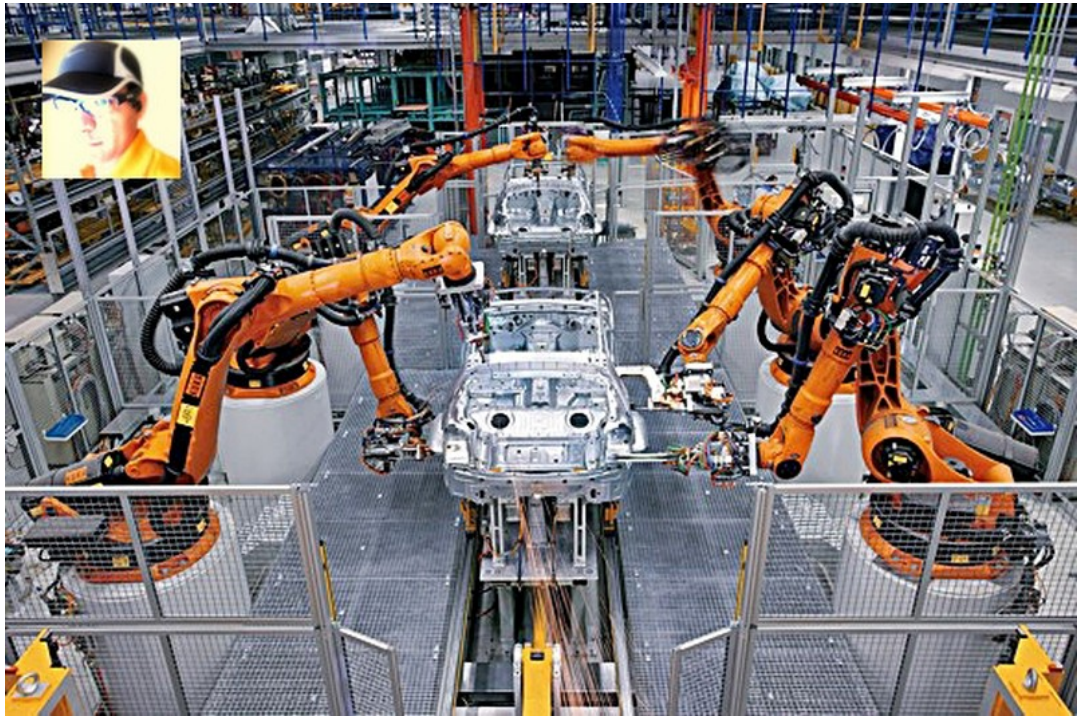
Massive Machine Type Communication (mMTC)

Industrial IoT



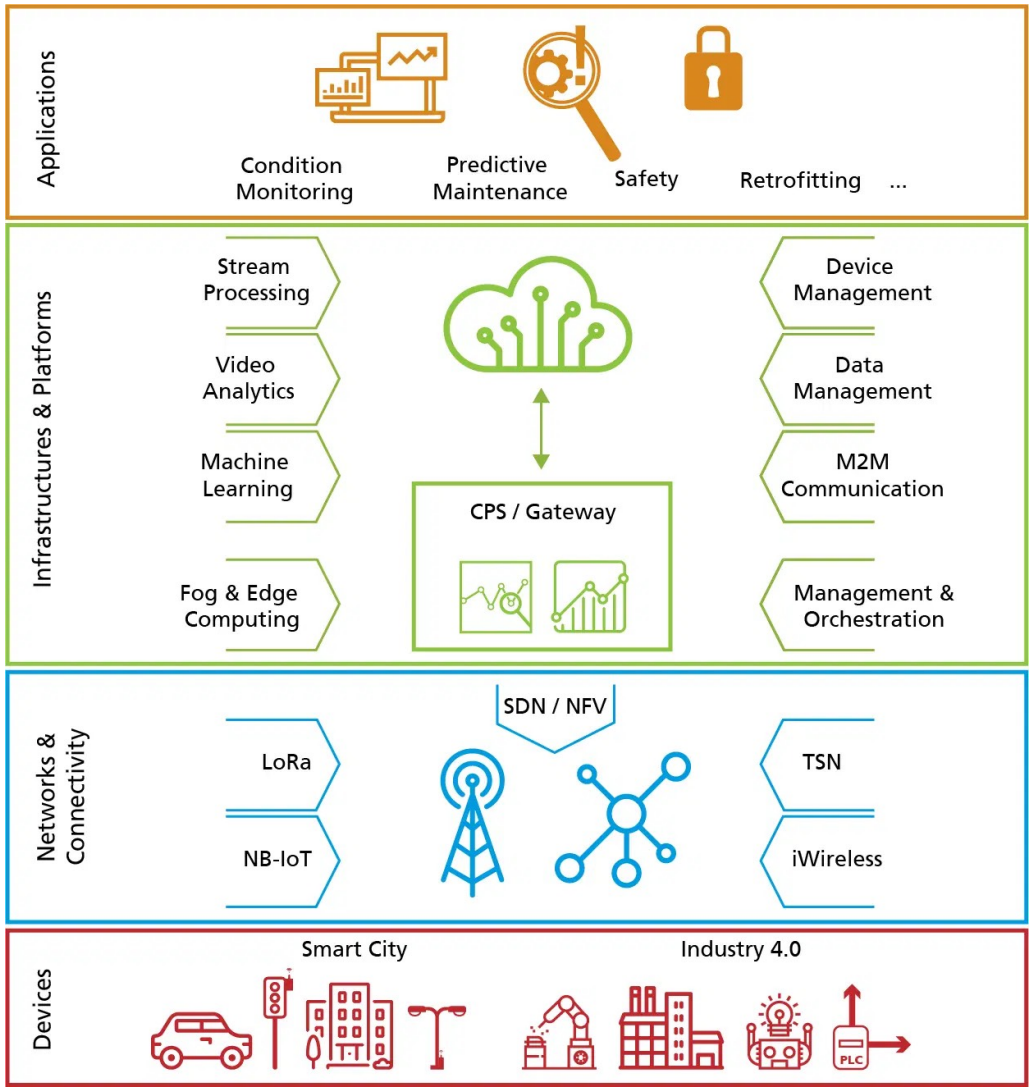
IIoT applications

IIoT is able to do …




Condition monitoring/
predictive maintenance
Advanced position,
force and material/
object sensing
Safe motion
control
Efficient/compact
power supplies
and chargers
Efficient/compact
servo motor drives
Virtual safety
fences w/
ToF and radar
scanners
Secured calibration,
logging and
authentication

IIoT Techs and Apps for Industry 4.0 and Smart Cities



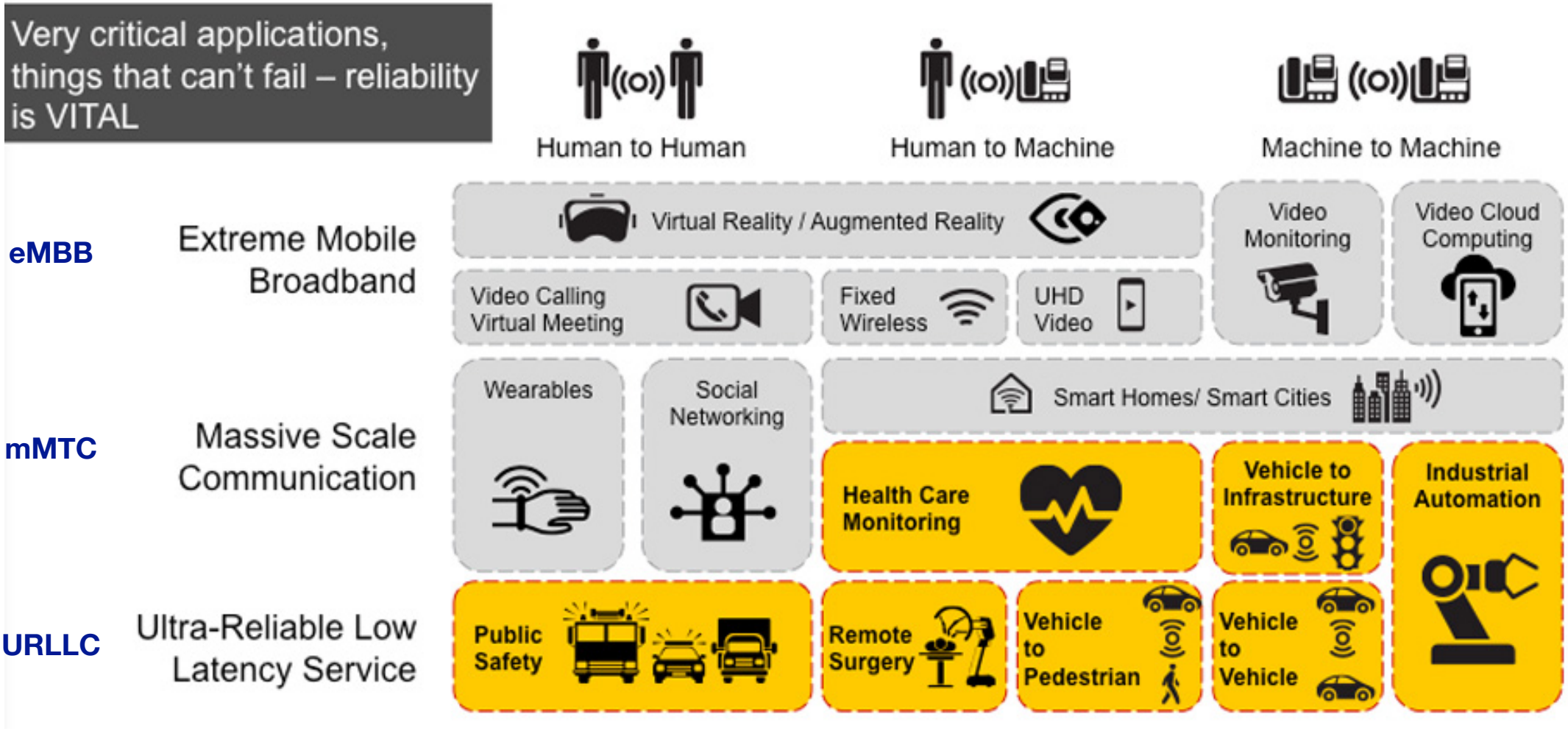
CPS：Cyber-Physical Systems
LoRa：Long Range
TSN：Time Sensitive Network

Cellular IoT (NB-IOT, CatM)

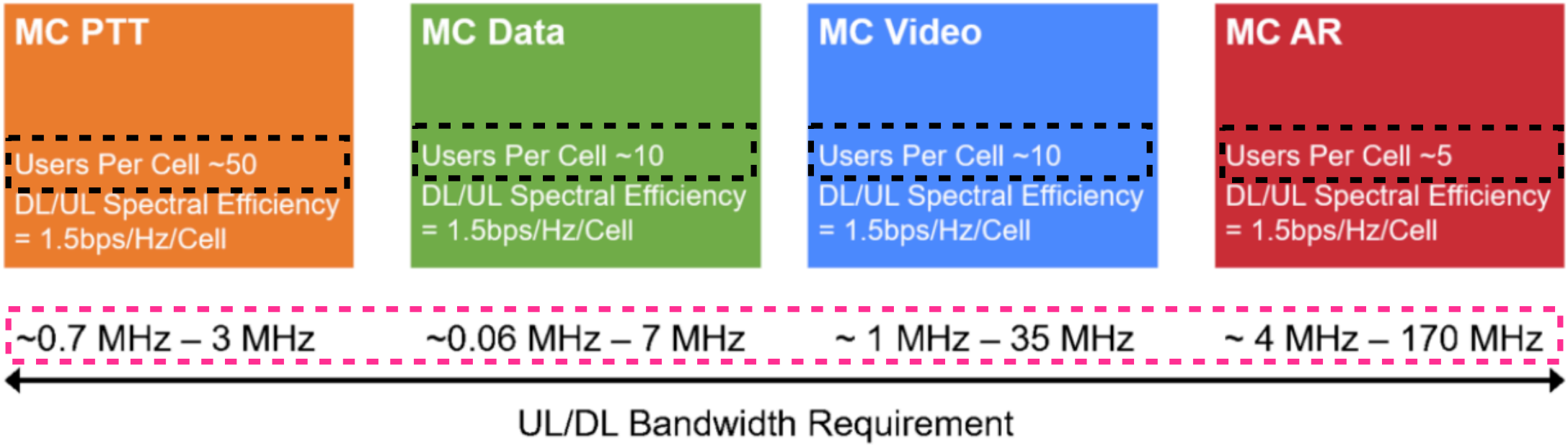
FeNB-IoT：Further Enhancement NB-IoT
NB-IoTenh3 (NB-IoTenh4)：Additional enhancements for NB-IoT

Release 13 NB-IoT	Release 14 eNB-IoT	Release 15 FeNB-IoT	Release 16 NB-IoTenh3	Release 17 NB-IoTenh4
Cat NB-1	Cat NB-2	Mixed Mode Multicarrier	Co-Existence with New Radio (NR)	Increase of Data Rates
Standalone/Guard band/In-Band	Enhance TBS/ Dual HARQ	SR Report	Connection to 5G Core	64 QAM Carrier Aggregation
Coverage Extension	Release Assistance Indicator	Wake Up Signal	Improve Multi carrier Operation	Power Enhancements
UL3.75 kHz and 15 kHz	Reconnection with RLF	Early Data Transmission	Mobile-Terminated (MT) Early Data Transmission	
Single Tone/Multi Tone	Positioning	New PRACH format	Enhance of SPS	
CP/UP	Measurement Report	Small Cell Support	Inter RAT-Cell Selection	
Multi-Carrier	Non-Anchor Carrier	TDD Support	UE group Wake up Signal	
PSM (Power Save Mode)	Single Cell Multicast	Reduced System Acquisition Time	SON	
eDRX	Maximum Tx Power 14dBm	UE Differentiation		

Mission Critical (MC) Internetworking with Legacy Systems



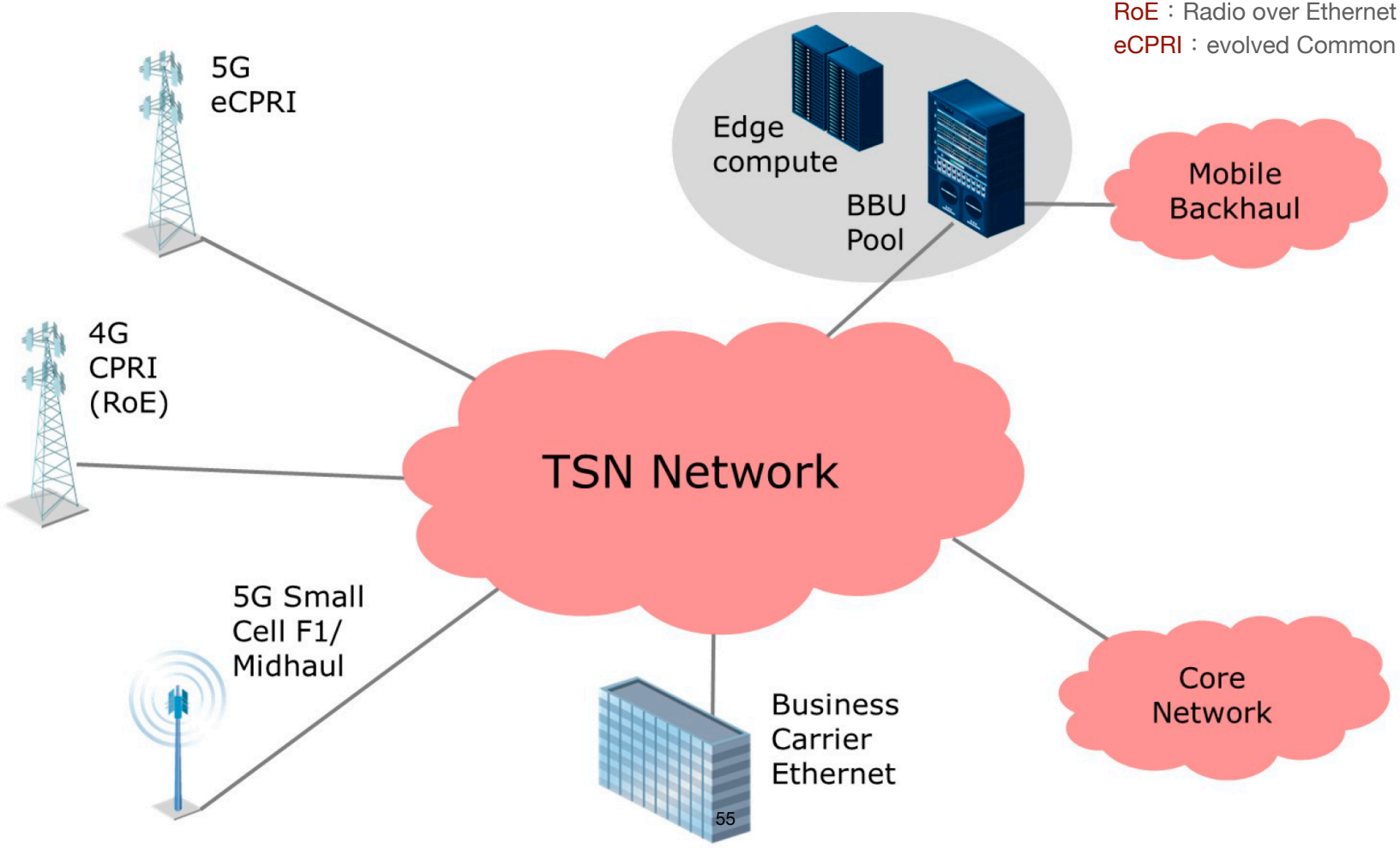
Traffic per cell = Users per cell * traffic per subscriber (Data rate)
Required Spectrum = Traffic per cell / Spectral Efficiency
Spectral Efficiency = 1.5bps/Hz/Cell



Spectrum requirements for different **Mission Critical (MC)** services for a spectrum efficiency of **1.5 bps/Hz**

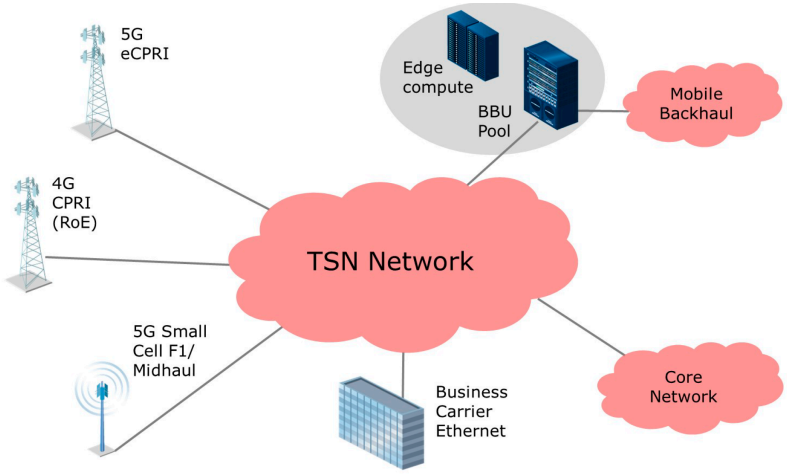
Time Sensitive Network (TSN)

CPRI：Common Public Radio Interface
RoE：Radio over Ethernet
eCPRI：evolved Common Public Radio Interface

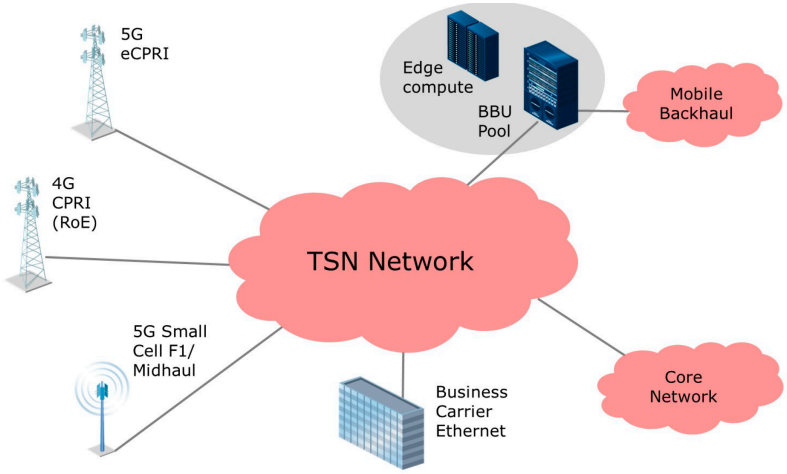


- **Time-Sensitive Networking (TSN)**
  - Define mechanisms for the time-sensitive transmission of data over deterministic Ethernet networks
  - Three basic components
    - **Time synchronization**: all devices that are participating in real-time communication need to have a common understanding of time
    - **Scheduling and traffic shaping**: all devices that are participating in real-time communication adhere to the same rules in processing and forwarding communication packets
    - **Selection of communication paths, path reservations and fault-tolerance**: all devices that are participating in real-time communication adhere to the same rules in selecting communication paths and in reserving bandwidth and time slots, possibly utilizing more than one simultaneous path to achieve fault-tolerance

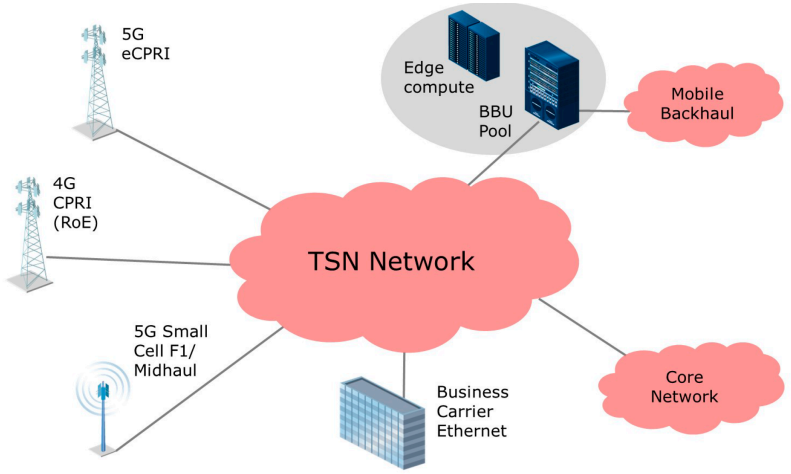
- **CPRI (Common Public Radio Interface)**
  - Used to connect baseband unit (BBU) and remote radio head (RRH) in cellular networks
  - CPRI traffic is transmitted over a constant bit rate, low latency, and jitter synchronous link
  - BBU sends I/Q data (modulated digital signals) and control words to RRH which converts the digital signals to radio signals



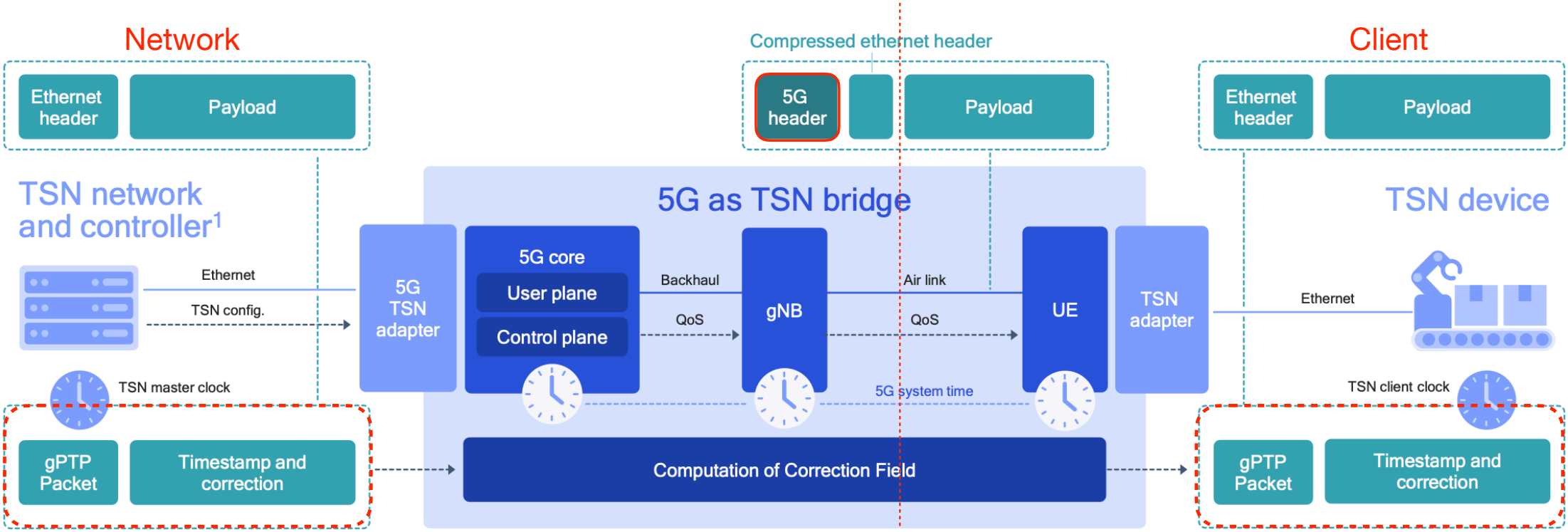
- **RoE (Radio over Ethernet)**
  - Evolves fronthaul to use Ethernet instead of CPRI's constant bit rate and synchronous links
  - BBU and RRH connect over Ethernet and can be geographically separated.
  - Scheduling, synchronization, and QoS mechanisms used to meet fronthaul requirements



- **eCPRI (Enhanced CPRI)**
  - Defines a packet-based fronthaul interface using Ethernet
  - Built on top of IEEE 802.1 TSN standards to provide deterministic latency and low jitter
  - Uses mechanisms like time synchronization, frame preemption, and traffic shaping for QoS



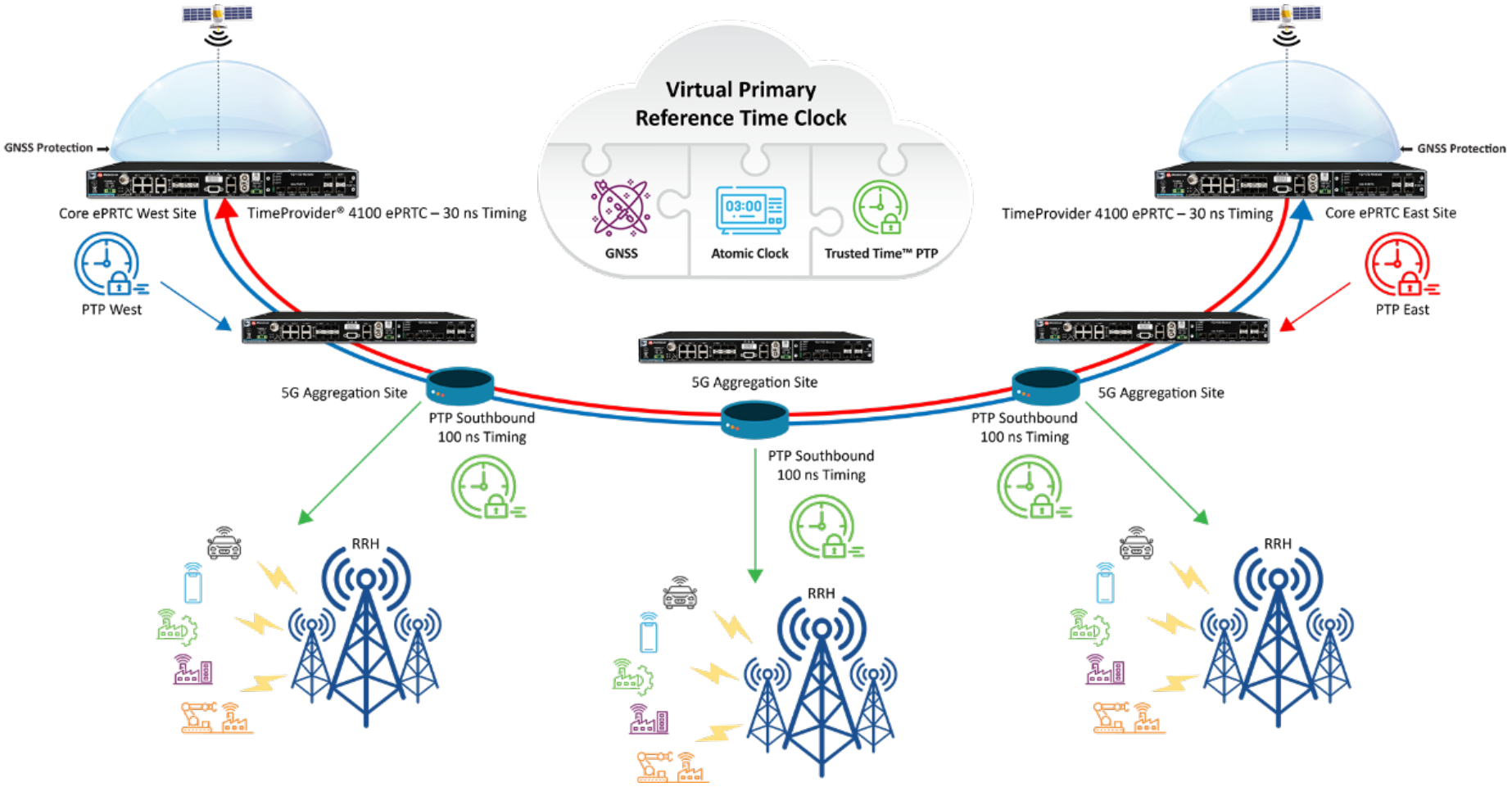
5G supports TSN



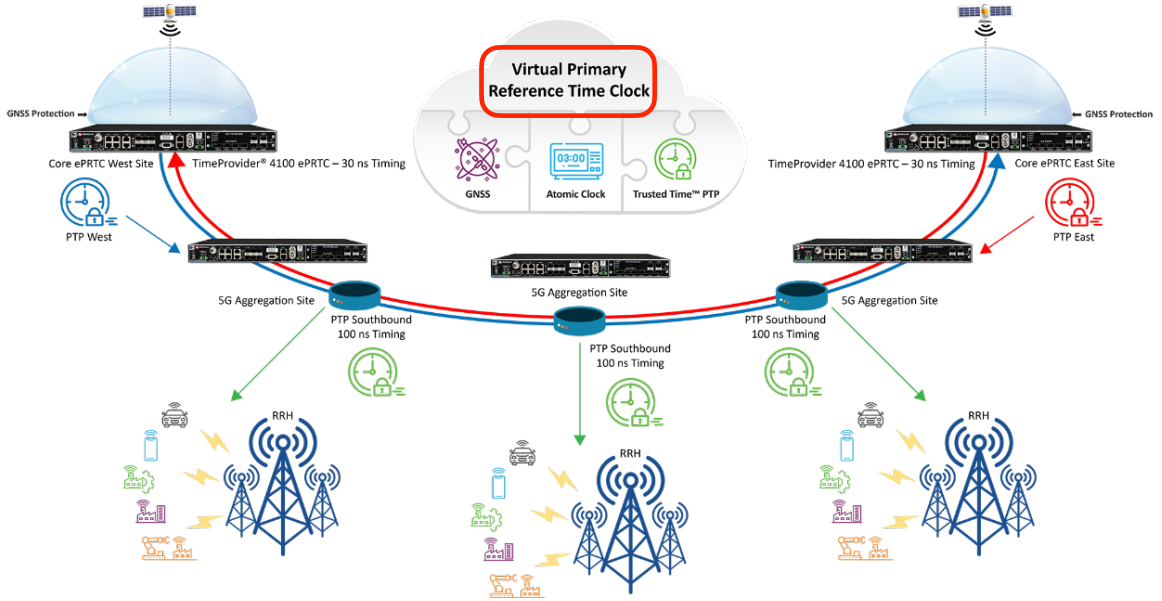
gPTP：general Precise Time Protocol

Resilient Timing

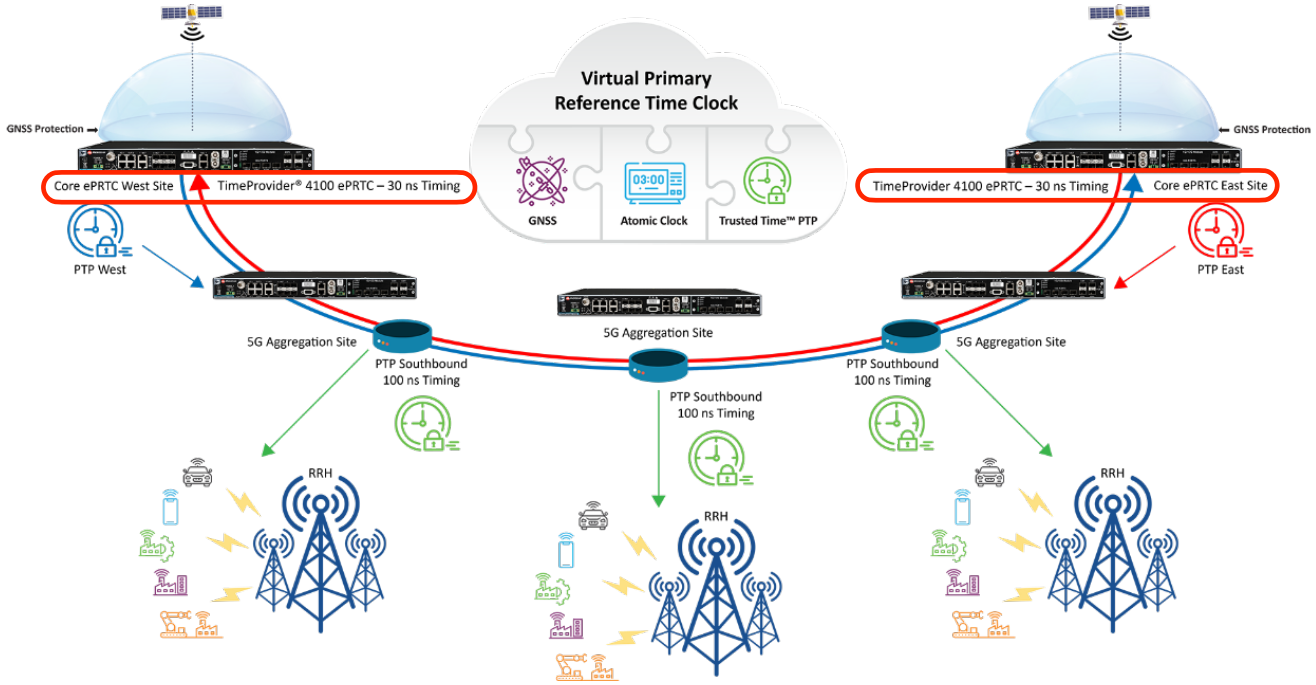
vPRTC：virtual Primary Reference Time Clock
ePRTC：enhanced Primary Reference Time Clock
PTP：Precision Time Protocol



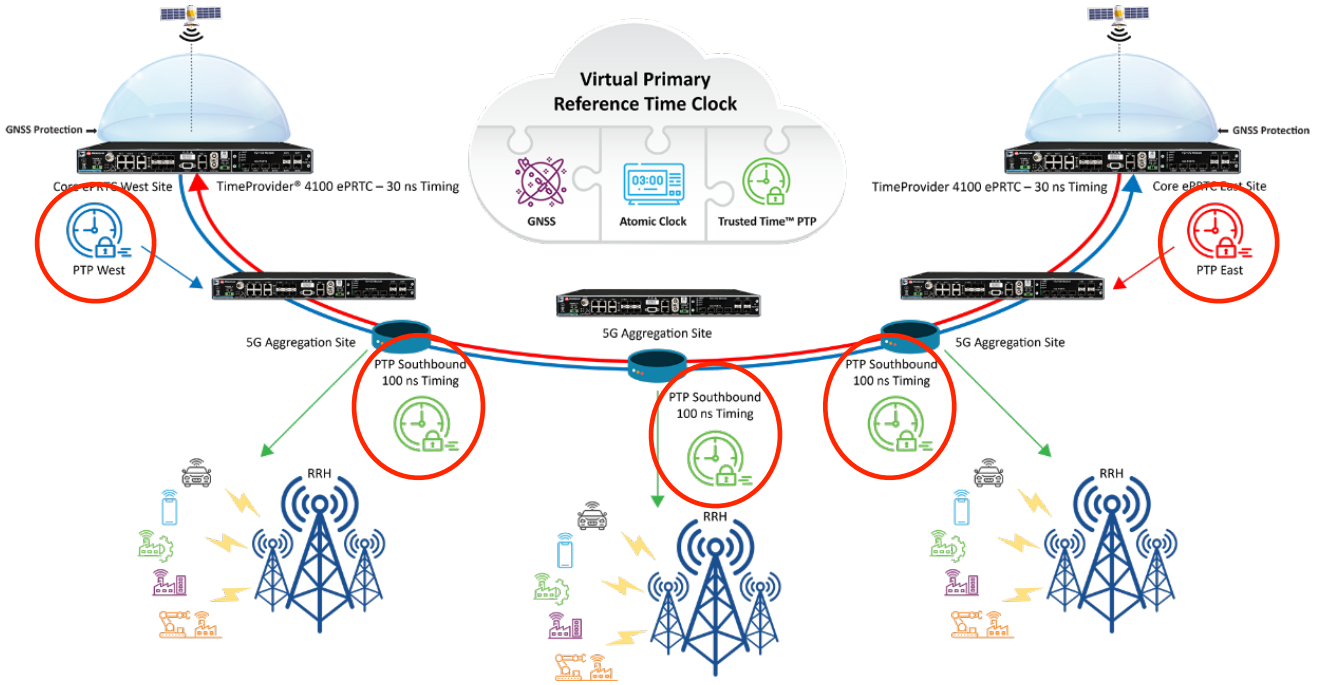
- Resilient timing
  - The **Primary Reference Time Clock (PRTC)** provides the reference time source in the network. It is GPS synchronized
  - The **virtual PRTC (vPRTC)** provides backup timing in case GPS signal is lost to the PRTC. It uses holdover oscillators to maintain time accuracy



- The **enhanced PRTC (ePRTC)** provides further redundancy by synchronizing with multiple PRTC/vPRTC sources. It selects the best timing source



- These PRTC variants provide resilient and redundant timing to base stations in case of GPS signal outage.
- The BSs distribute timing to gNBs using **Precision Time Protocol (PTP)** which provides accurate timing over packet networks



- Boundary clocks, transparent clocks and PTP redundancy mechanisms ensure accurate end-to-end timing across the mobile network
- Accurate timing from PRTC is ultimately delivered to the UE for time-sensitive operations and coordination functions