Intelligent Transportation Systems
V2X

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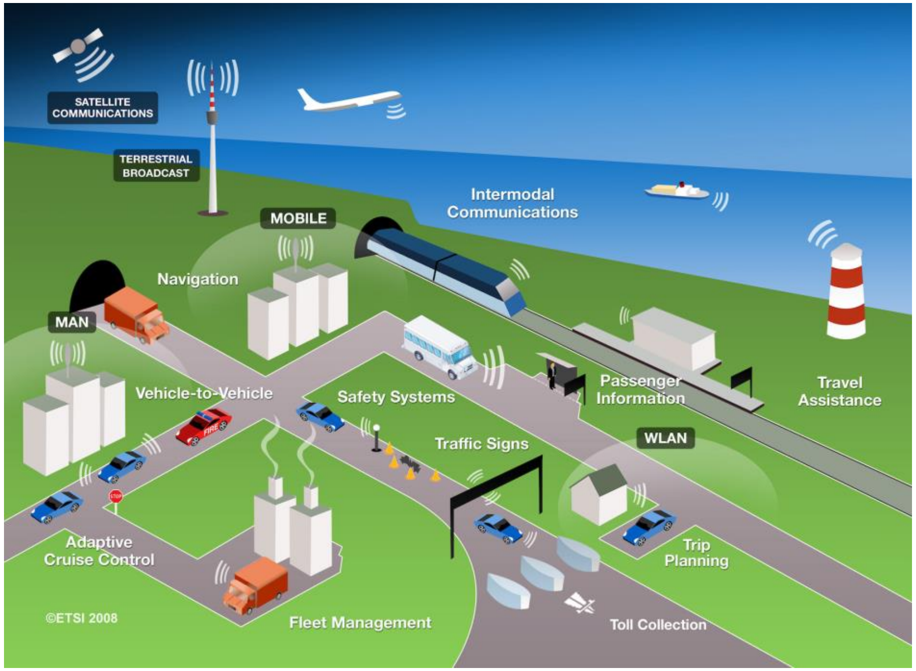
Intelligent transportation Systems - ITS

- ITS is the use of technology, communications and information to deliver informed and efficient mobility and transport.
- It includes smart motorways, autonomous/driverless and communicating vehicles, urban and inter-urban traffic management, enforcement of speed limits, transport safety and security, and improved mobility.



- ITSs optimize existing infrastructure to make transport more efficient, rather than to provide additional physical infrastructure with its environmental dis-benefits and financial costs.
- ITS is not a new technology or standard. It is instead a result of complementary technologies in a big number of fields, i.e. sensing, machine learning, cloud computing, wireless communications, etc.

Intelligent transportation Systems - ITS

These technologies allow the smart devices to:

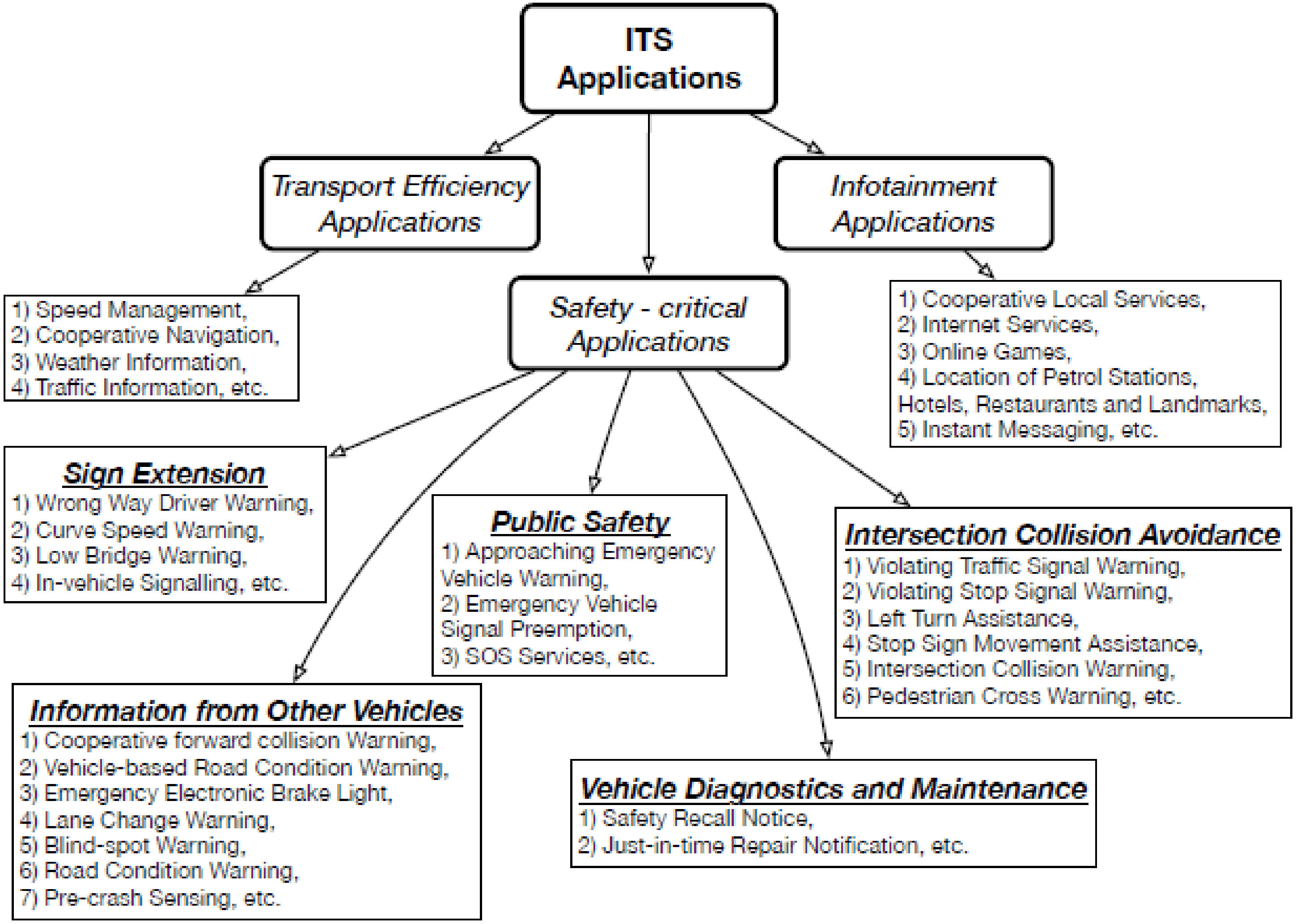
- **Be uniquely identified**:
  Each vehicle, traffic light, basestation, etc. within an ITS can be uniquely located, addressed and configured.

- **Communicate and Cooperate**:
  The different entities can create interconnected clusters, better utilize resources and enhance their services.

- **Sense and Act**:
  Information is collected from the surrounding environment and is either transmitted to another device or used.

- **Process data**:
  Certain computing capabilities are required for a smart device.

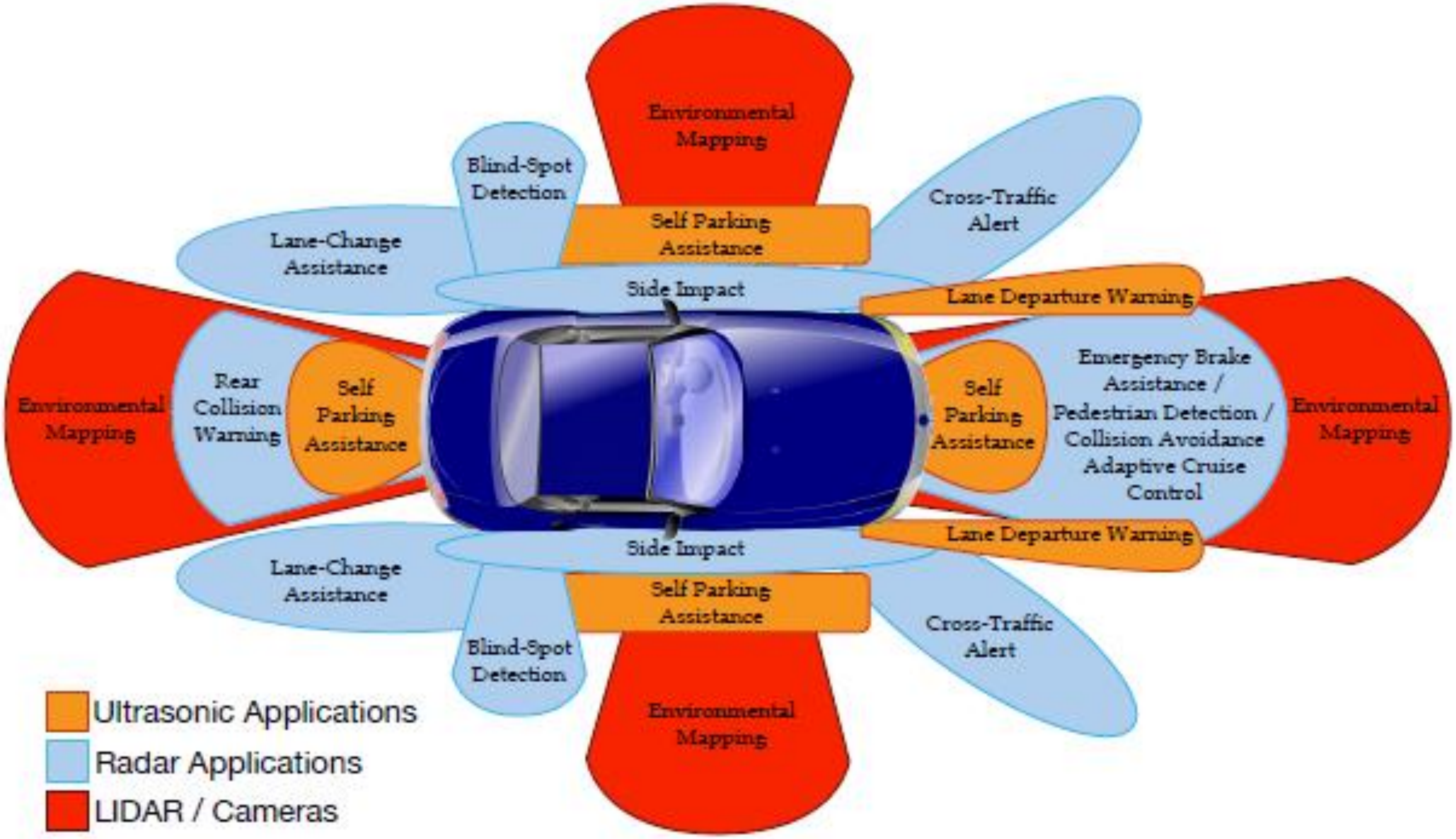
ITS Applications



Autonomous driving – 6 levels

Level	Autonomy	Driver Duties	Vehicle Duties
0	No Automation	Performs all tasks	No artificial help
1	Driver Assistance	Handles all the accelerating, braking, and monitoring of the surrounding environment	Assists with some functions, e.g., brake at the highway when close to another vehicle
2	Partial Automation	Responsible for most safety-critical functions and monitoring of the environment	Assist with steering or acceleration functions and allow the driver to disengage from some of their tasks
3	Conditional Automation	Disengage from "safety critical" functions like braking and leave it to the machine	Vehicle itself controls all monitoring of the environment and acts accordingly
4	High Automation	Driver enganged for driving only when conditions are "unsafe"	Capable of steering, braking, accelerating, monitoring the vehicle and the roadway responding to events
5	Complete Automation	Chooses the destination and becomes a passenger in the vehicle later	Driving requires absolutely no human attention and intervention

Vehicle – Sensors



VANETs vs MANETs

VANETs : Vehicular Ad-Hoc Networks
MANETs : Mobile Ad-Hoc Networks

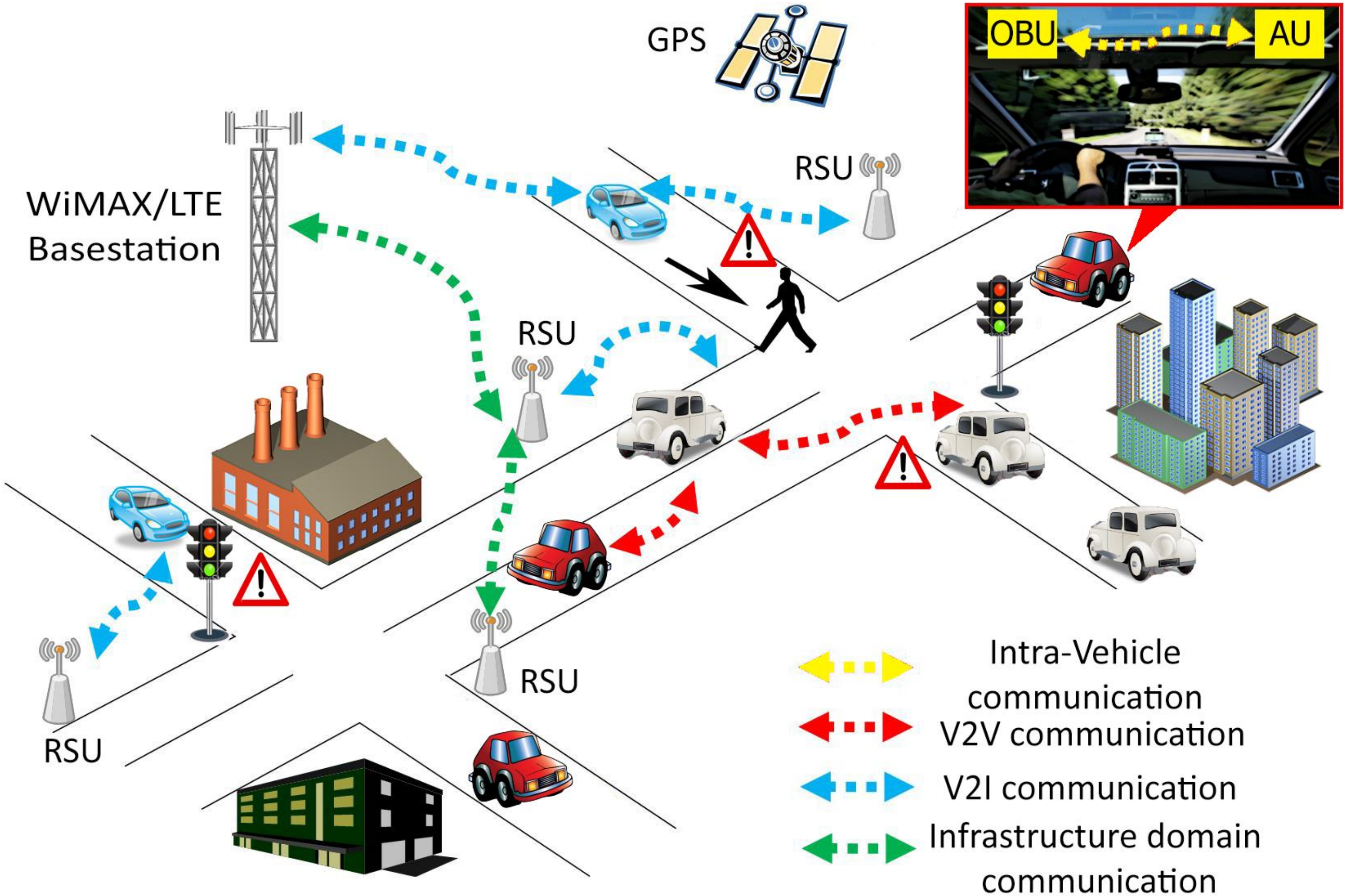
- **Mobility Models and their Effects on the Wireless Channel**
  - **Highway Mobility Models:** High-speed vehicles, limited presence of traffic lights and intersections, with a small number of obstacles, and variable density depending on the different time and day.
  - **City/Urban Mobility Models:** Low speed, pedestrians interfering with traffic, increased density, especially in the peak hours, and frequent acceleration/deceleration because of traffic lights, junctions and obstacles.
  - **Countryside/Rural Mobility Models:** Average speed with low vehicle density and without much surrounding building
- **Hardware Resource Constraints**
  - CPU, GPU, MCU, FPGA… (Processing)
- **Geographical Position, Time Reference and Sensor Data**
  - **GPS, IMU, Data fusion…**

VANETs vs MANETs

VANETs : Vehicular Ad-Hoc Networks
MANETs : Mobile Ad-Hoc Networks

- **QoS Requirements of Traditional ITS Applications**
  - Real-Time applications and services for road safety: Requires guaranteed access to the channel, low end-to-end delay with very low jitter, and low packet error rate.
  - Traffic management applications: Guaranteed low latency in the presence of high bandwidth traffic and control the maximum bandwidth per connection.
  - User-oriented/infotainment applications: Require high throughput and increased data rates, especially for the downlink.
  - Data offloading for forensics applications: Require low latency and high throughput for the uplink to offload data to a Cloud service.
- **QoS Requirements as we Move Towards Full Autonomy**

Vehicular Communication System



Vehicular Communication System

1. **On-Board Units (OBUs):** These devices are mounted inside a roaming car and are responsible for reliably exchanging safety and non-safety-critical information with other Road Side Units (RSUs) or OBUs. They are mainly used for accessing the wireless medium, IP mobility, geographical routing, etc.

2. **Application Units (AUs):** They are responsible for using the capabilities of an OBU, such as the mobility and the network functions. The AU can be a dedicated device for safety applications or a normal device, such as Rasberry Pi or a laptop, to provide access to the Internet. The AU is usually connected to the OBU through a wired or wireless connection, and the difference between them is in most cases logical and can be considered the brain of the OBU.

3. **Road Side Units (RSUs):** Fixed device along the side of the road or at central locations in the road network, such as the intersections. They represent the infrastructural network of a VANET. Main functions are the: extension of the network by redistributing or forwarding the information to other RSU or OBU, running safety-critical applications or providing internet access to the network devices. An RSU may be equipped with various wired or wireless radio interfaces. These interfaces will be used to provide access to cloud services, other networks, and connections to other RSUs to extend the communication range of the ad-hoc network.

Vehicular Communication Domains

1. **Intra-Vehicle domain:** Communication between OBU and AU. It can be either wired or wireless.
2. **Ad-Hoc domain:** For these types of communications, the vehicle should be equipped with an OBU and RSUs should be deployed in the network. In this domain, two different communication links can be found:
   - **Vehicle-to-Vehicle (V2V) links:** Vehicles using single-hop or multi-hop communications with other surrounding vehicles. If no direct link can be formed between two Vehicles, a relay node is responsible for forwarding the information towards the destination vehicle.
   - **Vehicle-to-Infrastructure (V2I) links:** Vehicles communicate with other nodes via an RSU, to increase their coverage. They can exchange data, share road information, utilizing the infrastructure network as a backbone link and exploiting the ability of the RSU for intense processing.
3. **Infrastructure Domain:** RSUs can be connected with the rest of the infrastructure network or the Internet, allowing OBUs to exchange information with other networks or have access to cloud/fog computing capabilities. The infrastructure network could be any host such as the Internet or a server for safety and non-safety vehicular applications.

Vehicular Communication Domains

- IEEE 1609.0-2013 – Wireless Access in Vehicular Environments (WAVE)
- Car-2-Car (C2C) Communication Consortium
- Dedicated Short Range Communications (DSRC)

RAT (Radio Access Tech.) for V2X Links

Feature \ RAT	IEEE 802.11p / DSRC [69]	IEEE 802.11px [70]	C-V2X (LTE-A Pro) [71], [72]	MmWaves (IEEE 802.11ad) [73]	MmWaves (IEEE 802.11ay) [73]
Frequency Band	5.85 GHz - 5.925 GHz	5.85 GHz - 5.925 GHz	450 MHz - 4.99 GHz 5.725 GHz - 5.765 GHz	57.05 GHz - 64 GHz	57.05 GHz - 64 GHz
Channel Bandwidth	10 MHz	10 MHz	Up to 640 MHz	2.16 GHz	Up to 8.64 GHz
Range	$\leq$ 1 km	$\leq$ 1 km	$\leq$ 30 km	$\leq$ 50 m	$\leq$ 500 m
Bit Rate	3 Mbps-27 Mbps	Up to 60 Mbps	Up to 3 Gbps	Up to 7 Gbps	Up to 44 Gbps
End-to-End Latency	$\leq$ 10 ms	$\leq$ 10 ms	30 ms to 50 ms (UL/DL) 20 ms to 80 ms (V2V)	$\leq$ 10 ms	$\leq$ 10 ms
Link Establishment Latency	~0 ms	~0 ms	40 ms to 110 ms	10 ms to 20 ms	10 ms to 20 ms
Coverage	Intermittent	Intermittent	Ubiquitous	Intermittent	Intermittent
Mobility Support	$\leq$ 130 km h^{-1}	Under Investigation	$\leq$ 350 km h^{-1}	$\leq$ 100 km h^{-1}	$\leq$ 100 km h^{-1}
QoS Support	Yes	Yes	Yes	Yes	Yes
Broadcast Support	Yes	Yes	Yes	No	No
V2I Support	Yes	Yes	Yes	Yes	Yes
V2V Support	Yes	Yes	Over PC5 Interface	Yes	Yes
Relay Mode	Yes	Yes	Yes	Yes	Yes
MIMO	No	Yes	Yes	No	Yes

RATs for V2X Communications within C-ITSs

- **IEEE 802.11p/DSRC and IEEE 802.11px**)
- **3GPP LTE-Advanced Pro and C-V2X**
- **Millimeter Wave Systems - IEEE 802.11ad and IEEE 802.11ay**

Onde électromagnétique

Qu’est ce que c’est une onde électromagnétique?

- Une onde électromagnétique est la résultante d’un champ électrique et d’un champ magnétique dont les amplitudes varient de façon sinusoïdale au cours du temps.
- Une onde électromagnétique peut être produite par un courant électrique variable.

$$\mathrm{div}(\vec{E}) = \frac{\rho}{\epsilon_0}$$
(Maxwell-Gauss)

$$\vec{\mathrm{rot}}\,(\vec{E}) = -\frac{\partial \vec{B}}{\partial t}$$
(Maxwell-Faraday)

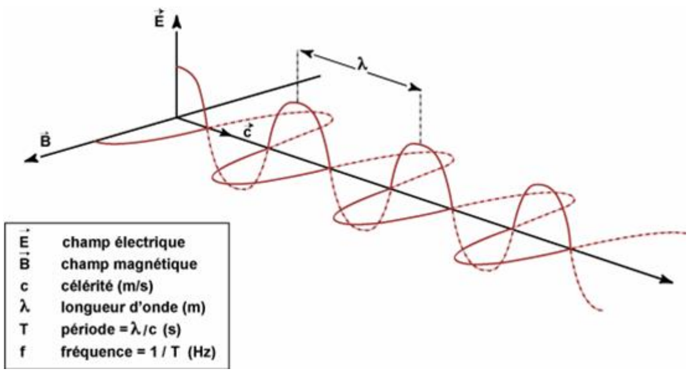
$$\mathrm{div}(\vec{B}) = 0$$
(Maxwell-Flux)

$$\vec{\mathrm{rot}}\,(\vec{B}) = \mu_0 \vec{J} + \frac{1}{c^2}\frac{\partial \vec{E}}{\partial t}$$
(Maxwell-Ampère)

Caractéristiques d’une onde électromgnétique

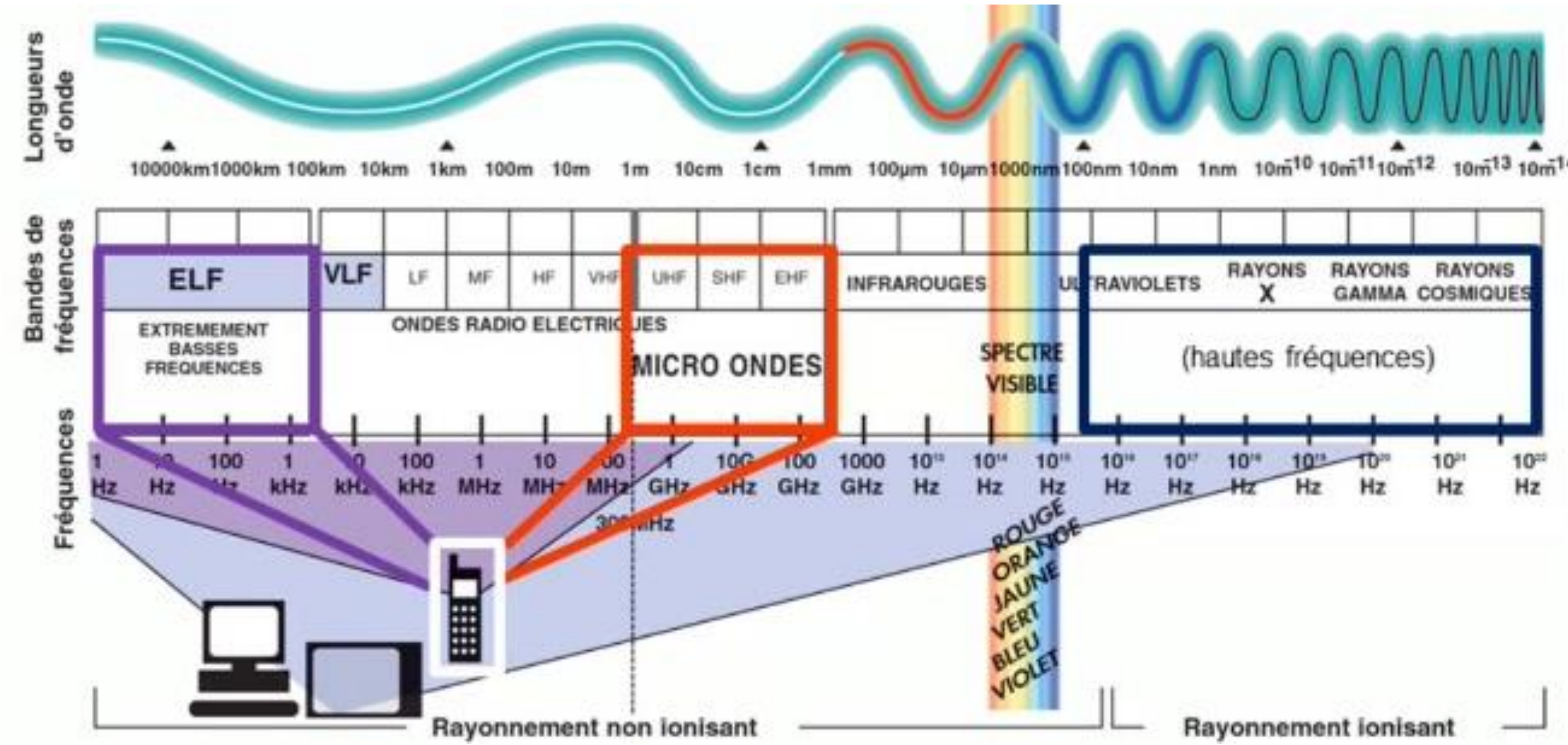
Comme toutes les ondes périodiques elle est caractérisée par:

- sa période T (peu utilisée)
- sa fréquence ν
- sa longueur d’onde λ
- son amplitude
- sa célérité c ou vitesse de propagation



- La fréquence est l’inverse de la période: ν = 1/T
- La période est par conséquent l’inverse de la fréquence: T = 1/ν
- La longueur d’onde est la distance sur laquelle se propage l’onde pendant la durée d’une période d’ou la relation λ= c.T mais on peur également l’exprimer en fonction de la fréquence λ= c/ν.

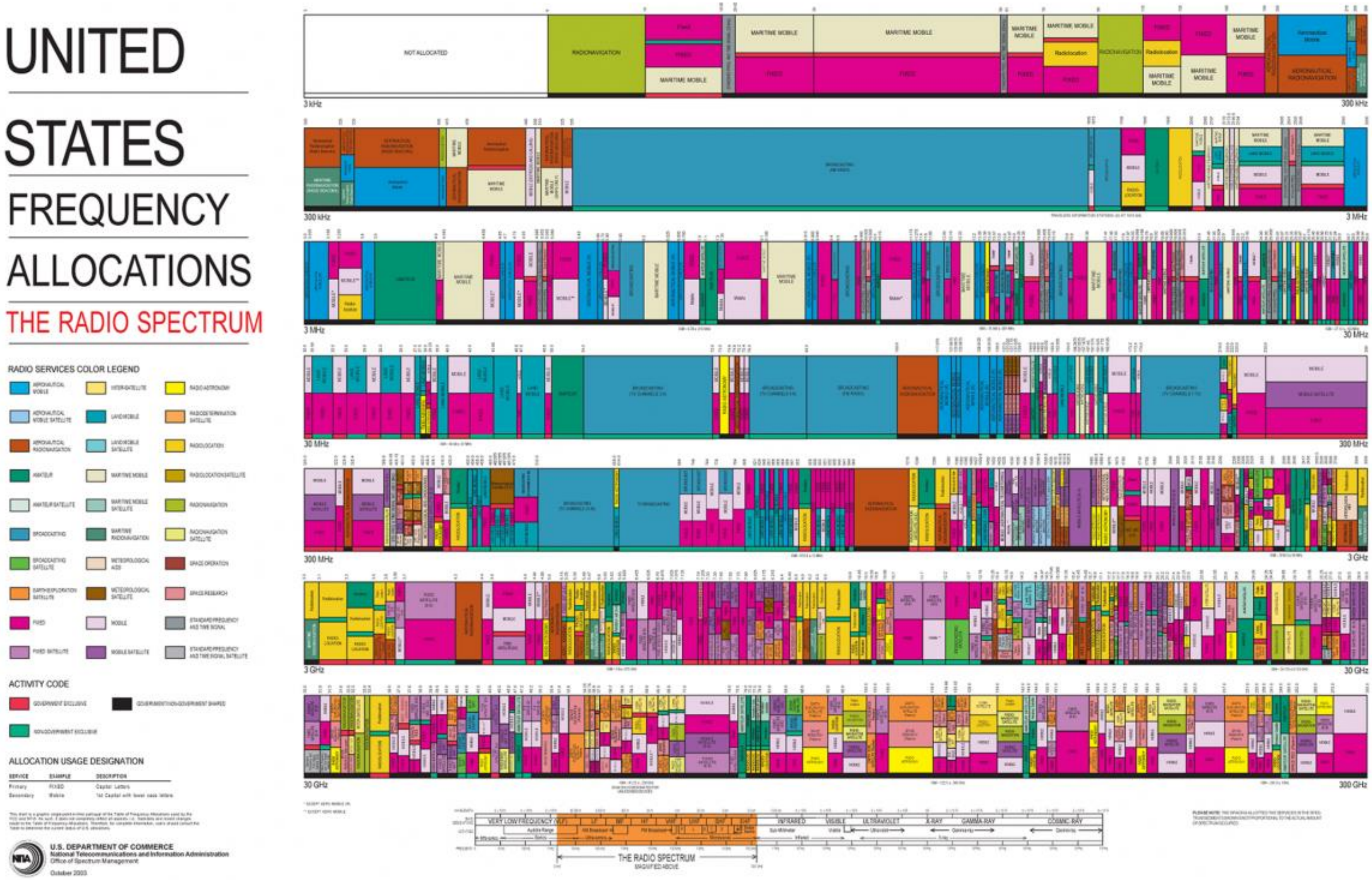
Spectre des ondes électromagnétiques



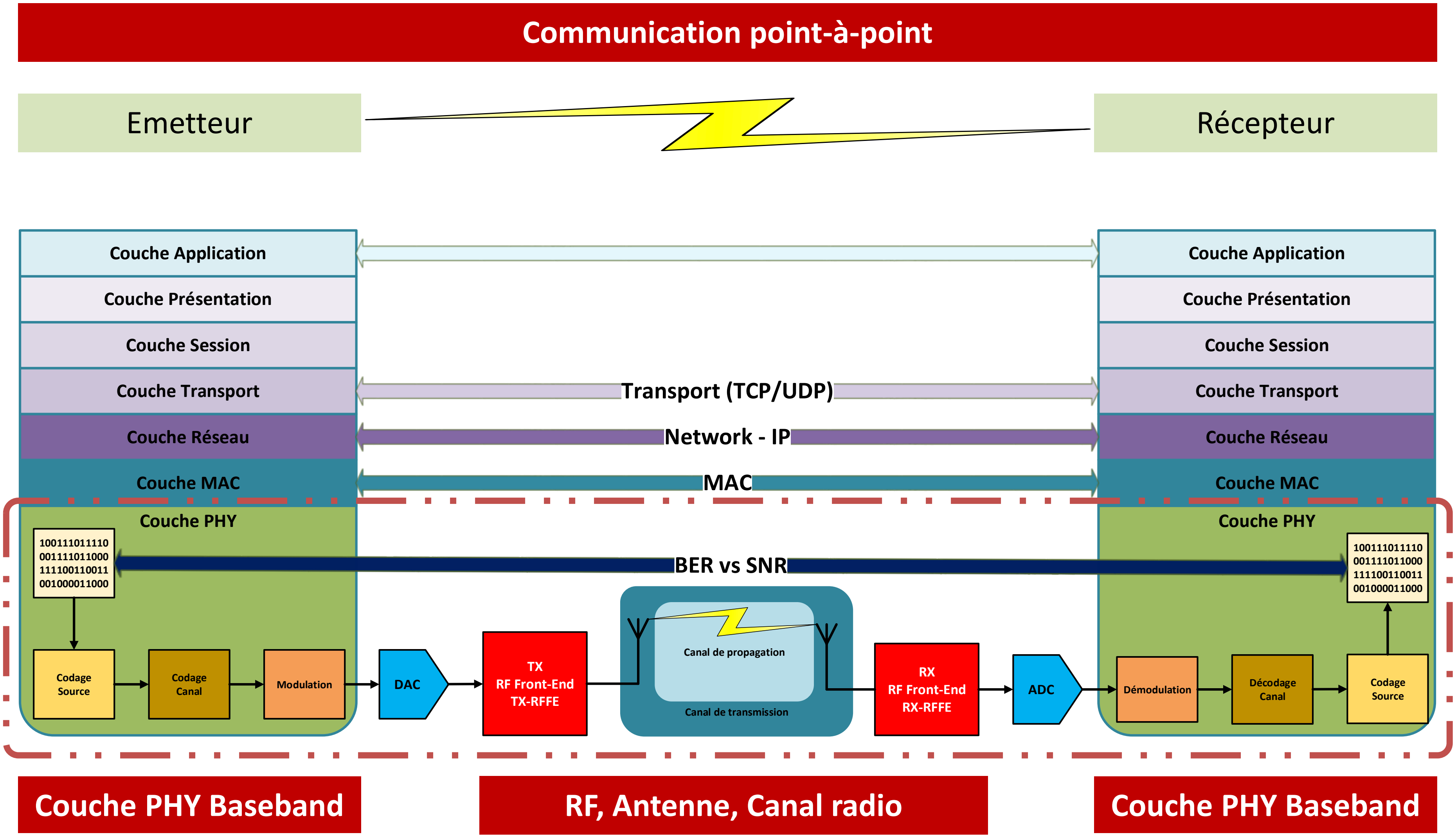
- Bande AM : [540 – 1,700] kHz
- Bande FM : [88 – 108] MHz
- Bandes GSM : 900 MHz, 1800 MHz
- Bandes ISM : 433 MHz, 868 MHz, 2,4 GHz, 60 GHz…

- Bandes GPS : L1 @ 1575,42 MHz, L2 @ 1227,6 MHz, L3 @ 1176,45 MHz
- Bandes WiFi : 2,4 GHz, 5 GHz
- Bandes LTE : 400 MHz – 6 GHz…

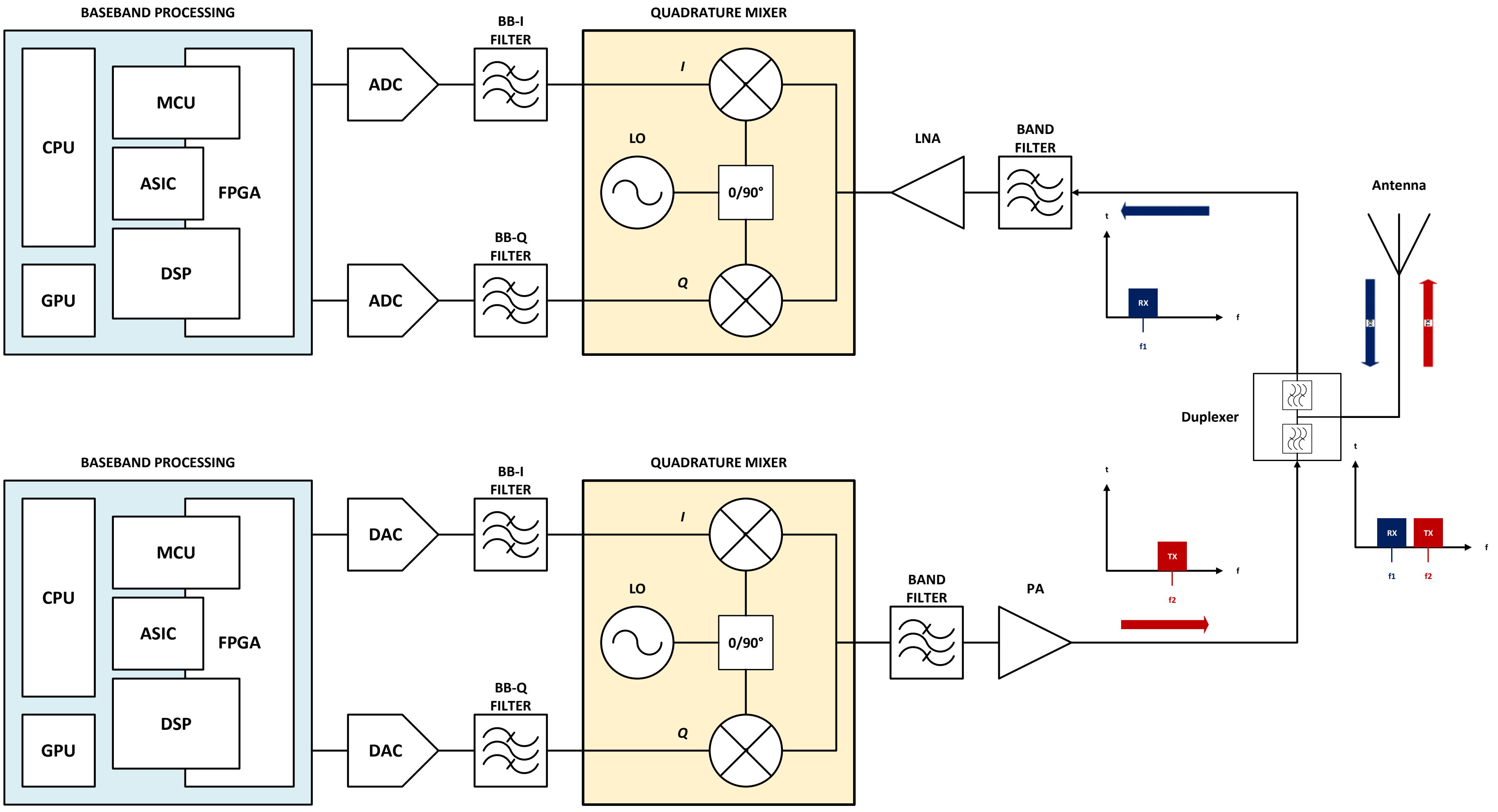
Allocation du spectre de fréquence aux U



Chaine de communication radio

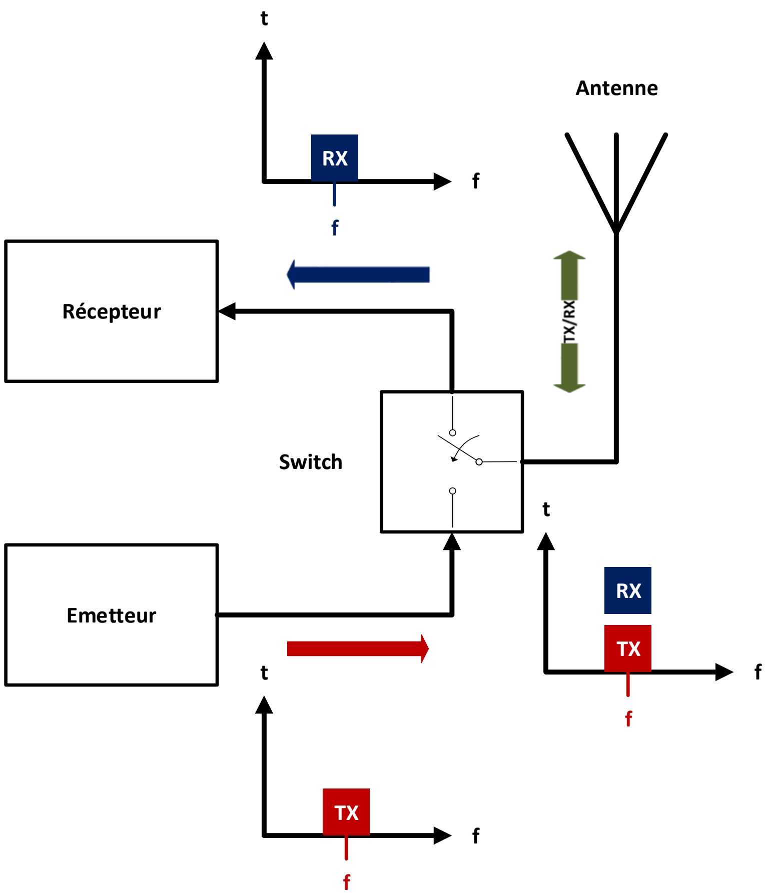


Emetteur/Récepteur – Conversion Direct

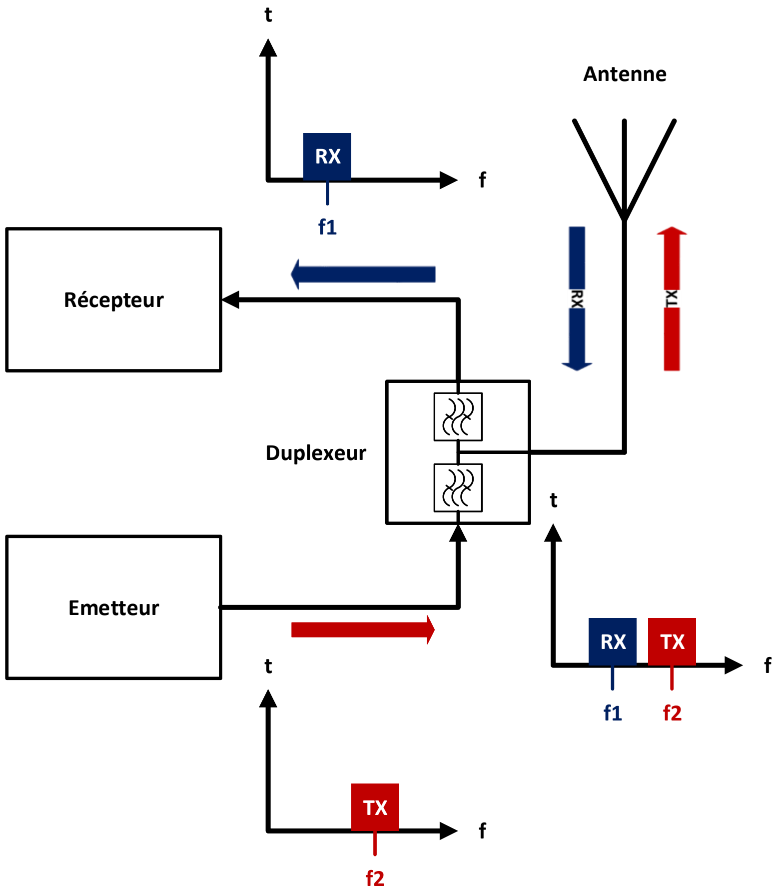


Mode de duplexage FDD/TDD

Mode TDD – Time Division Duplex



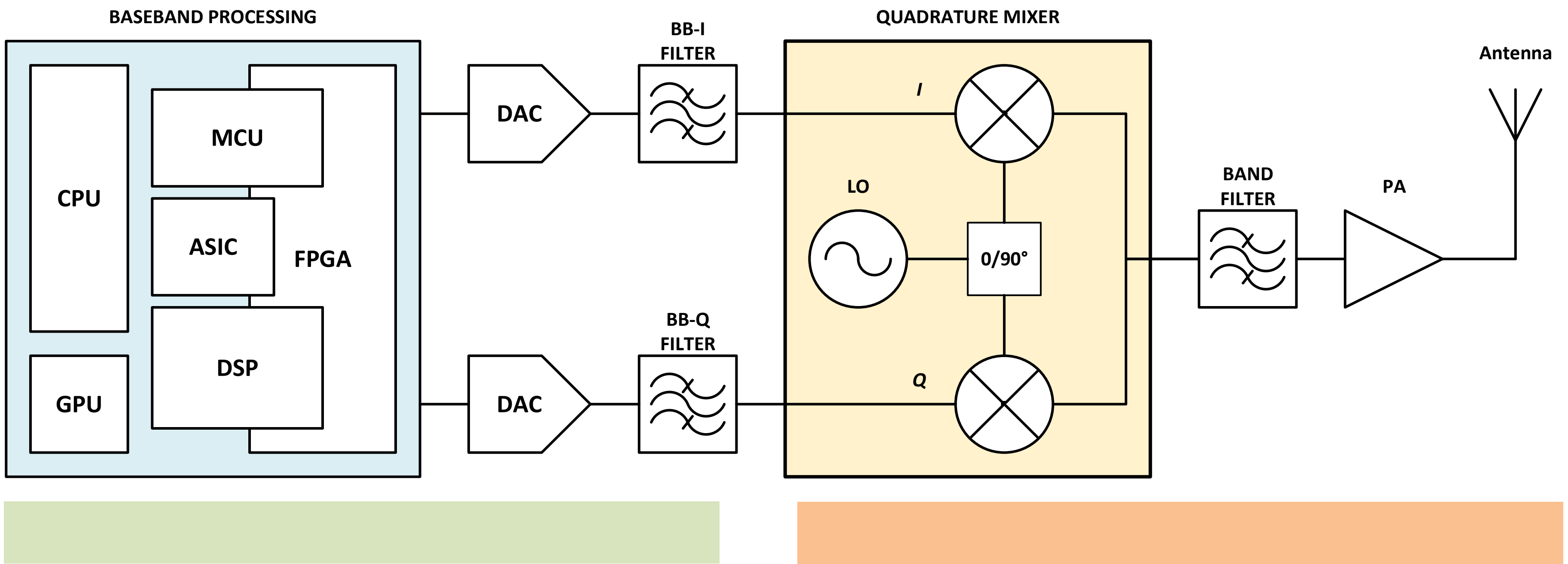
Mode FDD – Frequency Division Duplex



Contrainte au niveau de la disponibilité des fréquences – Coût des licences

Architecture des Front-End RF

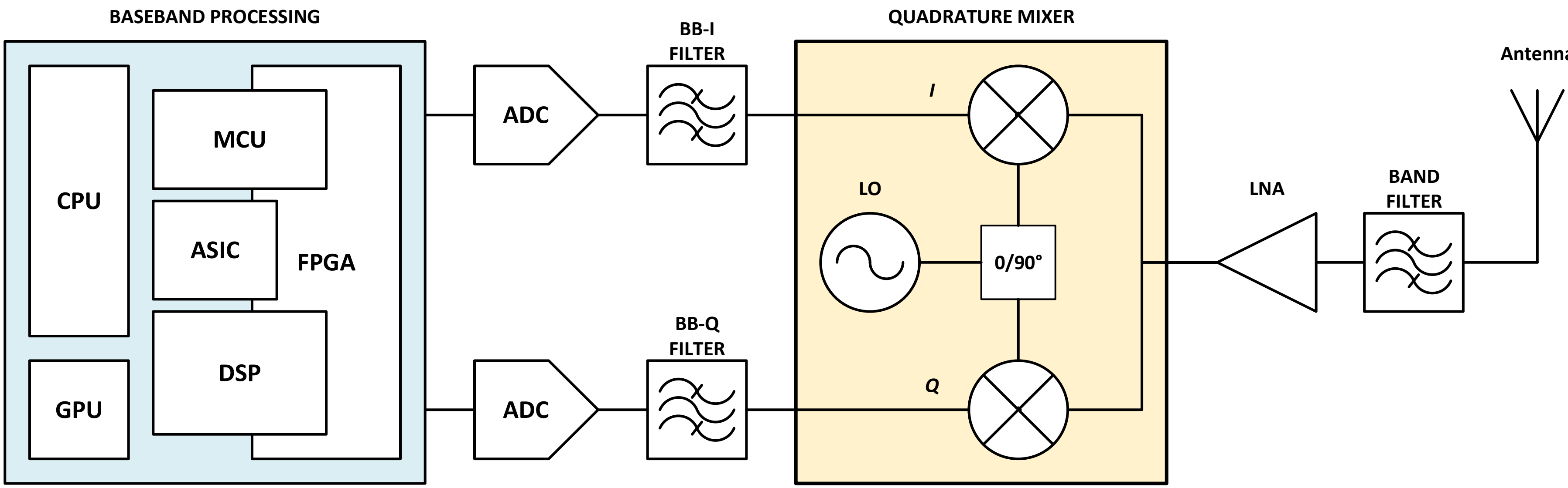
Architecture homodyne de l'émetteur



Fréquence porteuse = F_LO

Architecture des Front-End RF

Architecture homodyne du récepteur

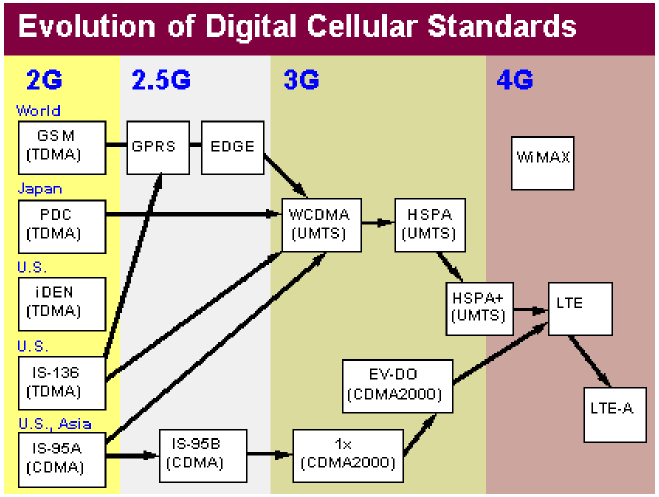


- Pas de problème d'image (F_LO = F_RF)
- Moins de composants RF, moins de complexité, moins de consommation,
- Plus d'intégration sur puce
- Réduction des coûts

- Problème du DC offset
- Parasites dus aux intermodulations d'ordre deux du LNA
- l'appariement des voies en quadrature ou déséquilibre IQ

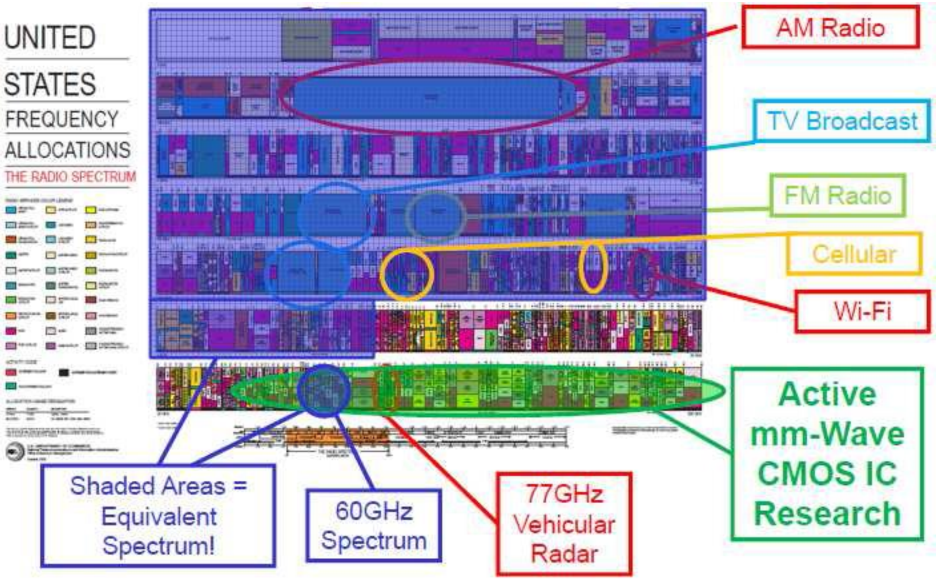
Fréquence porteuse = F_LO

Radio-logicielle – SDR

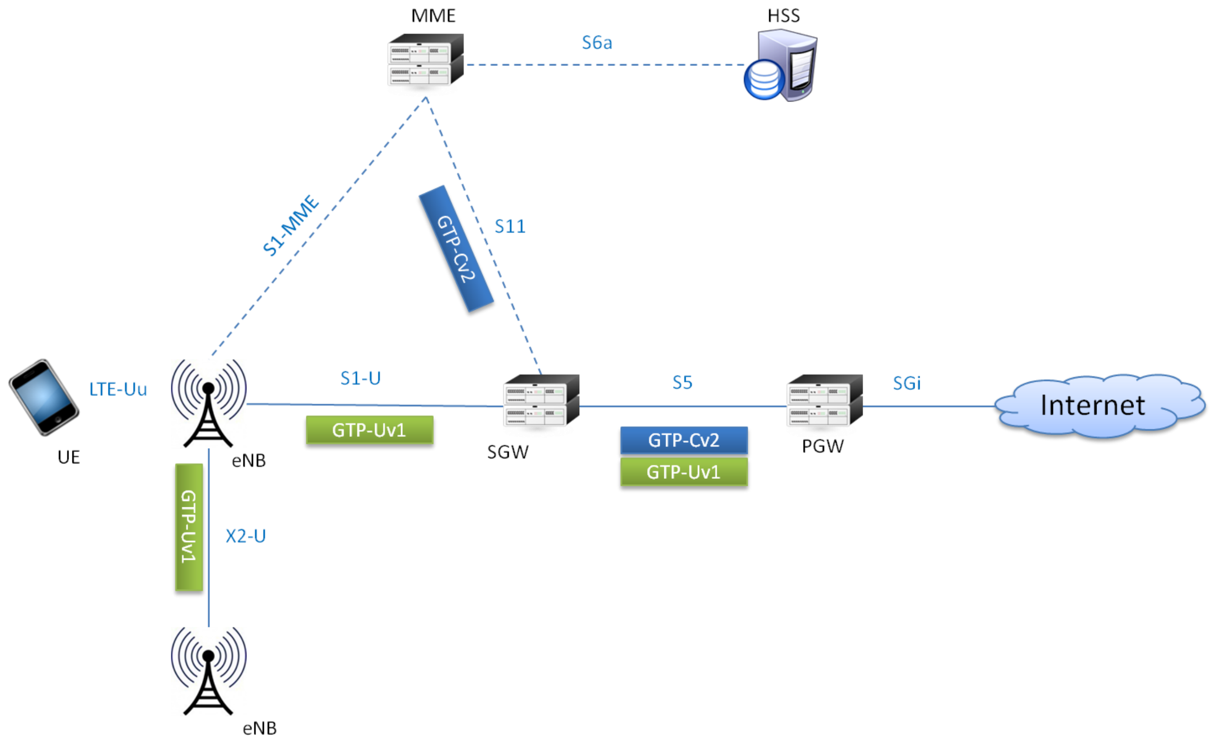


- ❑ Rapid technological evolution of cellular communication systems
- ❑ Broad band list of available Cellular networks (GSM, GPRS, CDMA,UMTS, LTE)
- ❑ Update and transition from old to new technologies are very expensive (time, budget…)
- ❑ UE support of different bands (America, EMEA, Asia).

- ❑ Spectrum scarcity
- ❑ mmWave frequency band
- ❑ **New paradigm for spectrum sharing**
- ❑ **Cognitive radio**
- ❑ **Wideband Radio systems**
- ❑ **Reconfigurable Radio**
- ❑ **Multiple standard system**



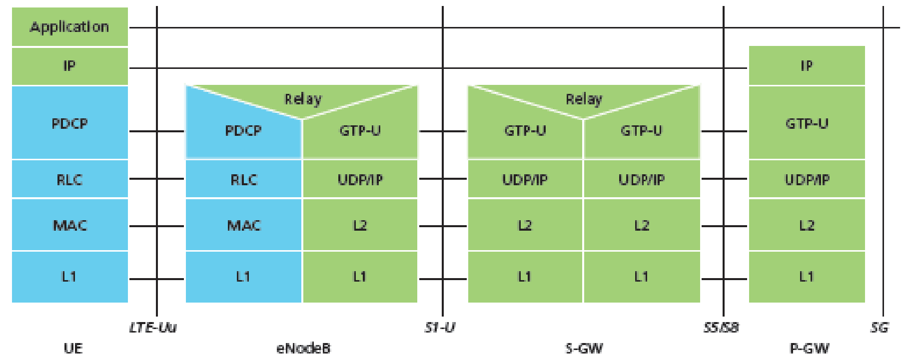
3GPP LTE/4G



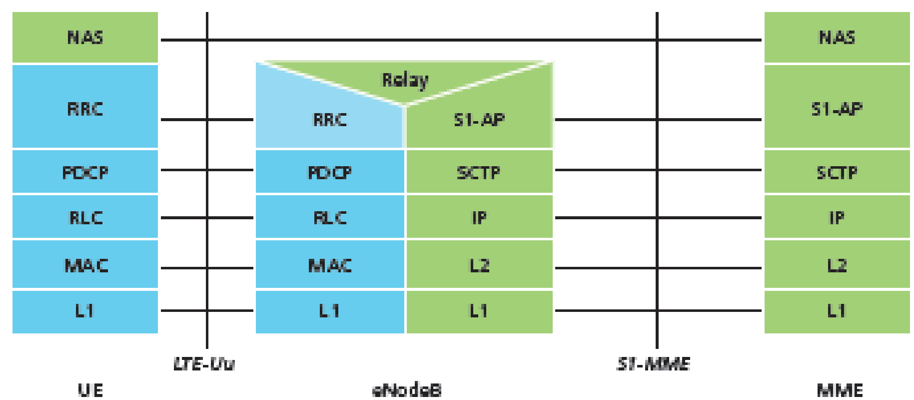
- **<u>LTE Uu :</u>** This is the air interface between UE and eNB. RRC is the protocol that is used for communication between UE and eNB. Above RRC there is a NAS layer in UE. This NAS layer terminates at MME and eNB shall silently pass the NAS messages to MME.
- **<u>S1-MME :</u>** eNB and MME communicate using this IP interface. S1-AP is application layer interface. The transport protocols used here is SCTP.
- **<u>X2-U :</u>** This interface is used by a eNB to communicate to an other eNB. This again is an IP interface with SCTP as transport. X2-AP is the application protocol used by eNBs to communicate.
- **<u>S1-U :</u>** User plane interface between eNB and SGW. GTP-U v1 is the application protocol that encapsulates the UE payload. GTP-U runs on UDP.
- **<u>S11 :</u>** An IP interface between MME and SGW. GTPv2 is the protocols used at the application layer. GTPv2 runs on UDP transport. This interface must and should run GTPv2.
- **<u>S5 :</u>** This is the interface between SGW and PGW. This again is an IP interface and has two variants. S5 can be a GTP interface or PMIP interface. PMIP variant is used to support non-trusted 3GPP network access.

3GPP LTE/4G – User vs Signaling Plane

- **PDCP:** In the uplink it performs sequence number addition, handover data handling, integrity protection, ciphering and header compression. In the downlink it does in sequence delivery, duplicate packet detection, integrity validation, deciphering, header decompression.
- **RLC:** In the uplink it provides buffer status report, segmentation and concatenation, ARQ(for AM mode). In the downlink it does re-ordering, assembly and ARQ(for AM mode).
- **MAC:** In the uplink it does channel mapping, multiplexing, handling control elements, random access procedure, logical channel priority, HARQ and sending BSRs. In the downlink it does channel mapping, de-multiplexing, DRX,Handling control elements, HARQ.
- **PHY:** CRC, Coding block, scrambling/descrambling, modulation/de-modulation, measurement, RE mapping/demapping, HARQ, MIMO, OFDMA, SC-FDMA



- **NAS:** Mobility Management, Session Management, Bearer Management, Paging Control, Security Management
- **RRC:** Configuration Management, Connection Management, Paging control, Security Management, Broadcast, Measurement configuration, Measurement Reporting, Cell selection and reselection, Mobility Management
- The lower layers (PDCP, RLC, MAC and PHY) perform the same functions as for the user plane with the exception that there is no header compression function for the control plane.



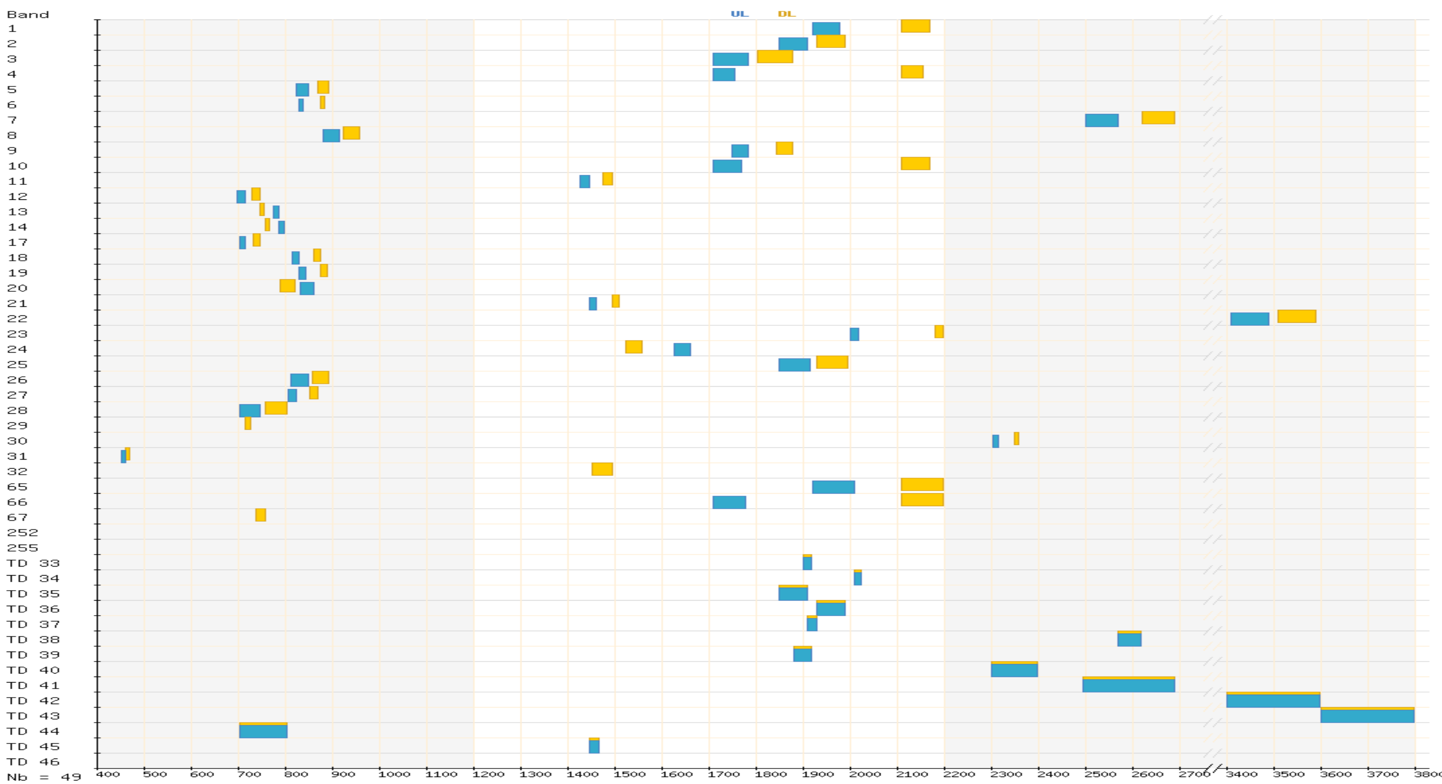
- NAS: Non Access Stratum
- RRC: Radio Resource Control
- PDCP: Packet Data Convergence Protocol
- RLC: Radio Link Control
- MAC: Medium Access Control

- IP: Internet Protocol
- UDP: User Datagram Protocol
- SCTP: Stream Control Transmission Protocol
- GTP: GPRS Tunneling Protocol

3GPP LTE/4G – Bande de Fréquence et mode de duplexage

LTE operating frequency bands
- 31 in FDD Mode
- 12 in TDD Mode

- 700, 800, 900 MHz
- 1700, 1800, 1900 MHz
- 2.1, 2.2, 2.3, 2.4, 2.5 and 2.6 GHz
- 3.4, 3.5, 3.6, 3.8 GHz
- Unlicensed Band 5.150 – 5.925 GHz (BW 775MHz)



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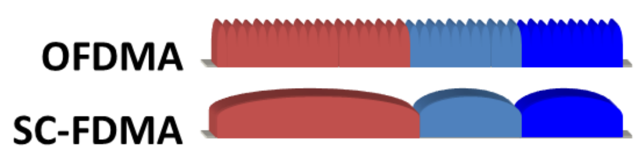
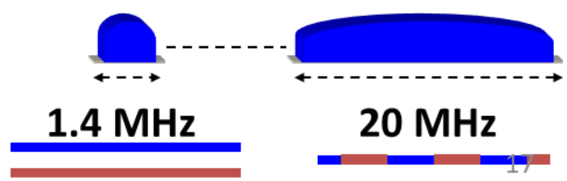
LTE radio access
Downlink: OFDM
Uplink: SC-FDMA

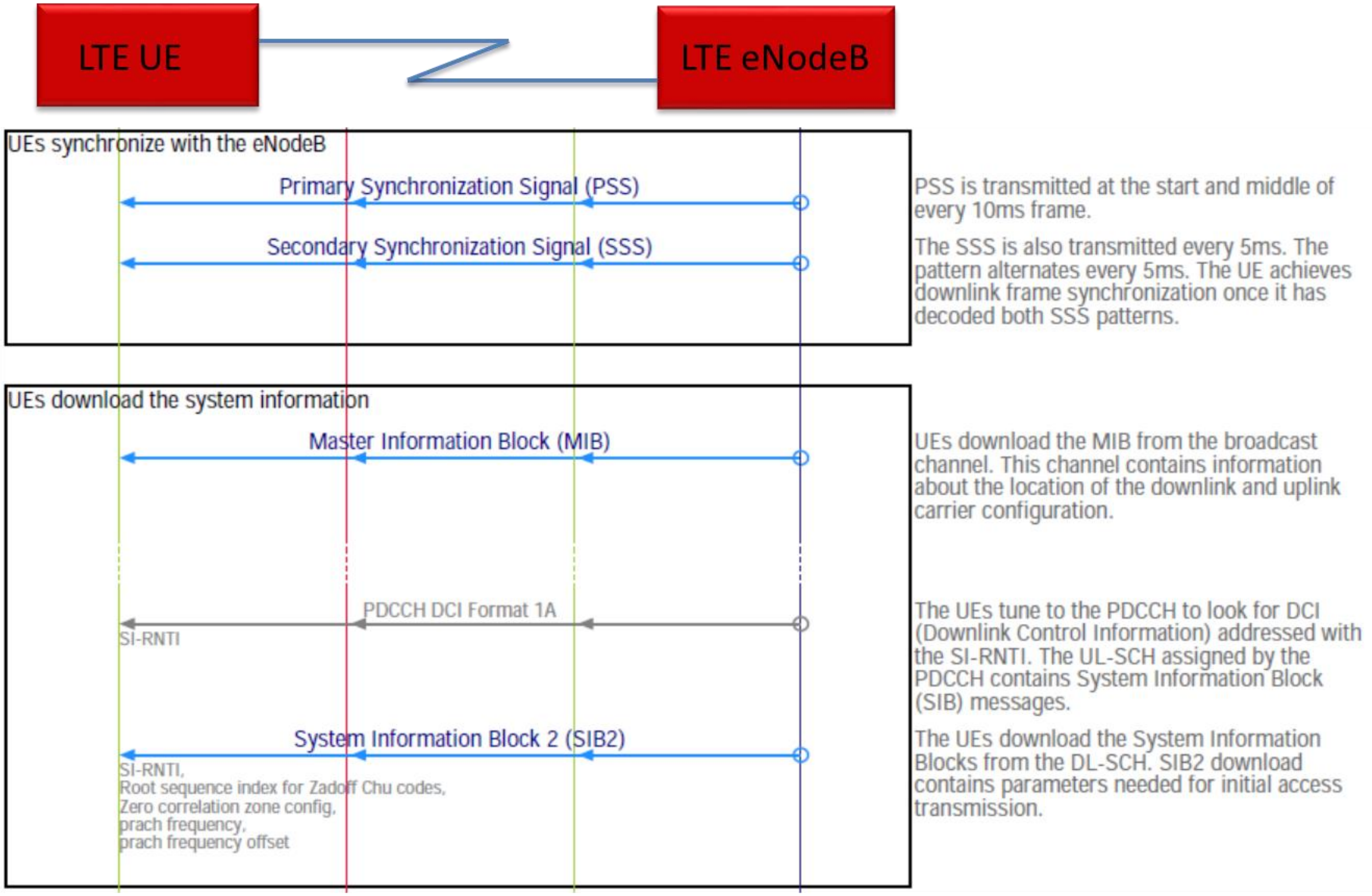


Advanced antenna solutions
Diversity
Beam-forming
Multi-layer transmission (MIMO)

Spectrum flexibility
Flexible bandwidth
New and existing bands
Duplex flexibility: FDD and TDD

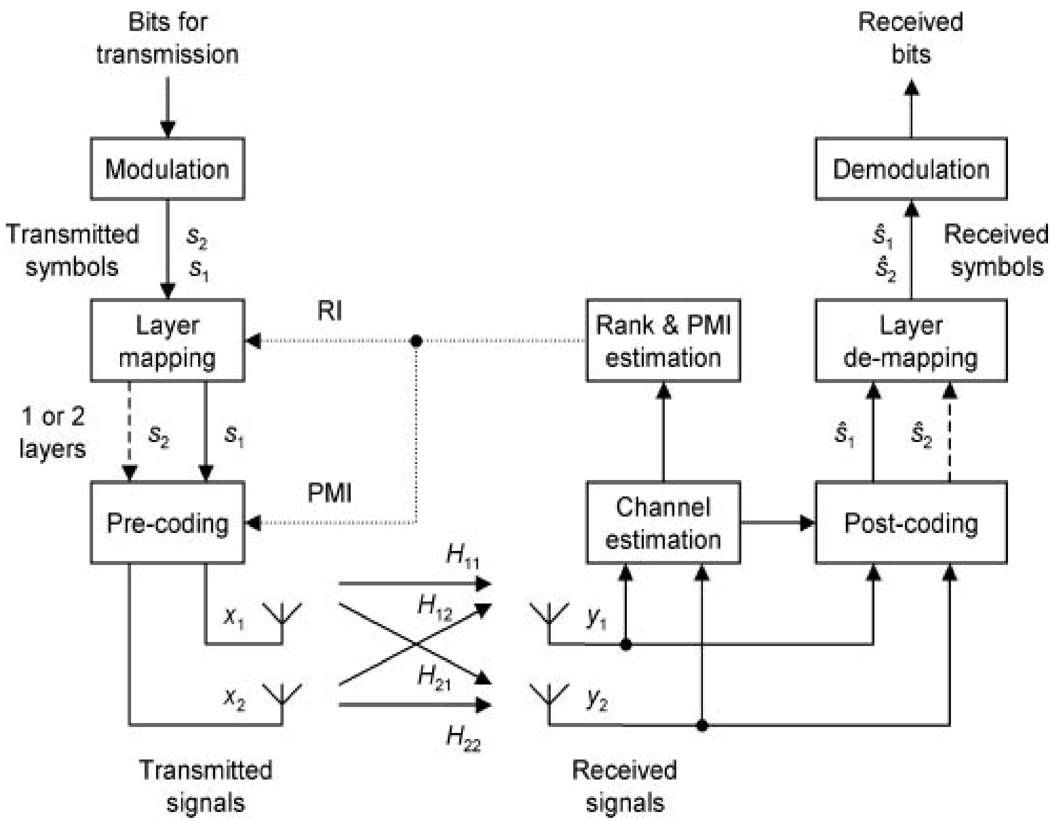


Attach Procedure



- MIB contains cell bandwidth and information about PHICH (Physical Hybrid Indicator Channel) and the SFN (System Frame Number).
- SIB contains list of PLMN IDs, TAC, CellId, CSG Identity (optional), neighbor cell information, etc.

Diversity - MIMO



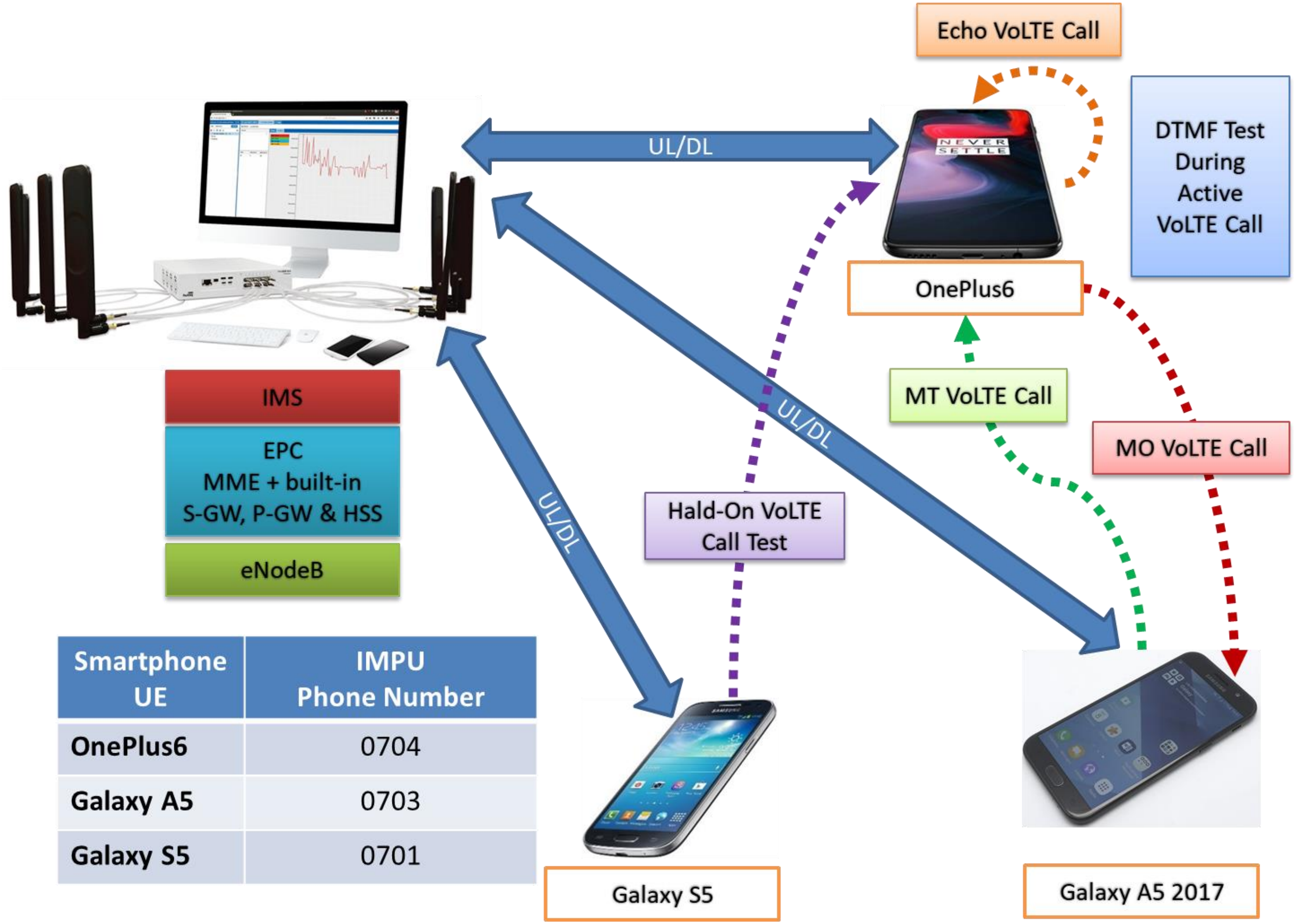
1. **RI : Rink Indication**
2. **PMI: Precoding Matrix Indicator**
3. **CQI: Channel Quality Indicator**

1. Riliability
2. Throughput

1. Ri = 2 ➔ x1 = s1 & x2 =s2
2. Ri = 1 ➔ x1 = s1 & x2 =s1

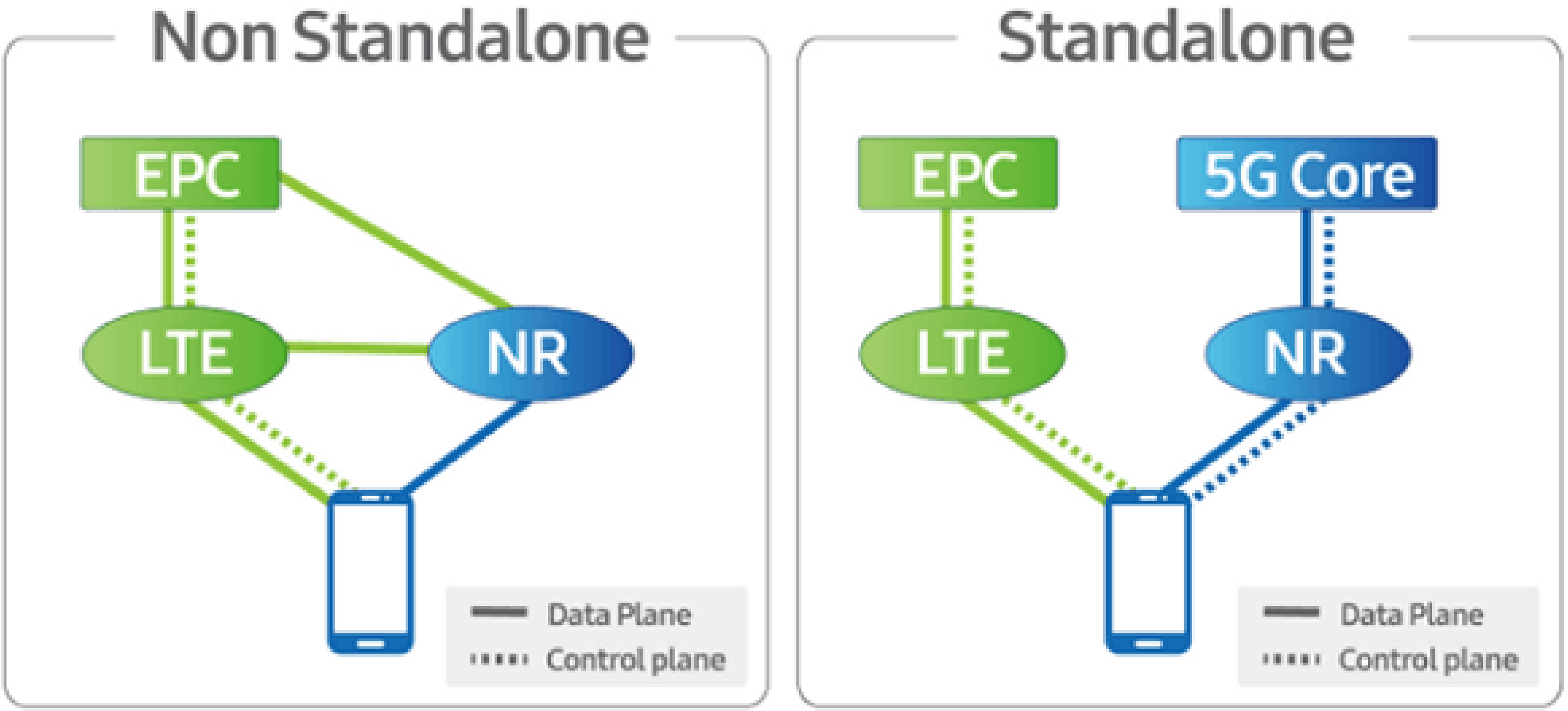
Spatial Diversity

3GPP LTE/4G – VoLTE (Voice over LTE)



Smartphone UE	IMPU Phone Number
OnePlus6	0704
Galaxy A5	0703
Galaxy S5	0701

Non-Standalone 5G-NR vs Standalone 5G NR



Non-Standalone 5G-NR vs Standalone 5G NR

- **Non-Standalone (NSA) 5G NR**

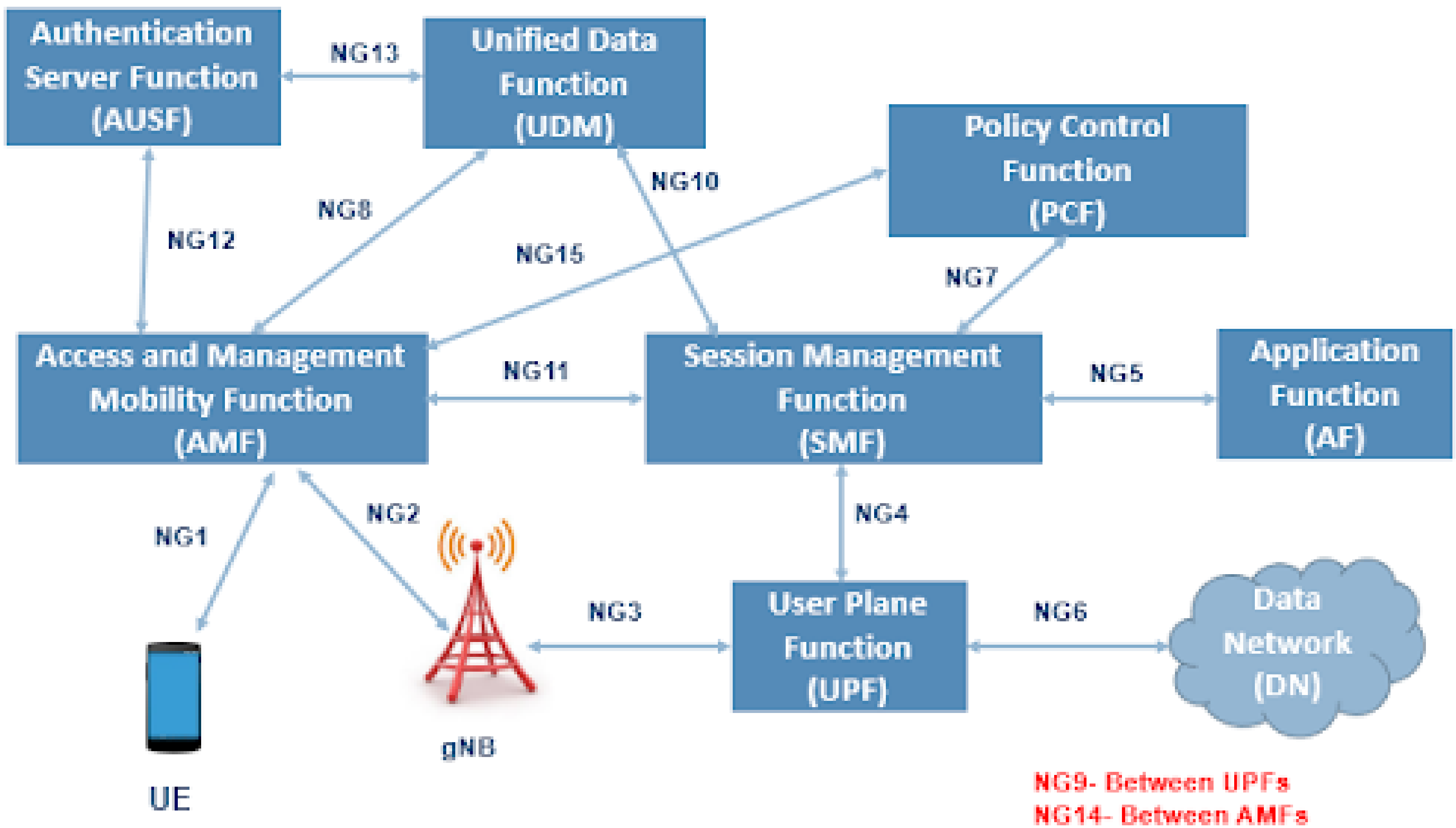
  NSA 5G-NR is the early version of Standalone 5G NR mode, in which 5G networks are supported by existing 4G infrastructure. Non-Standalone 5G NR primarily focuses on enhanced mobile broadband (eMBB), where the 5G supported mobiles will use mm-Wave frequencies for increased data capacity but will use existing 4G infrastructure for voice communications.

  - **Non-Standalone 5G NR will provide increased data-bandwidth by using two new radio frequency ranges:**
  - **Frequency Range 1 (450 MHz to 6000 MHz)** - This band overlaps with 4G LTE frequencies and is called as sub-6 GHz. Bands are numbered from 1 to 255.
  - **Frequency Range 2 (24 GHz to 52 GHz)** - This is the mm-Wave frequency band. The bands are numbered from 257 to 511.

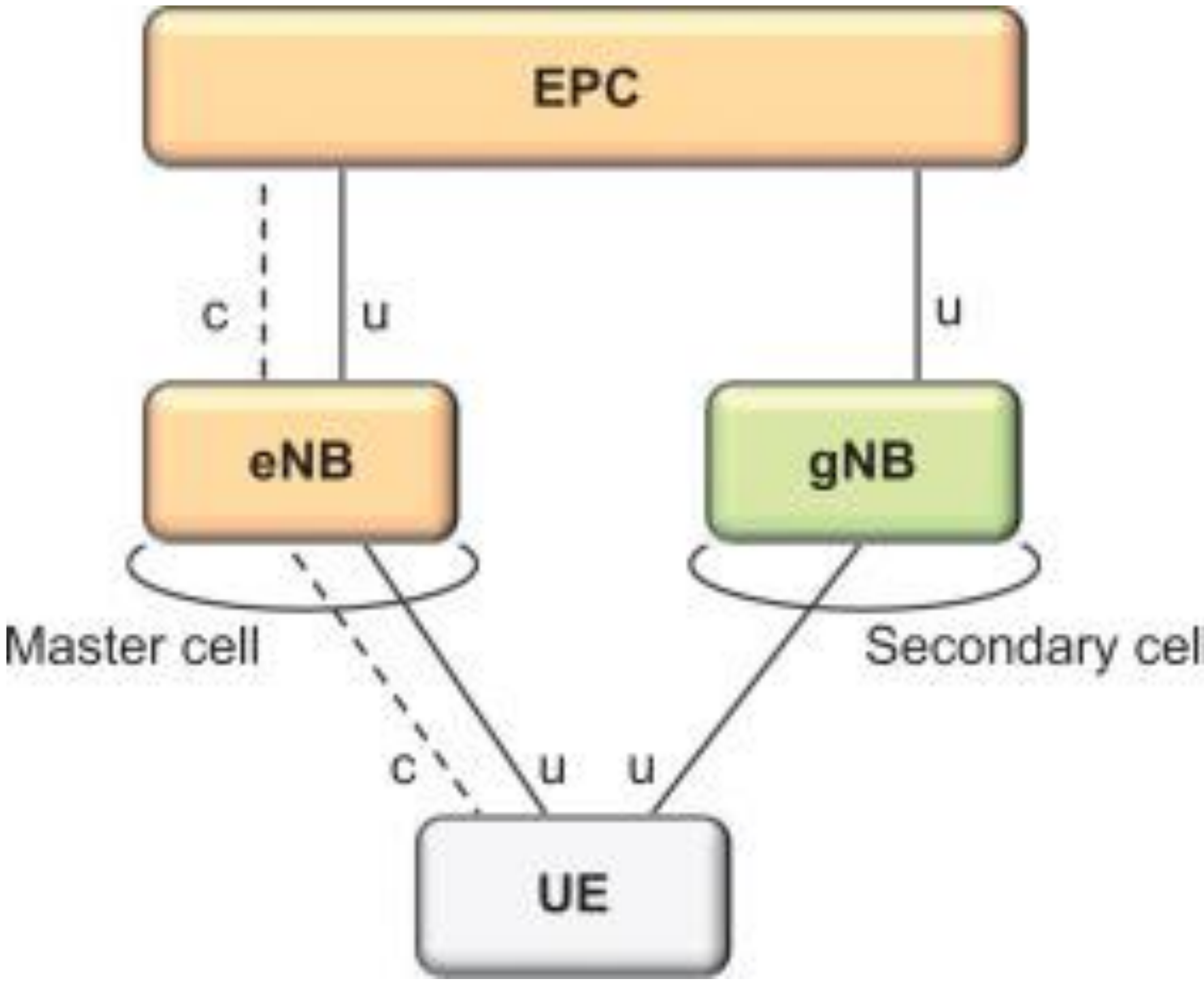
- **Standalone (SA) 5G NR**

  3GPP finalized the standalone 5G NR standard in 2018, which will work alongside the Non-Standalone 5G NR standard. Standalone 5G NR will have a new end-to-end architecture that will use mm-Waves and sub-GHz frequencies. This mode will not use existing 4G/LTE infrastructure. Standalone 5G NR will use enhanced mobile broadband (eMBB), Ultra-reliable and low latency communications (URLLC) and Massive machine type communications (mMTC) to provide multi-gigabit data rates with improved efficiency and lower costs.

5G Network Architecture



LTE & 5G Deployment



Cellular Vehicle-to-Everything (C-V2X)

In June 2017, 3GPP completed the standardization of Cellular Vehicle-to-Everything (C-V2X) technology. Based on LTE, this cellular technology is designed to connect vehicles to each other, to roadside infrastructure, to other road-users and to cloud-based services.

Why C-V2X?

- Leverage the comprehensive coverage of secure and well-established LTE networks
- Enable highly reliable, real-time communication at high speeds and in high-density traffic
- Support both short-range and long-range transmissions between vehicles and roadside infrastructure
- It is part of the roadmap to 5G connectivity

C-V2X employs two complementary transmission modes:

1. Direct communications
   - between vehicles,
   - between vehicles and infrastructure,
   - and vehicles and other road users, such as cyclists and pedestrians. In this mode, C-V2X works independently of the cellular networks.

2. Network communications, in which C-V2X employs the conventional mobile network to enable a vehicle to receive information about road conditions and traffic in the area.

How C-V2X Could Change Driving

C-V2X can be used in many different ways to improve road safety, while making more efficient use of transport networks and infrastructure. For example, it could support:

Platooning: The formation of a convoy in which the vehicles are much closer together than can be safely achieved with human drivers, making better use of road space, saving fuel and making the transport of goods more efficient.

Co-operative driving: Vehicles can use C-V2X to work together to minimize the disruption caused by lane changes and sudden braking.

Queue warning: Roadside infrastructure can use C-V2X to warn vehicles of queues or road works ahead of them, so they can slow down smoothly and avoid hard braking.

Avoiding collisions: Each vehicle on the road could use C-V2X to broadcast its identity, position, speed and direction. An on-board computer could combine that data with that from other vehicles to build its own real-time map of the immediate surroundings and alert the driver to any potential collisions.

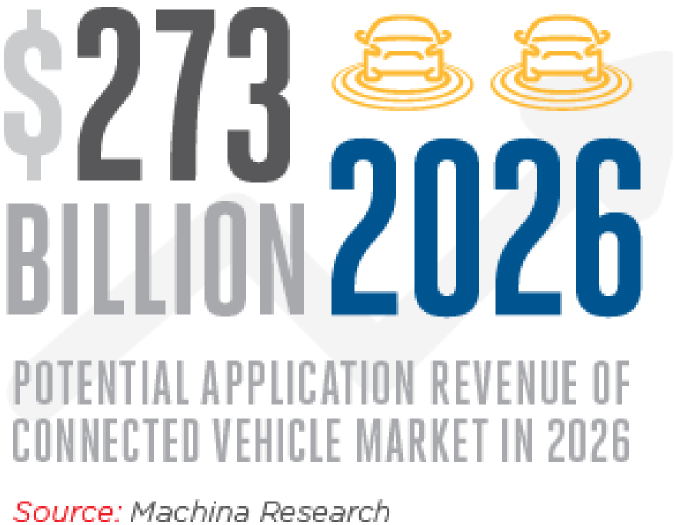
Hazards ahead warning: C-V2X can be used to extend a vehicle's electronic horizon, so it can detect hazards around a blind corner, obscured by fog or other obstructions, such as high vehicles or undulations in the landscape.

Increasingly autonomous driving: Along with other sensors and communications systems, C-V2X will play an important role in enabling vehicles to become increasingly autonomous.

Collecting road tolls: designed to reduce congestion and the impact of motor transport on the environment

Cellular Vehicle-to-Everything (C-V2X)

The connected vehicle market continues to grow rapidly. Advances in mobile technologies are enabling drivers and passengers to benefit from increasingly sophisticated infotainment, navigation, safety and telematics services. As demand rises around the world, the connected vehicle market is one of the fastest growing segments of the Internet of Things, potentially generating application revenue of US$273 billion by 2026, according to Machina Research's forecasts.



Cellular Vehicle-to-Everything (C-V2X)

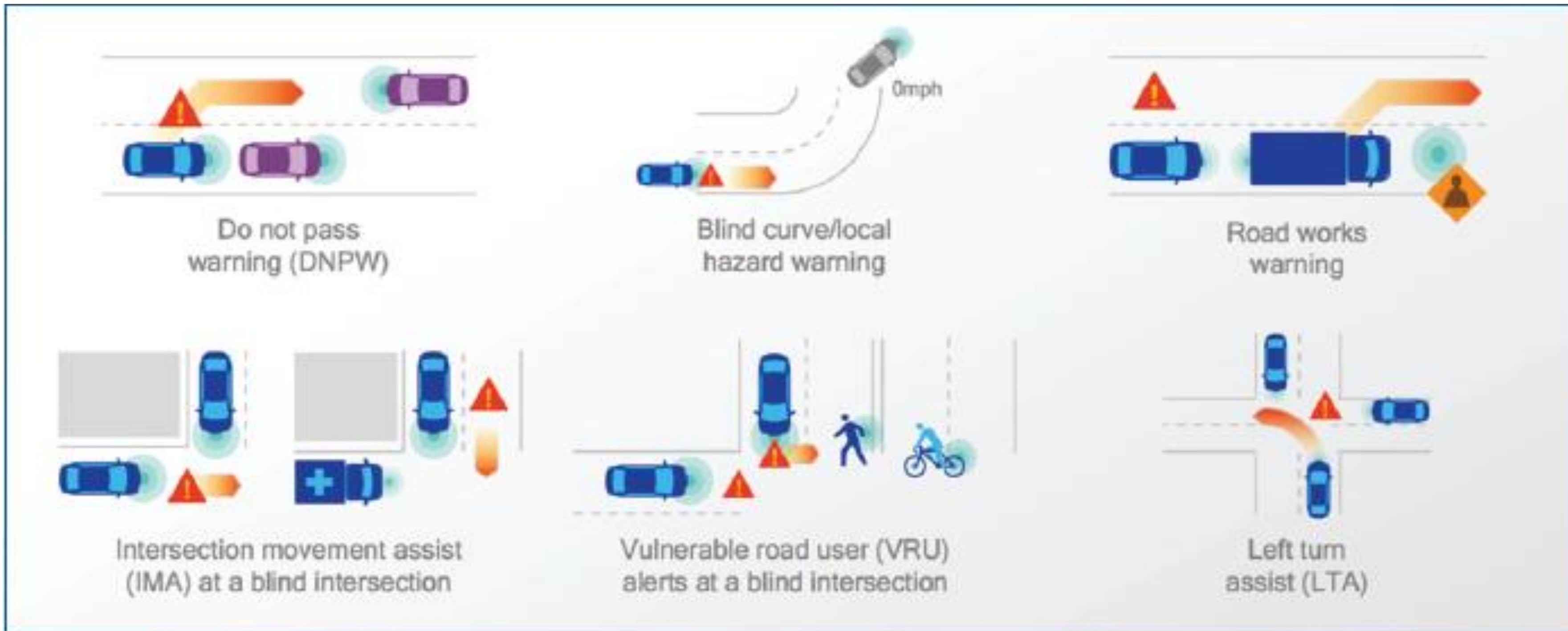
The latest vehicles on the world's roads contain very advanced information and communications technologies, including on-board computers, a wide range of sensors and, in many cases, both short-range and wide area connectivity. Many new vehicles rely on cellular networks to deliver a broad range of infotainment and telematics services, including pay-as-you drive insurance, navigation and automated emergency calling.
In particular, mobile networks are playing an increasingly important role in improving road safety and enhancing safety-critical systems on-board vehicles.

Mobile operators bring a number of assets to this market, including:

- ❑ Broad coverage via existing cellular net works and mobile ecosystem support
- ❑ Extensive experience in deploying, managing, and maintaining complex communication systems
- ❑ Complementary services, such as navigation, pay-as-you-drive insurance and vehicle diagnostics
- ❑ Public key infrastructure (PKI) certificate management
- ❑ Data storage and data analytics

How C-V2X Could Change Driving

C-V2X can be used in many different ways to improve road safety, while making more efficient use of transport networks and infrastructure. This section gives examples of the many scenarios in which C-V2X can help to enhance safety.



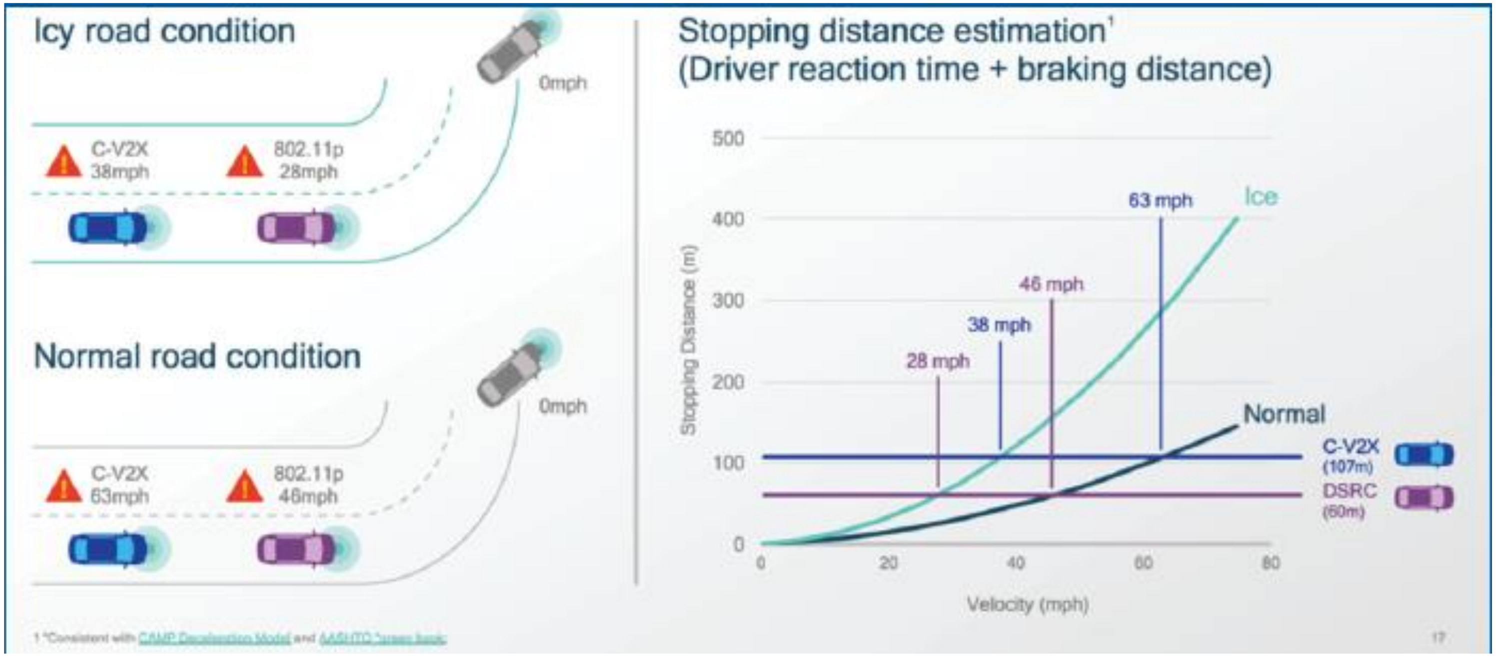
Platooning refers to the formation of a convoy in which the vehicles are much closer together than can be safely achieved with human drivers. Such automated convoys make better use of road space, save fuel and make the transport of goods more efficient. C-V2X can be used to enable communications between up to three vehicles in the platoon, so that they all slow down or speed up simultaneously. And C-V2X could also be used to signal the presence of the platoon to other vehicles and roadside infrastructure. Platoons will be flexible in that they will typically be established on a motorway, then broken up when a vehicle leaves the motorway.
For platoons of more than three vehicles, relaying information between vehicles takes too long to enable synchronous braking. Therefore, platoons of more than three vehicles will also need to make use of the low latency cellular network infrastructure that will be deployed with 5G.

Co-operative driving: Vehicles can use C-V2X to work together to make the best use of the available road space and minimize the disruption caused by lane changes and sudden braking. C-V2X can be used to convey intent to other road users. For example, once a vehicle has overtaken another vehicle, the most efficient way to re-enter a slower lane during periods of dense traffic, is for the vehicle in front of it to accelerate slightly, and for the following car to slow down slightly to make sufficient space for the merging car. The same process can also be used to smooth a vehicle’s entry on to a busy motorway.

Queue warning: Roadside infrastructure can also use C-V2X to warn vehicles of queues or road works ahead of them, so they can slow down smoothly and avoid hard braking. More broadly, the roadside infrastructure can use C-V2X to help vehicles retain a consistent speed and reduce the number of so-called phantom traffic jams caused by the ripple effect caused by sudden braking and lane changes on motorways.

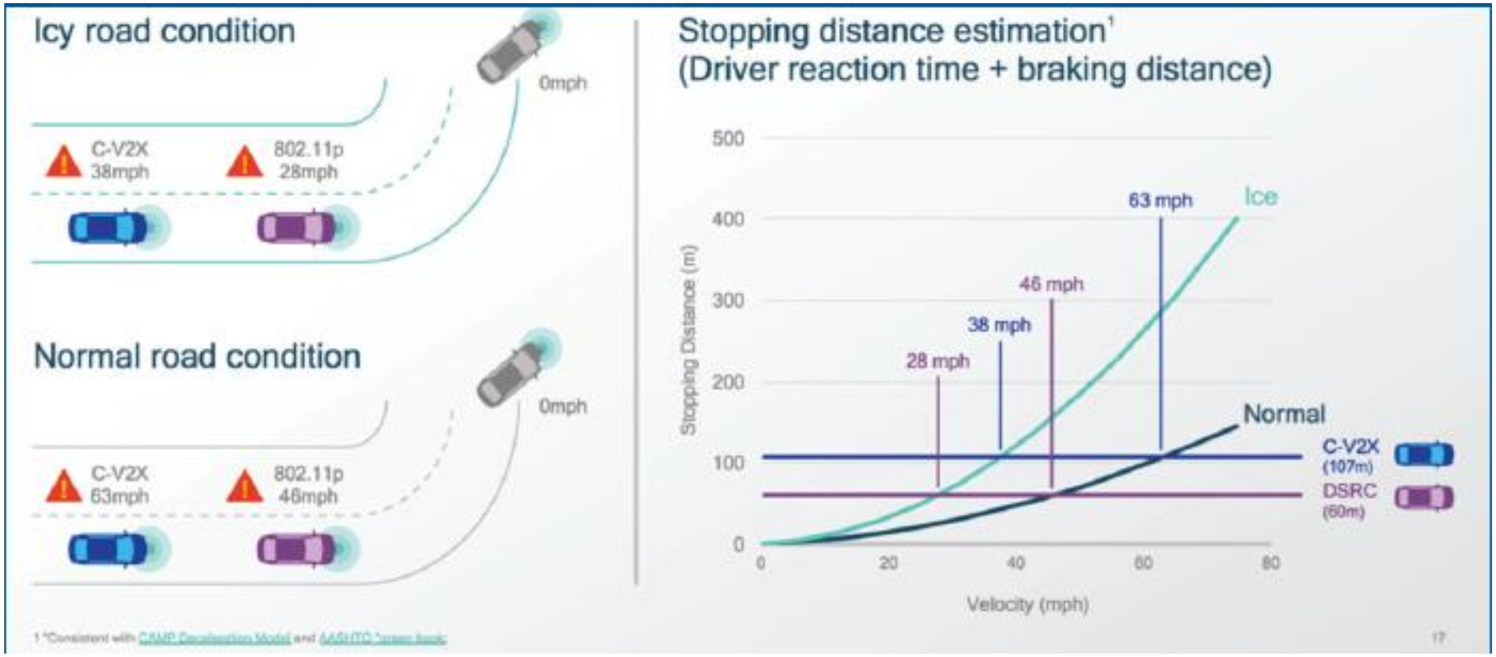
Avoiding collisions: Each vehicle on the road could use C-V2X to broadcast its identity, position, speed and direction. An on-board computer could combine that data with that from other vehicles to build its own realtime map of the immediate surroundings and determine whether any other vehicle is on a potential collision trajectory. The vehicles involved could then take evasive action, such as braking or accelerating, that will enable a collision to be avoided. In cases where a human driver is about to cause an accident, the information collected by C-V2X could be used to over-ride the manual controls. For example, if a driver is about to pull out at a junction into the path of another vehicle, the on-board computer could automatically apply the brakes and prevent the car moving forward.

Cellular Vehicle-to-Everything (C-V2X)



Hazards ahead warning: C-V2X can be used to extend a vehicle's electronic horizon, so it can detect hazards around a blind corner, obscured by fog or other obstructions, such as high vehicles or undulations in the landscape. Roadside signs could use C-V2X to broadcast hazard warnings to each vehicle on a particular stretch of road. Moreover, a vehicle could use C-V2X to send salient data captured by its sensors, such as ice on the road, to other vehicles travelling behind it. If a vehicle is braking hard, it could use C-V2X to transmit a warning to the vehicles behind it.

Cellular Vehicle-to-Everything (C-V2X)



Increasingly autonomous driving: Along with other sensors and communications systems, C-V2X will play an important role in enabling vehicles to become increasingly autonomous. For example, C-V2X could be used to give advance warnings of changes in traffic conditions so that the on-board computer can make better decisions on when to change lanes, accelerate or slow down.

How C-V2X Works

An advanced technology based on 4G, C-V2X can support a wider range of capabilities than earlier dedicated vehicle connectivity solutions, which are generally based on a Wi-Fi variant, known as 802.11p. C-V2X employs two complementary transmission modes to enable a very broad range of driving safety features. These modes are:

1. **Direct communications** between vehicles (V2V), between vehicles and infrastructure (V2I), and vehicles and other road users, such as cyclists and pedestrians (V2P). In this mode, C-V2X operates in the 5.9 GHz frequency band – the ITS (intelligent transport system) spectrum that has been identified and harmonized internationally for safety purposes. In this mode, C-V2X works independently of the cellular networks.

2. **Network communications,** in which C-V2X employs the conventional mobile network to enable the vehicle to receive information about road conditions and traffic in the area. In this mode, C-V2X operates in spectrum that has been licensed to mobile operators to provide connectivity to their customers.

Direct Communications

The ITS 5.9 GHz spectrum band has been set aside by governments worldwide to enable vehicles to talk to each other using dedicated frequencies that won't be subject to interference. Using this band, C-V2X can support direct low latency connections
over short distances, without the involvement of the cellular network. Like 802.11p, C-V2X employs the global navigation satellite system (GNSS) to determine the position of the vehicle and to synchronize communications between vehicles and with roadside infrastructure.

In this mode, no SIM card is required, as the vehicle doesn't need to connect to the cellular network. The vehicle and its driver remain anonymous, as no cellular subscription is required for direct safety communications.

C-V2X and 802.11p can co-exist in the ITS spectrum by employing different channels within the 5.9 GHz band. Just 10MHz of spectrum in the 5.9GHz band is required to support basic safety services, while 70MHz could support advanced safety services, such as sharing large amounts of data collected by on-vehicle sensors.

Network Communications

C-V2X can also support vehicle-to-network (V2N) applications delivered over commercially-licensed cellular spectrum. This mode can be used to provide network assistance for safety-related features, as well as commercial services, requiring the involvement of a mobile operator, providing access to cloud-based data or information. This mode also enables C-V2X to harness the data security and privacy of mobile networks.
Time-critical services can be supported by edge computing – the deployment of computer servers and data analytics on the edge of the network.

Developed to be both deployable in the near term and future-proof, C-V2X is versatile enough to support both today’s use cases, and those of tomorrow. Compatible with 4G and 5G cellular networks, it is intended to be both scalable and interoperable. In time, C-V2X will support Advanced Driver Assistance Systems (ADAS) where vehicles can cooperate, coordinate and share information collected by sensors, and ultimately, connected automated driving (CAD).

The Technical Advantages of C-V2X

	C-V2X: PC5	802.11p	C-V2X: PC5 ADVANTAGE
Synchronization	Synchronous	Asynchronous	Spectral Efficiency. Synchronization enables time division multiplexing (TDM) and lowers channel access overhead.
Resource Multiplexing Across Vehicles	FDM and Time Division Multi-plexing (TDM) Possible	TDM Only	Frequency Division Multiplexing allows for larger link budget and therefore longer range - or more reliable performance at the same range
Channel Coding	Turbo	Convolutional	Coding gain from turbo codes leads to longer range - or more reliable performance at the same range.
Retransmission	Hybrid Automatic Repeat Request (HARDQ)	No HARQ	Leads to longer range - or more reliable performance at the same range.
Waveform	SC-FDM	OFDM	Allows for more transmit power with the same power amplifier. Leads to longer range - or more reliable performance at the same range.
Resource Selection	Semi-persistent transmission with relative energy-based selection.	Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA)	Optimizes resource selection with selection of close to 'best' resource with no contention overheads. By contrast 802.11p protocol selects the first "good enough" resource and requires contention overhead.

Source: 5GAA

C-V2X : The Roadmap for Deployment

C-V2X has widespread support within the telecoms and automotive industries. The 5GAA, a cross industry consortia to help define 5G V2X communications, is a strong supporter of C-V2X.

Audi, BMW, Daimler, Ford, Jaguar Land Rover, Nissan, SAIC Motor and Volkswagen are among its members, along with most of the world's leading mobile operators and their equipment suppliers.

- Huawei, has run trials with China Mobile, SAIC Motor Corporation, Deutsche Telecom, Audi and Toyota, including a live demonstration at the G20 Summit in Hangzhou in September 2016, which simulated real-life driving conditions.
- In February 2017, Orange and PSA Group announced the completion of initial C-V2X field trials in France. The trials explored two use cases: "see through" between two connected vehicles on a road, and "emergency vehicle approaching," aiming at notifying drivers in real-time when an emergency vehicle is nearby. Orange and PSA said they employed a new radio access network configured with edge-computing features, to achieve an average delay of just 17 milliseconds for vehicle-to-network-to-vehicle communications at a vehicle speed of 100 km/h. This is in comparison to the 30-60 millisecond results measured in conventional LTE networks. These results were achieved in the 2.6 GHz frequency band, delivering a 100 Mbps performance.

C-V2X : The Roadmap for Deployment

Working with Qualcomm, Orange and the PSA Group are :

- Implementing a dedicated network slice to prioritize intelligent transportation system (ITS) vehicular traffic over other traffic

- Using the direct communication features of C-V2X to test V2V, V2I and V2P capabilities

- Helping to develop new use cases to assess how C-V2X with 5G NR features will support advanced applications, including traffic flow optimization, improved safety and automated driving

Questions & Discussion