

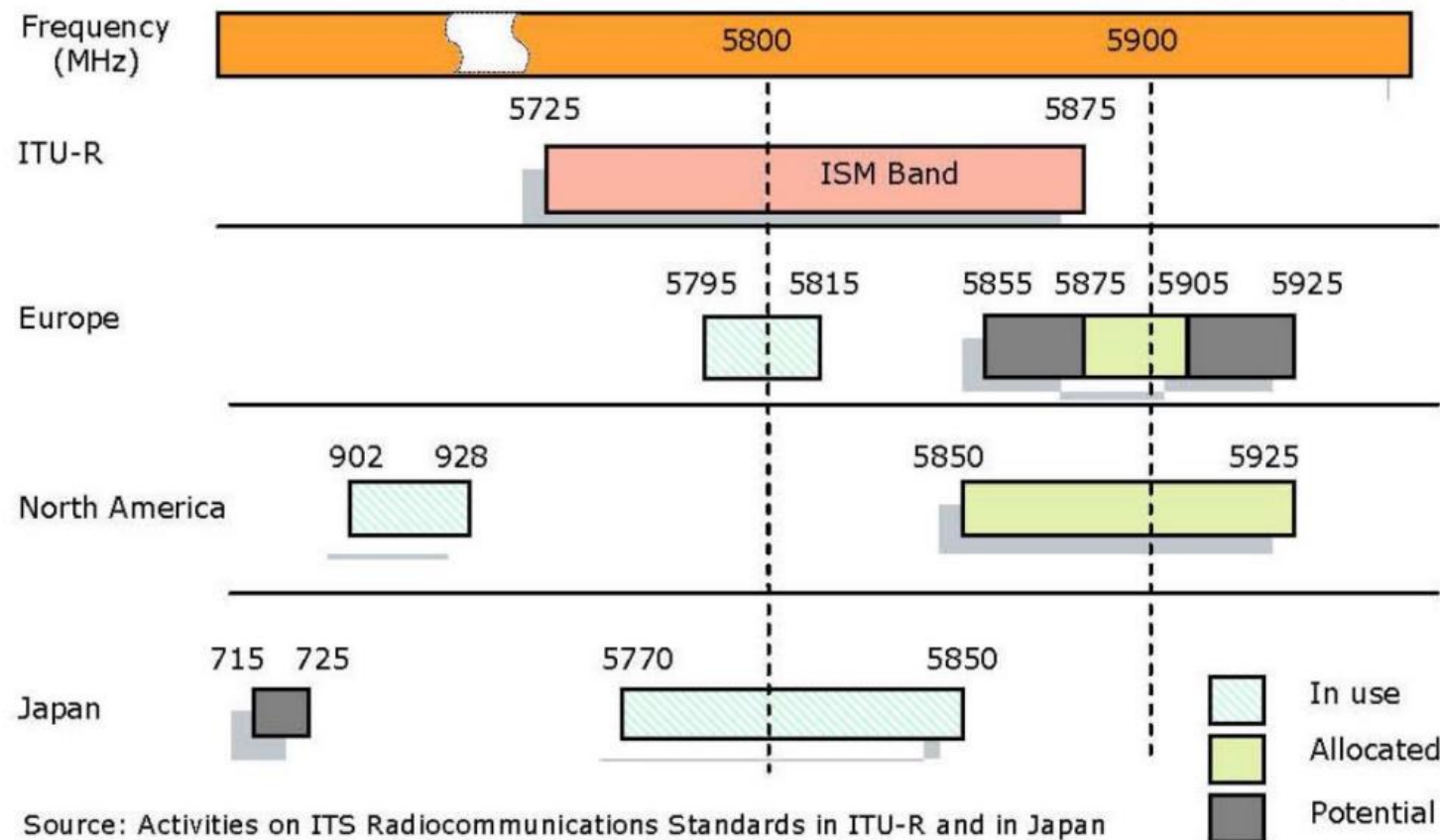


Intelligent Transportation Systems

Rolland Vida, BME TMIT

DSRC – Dedicated Short Range Communications

- Dedicated in 1999 by the FCC (Federal Communications Commission) to vehicular communications
 - 75 MHz of spectrum in the 5.9 GHz band (5.850-5.925 GHz)
- In Europe, ETSI allocated in 2008 30 MHz in the 5.9 GHz band for ITS
- Systems in US, Europe, Japan not really compatible with each other

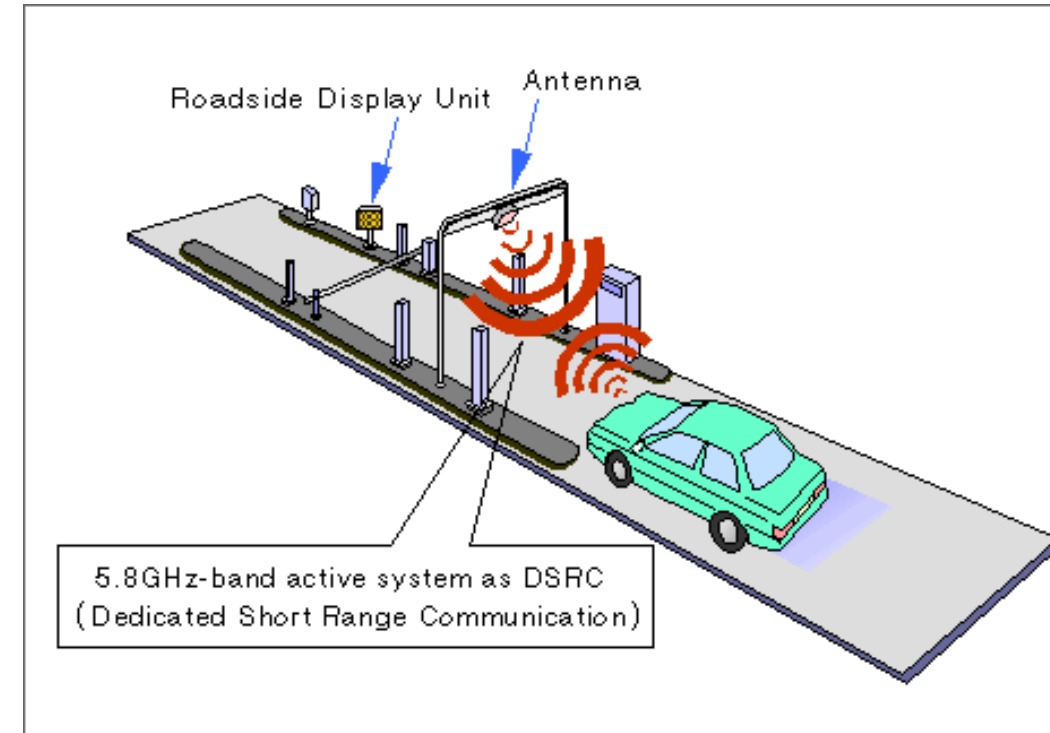


DSRC – Dedicated Short Range Communications

- Traditional ISM bands (Industry, Science, Medical) – 900 MHz, 2.4 GHz, 5 GHz
 - **Free, unlicensed bands**
 - Populated by many technologies – Wifi, Bluetooth, Zigbee
 - No restrictions other than some emission and co-existence rules
- DSRC band
 - **Free but licenced spectrum**
 - Restrictions in terms of usage and technologies
 - All radios should be compliant to a standard

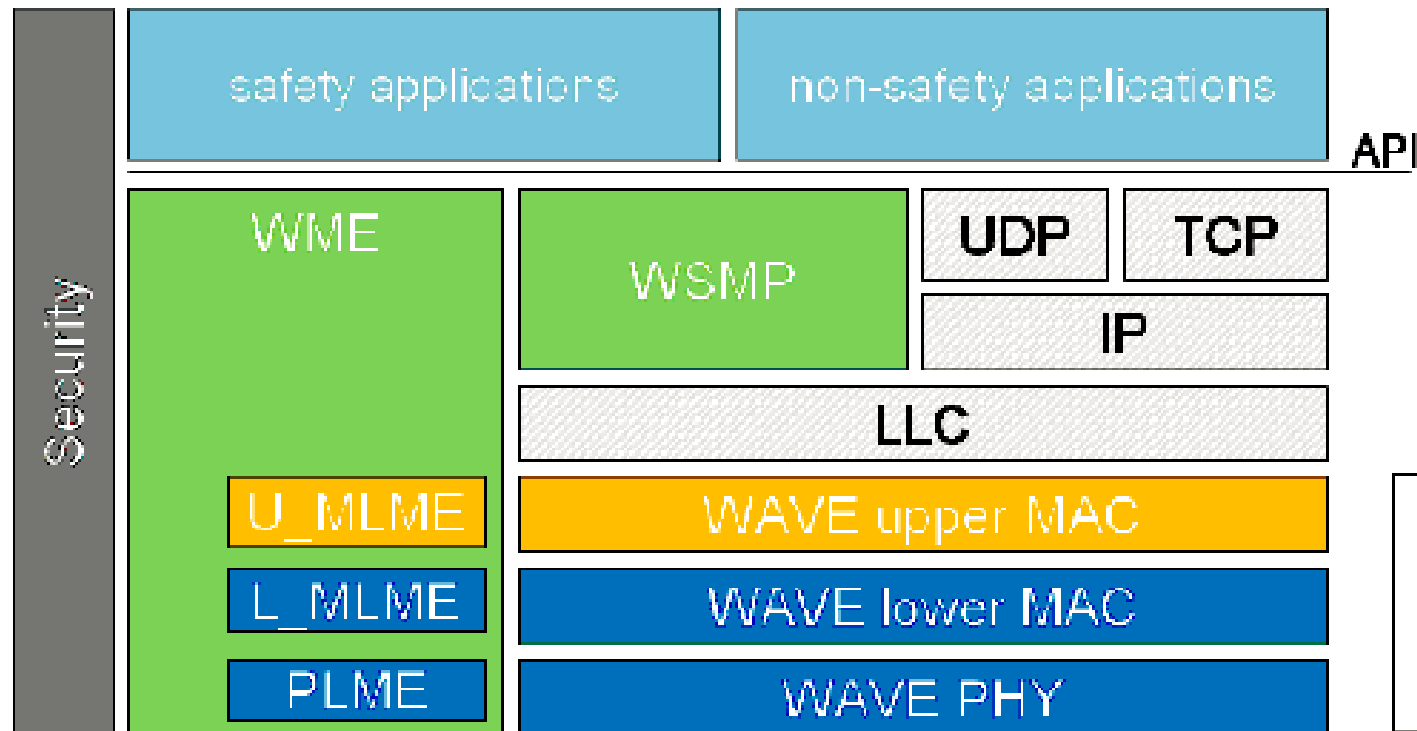
DSRC – Dedicated Short Range Communications

- **Basic goals of DSRC**
 - Support of low latency, secure transmissions
 - Fast network acquisition, rapid and frequent handover handling
 - Highly robust in adverse weather conditions
 - Tolerant to multi-path transmission
- **Mainly for public safety applications**, to save life and improve traffic flow
- Private services also permitted
 - Spread the deployment costs, encourage quick development and adoption
 - **Electronic Toll Collection (ETC)** was initially one of the main drivers



WAVE

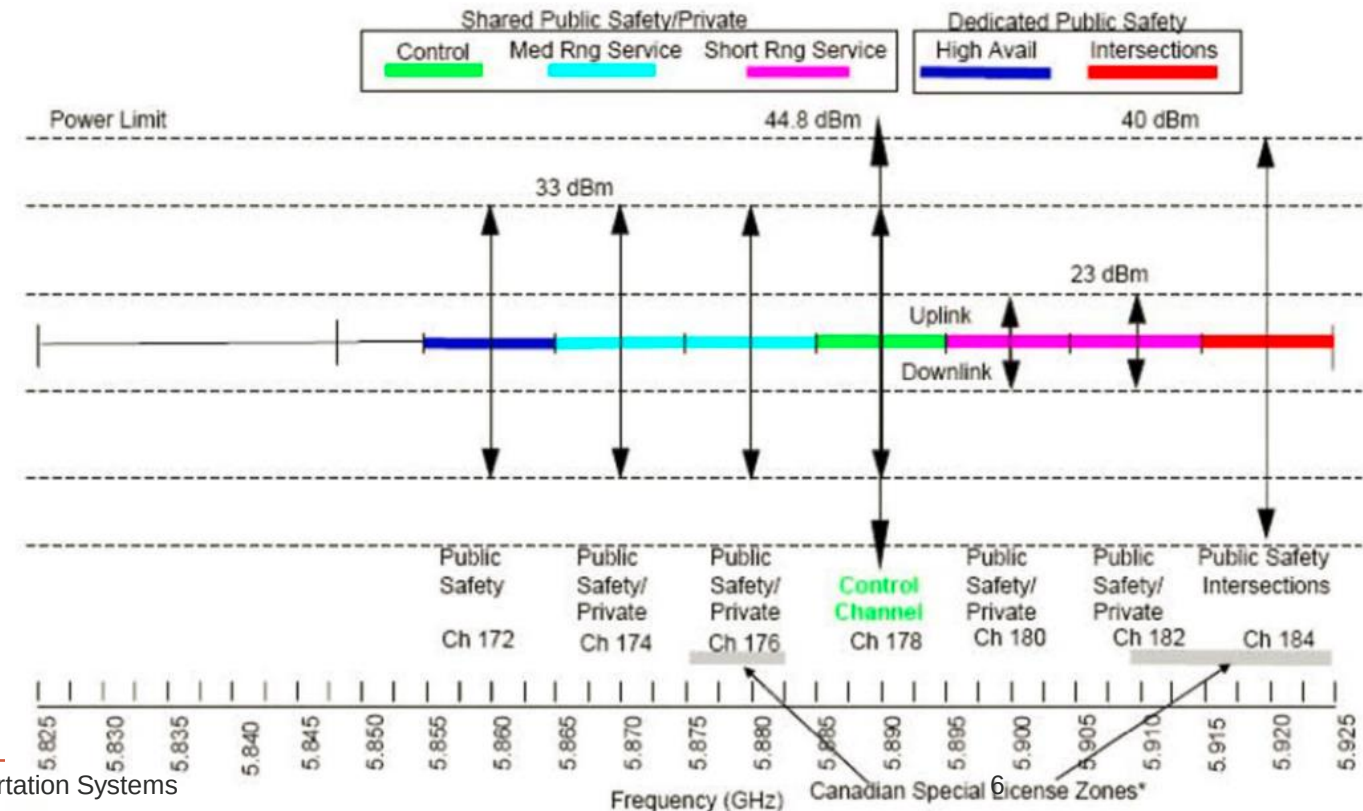
- IEEE 802.11
 - Collection of physical (PHY) and medium-access control (MAC) layer specifications for implementing WLAN
 - 802.11a (5 GHz, OFDM), 802.11b (2.4 GHz, DSSS), 802.11g (2.4 GHz, OFDM), 802.11n (2.4 and 5 GHz, MIMO-OFDM), 802.11ac (5 GHz, MIMO-OFDM)
 - **802.11p – part of WAVE (Wireless Access in Vehicular Environment)**



WME – WAVE Management Entity
PLME – Physical Layer Manag. Entity
MLME – MAC Layer Manag. Entity
LLC – Logical Link Control
WSMP – WAVE Short Message Prot.

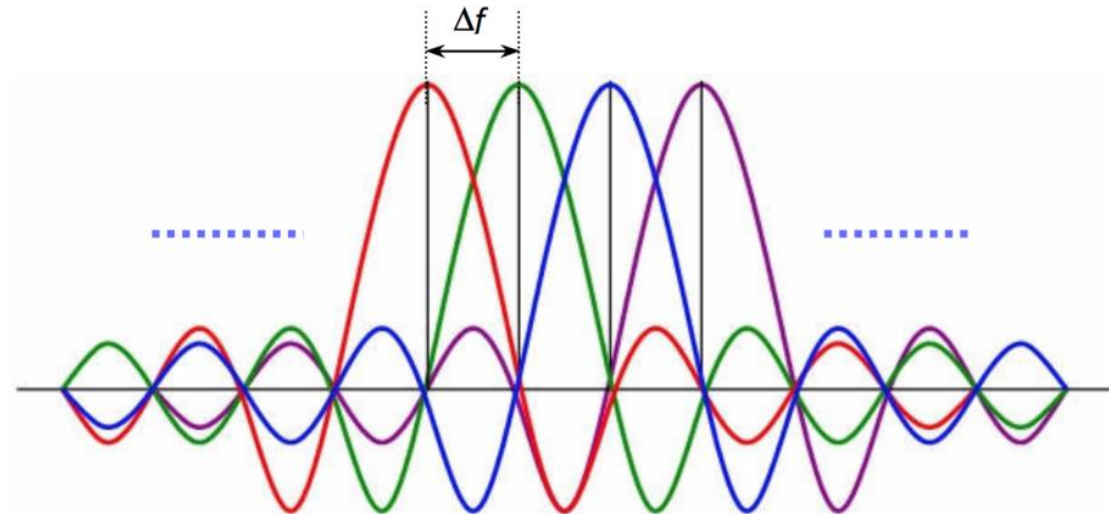
WAVE spectrum bands

- 75 MHz wide spectrum divided into 7x10 MHz wide channels, 5 MHz guard band
 - Channel 178 the **control channel (CCH)**
 - Transmit WAVE Short Messages (WSM)
 - Announce WAVE services
 - Channel 172 reserved for **high availability applications (future use)**
 - Channel 184 reserved for **intersections**
 - The other channels shared between public safety and private uses
 - Channels 174-176 and 180-182 can be combined to form a 20 MHz channel



WAVE (802.11p) vs IEEE 802.11

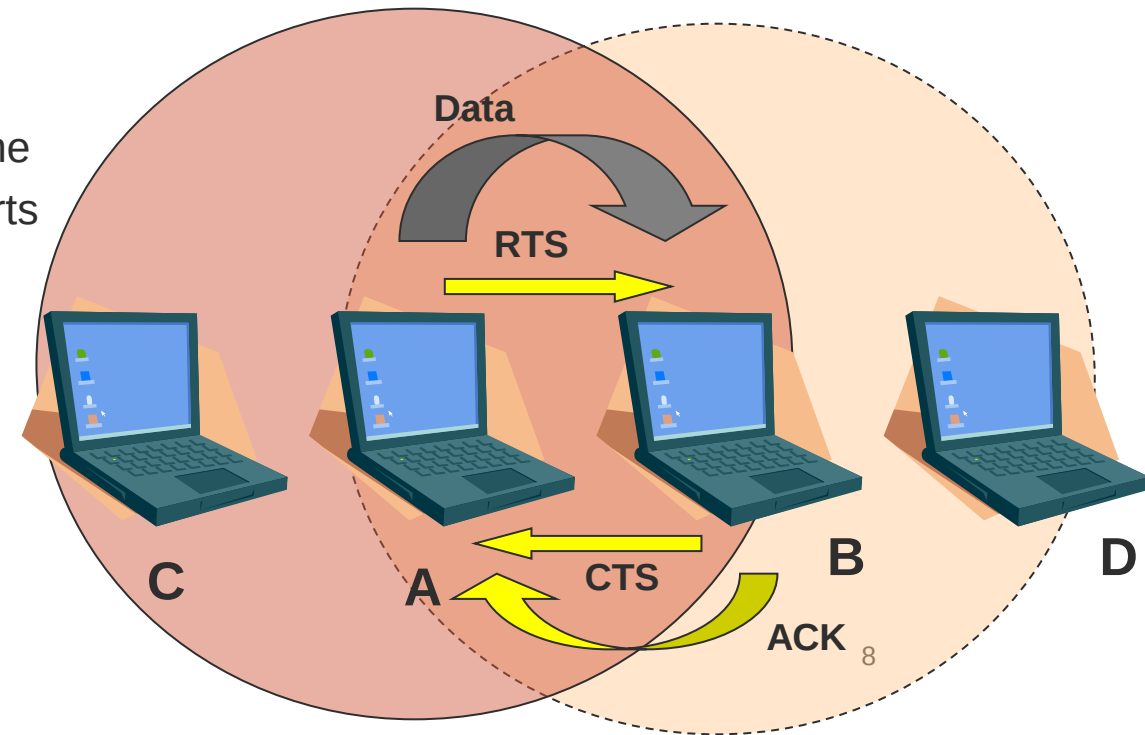
- 10 MHz channels instead of 20 MHz
- 3-27 Mbps instead of 6-54 Mbps
- Same modulation schemes (BPSK, QPSK, 16QAM, 64QAM)
- Carrier spacing reduced to 0.15625 MHz from 0.3125 MHz
 - 48 data subcarriers for both



Traditional IEEE 802.11 MAC (DCF)

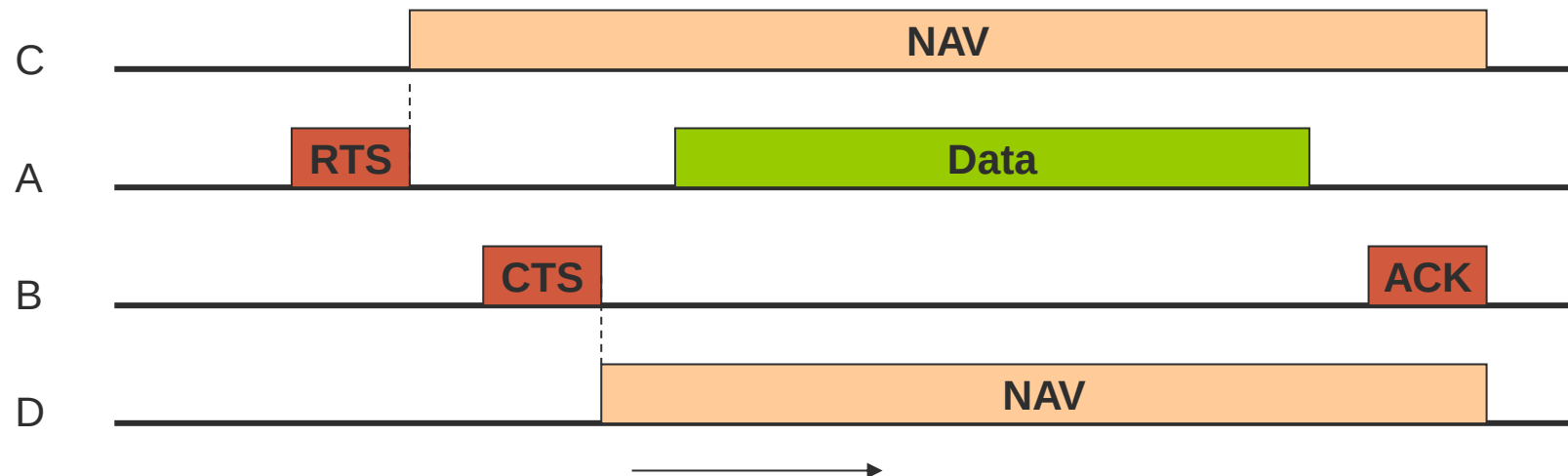
- **DCF – Distributed Coordination Function**

- A sends an **RTS** frame to B, asking the permission to send a data frame
 - **Request To Send**
- If B gives the permission, it sends back a **CTS** frame
 - **Clear To Send**
- A sends the data frame, and starts an ACK timer
 - If B receives the packets in order, it replies with an ACK frame
 - If the timer expires without receiving an ACK, everything starts from scratch



Traditional IEEE 802.11 MAC (DCF)

- C hears A, receives the RTS frame
 - Deduces that in the next moments someone will start to send data
 - It stops its own transmission, while the other conversation is not finished
 - Knows when it ends from the ACK timer, included in the RTS frame
 - It sets an internal reminder to himself, saying that the channel is **virtually occupied**
 - NAV – Network Allocation Vector
- D does not hear about the RTS, but hears the CTS
 - Also sets a NAV for himself



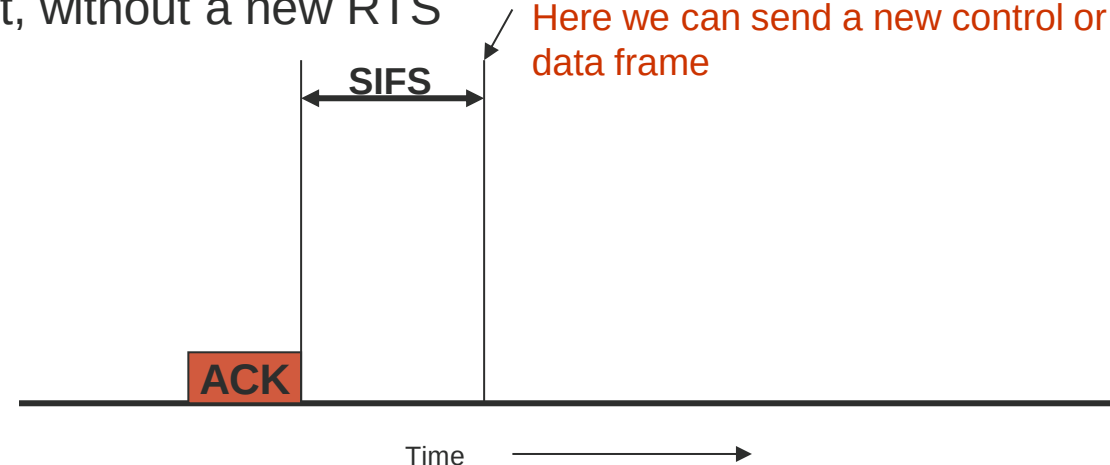
Traditional IEEE 802.11 MAC (PCF)

▪ PCF – Point Coordination Function

- An Access Point controls the access to the wireless channel
 - No collisions
- The AP polls the other stations, to find out who has data to send
 - The standard defines only some basic features of the poll
 - Does not define the frequency, or the order in which different stations are polled
 - Does not ask for equal treatment for all the stations
- The AP periodically sends a **beacon frame**
 - 10-100 beacons / s
 - It contains system parameters
 - Hopping sequence and dwell times (for FHSS), clock synchronization, etc.
 - New stations are invited to participate in the polling

Traditional IEEE 802.11 MAC (DCF & PCF)

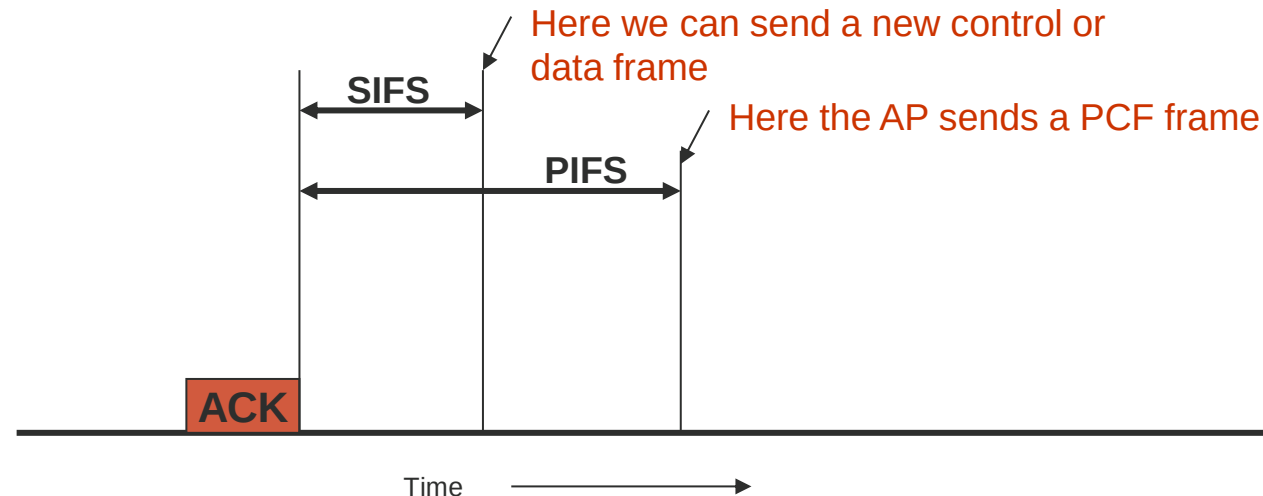
- PCF and DCF can operate in parallel inside the same cell
 - Distributed and centralized control in the same time?
 - Is possible, if carefully defined timers are used
 - After the sending of a frame, a certain guard time is required before any other transmission
- Four specific timers
 - **SIFS – Short Inter-Frame Spacing**
 - The shortest spacing, to support those devices that currently occupy the channel for a short conversation
 - After the SIFS, a receiver can send a CTS to an RTS
 - After the SIFS, a receiver can send an ACK for a given part of the data frame
 - A new part can be sent, without a new RTS



Traditional IEEE 802.11 MAC (DCF & PCF)

▪ PIFS – PCF Inter-Frame Spacing

- After an SIFS, only one specific station can send
- If nothing is sent until the end of the PIFS, the AP has the possibility to take over the channel, and send a new beacon or a polling frame
 - An ongoing conversation can be finished without disturbing it
 - The AP can access the channel without a contention
 - No contention with the greedy users

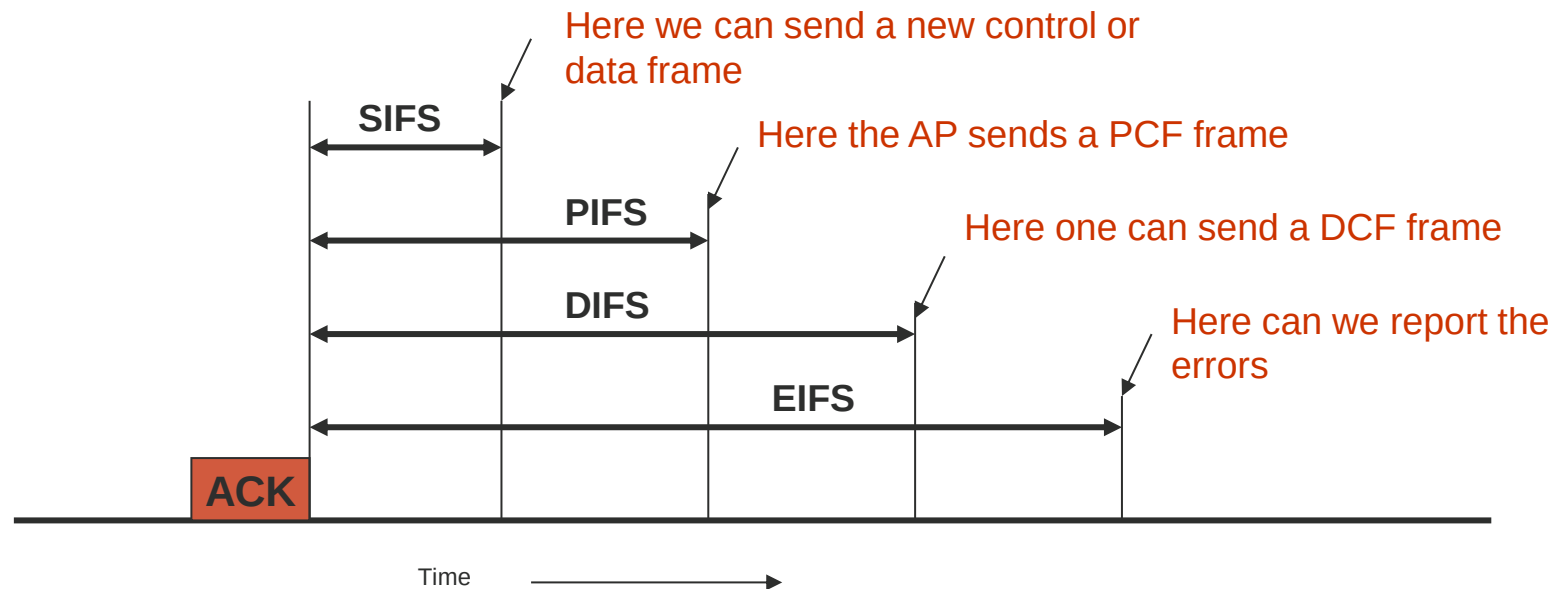


Traditional IEEE 802.11 MAC (DCF & PCF)

▪ DIFS – DCF Inter-Frame Spacing

- If the AP does not have anything to send, after the DIFS anyone can try to gain access to the channel
 - Usual contention rules
 - Exponentially increasing back off interval, if collision
- Same DIFS value for all traffic types

▪ EIFS – Extended Inter-Frame Spacing



802.11p MAC

- **Enhanced Distributed Coordination Access (EDCA)**

- Supports Quality of Service differentiation
 - 4 Access Categories – Voice, Video, Best Effort and Background

- **Arbitration Inter-Frame Spacing** to replace the static DIFS

- Different values for each Access Category
- By default...
 - Voice Queue 1 SIFS + 2 * slot time (AIFSN = 2)
 - Video Queue 1 SIFS + 2 * slot time (AIFSN = 2)
 - Best Effort Queue 1 SIFS + 3 * slot time (AIFSN = 3)
 - Background Queue 1 SIFS + 7 * slot time (AIFSN = 7)

802.11p beaconing

- Basic Service Set in traditional IEEE 802.11
 - Multiple handshakes to ensure distributed medium access
- **Wave Basic Service Set (WBSS)** in 802.11p
 - A node broadcasts a beacon, to advertise its WBSS
 - What kind of services it supports, how to join the WBSS
- Within the WBSS, nodes exchange beacons using the **Wave Short Message Protocol (WSMP)**
 - To create cooperative awareness
 - Information on speed, position, acceleration, direction
 - Sent at regular intervals (e.g., 10 Hz – 100 ms)
- Sent on the CCH, no ACK
 - After the channel is sensed free for AIFS
 - If not free, backoff for the size of a Contention Window, and try again
 - No doubling of the contention window
- As opposed to data sent on SCH, where ACK should be sent
 - If no ACK received, collision occurred, contention window doubled



IEEE 1609.x

- IEEE 1609.2 – security services
- IEEE 1609.3 – management services
 - Channel usage monitoring
 - IPv6 configurations
 - Received channel power indicator (RCPI)
 - Management parameters
- IEEE 1609.4 – QoS and multi-channel access
 - User Priorities mapped to Access Categories in EDCA
 - Multi-channel access for single radio 802.11p devices

IEEE 1609.4 channel swithcing

- 7 FDMA channel frequencies
- **Multi-channel radios** can send and receive over several channels simultaneously
- **Single channel radios** to access both CCH and SCH
 - Either transmit or receive on a single 10 MHz channel, but not simultaneously
- **Alternating access**
 - TDMA channel – repetitive periods of 100 ms
 - 46 ms allocated to the CCH channel
 - 46 ms allocated to the SCH channels
 - 4 ms guard interval for switching between CCH and SCH
 - Nodes should wait for a random backoff after the end of the guard interval, before starting to transmit
 - Time synchronisation needed to an external time reference
 - Coordinated Universal Time (UTC) from GPS or other devices
 - **WAVE Time Advertisement (WTA)** frame



IEEE 1609.4 channel switching

- **Continuous access**
 - Transmission can be continuous on the CCH and all SCHs
 - It cannot be guaranteed that all other stations will listen to the CCH outside the CCH slot
 - Safety messages sent over the CCH in the SCH slot might be ineffective
 - The usage of SCH not efficient if nodes listen to the CCH 50% of the time
- Alternative solutions to minimise the impact of channel switching?

IEEE 1609.4 channel switching

▪ Immediate access

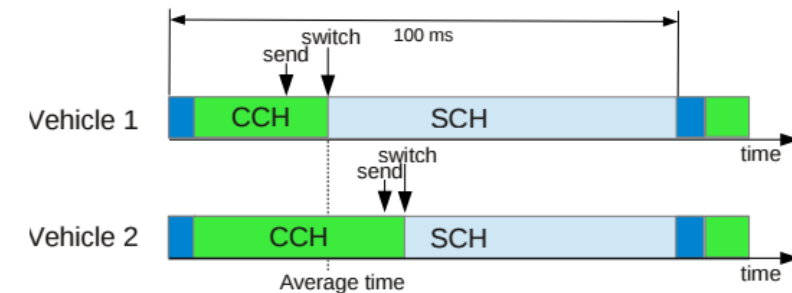
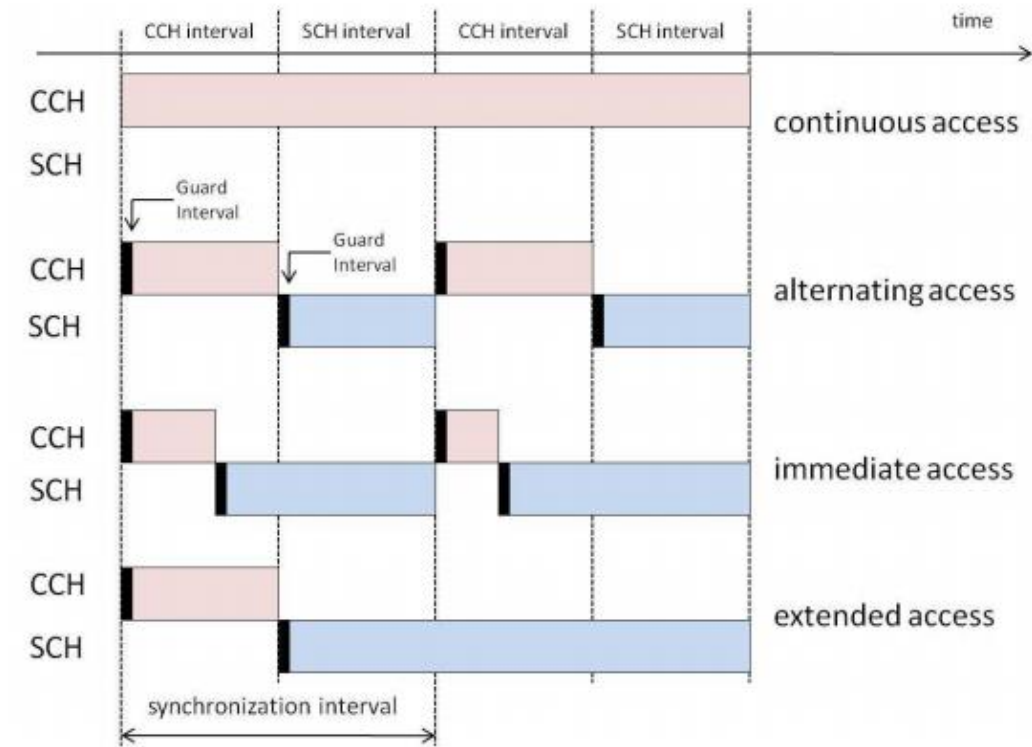
- The node does not have to wait until the CCH slot is over
- After the CCH transmission is over, switch to SCH
- Improve the performance of bandwidth-demanding non-safety applications in SCH, at the expense of the CCH

▪ Extended access

- Transmission on the SCH without waiting for the CCH

▪ Adaptive Independent Channel Switching

- If more vehicles, more beacons on the CCH
- Nodes can change their average switching time based on vehicle density
 - Long SCH intervals if not many vehicles
 - Fewer collisions at the start of the SCH, as nodes switch independently of each other
- Drawback is that not all nodes on the CCH in the same time
 - Vehicle 1 will miss the beacon of Vehicle 2



IEEE 1609.4 channel switching

▪ Fragmentation

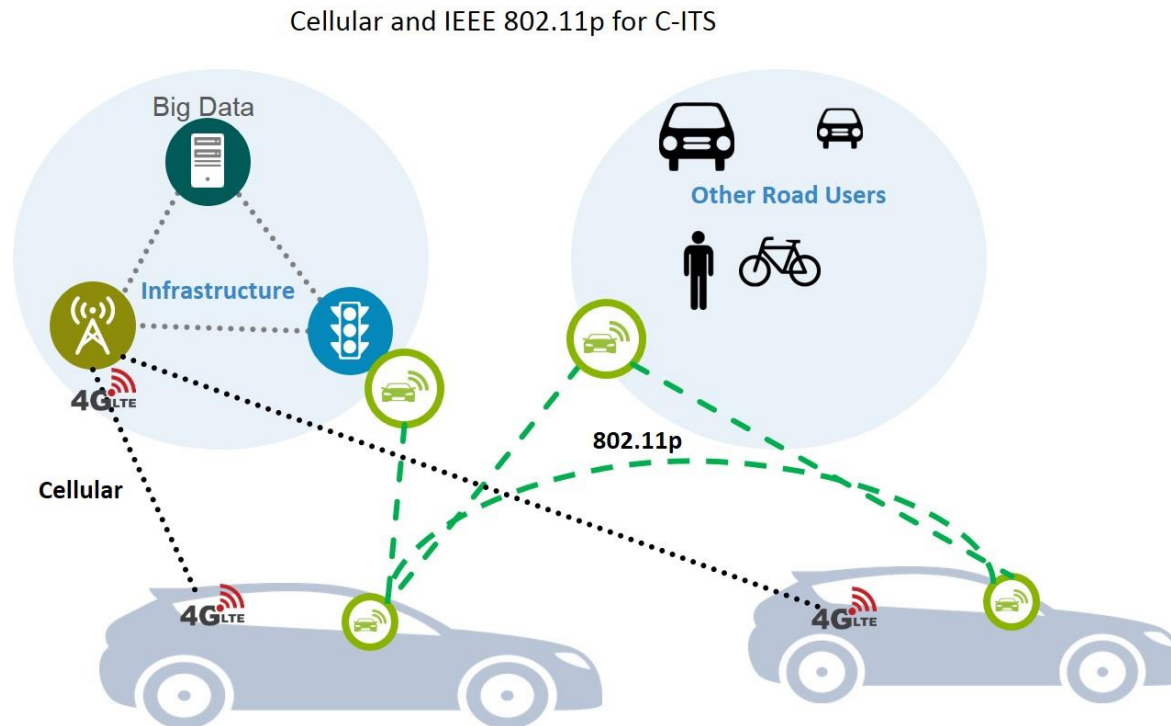
- To better utilise the residual time at the end of the SCH interval
- An extra fragmentation header should be used, which is a drawback
- Works for large packets (TCP)

▪ Best-fit scheme

- Send the packet that best fits the residual time at the end of the SCH interval
 - Better than fragmentation only if packets of different sizes are present in the queue
- Hard to know in advance the actual duration of transmission
 - Frequent changes in the channel congestion
 - Stochastic nature of backoff

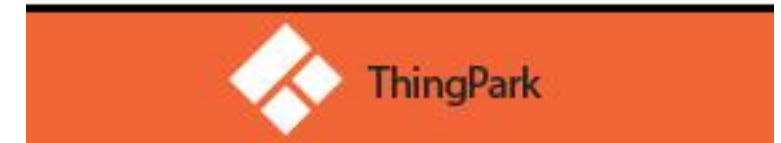
802.11p or LTE

- Requirements for Cooperative ITS systems
 - High relative speeds between transmitters and receivers
 - Extremely low latency in safety-related applications (<50 ms)
 - Tolerate high load generated by periodic transmission of multiple messages, and high vehicle density
 - V2x messages are mostly local in nature, are important for nearby receivers



802.11p or LTE

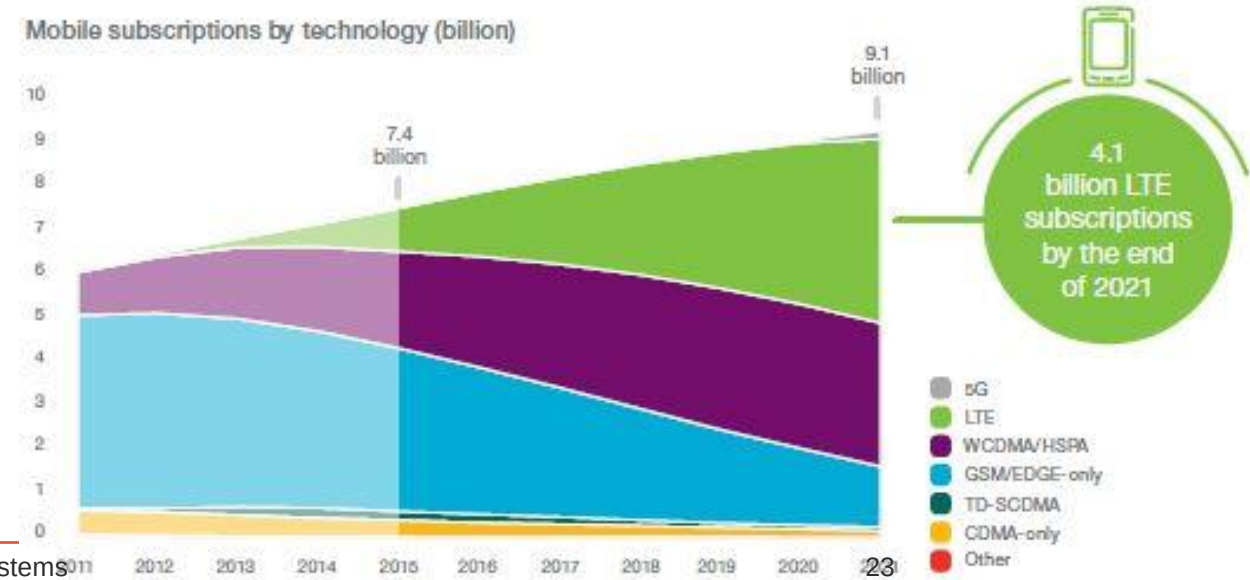
- **802.11p is here today**
 - Standard approved in 2009
 - Several ETSI ITS plug-test events
 - Next one November 9-18, 2016, in Italy
 - Testing the interoperability of different implementations, products
 - Extensive field trials
 - Safety Pilot, Drive C2X, Score@F, simTD, etc.
- Significant efforts in the last 10 years to validate 802.11p
 - This should be re-done for any other alternative technology



802.11p or LTE

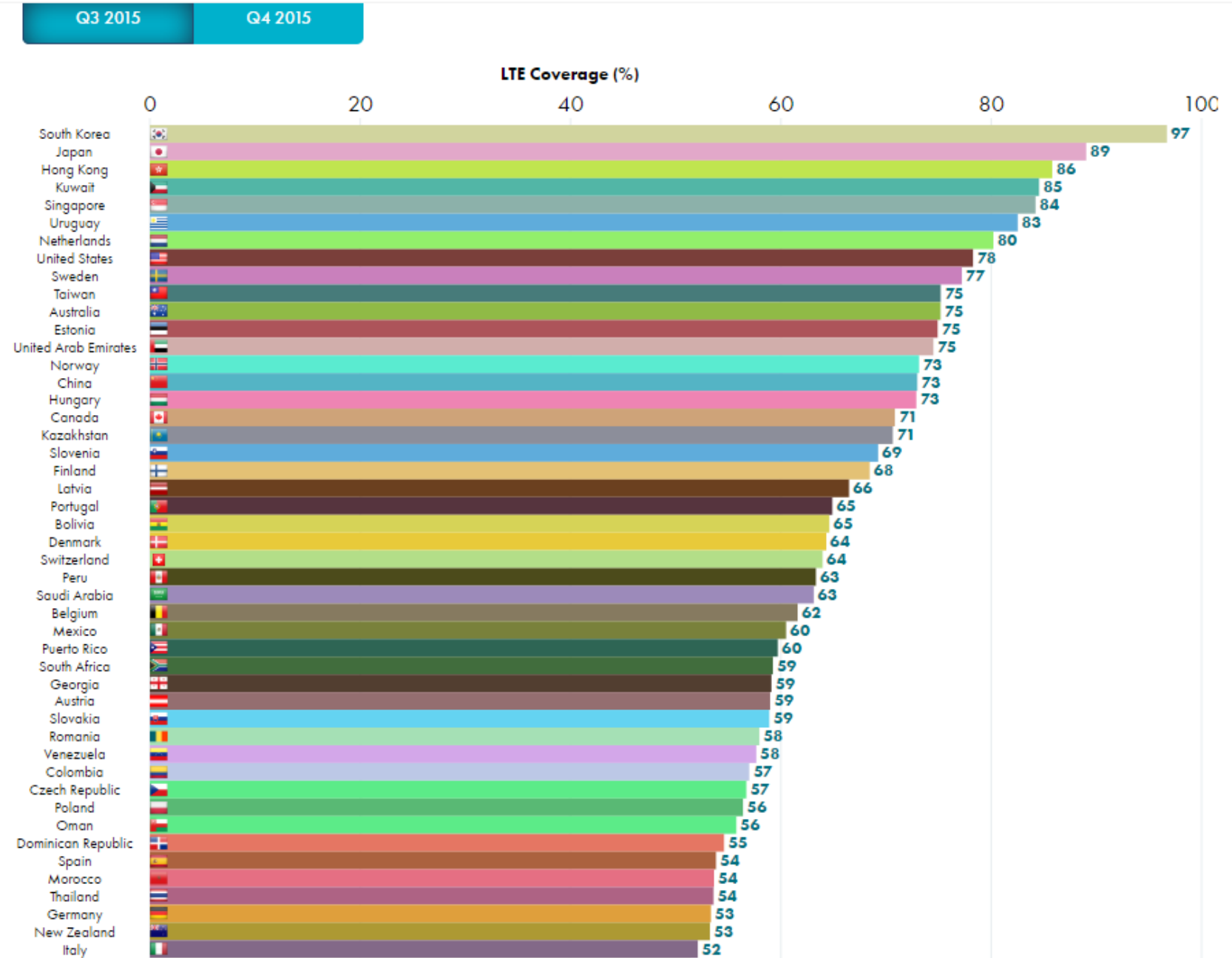
- (Some argue that) Cellular for V2V is still far out
- Cellular technology is by far the most successful wireless standard
 - 4.1 billion LTE subscriptions expected for 2021
- LTE (Rel. 8) dates back to 2009, 5G expected for 2020
 - Extensive cellular infrastructure, it takes time to upgrade
- Current versions of LTE can only address basic ITS use cases
 - No support for low latency and high mobility use cases
 - 3GPP V2x study group established in 2015

*Mobile subscriptions worldwide.
Source: Ericsson Mobility Report, Nov 2015*



State of LTE in 2016

- LTE coverage still far from 100%
- Around 50% is Germany, France, Italy
- Extensive 3G infrastructure



LTE support for V2x applications

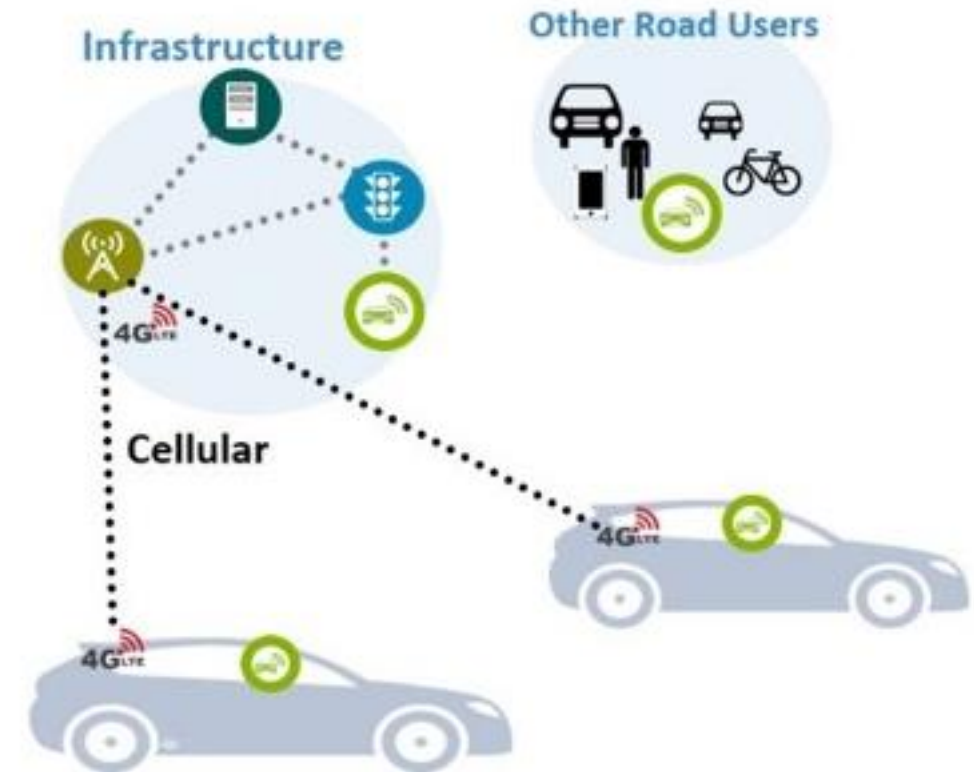
- LTE Release 8 can cover most of the V2I – I2V non-safety use cases
- Unclear how it will perform in very congested scenarios
 - evolved Multimedia Broadcast/Multicast Service (eMBMS) in LTE-A (Rel. 9)
 - Designed to support static scenarios – crowds in football stadiums
 - Not efficient when a large number of incoming and outgoing vehicles
- Unclear how handovers between MNOs (mobile network operators) and cooperation between application service providers will be managed
- Is there an I2V business case to justify the large investments?
 - Vehicles traditionally a lower priority for cellular industry
 - 8 billion cellular subscribers, but only 100 million cars per year worldwide

LTE support for V2x applications

- Safety-related use cases represent the real challenge
 - In theory could work, if there is complete coverage along the roads (which is not yet the case)
 - In practice it would need to handle high bandwidth with very low latency, not ready for this
- Some V2V use-cases require **continuous information exchange** (1 – 20 Hz)
 - **Think about cooperative awareness, autonomous cars**
 - Too much data for LTE networks to handle
 - A single car generates 0.5 Gbyte per month (256 bytes/message, 5 Hz, 4 hours of driving/day)
 - At the receiver side, assuming 30 cars in the area of interest, roughly 15 Gbytes per month
 - 1 autonomous car in 2020 – **4 Tbyte per day**
- MNOs typically bill based on resources used (\$ / bit / s), but V2V traffic should be free
 - Alternative business model to be developed to justify investments
- eMBMS might help, but not widely deployed

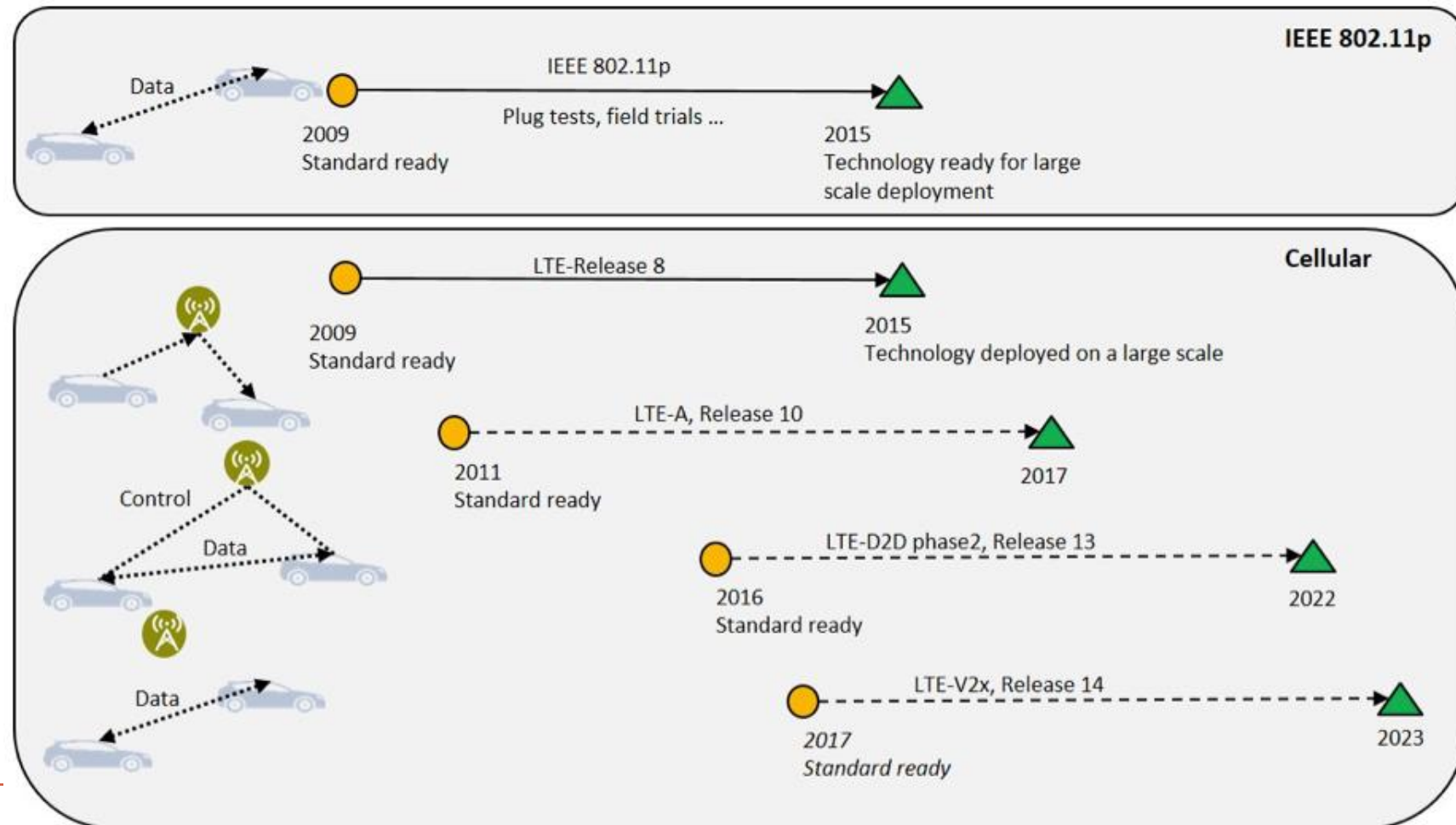
LTE support for V2x applications

- Some V2V use cases do not require high bandwidth, but **very low latency**
 - event-based broadcasting of Decentralized Environmental Notification messages (DENM)
- Could work in the cellular network, but not always
 - Across multiple MNOs, across borders, across cells
- **Another solution: develop direct communication technology, as part of the cellular system**
 - **Device-to-Device** communication, part of Release 12, but not suitable for V2V
 - If two devices want to communicate directly, the network allocates the time / frequency resources
 - The network manages the interference generated by the D2D communication
 - Signalling/control via the eNodeB
 - Direct data sending between the UEs
 - D2D will not work if no continuous network coverage



Timeline for cellular V2x

- 3GPP will surely find the technical solution, the question is **"when?"**
 - LTE-V2x probably in release 14, 15, by the end of 2017
 - Much time ahead until large scale deployment



V2x in 5G

- V2x probably part of 5G
 - Fundamentally redesigned hardware to support the architectural changes
 - Not before 2020

5G roadmap
Source: 5G Infrastructure
Public Private Partnership
(5G-PPP), 2015

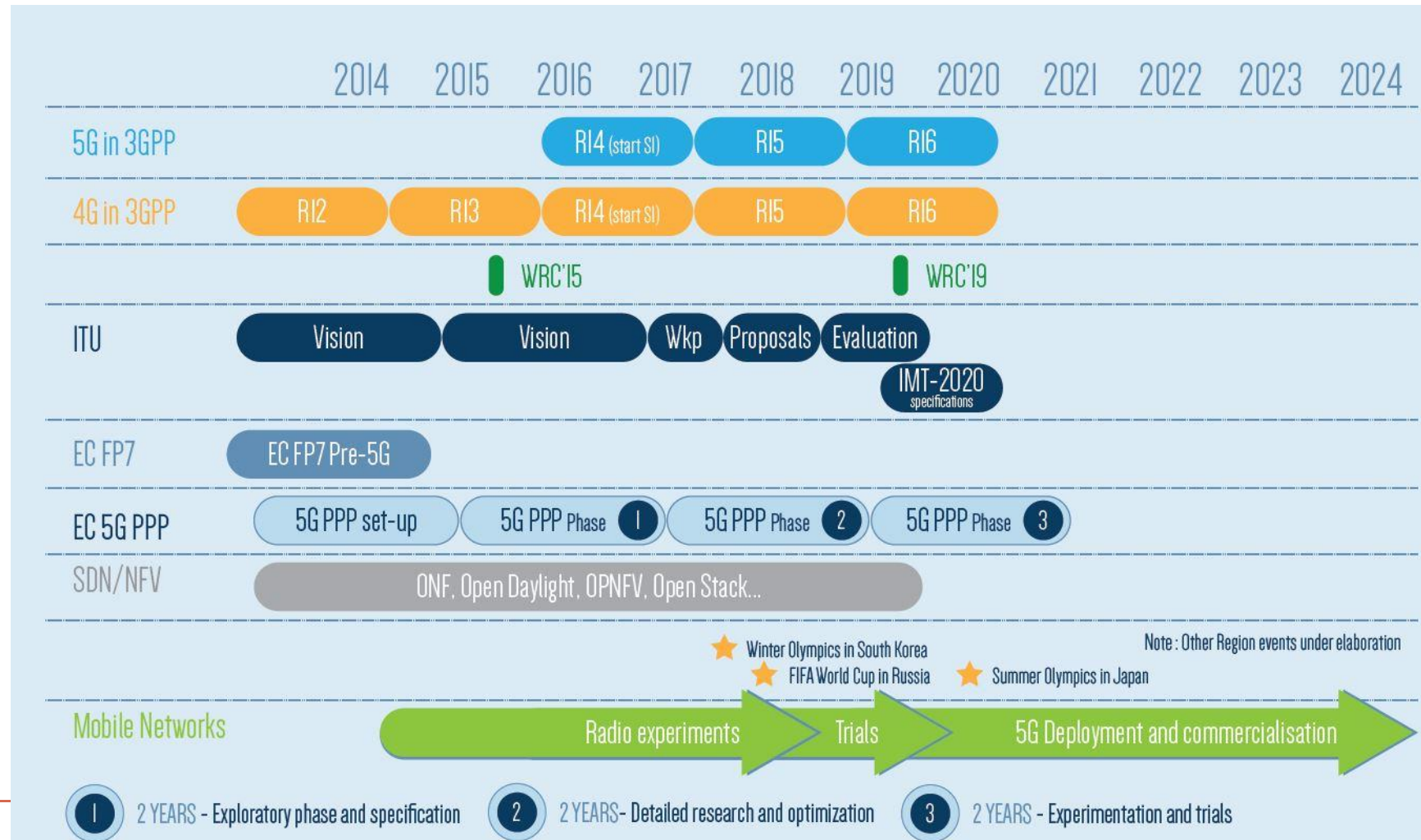


FIGURE 4. 5G ROADMAP