Intelligent Transportation Systems

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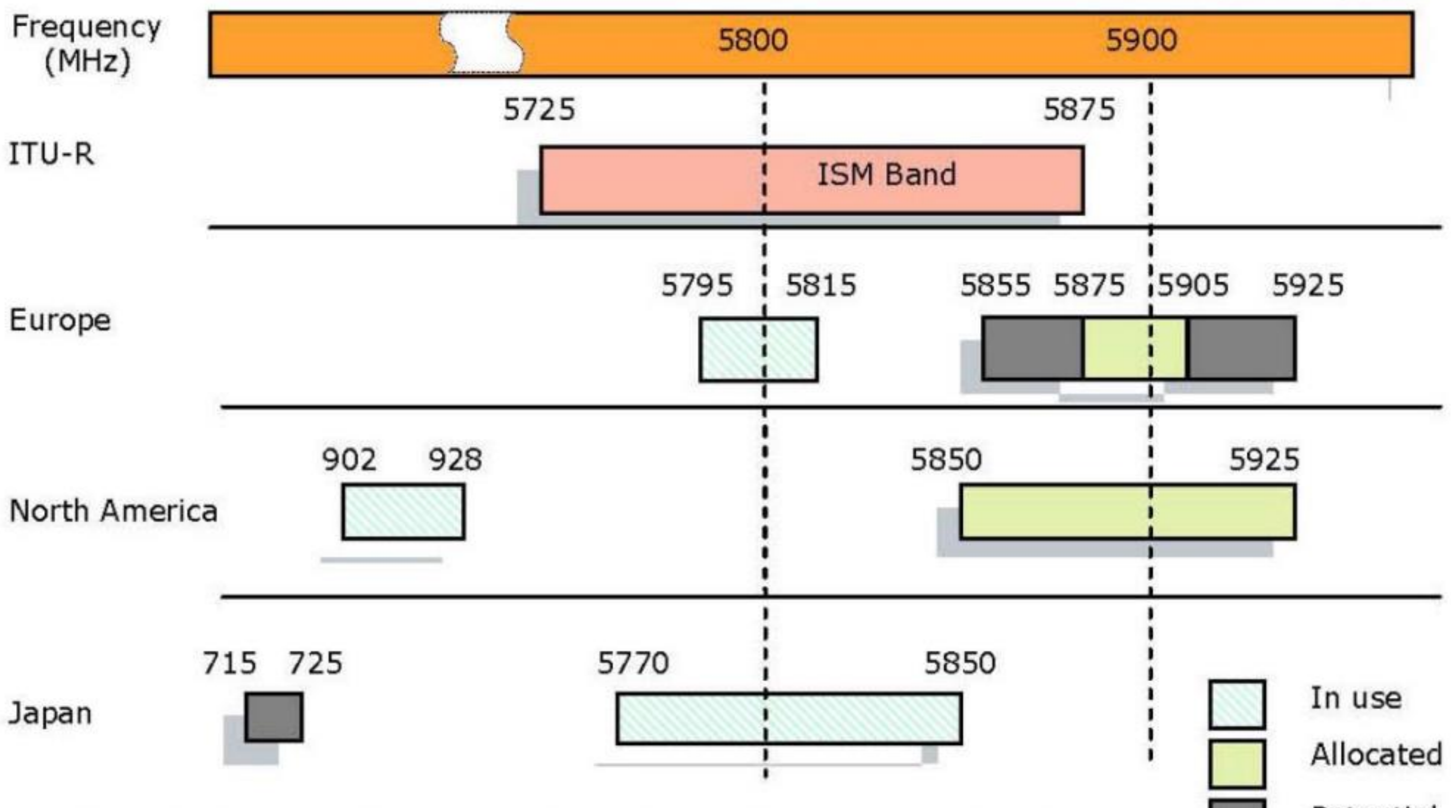
DSRC – Dedicated Short Range Communications

- 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



Source: Activities on ITS Radiocommunications Standards in ITU-R and in Japan

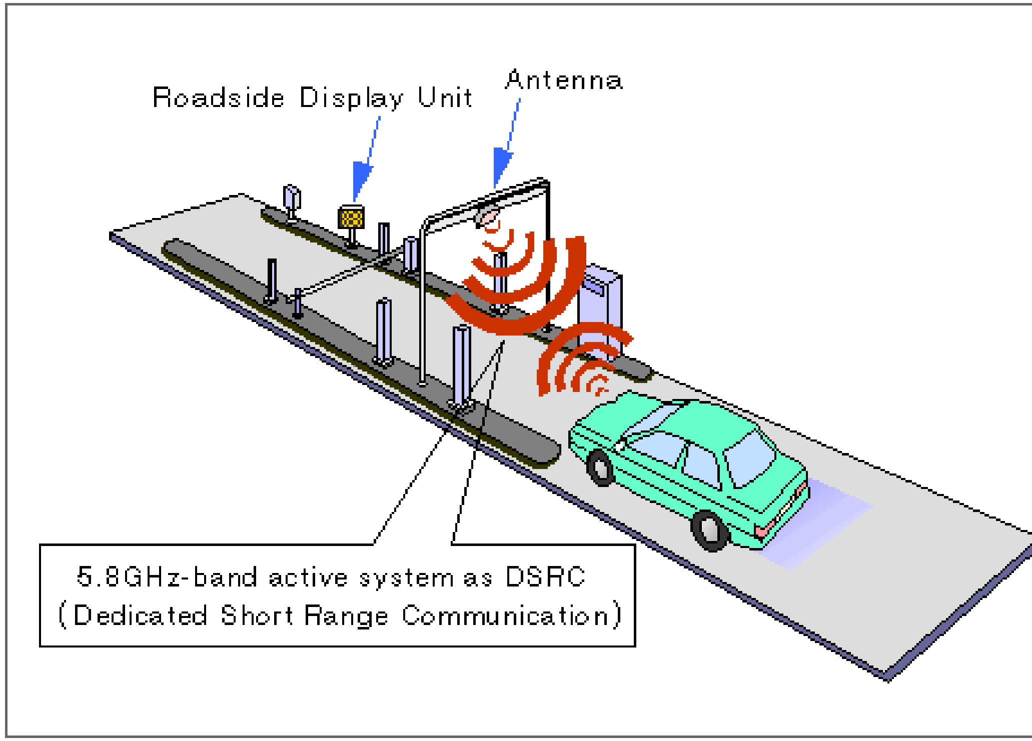
DSRC – Dedicated Short Range Communications

- Traditional ISM bands (Industry, Science, Medical) – 900 MHz, 2.4 GHz, 5 GHz
  - **Free, unlicenced bands**
  - Populated by many technologies – Wifi, Bluetooth, Zigbee
  - No restrictions other than some emmission and co-existance rules

- DSRC band
  - **Free but licenced spectrum**
  - Restrictions in terms of usage and technologies
  - All radios should be compliant to a standard

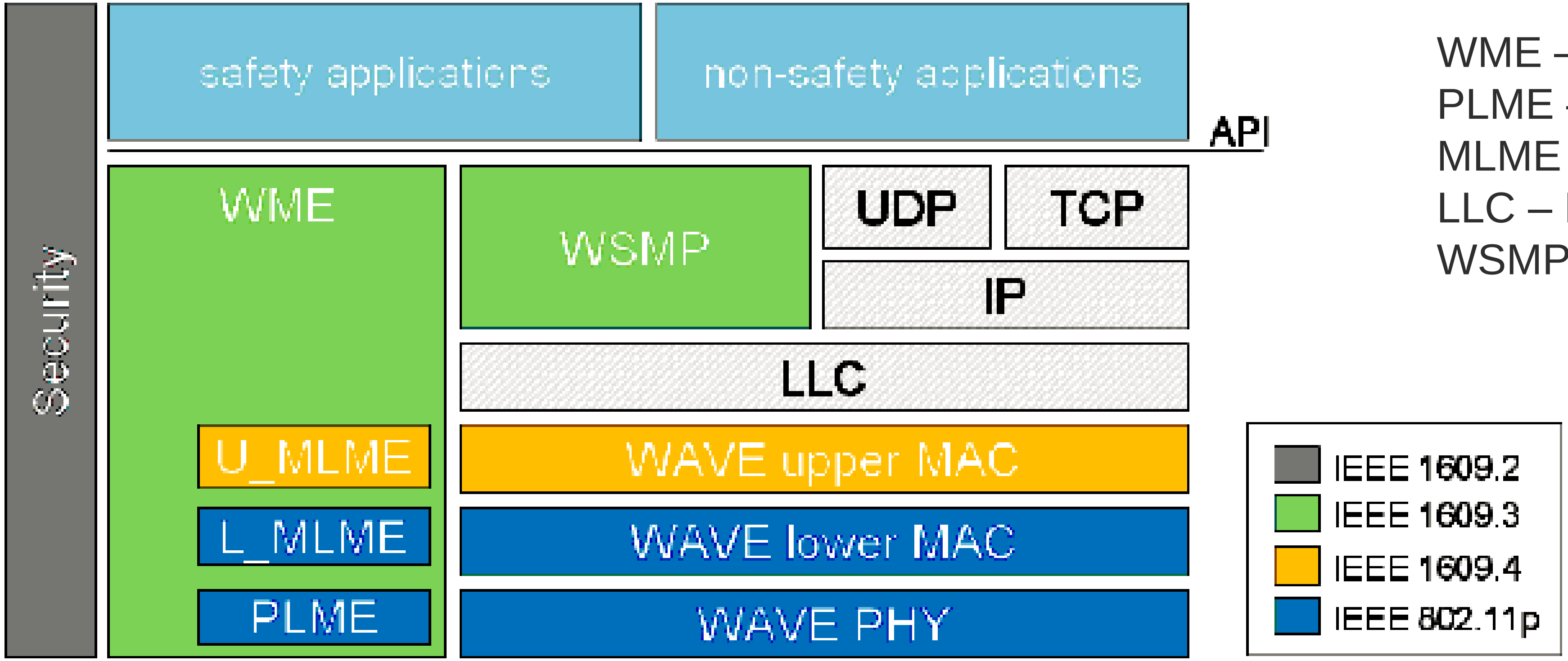
DSRC – Dedicated Short Range Communications

- **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

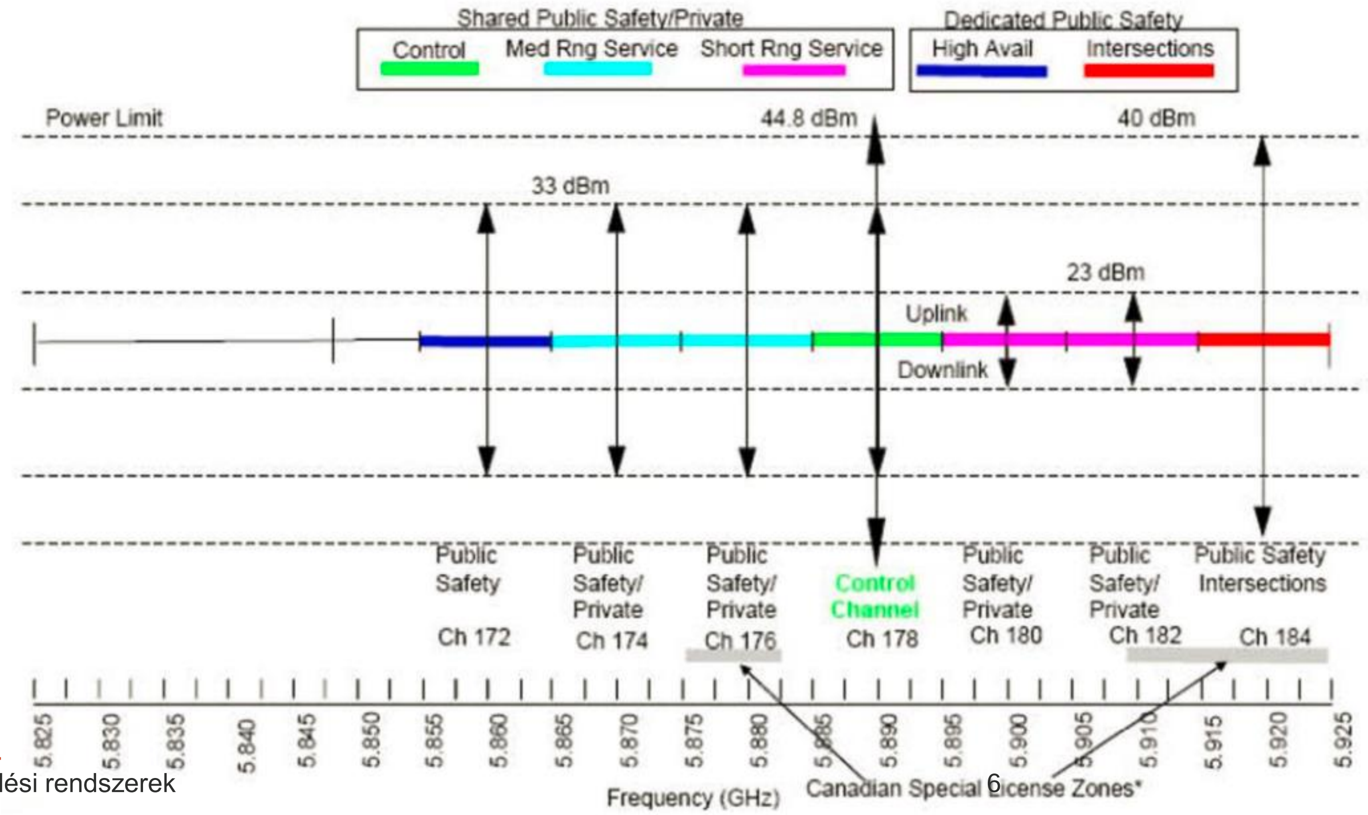
- IEEE 802.11
  - Collection of physical (PHY) and medium-access control (MAC) layer specifications for implementing WLAN
  - 802.11a (5 GHz, OFDM), 802.11b (2.4 GHz, DSSS), 802.11g (2.4 GHz, OFDM), 802.11n (2.4 and 5 GHz, MIMO-OFDM), 802.11ac (5 GHz, MIMO-OFDM)
  - **802.11p – part of WAVE (Wireless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

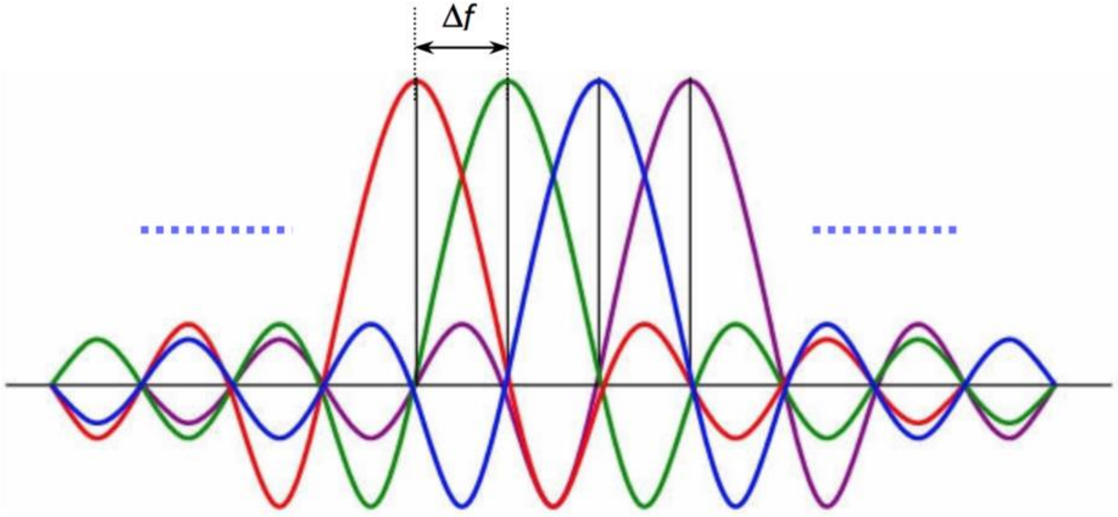
WAVE spectrum bands

- 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



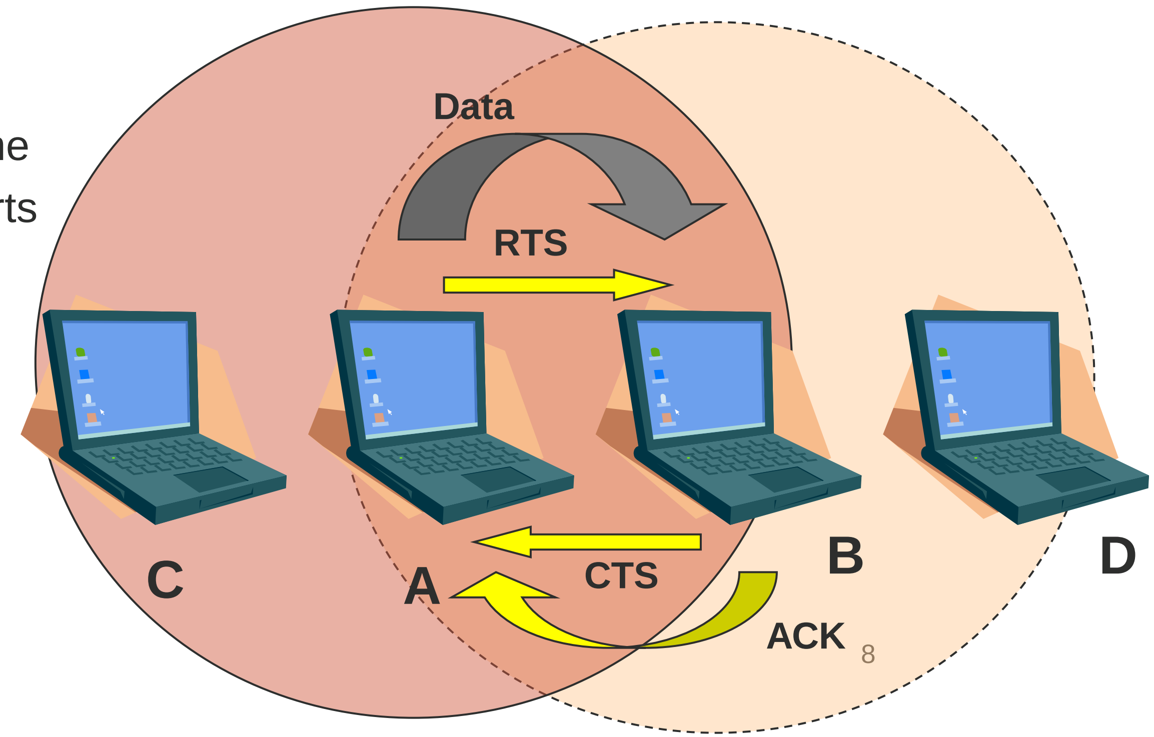
WAVE (802.11p) vs IEEE 802.11

- 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



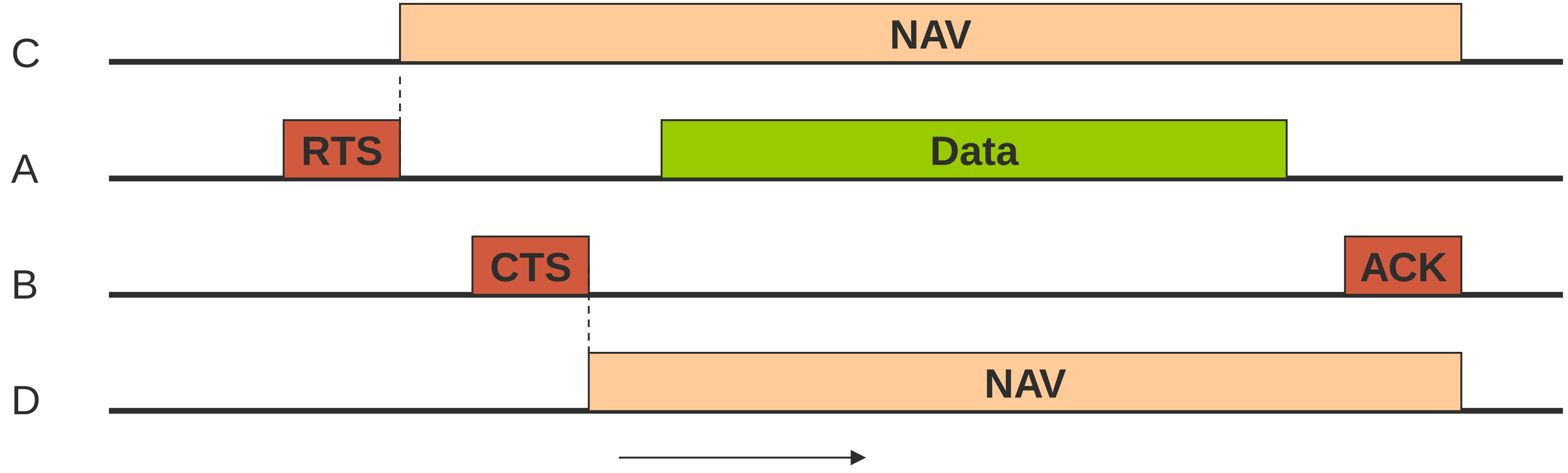
Traditional IEEE 802.11 MAC (DCF)

- **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

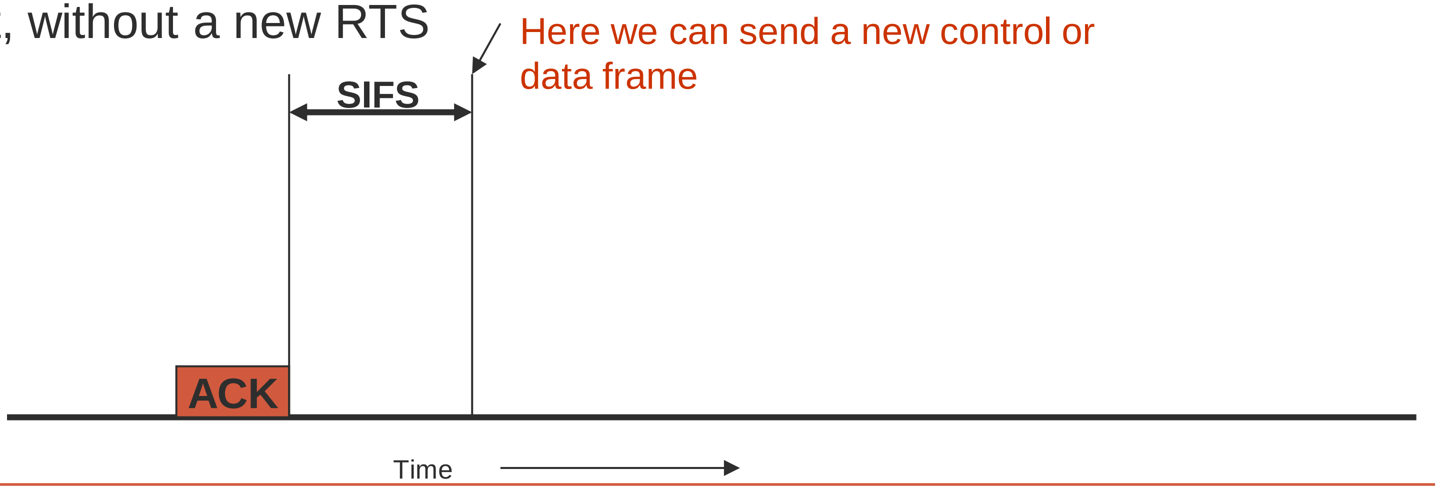


Traditional IEEE 802.11 MAC (PCF)

- **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

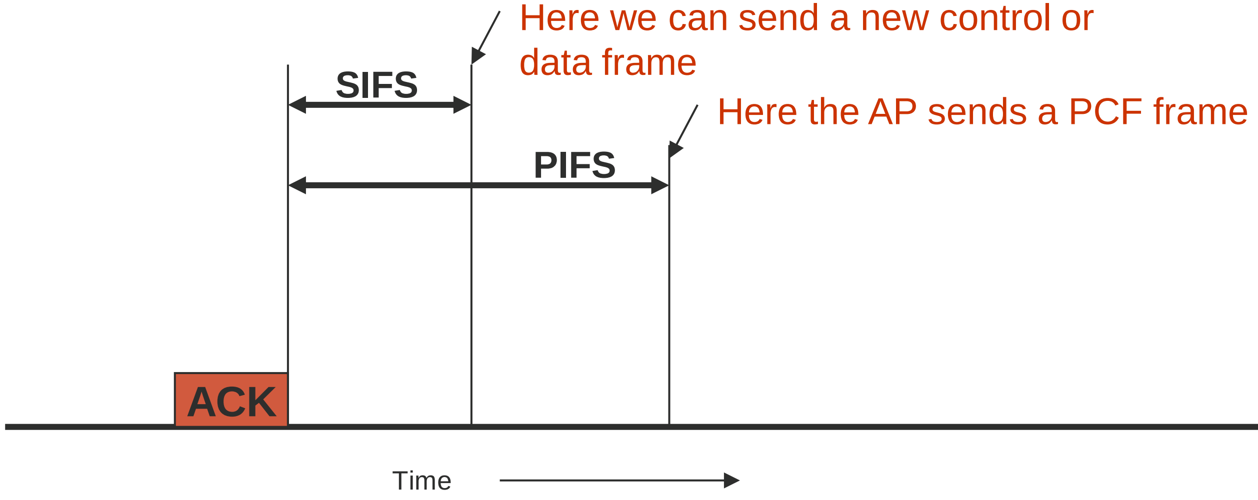
Traditional IEEE 802.11 MAC (DCF & PCF)

- 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



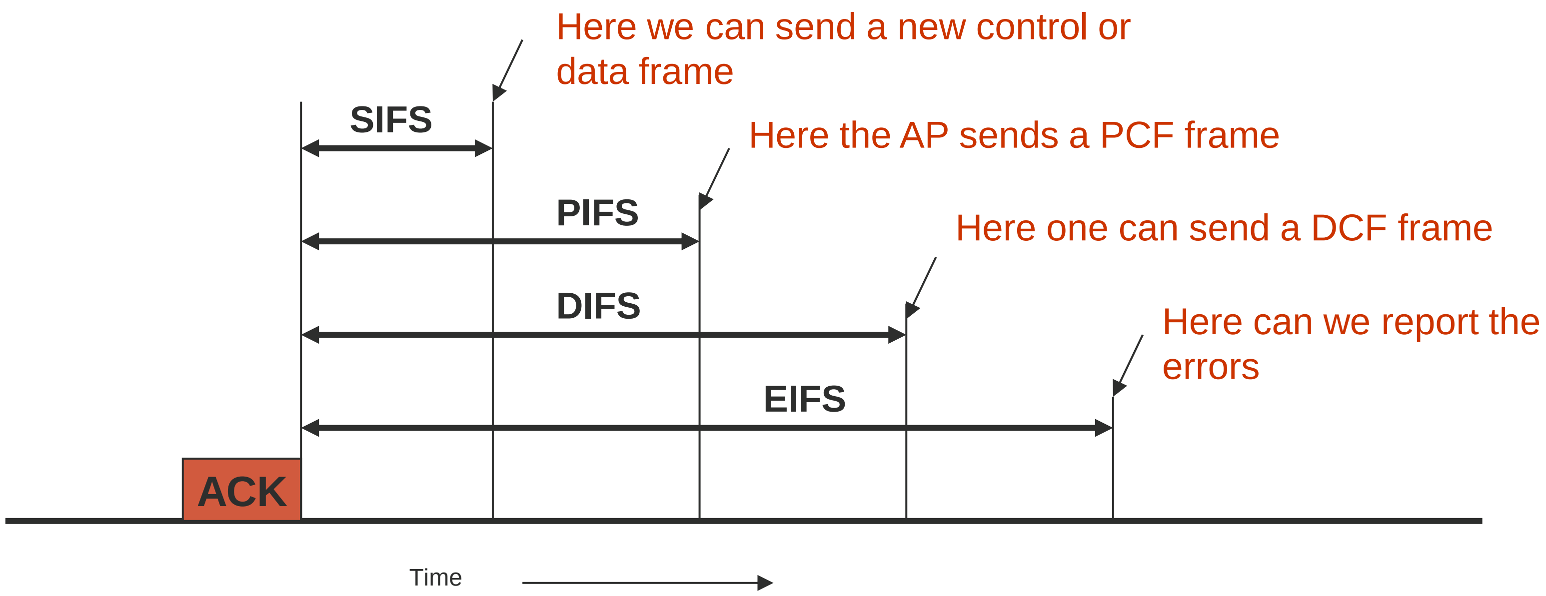
Traditional IEEE 802.11 MAC (DCF & PCF)

- **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

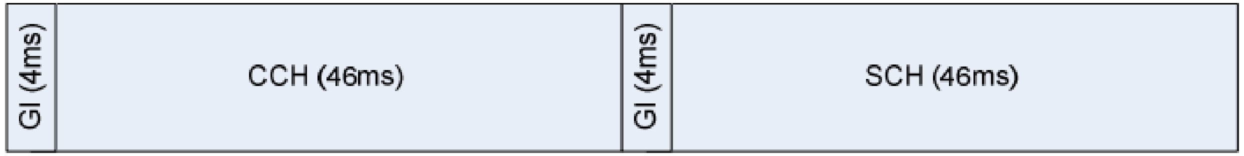
- Basic Service Set in traditional IEEE 802.11
  - Multiple handshakes to ensure distributed medium access
- **Wave Basic Service Set (WBSS)** in 802.11p
  - A node broadcasts a beacon, to advertise its WBSS
  - What kind of services it supports, how to join the WBSS
- Within the WBSS, nodes exchange 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 occured, 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
- **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



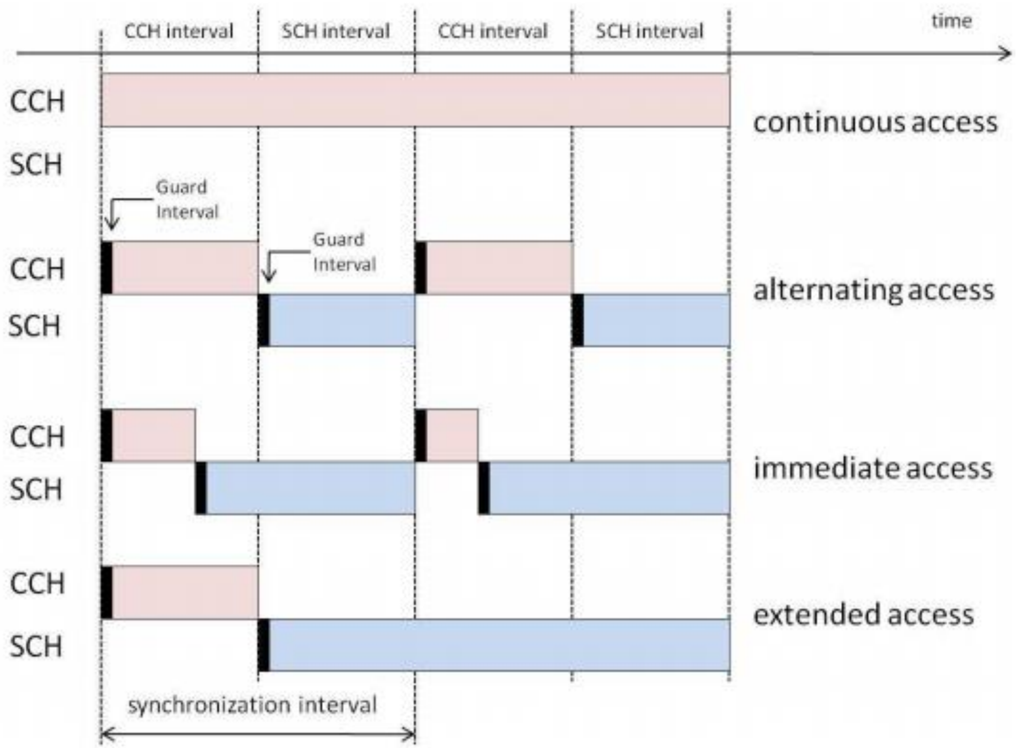
  - Time synchronisation needed to an external time reference
    - Coordinated Universal Time (UTC) from GPS or other devices
      - **WAVE Time Advertisement (WTA)** frame

IEEE 1609.4 channel switching

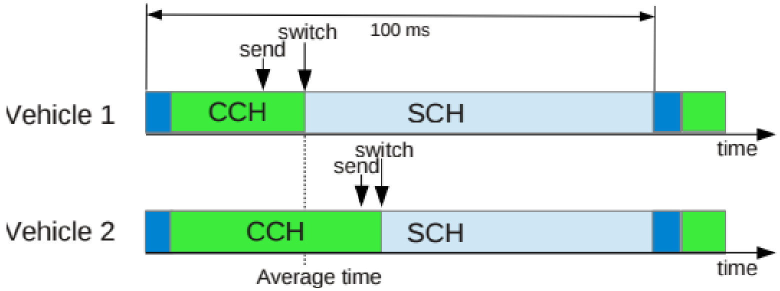
- **Continuous access**
  - Transmission can be continuous on the CCH and all SCHs
  - It cannot be guaranteed that all other stations will listen to the CCH outside the CCH slot
  - Safety messages sent over the CCH in the SCH slot might be ineffective
  - The usage of SCH not efficient if nodes listen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



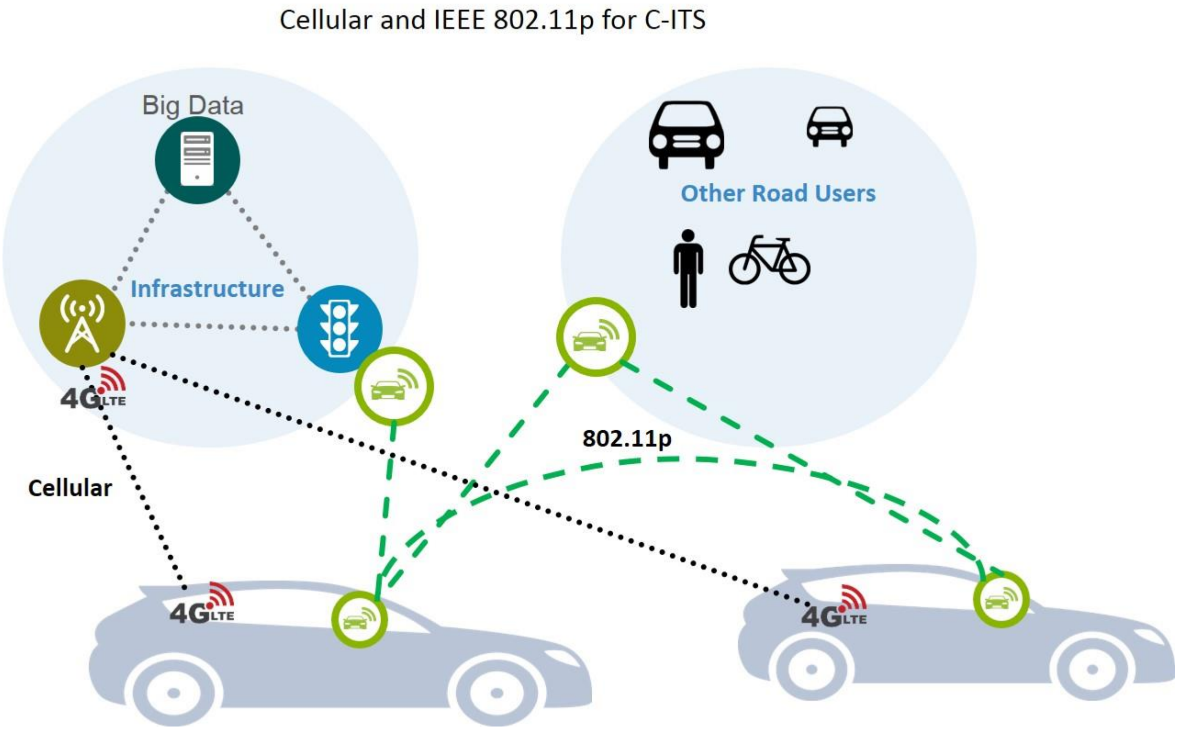
IEEE 1609.4 channel switching

- **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

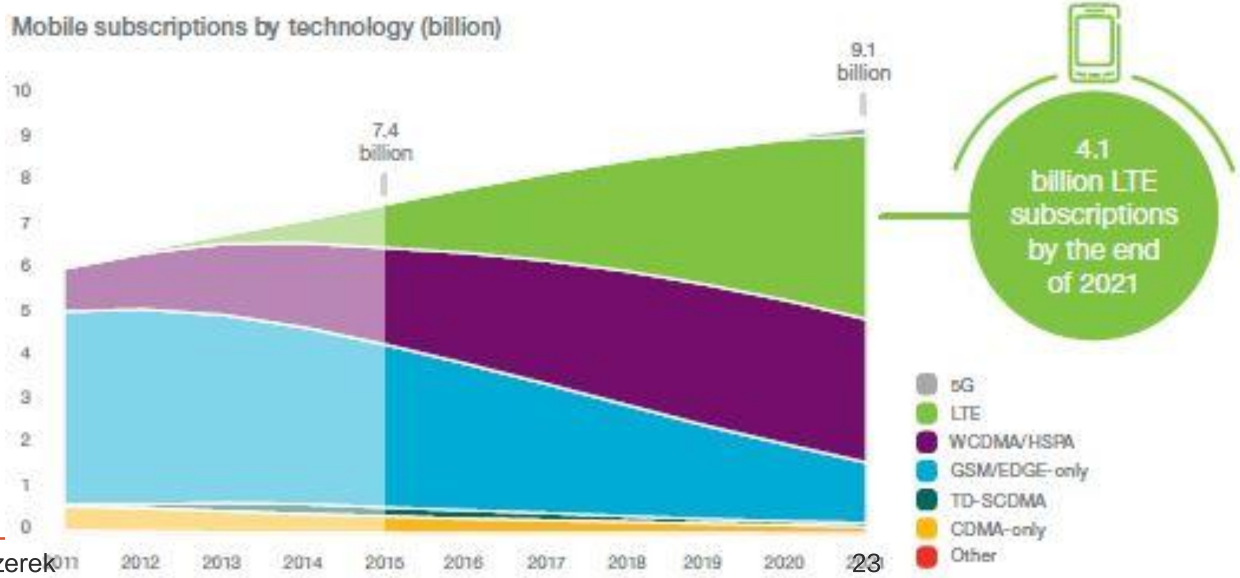
- **802.11p is here today**
  - Standard approved in 2009
  - Several ETSI ITS plug-test events
    - Next one November 9-18, 2016, in Italy
    - Testing the interoperability of different implementations, products
  - Extensive field trials
    - Safety Pilot, Drive C2X, Score@F, simTD, etc.

- 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

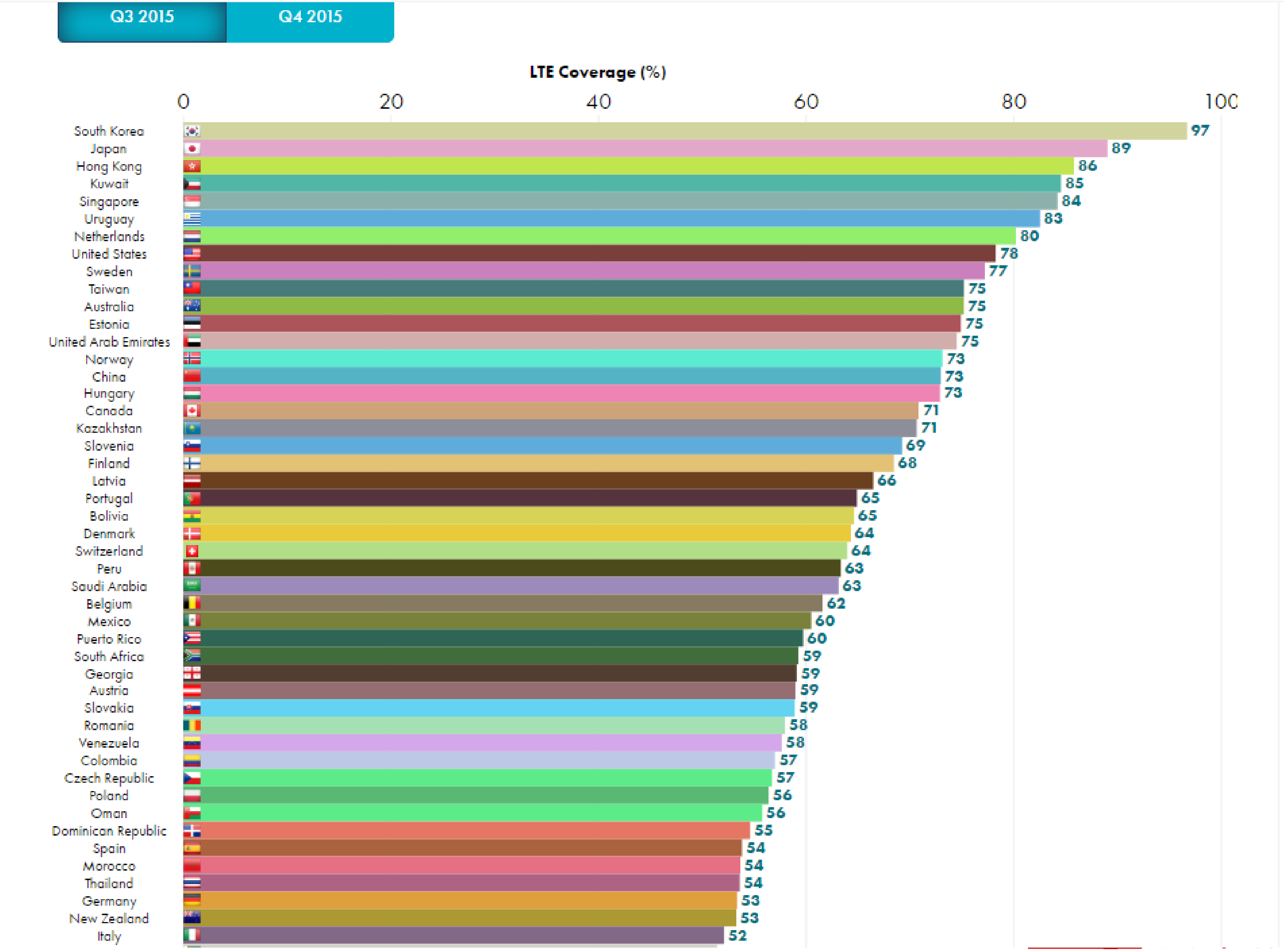
- **(Some argue that) Cellular for V2V is still far out**
- Cellular technology is by far the most successful wireless standard
  - 4.1 billion LTE subscriptions expected for 2021
- LTE (Rel. 8) dates back to 2009, 5G expected for 2020
  - Extensive cellular infrastructure, it takes time to upgrade
- 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

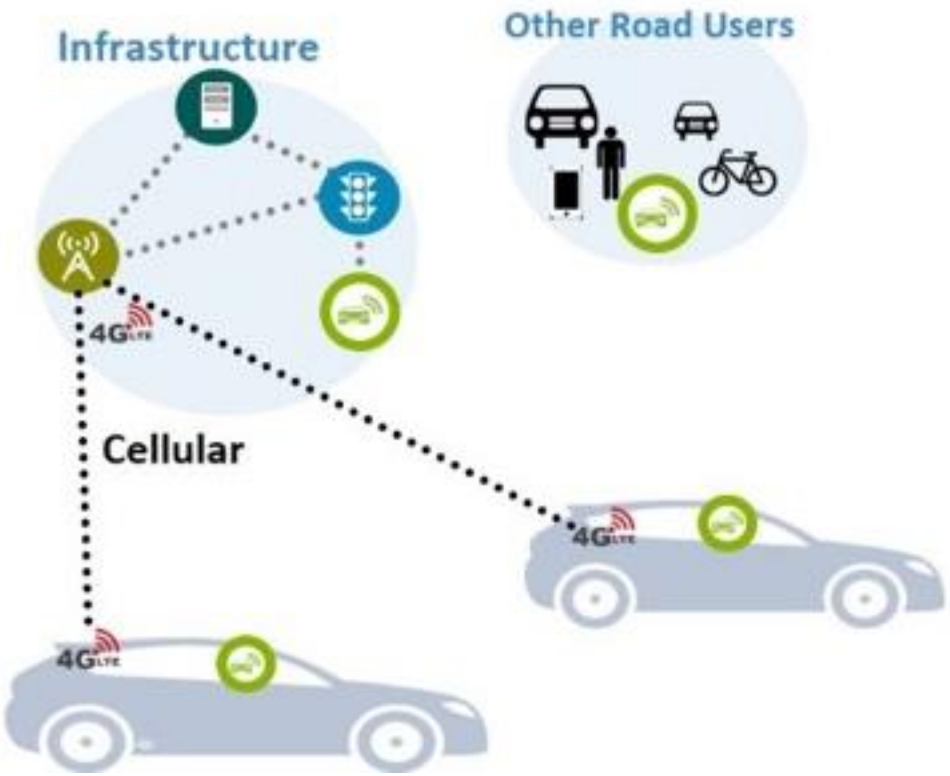
- LTE Release 8 can cover most of the V2I – I2V non-safety use cases
- Unclear how it will perform in very congested scenarios
  - evolved Multimedia Broadcast/Multicast Service (eMBMS) in LTE-A (Rel. 9)
    - Designed to support static scenarios – crowds in football stadiums
    - Not efficient when 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



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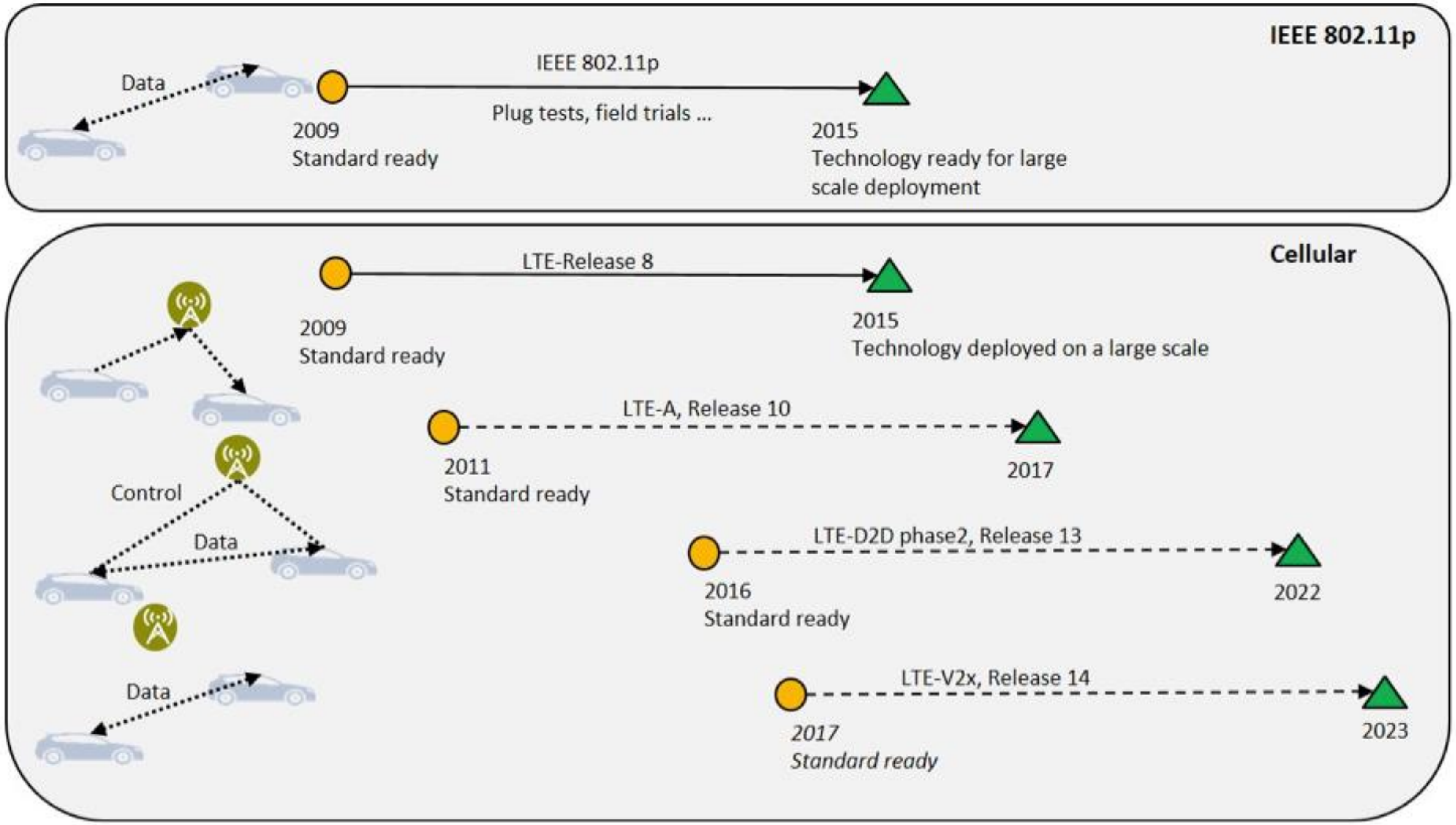
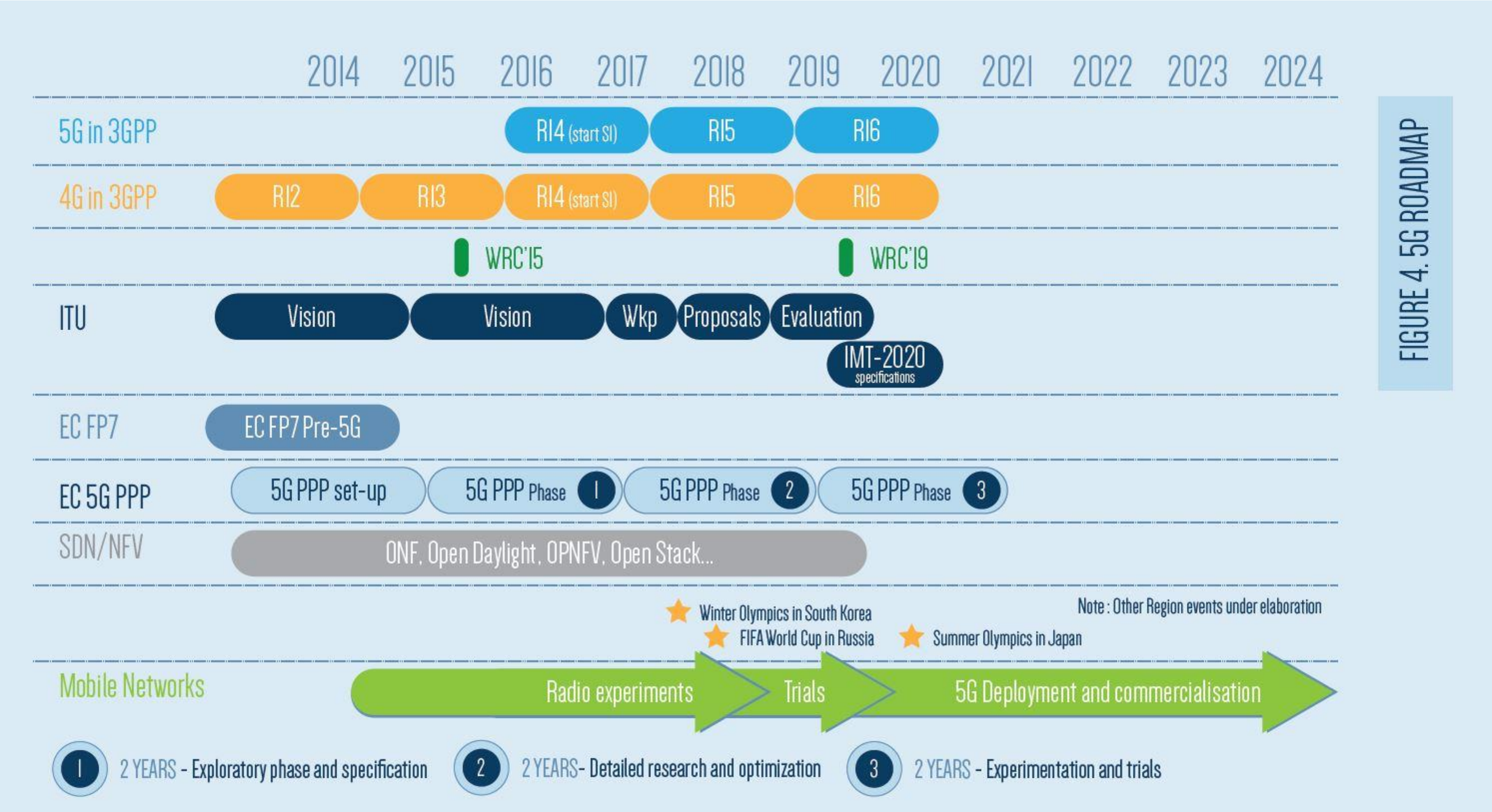
Timeline for cellular V2x

- 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