



IEEE 802.11p Intelligent Transportation Systems

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Kommunikációs architektúrák

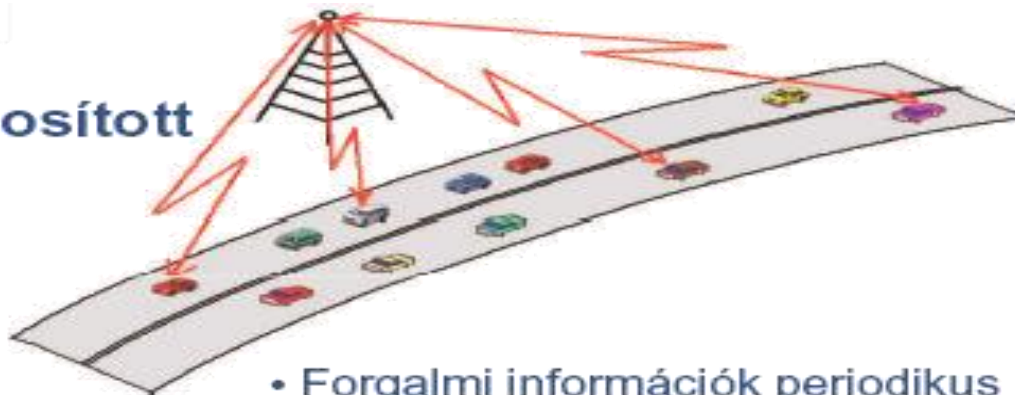
- Car-to-Car (C2C) vagy Vehicle-to-Vehicle (V2V)
 - Az autók közvetlenül egymással kommunikálnak

- Car-to-Infrastructure (C2I) vagy Vehicle-to-Infrastructure (V2I)
 - A járművek és a kiépített infrastruktúra közötti kommunikáció
 - Mobil hálózat bázisállomásai
 - Úttestben vagy útmentén elhelyezett szenzorok, adattárolók, átjárók
 - RSU – Road Side Unit

- Car-to-Pedestrian
 - Az autók és a gyalogosok közötti kommunikáció
 - Átmenet a C2C és a C2I között
 - Másfajta mobilitás modellek

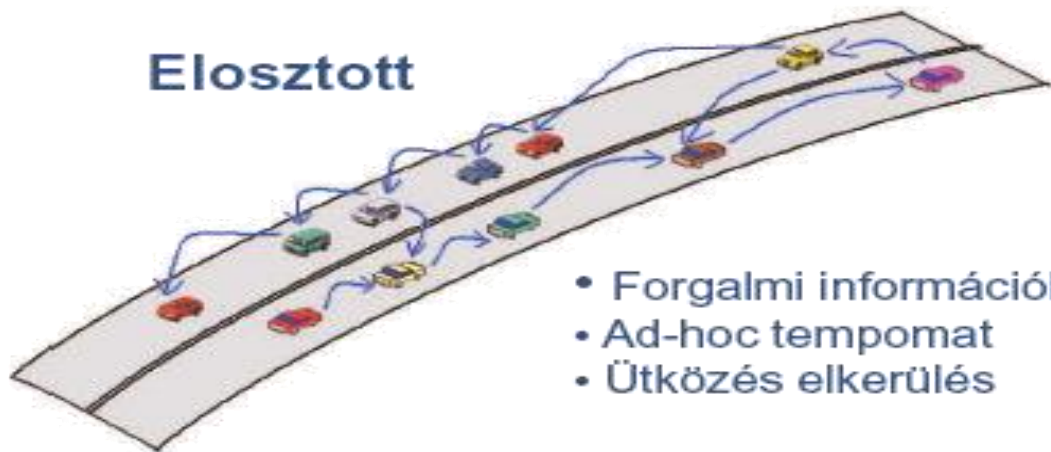
Kommunikációs architektúrák

Központosított



- Forgalmi információk periodikus küldése a központnak
- Minden autó a központtól kér útvonalat

Elosztott

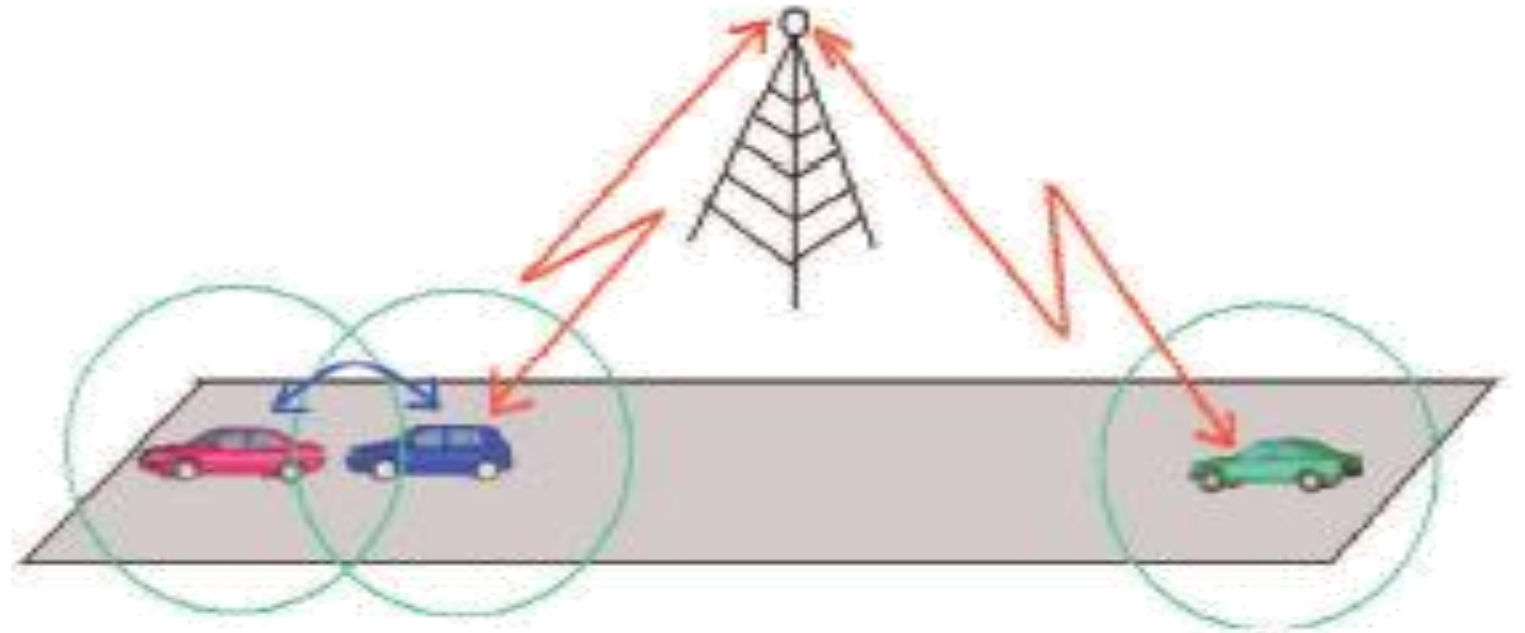


- Forgalmi információk
- Ad-hoc tempomat
- Ütközés elkerülés

	Központosított	Elosztott
Lefedettség/hatósugár	😊 teljes	😞 rövid (20-1000m) → szigetek
Sebesség	😞	😊
Megbízhatóság	😊	😞 ütközés, interferencia
Kapacitás	😞 korlátos	😞 korlátos
Ár	😞 van	😊 nincs

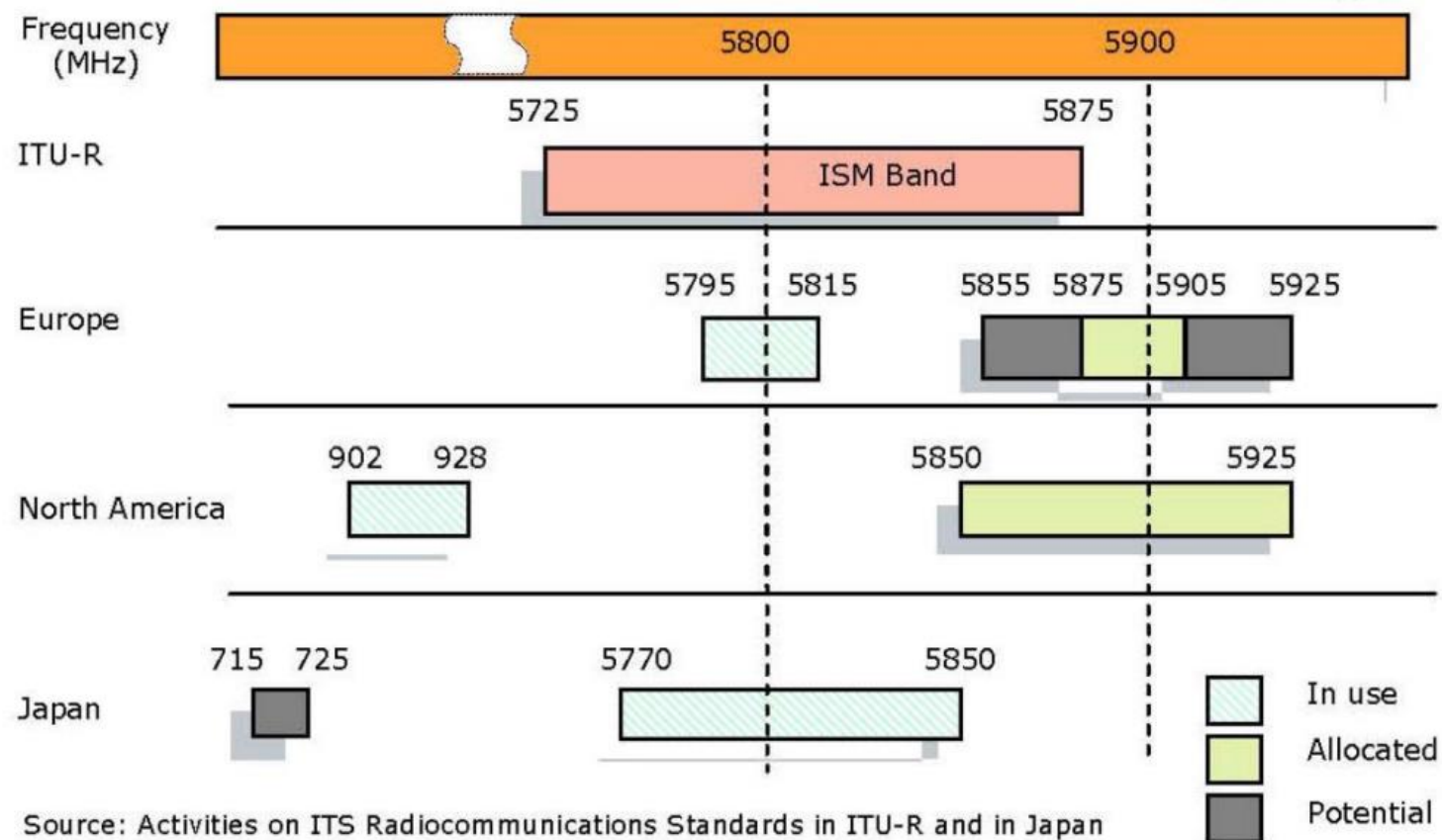
Hibrid megoldások

- Egyes járművek tudnak kommunikálni a központtal
 - Pl. LTE
- Mások csak egymással tudnak beszélni
 - Vagy csak nem érdemes szólítani a központnak



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

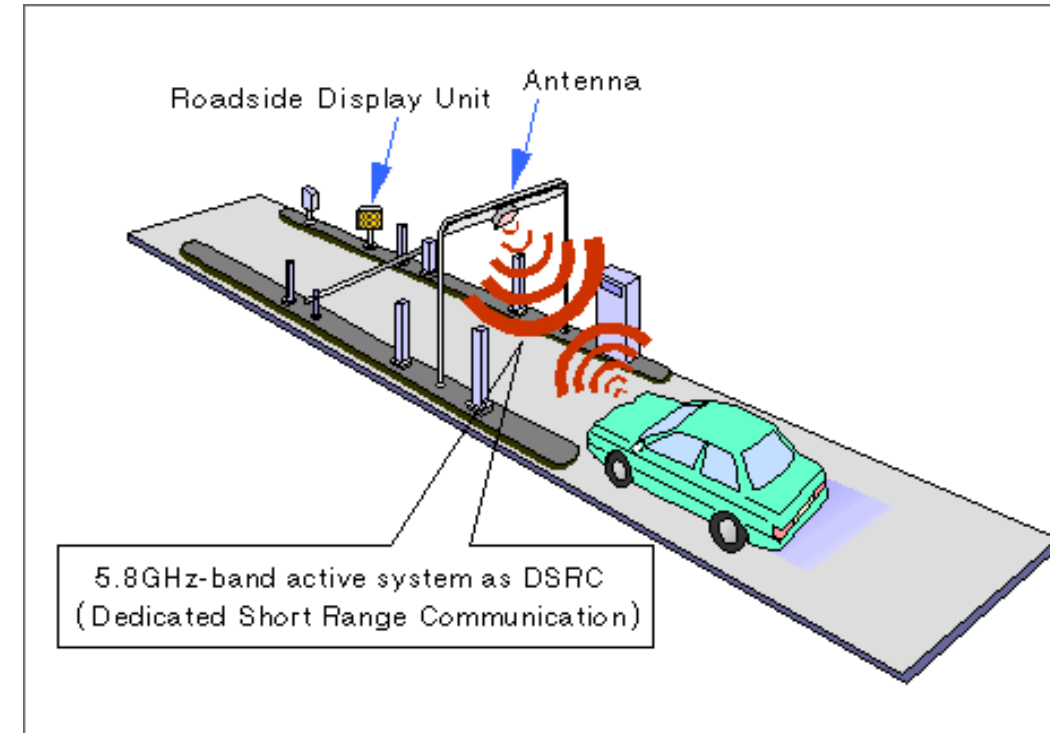
DSRC – Dedicated Short Range Communications

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

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

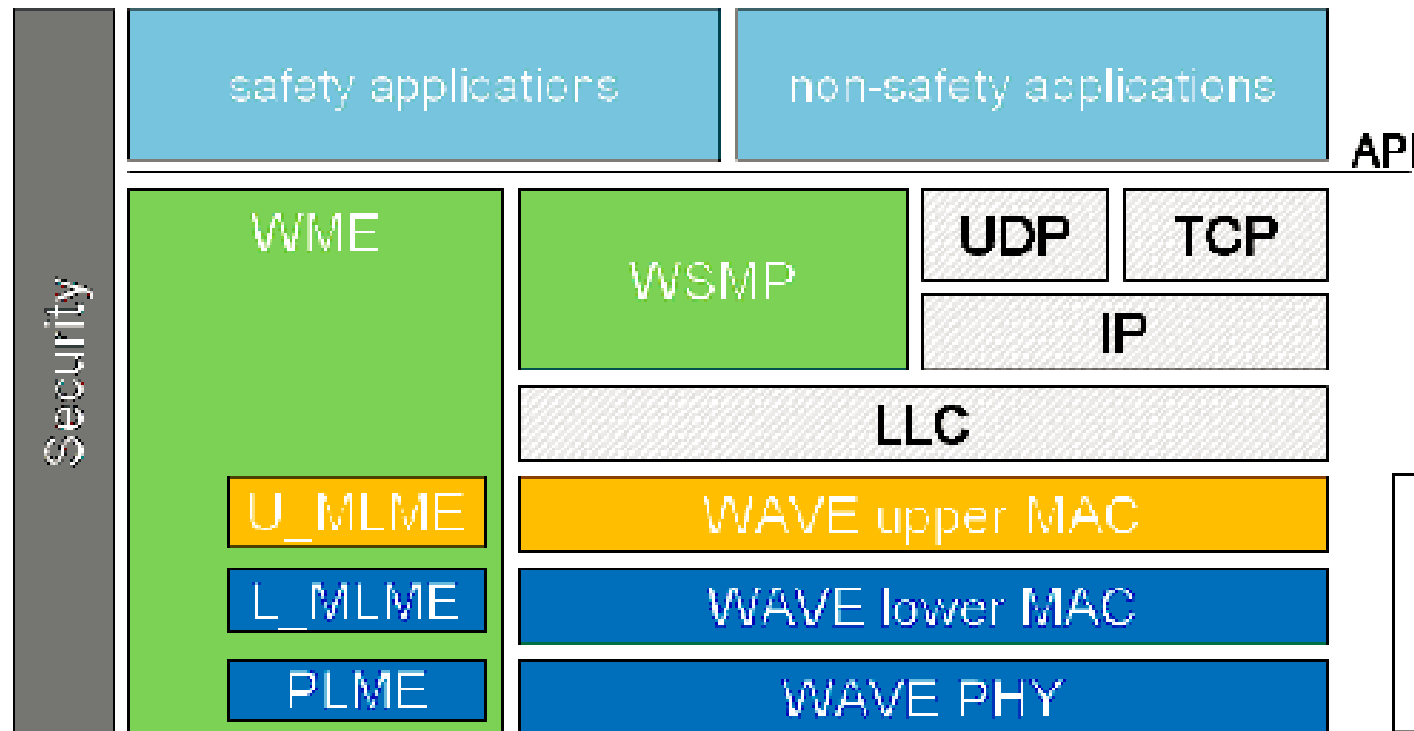
DSRC – Dedicated Short Range Communications

- **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

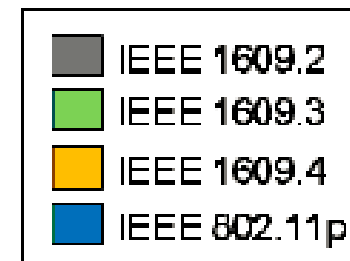


WAVE

- 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.

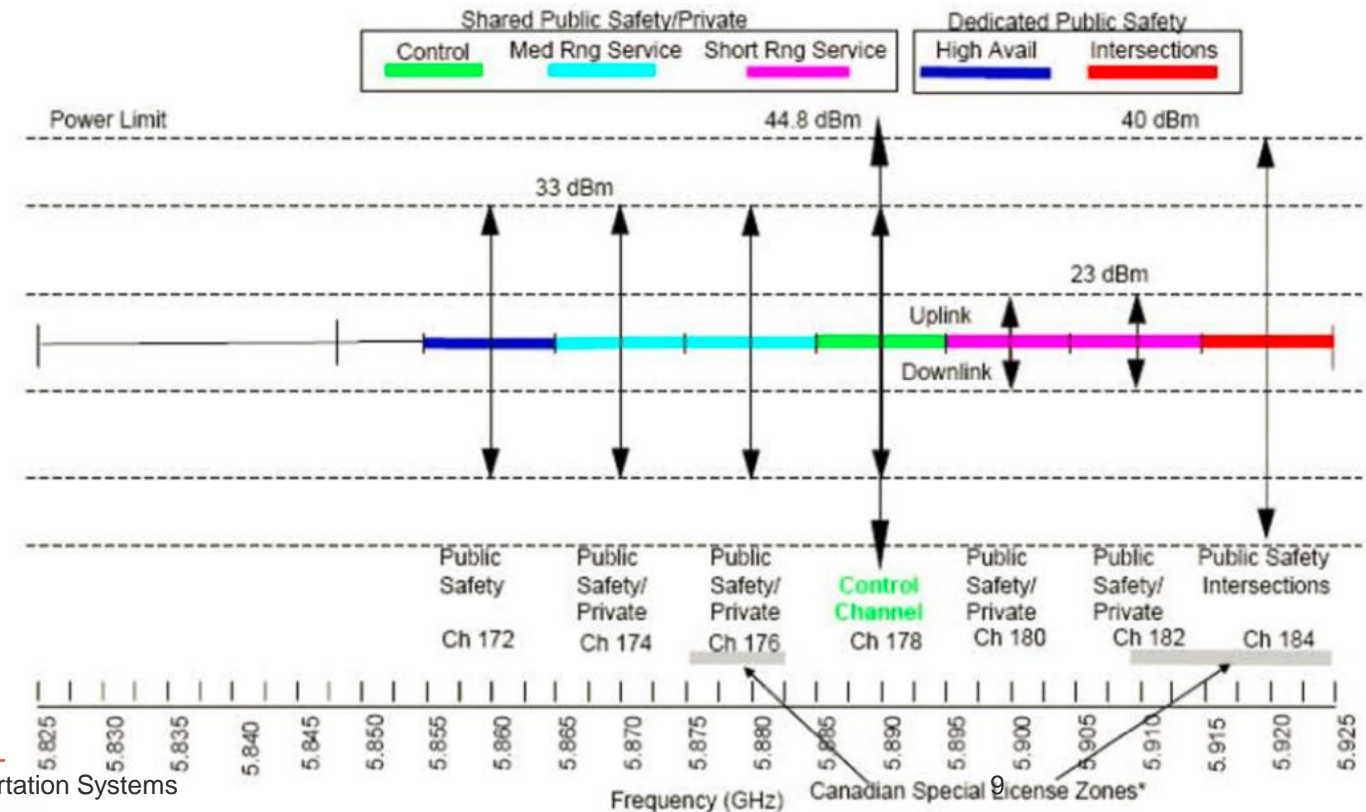


WAVE spectrum bands

- 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 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

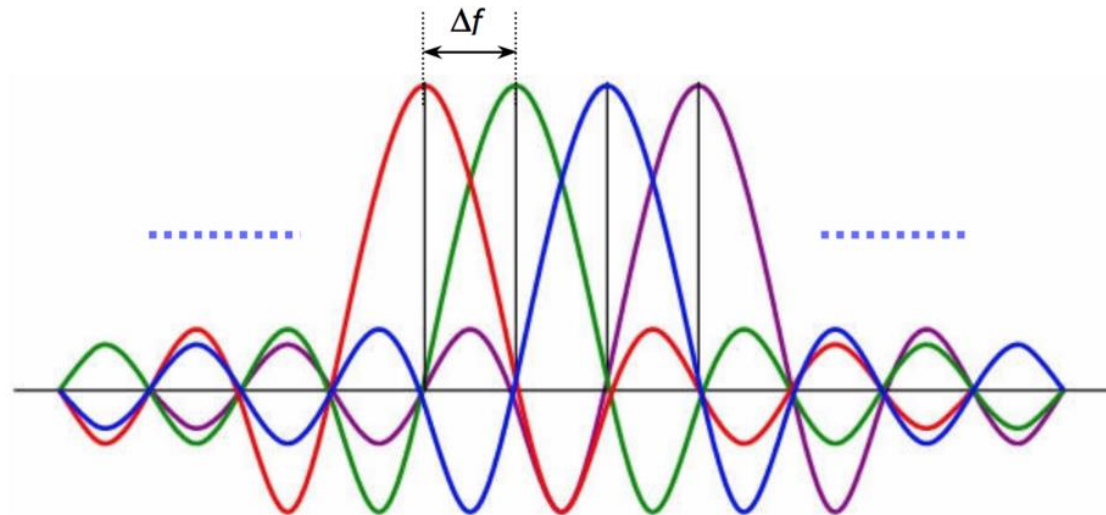
- In Europe the **ITS-G5 standard**

- ITS-G5B band:** 5.855 – 5.875 GHz
 - 172, 174 SCH – ITS non-safety app
- ITS-G5A band:** 5.875 – 5.905 GHz
 - 176, 178 SCH – ITS traffic safety app
 - 180 CCH
- ITS-G5D band:** 5.905 – 5.925 GHz
 - 182, 184 SCH – for future use



WAVE (802.11p) vs IEEE 802.11

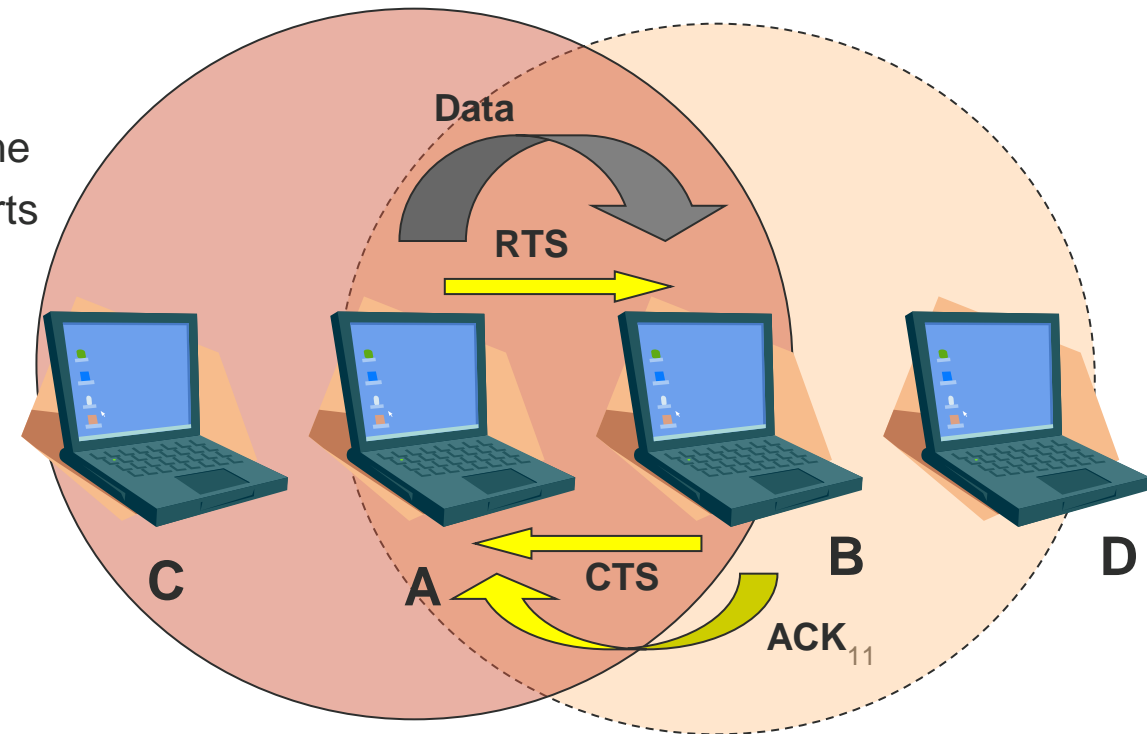
- 10 MHz channels instead of 20 MHz
- 3-27 Mbps instead of 6-54 Mbps
- Same modulation schemes (BPSK, QPSK, 16QAM, 64QAM)
- Carrier spacing reduced to 0.15625 MHz from 0.3125 MHz
 - 48 data subcarriers for both



Traditional IEEE 802.11 MAC (DCF)

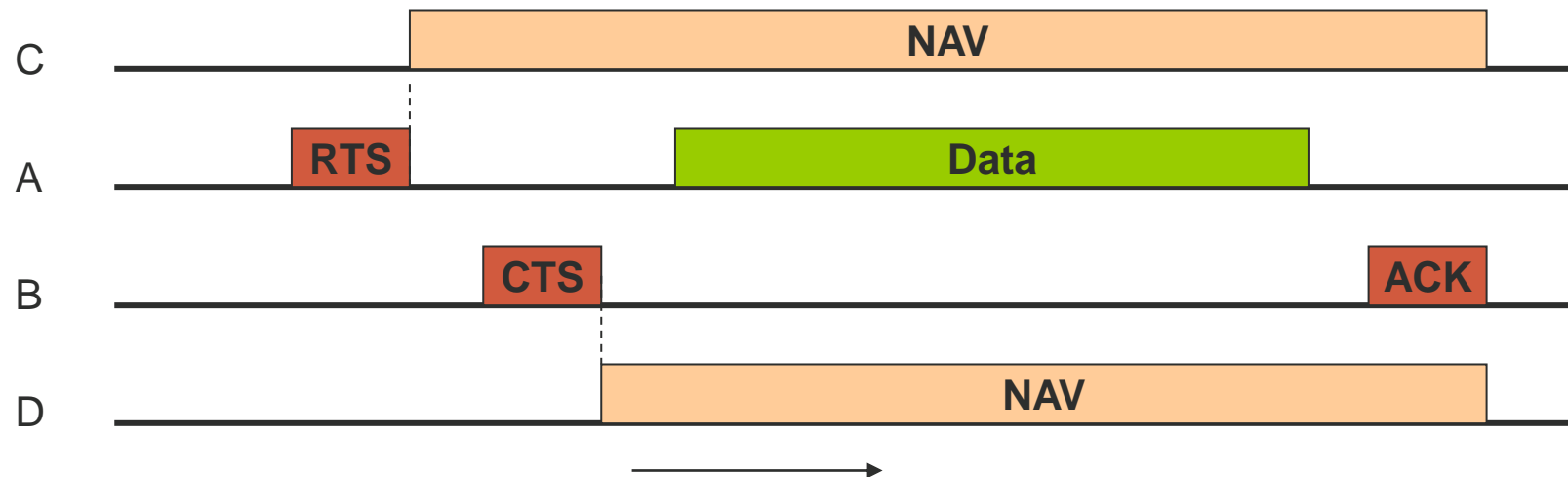
- **DCF – Distributed Coordination Function**

- 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



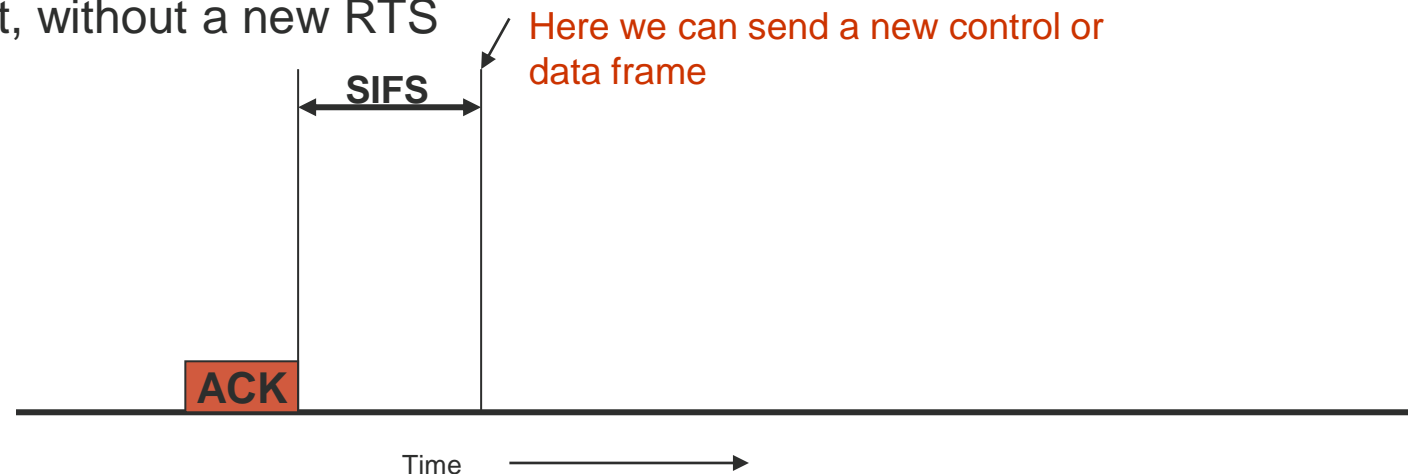
Traditional IEEE 802.11 MAC (PCF)

▪ 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)

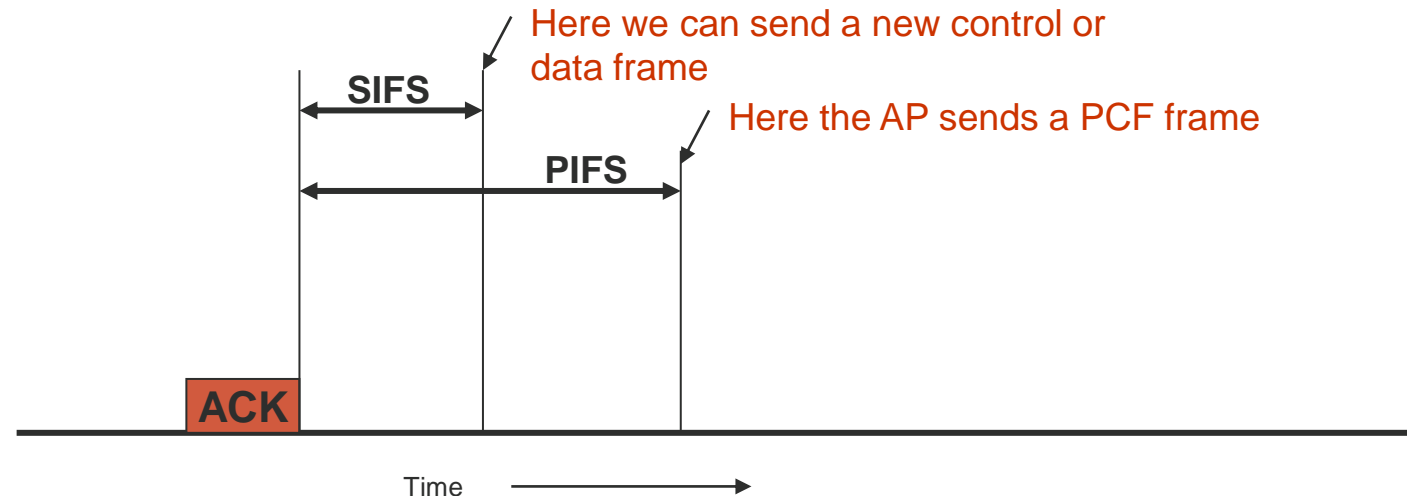
- PCF and DCF can operate in parallel inside the same cell
 - Distributed and centralized control in the same time?
 - Is possible, if carefully defined timers are used
 - After the sending of a frame, a certain guard time is required before any other transmission
- Four specific timers
 - **SIFS – Short 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

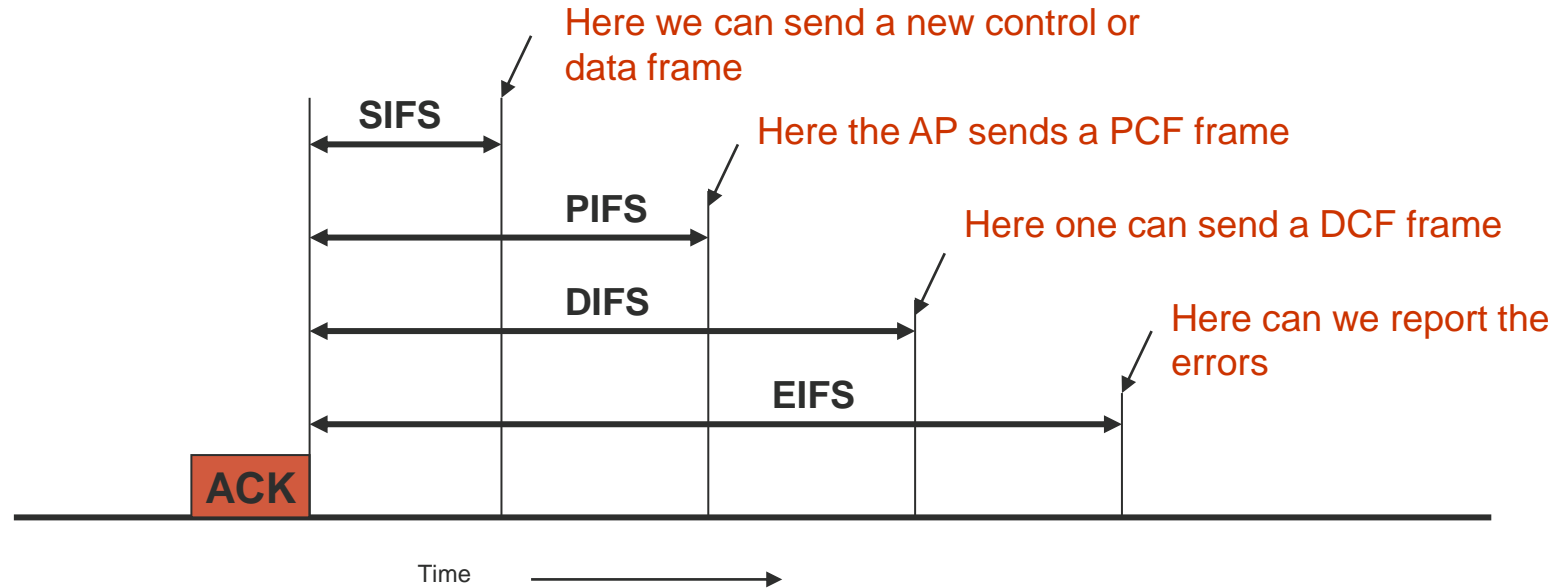


Traditional IEEE 802.11 MAC (DCF & PCF)

▪ DIFS – DCF Inter-Frame Spacing

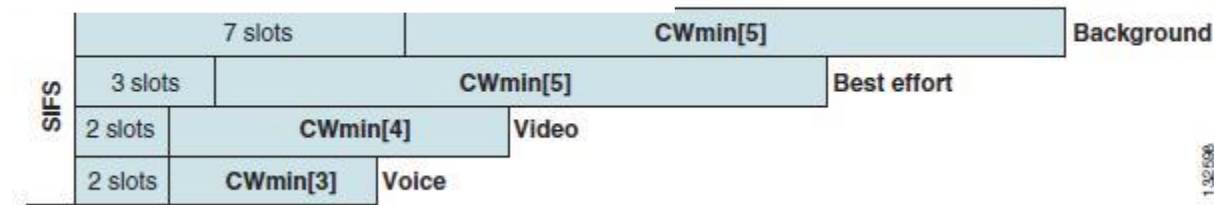
- If the AP does not have anything to send, after the DIFS anyone can try to gain access to the channel
 - Usual contention rules
 - Exponentially increasing back off interval, if collision
- Same DIFS value for all traffic types

▪ EIFS – Extended Inter-Frame Spacing



802.11e MAC - Enhanced Distributed Coordination Access (EDCA)

- To support **Quality of Service differentiation**
- **Arbitration Inter-Frame Spacing** to replace the static DIFS
 - Different values for each **Access Category**
 - $AIFS = 1 \text{ SIFS} + AIFSN * \text{slot time}$
 - By default...
 - Voice Queue (AIFSN=2) $1 \text{ SIFS} + 2 * \text{slot time}$
 - Video Queue (AIFSN=2) $1 \text{ SIFS} + 2 * \text{slot time}$
 - Best Effort Queue (AIFSN = 3) $1 \text{ SIFS} + 3 * \text{slot time}$
 - Background Queue (AIFSN = 7) $1 \text{ SIFS} + 7 * \text{slot time}$
 - When AIFS expires, choose a random value between 0 and **CWmin (minimum contention window)**
 - Start decrementing a backoff timer
 - If another node starts transmitting, access is deferred until the channel is free again
 - Then backoff timer decrementation is resumed from where it was stopped
 - If backoff = 0, transmission starts
 - If collision, no ACK received – CWmin is doubled until it reaches CWmax



802.11p MAC

- **Enhanced Distributed Coordination Access (EDCA)**
 - Defined in IEEE 802.11e, to support **Quality of Service differentiation**
 - In 802.11e four Access Categories (AC)
 - Voice, Video, Best Effort and Background
 - In 802.11p ACs to differentiate between:
 - **safety critical and non-safety applications**

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



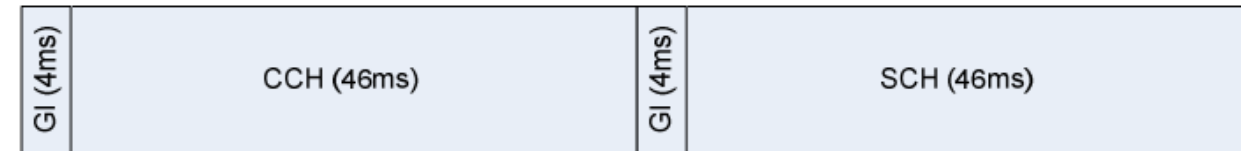
IEEE 1609.x

- IEEE 1609.2 – security services
- IEEE 1609.3 – management services
 - Channel usage monitoring
 - 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**
 - 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

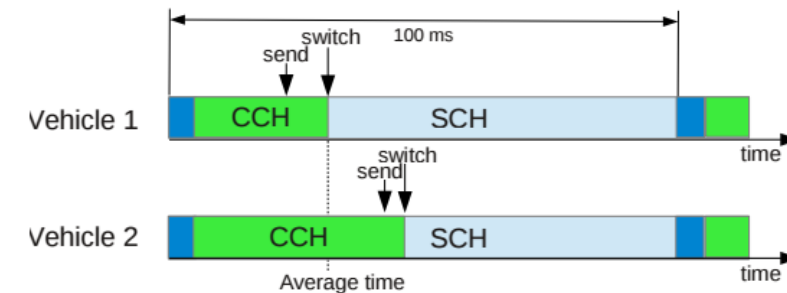
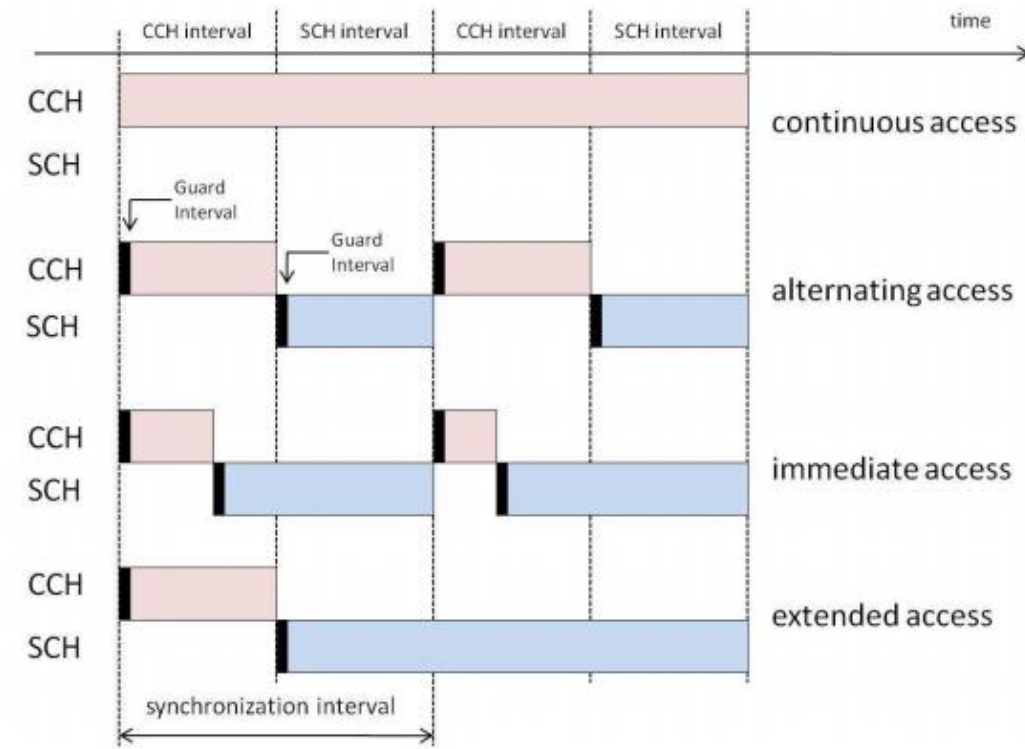
- The node does not have to wait until the CCH slot is over
- After the CCH transmission is over, switch to SCH
- Improve the performance of bandwidth-demanding non-safety applications in SCH, at the expense of the CCH

▪ 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