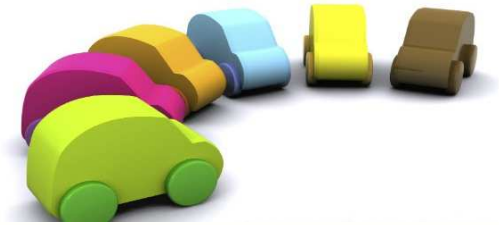
A leading institution at the heart of the digital society

EURECOM
Sophia Antipolis

V2X Communications for CCAM – Status and Future Trends and Challenges

Prof. Jérôme Härri, EURECOM

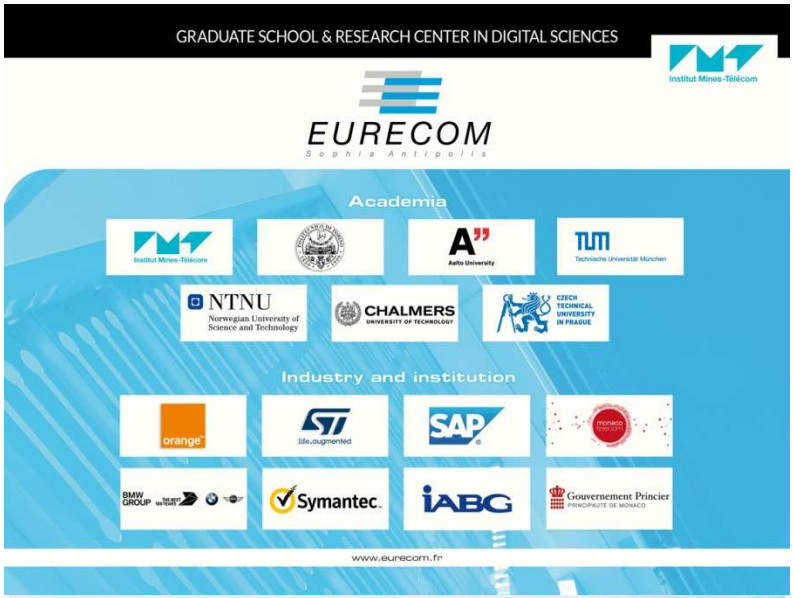


vs.

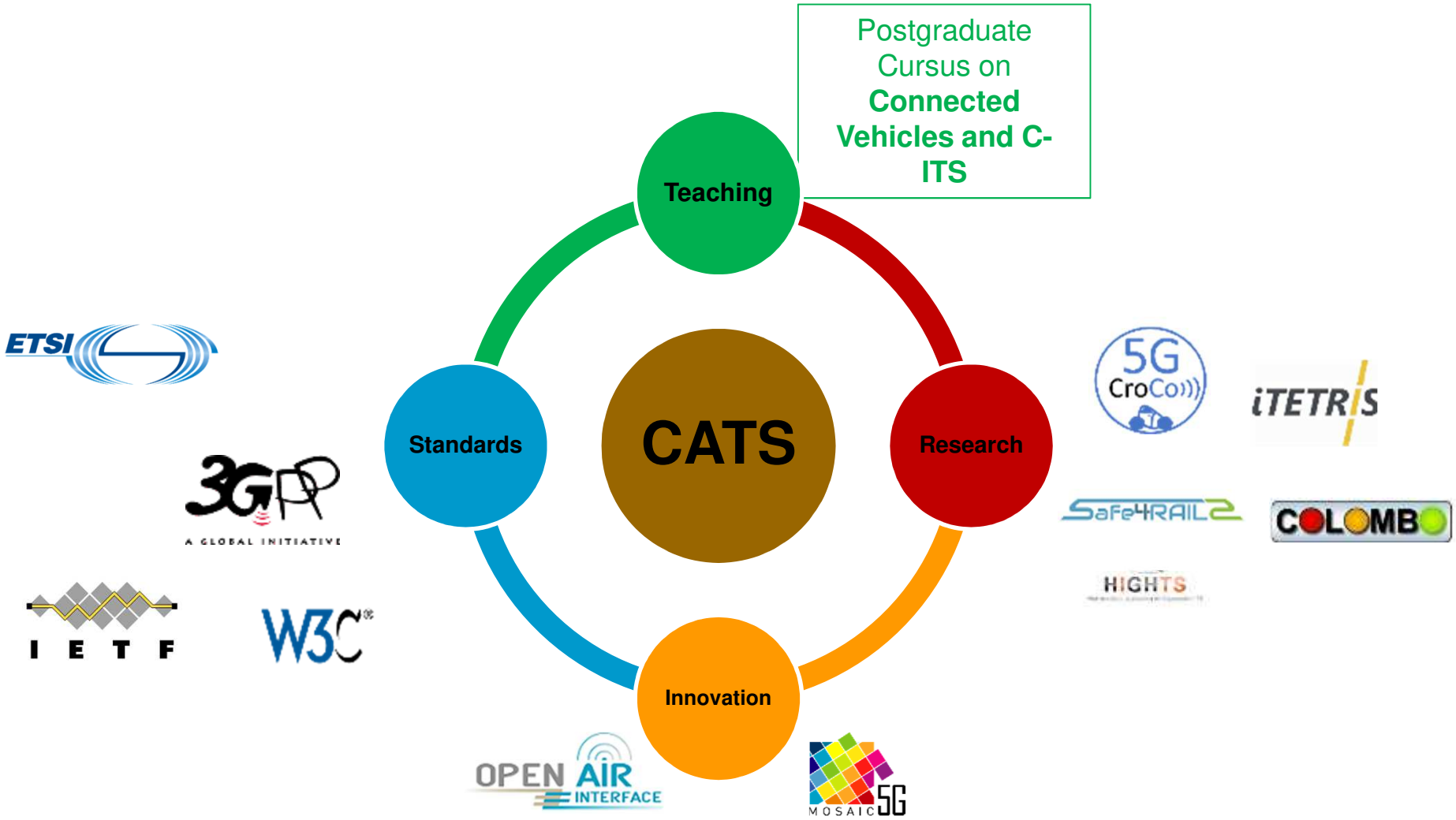
Cti
Commission des Titres d'Ingénieur

What is EURECOM ?

- **A consortium with a private status (EIG) that brings together:**
  - 8 Universities: Politecnico di Torino ITALY, Aalto FINLAND, TUM GERMANY, NTNU NORWAY, Chalmers SWEDEN, CTU CZECH REPUBLIC, TU Wien, AUSTRIA
  - 6 International Companies: Orange, STMicroelectronics, SAP, BMW Group, Symantec, IABG Munich
  - The Government of Monaco
- **A strong French-German relationship (Munich)**
  - TUM, BMW, IABG, SAP, DLR, SIEMENS
- **Three Departments:**
  - Digital Security
  - Data Science.
  - Communication Systems

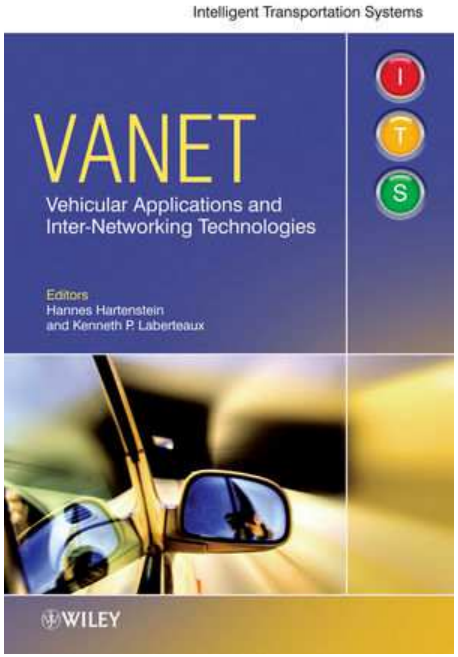


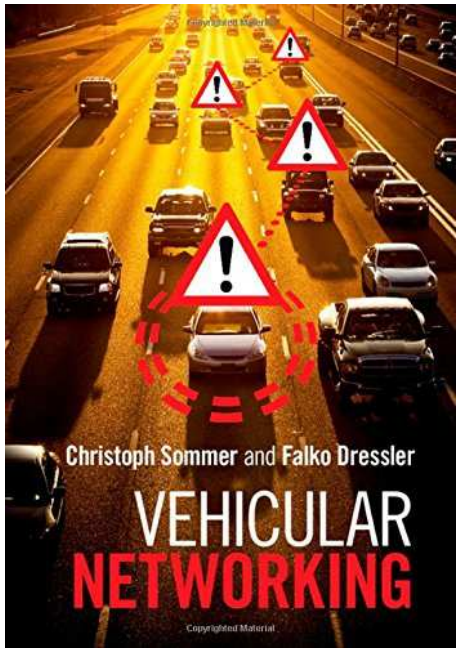
Cooperative Connected Automated Transport Systems (CATS)

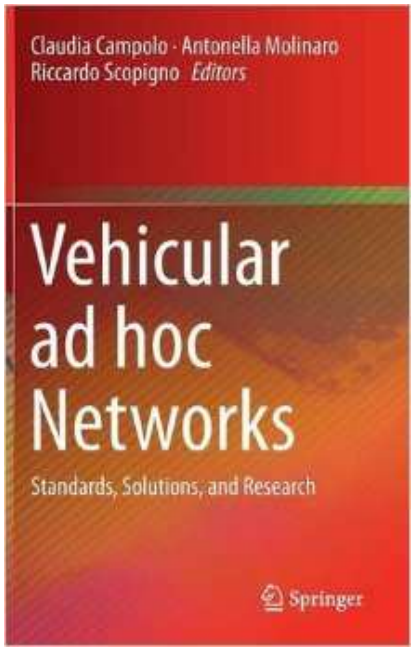


Related Books and References

http://www.amazon.co.uk/dp/1107046718







http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0470740566.html

http://link.springer.com/book/10.1007/978-3-319-15497-8

Part I

INTRODUCTION TO C-ITS

V2X Communication – Back to the Future !!

- **GM Futurama - 1939**

https://www.youtube.com/watch?v=aIu6DTbYnog (time code: 14:27)

From the early steps to current achievements

- **Visionary aspect: GM Futurama in 1939 and 1964 !!**
- **1970-1987: Electronic Route Guidance System (ERGS) - USA**
  - Deployment stopped due to expensive roadside infrastructure
- **1973-1979: Comprehensible Automobile Traffic Control (CACS) – Japan**
- **1988 – 1994 EUREKA - PROMETHEUS – EU**
- **1997: Cooperative autonomous driving demo: PATH, USA**
- **From the mid 1990:**
  - Game Changer: 5.9 DSRC – 802.11p, later known as IEEE 802.11-2012 OCB / ITS G5

Game Changer: IEEE 802.11-2016 OCB @ 5.9 GHz

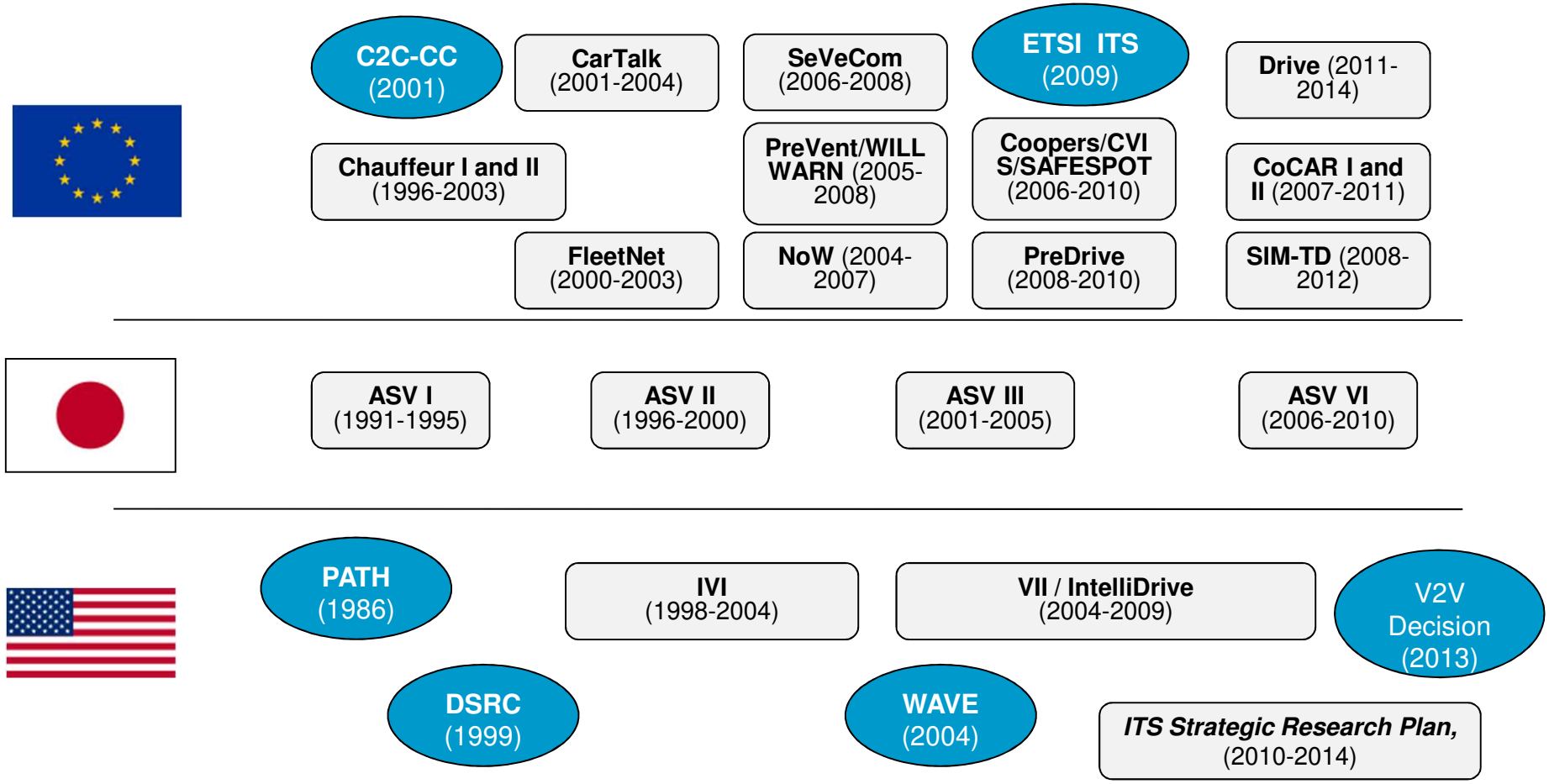
- **In 1994, the US Federal Communication Commission (FCC) allocated a 16 MHz band (unlicensed) at 902 MHz for ETC called Dedicated Short Range Communication (DSRC)**
  - In Europe, DSRC has been introduced solely for ETC at 5.8 GHz

- **In 1999, the FCC allocated a second DSRC frequency band at 5.9 GHz to be used specifically for inter-vehicular communication.**
  - **Primary Application**:
    - Saving lives by avoiding accident
    - Saving money by reducing traffic congestion
  - **Secondary Application**:
    - Comfort (infotainment) application to ease the early deployment of this technology.

- **Since 2001 Japan has developed, implemented and deployed DSRC applications under the name ARIB STD T-75 & 88.**

- **The European Commission allocated a 30 MHz frequency band at 5.9 GHz for safety applications in August 2008**

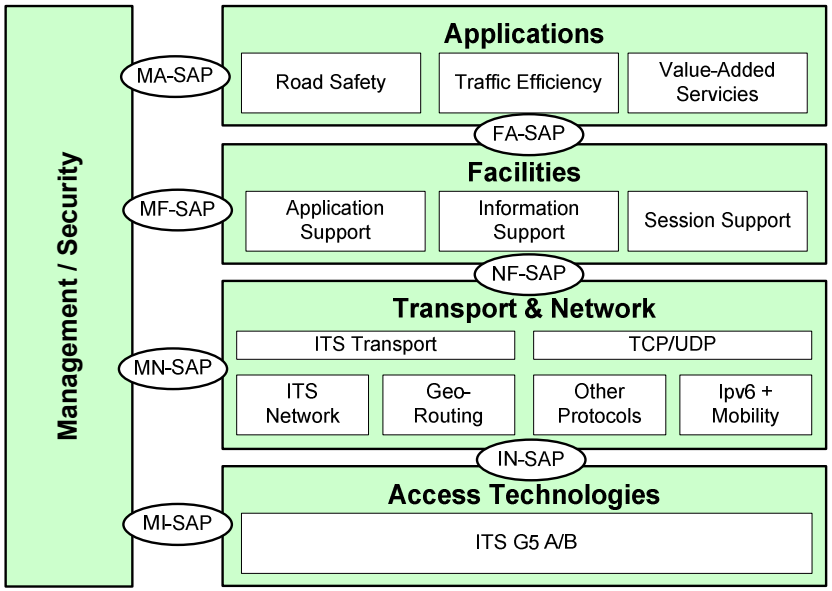
Non-exhaustive Overview of Projects

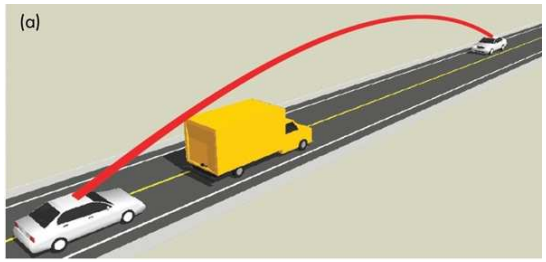


[Partial Reproduction of : H. Hartenstein, *VANET: Vehicular Applications and Inter-Networking Technologies"*, Chapter 1 – Introduction, Wiley, 2010]

V2X Communication – Day 1
Architecture, Technologies & Applications

- **ETSI Technical Committee on ITS**





Source: C2C-CC

- **Applications**
  - **Active Road Safety**
    - Cooperative awareness
    - Hazard warning
  - **Cooperative Traffic Efficiency**
    - Adaptive speed management
    - Cooperative navigation
- **Technology**
  - **DSRC**
    - IEEE 802.11 for vehicular environment
    - a.k.a: 802.11p, **ITS-G5**

V2X Communication - DAY 2
Objective: Highly Autonomous Driving

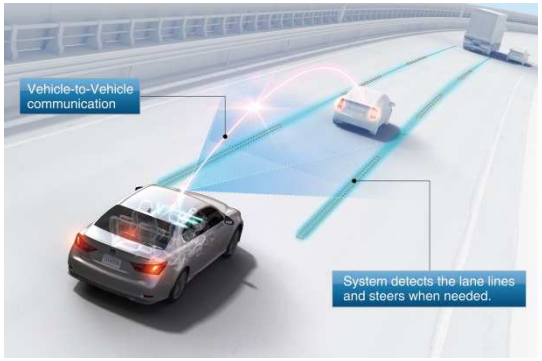
- **Not such a new idea**

- **A very marketized idea**

Source: google

- **…yet a very ambitious idea**

Source: US Peloton

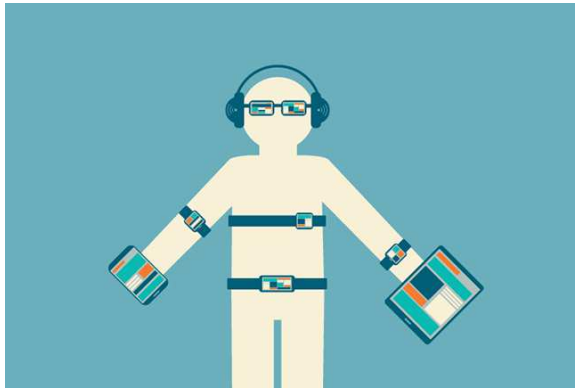


Source: toyota

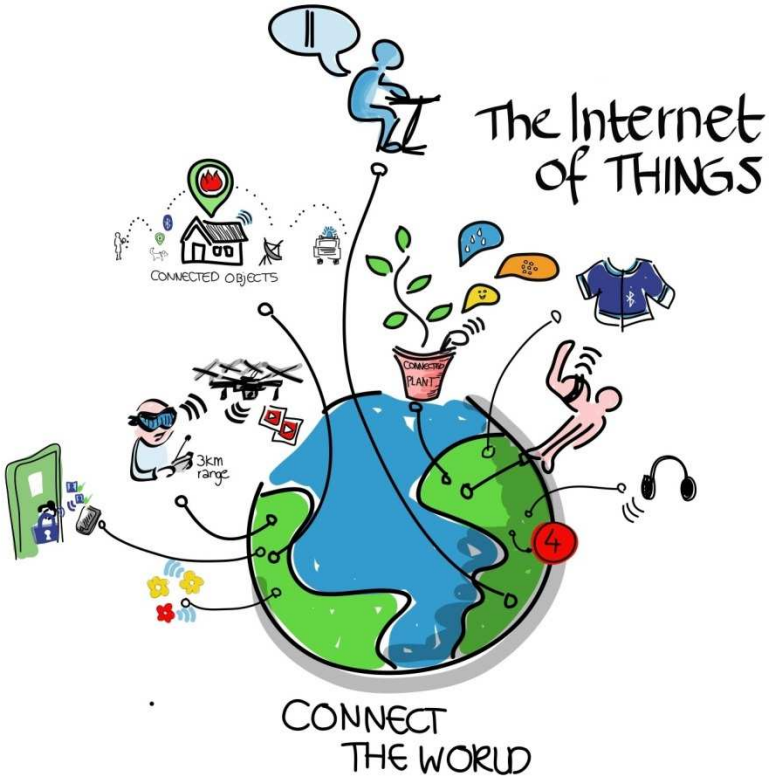
V2X Communication - DAY 2
Objective: Vulnerable Road Users

- **V2X not only between Vehicles**

- **V2X connects to wearable devices**



- **V2X is part of the Internet-of-things (IoT)**

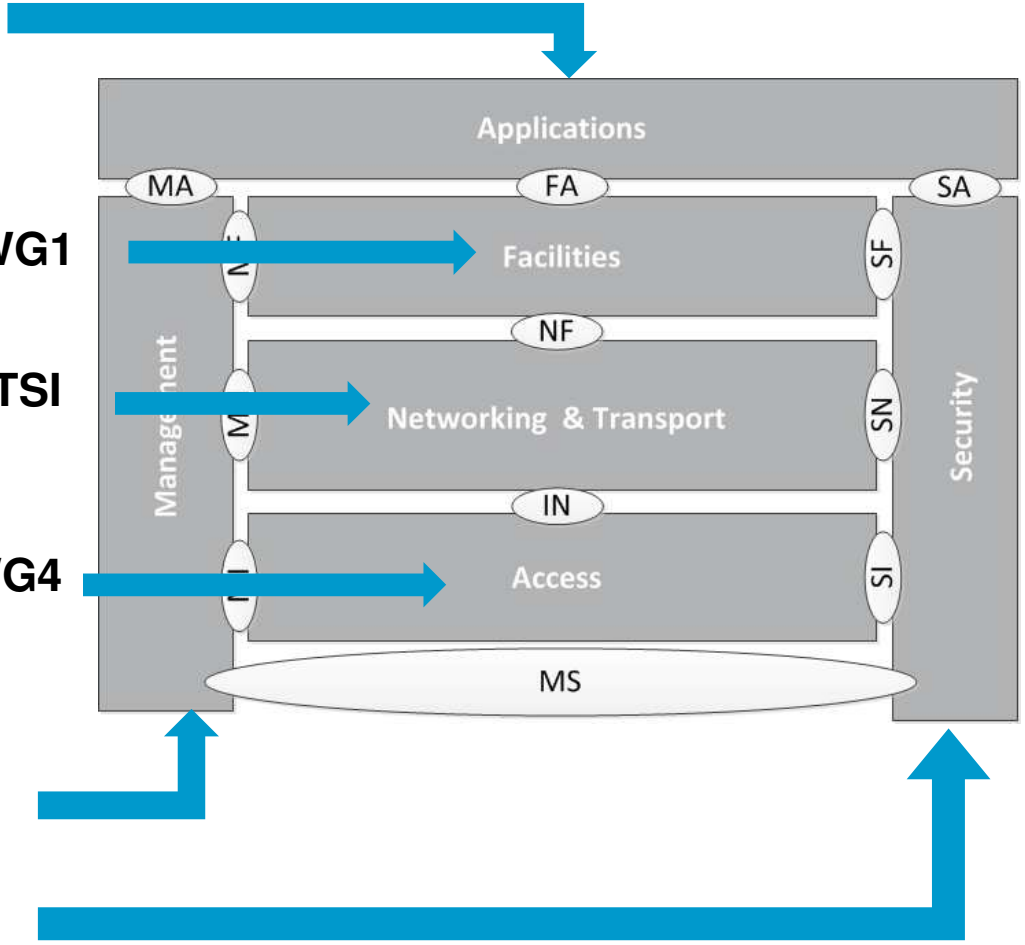


Part II

OVERVIEW OF KEY ETSI STANDARDS

ETSI Communication Architecture

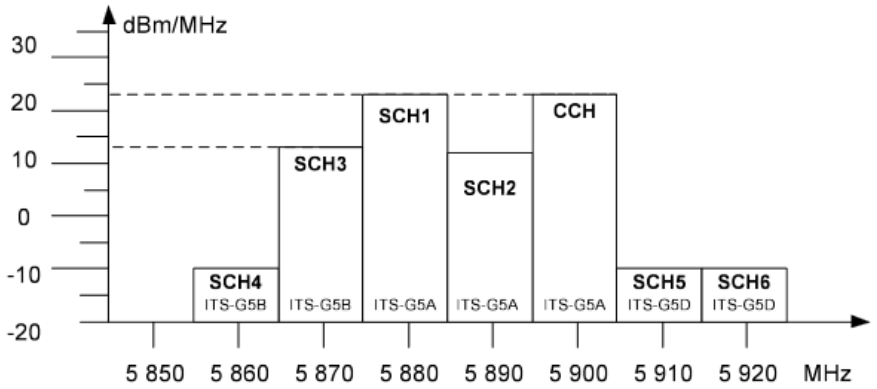
- **Applications are standardized by ETSI TC WG1 & CEN**
- **Facilities is handled by ETSI TC WG1**
- **Network & Transport is done in ETSI TC WG3**
- **Access is specified by ETSI TC WG4**
- **Management & Cross-Layer is handled by ETSI WG 2**
- **Security is specified by ETSI TC WG5**



ETSI ITS Access - ITS-G5 (EN 302 663, EN 302 571, TS 102 724)

- **ETSI EN 302 571**
  - Harmonized Standard for Radio-communications equipment operating in the 5 855 MHz to 5 925 MHz frequency band;
- **EN 302 663**
  - Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band
- **TS 102 724**
  - Harmonized Channel Specifications for Intelligent Transport Systems operating in the 5 GHz frequency band

Name	Center Frequency	Type
SCH6	5920	ITS-G5D - Future ITS
SCH5	5910	
SCH4	5860	ITS-G5B - Non-Safety related
SCH3	5870	
SCH2	5880	ITS-G5A - Safety-Related
SCH1	5890	
CCH	5900	



Missing: **ITS-G5C @ 5470 – 5710MHz**
- RLAN (EN 301 893)

ETSI Harmonized Standard for Radio-communications in 5 GHZ (EN 302 571)

- **European Norm –**
  - EU-level enforcement

National transposition dates	
Date of adoption of this EN:	6 February 2017
Date of latest announcement of this EN (doa):	31 May 2017
Date of latest publication of new National Standard or endorsement of this EN (dop/e):	30 November 2017
Date of withdrawal of any conflicting National Standard (dow):	30 November 2018

- **EN 302 571 – Provides the Highest Level Specifications for accessing 5GHz bands**
  - Technical Specifications:
    - Spectrum Access Rights (Safety/non-safety)
    - Spectrum protection –
      - Maximum TX power
      - Out-of-Band emission
    - Coexistence between different technologies
    - Receiver Sensitivity
    - Distributed Congestion Control requirements
  - Bound by Law
    - IEEE 802.11-2016 is just an industry standard…

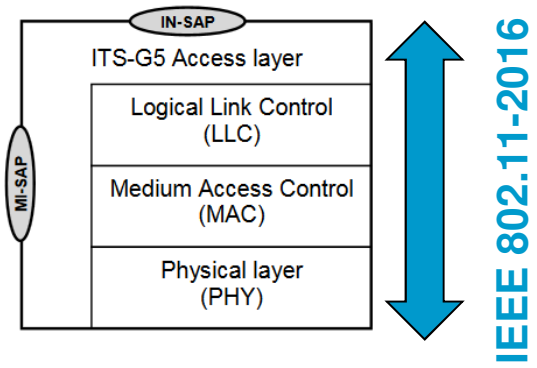
ETSI Profile Standard for ITS-G5 (EN 302 663)

- **European Norm –**
  - EU-level enforcement

National transposition dates	
Date of adoption of this EN:	2 July 2013
Date of latest announcement of this EN (doa):	31 October 2013
Date of latest publication of new National Standard or endorsement of this EN (dop/e):	30 April 2014
Date of withdrawal of any conflicting National Standard (dow):	30 April 2014

- **EN 302 663 - Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band**
  - Provides the access bands (ITS-G5A/B/C/D)
  - Provides the PHY/MAC specifications for ITS-G5 (so far)
  - Provides either specification or restrictions from EEE 802.11-2016
    - Example:
      - IEEE 820.11-2016 OCB only
      - PHY and MAC parameters

	Frequency range [MHz]	Usage	Regulation	Harmonized standard
ITS-G5D	5 905 to 5 925	Future ITS applications	ECC Decision ECC/DEC(02)01 [i.4]	EN 302 571 [1]
ITS-G5A	5 875 to 5 905	ITS road safety related applications	Commission Decision 2008/671/EC [i.7]	EN 302 571 [1]
ITS-G5B	5 855 to 5 875	ITS non-safety applications	ECC Recommendation ECC/REC/(08)01 [i.2]	EN 302 571 [1]
ITS-G5C	5 470 to 5 725	RLAN (BRAN, WLAN)	ERC Decision ERC/DEC(99)23 [i.3] Commission Decisions 2005/513/EC [i.5] and 2007/90/EC [i.6]	EN 301 893 [i.14]



ETSI Facilities Layer – Main Topics

- **ETSI Basic Set of Applications** (TS 102 637-1, TS 102 869-1, TR 102 638)
  - Users & Applications requirements (Draft TS 102 894)
  - List of supported ETSI ITS applications and requirements

- **Local Dynamic Map (LDM)** (EN 302 895, TR 102 863)
  - Geographic data base of all ITS-related information (i.e. the brain)

- **Common Awareness Message (CAM**) (EN 302 637-2, TS 101 539-1)
  - Periodic broadcast message of a node's status information, including position, heading, speed, and other traffic relevant information.
  - Some inputs are similar to Geonet header
    - Could lead to doubling information

- **Decentralised Environmental Notification Message (DENM)** (EN 302 637-3)
  - Event triggered broadcast message that includes a description of the triggering event and its duration

ETSI Facilities Layer – DAY ONE Applications

- **Road Hazard Signaling (Draft TS 101 539-1)**
  - Emergency vehicle approaching, slow vehicle, stationary vehicle, emergency electronic brake lights, wrong way driving, adverse weather condition, hazardous location, traffic condition, road work, People on the road.

- **Intersection Collision Risk Warning Specification (Draft TS 101 539-2)**
  - Traffic signal violation warning, monitoring of vehicle trajectories at road crossings (data from CAM).

- **Longitudinal Collision Risk Warning Specification (Draft TS 101 539-3)**
  - Forward collision:
    - Dangerous lane change, emergency braking, road work, stationary vehicle, vehicle out of control.
  - Frontal collision:
    - Wrong way driving, dangerous overtaking, vehicle out of control.
  - Accounts for car types/abilities, speed , distance, weather, and driver intentions (e.g. overtake, turn...).

- **Electric Vehicle Charging Spot Notification Specification (Draft TS 101 556-1)**
  - Automatic booking of charging spots for electric vehicles

ETSI Facilities Layer – DAY TWO Applications

Applications

- **C-ACC Pre-standardization study (TR 103 299)**
  - Early discussion of the definition, scenario and KPI of C-ACC
- **Platooning pre-standardization study (TR 103 298)**
  - Early discussion of the definition, scenario and KPI of Platooning
- **Cooperative Vulnerable Road Users (VRU) (TR 103 300)**
  - Early discussion of the definition, scenario and KPI of Vulnerable Road Users
- **Multimedia Content Dissemination Basic Service specification (TS 103 152)**
  - V2X exchange of multimedia information comprising video, audio, images and data.

Messages

- **Collective Perception Service update (TS 103 324)**
  - aims at sharing information about the current driving environment with other ITS-Ss.
- **Facilities layer protocols and communication requirements for infrastructure services (TS 103 301)**
  - In Vehicle Information (IVI)
  - Traffic Light Control
- **Facility Position and Time (POTI) (TS 102 890-2)**
  - Transmit time and raw position data between vehicle according to functional requirements
- **Facilities Service Announcement (TS 102 890-1)**
  - Service Announcement Message (SAM)

Part II

WIFI-BASED V2X COMMUNICATIONS

ITS-G5: Key Messages for Safety-related ITS Applications

Periodic

Cooperative Awareness Message (CAM)

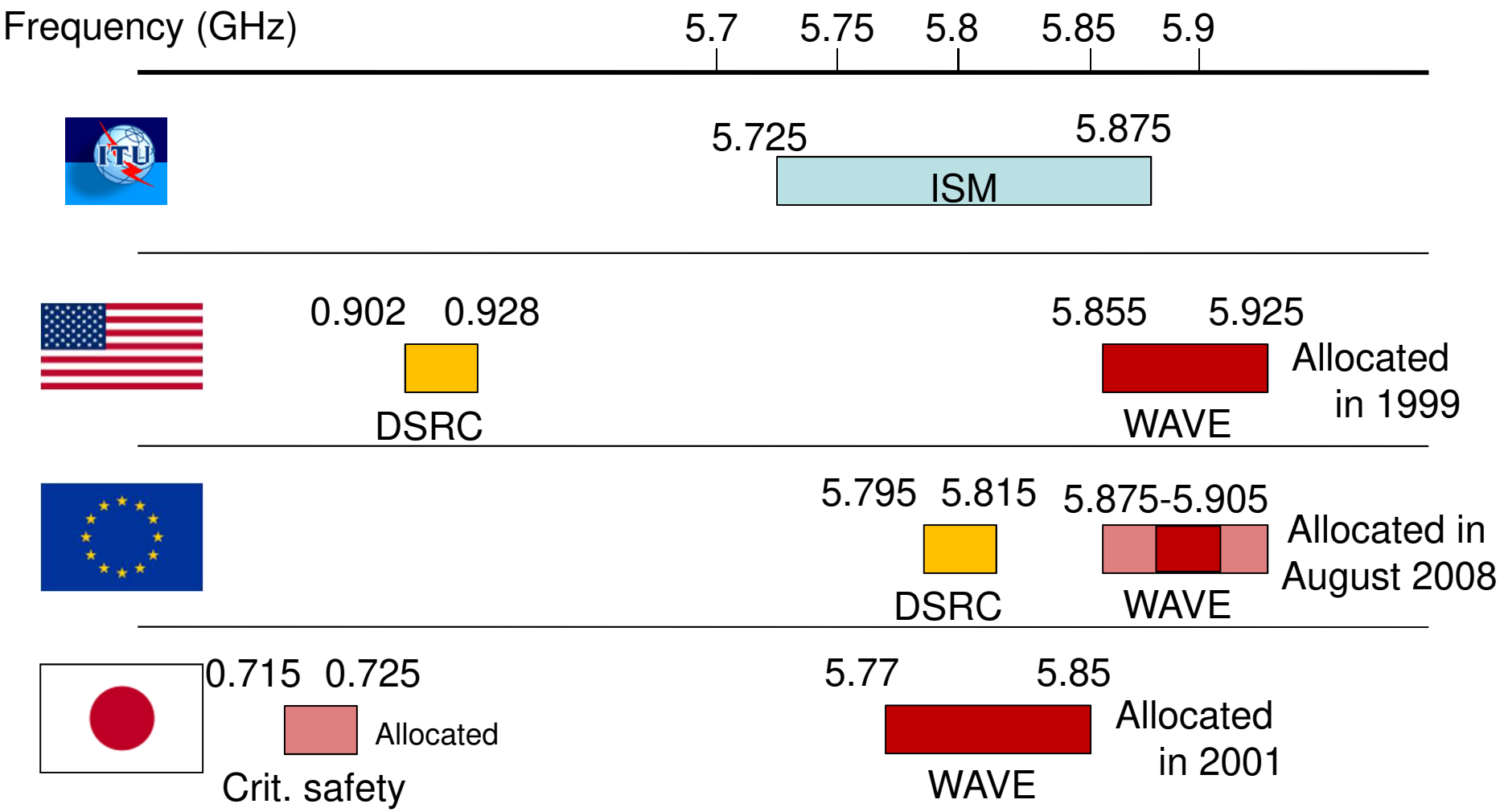
- One-Hop **broadcast**
- Transmit the status and position of a vehicle.
- Transmitted at 10Hz

Event-driven

Decentralized Environment Notification Message (DENM)

- Multi-Hop **broadcast**
- Transmit emergency or application-based messages
- Triggered, very high rate during a short time (1s)

Frequency Allocation



Three Frequency Bands in 5 GHz Band

RLAN bands (U-NII2, WLAN, BRAN, HiperLAN2)

5.50 5.7 5.855 5.875 5.905 5.925 GHz

Power: 1W EIRP

ITS G5 C
Shared Spectrum
Dynamic Channel Selection & Power Control

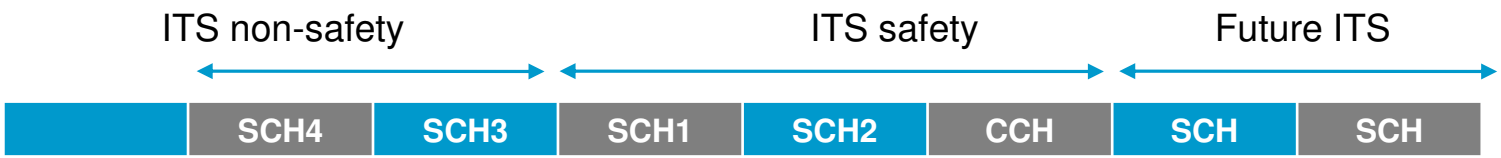
ITS G5 B
ITS Dedicated Spectrum

ITS G5 A
ITS Dedicated Spectrum

ITS G5 D
Future Usage

EIRP : Effective Isotropic Radiated Power

Dedicated ITS bands



5.855 5.865 5.875 5.885 5.895 5.905 5.915 GHz

Bandwidth: 10Mhz

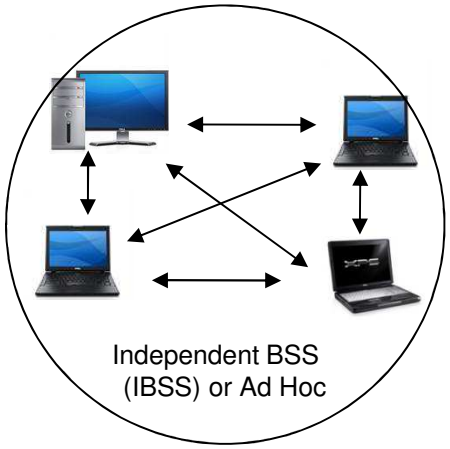
SCH – ITS Service Channel

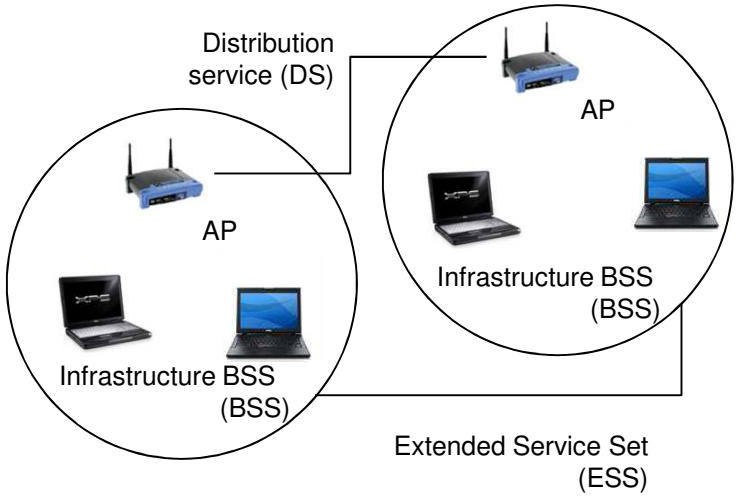
CCH – ITS Control Channel

Power: 2W CCH &SCH1; 200MW SCH2 & 3; 1mW SCH4

Forming a Wireless Network: Architecture

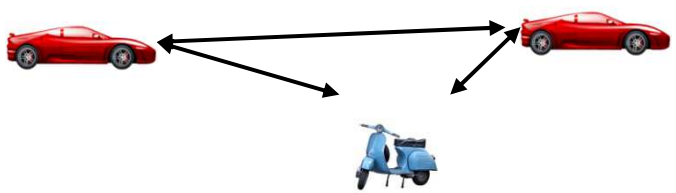
- **Basic Service Set (BSS)**
  - A station must join a BSS and an AP before being allowed to communicate





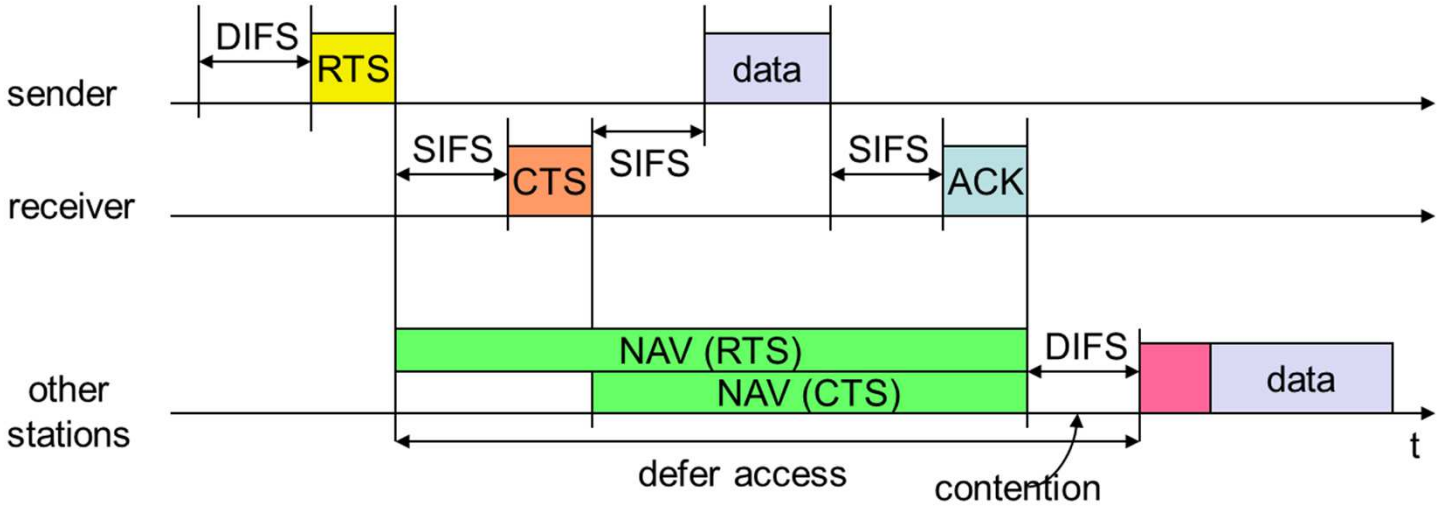
- **Communicating Outside of the Context of a BSS**
  - Vehicular-specific extension of the IEEE 802.11 not requiring a BSS to communicate

Comm. Outside
Context of BSS
(OCB)



IEEE 802.11 Distributed Coordination Function (DCF)

- **Listen before Talk Principle**
  - If medium is free for a DIFS time, station sends data or control packet
  - receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)
  - automatic retransmission of data packets in case of transmission errors
- **Contention-based Access**
  - Contend for the channel access, back-off if you loose

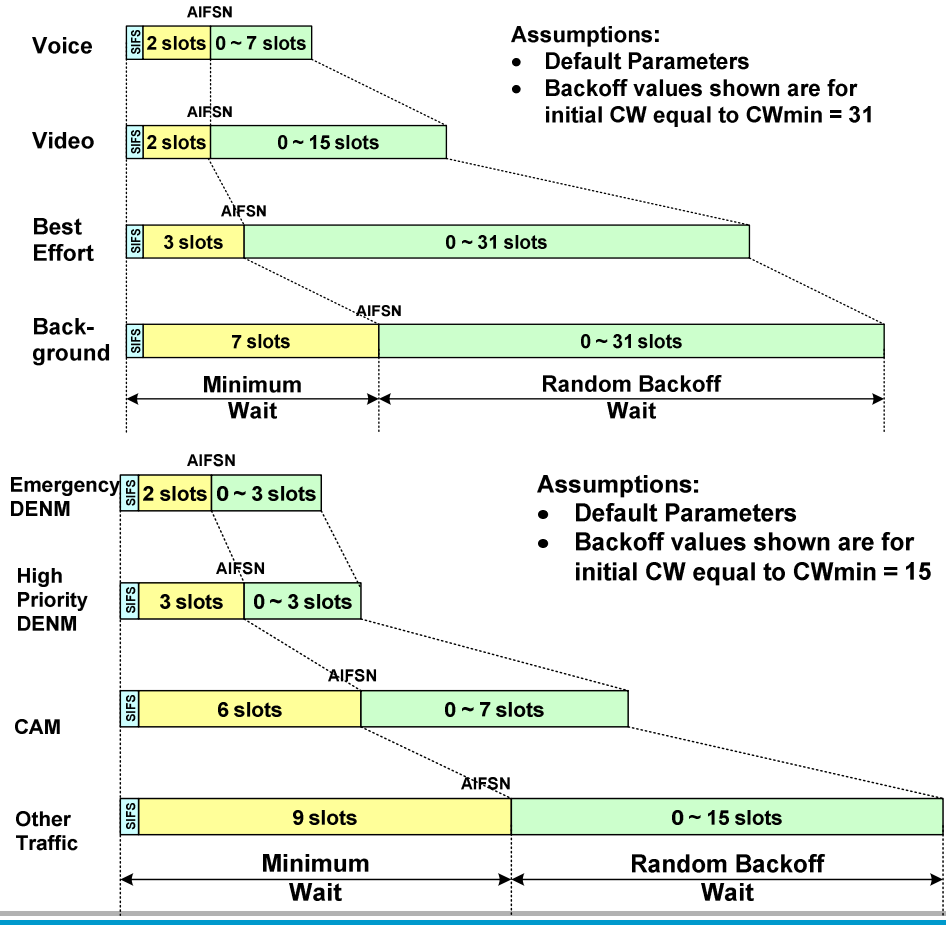


EDCA Parameter Results – DSRC/ITS-G5 OCB

- **The IEEE EDCA is modified to improve the prioritization of messages**

  - **IEEE 802.11e EDCA**

  - **DSRC/ITS-G5 EDCA**



DSRC/ITS-G5 Channel Characterization

- **How does the channel characteristic at 5.9 GHz for 802.11p look like?**

Delay spread	**~ 0.8 µs**
Coherence Bandwidth	**~ 1.25 MHz**
Coherence Time	**~ 1.02 ms**
Doppler spread	**~ 2 kHz**

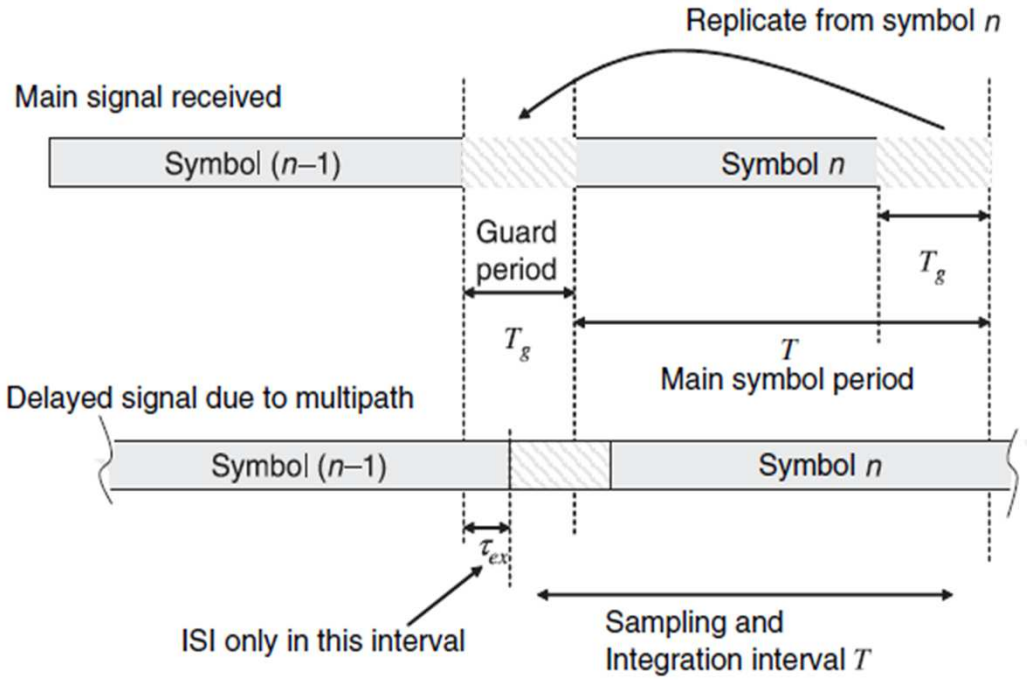
Source: Measurement and Analysis of Wireless Channel Impairments in DSRC Vehicular Communications, Laberteaux et al, 2008

- **What does it tell us?**
  - We have a **time- and frequency-selective** channel
  - We have a **doppler spread** which needs to be considered

- **Actions:**
  - We have to use narrow-band communication to mitigate frequency-selective channel
  - We have to make sure that successive OFDM symbols are sufficiently separated in time to avoid ISI
  - We have to make sure that the 52 OFDM sub-carriers are have an inter-carrier distance of at least 2 kHz to avoid ICI

DSRC/ITS-G5 PHY Countermeasures

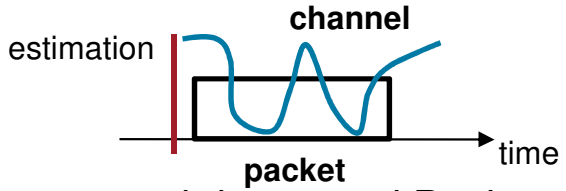
- **Mitigating Inter-Symbol Interference**
  - OFDM introduces a guard period after each OFDM symbol to protect symbols from ISI



Source: Antennas and Propagation for Wireless Communication Systems, Simon R. Saunders and Alejandro Aragón-Zavala, 2007, John Wiley & Sons, Ltd

DSRC/ITS-G5 PHY Countermeasures

- **Mitigating Inter-Carrier Interference**
  - 802.11p OFDM uses a carrier spacing of 156.25 kHz
  - The Doppler Spread of 2 kHz is “easily” covered by this spacing..
- **Mitigating Time-selectivity (or narrowband fast fading)**
  - Problem: the channel estimation at the beginning of a packet may be invalid at the end of the packet



    - This results in an increased Bit error rate and decreased Packet reception rate
  - <u>Several solutions</u>:
    - Increase data-rate to reduce transmission time below channel coherence time
    - Estimate the channel several times during the transmission
    - Use modulation schemes which overcome the channel fading, e.g. differential BPSK

DSRC/ITS-G5 - Summary

- **Key PHY characteristics**
  - 5.9 GHz frequency domain
  - Based on IEEE 802.11a (OFDM PHY)
  - 10 MHz channel bandwidth
  - Rates: 3, 4.5, 6, 9, 12, 18, 24, 27 Mbps
  - Symbol time: 8µs (1.6µs guard interval + 6.4µs data symbol)

- **Key MAC characteristics**
  - Adapted EDCA (QoS) parameters
  - OCB mode (no BSS)
  - Congestion Control (adaptive TX power, TX rate, multi-channel)

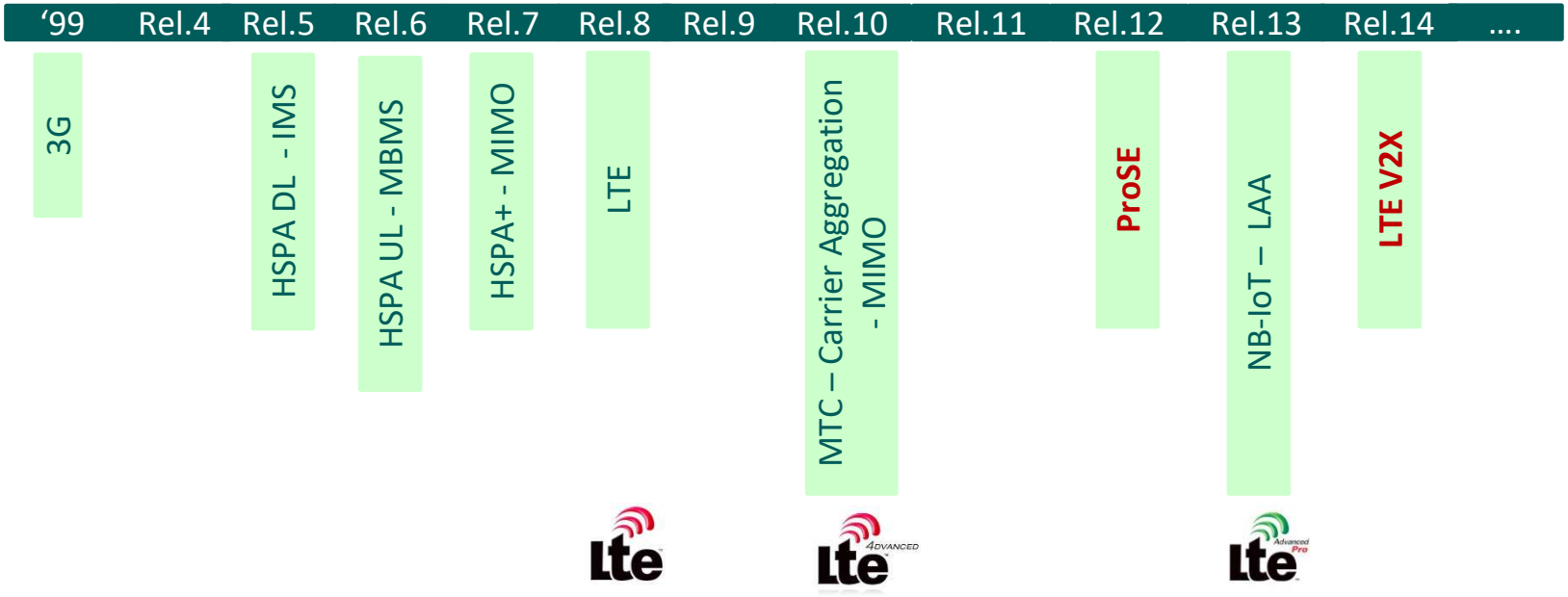
Classic 802.11 WLAN	DSRC/ITS-G5
Synchronizing	**OPTIONAL HIGHER LAYER** Synchronization
Scanning	**NO** Scanning
Authentication	**HIGHER LAYER** Authentication
Association	**IMPLICIT** Association
Communication	**DIRECT** Communication
Concept of Basic Service Sets (BSS)	"Communication outside of the context of the BSS"

Part III

CELLULAR-BASED V2X COMMUNICATIONS

3rd Generation Partnership Project

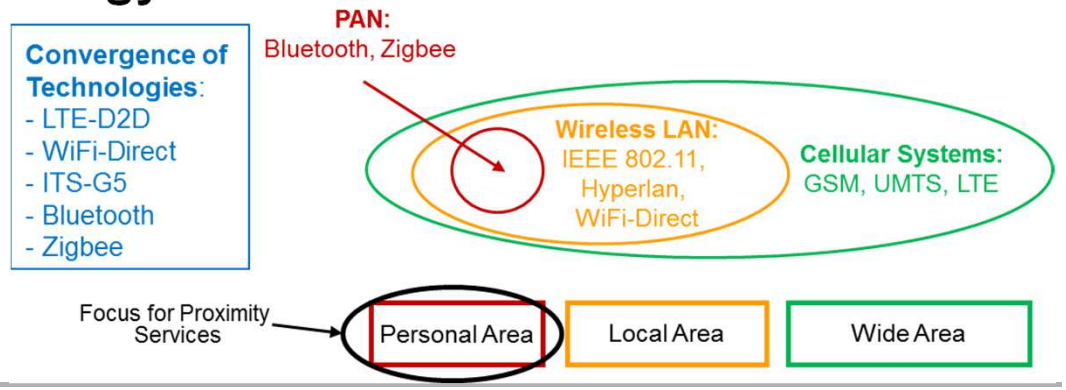
- **Progress and Releases**
  - 3GPP technologies are evolving through ‘Generations’
  - Progresses are measured by milestones known as ‘release’



LTE Proximity Service (ProSe)

- **Evolution of Proximity Services**

- **Evolution of Proximity Technology**



LTE Proximity Service (ProSe) - Motivations

- **General advantages**
  - improve spectrum utilization
  - improve overall throughput and performance
  - improve energy consumption
  - enable new peer-to-peer and location-based applications and services

- **Advantages related to public safety**
  - fallback public safety networks that must function when cellular networks are not available or fail
  - closing the evolution gap of safety networks to LTE

- **Challenges and risks**
  - Business opportunity related to the long-standing cellular architecture

LTE Proximity Services (ProSe)

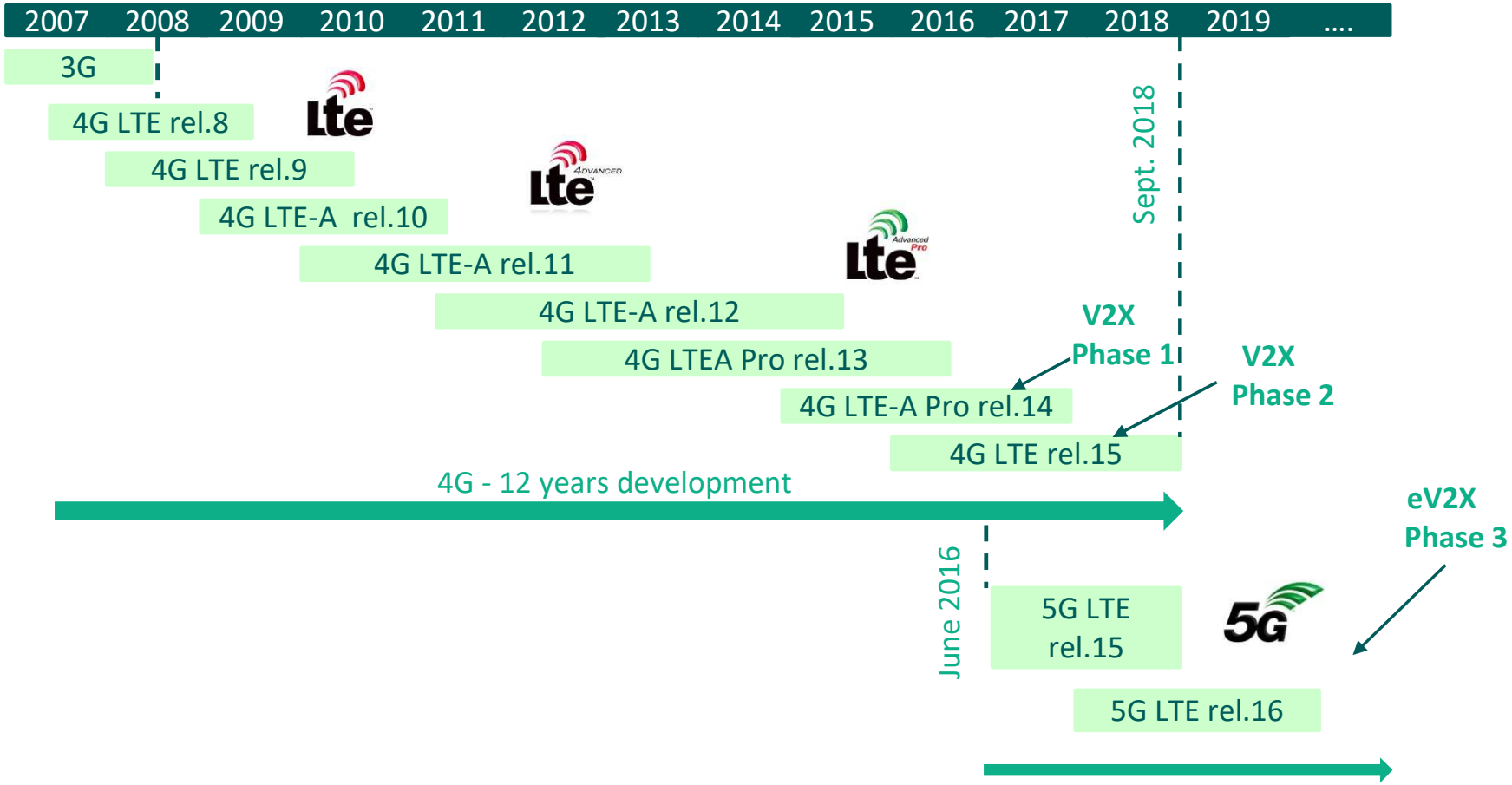
- **LTE ProSe enables establishment of communication paths between two or more ProSe-enabled UEs.**
  - Radical architecture change for D2D
  - Since LTE Rel.12

- **LTE ProSe enables communication functions**
  - One-to-One – Direct UE-to-UE Communication
  - One-to-Many - Communication to a ProSe group

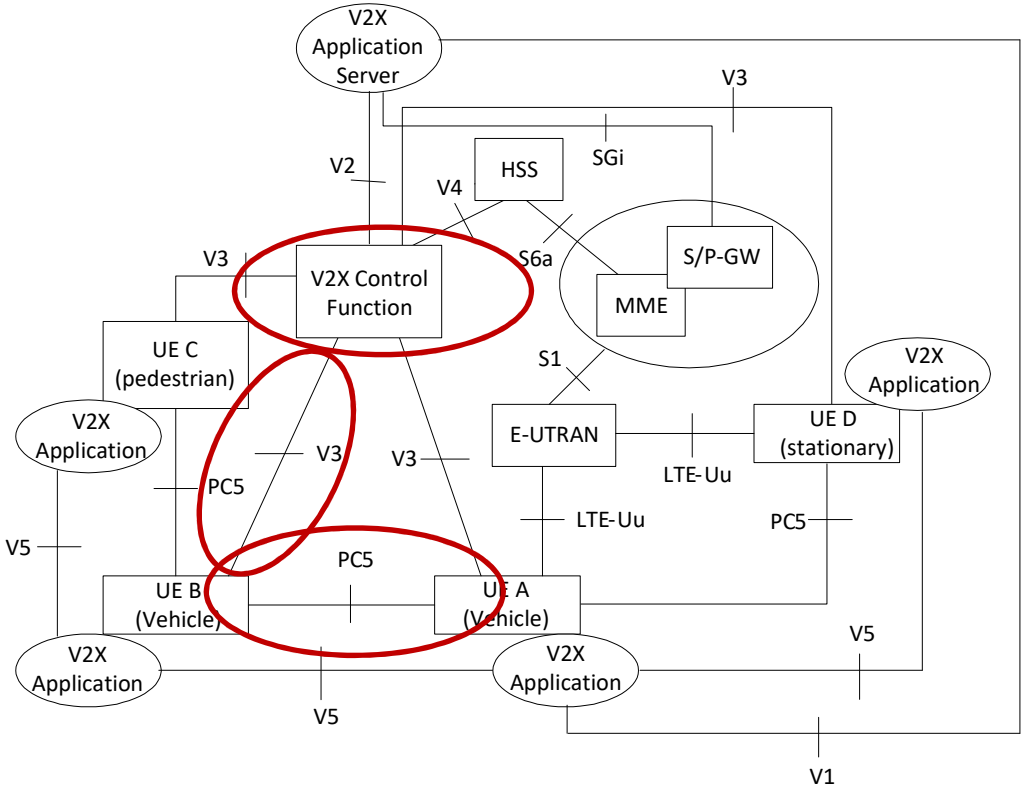
- **LTE ProSe Functions:**
  - Discovery
    - Mode A – 'I am here'
    - Mode B – 'how is there ?'
  - Direct Communication
    - Mode 1 – Coordinated by eNB
    - Mode 2 – Ad-Hoc mode

Restricted to Public Safety & V2X (rel.14)

LTE Vehicular-to-Everything (V2X)



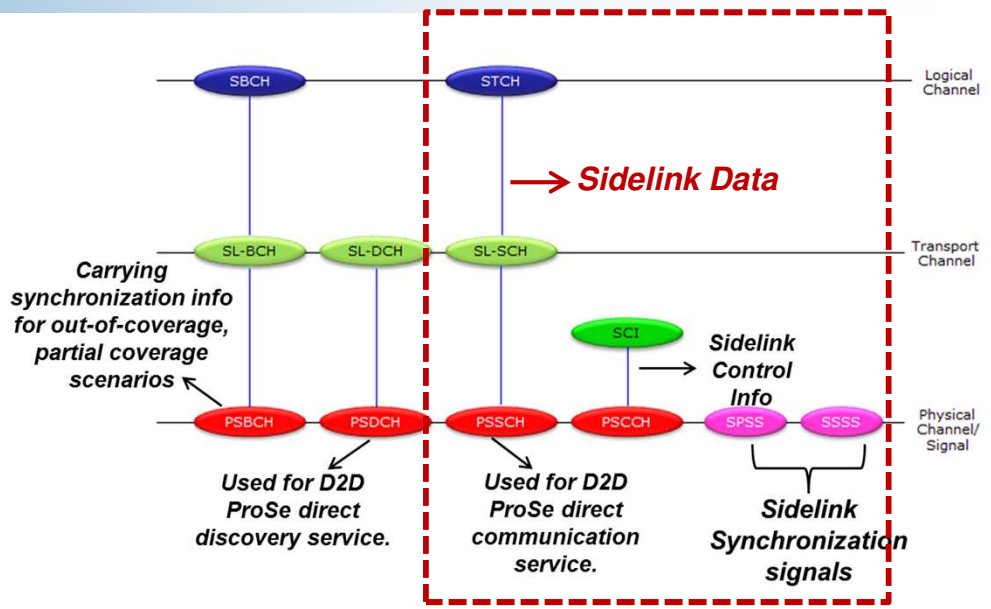
LTE V2X Extended Architecture

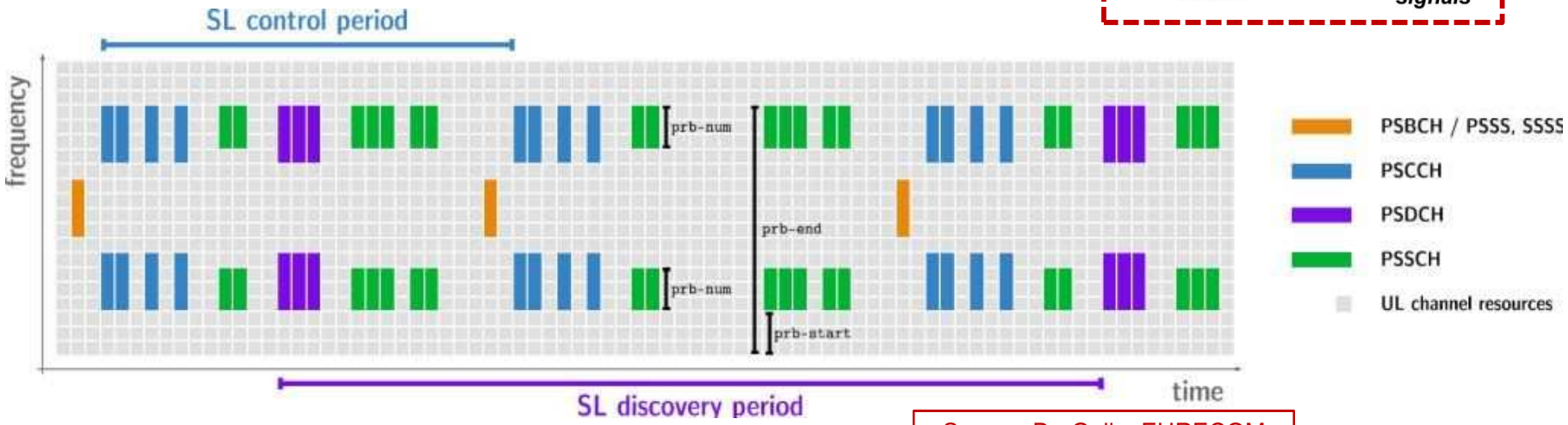


- **New Architecture Elements:**
  - V2X Control Function – similar to Prose Function
  - PC5 interface – as D2D Prose
  - V3 interface – as PC3, but with V2X-related messages

LTE-V2X – 'Slidelink' (SL) Channels

- **Slide link channels**
  - Reduced set
    - No discovery
    - Only one-to-many
- **Sidelink Pool**
  - Modified PSCCH on same Subframe as PSSCH
    - Reduced delay





Source: Dr. Gallo, EURECOM

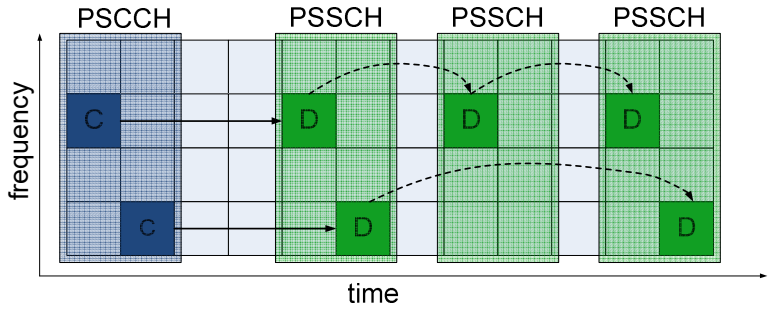
LTE V2X - Sidelink Resource Allocations

- **In off-network or partial on-off-network scenarios: SLSS & MIB-SL**

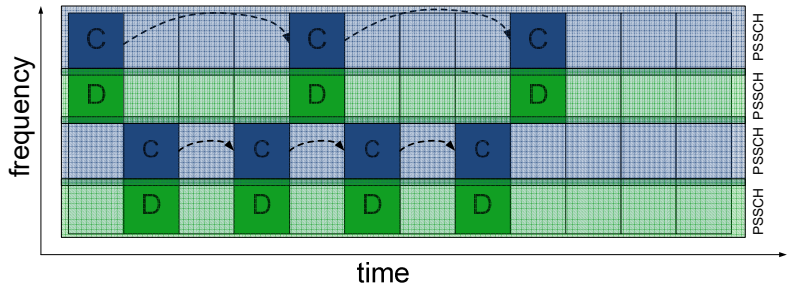
	Scheduled	**Ad-Hoc**
Comm.	**Mode 3** • Only in-coverage • Resources for transmission on PSCCH and PSSCH are indicated using Downlink Control Information from eNB	**Mode 4 (SPS)** • Out of coverage • Resource pools config. for D2D transmission and reception on PSCCH and PSSCH (up to 8) preconfigured
Discovery	**Type 5a (Semi-Persistent Scheduling)** • Only in-coverage • Resources for transmission on PSDCH are indicated using Downlink Control Information from eNB	**Type 4** • Out of coverage • Resource pools configurations for D2D transmission and reception on PSDCH preconfigured

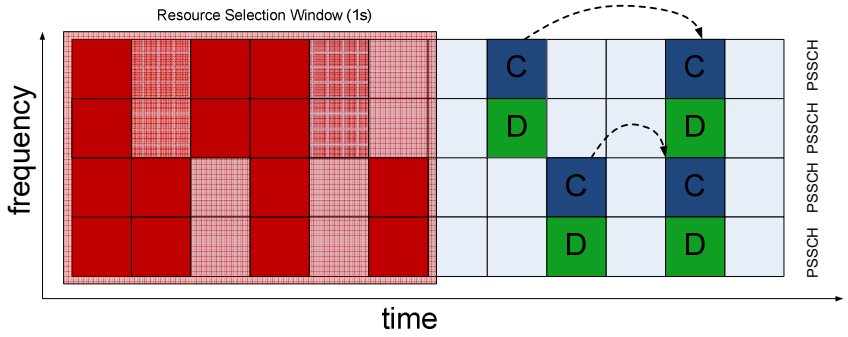
LTE-V2X – Distributed Scheduler

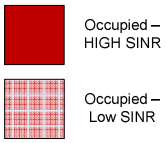
- **LTE V2X mode 3 (eNB)**
  - multiple SPS configurations can be active
  - can be different period/MCS for flexibility
  - UE does not have to transmit if no data



- **LTE V2X mode 4 (Ad-Hoc)**
  - resource location and MCS selected autonomously
  - resources are reserved in advance (“SPS”)
  - control-data in the same subframe (Reduced latency)



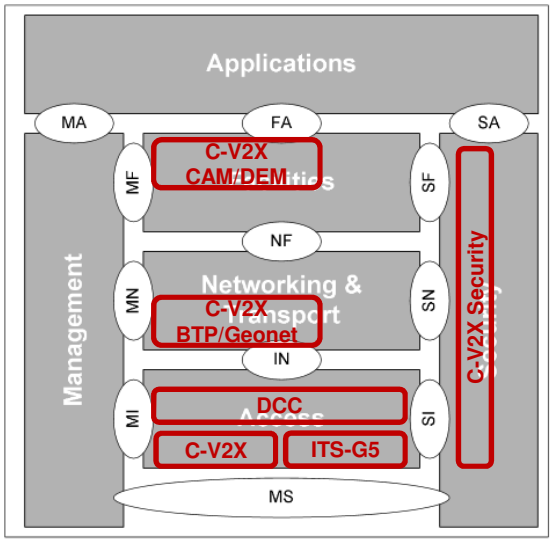




- **LTE V2X mode 4 Resource Allocation**
  - 1s monitoring windows
  - Selection of the 20% RB with lowest RSSI

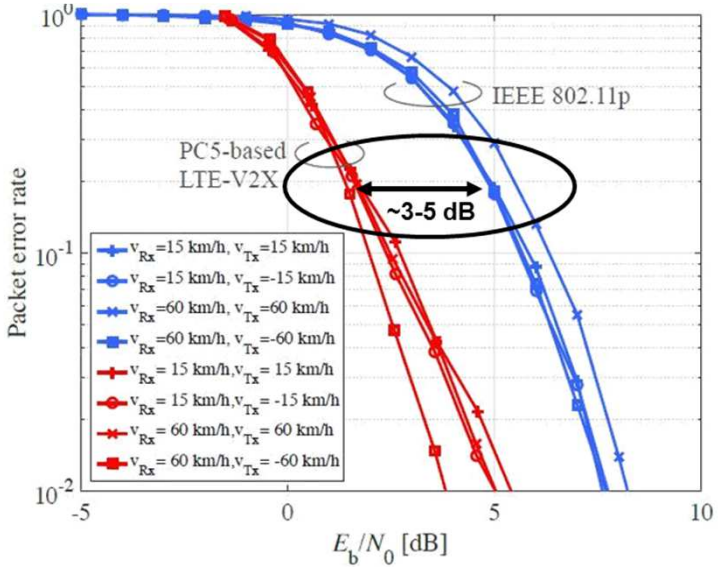
Cellular LTE-V2X – Standardization Status

- **3GPP specification freeze in July 2017**
- **In January 2017, the CAR 2 CAR initiated a WI on LTE-V2X**
  - CAR 2 CAR White Paper – “Technical Evaluation and Open Issues”
- **Objectives:**
  - Introduce new concepts behind LTE-V2X
  - Define common scenarios and parameters
  - Identify required architecture extension
  - Gather open challenges
- **In October 2017, Cellular Stakeholders proposed multiple WI to ETSI ITS for LTE-V2X**
  - C-V2X is expected to be integrated in ETSI ITS in 2018
  - Access Technology -
    - LTE-V2X mode 3-4 rel.14 on PC5 for V2V
    - LTE-V2X on Uu for V2I/V2N communication

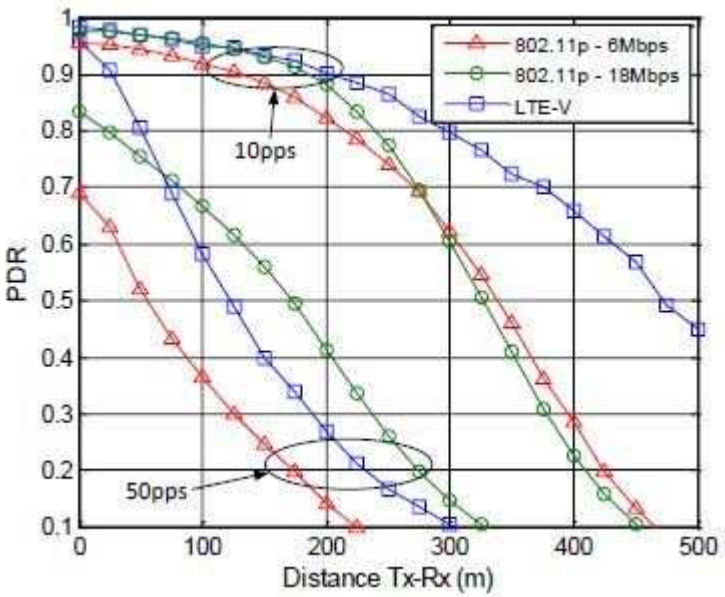


LTE-V2X vs. ITS-G5 – Comparison

- **Link-level vs. Packet-level Comparisons**



Source: J. Kenney et al., ITS-World Congress 2016

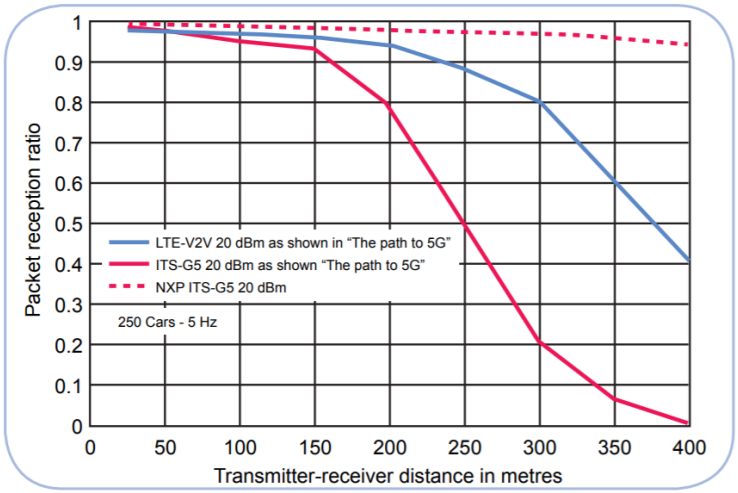


Source: R. M. Masegosa, J. Gozalvez, "LTE-V for Sidelink 5G V2X Vehicular Communications", IEEE Vehicular Technology Magazine, Dec. 2017

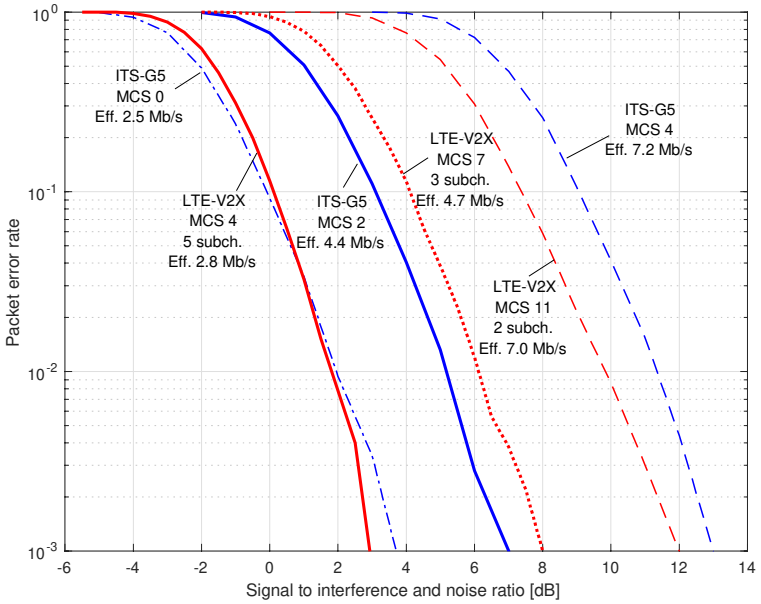
Disclaimer: **Not meant** to **advocate one technology over another**, but rather to **emphasize** the **complexity** of their **comparison** and true performance

LTE V2X vs. ITS-G5 – Comparison

- **Need to compare an apple with an apple**
  - ITS-G5 is not only IEEE 802.11p (a.k.a 'old' technology)
    - Industry-grade products include improved channel tracking
  - When comparing state-of-art ITS-G5 and LTE V2X, their respective performance becomes similar.



Source: A. Turley, K. Moeman, A. Filippi, V. Martinez, C-ITS: Three observations on LTE-V2X and ETSI ITS-G5—A comparison, NXP White Paper



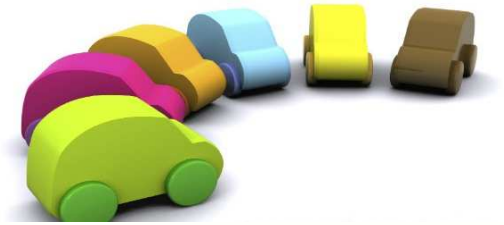
Source: A Bazzi, et al. , Co-channel Coexistence: Let ITS-G5 and Sidelink C-V2X Make Peace, 2020

A leading institution at the heart of the digital society

EURECOM
Sophia Antipolis

Time for a Break…

Meet again in 15 minutes



vs.

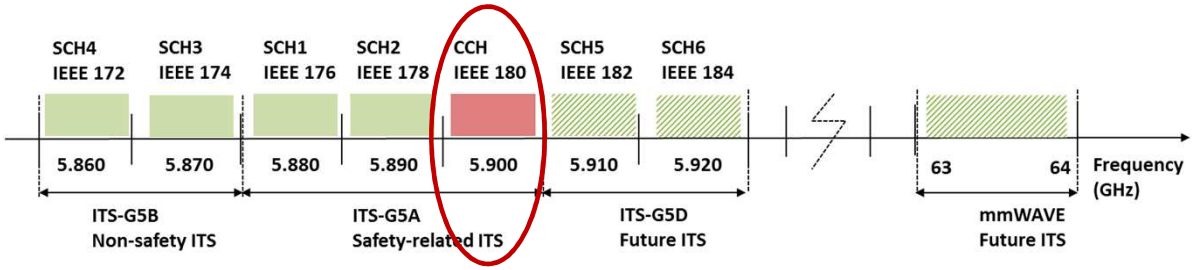
Cti
Commission des Titres d'Ingénieur

Part IV

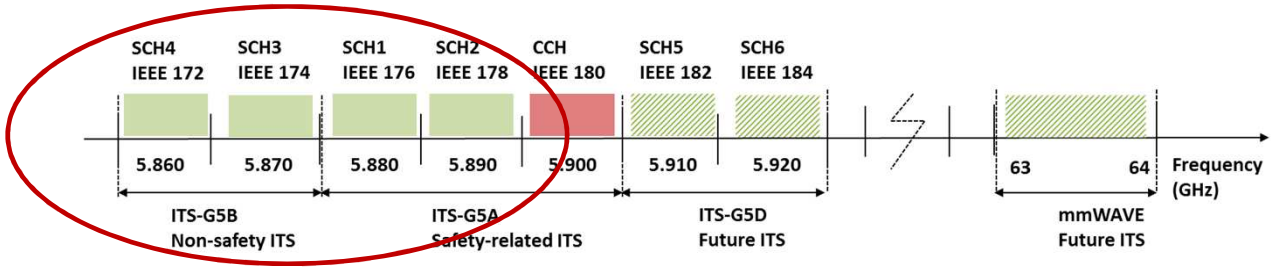
COEXISTENCE AND REGULATIONS

Coexistence with ITS-G5 – Spectrum issue..

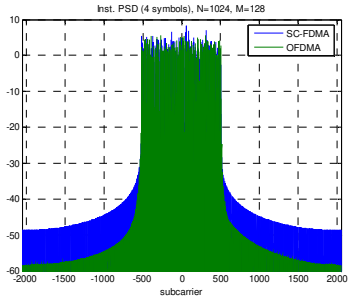
- **EU imposes a Technology Neutrality approach to ITS-G5 spectrum**
  - Both ITS-G5 and LTE-V2X can use ITS-G5-A spectrum if safety-related



  - Also increasing interest from WiFi (IEEE 802.11ac/ax) on the lower ITS-G5 band
  - …and LTE-U, resp. NR-U for Private 5G networks



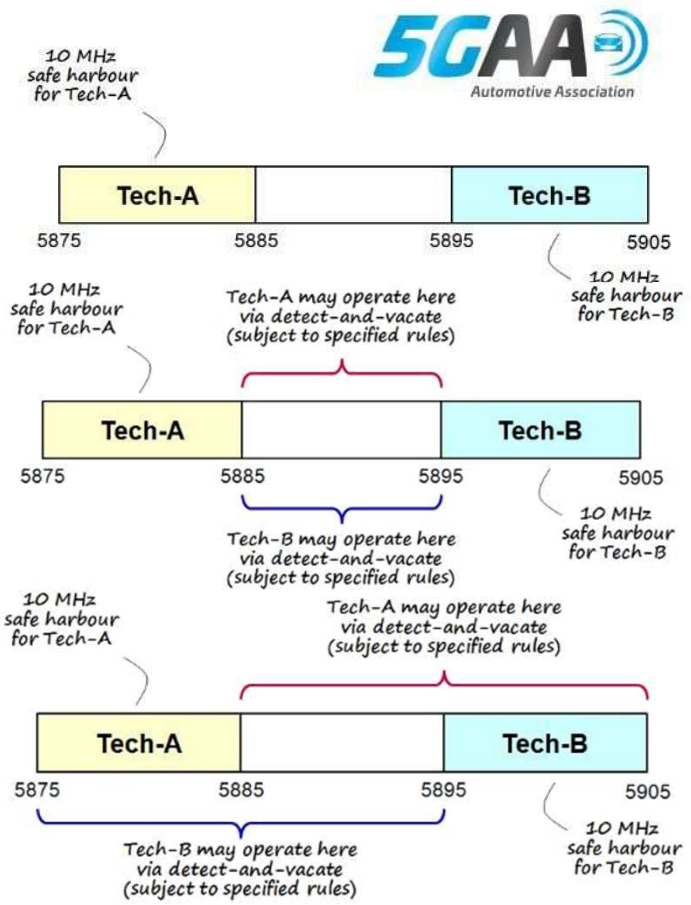
Coexistence ITS-G5 – LTE-V2X



- **Based on the technology neutrality of the ITS-G5 band**
  - Both ITS-G5 and LTE-V2X can be granted access

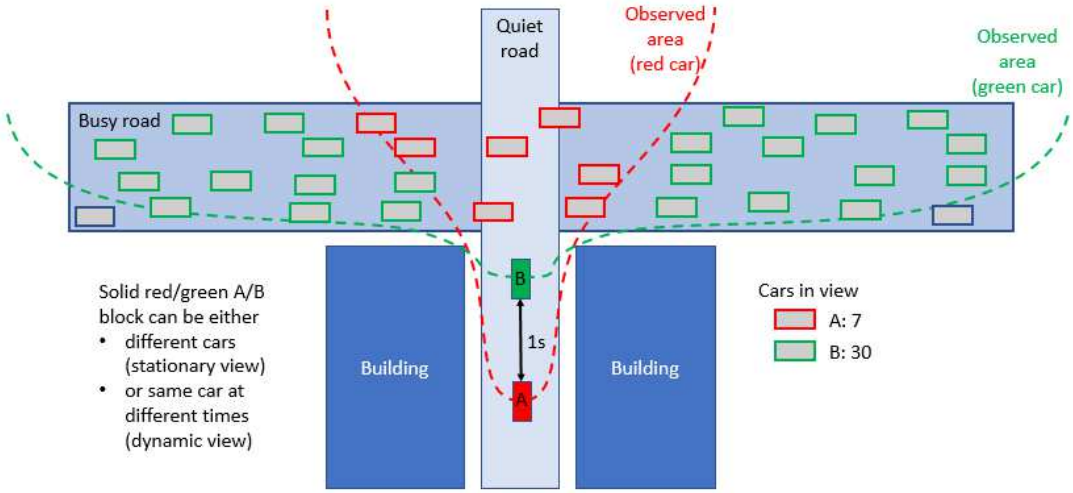
- **Three phases coexistence:**
  - Phase 1 – LTE-V2X and ITS-G5 on different 10Mhz isolated bands
  - Phase 2 – LTE-V2X and ITS-G5 may coexist on additional shared band based on 'detect and avoid'
  - Phase 3 – LTE-V2X and ITS-G5 coexist on the full ITS-G5 band based on the detect and avoid mechanism

source:



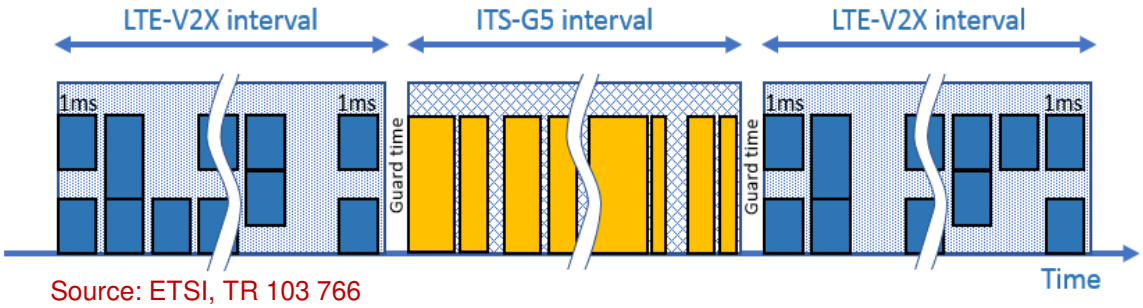
Coexistence ITS-G5 – LTE-V2X – Problem Statement

- **Typical Use Case**



Source: ETSI, TR 103 766

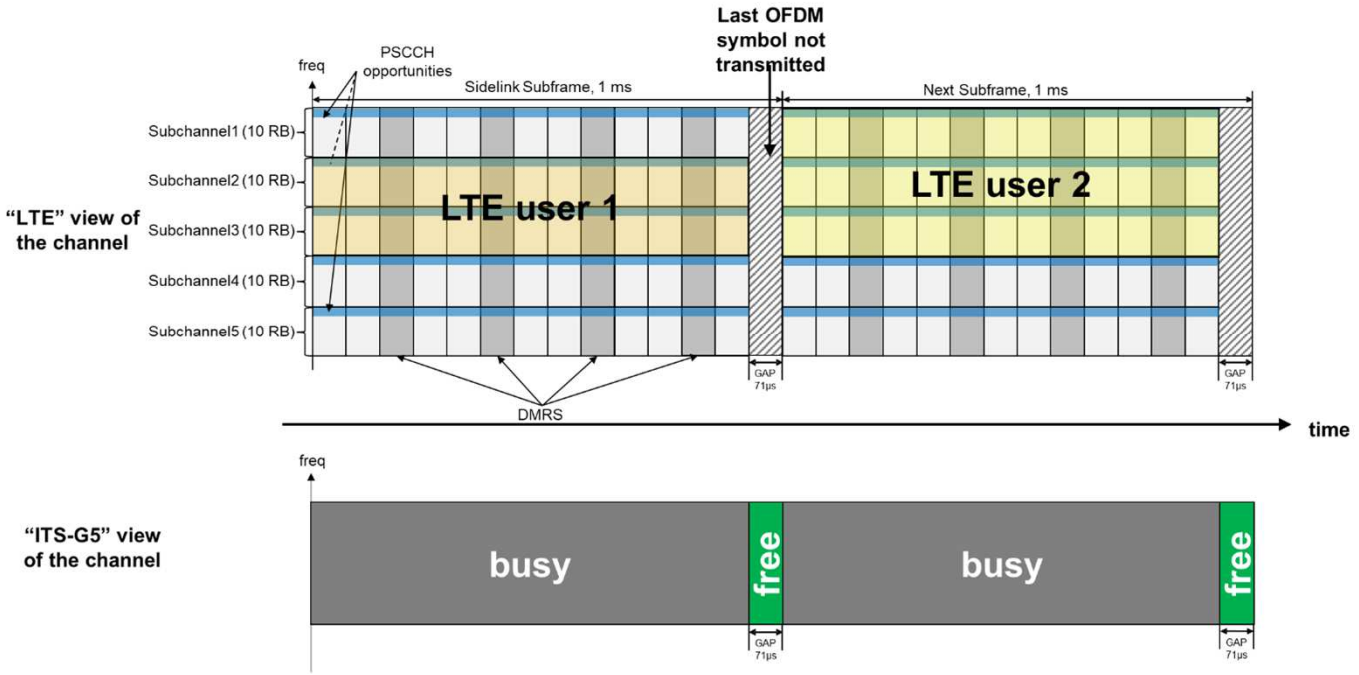
- **Potential Coexistence in Time Domain**



Source: ETSI, TR 103 766

Coexistence ITS-G5 – LTE-V2X – Problem Statement

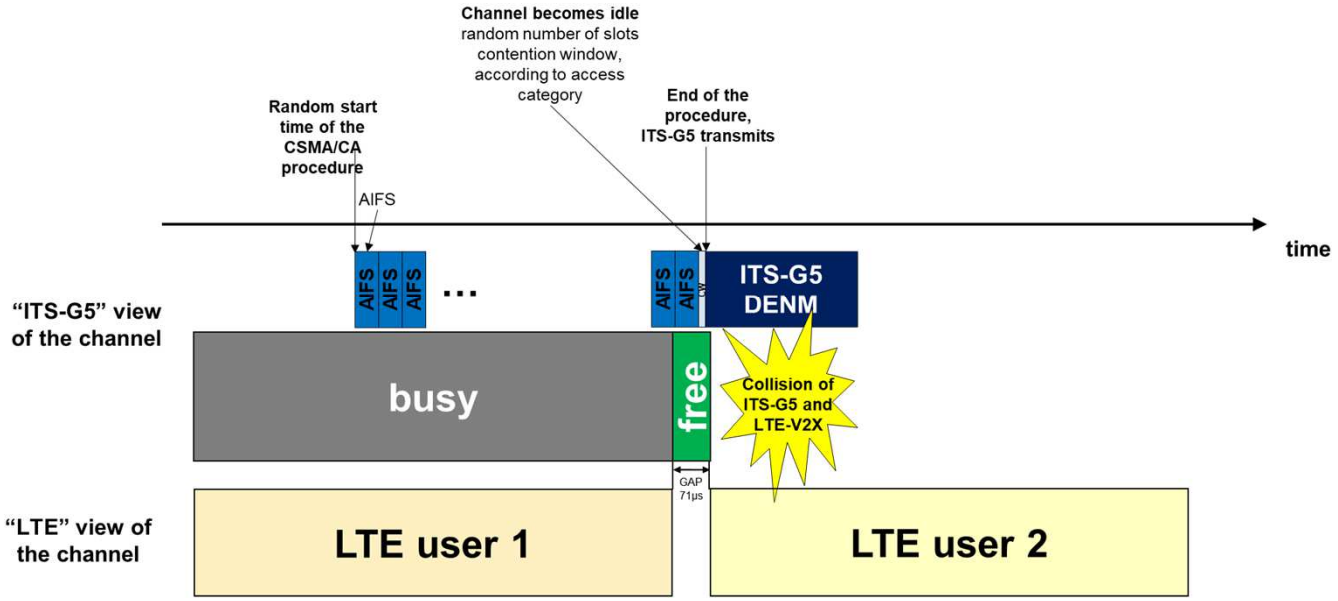
- **The last symbol gap problem**



Source: ETSI, TR 103 766

Coexistence ITS-G5 – LTE-V2X – Problem Statement

- **The last symbol gap problem**



Source: ETSI, TR 103 766

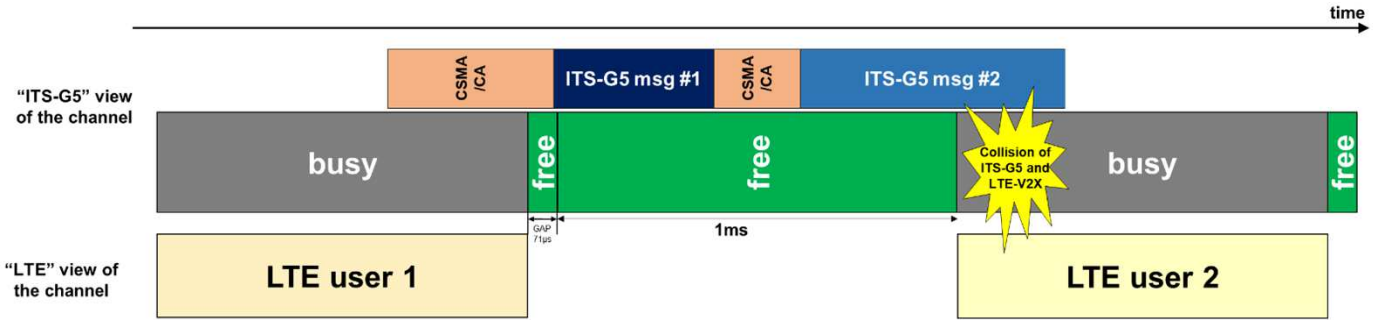
- **Reminder: ITS-G5 EDCA values**

AC	CW_{min}	CW_{max}	*AIFS*	Intended use
AC_VO	3	7	58 µs	High priority DENM
AC_VI	7	15	71 µs	DENM
AC_BE	15	1 023	110 µs	CAM
AC_BK	15	1 023	149 µs	others

Coexistence ITS-G5 – LTE-V2X – Problem Statement

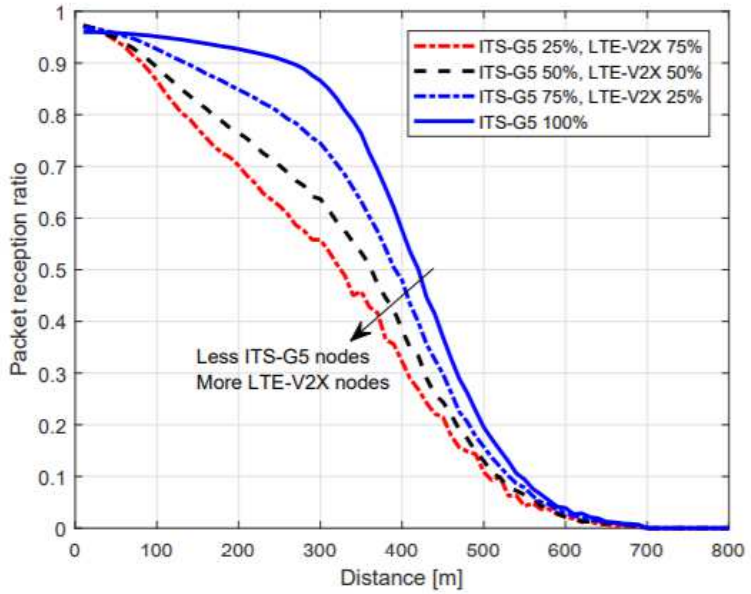
- **The last symbol gap problem**

AC	*CW*	*AIFS**	Possible duration of the inner state machine*	Gap problem occurrence chances*
AC_VO	3	***58 µs***	[***0,1***,2,3] CW = [***0, 13 µs***, 26 µs, 39 µs]	***50%*** (2 chances out of 4)
AC_VI	7	***71 µs***	[***0***,1,2…7] CW = [***0***, 13 µs, 26 µs…]	***12.5%*** (1 chance out of 8)
AC_BE	15	110 µs	n/a	n/a
AC_BK	15	149 µs	n/a	n/a
*the numbers in bold and italic are the values for which the last symbol gap problem can occur				

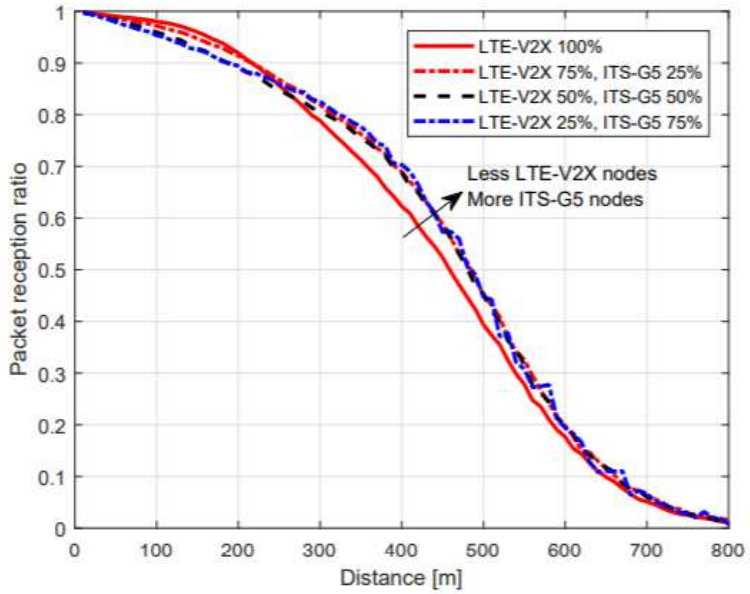


Source: ETSI, TR 103 766

Coexistence ITS-G5 – LTE-V2X – Evaluation..



(a) ITS-G5.

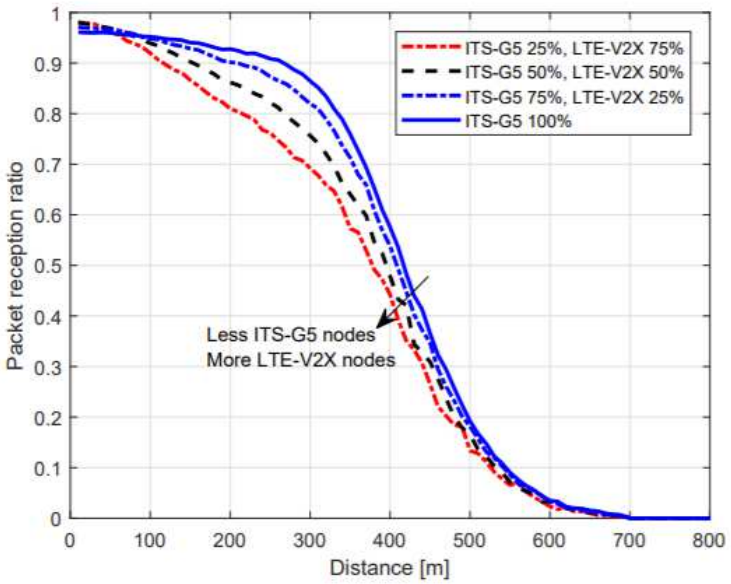


(b) LTE-V2X.

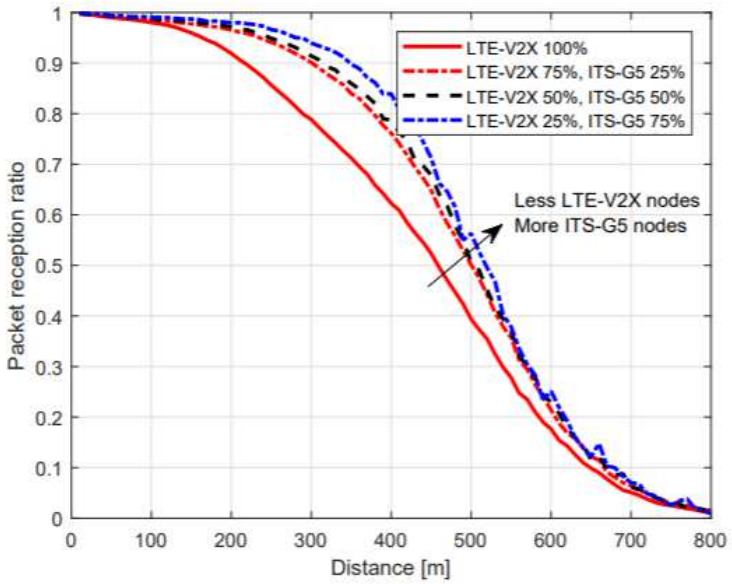
Source: A Bazzi, et al. , Co-channel Coexistence: Let ITS-G5 and Sidelink C-V2X Make Peace, 2020

- **Scenario:**
  - Dense Highway; Normal CAM trigger
- **Observations:**
  - The maximum distance of ITS-G5 to achieve PER above 0.9 is reduced by 50% when 50% of vehicles adopt LTE-V2X.
  - No major impact on LTE V2X from ITS-G5

Coexistence ITS-G5 – LTE-V2X – Evaluation..



(a) ITS-G5.



(b) LTE-V2X.

Source: A Bazzi, et al. , Co-channel Coexistence: Let ITS-G5 and Sidelink C-V2X Make Peace, 2020

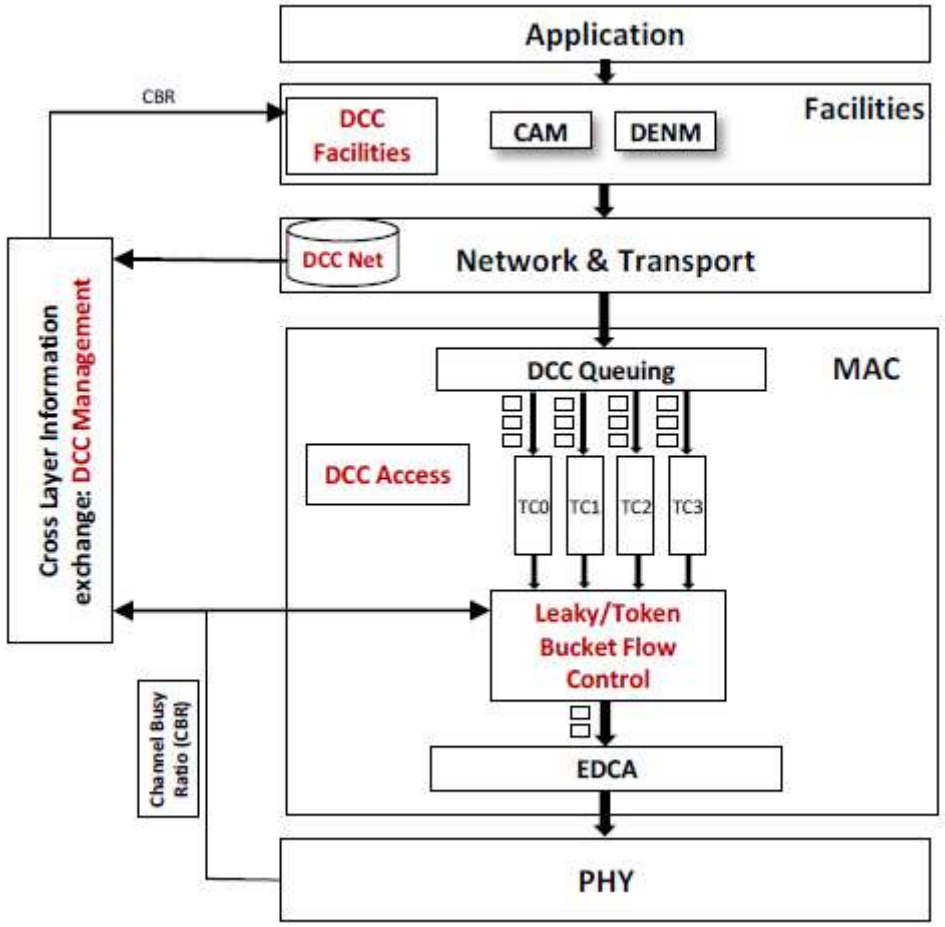
- **Scenario:**
  - Dense Highway; Periodic CAM Tx (more favorable to SPS)
- **Observations:**
  - Impact of LTE V2X on ITS-G5 is reduced; and conversely.
  - Problem: not standard compliant (but Q'com compliant)

Part V

CHALLENGES – COMMUNICATION CONGESTION CONTROL

ETSI Decentralized Congestion Control

- **List of Standards**
  - DCC Access:
    - ETSI TS 102687
  - DCC Net:
    - ETSI TS 102 636-4-2
  - DCC Fac:
    - ETSI TS 103 141
  - DCC Mgnt:
    - ETSI TS 103 175
  - Harmonized Standard:
    - EN 302 663

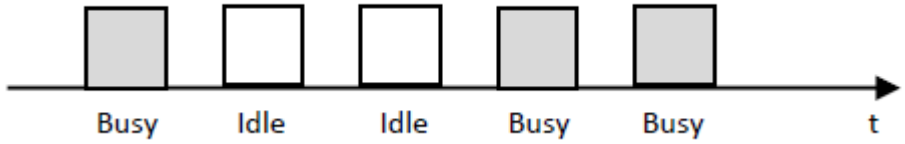


Source: I. Khan, EURECOM

Channel Condition Monitoring: ITS-G5

- **Channel Load Calculation**

$$BR_{measured} = \frac{Samples_{busy}}{Samples_{per_{cycle}}}$$



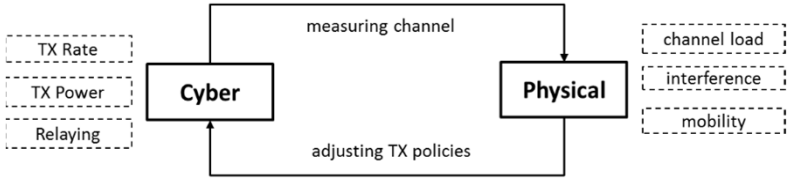
Source: I. Khan, EURECOM

- **Channel Load Filtering**

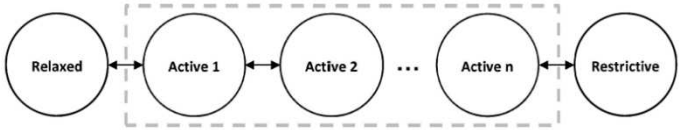
$$CBR_t = a * CBR_{measured} + b * CBR_{t-1}$$

Communication Congestion Control – Transmit Rate Control

- **Cyber-Physical Approach**



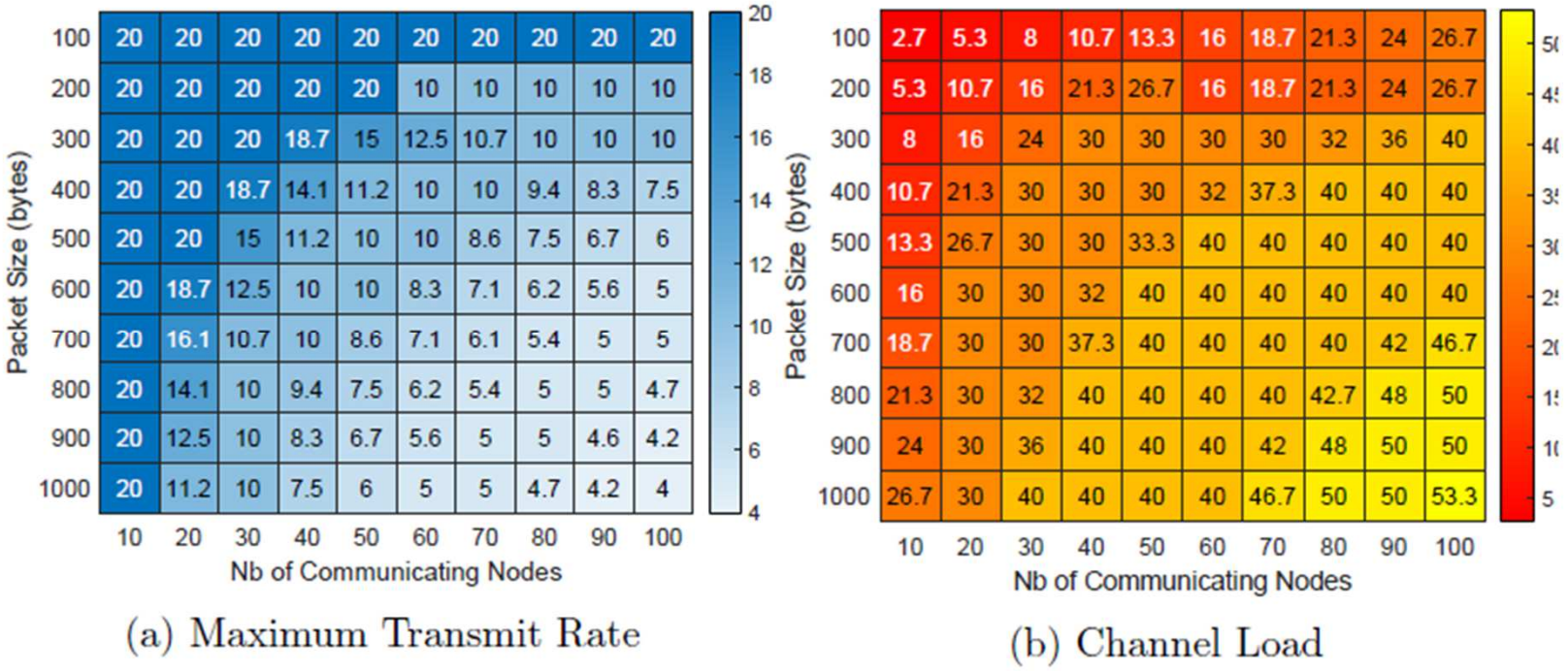
- **State-based Strategy**



- **Table Lookup**

State	CBR	Packet rate (packet airtime 500 µs)	Toff (airtime 500 µs)	Packet rate (packet airtime 1000 µs)	Toff (airtime 1000 µs)
Relaxed	<30 %	20 Hz	50 ms	10 Hz	100 ms
Active 1	30 % to 39 %	10 Hz	100 ms	5 Hz	200 ms
Active 2	40 % to 49 %	5 Hz	200 ms	2,5 Hz	400 ms
Active 3	50 % to 65 %	4 Hz	250 ms	2 Hz	500 ms
Restrictive	>65 %	1 Hz	1 000 ms	1 Hz	1 000 ms

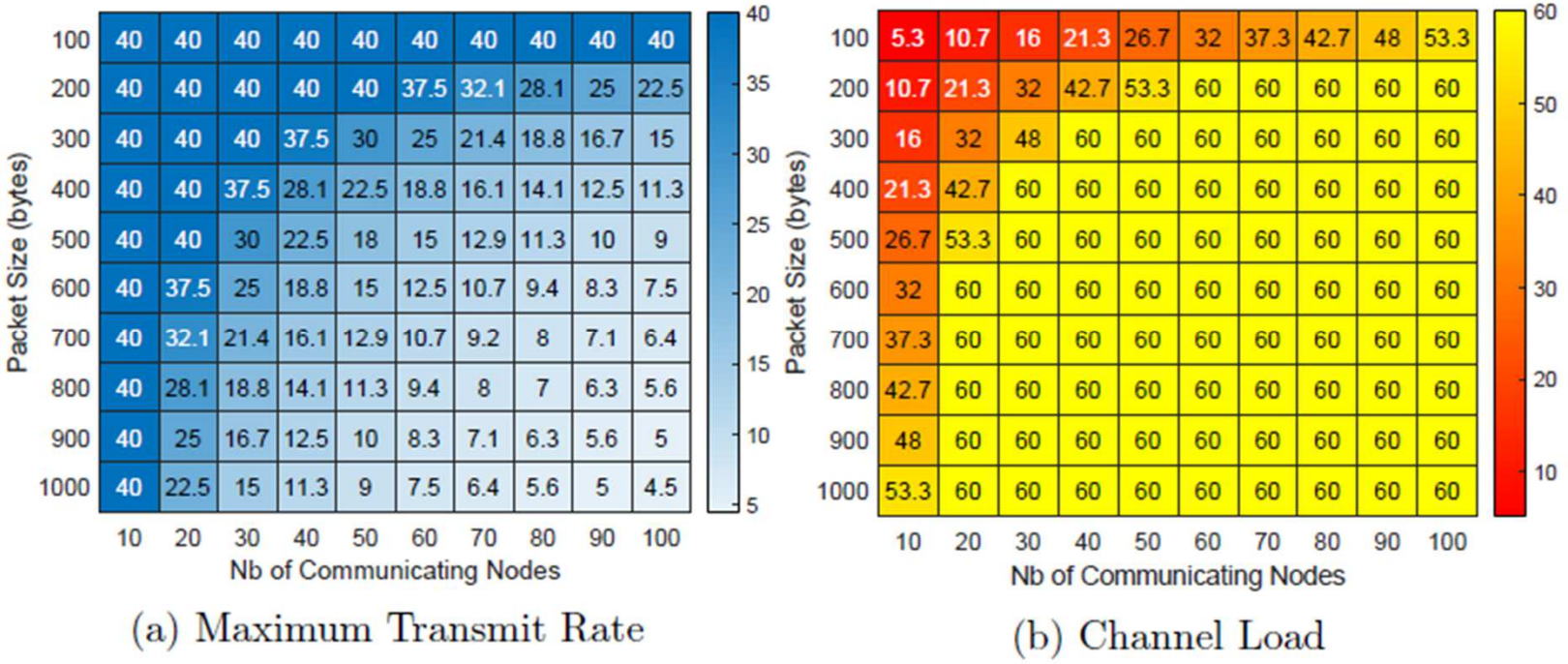
Communication Congestion Control – Efficient Channel Usage



Source: I. Khan, **Multi-Service Resource Orchestration for Vehicular Safety Communications**, EURECOM, 2019

- **Example: 30 vehicles**
  - Generated Channel load: 30%, so 70% channel unused
    - But DCC limits the Tx Rate to 15Hz…

Communication Congestion Control – Efficient Channel Usage



Source: I. Khan, **Multi-Service Resource Orchestration for Vehicular Safety Communications**, EURECOM, 2019

- **A different approach: Optimal Channel Limit**
  - Fixe a target Channel Usage Limit: e.g. 60%
  - Allows Transmit Rate until this limit is reached
  - Benefit: 30 nodes: 30Hz (2x better)

Part VI

FUTURE V2X - IEEE 802.11BD

ITS-G5 Release 2 – Design Directions

- **In November 2016, the CAR 2 CAR initiated a WI on ITS-G5 Rel. 2**
  - CAR 2 CAR white paper – "Enhanced 11p Investigations and Proposal"
- **Design directions:**
  - Enhanced channel usage (modulation, congestion control)
  - Enhanced information exchange (Tx what is 'required')
  - Enhanced PHY & MAC
  - Enhanced Capacity
    - mmWAVE bands
- **Input currently under discussions at the CAR 2 CAR**
  - Objectives:
    - > 5dB gain at 5GHz
    - 10x capacity at 60Hz

802.11 for Next Generation V2X Communication

- **IEEE 802.11 new Study Item created on March 9th 2018**
  - Following the proposal from the CAR 2 CAR
  - Take the state-of-art IEEE 802.11 technology (IEEE 802.11ac)
    - Turn it half-clock (10Mhz)
    - Add minor 'magic'

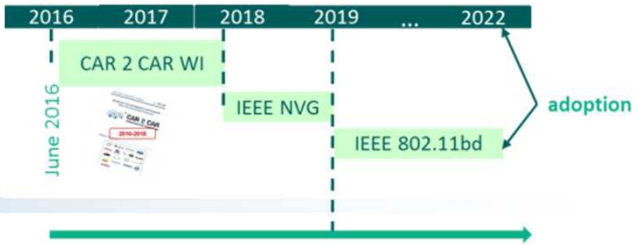
Disclaimer: **All current** C-ITS applications can be handled by **ITS-G5**. This **new SI** is to match the **future** 5G-V2X for next **Generation C-ITS**

  - Potential Innovations:
    - Advanced Channel Estimation
    - LDPC codes
    - Space-Time Block Codes (STBC)
    - Higher Modulation & Capacity
    - Multi-Channel managements

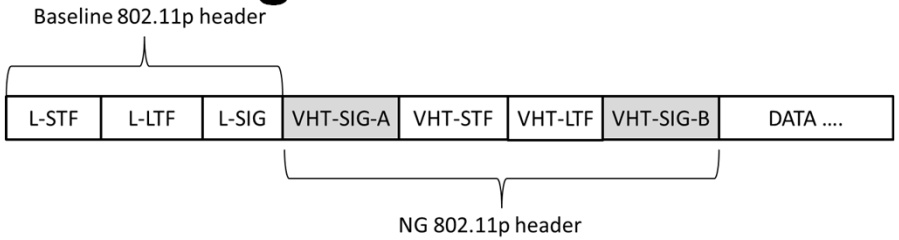
Features	IEEE 802.11p	IEEE 802.11bd	Benefit from 802.11bd
Modulation	BPSK, QPSK, 16-QAM, 64-QAM	BPSK, QPSK, 16-QAM, 64-QAM, 256 QUAM	33% increased throughput
Data subcarriers	48	48+52	8% increased capacity
MIMO	None	2xMIMO	2x higher capacity
Bandwidth	10Mhz	10Mhz & 20Mhz	Improved sensitivity
Spectrum	5.9GHz	5.9GHz & 60GHz	New application & increased capacity
Channel Coding	BCC	LDPC	3db lower sensitivity = range extension
Adaptive Re-Transmission	None	1-3 retransmission (as function of CBR)	Range extension/ higher reliability
Channel Tracking	Proprietary	Proprietary & midamble	Lower complexity receiver
Sub-carrier spacing	156.25kHz	312.5kHz, 156.25kHz, 78.125 kHz	Higher flexibility
MIMO	None	2xMIMO	2x higher capacity

  - Release: rather fast, probably end 2022

WiFi V2X - IEEE 802.11bd

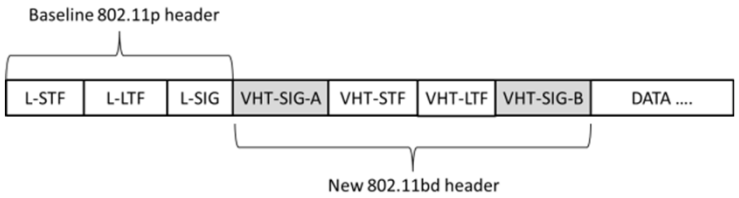


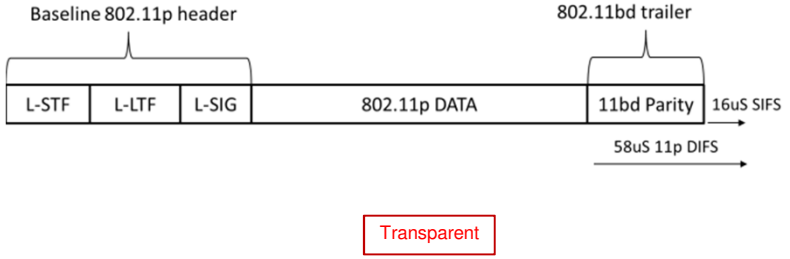
- **Frame Structuring…**



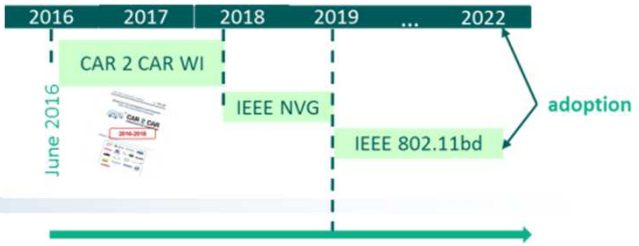
- **Midamble approach**

- **Coexistence**

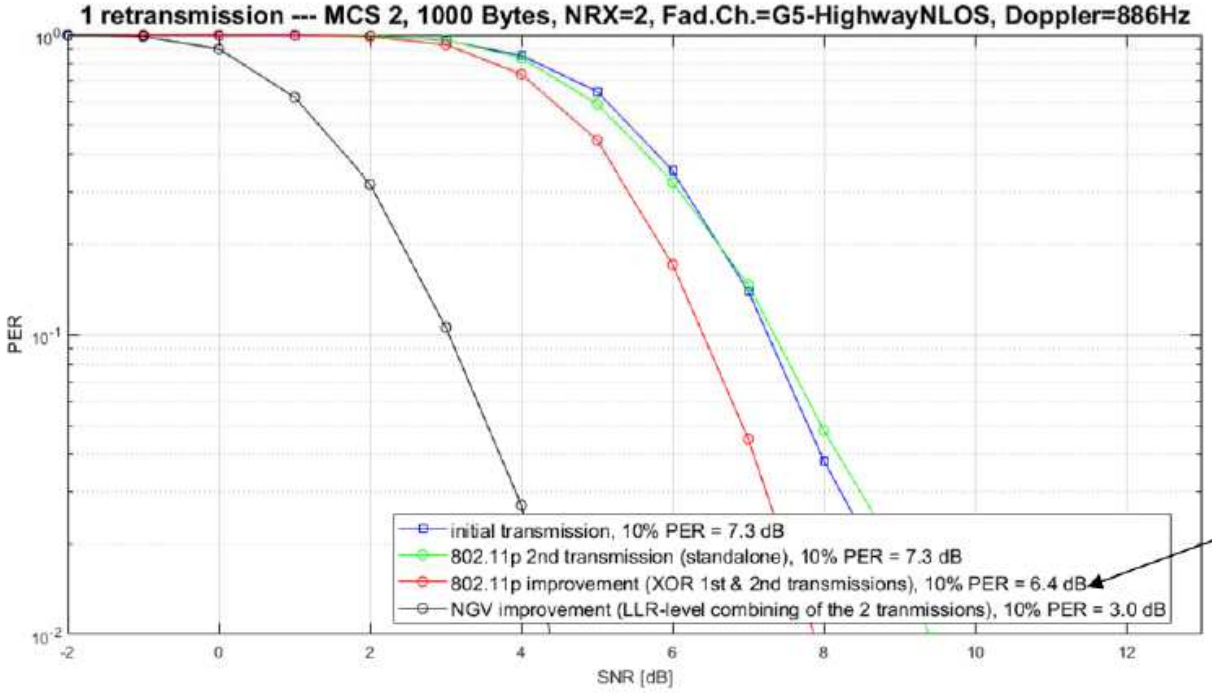




WiFi V2X - IEEE 802.11bd



- **Link Level Performance Evaluation…**



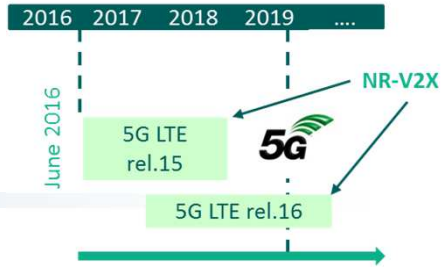
Source: IEEE 802.11bd – Fischer, Philippi, Martinez, NXP

Should be understood as « Boolean OR of the CRC-pass results », we take the best of the 2 tries:
- trans#1 FAIL + trans#2 FAIL = FAIL
- trans#1 FAIL + trans#2 PASS = PASS
- trans#1 PASS + trans#2 FAIL = PASS
- trans#1 PASS + trans#2 PASS = PASS

Part VII

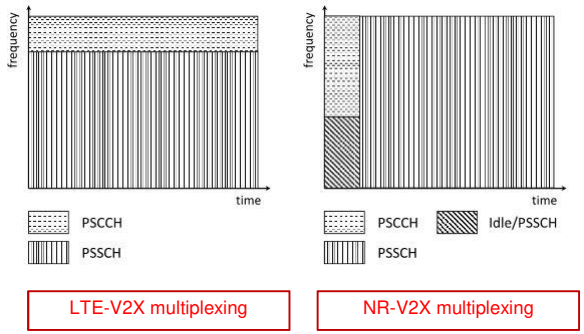
FUTURE V2X – NR V2X

3GPP V2X - NR V2X

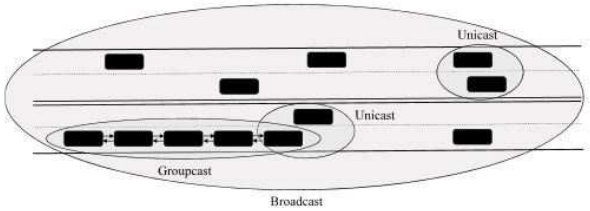


- **New Radio V2X**
  - 5G-V2X Rel. 15 and up..
  - Provide additional capacity for V2X use cases <u>not supported by LTE-V2X</u>

- **New Channel Multiplexing**
  - Time rather than frequency multiplexing between control and data channels



- **New Communication Types:**
  - Unicast
  - Groupcast

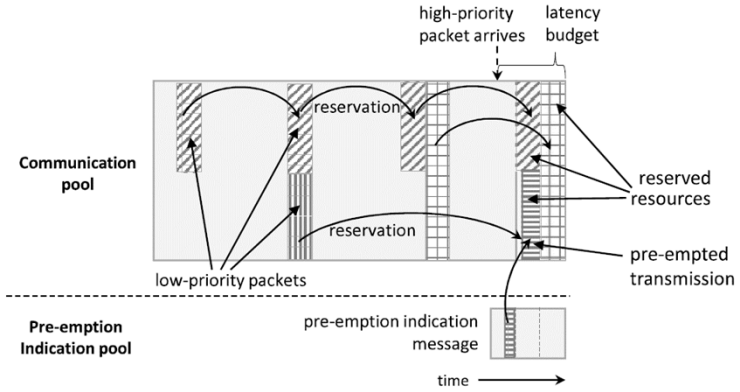


- **New Channel:**
  - Physical Feedback Channel (PSFCH)
    - Provides feedback on groupcast reception

- **New Numerology:**
  - NR-V2X mode 1 – Network Assisted
  - NR-V2X mode 2(a/d) – Ad-hoc (CH assist)

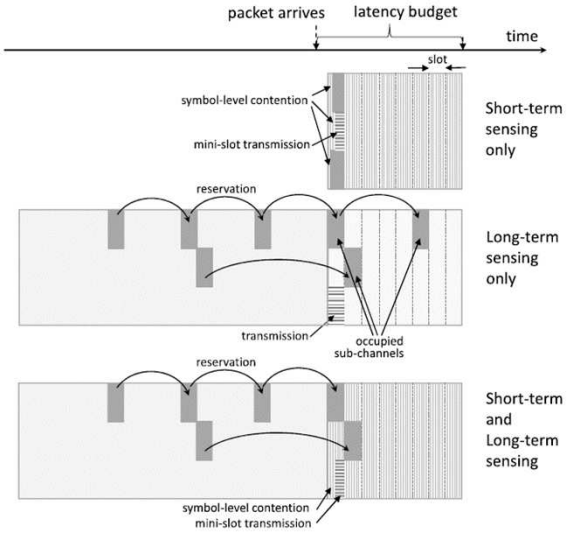
3GPP V2X - NR V2X

- **New Preemption Strategy…**



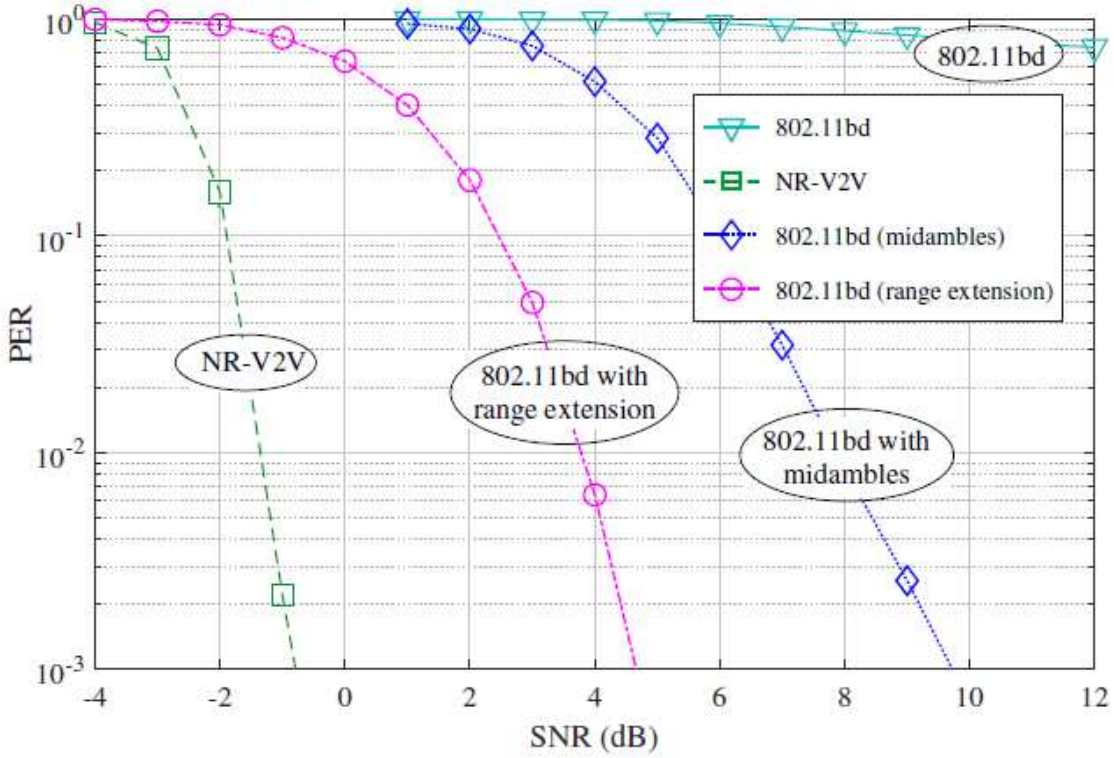
Source: Naik et al., IEEE 802.11bd & 5G NR V2X: Evolution of Radio Access Technologies for V2X Communications

- **Mini-Slots Approach…**



3GPP V2X - NR V2X – Performance Evaluations

- **Link Level Performance Evaluation…**

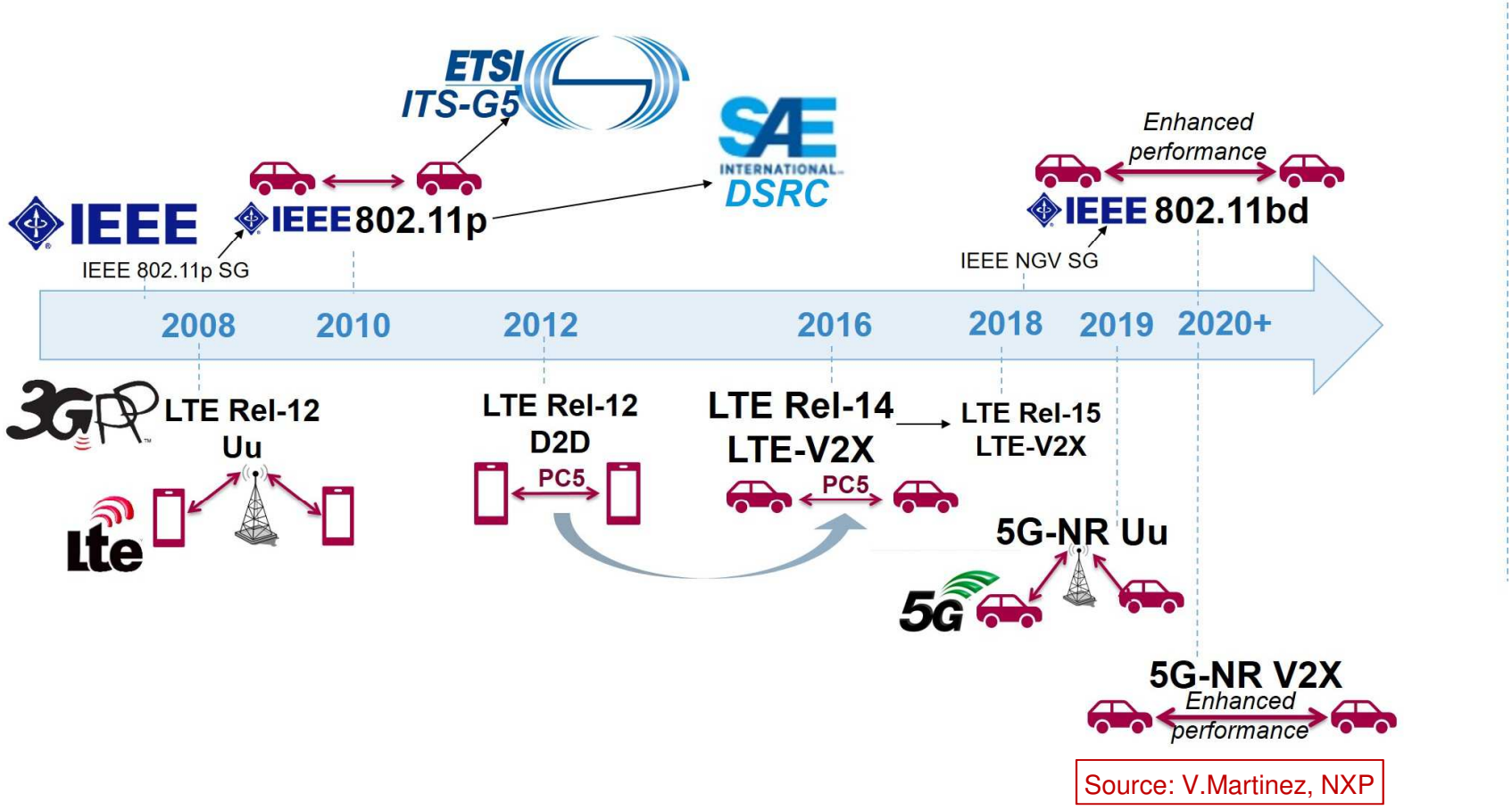


Source: Anwar et al., On the Reliability of NR-V2X and IEEE 802.11bd

Part VIII

DISCUSSION – ROAD AHEAD AND CHALLENGES

V2X – Roadmap and Timeline



Source: V.Martinez, NXP

European Commission Delegated Regulation

- **What:**
  - EU-Wide delegated regulation for new connected vehicles
  - Supplementing: Directive 2010/40/EU
- **Purpose:**
  - Deployment and operational use of cooperative intelligent transport systems (C-ITS)
- **When:**
  - Adopted by the EC on 13.3.2019
  - Adopted by the EU Parliament a month later
  - Rejected in May 2019 by the EU states
- **In a Nutshell**
  - Day One C-ITS Applications
    - C-ROADs & CAR 2 CAR Use Cases
  - Day One C-ITS Technology
    - Hybrid Approach: ITS-G5 V2V / LTE V2N
  - Day One Coexistence (toll systems)
  - EU Budget for Market Introduction…


EUROPEAN COMMISSION

Brussels, 13.3.2019
C(2019) 1789 final

COMMISSION DELEGATED REGULATION (EU) .../...

of 13.3.2019

supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to the deployment and operational use of cooperative intelligent transport systems

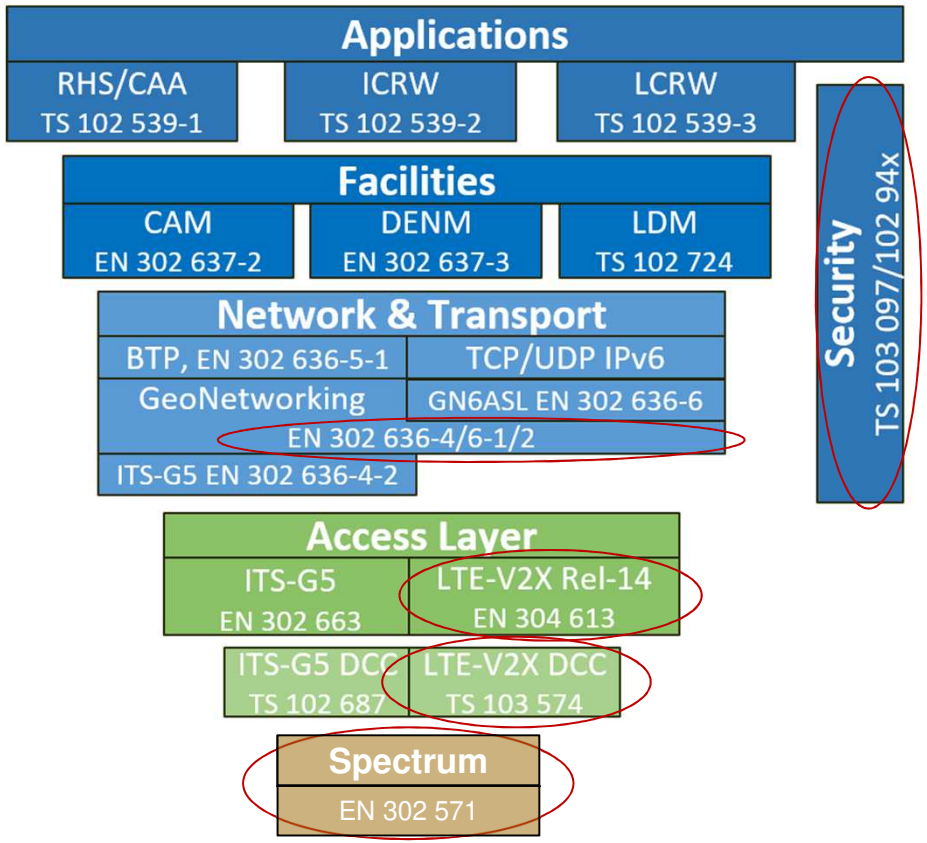
(Text with EEA relevance)

{SEC(2019) 100 final} - {SWD(2019) 95 final} - {SWD(2019) 96 final}

Rejected May 2019

V2X Standardization Status at ETSI ITS

- **ETSI ITS Stack**



- **Modified/New standards**
  - EN 302 636-4 – Geonetworking
  - EN 304 613 – LTE-V2X Access Layer
  - TS 103 574 – DCC for LTE-V2X
  - TS 102 94x – Security for LTE-V2X
  - EN 302 571 – ITS Spectrum

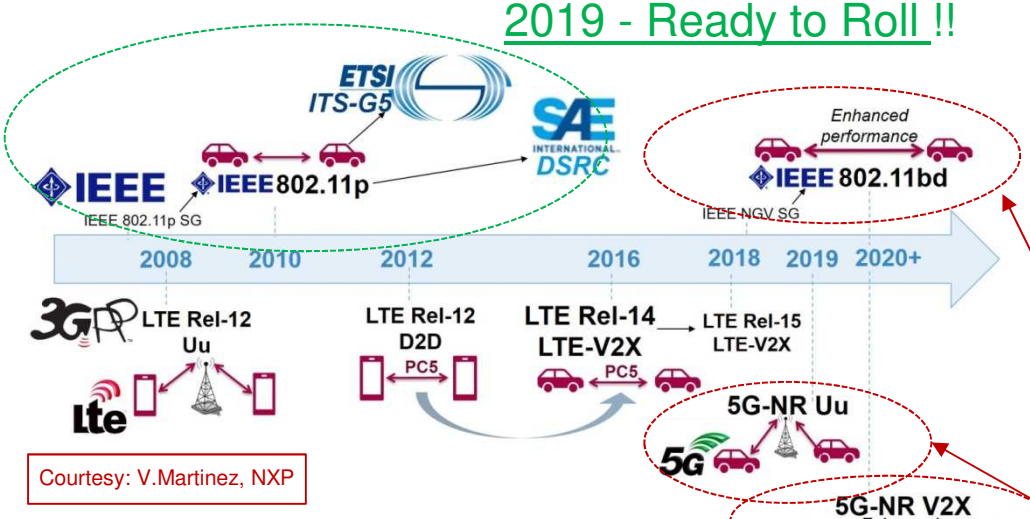
Disclaimer: LTE V2X cannot be used in EU before the updated ETSI standards are approved !!

So…what's next ??

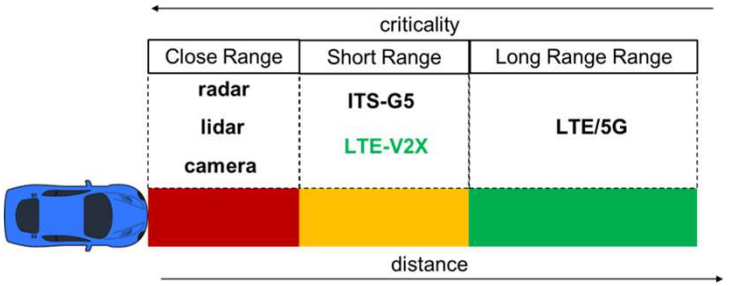
- **Back to Square One !!**
  - …well, not completely..
- **Roadmap for V2X communications**
  - ETSI Standards for multi-technology: completed
  - ETSI first interoperability: successful
  - Latest results of ITS-G5 vs. LTE V2X: comparable results
  - Coexistence studies: progressing…
- **Real Challenge now is…corporate decision**
  - Should LTE V2X be actually deployed?
    - No forward compatibility – cars will need to update their V2X devices to get NR V2X
    - NR V2X first prototype – most likely 2022…
- **Next (current) Challenges:**
  - 3GPP Rel. 17 – brand new world !!
    - Multi-hop Cellular Ad-Hoc Networks
    - Wireless Time Sensitive Networking (TSN) (i.e. deterministic networks)

Back to the Future: V2X Roadmap and Timeline

V2X for Connected Vehicles:
2019 - Ready to Roll !!



Courtesy: V.Martinez, NXP



Two technologies are an advantage:
can provide redundancy and be more resilient to failure and attacks !!

Het-V2X for Connected Automated Vehicles:
The Future is bright !!

Jérôme Härri, EURECOM, haerri@eurecom.fr

ETSI ITS Innovative Work Items

TR 102 638	BSA Release 2 (incorporation of the new services)
TS 102 890-2 (EN 302 890-2)	Facility Position and Time
TS 103 141	Facility Communication Congestion Control
TR 103 298	Platooning pre-standardisation study
TR 103 299	C-ACC pre-standardisation study
TR 103 300-1	VRU pre-standardisation study
TS 103 300-2	VRU Architecture
TS 103 300-3	VRU Service
TR 103 562	Informative Report Collective Perception
TS 103 324	Collective Perception Service
TS 103 561	Maneuver Coordination Service
TR 103 579	Charging/Tolling applications via ITS-G5 pre-standardisation study
TR 103 439	Multi Channel Operation study

LTE V2X - List of Standards (all Rel. 14)

- ***V2X***
  - TS 36 300 - Evolved Universal Terrestrial Radio Access Network (E-UTRAN)
  - TS 36.101 - User Equipment (UE) radio transmission and reception
  - TS 23.285 - Architecture enhancements for V2X services
  - TS 22.185 - Service requirements for V2X services;
  - TS 22.186 - Enhancement of 3GPP support for V2X scenarios;
  - TS 24.386 - User Equipment (UE) to V2X control function; protocol aspects
- ***RRC signaling***
  - *TS 36.331 – E-UTRA Radio Resource Control (RRC);Protocol specification*
- ***PDCP Procedures***
  - *TS 36.323 – E-UTRA Packet Data Convergence Protocol (PDCP) specification*
- ***MAC layer Procedures***
  - *TS 36.321 – E-UTRA* Medium Access Control (MAC) protocol specification
- ***Physical Layer Procedures***
  - *TS 36.211 – E-UTRA Physical Channels and Modulations*
  - *TS 36.212 - E-UTRA Multiplexing and channel coding*
  - *TS 36.213 – E-UTRA* Physical layer procedures
  - *TS 36.214 – E-UTRA Physical Layer - measurements*

Selected Reference Papers

- A. Turley, K. Moeman, A. Filippi, V. Martinez, **C-ITS: Three observations on LTE-V2X, and ETSI ITS-G5—A comparison**, NXP White Paper, 2019.
- ETSI, TR 103 766 V0.0.9, **Co-channel co-existence between ITS-G5 and LTE-V2X**, 2020
- ETSI, TR 103 667 V0.0.4, **Study on Spectrum Sharing between ITS-G5 and LTE-V2X technologies in the 5 855 MHz-5 925 MHz band**, 2020
- K. Moerman, **Next Generation Vehicular Networks: IEEE 802.11b**, ETSI Workshop, 2019.
- R. M. Masegosa, J. Gozalvez, **LTE-V for Sidelink 5G V2X Vehicular Communications**, IEEE Vehicular Technology Magazine, Dec. 2017
- A. Bazzi, A. Zanella, I. Sarris, V. Martinez, **Co-channel Coexistence: Let ITS-G5 and Sidelink C-V2X Make Peace**, Arxiv: **https://arxiv.org/abs/2003.09510,** 2020
- G. Naik, B. Choudhury, J-M Park, **IEEE 802.11bd & 5G NR V2X: Evolution of Radio Access Technologies for V2X Communications**, IEEE Access, Vol. 7, 2020.
- W. Anwar, N, Franchi, G. Fettweis, A. Trassl, **On the Reliability of NR-V2X and IEEE 802.11bd**., in Proc. of IEEE PIMRC, 2019.
- W. Anwar, N, Franchi, G. Fettweis, A. Trassl, **Physical Layer Evaluation of V2X Communications Technologies: 5G NR-V2X, LTE-V2X, IEEE 802.11bd, and IEEE 802.11p**, in proc. of the IEEE 90th Vehicular Technology Conference (VTC2019-Fall), 2019.
- A. Bazzi , G. Cecchini , M. Menarini, B. M. Masini and A. Zanella, **Survey and Perspectives of Vehicular Wi-Fi versus Sidelink Cellular-V2X in the 5G Era**, Future Internet 11(6):122 · May 2019.
- I. Khan, **Multi-service resource orchestration for vehicular safety communications**, PhD Thesis, EURECOM, 2019.