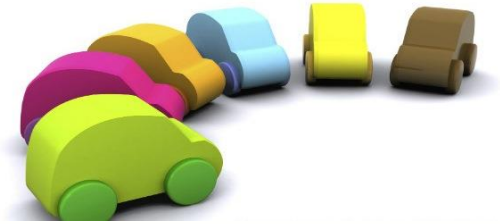
A leading institution at the heart of the digital society

EURECOM
Sophia Antipolis

V2X Communications for CCAM – Statuts and Future Trends and Challenges

Prof. Jérôme Härri, EURECOM

March 26th 2021

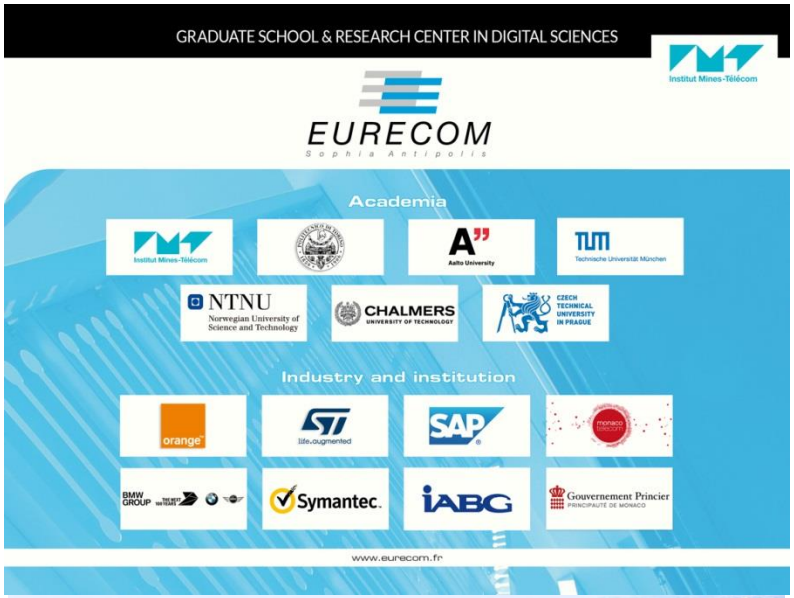


vs.

Cti
Commission des Titres d'Ingénieur

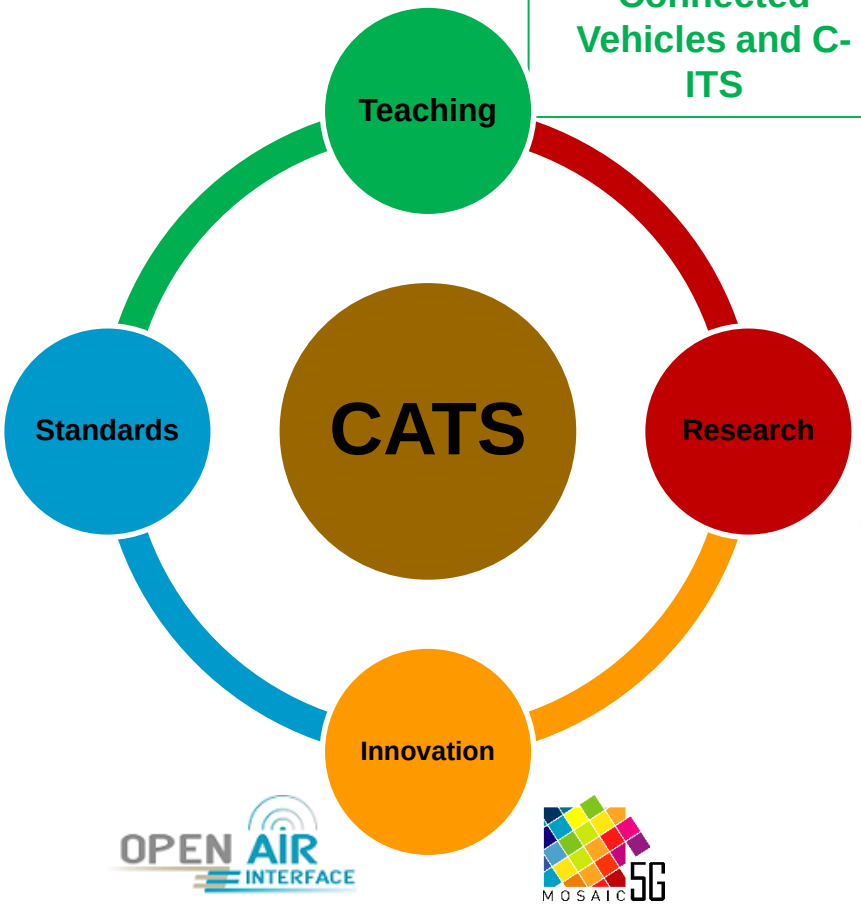
What is EURECOM ?

- **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



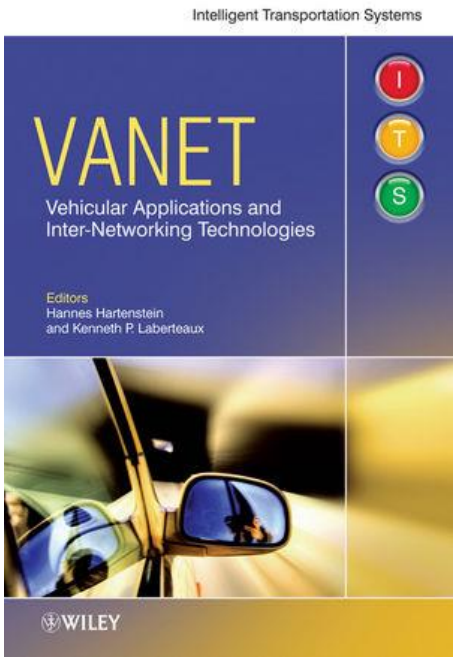
Cooperative Connected Automated Transport Systems (CATS)

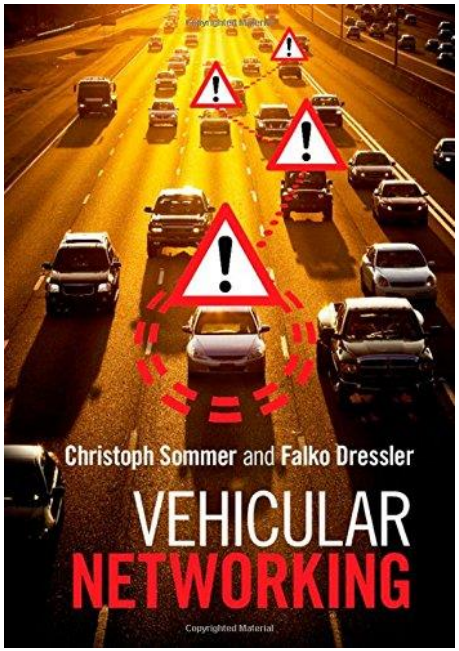
Postgraduate Cursus on **Connected Vehicles and C-ITS**

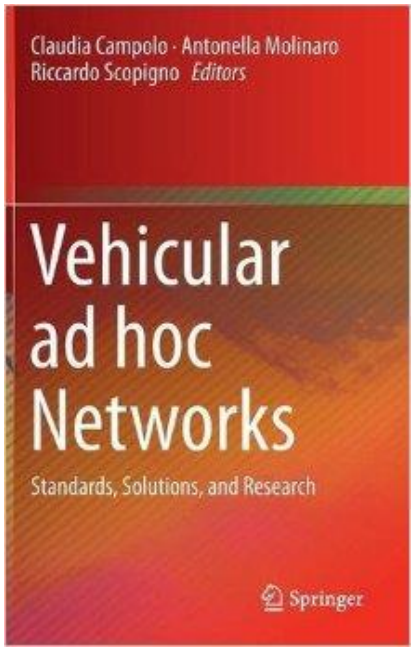


Related Books and References

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

C2C-CC (2001)

CarTalk (2001-2004)

SeVeCom (2006-2008)

ETSI ITS (2009)

Drive (2011-2014)

Chauffeur I and II (1996-2003)

PreVent/WILL WARN (2005-2008)

Coopers/CVIS/SAFESPOT (2006-2010)

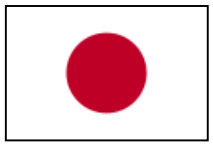
CoCAR I and II (2007-2011)

FleetNet (2000-2003)

NoW (2004-2007)

PreDrive (2008-2010)

SIM-TD (2008-2012)



ASV I (1991-1995)

ASV II (1996-2000)

ASV III (2001-2005)

ASV VI (2006-2010)

PATH (1986)

IVI (1998-2004)

VII / IntelliDrive (2004-2009)

V2V Decision (2013)

DSRC (1999)

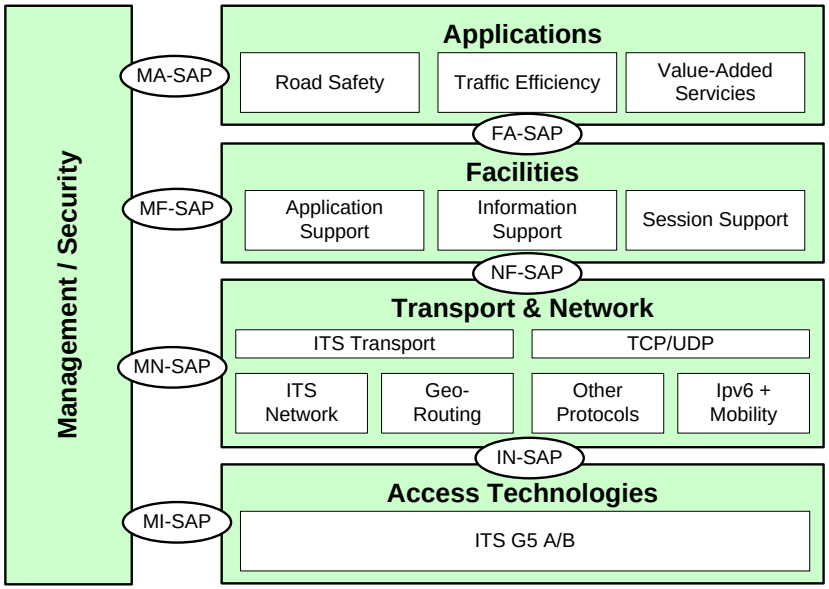
WAVE (2004)

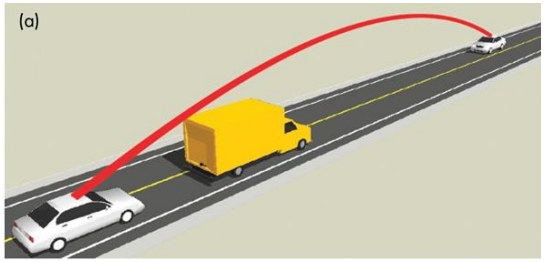
ITS Strategic Research Plan, (2010-2014)

[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**

EURECOM

V2X Communication - DAY 2
Objective: Highly Autonomous Driving

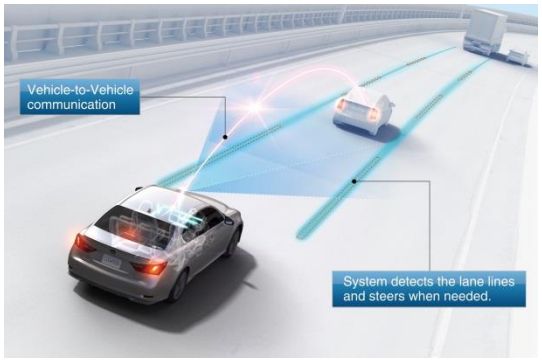
- **Not such a new idea**

- **A very marketized idea**

Source: google

- **…yet a very ambitious idea**

Source: US Peloton



Source: toyota

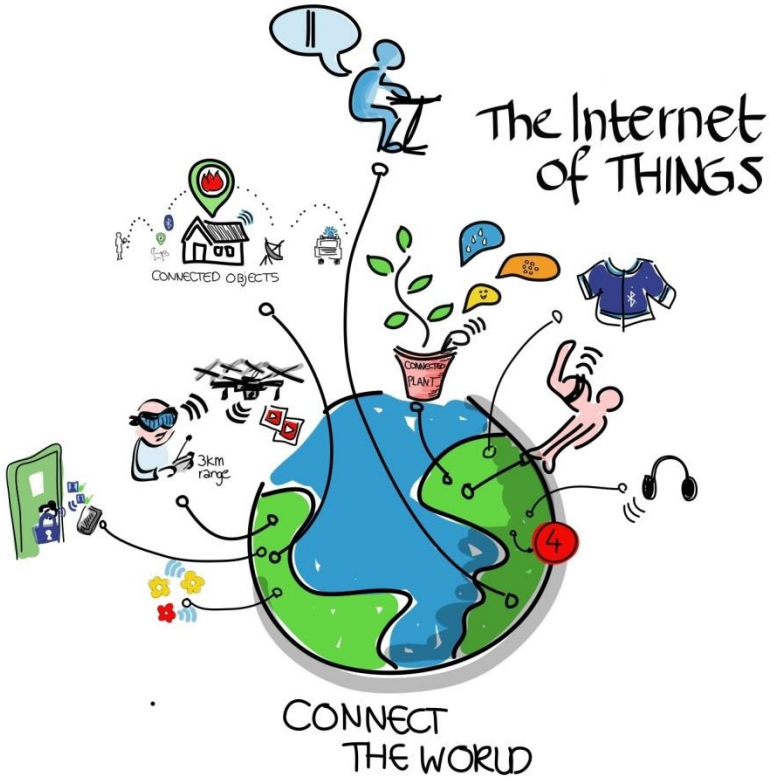
EURECOM
Sophia Antipolis

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)**

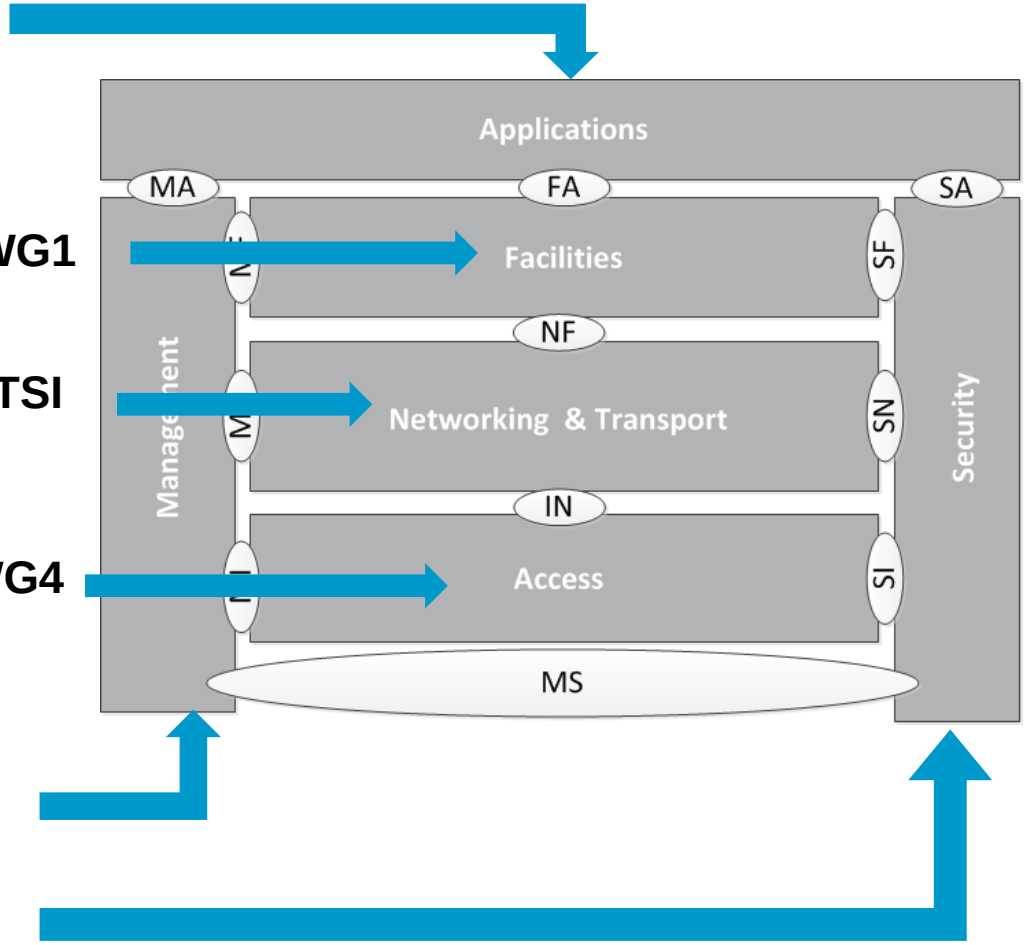


Part II

OVERVIEW OF KEY ETSI STANDARDS

ETSI Communication Architecture

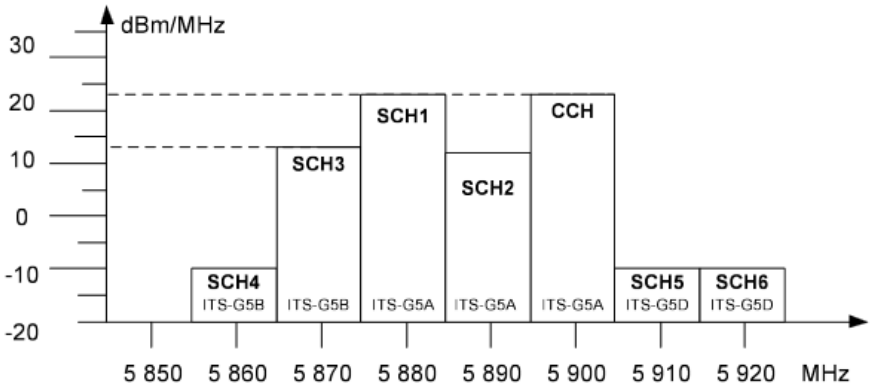
- **Applications are standardized by ETSI TC WG1 & CEN**
- **Facilities is handled by ETSI TC WG1**
- **Network & Transport is done in ETSI TC WG3**
- **Access is specified by ETSI TC WG4**
- **Management & Cross-Layer is handled by ETSI WG 2**
- **Security is specified by ETSI TC WG5**



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

- **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	
SCH1	5890	ITS-G5A - Safety-Related
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…

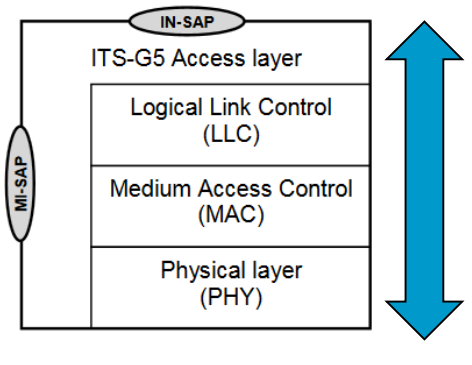
ETSI Profile Standard for ITS-G5 (EN 302 663)

- **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** (TR 102 638, TS 102 637-1)
  - Users & Applications functional requirements
  - Common data dictionary (TS 102 894)

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

- **Longitudinal Collision Risk Warning Specification (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 (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.

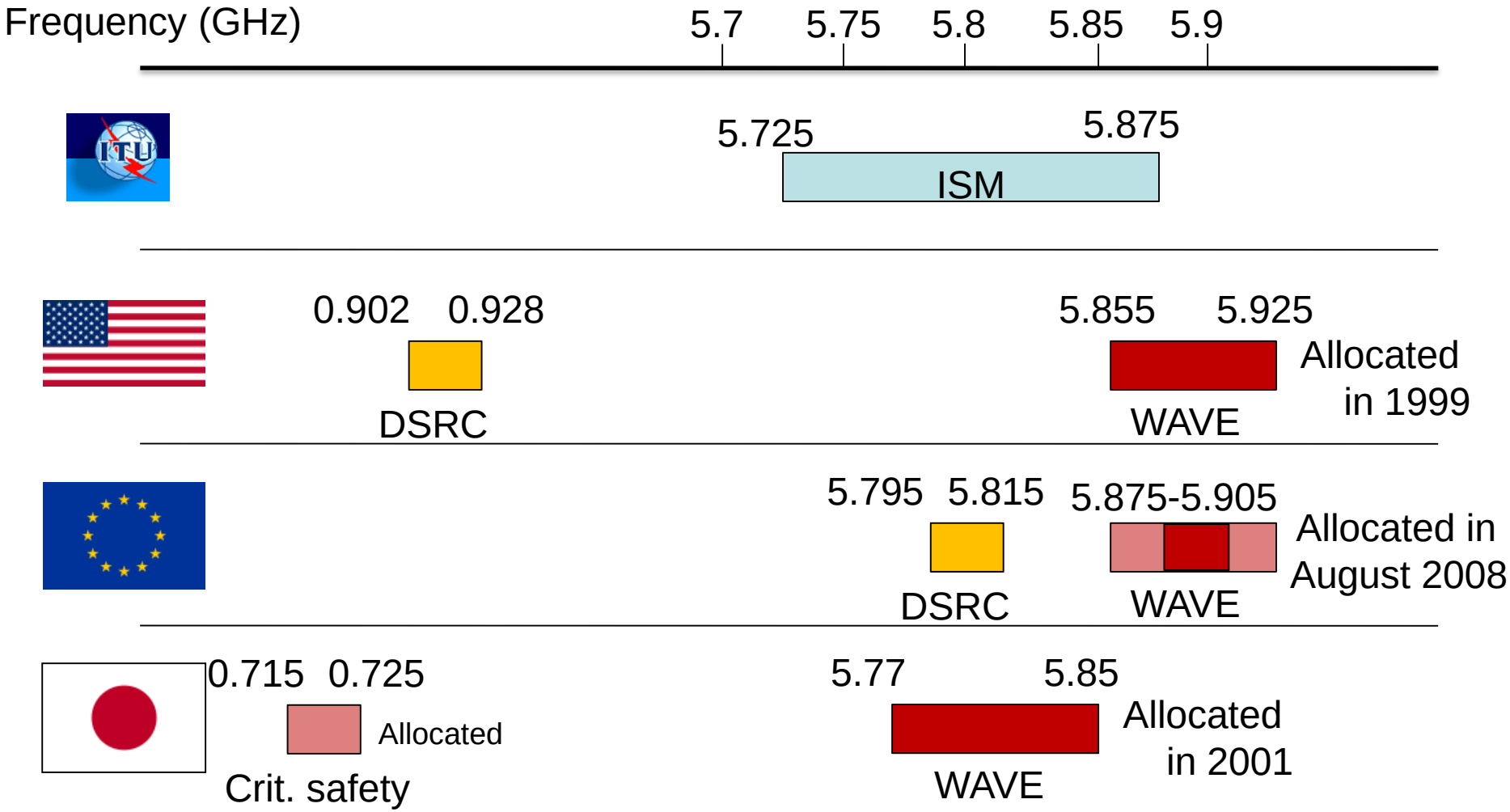
Messages

- **Collective Perception Service (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)
- **Maneuver Coordination Service (TS 103 561)**
  - Interaction protocol and corresponding messages to coordinate maneuvers between two or more vehicles
- **Diagnose, Status and Logging Service (TS 103 693)**
  - Information exchange between ITS-S related to maintenance of ITS-S

Part II

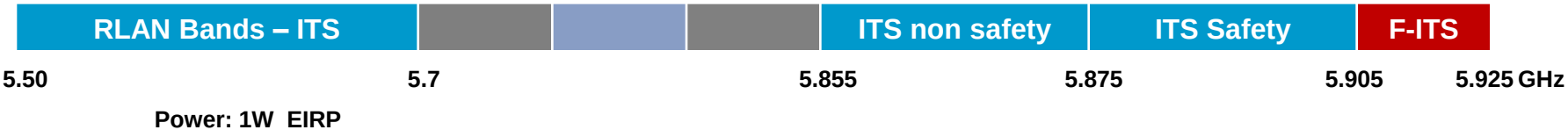
WIFI-BASED V2X COMMUNICATIONS

Frequency Allocation



Three Frequency Bands in 5 GHz Band

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



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

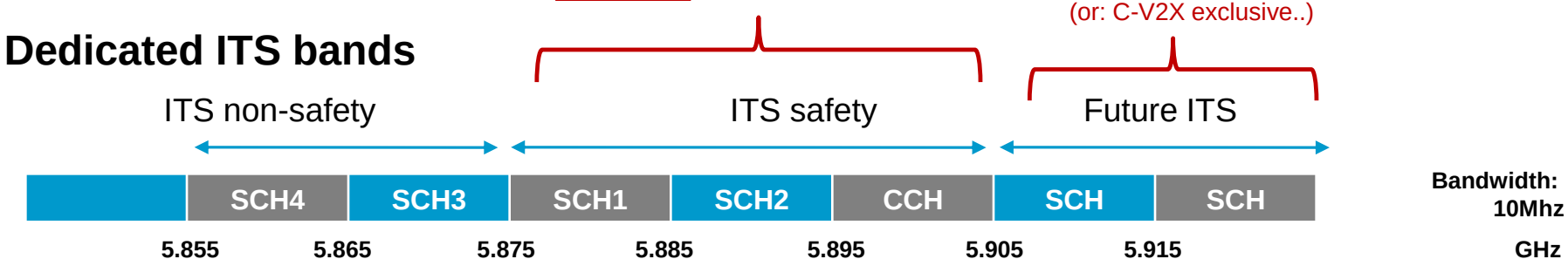
ITS G5 D
Future Usage

EIRP : Effective Isotropic Radiated Power

Dedicated ITS bands

New since 2020: discussions on Coexistence between ITS-G5/C-V2X

New since 2020: Urban Rail (or: C-V2X exclusive..)



Bandwidth: 10Mhz

SCH – ITS Service Channel

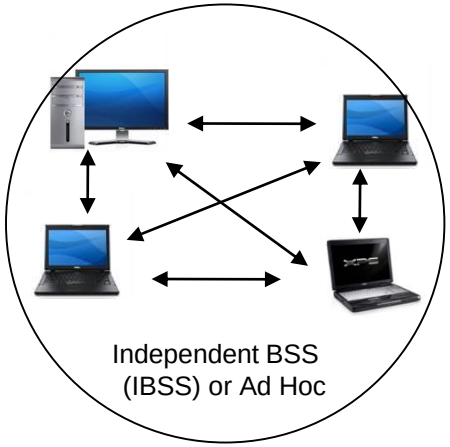
CCH – ITS Control Channel

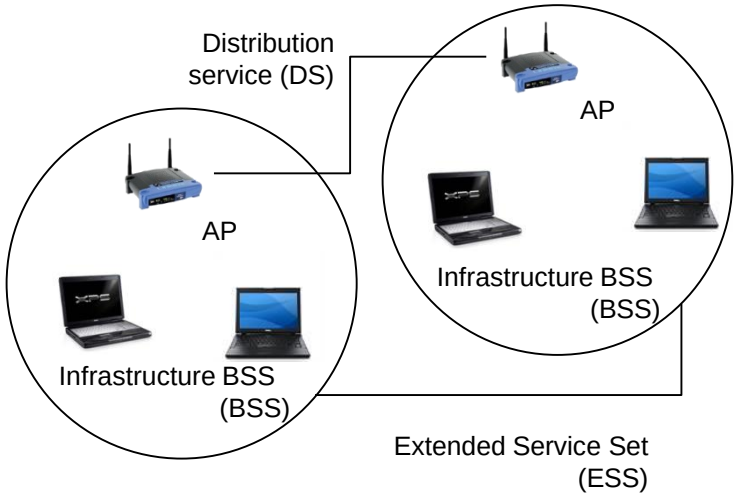
Power: 2W CCH &SCH1; 200MW SCH2 & 3; 1mW SCH4

EURECOM
Sophia Antipolis

Forming a Wireless Network: Architecture

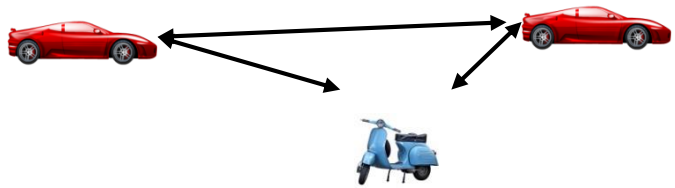
- **Basic Service Set (BSS)**
  - A station must join a BSS and an AP before being allowed to communicate





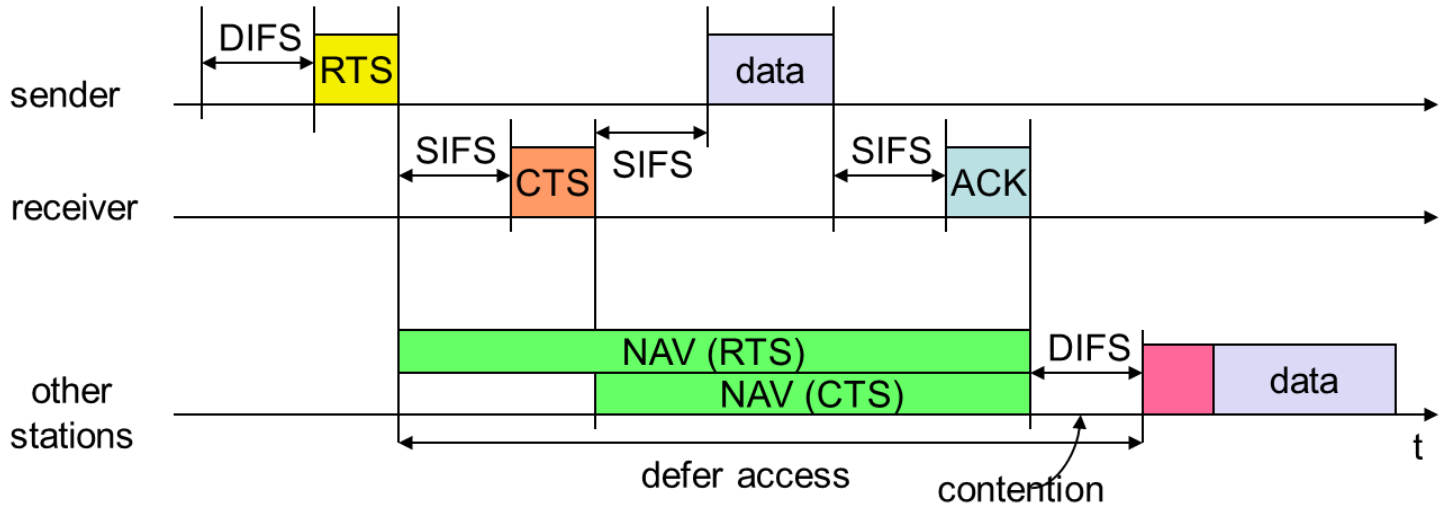
- **Communicating Outside of the Context of a BSS**
  - Vehicular-specific extension of the IEEE 802.11 not requiring a BSS to communicate

Comm. Outside
Context of BSS
(OCB)



IEEE 802.11 Distributed Coordination Function (DCF)

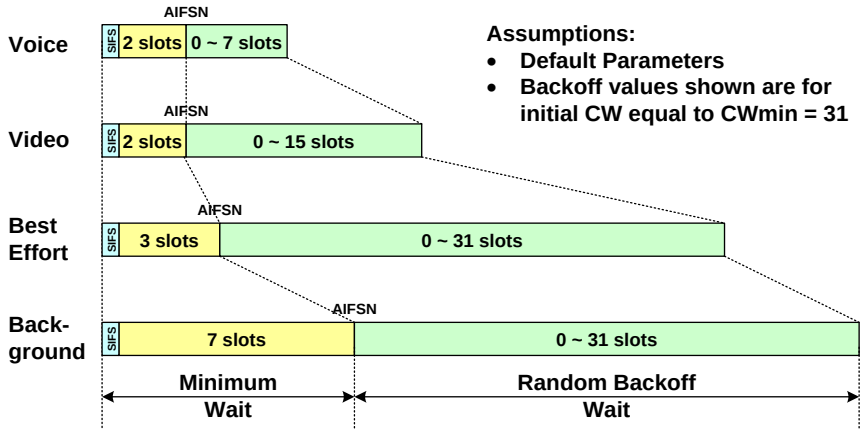
- **Listen before Talk Principle**
  - If medium is free for a DIFS time, station sends data or control packet
  - receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)
  - automatic retransmission of data packets in case of transmission errors
- **Contention-based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



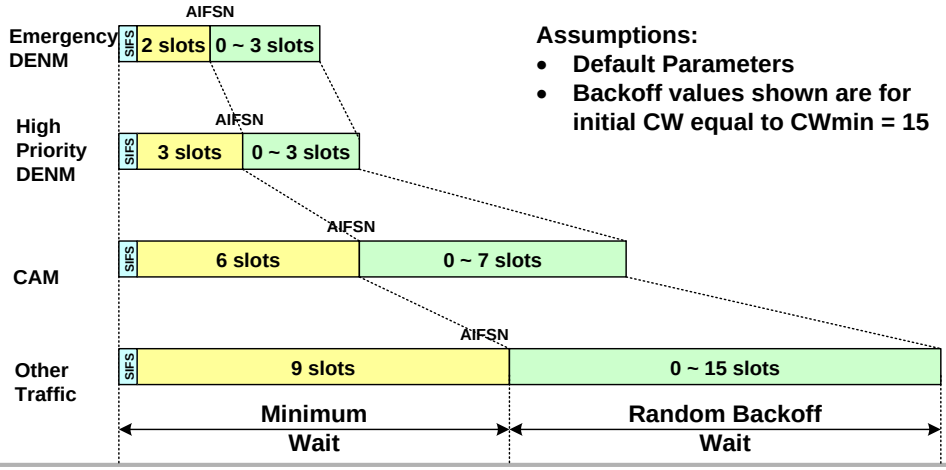
EDCA Parameter Results – DSRC/ITS-G5 OCB

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

➢ **IEEE 802.11e EDCA**



➢ **DSRC/ITS-G5 EDCA**



EURECOM
Sophia Antipolis

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**

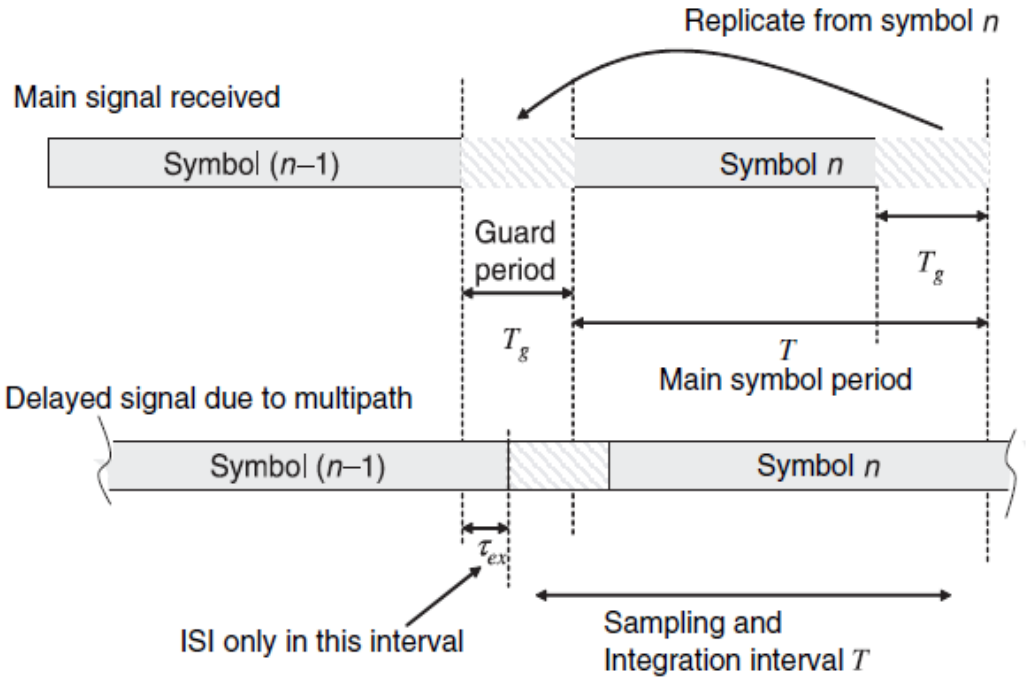
Source: Measurement and Analysis of Wireless Channel Impairments in DSRC Vehicular Communications, Laberteaux et al, 2008

- **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

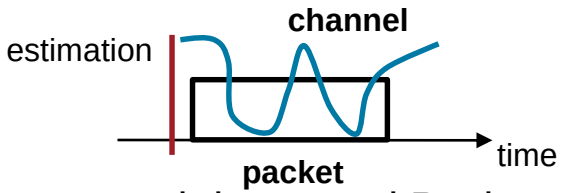
- **Mitigating Inter-Symbol Interference**
  - OFDM introduces a guard period after each OFDM symbol to protect symbols from ISI



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
  - Several solutions:
    - 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**
  - EDCA QoS Provisioning
  - Multi-channel Operation (1 CCH, several SCHs) (not discussed here..)
  - Congestion Control (adaptive TX power, TX rate, multi-channel)

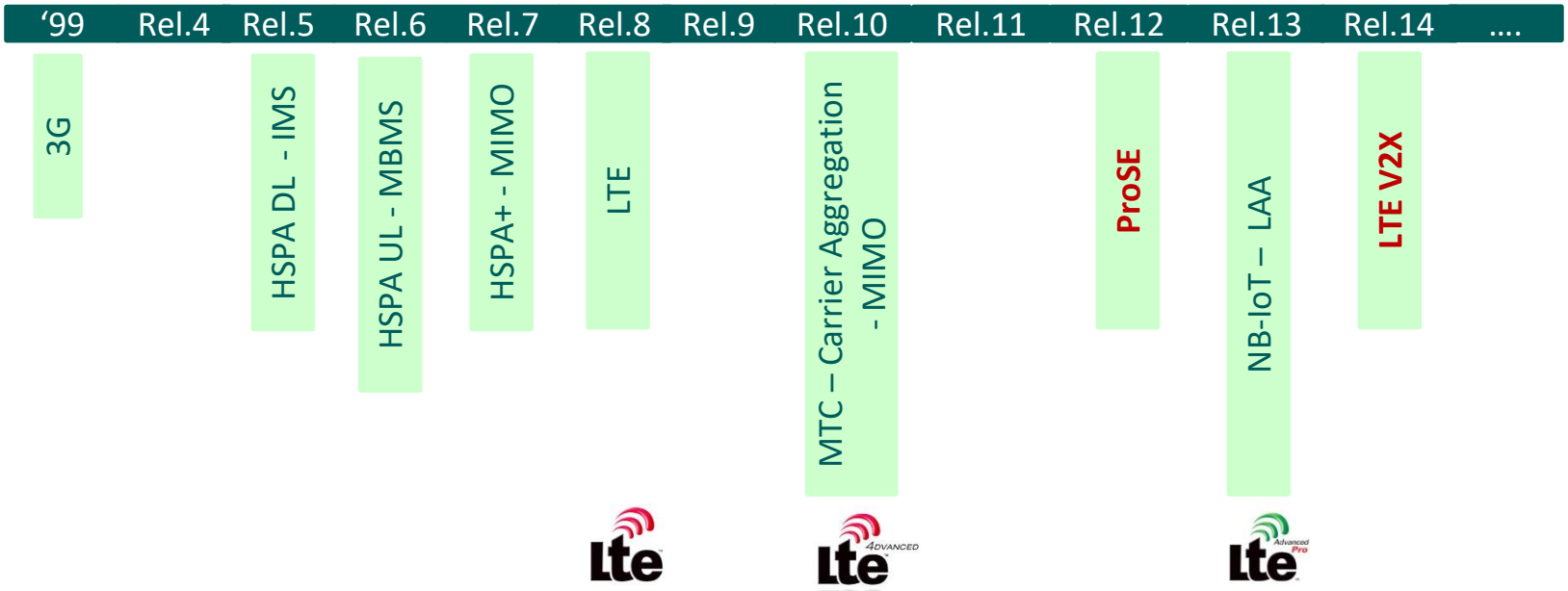
Classic 802.11 WLAN	DSRC/ITS-G5
Synchronizing	**OPTIONAL HIGHER LAYER** Synchronization
Scanning	**NO** Scanning
Authentication	**HIGHER LAYER** Authentication
Association	**IMPLICIT** Association
Communication	**DIRECT** Communication
Concept of Basic Service Sets (BSS)	"Communication outside of the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

Part III

CELLULAR-BASED V2X COMMUNICATIONS

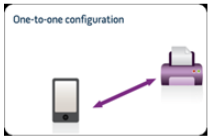
3rd Generation Partnership Project

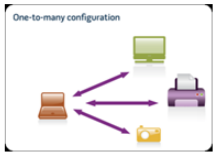
- **Progress and Releases**
  - 3GPP technologies are evolving through ‘Generations’
  - Progresses are measured by milestones known as ‘release’



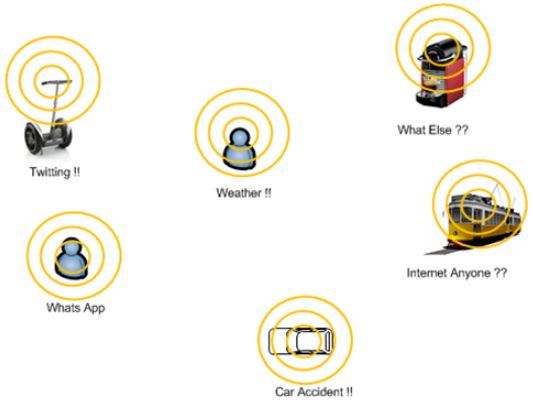
LTE Proximity Service (ProSe)

- **Evolution of Proximity Services**



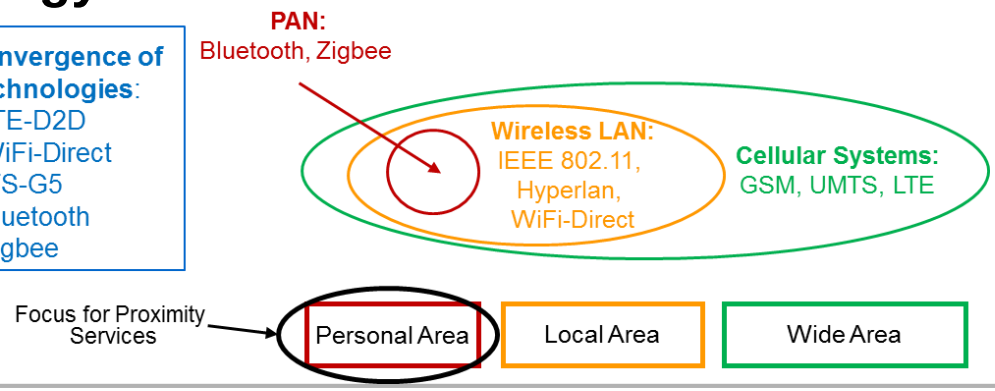


Convergence of Actors:
- Pedestrians
- Cars, Buses, Trains
- Any-'Wheelers'
- Your coffee machine !!



- **Evolution of Proximity Technology**

Convergence of Technologies:
- LTE-D2D
- WiFi-Direct
- ITS-G5
- Bluetooth
- Zigbee



EURECOM
Sophia Antipolis

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)

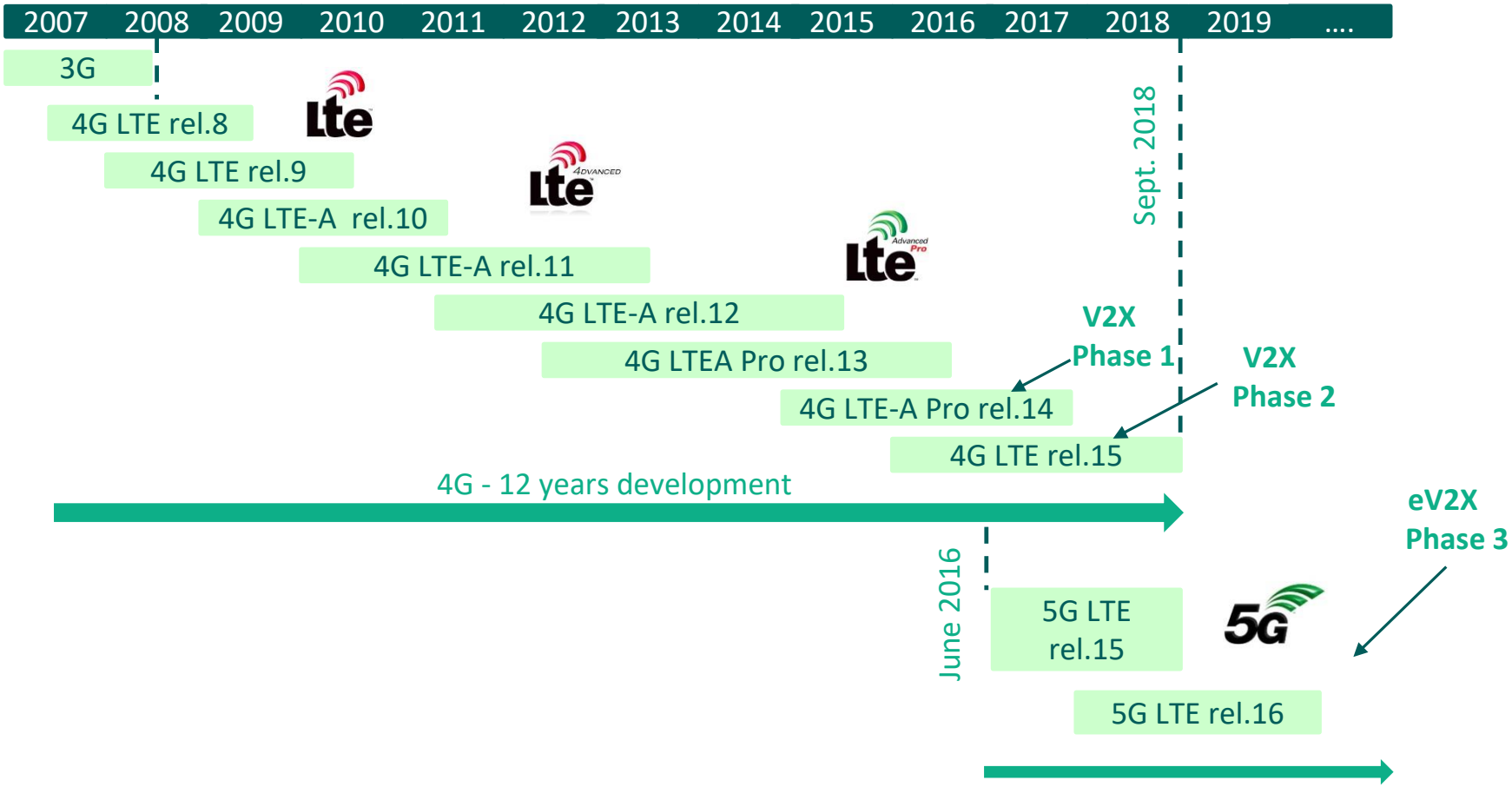
- **LTE ProSe enables establishment of communication paths between two or more ProSe-enabled UEs.**
  - Radical architecture change for D2D
  - Since LTE Rel.12

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

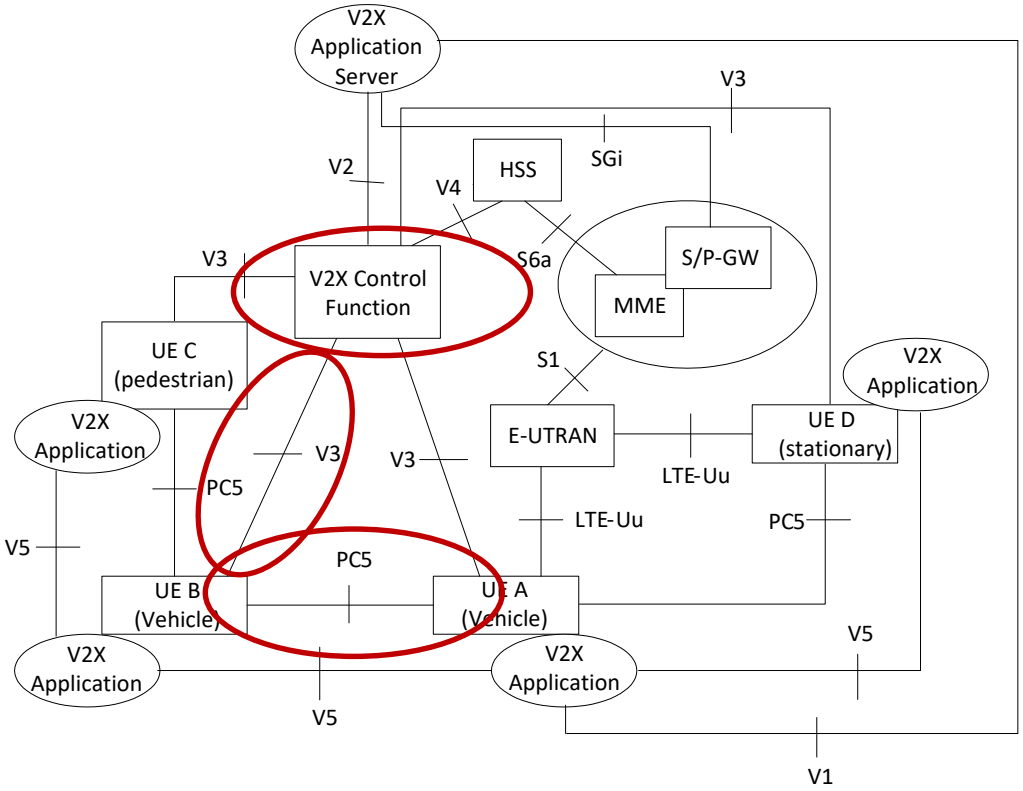
- **LTE ProSe Functions:**
  - Discovery
    - Mode A – 'I am here'
    - Mode B – 'how is there ?'
  - Direct Communication
    - Mode 1 – Coordinated by eNB
    - Mode 2 – Ad-Hoc mode

Restricted to Public Safety & V2X (rel.14)

LTE Vehicular-to-Everything (V2X)



LTE V2X Extended Architecture

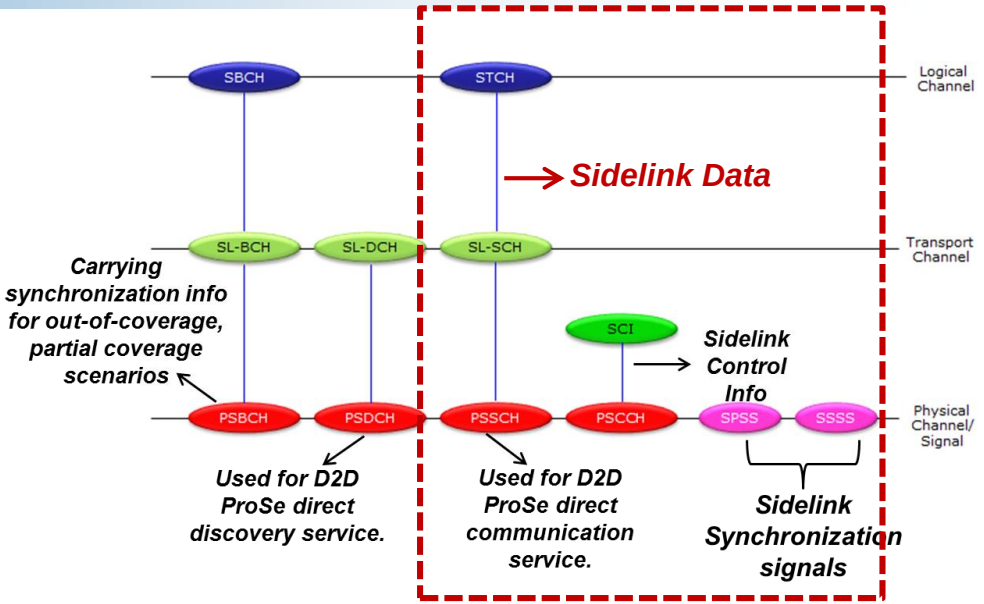


- **New Architecture Elements:**
  - V2X Control Function – similar to Prose Function
  - PC5 interface – as D2D Prose
  - V3 interface – as PC3, but with V2X-related messages

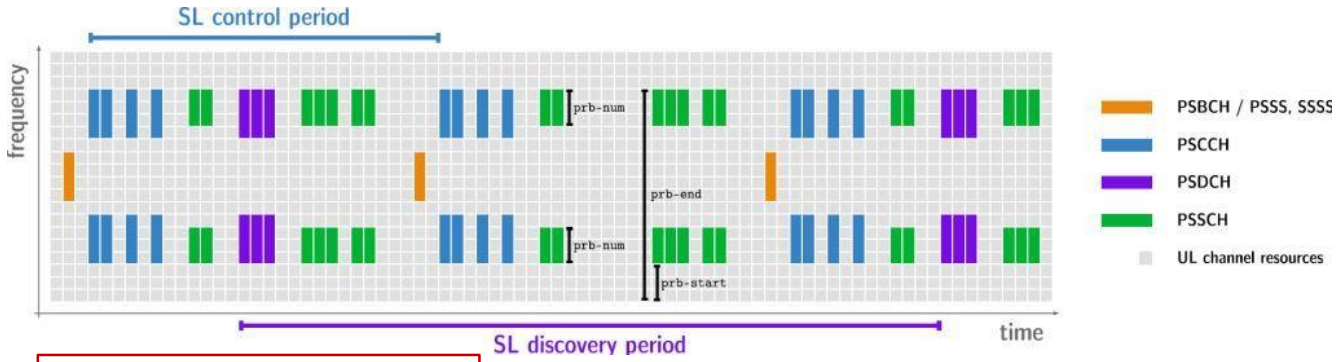
LTE-V2X – 'Slidelink' (SL) Channels

Channels of interest for our V2X direct communication use cases.

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

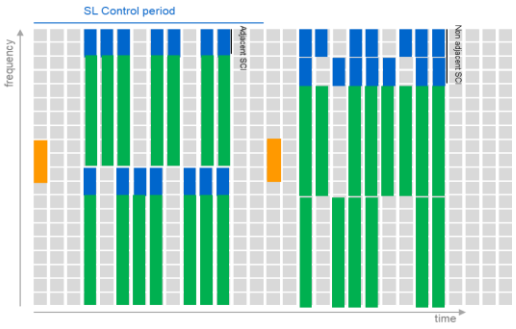


ProSe D2D



Source: Dr. Gallo, EURECOM

ProSe V2X

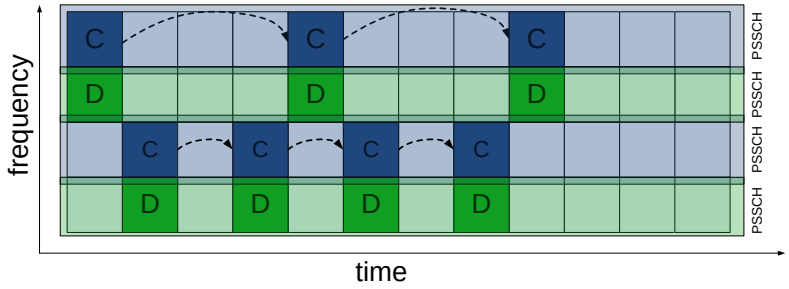


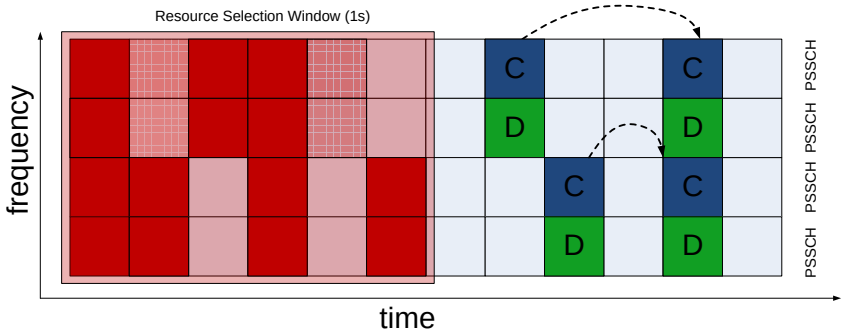
EURECOM
Sophia Antipolis

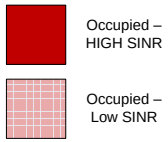
LTE-V2X – Distributed Scheduler

- **LTE V2X mode 3 (eNB)**
  - Dynamic or SPS scheduling allowed
  - can be different period/MCS for flexibility

- **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)



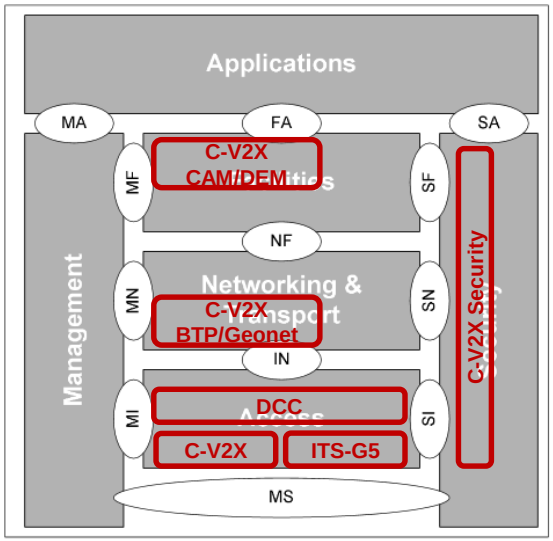




- **LTE V2X mode 4 Resource Allocation**
  - 1s monitoring windows
  - Selection of the 20% RB with lowest RSSI
  - Exclude any reserved resources

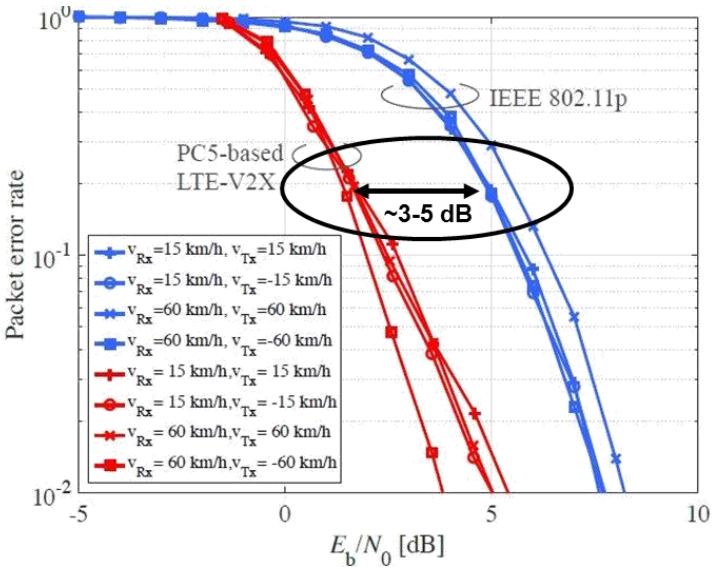
Cellular LTE-V2X – Standardization Status

- **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

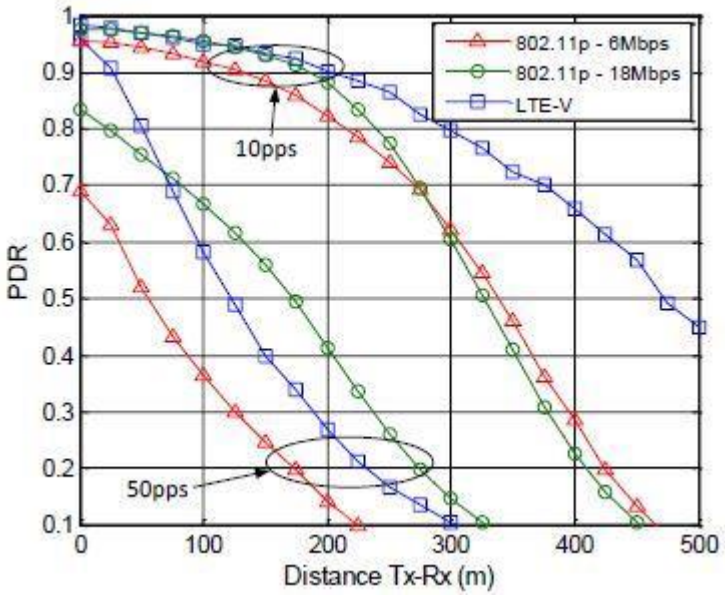


LTE-V2X vs. ITS-G5 – Comparison

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



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



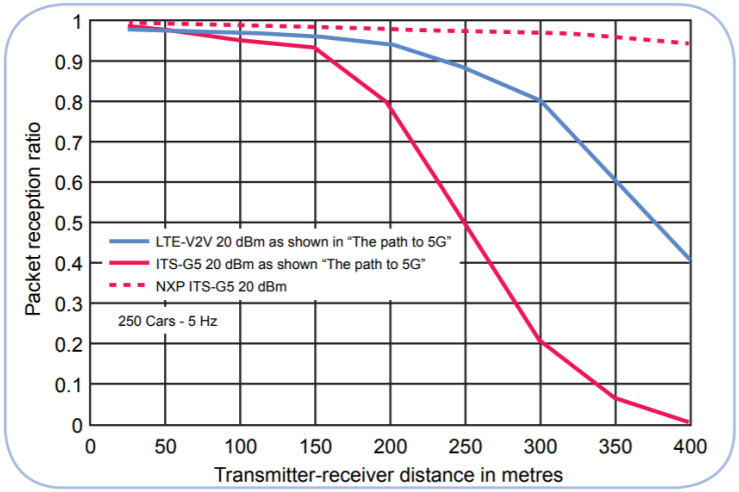
Source: R. M. Masegosa, J. Gozalvez, "LTE-V for Sidelink 5G V2X Vehicular Communications", IEEE Vehicular Technology Magazine, Dec. 2017

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

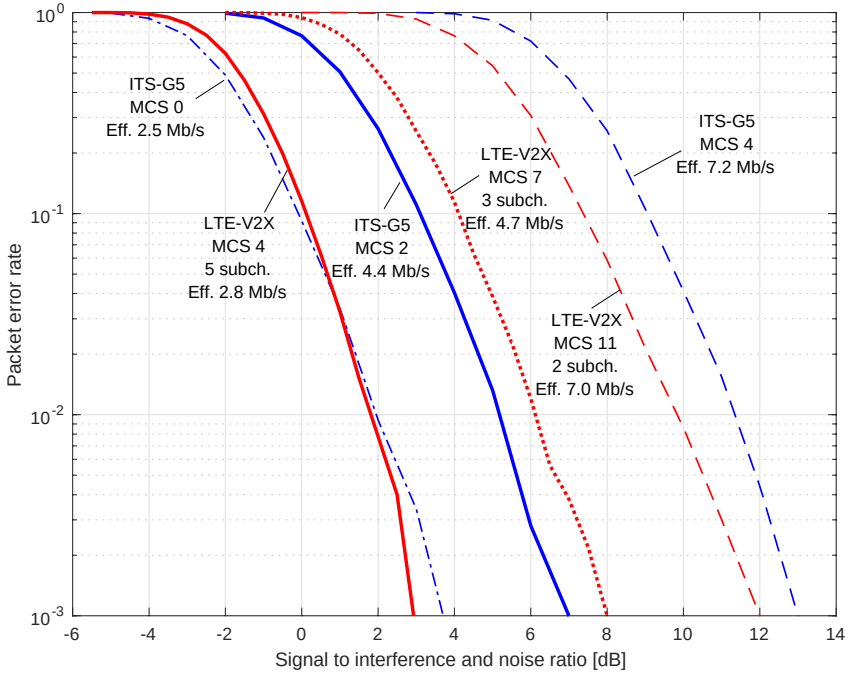
EURECOM

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)
    - Improved channel tracking has been developed (e.g. NXP)



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

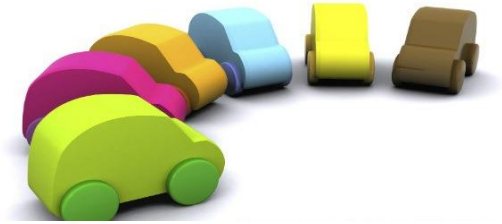


Source: A Bazzi, et al. , Co-channel Coexistence: Let ITS-G5 and Sidelink C-V2X Make Peace, 2020

EURECOM
Sophia Antipolis

Time for a Break…

Meet again in 15 minutes



vs.

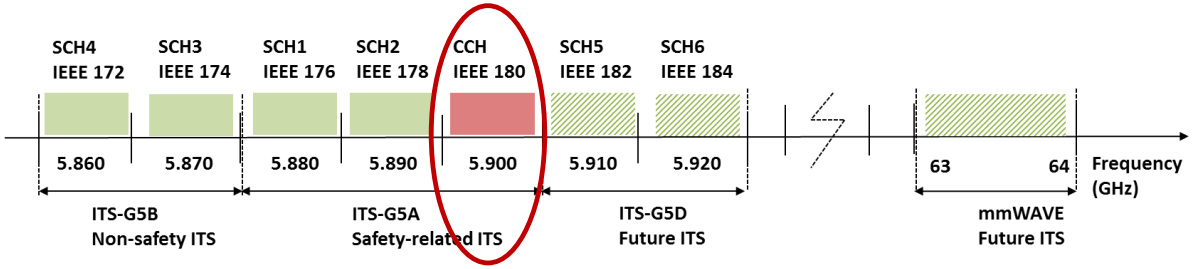
Cti
Commission des Titres d'Ingénieur

Part IV

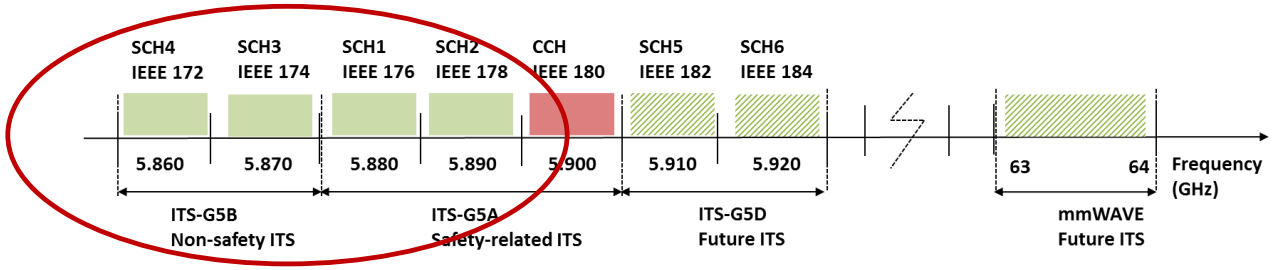
COEXISTENCE AND REGULATIONS

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



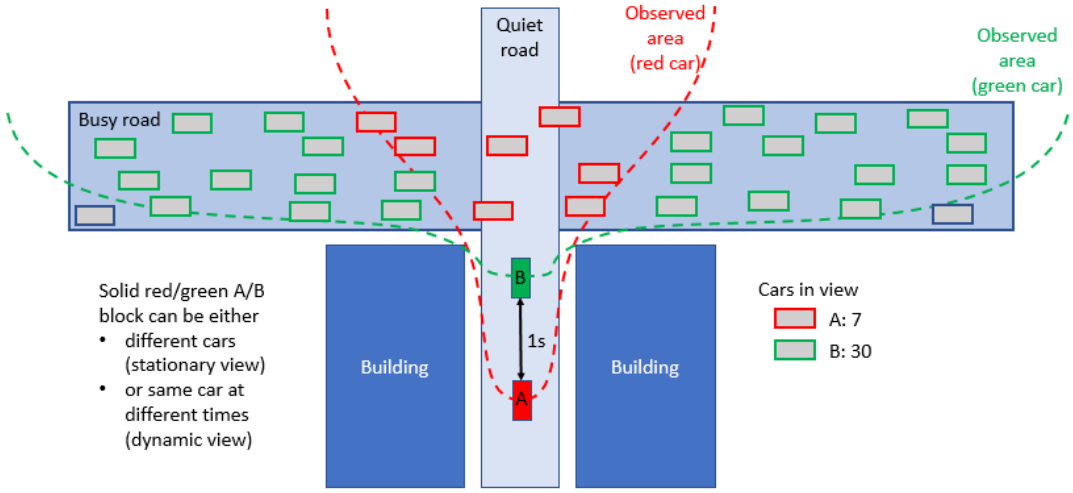
  - Also increasing interest from WiFi (IEEE 802.11ac/ax) on the lower ITS-G5 band
  - …and LTE-U, resp. NR-U for Private 5G networks



EURECOM
Sophia Antipolis

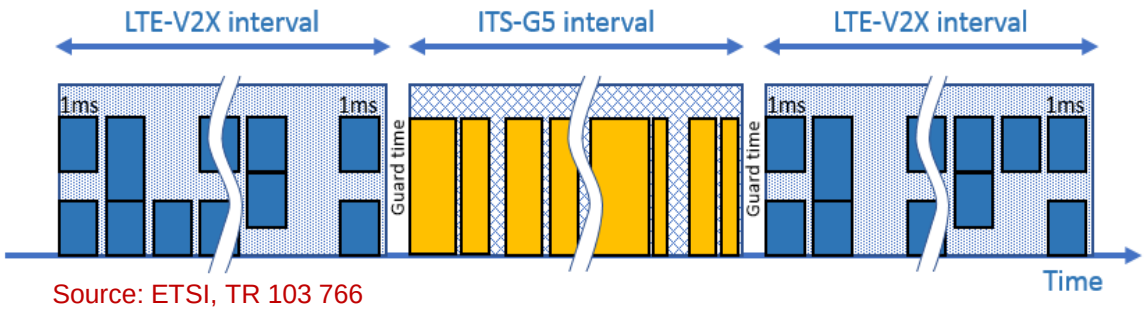
Coexistence ITS-G5 – LTE-V2X – Problem Statement

- **Typical Use Case**



Source: ETSI, TR 103 766

- **Potential Coexistence in Time Domain**

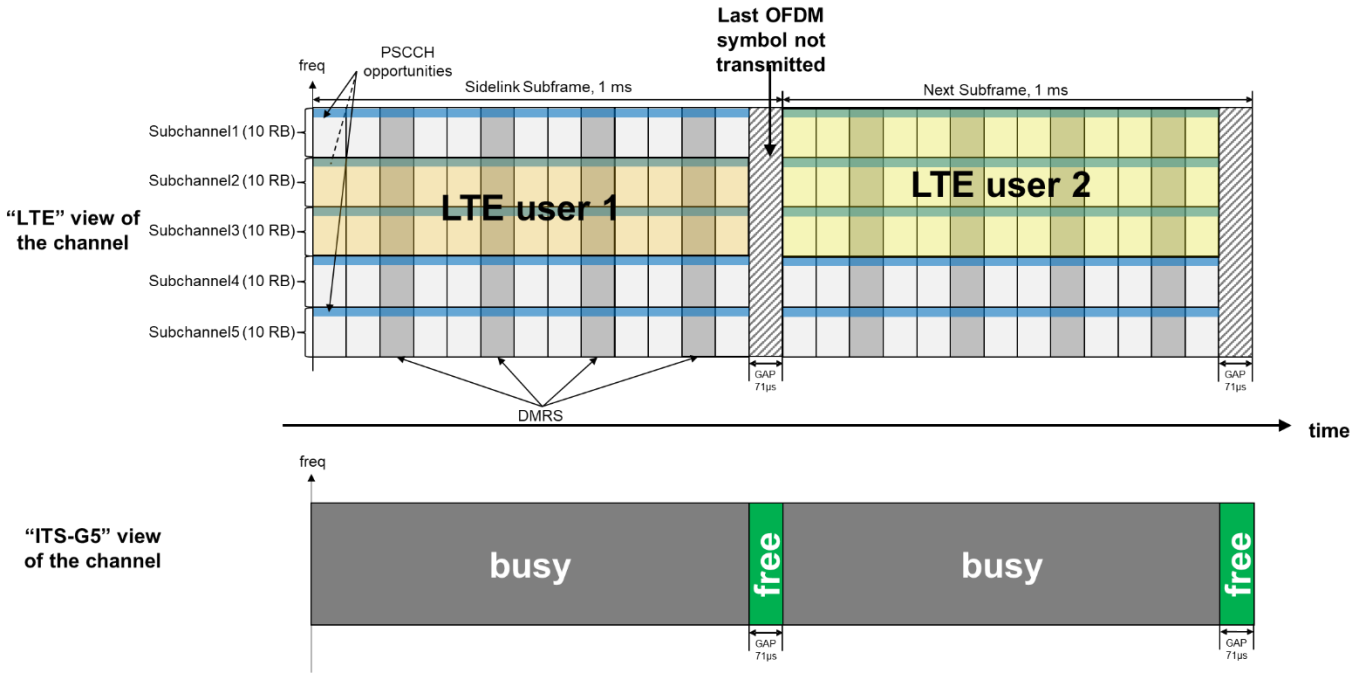


Source: ETSI, TR 103 766

EURECOM

Coexistence ITS-G5 – LTE-V2X – Problem Statement

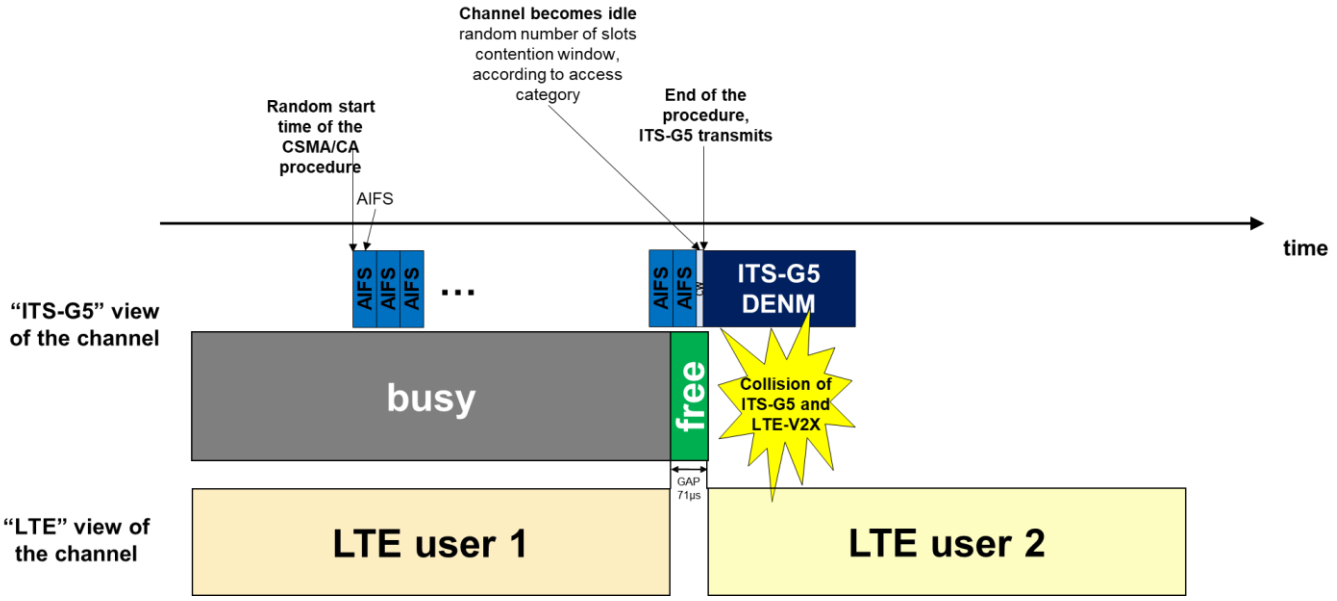
- **The last symbol gap problem**



Source: ETSI, TR 103 766

Coexistence ITS-G5 – LTE-V2X – Problem Statement

- **The last symbol gap problem**



Source: ETSI, TR 103 766

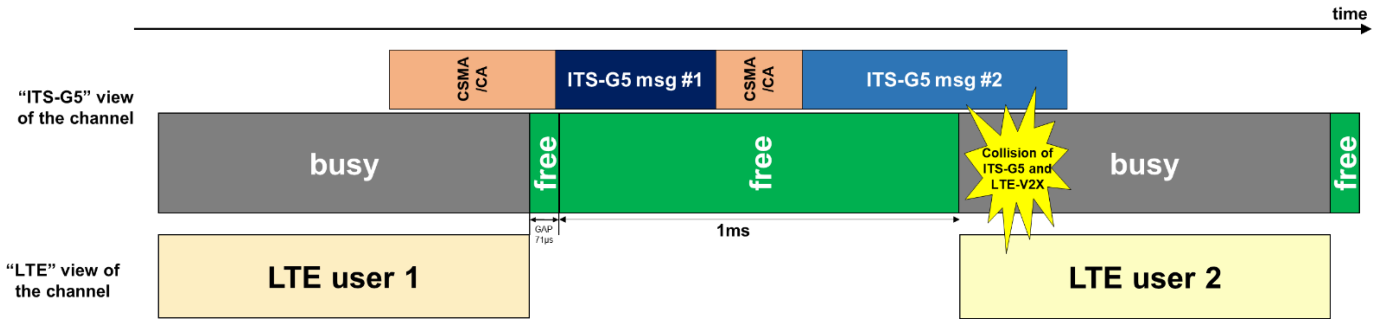
- **Reminder: ITS-G5 EDCA values**

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**

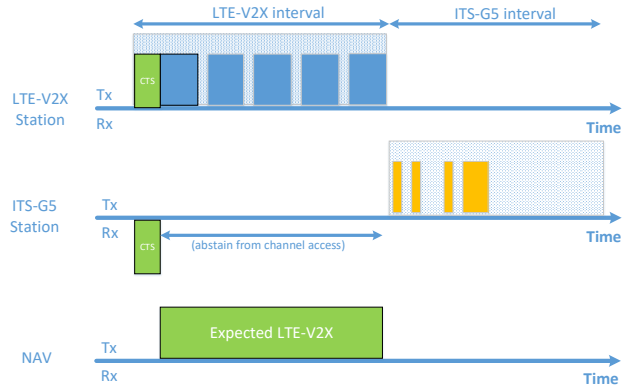
AC	*CW*	*AIFS**	Possible duration of the inner state machine*	Gap problem occurrence chances*
AC_VO	3	***58 µs***	[***0,1***,2,3] CW = [***0, 13 µs***, 26 µs, 39 µs]	***50%*** (2 chances out of 4)
AC_VI	7	***71 µs***	[***0***,1,2…7] CW = [***0***, 13 µs, 26 µs…]	***12.5%*** (1 chance out of 8)
AC_BE	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				

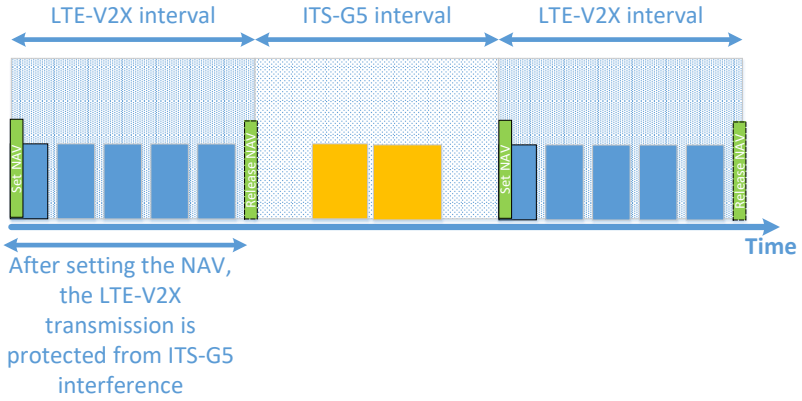


Source: ETSI, TR 103 766

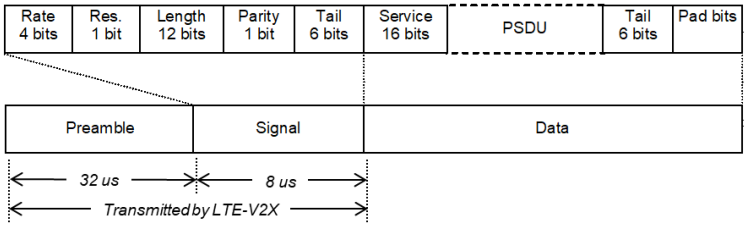
Potential Coexistence Strategies…

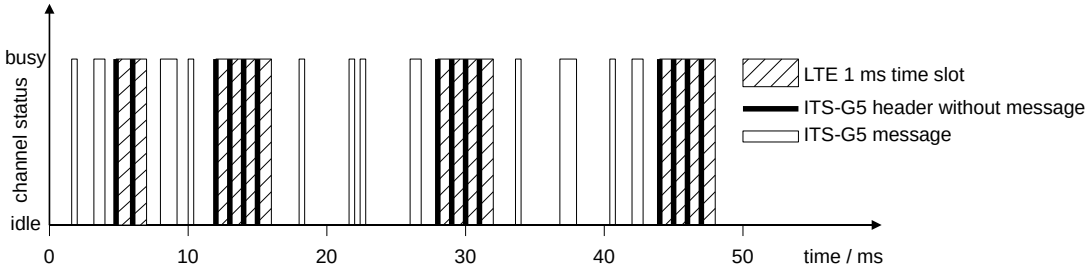
- **NAV setting and CTS-to-Self**





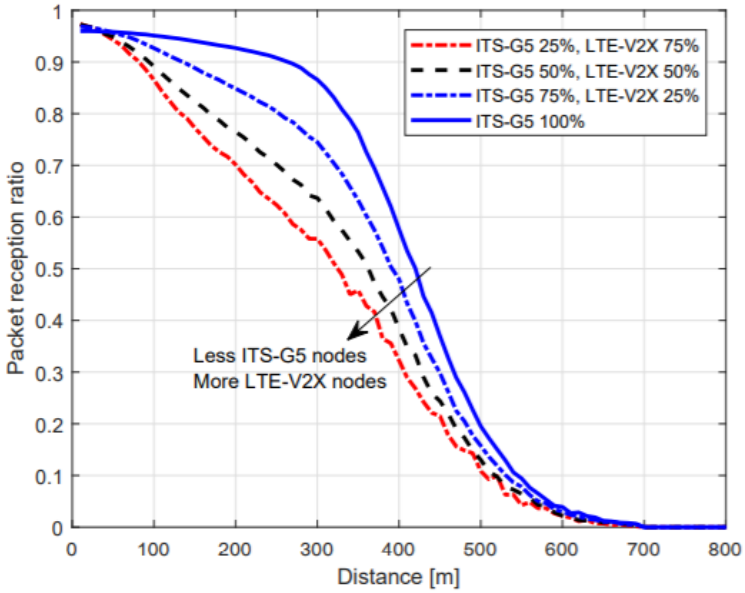
- **LTE V2X PHY Header insertion**



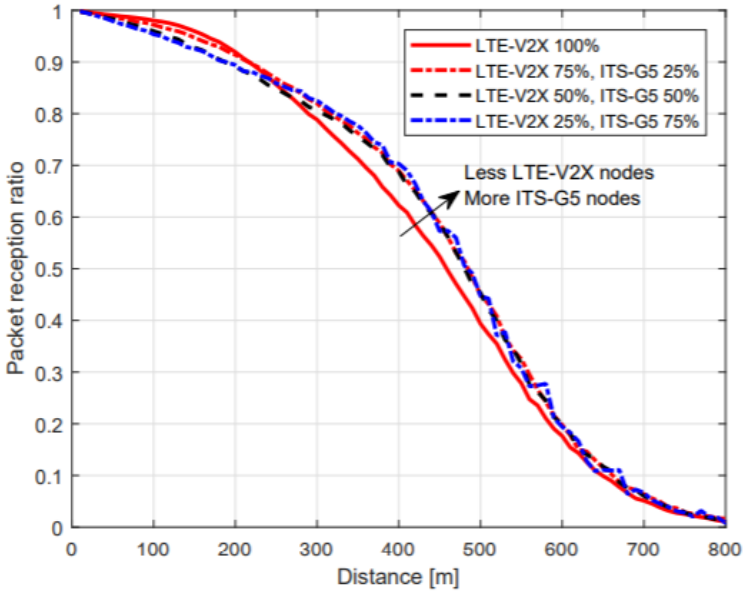


Source: ETSI, TR 103 766

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



(a) ITS-G5.

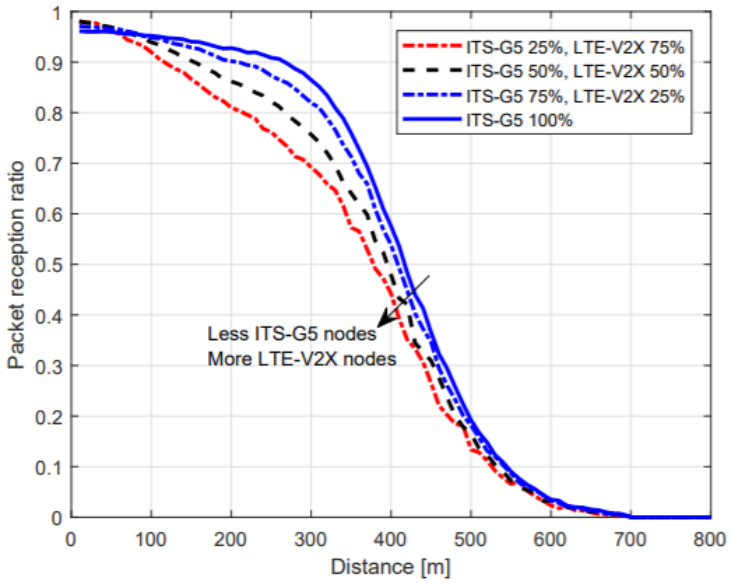


(b) LTE-V2X.

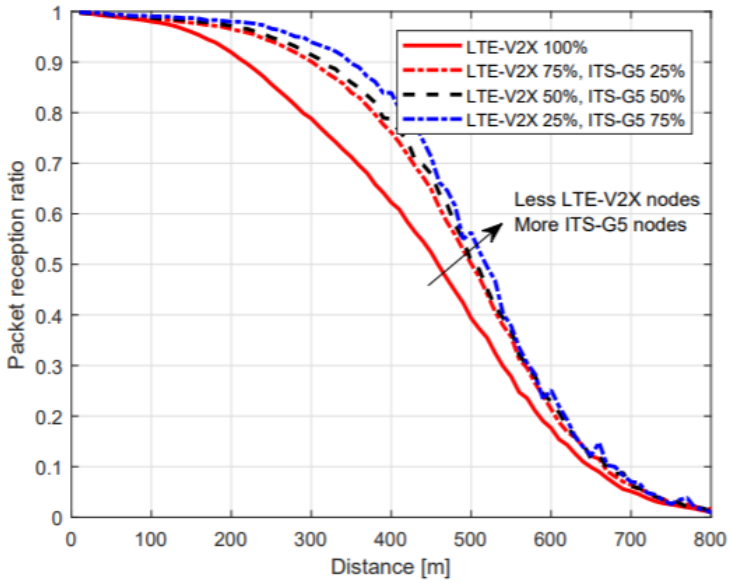
Source: A Bazzi, et al. , Co-channel Coexistence: Let ITS-G5 and Sidelink C-V2X Make Peace, 2020

- **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)

EURECOM

Part VI

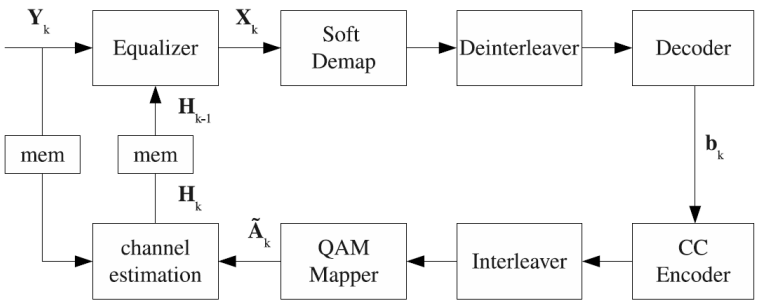
FUTURE V2X - IEEE 802.11BD

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



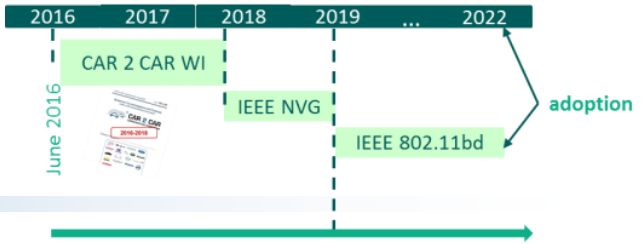
Data-Aided Channel Estimation (DACE) - A. Agnoletto, "Data Decoding Aided Channel Estimation Techniques for OFDM Systems in Vehicular Environment," March 2010.

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**

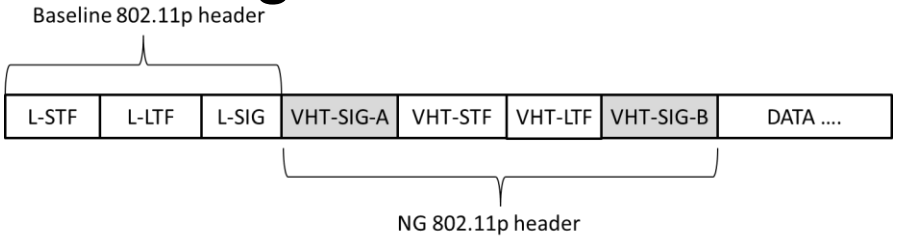
Features	IEEE 802.11p	IEEE 802.11bd	Benefit from 802.11bd
Modulation	BPSK, QPSK, 16-QAM, 64-QAM	BPSK, QPSK, 16-QAM, 64-QAM, 256 QUAM	33% increased throughput
Data subcarriers	48	48+52	8% increased capacity
MIMO	None	2xMIMO	2x higher capacity
Bandwidth	10Mhz	10Mhz & 20Mhz	Improved sensitivity
Spectrum	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

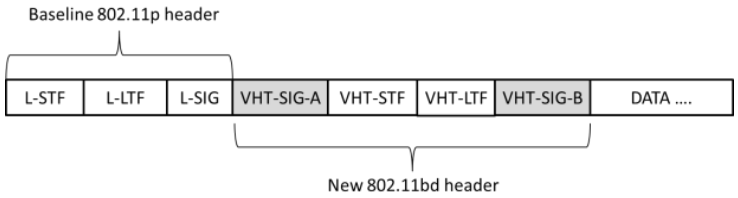


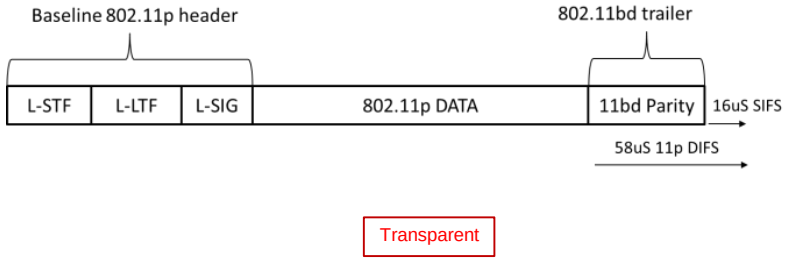
- **Frame Structuring…**



- **Midamble approach**

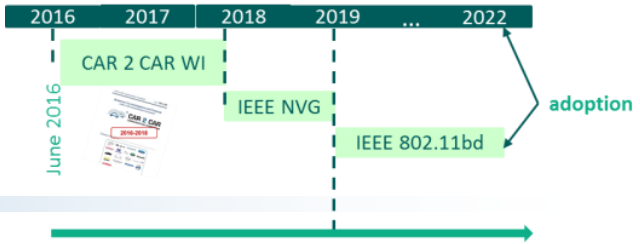
- **Coexistence**



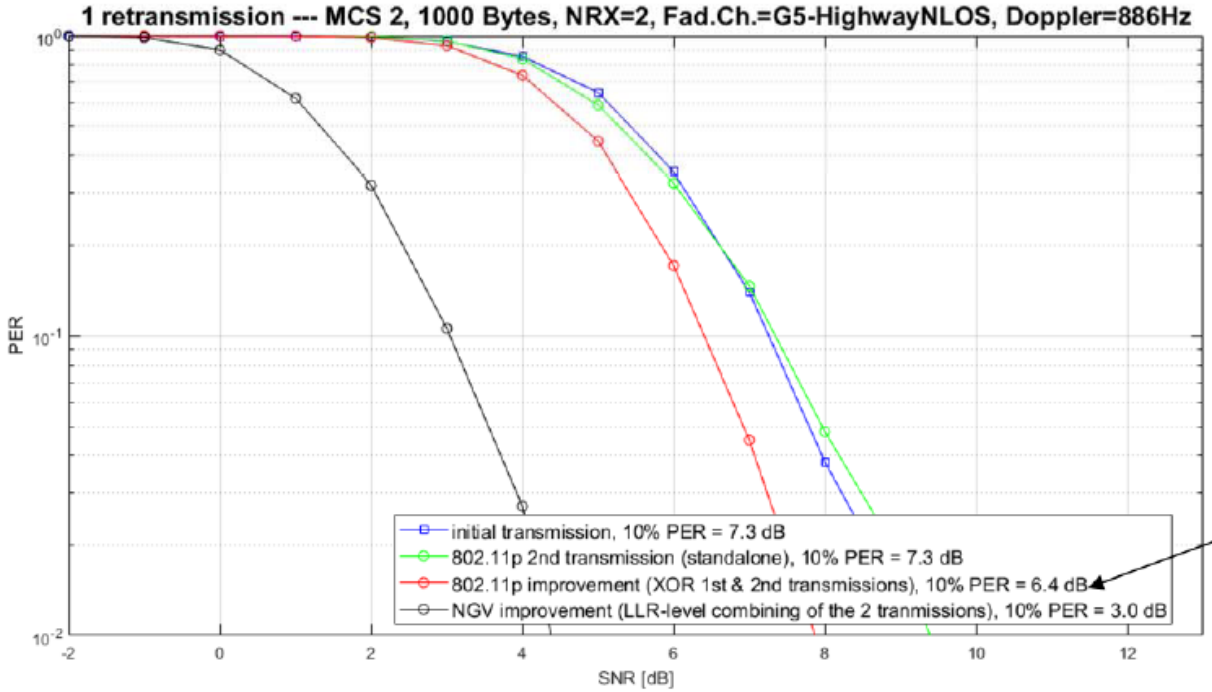


EURECOM
Sophia Antipolis

WiFi V2X - IEEE 802.11bd



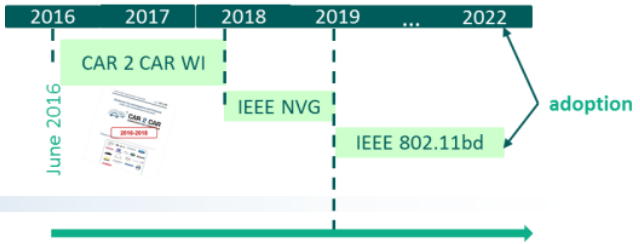
- **Link Level Performance Evaluation…**
  - Retransmission strategy



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

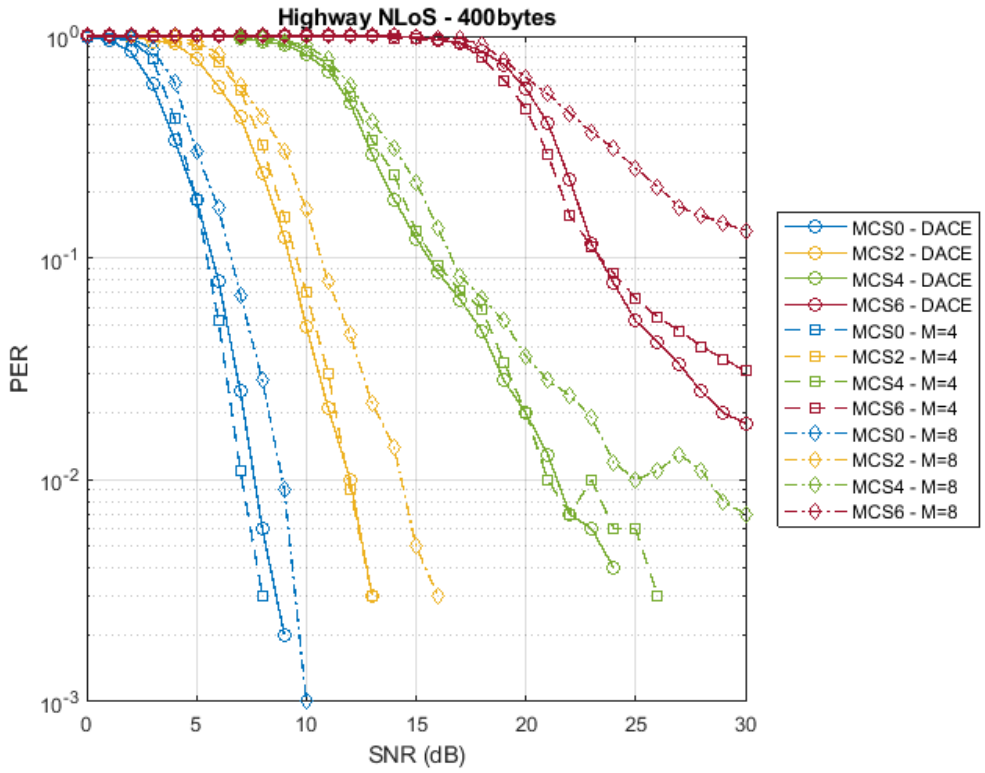
Should be understood as « Boolean OR of the CRC-pass results », we take the best of the 2 tries:
- trans#1 FAIL + trans#2 FAIL = FAIL
- trans#1 FAIL + trans#2 PASS = PASS
- trans#1 PASS + trans#2 FAIL = PASS
- trans#1 PASS + trans#2 PASS = PASS

WiFi V2X - IEEE 802.11bd



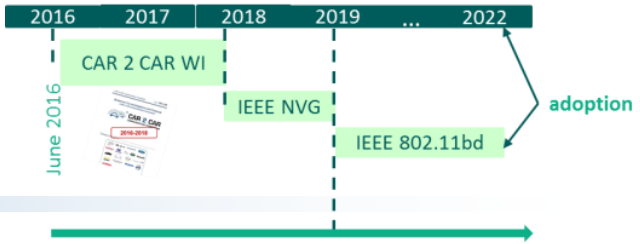
- **Link Level Performance Evaluation…**
  - Channel tracking vs. Midamble Channel Estimation (MCE)

- **SNR vs PER**
  - MCE M=4, similar performance to DACE
  - MCE M=8, worse performance than DACE

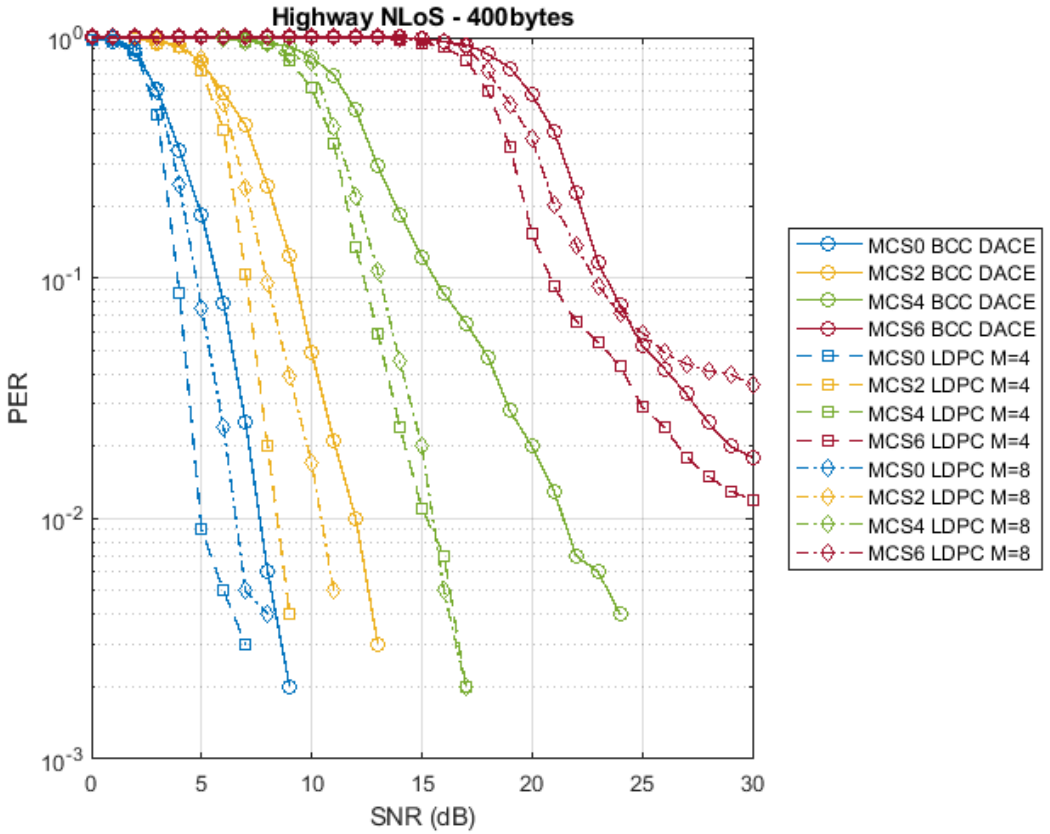


Source: I. Sarris, ublox, IEEE 820.11-19/1104r1

WiFi V2X - IEEE 802.11bd

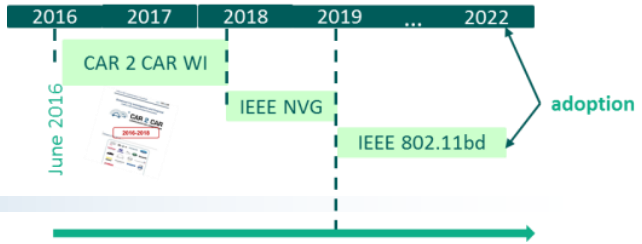


- **Link Level Performance Evaluation…**
  - BCC vs LDPC
- **SNR vs PER**
  - LDPC gives a 1-2 dB enhancement compared to DACE
  - Again, performance also depends on the MCE scheme used



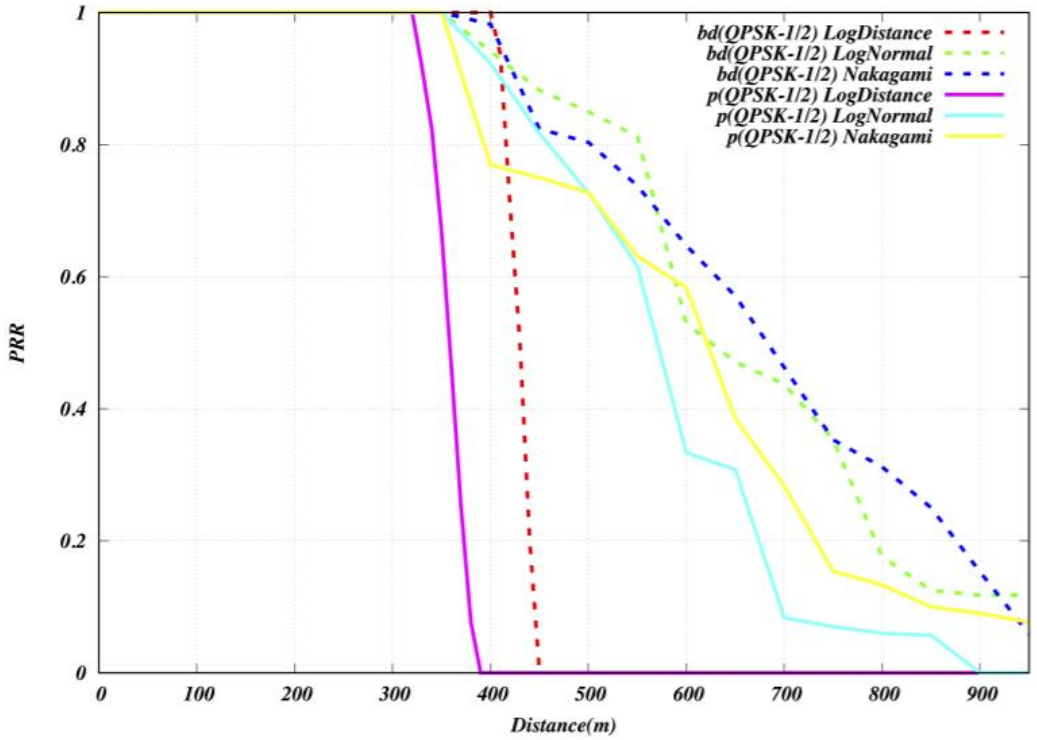
Source: I. Sarris, ublox, IEEE 820.11-19/0310r0

WiFi V2X - IEEE 802.11bd



- **Packet-level Evaluation**
  - Ublox model embedded into ns-3 (BCC, MCE)

- **PRR vs Distance**
  - DOTBD provides between 20% and 50% range extensi as function of the channel environement

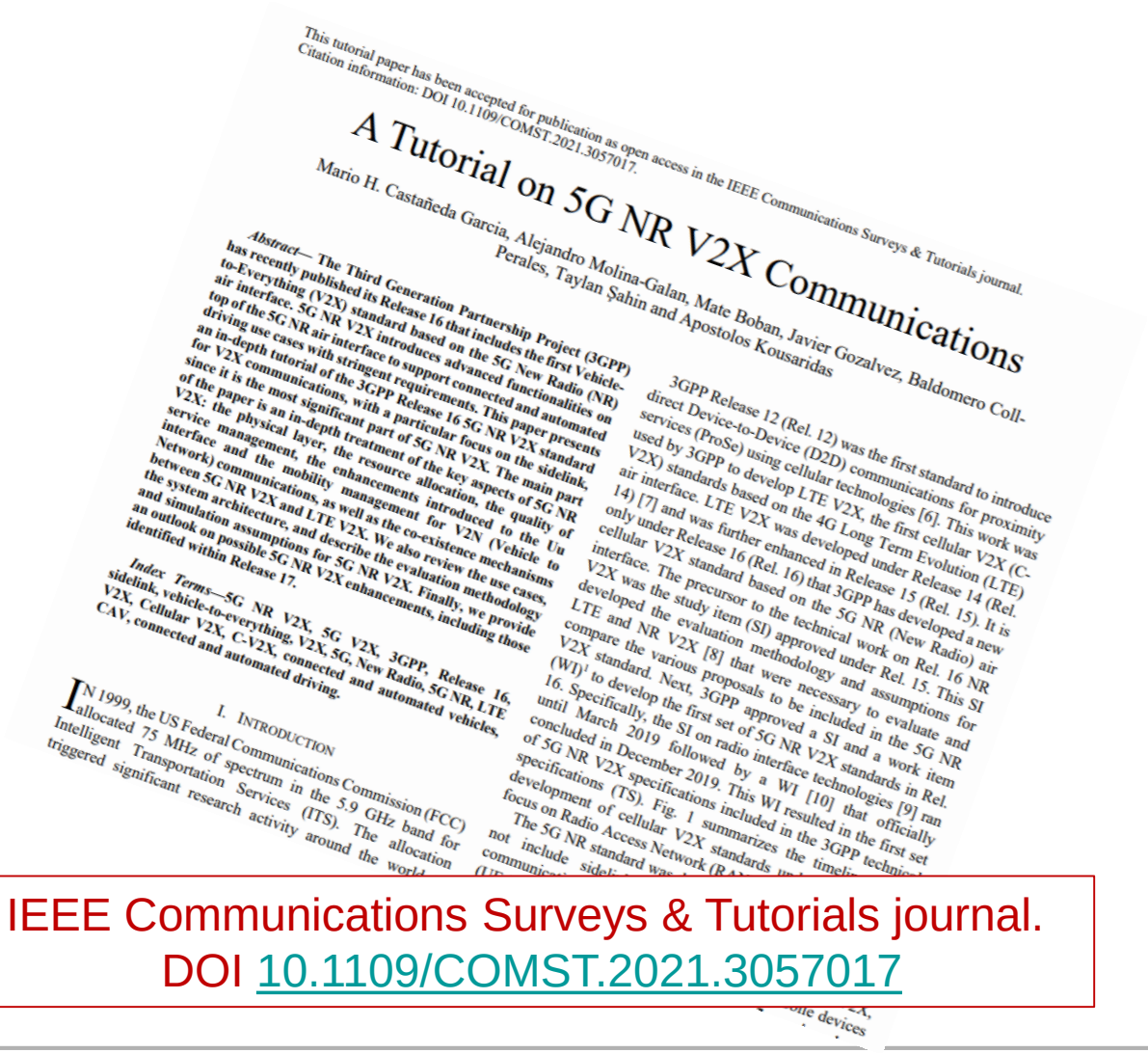


Source:Sasi Paidimarri, I. Khan, J. Härri, Network-level evaluation of IEEE 802.11bd, 2021

Part VII

FUTURE V2X – NR V2X

Excellent Document to Read



This tutorial paper has been accepted for publication as open access in the IEEE Communications Surveys & Tutorials journal.
Citation information: DOI 10.1109/COMST.2021.3057017.

A Tutorial on 5G NR V2X Communications

Mario H. Castañeda Garcia, Alejandro Molina-Galan, Mate Boban, Javier Gozalvez, Baldomero Coll-Perales, Taylan Şahin and Apostolos Kousaridas

Abstract— The Third Generation Partnership Project (3GPP) has recently published its Release 16 that includes the first Vehicle-to-Everything (V2X) standard based on the 5G New Radio (NR) air interface. 5G NR V2X introduces advanced functionalities on top of the 5G NR air interface to support connected and automated driving use cases with stringent requirements. This paper presents an in-depth tutorial of the 3GPP Release 16 5G NR V2X standard for V2X communications, with a particular focus on the sidelink, since it is the most significant part of 5G NR V2X standard of the paper is an in-depth treatment of the key aspects of 5G NR V2X: the physical layer, the resource allocation, the quality of service management, the enhancements introduced to the Uu interface and the mobility management for V2N (Vehicle to Network) communications, as well as the co-existence mechanisms between 5G NR V2X and LTE V2X. We also review the use cases, the system architecture, and describe the evaluation methodology and simulation assumptions for 5G NR V2X. Finally, we provide an outlook on possible 5G NR V2X enhancements, including those identified within Release 17.

Index Terms—5G NR V2X, 5G V2X, 3GPP, Release 16, sidelink, vehicle-to-everything, V2X, 5G, New Radio, 5G NR, LTE V2X, Cellular V2X, C-V2X, connected and automated vehicles, CAV, connected and automated driving.

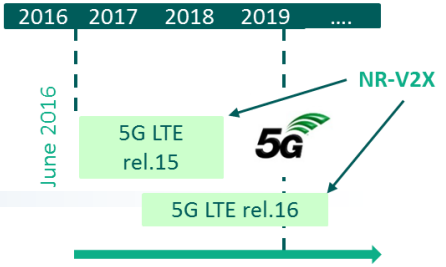
I. Introduction

IN 1999, the US Federal Communications Commission (FCC) allocated 75 MHz of spectrum in the 5.9 GHz band for Intelligent Transportation Services (ITS). The allocation triggered significant research activity around the world

3GPP Release 12 (Rel. 12) was the first standard to introduce direct Device-to-Device (D2D) communications for proximity services (ProSe) using cellular technologies [6]. This work was used by 3GPP to develop LTE V2X, the first cellular V2X (C-V2X) standards based on the 4G Long Term Evolution (LTE) air interface. LTE V2X was developed under Release 14 (Rel. 14) [7] and was further enhanced in Release 15 (Rel. 15). It is only under Release 16 (Rel. 16) that 3GPP has developed a new cellular V2X standard based on the 5G NR (New Radio) air interface. The precursor to the technical work on Rel. 16 NR V2X was the study item (SI) approved under Rel. 15. This SI developed the evaluation methodology and assumptions for LTE and NR V2X [8] that were necessary to evaluate and compare the various proposals to be included in the 5G NR V2X standard. Next, 3GPP approved a SI and a work item (WI)[1] to develop the first set of 5G NR V2X standards in Rel. 16. Specifically, the SI on radio interface technologies [9] ran until March 2019 followed by a WI [10] that officially concluded in December 2019. This WI resulted in the first set of 5G NR V2X specifications included in the 3GPP technical specifications (TS). Fig. 1 summarizes the timeline of development of cellular V2X standards [...] focus on Radio Access Network (RAN) [...] The 5G NR standard was [...] not include [...] communications [...]

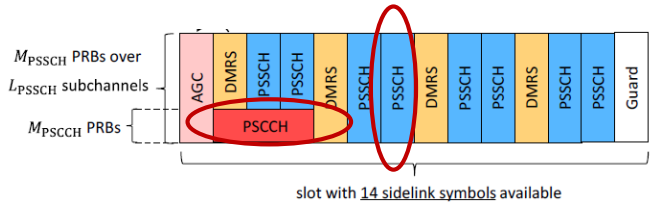
IEEE Communications Surveys & Tutorials journal.
DOI 10.1109/COMST.2021.3057017

3GPP V2X - NR V2X



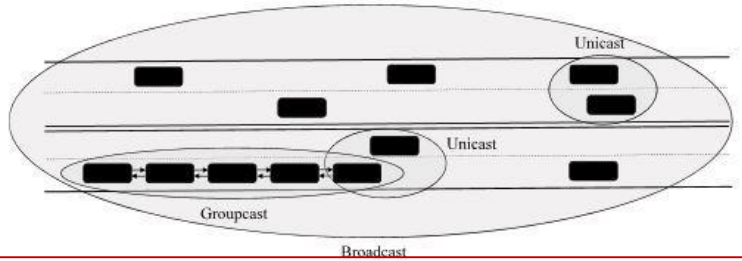
- **New Radio V2X**
  - 5G-V2X Rel. 16 and up..
  - Provide additional capacity for V2X use cases not supported by LTE-V2X

- **New Channel Multiplexing**
  - Slot rather than freq/time multiplexing between control and data channels



Source: Garcia et al., A Tutorial on 5G NR V2X Communications

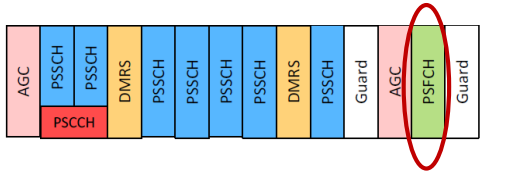
- **New Communication Types:**
  - Unicast
  - Groupcast



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

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

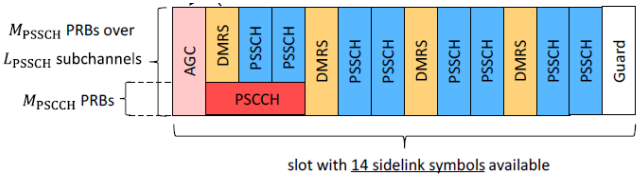
- **New Numerology:**
  - NR-V2X mode 1 – Network Assisted
  - NR-V2X mode 2(a/d) – Ad-hoc (CH assist)

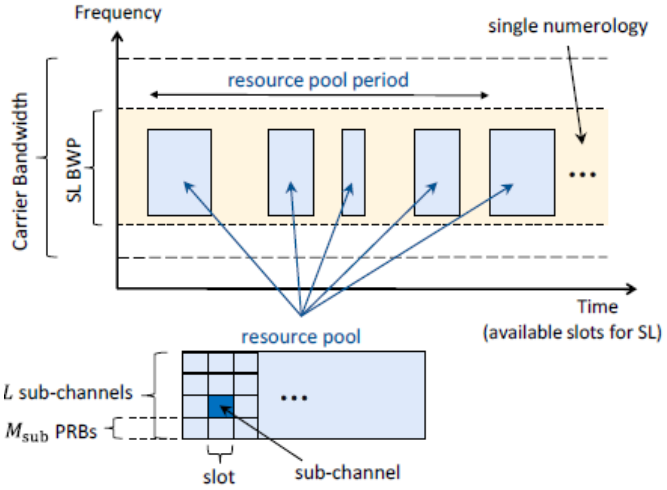


Source: Garcia et al., A Tutorial on 5G NR V2X Communications

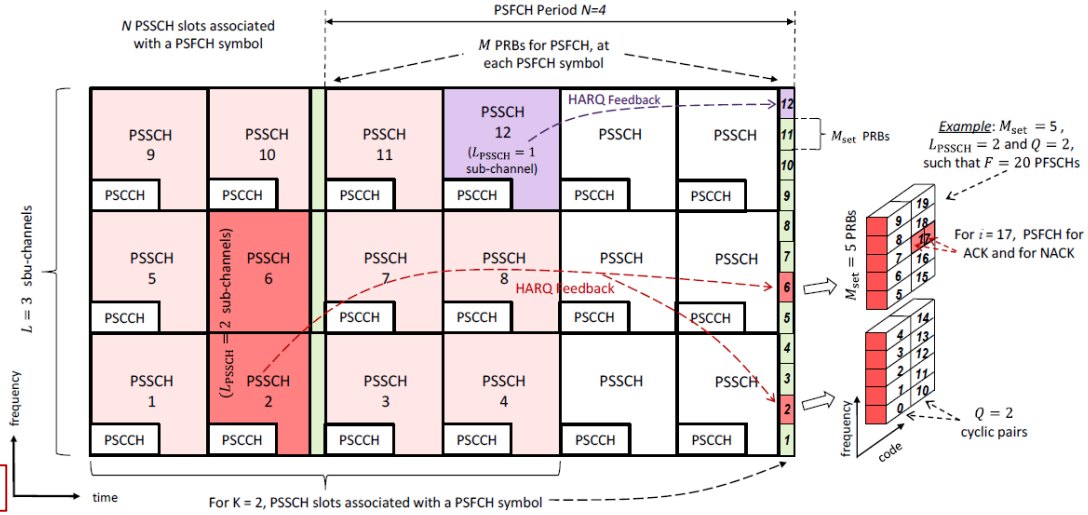
3GPP V2X - NR V2X

- **NR SL PSSCH/PSCCH multiplexing**





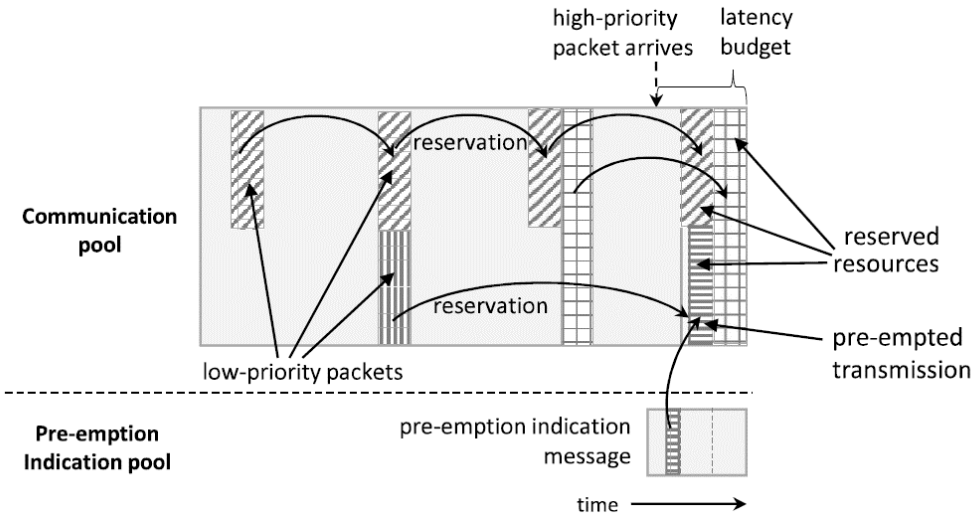
- **New NR SL Feedback Channel**



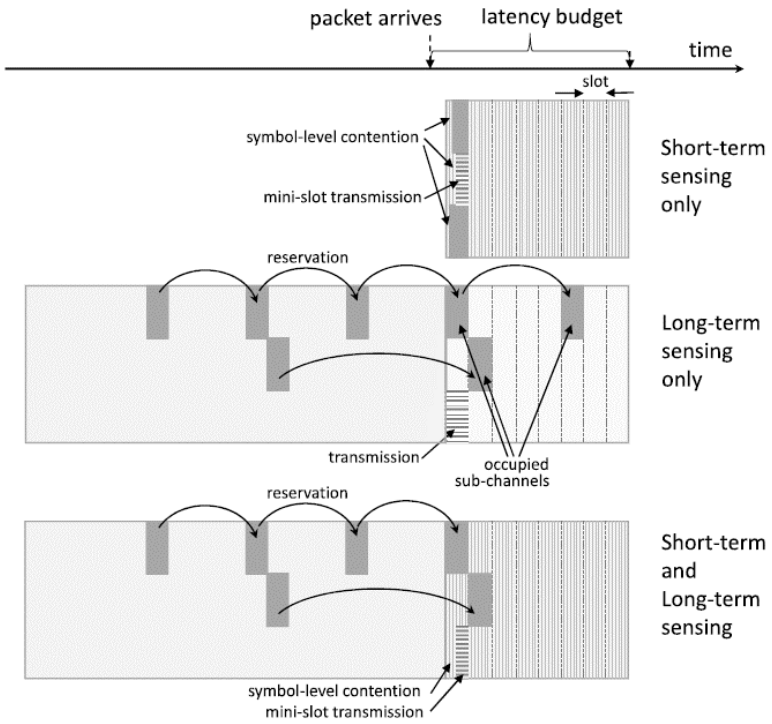
Source: Garcia et al., A Tutorial on 5G NR V2X Communications

3GPP V2X - NR V2X

- **New Preemption Strategy…**



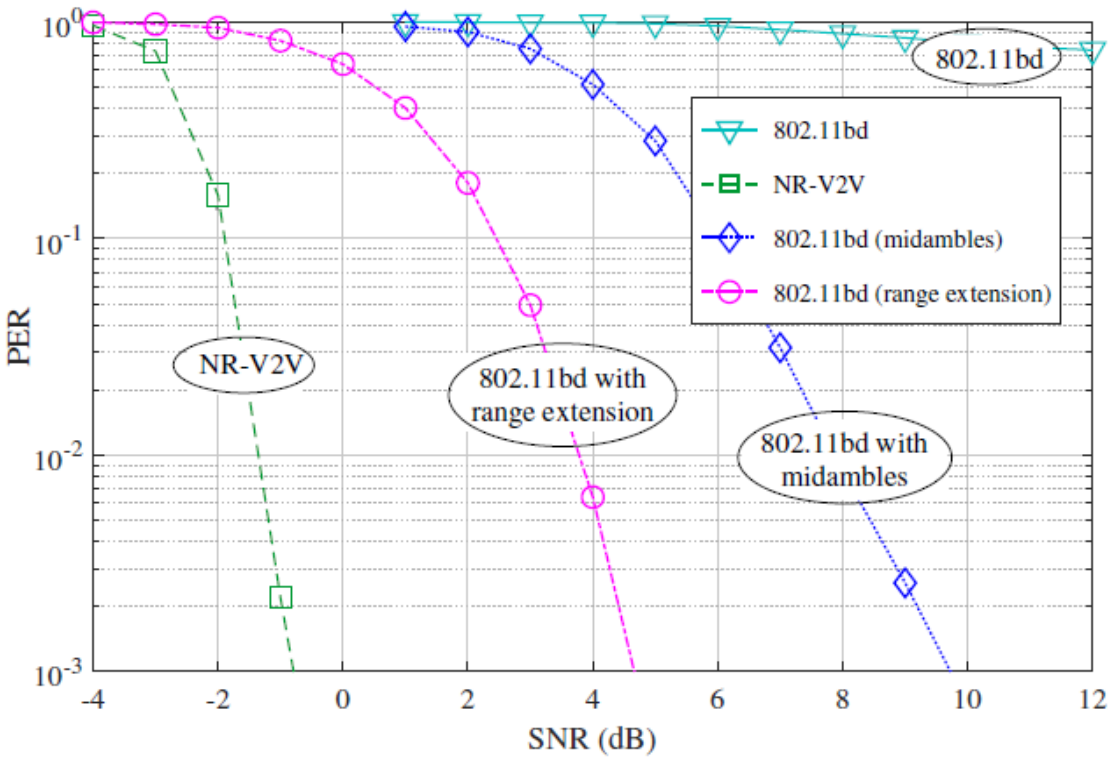
- **Mini-Slots Approach…**



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

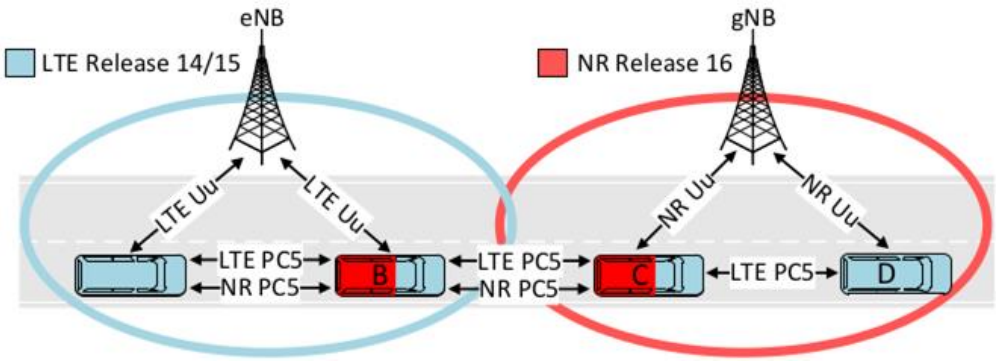
3GPP V2X - NR V2X – Performance Evaluations

- **Link Level Performance Evaluation…**

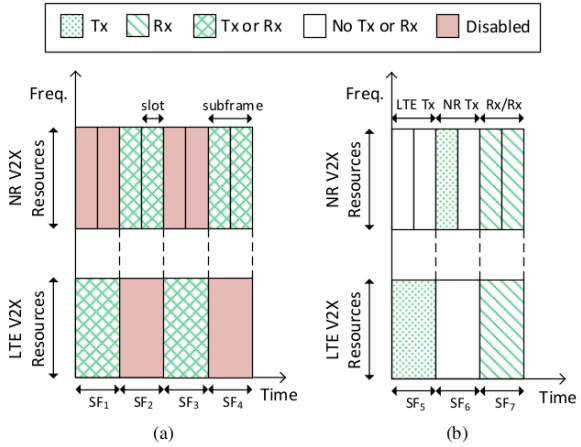


Source: Anwar et al., On the Reliability of NR-V2X and IEEE 802.11bd

NR-V2X coexistence with LTE-V2X

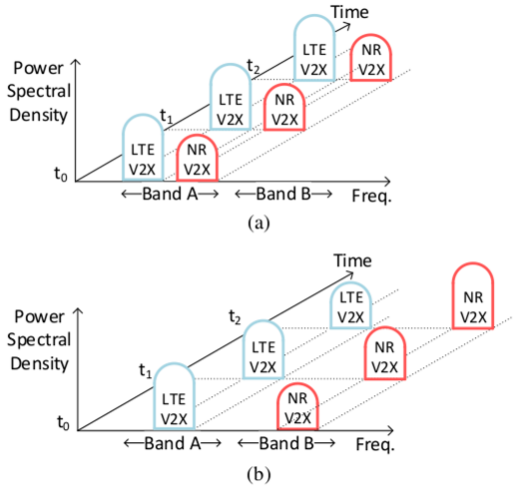


Source: Garcia et al., A Tutorial on 5G NR V2X Communications



Source: Garcia et al., A Tutorial on 5G NR V2X Communications

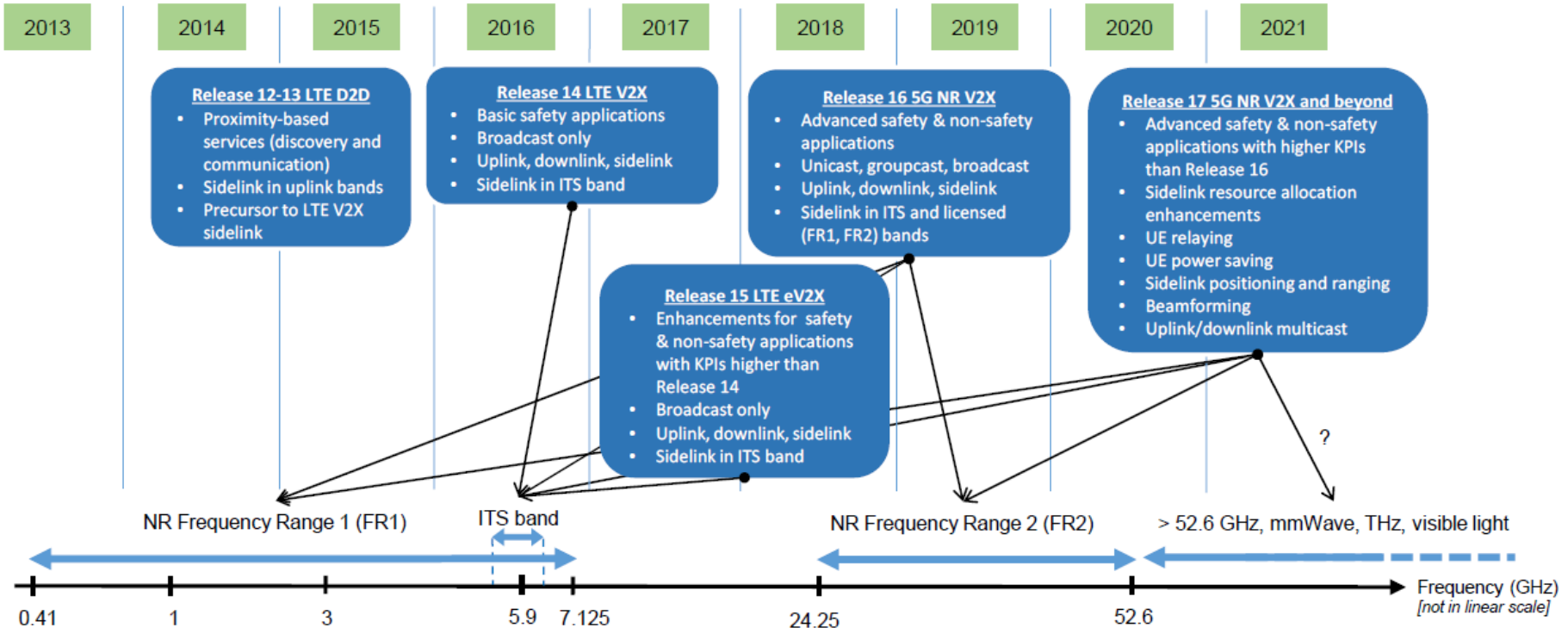
- **Coexistence mechanisms**
  - Time Division Multiplexing(TDM)
    - Statically allocated (gNB+eNB)
    - Dynamically allocated (need geographic coordinates)
  - Frequency Division Multiplexing (FDM)
    - In-band and out-of-band tx power adaptation required



Part VIII

DISCUSSION – ROAD AHEAD AND CHALLENGES

V2X – Roadmap and Timeline



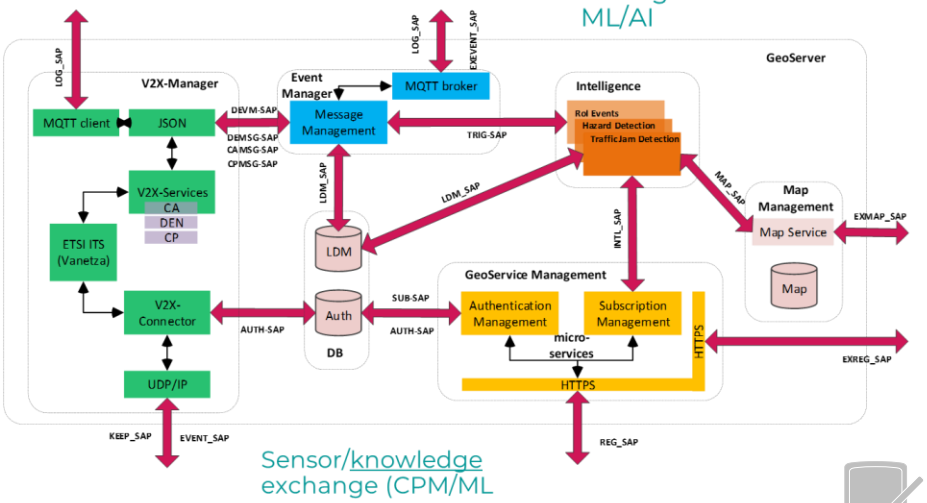
Source: Garcia et al., A Tutorial on 5G NR V2X Communications

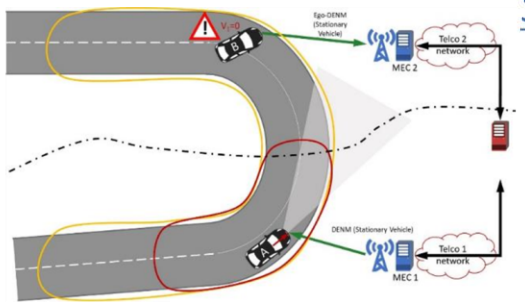
EURECOM
Sophia Antipolis

V2X Services and IoT –Heterogeneous Backend

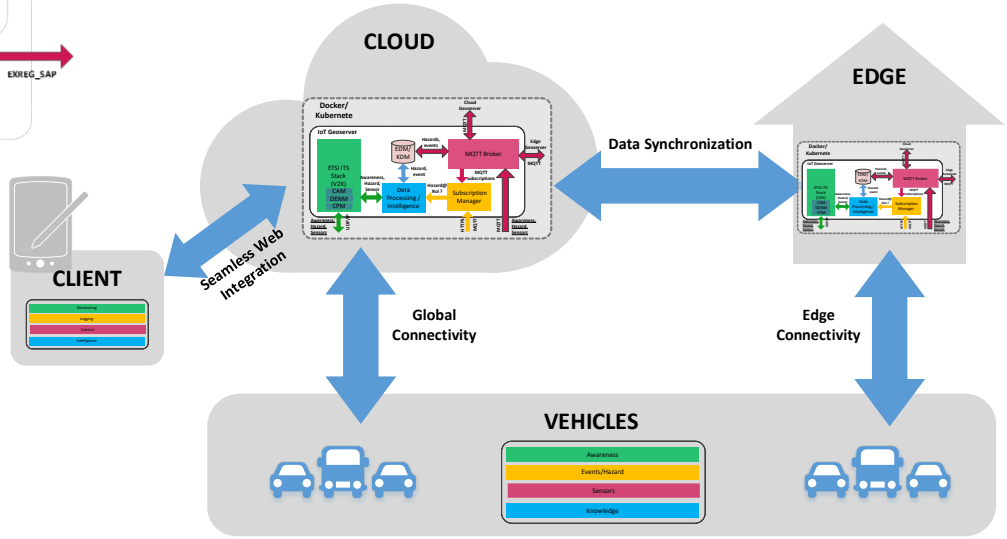
Edge IoT

Edge Geoservice



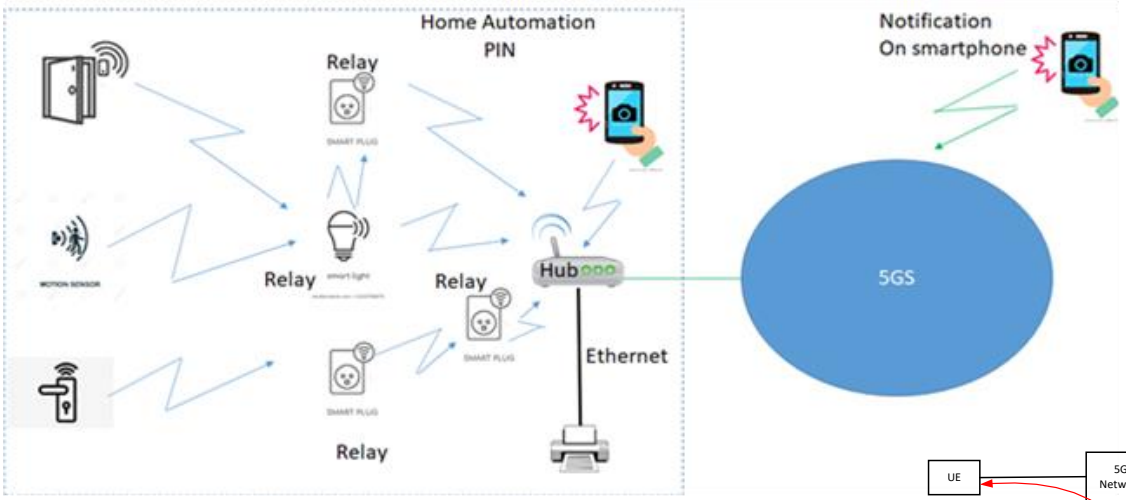


Cross-domain hazard avoidance

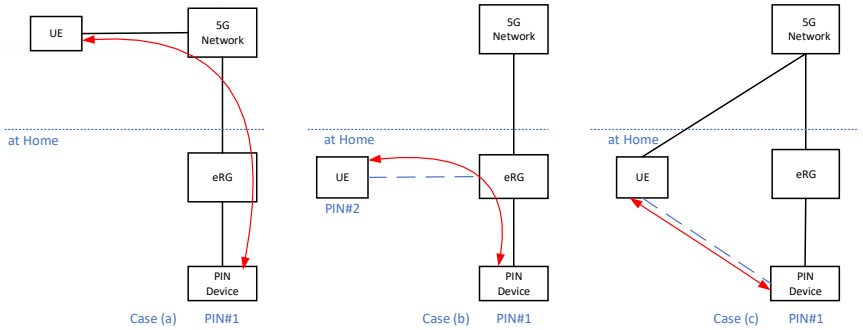


Personal IoT Networks – Heterogeneous Vehicular Networks

- **From Vertical IoT ‘silos’ to decentralized IoT**
  - Applications to vehicular sensors…
  - 3GPP TR 22.859 rel.17



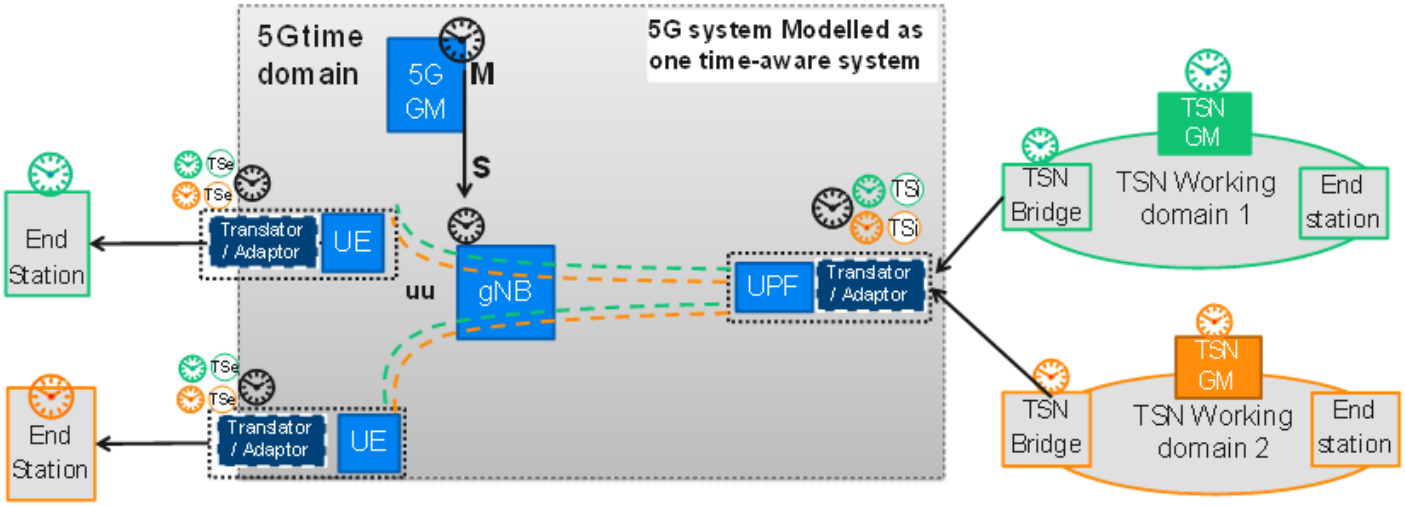
source: 3GPP



EURECOM

Time Sensitive Vehicular Networks (TSVN)

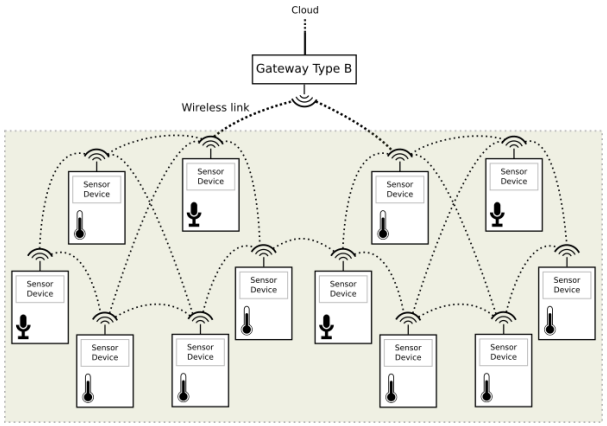
- **TSN as Functional Safety enabler**
  - TSN expected for functional safety of dTLC
  - Fully distributed TSN model is defined in IEEE 802.1Qcc
  - Impact on 5G networks (Cellular IoT or D2D)
  - 3GPP TS 23.734 rel.17

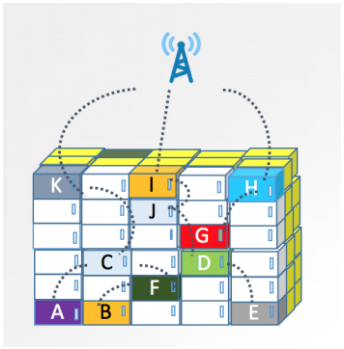


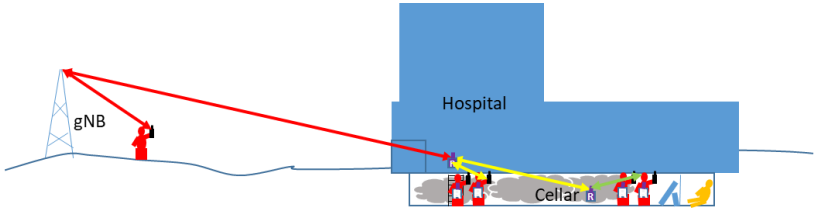
source: 3GPP

5G Cellular Multi-hop Network

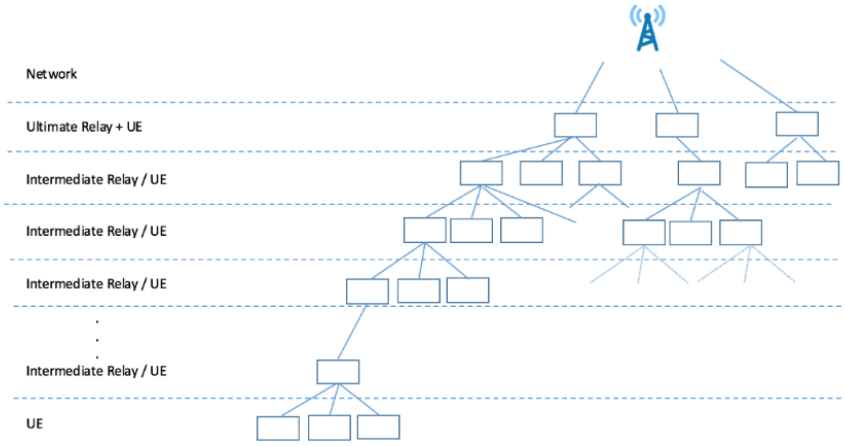
- **UE-2-UE relaying…MACNET is back ?**
  - 3GPP TR 22.866 rel. 17
  - 3GPP TR 38.836 rel. 17







source: 3GPP

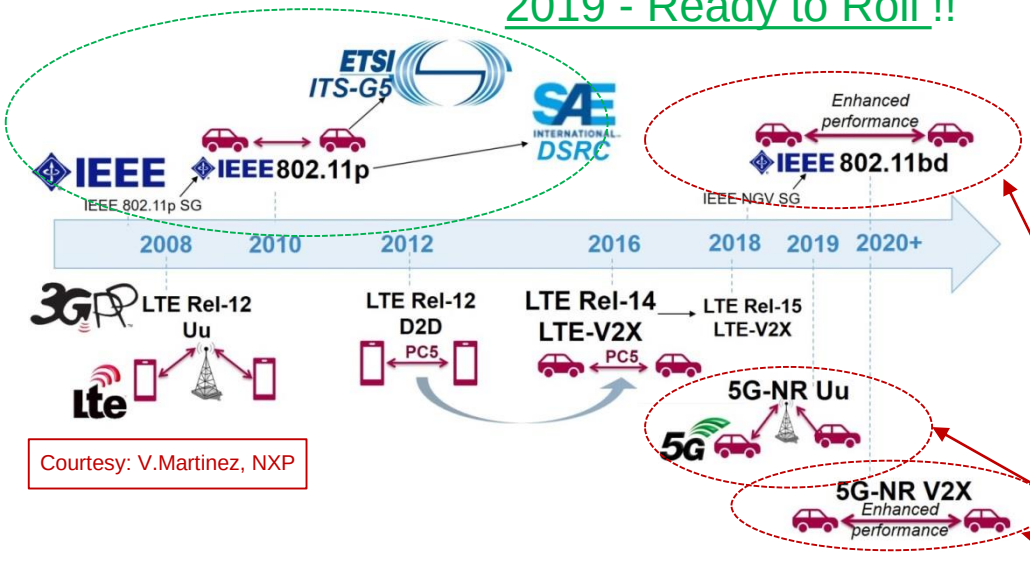


So…what's next ??

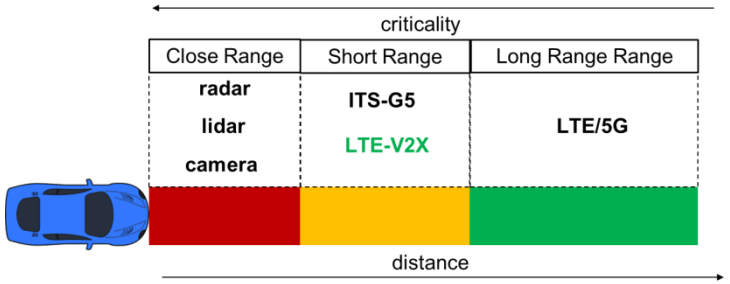
- **Back to Square One !!**
  - …well, not completely..
- **Roadmap for V2X communications**
  - ETSI Standards for multi-technology: completed
  - ETSI first interoperability: successful
  - Latest results of ITS-G5 vs. LTE V2X: comparable results
  - Coexistence studies: progressing…
- **Real Challenge 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)
    - V2X & IoT

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.
- Garcia et al., **A Tutorial on 5G NR V2X Communications**, IEEE Communication Surveys and Tutorials, 2021