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Challenges and Opportunities of WiFi-based V2X Communications

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WiFi-based V2X Communication in a Nutshell IEEE 802.11p / ITS-G5

- **Specification completed in 2010 (IEEE 802.11p-2010)**
  - Later integrated in IEEE 802.11-2012
- **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

CAR 2 CAR
COMMUNICATION CONSORTIUM

- **Key MAC characteristics**

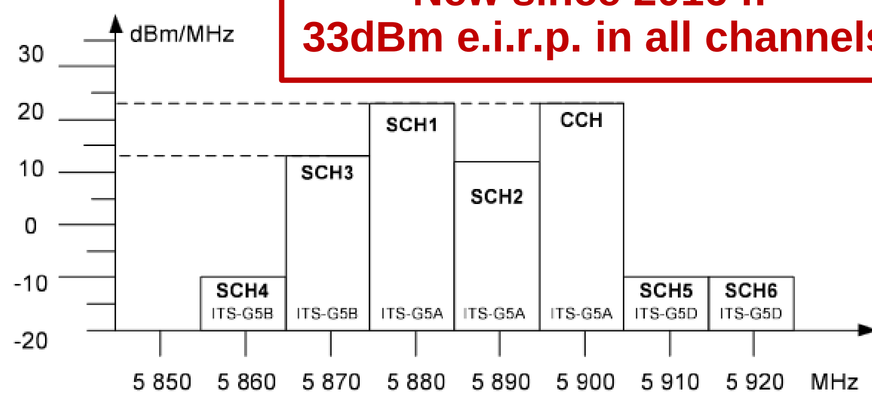
Classic 802.11 WLAN	DSRC/ITS-G5
Synchronizing	**OPTIONAL HIGHER LAYER** Synchronization
Scanning	**NO** Scanning
Authentication	**HIGHER LAYER** Authentication
Association	**IMPLICIT** Association
Communication	**DIRECT** Communication
Concept of Basic Service Sets (BSS)	"Communication outside of the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

Dissection of ETSI ITS-G5 main standards (published 2016)

- **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	

New since 2016 !!
33dBm e.i.r.p. in all channels



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

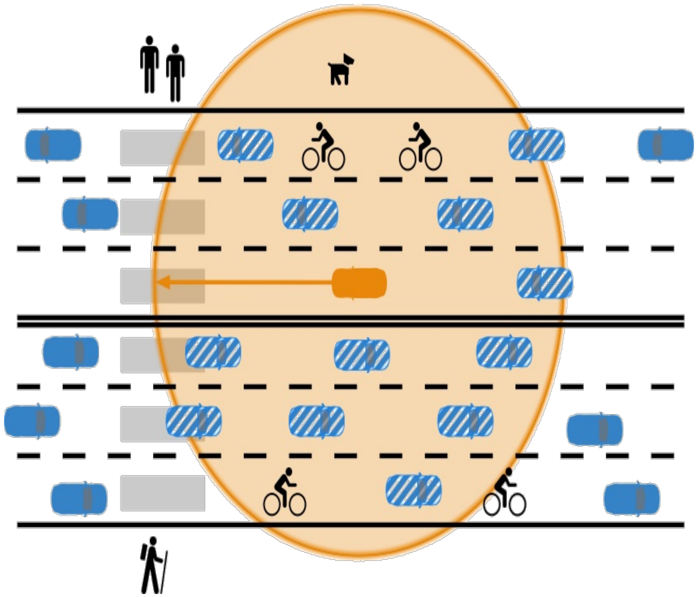
ITS-G5 main Focus: Safety Critical V2X

- Periodical GPS / speed / heading updates (CAM / BSM)

- Geographic broadcast: all of the road users in proximity are recipients

- Purpose: spread and acquire awareness
  - Delay-sensitive information

- Building block for Cooperative Intelligent Transportation Systems (C-ITS)



Challenges of ITS-G5 for V2X Communications

- **Challenging Safety-critical V2X Communications:**
  - Safety-critical application **require 'periodic TX'**
    - DSRC has been optimized for busty traffic
  - **Unacknowledged broadcast traffic** – reliable for low traffic density
    - All cars TX at 10Hz up to 500m – congested channel
  - **Hidden Terminal** – DSRC cannot detect a transmission on the channel
    - Solutions exist for Unicast; not for Broadcast
    - Low mutual mobility & Similar transmit range
      - Recurring hidden terminal on same nodes

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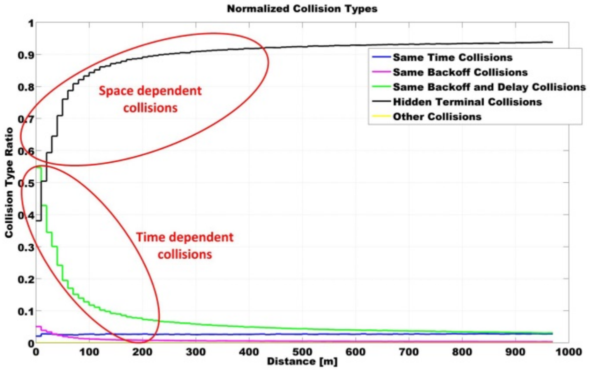
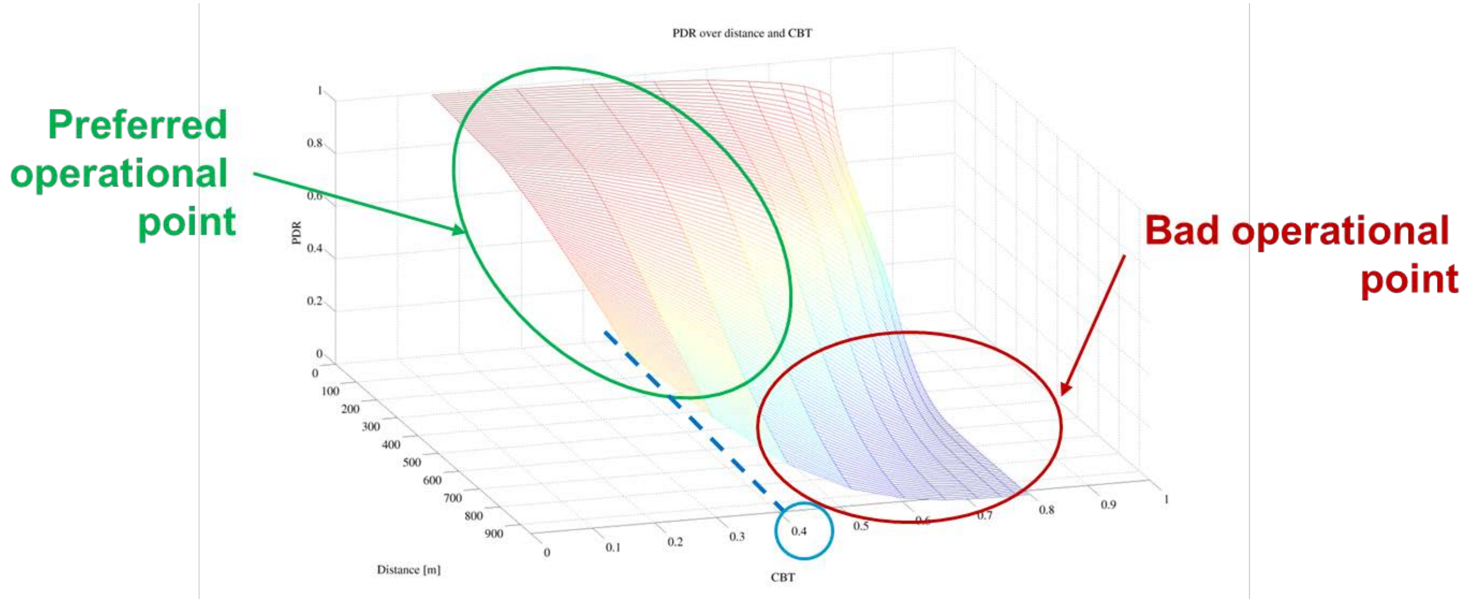


- **The underlying challenge:**
  - **Dependable 1-hop broadcast !!**
    - In space & in time

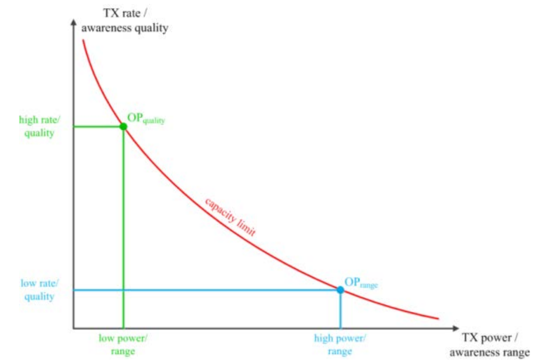
ITS-G5 Challenge - Dependable 1-Hop Broadcast

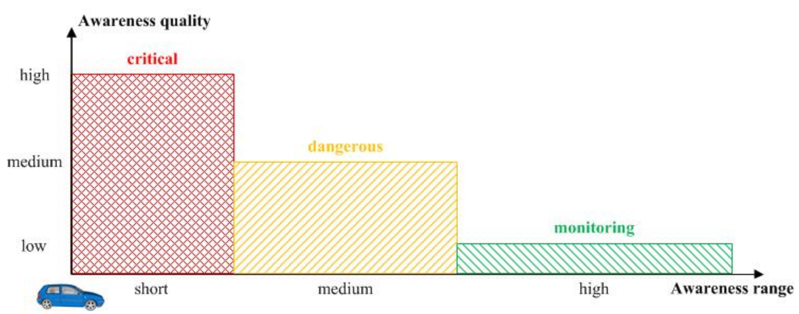
- **<u>Reminder</u>: WLAN and does not provide real QoS services**
  - Using broadcast: not any feedback on correct transmission !
  - Need to 'trust' WLAN
- **<u>Rule of thumb</u>:**
  - The IEEE 802.11p system works fine at **'medium' channel load**
  - What is 'medium??

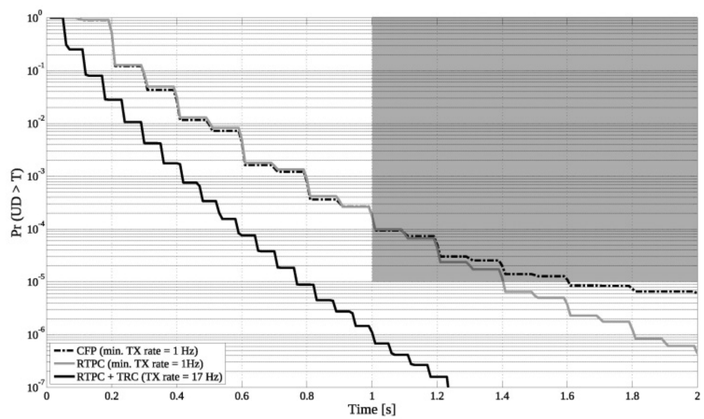


Decentralized Congestion Control for Dependable 1-Hop Broadcast for ITS-G5

- **Strategy: Decentralized Congestion Control**
  - Adjust Tx parameters to maintain the channel load in an operational limit
    - Called RRM in 3GPP
  - Based on cooperation between vehicles
  - Mostly adaptation of Tx power and scheduling (flow control)



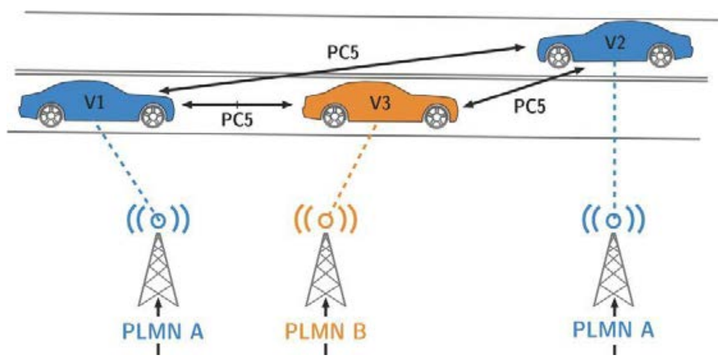




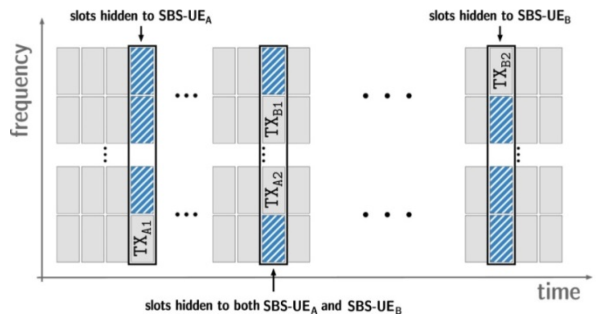
- **Selected Publications:**
  - Bernhard Kloiber, Jérôme Härri, Thomas Strang, Stefan Sand, Cristina Rico Garcìa, **Random Transmit Power Control for DSRC and its Application to Cooperative Safety**, *IEEE Transaction of Dependable and Secured Communication,* 2015
  - Bernhard Kloiber, Jérôme Härri, Thomas Strang, **Dice the TX power - Improving awareness quality in VANETs by Random Transmit Power Selection**, *IEEE Vehicular Networking Conference (VNC)*, 2012.
  - Fatma Hrizi, Jérôme Härri, Christian Bonnet, **Can Mobility Predictions be Compatible with Cooperative Active Safety for VANET?**, Prof of the *9th ACM Workshop on VehiculAr Inter-NETworking, Systems, and Applications (VANET),* 2012.
  - Miguel Sepulcre, Javier Gonzalvez, Jérôme Härri, Hannes Hartenstein, **Contextual Communications Congestion Control for Cooperative Vehicular Networks**, *IEEE Transaction on Mobile Computing, 2011.*

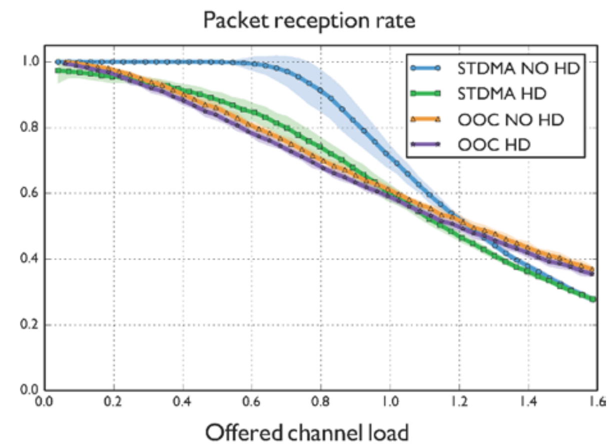
Decentralized Congestion Control for Dependable 1-Hop Broadcast for Cellular Ad-Hoc LTE-V2X

- **LTE-V2X Radio Resource Management**
  - Supervised: centralized RRM/CC (eNB)
  - Unsupervised: distributed RRM/CC
    - Challenge: avoid collision !!
  - Resource Allocation Mechanism:
    - Random – Optical Orthogonal Codes
    - TDMA – Self-Organized TDMA



- **LTE-V2X Mode 4 (unsupervised)**
  - Advantage:
    - Does not rely on any infrastructure
  - Drawback
    - Synchronization
    - Half-duplex
    - …



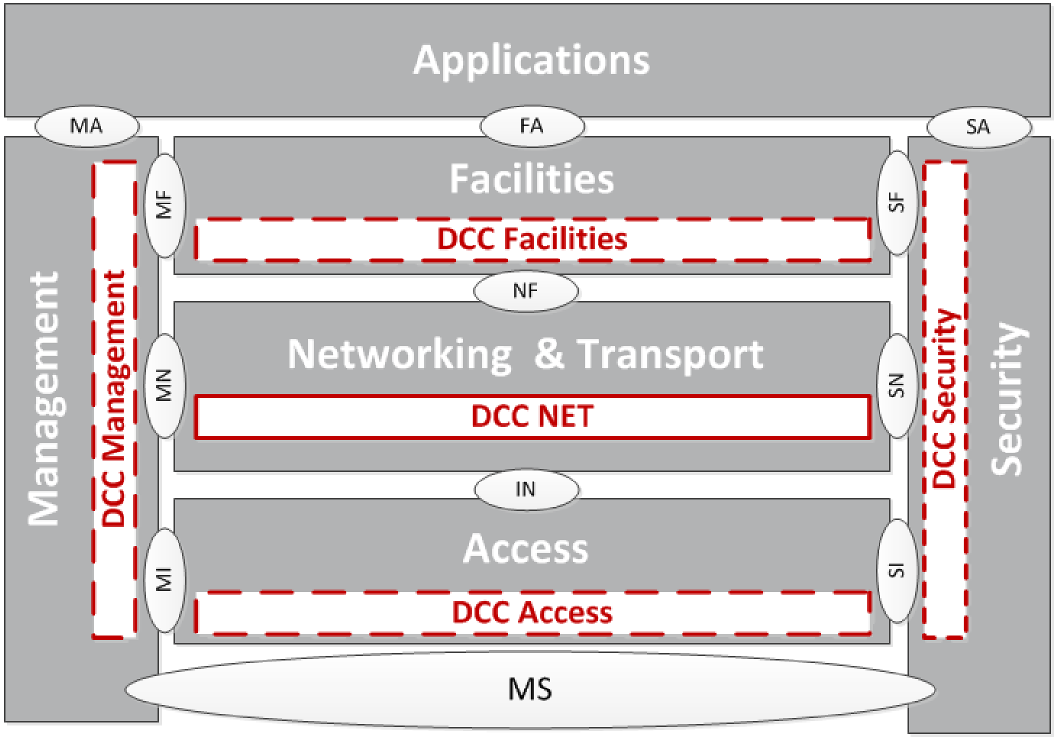


- **Selected Publications:**
  - Laurent Gallo, Jérôme Härri, **Unsupervised LTE D2D -– Case Study for Safety-Critical V2X Communications**, *IEEE Vehicular Technology Magazine, 2017.*
  - Laurent Gallo, Jérôme Härri, **Analytical Study of Self-organizing TDMA for V2X Communications**, *1st IEEE ICC Workshop on Dependable Vehicular Communications*, 2015
  - Gallo, Laurent; Härri, Jérôme**, Short paper: A LTE-direct broadcast mechanism for periodic vehicular safety communications**, *IEEE Vehicular Networking Conference (VNC)*, 2013.

ETSI DCC Architecture (TS 103 175, TS 102 687, TS 102 636-4-2)

- **The Wireless Vehicular Radio Channel has limited resource**
  - WiFi is only best effort
  - In Ad-hoc (OCB): requires coordinated access

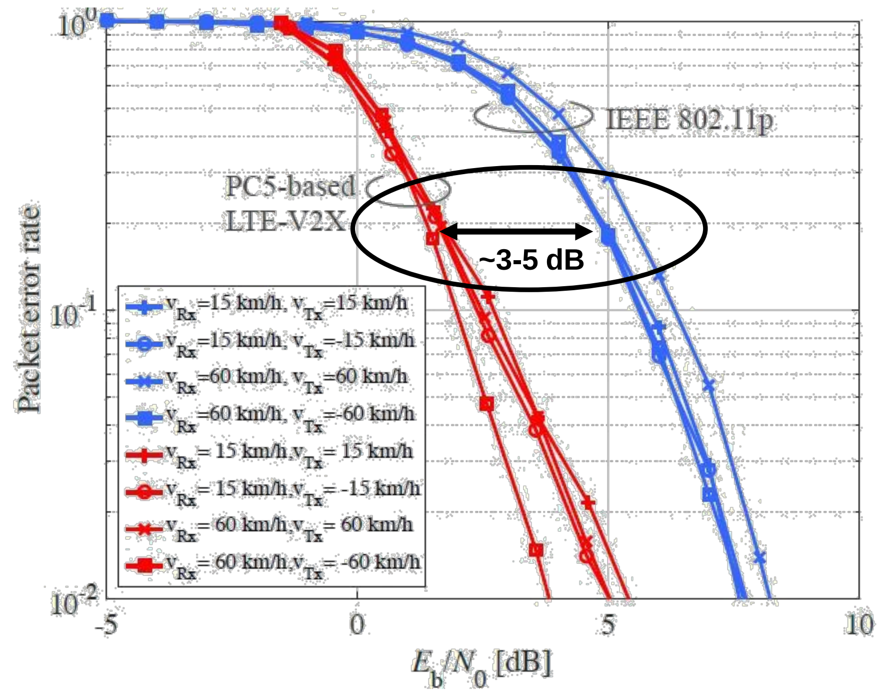
- **DCC controls the load with various mechanisms**
  - Adjust Tx Rate – DCC FAC
  - Adjust Tx Power – DCC NET
  - Adjust Modulation (MCS) – DCC FAC
  - Adjust Sensing Threshold – DCC ACC
  - Offloading on different channels – DCC MGMT



ITS-G5 RELEASE 2

ITS-G5 – competition from LTE-V2X

- **LTE-V2X v.s. ITS-G5**
  - A PHY-layer Comparison
  - Observation:
    - LTE-V2X performs better than ITS-G5
      - ~3-5dB increase
    - This increase comes from the superior features of LTE
      - Turbo-codes
      - Antenna Diversity
      - ….



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

- **Is ITS-G5 doomed?**
  - No, as LTE enhanced PHY features also exist in SotA WLAN

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

- **Input currently under discussions at the CAR 2 CAR**
  - <u>Objective</u>: > 5dB gain

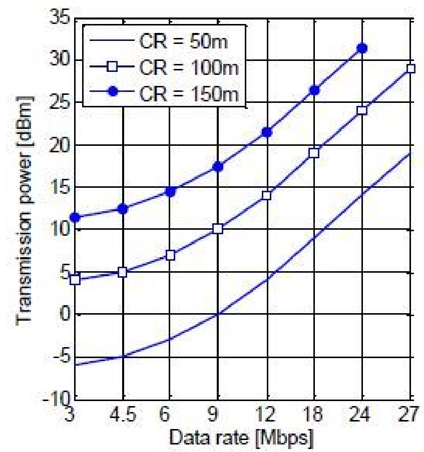
ITS-G5 rel. 2 – Enhanced Channel Usage

- **ETSI EN 302 571 specifies a default QPSK ½ modulation (6mbps) modulation on CCH**
  - Why? Seminal work (2008)
    - D. Jiang, Q. Chen, L. Delgrossi, “Optimal data rate selection for vehicle safety communications”, Proc. ACM international workshop on VehiculAr Inter-NETworking (VANET), San Francisco, California, USA, pp. 30-38, 15 Sept. 2008.
  - Hypothesis: **Constant TX power**
    - Hypothesis no longer valid…

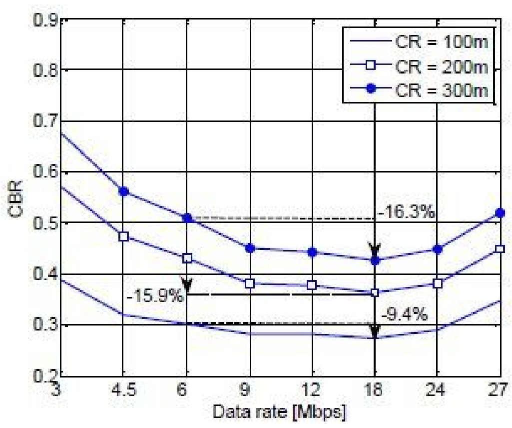
- **What is then the ‘optimal’ data rate for CCH?**
  - Recent paper (**2017**):
    - M. Sepulcre, J. Gozalvez, B. Coll-Perales "Why 6Mbps is not (always) the Optimum Data Rate for Beaconing in Vehicular Networks", IEEE Transactions on Mobile Computing, Early Access, 2017.
  - Conclusions: default data rate can go up to 18 Mbps on CCH
    - **Up to 3x channel capacity of ITS-G5 rel. 1**

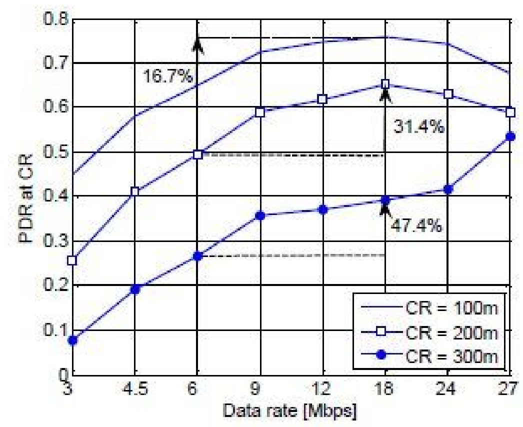
ITS-G5 rel. 2 – Enhanced Channel Usage

- **Principle:**
  - Joint adjustment of Tx power and data rate to optimize the channel occupancy 'footprint'
    - <u>In a nutshell</u>: considers the impact of Tx power in perturbing remote neighbors
  - <u>Objective</u>: adjusting Tx power (and modulation) to guarantee a 95% PDR at a given TX range



- **ITS-G5 default 18 mbps on CCH**
  - The Channel Load (CBR) is reduced by 9%-16% as function of the intended distance
  - The Packet Delivery Ratio is improved by 16%-47%





<u>Source</u>: M. Sepulcre, J. Gozalvez, B. Coll-Perales "Why 6Mbps is not (always) the Optimum Data Rate for Beaconing in Vehicular Networks", IEEE Transactions on Mobile Computing

ITS-G5 rel. 2 – Enhanced Information Exchange

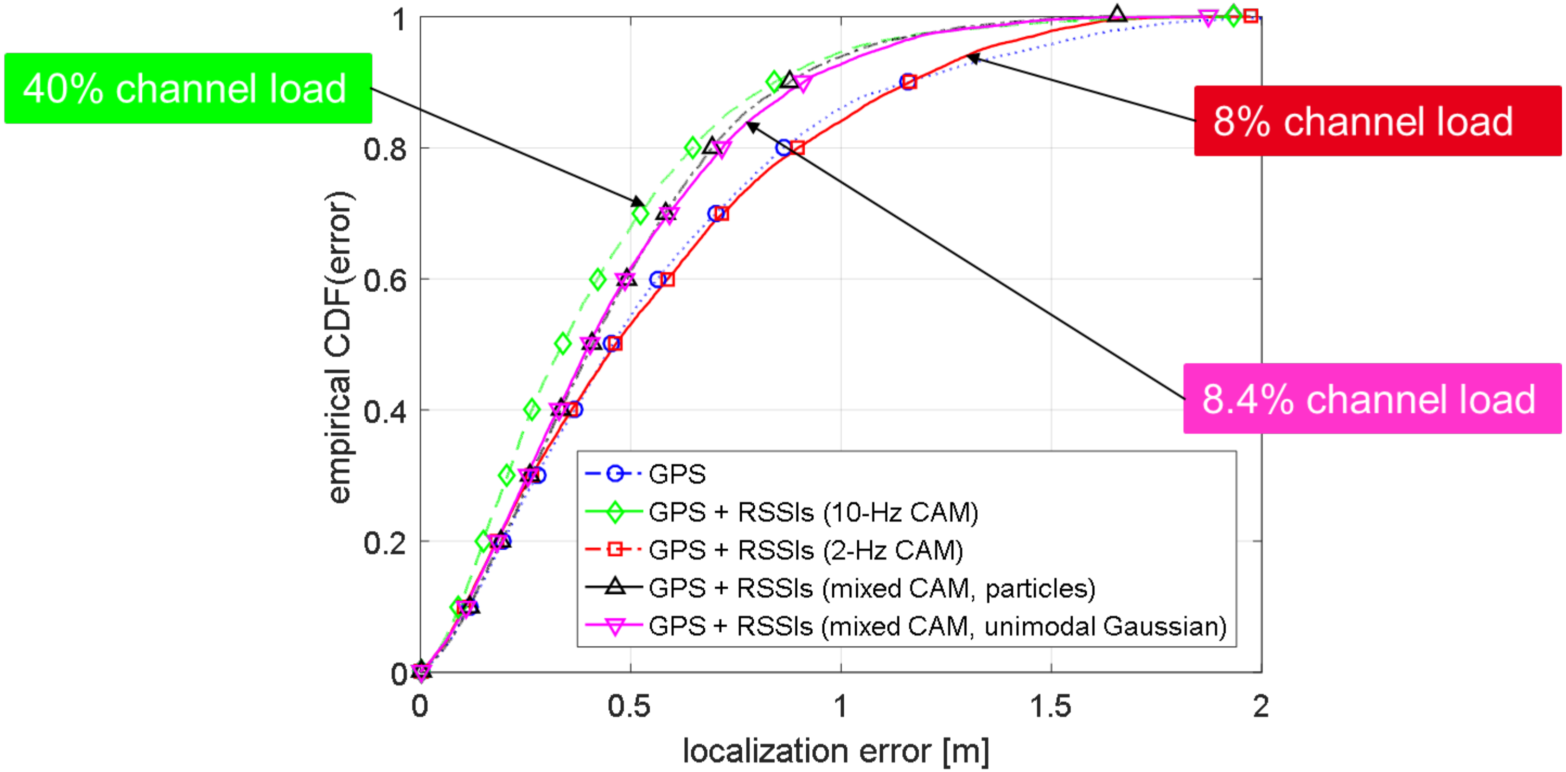
- **V2X Safety-related Communication is all about CAM (Cooperative Awareness Message)**
  - Periodic transmission of the sender's GPS + Speed + other info
  - <u>Day 1</u> – 10Hz default Tx rate
    - Require congestion control to keep good performance
  - <u>Day 2</u> – aims at > 30Hz Tx rate
    - CCH might not sustain it…but is it the real objective?
- **Objective: all neighbors know the highly precise (> 25cm) position of a sender**
  - <u>Generic figure</u>: at 20m/s, requires 100Hz
    - Yet, GPS has 2-20m error
    - Seeking higher rate does not make any sense !
  - New messages are being discussed
    - CAM - for baseline TX
    - Tiny CAM (<< CAM) - for enhanced position

Standard CAM
(Actually "fat" due to location info)

"Tiny CAM"*
(Just the ID / ~ping message)

ITS-G5 rel. 2 – Enhanced Information Exchange

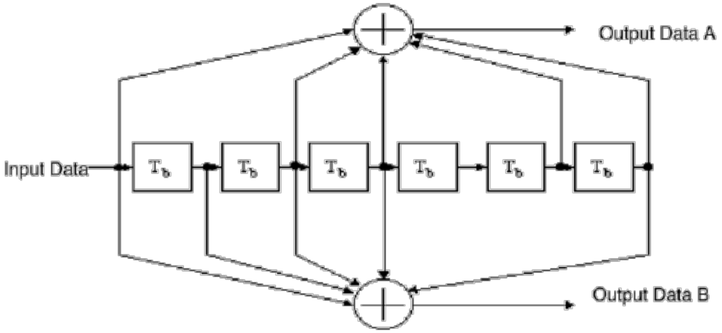
- **New types of message and TX strategy**
  - Divides the channel load by 5
  - No loss in precision



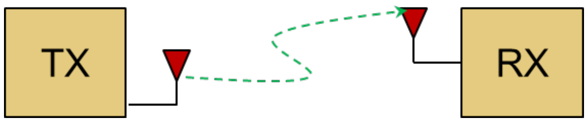
Source: Hoang, Denis, Härri, and Slock , On communication aspects of particle-based cooperative positioning in GPS-aided VANETs, IEEE Intelligent Vehicles Symposium, June 19-22, 2016,

ITS-G5 Rel. 2 - Enhanced PHY

- **Main limitations of the ITS-G5 PHY:**
  - Convolutional Encoder
  - No Antenna Diversity
    - MIMO not applicable, but basic antenna diversity OK
  - Channel estimation
    - Estimation only before packet Tx
  - Time allocation (OFDM)
    - No Frequency allocation (OFDMA)
  - Subject to hidden terminals
    - Graceful degradation with distance
  - Capacity limits (27Mbps)



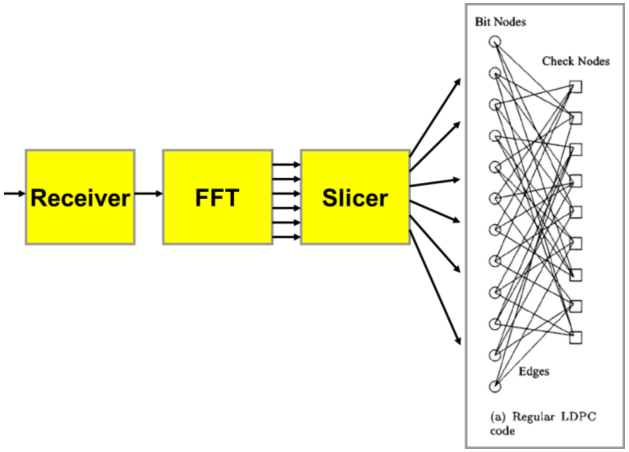
Source: IEEE 802.11-2012



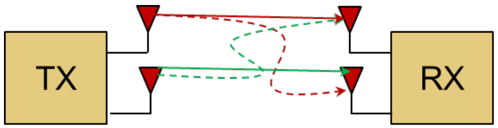
ITS-G5 Rel. 2 - Enhanced PHY
Enhanced 802.11ac overview

- **Some History:**
  - Amendment to IEEE 802.11-2012
    - Integrated in 2014
  - <u>Objective</u>: 1Gbps

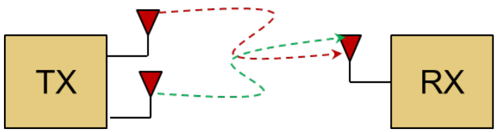
- **Main features**
  - Physical Layer:
    - LDPC coding
    - STBC code (antenna diversity)
    - Enhanced channels width: 80Mhz, 160Mhz



Source: IEEE 802.11-2012



2x2 MIMO



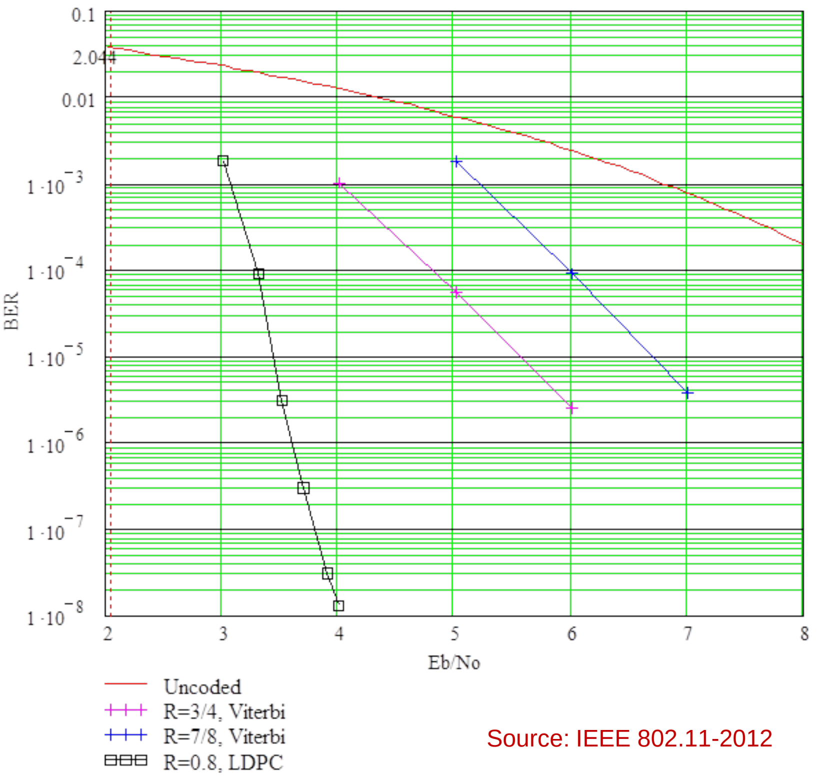
2x1 Legacy

ITS-G5 Rel. 2 - Enhanced PHY
Enhanced 802.11ac overview

- **LDPC vs. Conv. Codes Comparison**

- **LDPC codes get closer to optimal Shannon capacity**
  - At Pe = 10^{-5} the LDPC code is <1.5dB from Capacity.

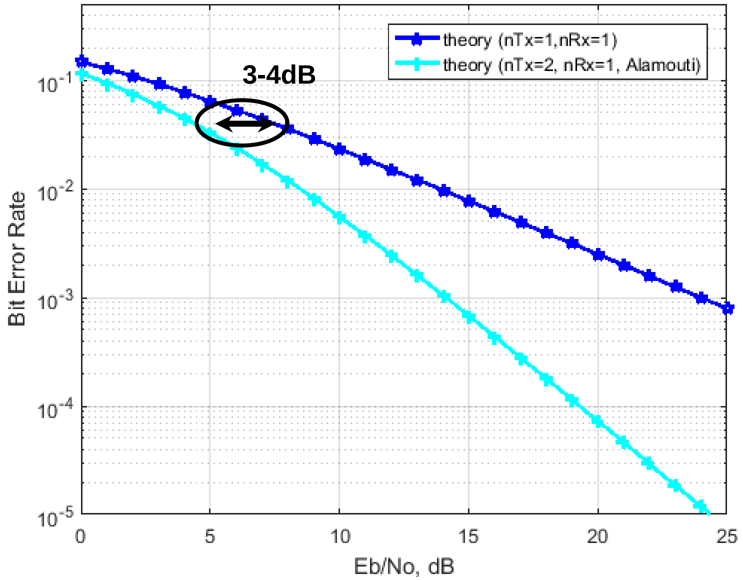
- **<u>Challenges in V2X</u>:**
  - High Mobile Channel…
    - LDPC might need specific codes
    - LDPC: might not be adapted..
  - To be investigated in CAR 2 CAR in 2017/2018



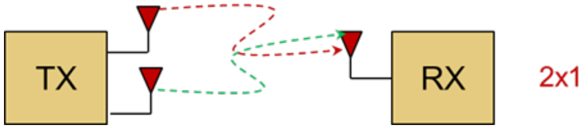
Source: IEEE 802.11-2012

ITS-G5 Rel. 2 - Enhanced PHY
Enhanced 802.11ac overview

- **STBC - Alamouti Space-Time Schema:**
  - $S = \begin{pmatrix} s_1 & s_2 \\ s_2^* & s_1^* \end{pmatrix}$
  - Time domain: two symbols transmitted in two time slots
  - Frequency domain: complex conjugate next/previous symbol

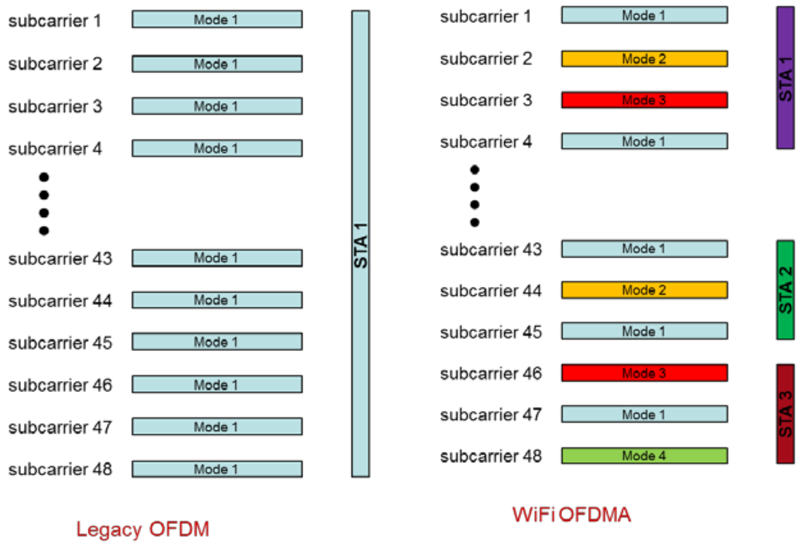


- **STBC provides an enhanced BER**
  - already 2-3 dB gain in a 2Tx, 1RX configuration
  - Potentially better for 2x2 MIMO…
- **Challenges in V2X:**
  - **None..it can already be done !!**
    - Most cars have 2 antennas
    - CohdaWireless claims it can do it already
      - ☞ will test it on our campus…



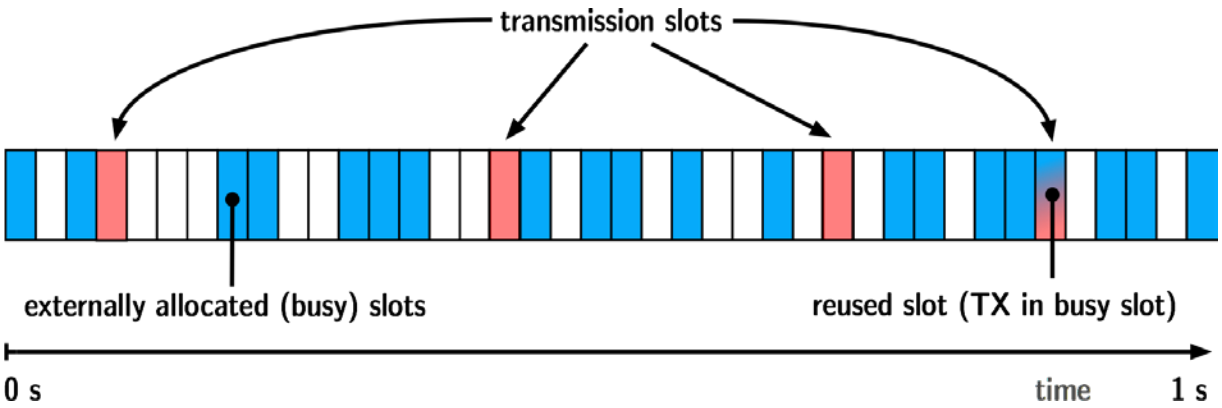
ITS-G5 Rel. 2 - Enhanced PHY/MAC IEEE 802.11ax overview

- **Some History:**
  - Amendment to IEEE 802.11-2012
    - To be integrated in 2019
  - Objective: 10Gbps
- **Main features:**
  - Physical Layer:
    - OFDMA
    - 1024 QAM & MU-MIMO
    - Sub-Carrier-based modulation/allocation
- **<u>Challenge in V2X</u>:**
  - IEEE 802.11ax OCB mode not clear !!



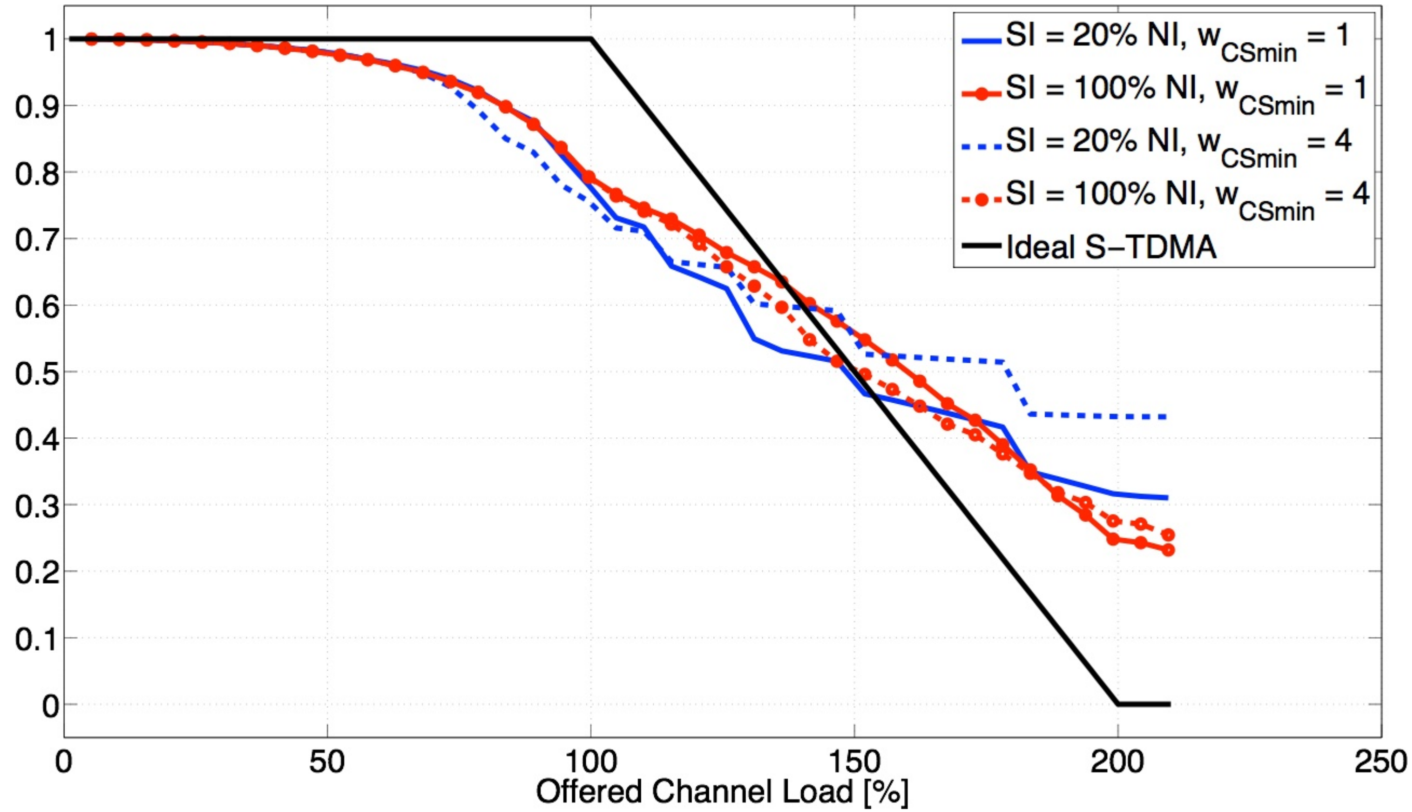
ITS-G5 Rel. 2 – Enhanced MAC
Self-Organizing TDMA

- **Optimized MAC for periodic resource allocation**
  - Provides bounds to channel access time
- **Already applied in airborne / shipborne operations for periodical position reporting**
- **Context-aware channel access**
  - Access delay bounds !!
- **Challenge in V2X:**
  - **None…considered by ETSI as alternative to CSMA/CA [TR102861]**



ITS-G5 Rel. 2 – Enhanced MAC
Self-Organizing TDMA

- **S-TDMA – analytical evaluation**
  - Still provides 80% PDR at 100% Channel Load



ITS-G5 Rel. 2 – Opportunities

- **Short Term Opportunities**
  - Increased/adaptive default ITS-G5 modulation (18 mbps)
    - Up to 40% PDR at 300m
  - Antenna Diversity – 2 Tx antennas, 1 Rx antenna
    - Up to 4dB gain (increased range & reliability)
  - Differentiated packet transmissions (CAM + tiny CAM)
    - 1/5 channel capacity at same location precision

- **Medium Term Opportunities**
  - LDPC support (with backward compatibilities)
    - Up to 3dB gain
  - STBC (Alamouti) 2x2
    - Up to 3dB gain

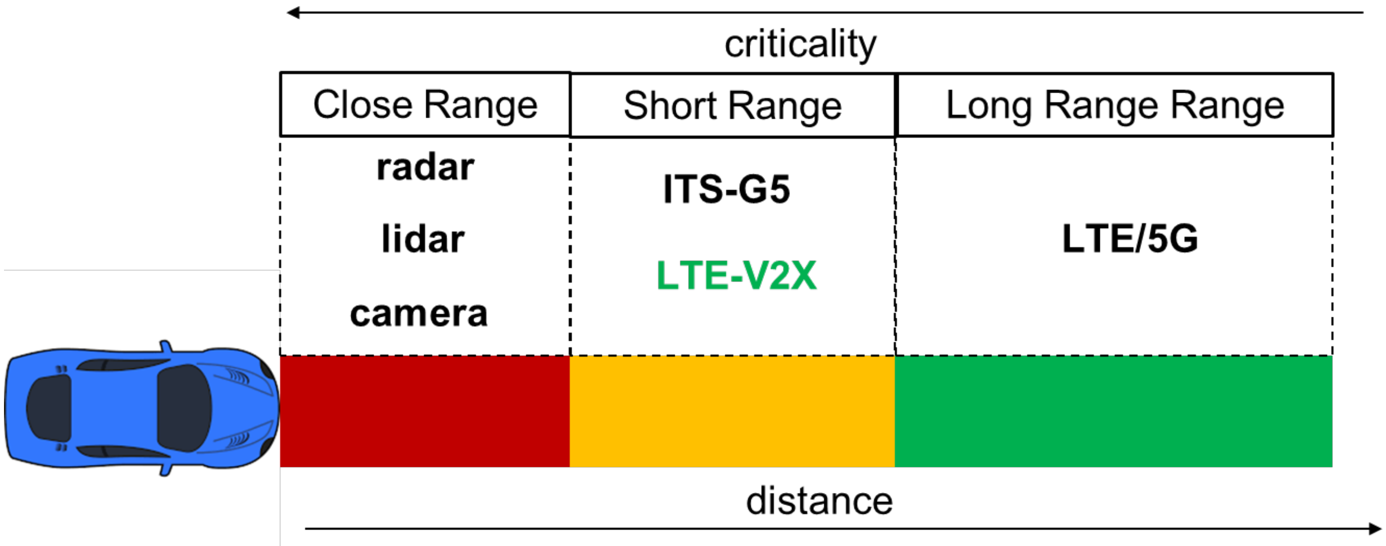
- **Longer Term Opportunities**
  - optimized MAC

Key Message – ITS-G5 is not the issue; rather the way we use it !!

V2X Communication Redundancy

- **Future HAD will be critically based on V2X communication**
  - So far, one technology only (ITS-G5) !
    - can fail, can be hacked, can be jammed
- **Parallel to Avionics**
  - Redundant Paths – each communication path is redundant !!
  - Functional Redundancy – each function is redundant !!
    - Example: Speed measurement: 3 probes from at least two constructors
  - Design Diversity – different computer design, different software development tools, etc…
- **What about future Autonomous Cars (cars in 'autopilot') ?**
  - Will also need similar strategies….
- **LTE-V2X and ITS-G5 two different technologies aiming at providing a similar service…**
  - Friends or Foes ?

ITS-G5 & LTE-V2X – Friends or Foes ?



- **Redundant V2X Communication**
  - Required for fully dependable V2X communication
  - Based on **Design Diversity**
    - Different Technology
    - Different Protocols
    - Different Frequency Range

Coexistence ITS-G5 – LTE-V2X

- **5GAA White Paper (under work)...**
- **Based on the technology neutrality of the ITS-G5 band**
  - Both ITS-G5 and LTE-V2X *could* 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
- **Challenges for V2X (and ITS-G5):**
  - 10Mhz space not sufficient to avoid co-channel interference
  - LTE-V2X and ITS-G5 would need to be synchronized even in different channels
    - ITS-G5 signal will blind LTE-V2X when active..
  - Separation antennas (on board of cars) not sufficient for dual TX
  - …

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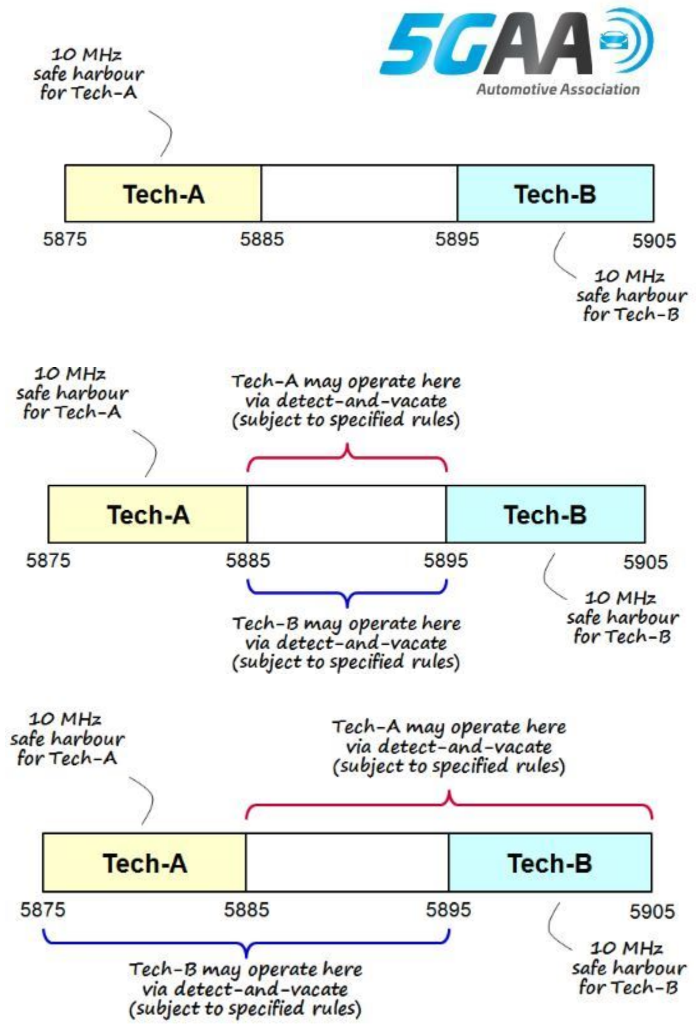

Conclusions

- **ITS-G5 is the <u>only current technology</u> than can provide <u>critical safety communication</u> at that time..**
  - **ITS-G5 is available now !!**
- **ITS-G5 has limitations…**
  - The CAR 2 CAR Consortium initiated work on a ITS-G5 release 2
    - <u>Objective</u>: release 2 ready when LTE-V2X will be ready
- **Yet, LTE-V2X is a promising technology**
  - The current ‘fight’ between LTE-V2X and ITS-G5 is senseless…
  - LTE-V2X and ITS-G5 should instead be seen as two complementary technologies required for future HAD
    - HAD will not work with only one of them…both are required !!
- **ITS-G5 roll-out is actually an asset for LTE-V2X**
  - will make it better !!

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BACKUP SLIDES

ITS-G5 & LTE-V2X – Friends or Foes ?