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V2X Communications for Autonomous Driving – Roadmap for WiF-V2X and Cellular-V2X

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Cooperative Communication for Automated Driving - WiFi-based V2X ITS-G5

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

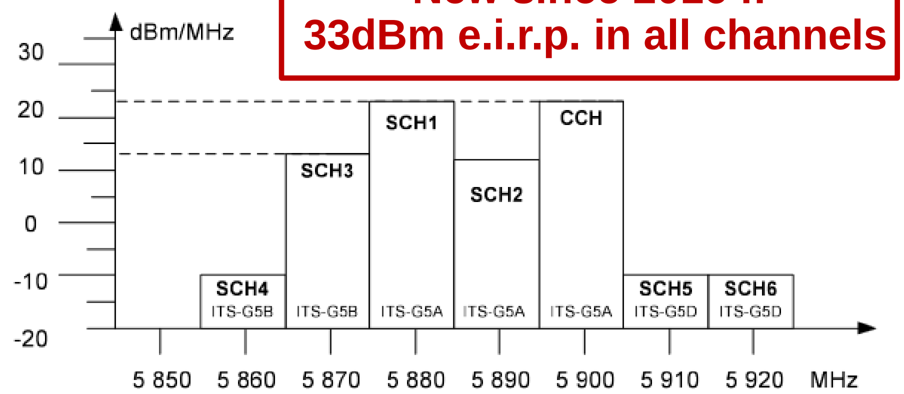
- **Key characteristics**
  - 5.9 GHz frequency domain
  - Based on IEEE 802.11a (OFDM PHY)
  - BCC encoder
  - 10 MHz channel bandwidth
  - Rates: 3, 4.5, 6, 9, 12, 18, 24, 27 Mbps
  - Operates without a BSS

CAR 2 CAR
COMMUNICATION CONSORTIUM

- **ITS Frequency Band**

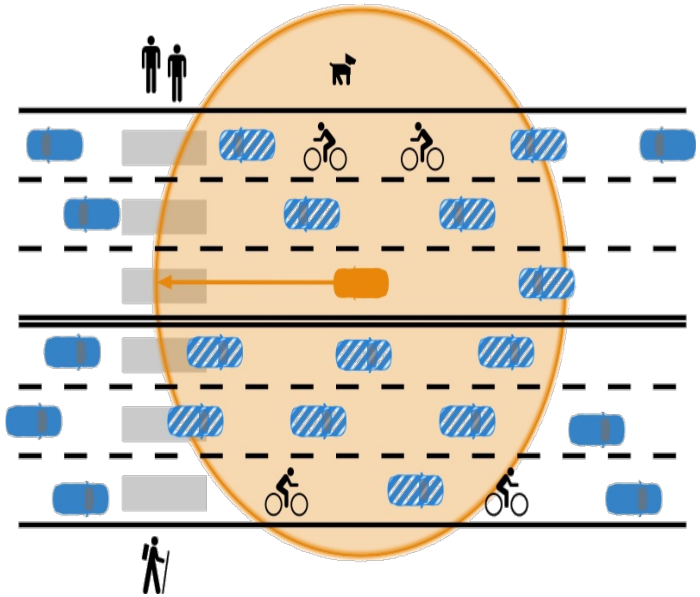
Name	Center Frequency	Type
SCH6	5920	ITS-G5D - Future ITS
SCH5	5910	
SCH4	5860	ITS-G5B - Non-Safety related
SCH3	5870	
SCH2	5880	ITS-G5A - Safety-Related
SCH1	5890	
CCH	5900	

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



ITS-G5 main Focus: Safety Critical V2X

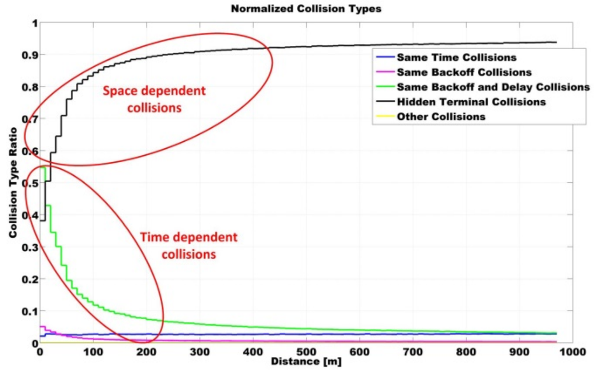
- Periodical GPS / speed / heading updates (CAM / BSM)
- Geographic broadcast: all of the road users in proximity are recipients
- Purpose: spread and acquire awareness
  - Delay-sensitive information
- Building block for Cooperative Intelligent Transportation Systems (C-ITS)



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

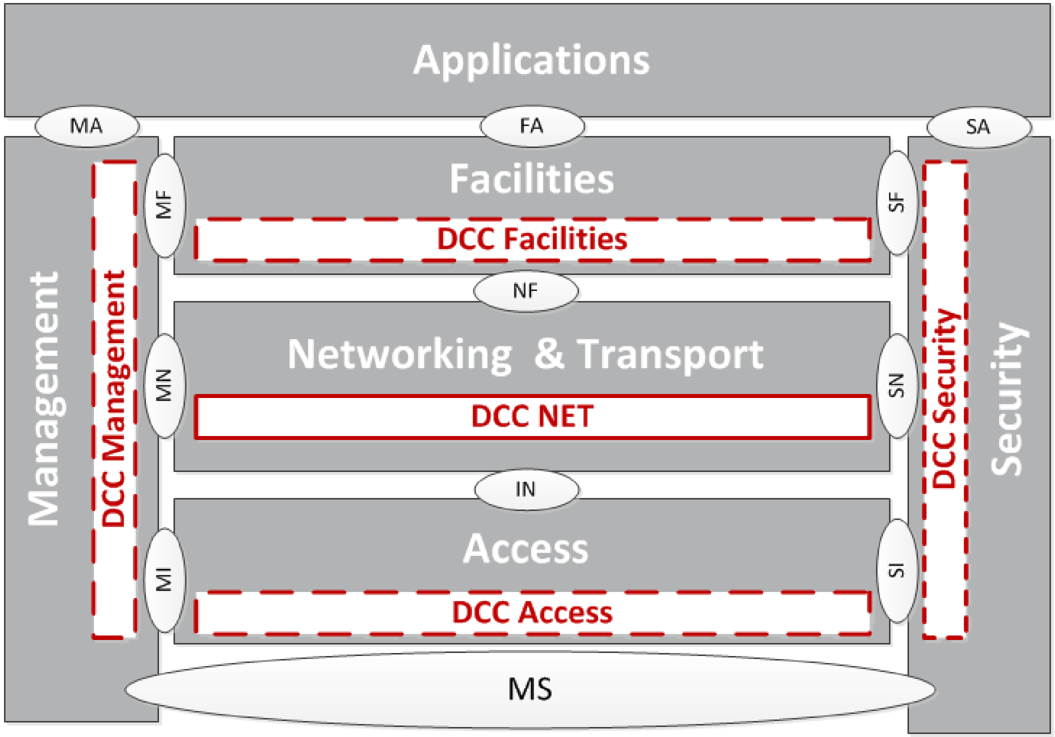
- **The underlying challenge:**
  - **Dependable 1-hop broadcast !!**
    - In space & in time



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

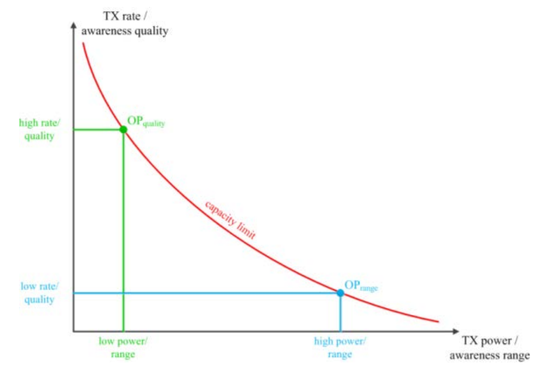
- **The Wireless Vehicular Radio Channel has limited resource**
  - WiFi is only best effort
  - In Ad-hoc (OCB): requires coordinated access

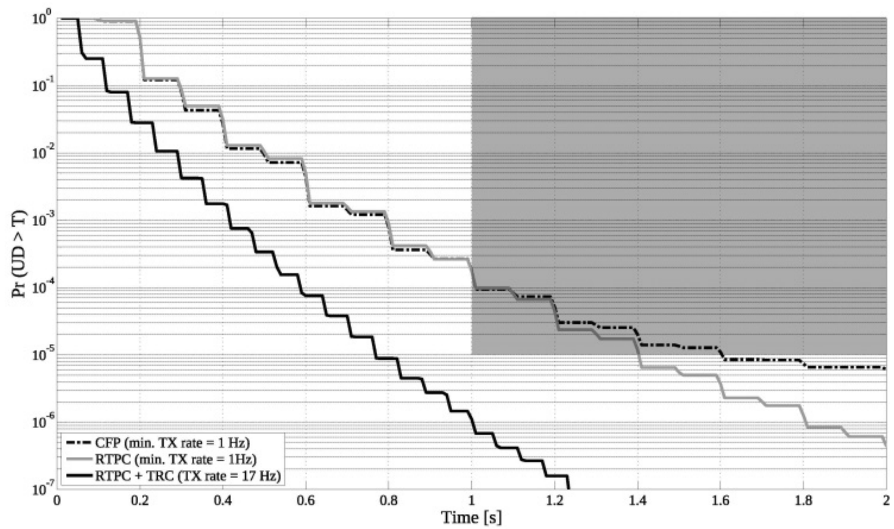
- **DCC controls the load with various mechanisms**
  - Adjust Tx Rate – DCC FAC
  - Adjust Tx Power – DCC NET
  - Adjust Modulation (MCS) – DCC FAC
  - Adjust Sensing Threshold – DCC ACC
  - Offloading on different channels – DCC MGMT

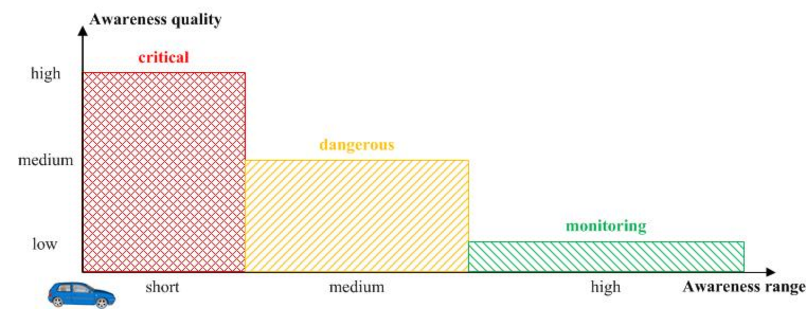


Decentralized Congestion Control for ITS-G5

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







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

DAY 2 C-ITS Applications

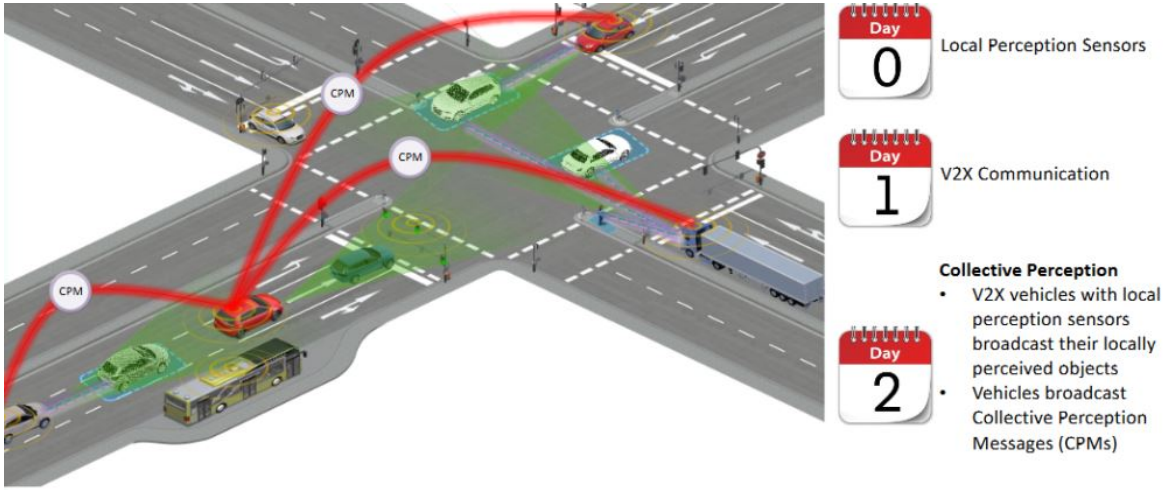
NEW WORK ITEMS AND MESSAGE SETS

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 Manoeuvre Coordination Service
- TR 103 579 Charging/Tolling applications via ITS-G5 pre-standardisation study
- TR 103 439 Multi Channel Operation study

Sharing Sensor Information for Automated Vehicles

- **Collective Perception Message (CPM) –**
  - TS 103 324, TR 103 562



Source: Hendrik-Jörn Günther (VW), ETSI

- **Message Structure:**
  - As CAM – one-hop broadcast
  - Contains Raw & Processed Sensor data of a car
    - Can also piggyback those from one car in front

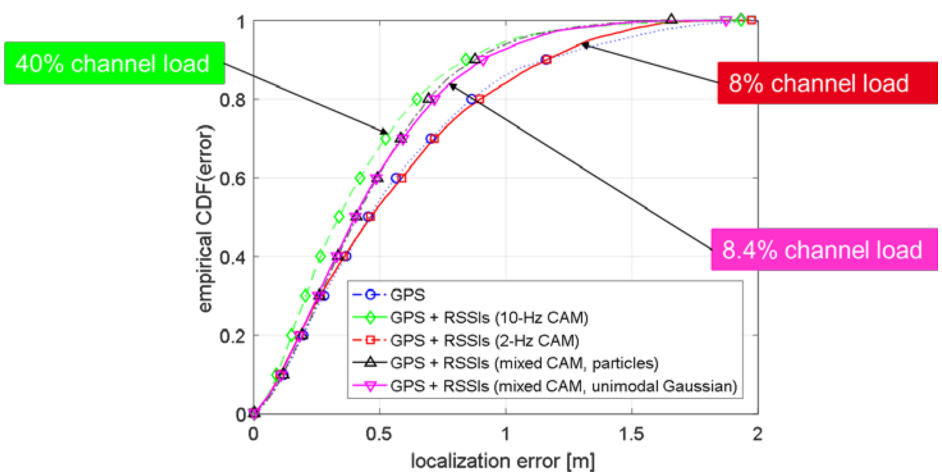
ITS-PDU header	Origin Station	Sensor Information	Detected Objectt

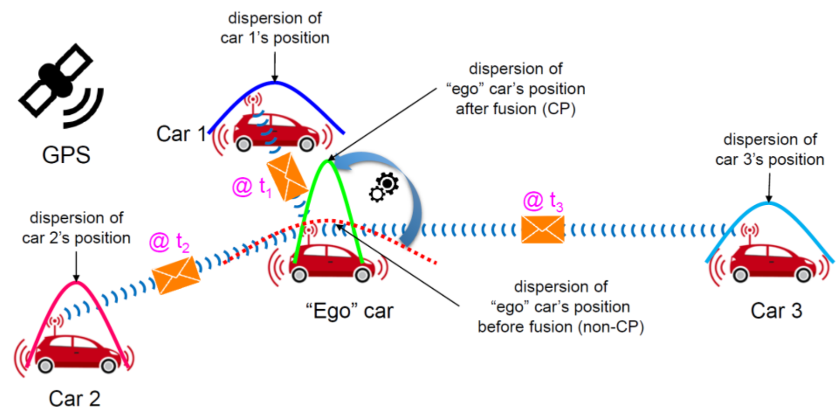
Reference - Hendrik-Jörn Günther et al., **Realizing Collective Perception in a Vehicle**, IEEE Vehicular Networking Conference (VNC), 2016

Improving Positioning for Automated Vehicles

- **Precise Awareness Message (PAM) –**
  - Providing sub-meter awareness 'precision'

Source: Minh Hoang, CEA - EURECOM





Source: Irfan Khan, EURECOM

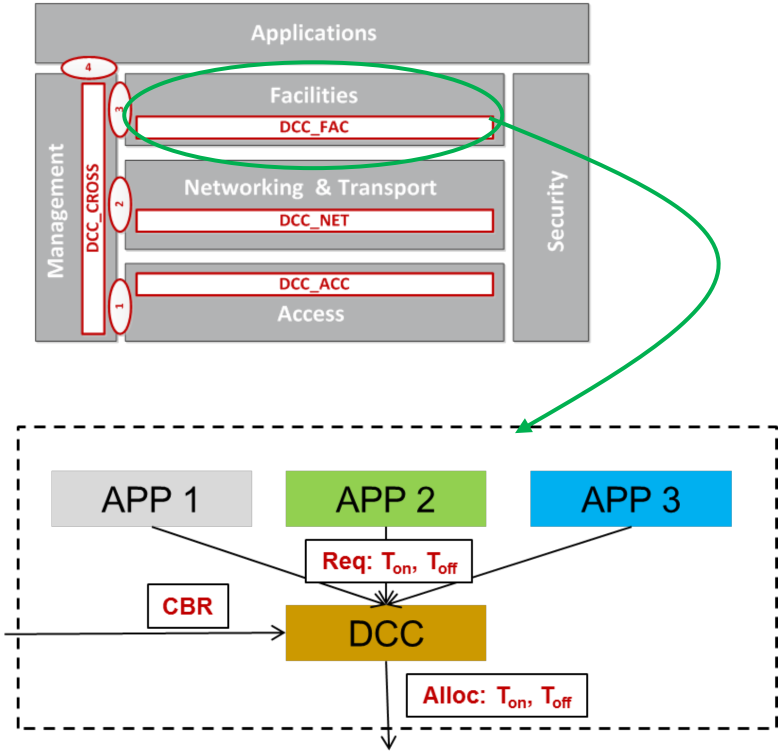
Position 2 x 4 byte scalar
Covariance Matrix 3 x 4 byte scalar
Timestamp 1 x 8 byte
Headers, MAC & PHY 42 byte
Total Packet Size = 70 bytes

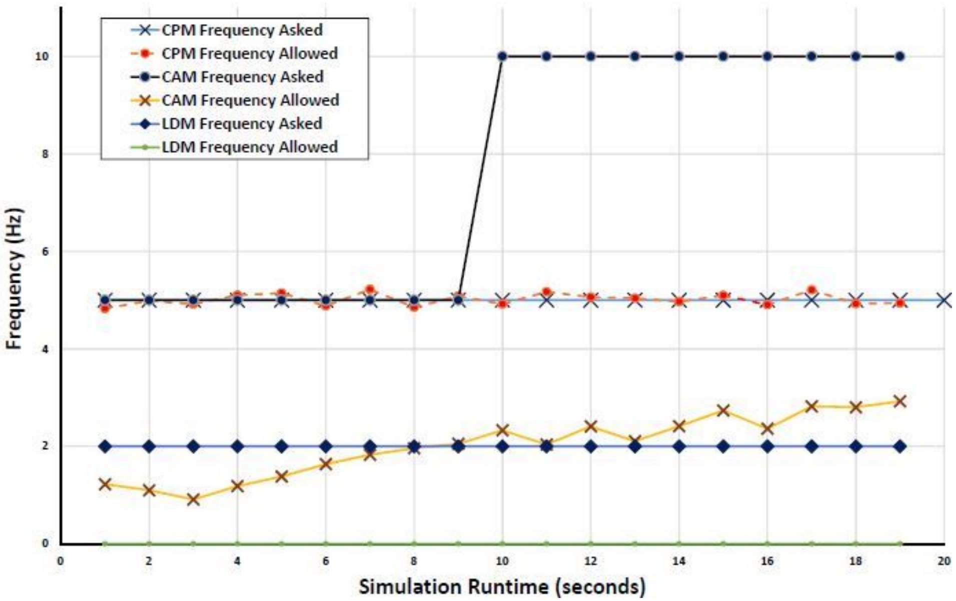
- **Message Structure:**
  - No GPS transmission, rather fusion data
  - Smaller (70 bytes)
  - Can reach 100Hz at 60% channel load

More details: Irfan Khan, Minh Gia Hoang Jérôme Härri, "Rethinking Cooperative Awareness for Future V2X Safety-critical Applications", later **today at 16:30** at VNC 2017

Multi-Message Congestion Control

- **Facilities-layer DCC – TS 103 141**
  - Objective: provide fair 'channel access time' to all message
    - Potentially irrespective to the technology





Source: Irfan Khan, EURECOM

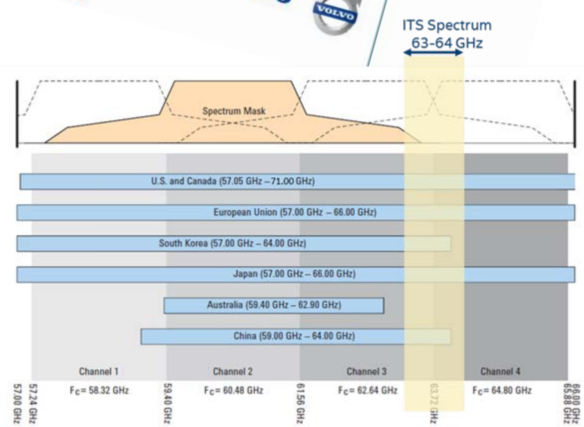
IEEE 802.11px

ITS-G5 RELEASE 2

ITS-G5 rel. 2 – Design Directions & Roadmap

- **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**
  - <u>Objectives</u>:
    - > 5dB gain at 5GHz
    - 10x capacity at 60Hz



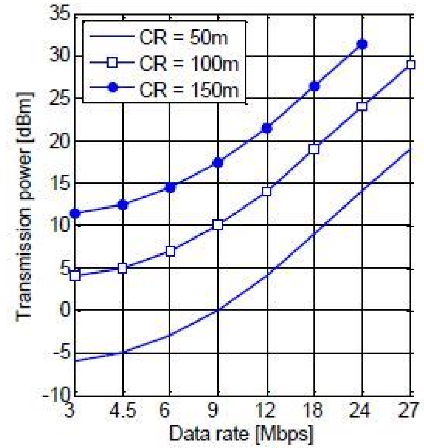
ITS-G5 rel. 2 – Enhanced Channel Usage

- **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…

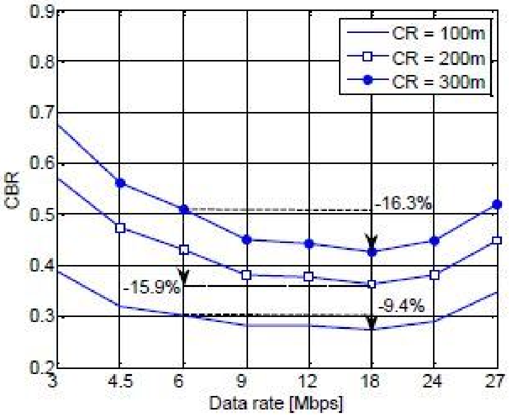
- **What is then the 'optimal' data rate for CCH?**
  - Recent paper (**2017**):
    - M. Sepulcre, J. Gozalvez, B. Coll-Perales "Why 6Mbps is not (always) the Optimum Data Rate for Beaconing in Vehicular Networks", IEEE Transactions on Mobile Computing, Early Access, 2017.
  - Conclusions: default data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

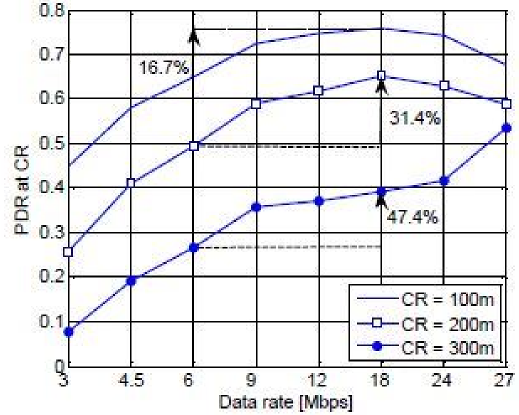
ITS-G5 rel. 2 – Enhanced Channel Usage

- **Principle:**
  - Joint adjustment of Tx power and data rate to optimize the channel occupancy 'footprint'
    - In a nutshell: considers the impact of Tx power in perturbing remote neighbors
  - Objective: 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%

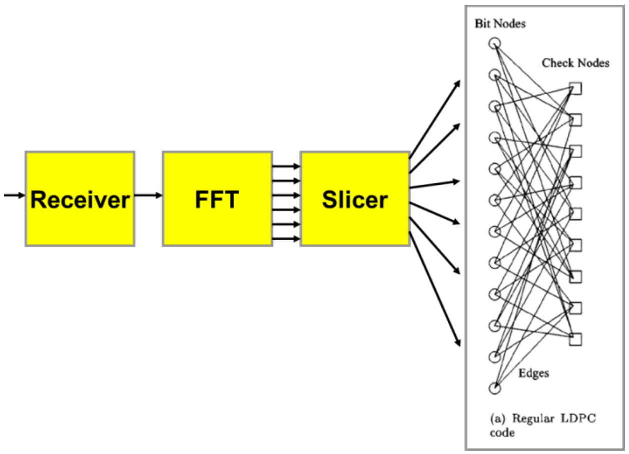




Source: M. Sepulcre, J. Gozalvez, B. Coll-Perales "Why 6Mbps is not (always) the Optimum Data Rate for Beaconing in Vehicular Networks", IEEE Transactions on Mobile Computing

ITS-G5 rel. 2 – IEEE 802.11px enhanced PHY

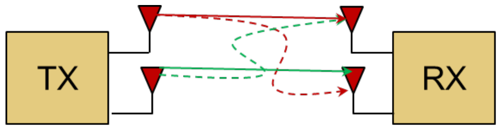
- **Critics says: IEEE 802.11p is an old technology**
  - Indeed developed 10 years ago
  - But not the limit of what WiFi can do !!



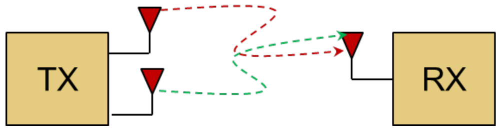
Source: IEEE 802.11-2012

- **IEEE 802.11ac**
  - <u>Current state-of-art WiFi Technology</u>
  - **Up to 1Gbps**

- **Main features**
  - Physical Layer:
    - LDPC coding
    - STBC (space-time coding)
    - Enhanced channels width: 80Mhz, 160Mhz



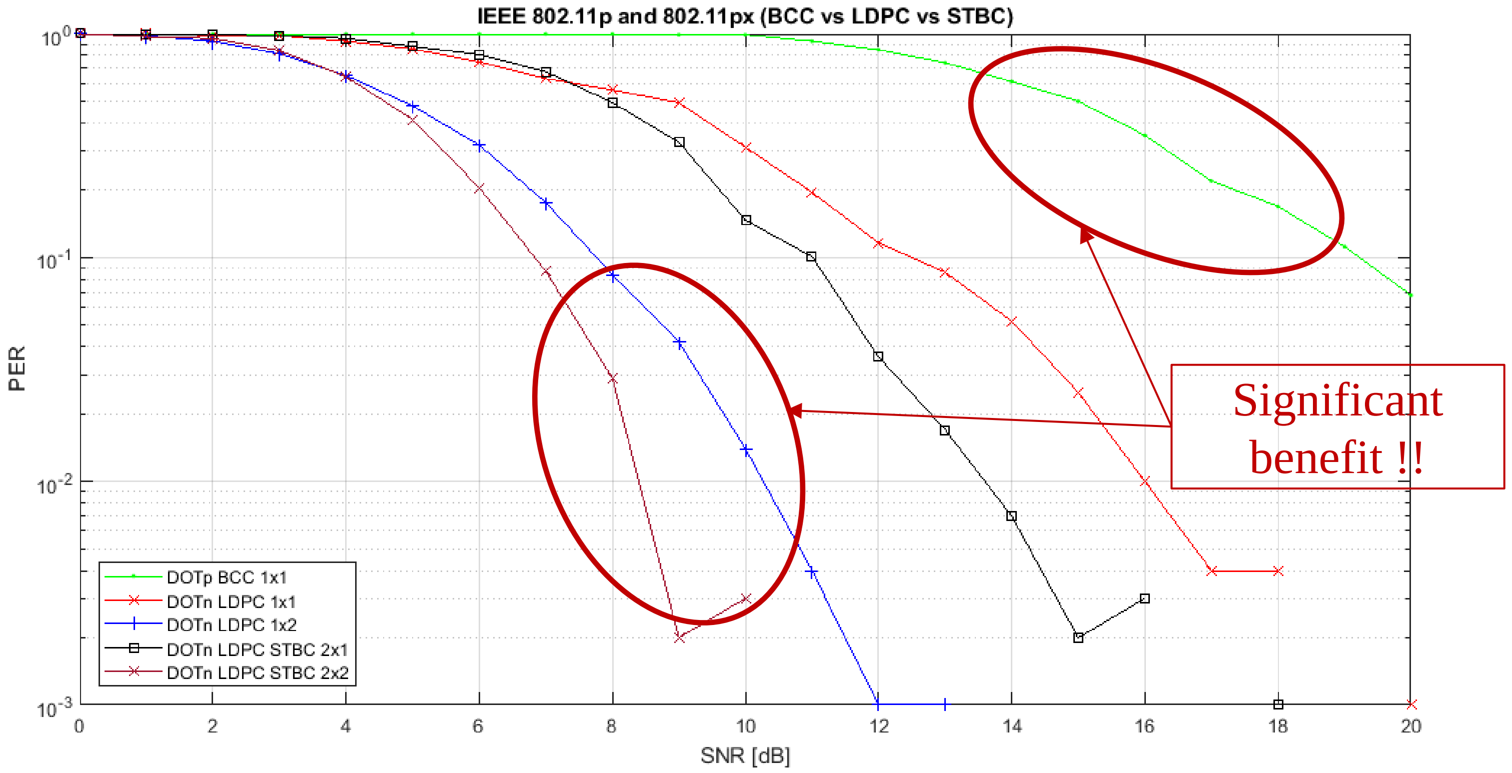
2x2 MIMO



2x1 Legacy

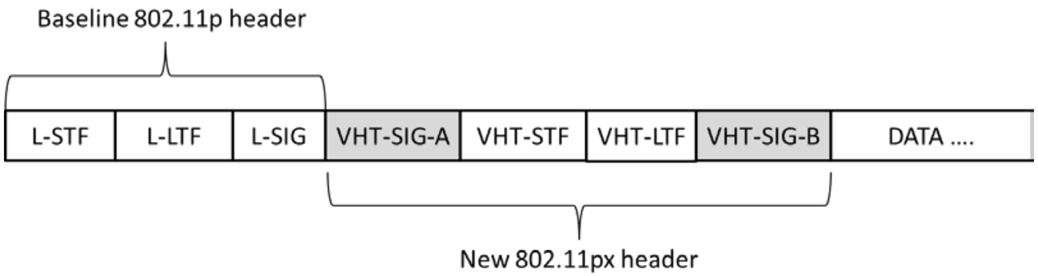
- **Design Guideline of IEEE 802.11px**
  - Take the 802.11ac PHY
  - Adapt it to OCB and High Mobility
  - Keep Backward compatible with 802.11p

IEEE 802.11px – Impact of LDPC w/o STBC



IEEE 802.11px – Basic Proposal

- **IEEE 802.11px – on IEEE 802.11-2016**
  - dotOCBActivated = TRUE – OCB mode for WiFi
  - VHT PHY – provision for LDPC and STBC
    - **STBC** code with two streams (2x1)
    - **LDPC** flag in **VHT-SIG-A** turned to 1
  - 10Mhz half-clock rate – mitigate coherence time and Doppler spread
  - 5.9 GHz band in Europe (5.855–5.925 GHz) – default channel to operate the OCB mode.
    - Ethertype Protocol discrimination shall also be used as mentioned in 802-2014.
  - Header:



IEEE 802.11px – Coexistence & Backward compatibility

- **Coexistence with Legacy 802.11p**
  - IEEE 802.11px devices
    - IEEE 802.11px profile able to understand each other
  - IEEE 802.11px vs. Legacy
    - any IEEE 802.11-2016 VHT PHY device may also decode non-HT preamble, any legacy IEEE 802.11p will be decoded and understood at the same Sensitivity level (no PHY hidden terminal).
  - Legacy vs. IEEE 802.11p
    - any IEEE 802.11-2016 VHT PHY includes a non-HT preamble, and as such at least the preamble of any IEEE 802.11-2016 PHY PSDU will be decoded
  - Legacy vs. Legacy
    - As current situation

- **For Legacy IEEE 802.11p to decode IEEE 802.11px**
  - Double payload – any IEEE 802.11-2016 VHT PHY shall integrate two aggregated data parts: VHT-related data (LDPC, STBC encoded), non-HT data (BCC encoded).
  - Double transmission – any IEEE 802.11px device shall transmit twice the same message, once using VHT and once with Non-HT

IEEE 802.11px – Channel Capacity

Mod	Coding rate (R)	Coded bits per subcarrier (NBPSC)	Coded bits per OFDM symbol (NCBPS)	Data bits per OFDM symbol (NDBPS)	Data rate [Mb/s] (20 MHz channel spacing) short/long GI	Minimum Sensitivity [dBm]	SINR Threshold (dB)
BPSK	1/2	1	52	26	**6.5 / 7.2**	**-82**	**5**
QPSK	1/2	2	104	52	**13.0 / 14.4**	**-79**	**10**
QPSK	3/4	2	104	78	**19.5 / 21.7**	**-77**	**13**
16-QAM	1/2	4	208	104	**26.0 / 28.9**	**-74**	**16**
16-QAM	3/4	4	208	156	**39.0 / 43.3**	**-70**	**19**
64-QAM	2/3	6	312	208	**52.0 / 57.8**	**-66**	**22**
64-QAM	3/4	6	312	234	**58.5 / 65.0**	**-65**	**25**
64-QAM	5/6	6	312	260	**65.0 / 72.2**	**-64**	**27**
256-QAM	3/4	8	416	312	**78.0 / 86.7**	**-59**	**30**

IEEE 802.11px – Profile and Next steps

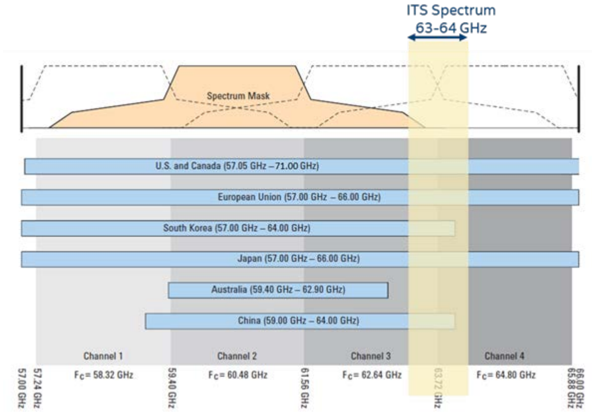
- **Default Parameters:**
  - Preamble/PHY header (non-HT and VHT fields): BPSK ½
  - Data: 64-QAM
  - Dynamic transmit power for homogeneous SINR at range R
- **New Congestion control required**
  - significantly shorter air-time
  - required dynamic transmit power adjustments

- **Next Steps:**
  - Developing LDPC codes for IEEE 802.11px (2017)
  - Performance Evaluation (2017-2018)
  - Proposal to IEEE 802.11 (2018)
    - 10Mhz VHT PHY
    - OCB on VHT PHY
    - New LDPC codes for VHT PHY when OCB

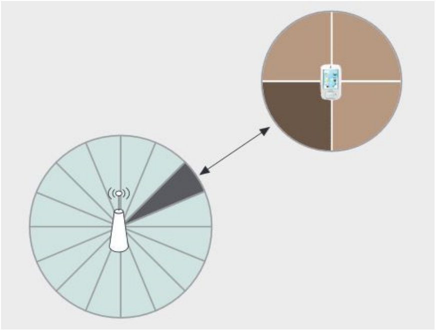
Minor modification required !!

IEEE 802.11px – mmWAVE PHY

- **mmWAVE - C-ITS reserved band**
  - 63-64GHz
- **IEEE 802.11ad**
  - Release 2012
  - Extension of IEEE ac for mmWAVE
  - Sectorial MAC mechanisms for management
  - ..



- **IEEE 80211ad aims at 4-6 Gbps**
  - Products already available !!
  - IEEE 802.11px expected to have minor modifications



- **Design Guideline of IEEE 802.11px @ 60GHz**
  - Optimize IEEE 802.11ad for mmWAVE C-ITS Bands VHT PHY OCB

Source: Thomas Nitsche, IEEE Com. Magazine

IEEE 802.11px – Road Map

- **Short Term Opportunities**
  - Increased/adaptive default ITS-G5 modulation (18 mbps)
    - Up to 40% PDR at 300m
- **Medium Term Opportunities**
  - LDPC support (with backward compatibilities)
    - Up to 6dB gain
  - STBC (Alamouti) 2x2
    - Up to 3dB gain
  - Adapted Modulation & Congestion Control (60mbps)
    - Up to 10x capacity gain
  - mmWAVE PHY
    - 1.5 – 4 Gbps capacity
- **Longer Term Opportunities**
  - optimized MAC

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

(some) References

- **Research**
  - 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
  - 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, 2017*
  - Hendrik-Jörn Günther et al., Realizing Collective Perception in a Vehicle, *IEEE Vehicular Networking Conference (VNC)*, 2016
  - Irfan Khan, Minh Gia Hoang Jérôme Härri, “Rethinking Cooperative Awareness for Future V2X Safety-critical Applications”, *IEEE Vehicular Networking Conference , Torino, 2017*
  - Irfan Khan, Jérôme Härri, “Evaluation of Facility-Layer Decentralized Congestion Control”, *to be submitted*
- **Standards**
  - CAR 2 CAR White Paper - Enhanced 11p Investigations and Proposal, 2017
  - IEEE 802.11-2016