CAR 2 CAR COM/ARCH

IEEE 802.11p Extension Roadmap

2017/11/29

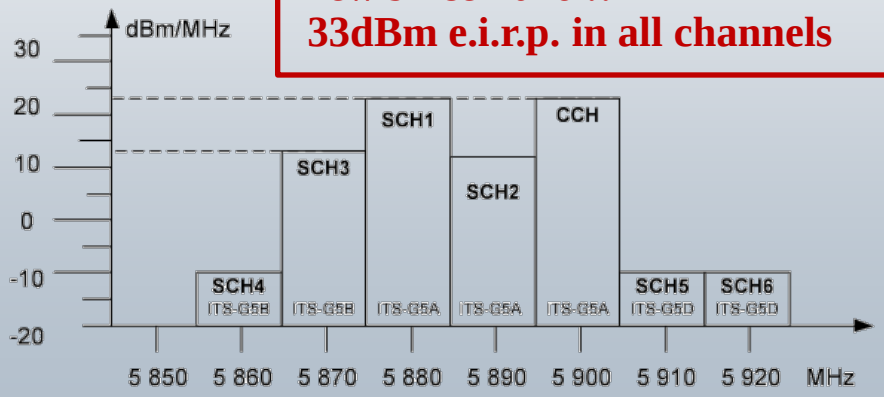
Jérôme Härri (EURECOM), Matthias Alles (CREONICS), Friedbert Berens (FBConsulting)

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
- 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 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
  - Objectives:
    - > 5dB gain at 5GHz
    - 10x capacity at 60Hz

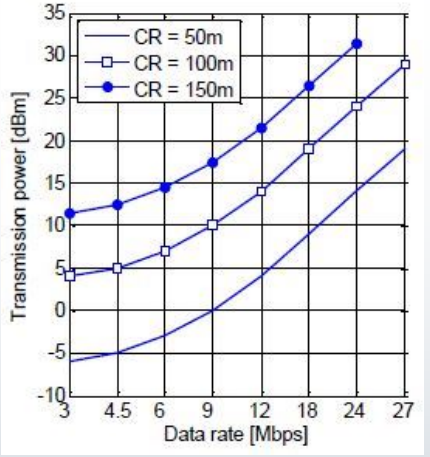
ITS-G5 rel. 2 – Enhanced Channel Usage

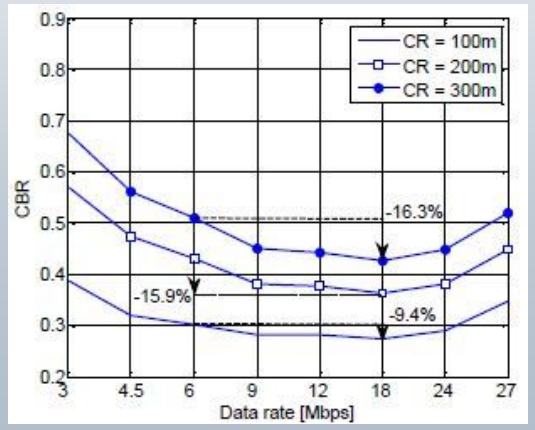
- ETSI EN 302 571 specifies a default QPSK ½ modulation (6mbps) modulation on CCH
  - Why? Seminal work (2008)
    - D. Jiang, Q. Chen, L. Delgrossi, “Optimal data rate selection for vehicle safety communications”, Proc. ACM international workshop on VehiculAr Inter-NETworking (VANET), San Francisco,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    - Hypothesis no longer valid…

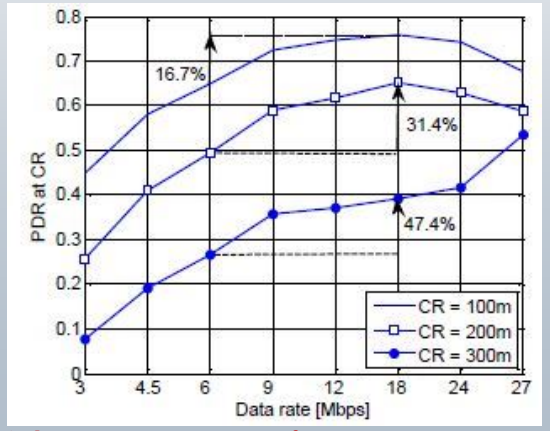
- What is then the ‘optimal’ data rate for CCH?
  - Recent paper (**2017**):
    - M. Sepulcre, J. Gozalvez, B. Coll-Perales "Why 6Mbps is not (always) the Optimum Data Rate for Beaconing in Vehicular Networks", IEEE Transactions on Mobile Computing, Early Access, 2017.
  - Conclusions: default data 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%



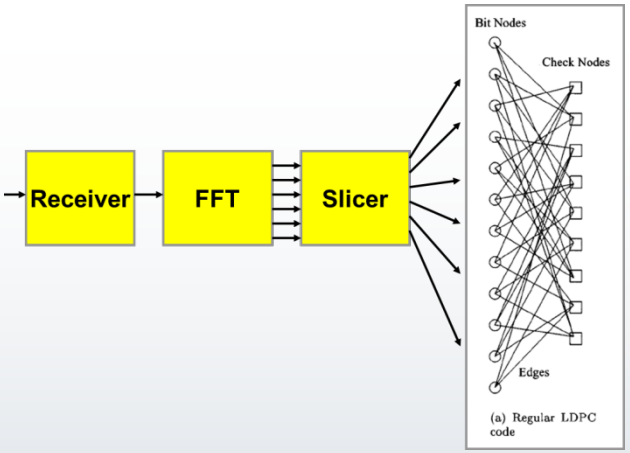




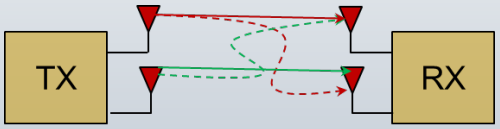
Source: M. Sepulcre, J. Gozalvez, B. Coll-Perales "Why 6Mbps is not (always) the Optimum Data Rate for Beaconing in Vehicular Networks", IEEE Transactions on Mobile Computing

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 !!
- IEEE 802.11ac
  - Current state-of-art WiFi Technology
  - **Up to 1Gbps**
- **Main features**
  - Physical Layer:
    - LDPC coding
    - STBC (space-time coding)
    - Enhanced channels width: 80Mhz, 160Mhz
- **Design Guideline of IEEE 802.11px**
  - Take the 802.11ac PHY
  - Adapt it to OCB and High Mobility
  - Keep Backward compatible with 802.11p



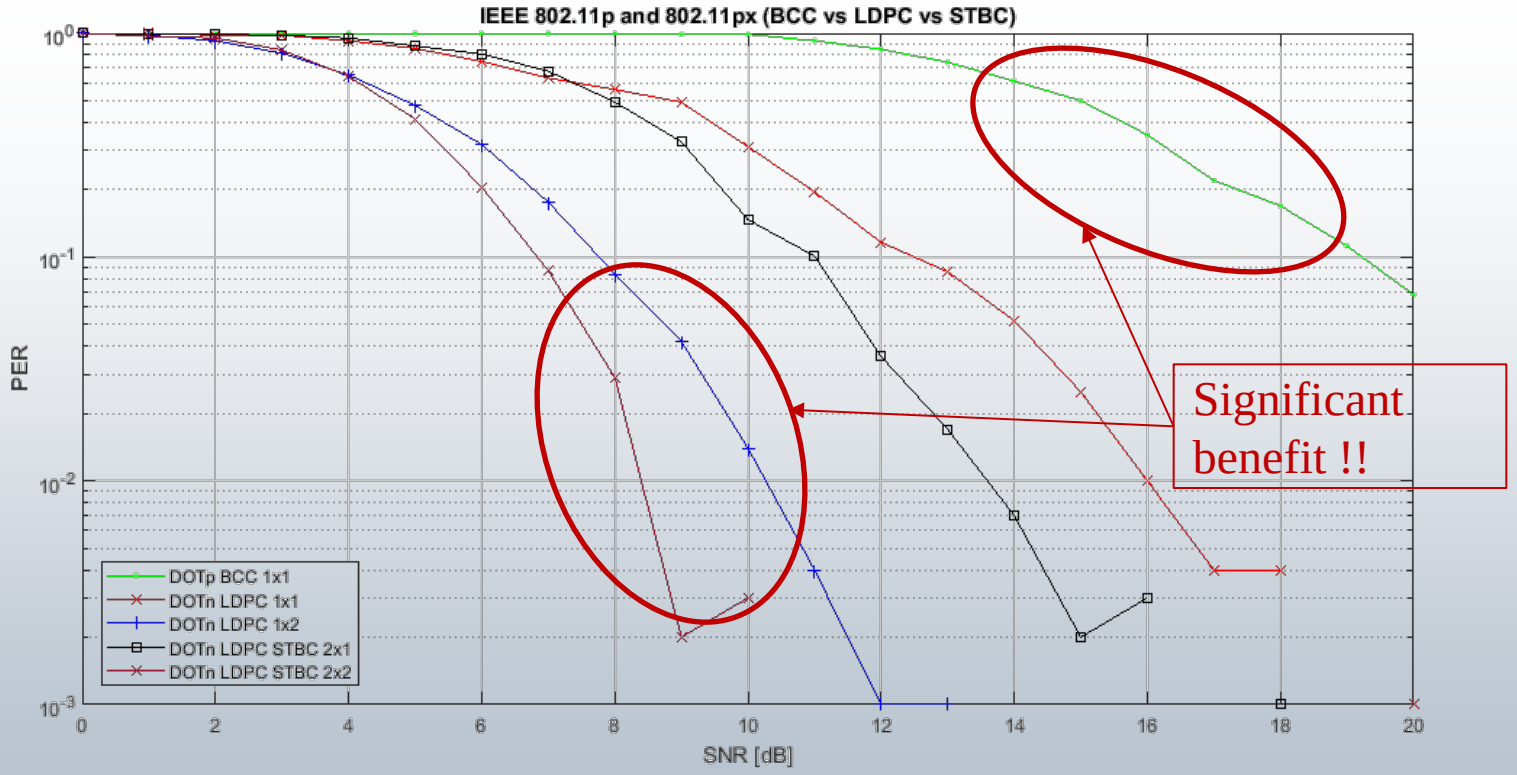
Source: IEEE 802.11-2012



2x2 MIMO

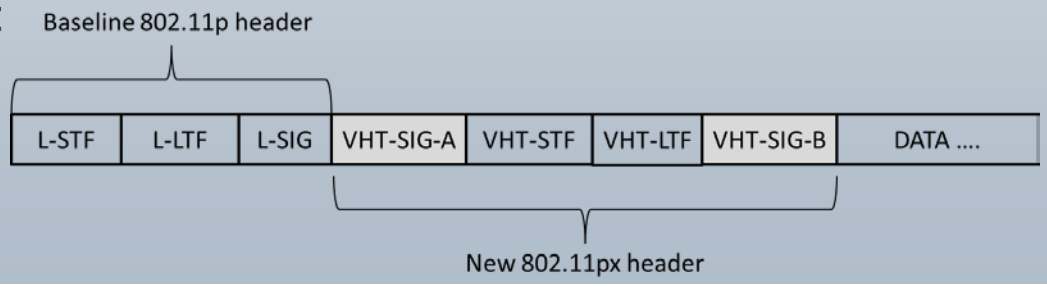
2x1 Legacy

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

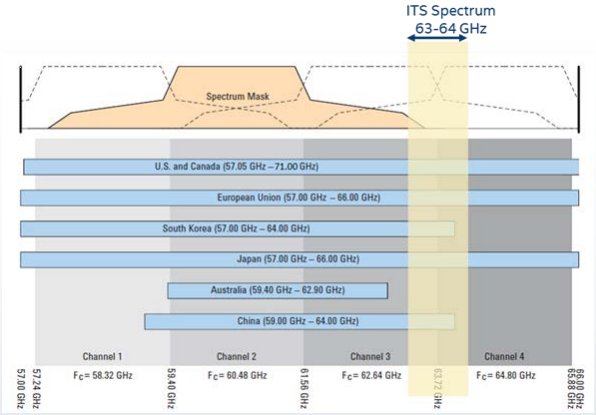
- Default Parameters:
  - Preamble/PHY header (non-HT and VHT fields): BPSK ½
  - Data: 64-QAM
  - Dynamic transmit power for homogeneous SINR at range R
- New Congestion control required
  - significantly shorter air-time
  - required dynamic transmit power adjustments

- 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
    - *(If necessary)New LDPC codes for VHT PHY when OCB*

Minor modification required !!

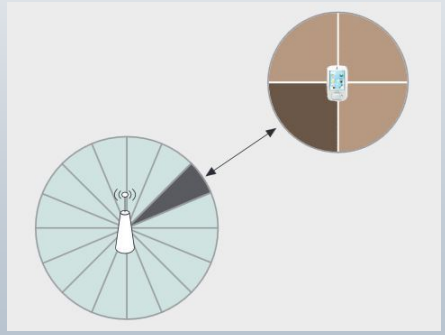
IEEE 802.11px – mmWAVE PHY

- 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 !!
  - Minor adaptation to IEEE 802.11px (similar from .ac to .px)

- 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

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