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

- ITS Frequency Band

<table>
<thead>
<tr>
<th>Name</th>
<th>Center Frequency</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>SCH6</td>
<td>5920</td>
<td>ITS-G5D - Future ITS</td>
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<tr>
<td>SCH5</td>
<td>5910</td>
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<tr>
<td>SCH4</td>
<td>5860</td>
<td>ITS-G5B - Non-Safety related</td>
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<tr>
<td>SCH3</td>
<td>5870</td>
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<tr>
<td>SCH2</td>
<td>5880</td>
<td></td>
</tr>
<tr>
<td>SCH1</td>
<td>5890</td>
<td>ITS-G5A - Safety-Related</td>
</tr>
<tr>
<td>CCH</td>
<td>5900</td>
<td></td>
</tr>
</tbody>
</table>

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 busy 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
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)

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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

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

Source: Hendrik-Jörn Günther (VW), ETSI

Improving Positioning for Automated Vehicles

- Precise Awareness Message (PAM) –
  - Providing sub-meter awareness ‘precision’

- 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
In November 2016, the CAR 2 CAR initiated a WI on ITS-G5 Rel. 2

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
ETSIs EN 302 571 specifies a default QPSK ½ modulation (6mbps) modulation on CCH


- Hypothesis: Constant TX power
  - Hypothesis no longer valid…

**What is then the ‘optimal’ data rate for CCH?**

- Recent paper (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 20/10/2017 - - p 14
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
IEEE 802.11px – Impact of LDPC w/o STBC

Significant benefit!!

PER vs SNR for IEEE 802.11px and 802.11p (BCC vs LDPC vs 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

<table>
<thead>
<tr>
<th>Mod</th>
<th>Coding rate (R)</th>
<th>Coded bits per subcarrier (NBPSC)</th>
<th>Coded bits per OFDM symbol (NCBPS)</th>
<th>Data bits per OFDM symbol (NDBPS)</th>
<th>Data rate [Mb/s] (20 MHz channel spacing) short/long GI</th>
<th>Minimum Sensitivity [dBm]</th>
<th>SINR Threshold (dB)</th>
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<tbody>
<tr>
<td>BPSK</td>
<td>1/2</td>
<td>1</td>
<td>52</td>
<td>26</td>
<td>6.5 / 7.2</td>
<td>-82</td>
<td>5</td>
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<tr>
<td>QPSK</td>
<td>1/2</td>
<td>2</td>
<td>104</td>
<td>52</td>
<td>13.0 / 14.4</td>
<td>-79</td>
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<tr>
<td>QPSK</td>
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<td>2</td>
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<td>78</td>
<td>19.5 / 21.7</td>
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<td>13</td>
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<tr>
<td>16-QAM</td>
<td>1/2</td>
<td>4</td>
<td>208</td>
<td>104</td>
<td>26.0 / 28.9</td>
<td>-74</td>
<td>16</td>
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<tr>
<td>16-QAM</td>
<td>3/4</td>
<td>4</td>
<td>208</td>
<td>156</td>
<td>39.0 / 43.3</td>
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<tr>
<td>64-QAM</td>
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<td>78.0 / 86.7</td>
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<td>30</td>
</tr>
</tbody>
</table>
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

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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

**Key Message** – ITS-G5 is not the issue; rather the way we use it!!
(some) References

- **Research**
  - 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
  - Irfan Khan, Jérôme Härri, “Evaluation of Facility-Layer Decentralized Congestion Control”, *to be submitted*

- **Standards**
  - IEEE 802.11-2016