CAR 2 CAR COM/ARCH

IEEE 802.11p Extension Roadmap

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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>
</tr>
</thead>
<tbody>
<tr>
<td>SCH6</td>
<td>5920</td>
<td>ITS-G5D - Future ITS</td>
</tr>
<tr>
<td>SCH5</td>
<td>5910</td>
<td></td>
</tr>
<tr>
<td>SCH4</td>
<td>5860</td>
<td>ITS-G5B - Non-Safety related</td>
</tr>
<tr>
<td>SCH3</td>
<td>5870</td>
<td></td>
</tr>
<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>
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
ITS-G5 rel. 2 – Enhanced Channel Usage

- ETSI 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    - Hypothesis no longer valid…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
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!!
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:
  - Baseline 802.11p header
    - L-STF L-LTF L-SIG VHT-SIG-A VHT-STF VHT-LTF VHT-SIG-B DATA ....
  - New 802.11px 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>
</tr>
</thead>
<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>
</tr>
<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>
<td>10</td>
</tr>
<tr>
<td>QPSK</td>
<td>3/4</td>
<td>2</td>
<td>104</td>
<td>78</td>
<td>19.5 / 21.7</td>
<td>-77</td>
<td>13</td>
</tr>
<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>
</tr>
<tr>
<td>16-QAM</td>
<td>3/4</td>
<td>4</td>
<td>208</td>
<td>156</td>
<td>39.0 / 43.3</td>
<td>-70</td>
<td>19</td>
</tr>
<tr>
<td>64-QAM</td>
<td>2/3</td>
<td>6</td>
<td>312</td>
<td>208</td>
<td>52.0 / 57.8</td>
<td>-66</td>
<td>22</td>
</tr>
<tr>
<td>64-QAM</td>
<td>3/4</td>
<td>6</td>
<td>312</td>
<td>234</td>
<td>58.5 / 65.0</td>
<td>-65</td>
<td>25</td>
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<tr>
<td>64-QAM</td>
<td>5/6</td>
<td>6</td>
<td>312</td>
<td>260</td>
<td>65.0 / 72.2</td>
<td>-64</td>
<td>27</td>
</tr>
<tr>
<td>256-QAM</td>
<td>3/4</td>
<td>8</td>
<td>416</td>
<td>312</td>
<td>78.0 / 86.7</td>
<td>-59</td>
<td>30</td>
</tr>
</tbody>
</table>
IEEE 802.11px – Profile and Next steps

- **Default Parameters:**
  - Preamble/PHY header (non-HT and VHT fields): BPSK $\frac{1}{2}$
  - 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!!