Enabling Enhanced Mobile Broadband by mm-Waves and the Road to 5G V2X

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Enhanced Mobile Broadband (eMBB)

Technical Challenges

- 100 MHz bandwidth at < 6 GHz
- 800 … 2 GHz bandwidth at > 6 GHz
- mmWave frequencies (candidate bands: ~28 GHz, ~39 GHz, ~70 GHz) especially for high data rate applications
- Highly directional transmission is needed to compensate severe path loss (beamforming used at Tx and Rx), Dynamic beam adaptation is essential
- Research on new channel models
- New 5G signal waveform for high bandwidth operation at mmWave
- “Over-The-Air“ (OTA) instead of conducted measurements; up to 1024 Tx/Rx antenna elements
- Bandwidth and waveform type have impact on 5G capable components (PAs, filters, D/A, A/D…)
Considered frequency ranges and bands for 5G at cm- and mm-Waves:
- 24.25 to 27.5 GHz
- 31.8 to 33.4 GHz
- 37.0 to 43.5 GHz
- 45.4 to 50.2 GHz
- 50.4 to 52.6 GHz
- 66 to 76 GHz
- 81 to 86 GHz.

- 27.5 to 29.5 GHz band is not listed, but is still expected to play an important role for anticipated 5G deployments.
### Deployment scenarios

Source: 3GPP TR 38.913 Version 0.3.0 (2016-03)

- **Frequency range beyond 6 GHz:** 24 – 40 GHz and 66 – 86 GHz
- **Maximum total modulation BW:** 1 GHz
- **Maximum number of UE antenna elements:** 32
- **Maximum number of BS antenna elements:** 256

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Indoor hotspot</th>
<th>Dense urban</th>
<th>Rural</th>
<th>Urban macro</th>
<th>High speed&lt;sup&gt;(8)&lt;/sup&gt; (500 km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carrier frequency range (aggregated system BW)</strong></td>
<td>4GHz (200MHz)</td>
<td>4GHz (200MHz)</td>
<td>700MHz-2GHz (2GHz)</td>
<td>2GHz (TBD)</td>
<td>4GHz (200MHz)</td>
</tr>
<tr>
<td><strong>BS / UE antenna elements</strong></td>
<td>256/32</td>
<td>256/8 (4GHz)</td>
<td>256/32 (30GHz)</td>
<td>256/8 (4GHz)</td>
<td>256/32 (30GHz)</td>
</tr>
<tr>
<td><strong>Coverage range (indoor/outdoor user distribution in %)</strong></td>
<td>20 m 100%/0%</td>
<td>200 m Macro (3 micro TRPs&lt;sup&gt;(5)&lt;/sup&gt; per macro) 80%/20%</td>
<td>1732 / 5000 m 50%/50%</td>
<td>500 m 80%/20%</td>
<td>1732 m 100% users in train</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Extreme rural&lt;sup&gt;(7)&lt;/sup&gt;</th>
<th>Urban coverage for mMTC</th>
<th>Highway</th>
<th>Urban grid for connected car&lt;sup&gt;(9)&lt;/sup&gt;</th>
<th>Air to Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carrier frequency range (aggregated system BW)</strong></td>
<td>&lt;3GHz (40MHz)</td>
<td>700 MHz (TBD)</td>
<td>&lt;6GHz (200MHz)</td>
<td>&lt;6GHz (200MHz)</td>
<td>tbd</td>
</tr>
<tr>
<td><strong>BS / UE antenna elements</strong></td>
<td>&lt;TBD&gt;</td>
<td>2, 4, 8 (optional) / 1</td>
<td>32/32 (RSU&lt;sup&gt;(9)&lt;/sup&gt;)</td>
<td>32/32</td>
<td>[40MHz]</td>
</tr>
<tr>
<td><strong>Coverage range (indoor/outdoor user distribution in %)</strong></td>
<td>100 km (even up to 300 km)</td>
<td>500 / 1732 m 80%/20%</td>
<td>500 m</td>
<td>100% in vehicles</td>
<td>500 m Vehicles, bicycles, pedestrian</td>
</tr>
</tbody>
</table>

Note 1: Deployment scenarios for mMTC and URLLC are still to be defined.
Note 2: Number of antenna elements is a working assumption for the maximum value expected.
Note 3: A range of bands from 24 GHz – 40 GHz identified for WRC-19 are currently being considered and around 30 GHz is chosen as a proxy for this range.
Note 4: A range of bands from 66 GHz – 86 GHz identified for WRC-19 are currently being considered and around 70 GHz is chosen as a proxy for this range.
Note 5: 10 users per TRP is the baseline with full buffer traffic.
Note 6: Macro cell @ 4GHz (BS to onboard relay), micro cell (onboard relay to UE) @ 4, 30 or 70 GHz.
Note 7: For the provision of minimal services over very long distances with < 30 kbps/user/hour.
Note 8: RSU (road side unit) logical entity for V2X applications.
Note 9: Urban grid model, i.e. car lanes and pedestrian/bicycle sidewalks placed around a road block.
Massive MIMO / Beamforming at cm-/mm-Wave Frequencies

Active antennas are fundamental

Supporting mobility leads to rapidly changing channel conditions

At cm/mm-Wave frequencies small changes in the environment significantly change/impact performance

Beam-steering AND beam-tracking techniques are required to create and adapt highly directional gain
Why channel modeling?

Objectives

• The performance of a radio system is ultimately determined by the radio channel

• The channel models basis for
  • System design
  • Algorithm design, antenna design

• Without reliable channel models, it is hard to design radio systems that work well in real environments.

• New **challenges** within “5 G mm-waves”
  • *Extremely extended frequency range i.e. frequency dependency of parameters (6 – 100 GHz)*
  • *Spatial information / 3D beamforming / spatial consistency*

- Some examples:
  - behavior in time/place?
  - behavior in frequency?
  - directional properties?
  - bandwidth dependency?
  - behavior in delay?
Channel Modeling Approaches

- Full Electromagnetic Solutions => exact geometry, materials
- Deterministic (Raytracing) => exact geometry, materials
- Quasi Deterministic + Stochastic (3D geometry-based stochastic channel models GSCM) => some geometry, large scale parameters needed, complexity at acceptable level
Channel impulse response CIR is a theoretical measure to describe the wave propagation: Idea is to excite the channel with a Dirac impulse and to measure the arrivals of that impulse at the receiver. Due to multipath each pulse response is attenuated, delayed and phase shifted.

\[ h(\tau, t) = \sum_{i=0}^{L-1} a_i(t) e^{j\phi_i(t)} \delta(\tau - \tau_i) \]

\[ |h|^2 \]

Power delay profile PDP: 2 dimension graph to indicate the pulse response, power versus time. Note: the phase can not be seen in this figure.

Separability of MPC

Identify each MPC.

\[ \tau_{RES} \approx \frac{1}{B} \]

Minimum measurement duration

Delay spread
R&S Test Solution

5G wideband signal generation and signal analysis

Signal Analysis:
- FSW (RTO) up to 85 GHz and 2GHz bandwidth
- FSW: No down-conversion needed up to 85 GHz
- Signal Analysis with FSW up to 100+ GHz (using external mixer)
- FSW internal support for 500MHz bandwidth

Signal Generation:
- SMW: up to 40GHz without up-conversion (best signal quality)
- Bandwidth up to 2GHz
- Signal Generation > 40GHz using up-converter
- SMW with 2 RF ports up to 20GHz (IF + LO for up-conversion out of 1 box)
SMW Flatness Measurements

Measured I/Q modulation frequency response with internal wideband baseband

- Extraordinary flatness due to automatic internal response compensation
- Big advantage over setups with separate ARB + VSG
- No external calibration needed
- Demonstrate Flatness with SMW + Power Sensor + Excel Sheet
Enhanced Mobile Broadband (eMBB)

Solution examples

Channel Sounding Solution

- Generation of sounding sequences
- Real world environment
- I/Q data capturing
- Data analysis software

- R&S® SMW200A
- R&S® FSW
- R&S® TS-5GCS

- fast measurement in time domain
- support for in- and outdoor sounding
- very high dynamic range
Experimental setup of the channel sounding measurement system (17 GHz)
Sounding @ 82.5 GHz
R&S 5G mmWave Expert Day September 2015

500 MHz BW transmitter AFQ100B + SMW200A

500 MHz BW receiver FSW85
• One typical power delay profile taken at 20s from set of measurements

• Local averaging (small scale averaging) over 250 snapshots (1 cm)

• LOS component + several strong multipath components
Channel sounding – 5G request

Each multipath component is characterized by:
- Time $t$
- Angle of arrival $\Delta \phi$
- Doppler shift
- Excess delay $\Delta T$
- Phase shift
- In MIMO condition it would end up in a $N \times M$ matrix set

Channel impulse response CIR: time variant and depending on direction of arrival

$$h(t, \tau, \varphi) = \sum_{\Delta \varphi = 0^\circ}^{360^\circ} \Delta \varphi \sum_{l=0}^{L-1} a_l(t) \cdot e^{j \Phi(t)} \cdot \delta(\tau - \tau_l)$$
Directional Information: Spatial Filtering

- Direct measurements of angles of arrivals
- Mechanical scanning is very slow, only suitable for static channels
- Mechanical scanning is very simple
- Limited resolution
- Ambiguity through overlapping patterns owing to the antenna characteristic
Estimation of direction of arrival using array signal processing (MUSIC etc.)

- High hardware effort
- High measurement speed
- Sensitive to phase errors

Directional Information: Estimation Algorithm

\[ \Delta x \]

RX 1
RX 2
RX 3
RX 4

MIMO ✔
Estimation of direction of arrival using array signal processing (MUSIC etc.)

- Less hardware effort (in comparison to mechanical antenna)
- High measurement speed
- Typically cylindrical switched array
- Linear, circular or 3D movements for virtual array
- No calibration needed for virtual array
- Sensitive to phase errors
Directional Information: Estimation Algorithm

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Using amplitude PDP and phase information and apply post-processing, e.g. MUSIC

Switched Array ✓ Virtual Array ✓
Circular Switched Array Antenna (by HHI) for 3D DoA Measurements

- Design for frequencies up to 18 GHz available
- Uniform cylindrical array
- 16 columns, 4 dual-polarized patch elements per column => 128 elements in total
- Alignment of switching by Synchronomat
- Target frequency 3.75GHz
- Target bandwidth 800MHz
- Successfully applied for industry measurements, publication in preparation.
Angular Information from Virtual Arrays: Proof of Concept

- Indoor measurement in the Rohde & Schwarz R&D center “atrium”
- Frequency: 17 GHz
- Linear moving receiver
- 1 ms snapshot rate
- Measurement bandwidth: 250 MHz
- Direct outcome of measurements at 17 GHz
- 60,000 snapshots in 60s, distance 25m
- In the first 10s no movement
- Line-Of-Sight Path (LOS) and reflected components (multipath contributions: MPC)
- Channel length: 1µs
- Large-scale fading of MPCs due to RX movement
Channel model measurements (17 GHz): Position matters
R&S Channel Sounding

Based on off-the-shelf T&M equipment

- Industry 4.0: R&S conducted own channel sounding campaigns in industrial surrounding

Power delay profile measurements in the factory
Frequencies: 38GHz with 160MHz 500MHz and 2GHz bandwidth (path resolution)
Virtual circular array by fast rotating omnidirectional antenna
Design suitable for lower frequencies up to 110 GHz
Alignment of rotation and measurements by HHI
Synchronomat
Very fast acquisition within several ms
Working Prototype

\[ d_{UCA} \cdot \sin \left( \frac{\theta}{N_{UCA}} \right) \leq \frac{\lambda}{2} \]
MUSIC Spectrum (calculated from simulated measurement results)

\[ d_{UCA} = 10 \lambda \]
\[ N_{DOA} = 10 \]
\[ SNR = 20 \text{ dB} \]
URLLC: The Road to 5G V2X
5G Challenges – Second main Example from T&M Perspective
Internet of Things and New Verticals: How to Solve the Security Nightmare?

Security Solutions at R&S

- IP Traffic Monitoring
- End to End Encryption
- Next Generation Firewalls

Take Control
Steal Information
Service Disruption

Door Locks
Computers
Utilities

Door Locks
Infotainment
Engine

Entrance
Project
Production

Insulin pumps
Fitness Trackers
Pacemakers

ROHDE & SCHWARZ
NGMN V2X Task Force: Automotive View on V2X

MNO Networks

DSRC / pWLAN

~ 2002 2016/17/18 ~ 2020

use cases initially planned for DSRC are developed case by case on 2G/3G/4G

continuous functional improvements

use cases which REQUIRE
• low latency
• reliability (in & out of coverage)
• cross-operator

New requirements

CONFIDENCE
• technical feasibility
• spectrum / regulation
• scalability
• costs / business model
• others

use case oriented decision between DSRC and LTE-V2X

possible deployment scenarios
(1) co-existence of DSRC and LTE-V2X
(2) migration from DSRC to LTE-V2X
(3) others

LTE-V2X (Release 14)
 latency: max. 100ms (V2V/PC5/uU)

5G-V2X (*) (Release 15ff)
 latency: <10ms (V2V/PC5/uU)

~ 2002

(~: except new 5G radio interface)

latency: max. 100ms (V2V/PC5/uU)

~ 2016/17/18

~ 2020

5G-V2X (*) (Release 15ff)
 latency: <10ms (V2V/PC5/uU)

(*) except new 5G radio interface

ROHDE & SCHWARZ
3GPP is currently working on cellular-based V2X support using LTE (Release-14), expected to finish 1Q 2017.

<table>
<thead>
<tr>
<th>Stage-1</th>
<th>Stage-2</th>
<th>Stage-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Q '15</td>
<td>3Q '15</td>
<td>4Q '15</td>
</tr>
<tr>
<td>1Q '16</td>
<td>2Q '16</td>
<td>3Q '16</td>
</tr>
<tr>
<td>4Q '16</td>
<td>1Q '17</td>
<td></td>
</tr>
</tbody>
</table>

Completion of V2V

<table>
<thead>
<tr>
<th>General</th>
<th>Stage-1</th>
<th>Stage-2</th>
<th>Stage-3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Service description from a service-user's point of view</td>
<td>Devising an abstract architecture, the information flows, the reference points.</td>
<td>the concrete implementation of the functionality and of the protocols</td>
</tr>
</tbody>
</table>

| V2X | Analysis of 27 use cases on - V2V/V2I/V2P/V2N - Safety and non-safety | Overall architecture for V2X - Architecture enhancement for cellular-based routing for delay sensitive V2X message | Enhancement of radio protocol: - Enhancement of sidelink (PC5) - Protocol enhancement to meet QoS requirements (e.g., resource allocation, etc.) |
|     | Security | Security enhancement for V2X | Security enhancement for V2X |
Initial Cellular V2X standard completed
“V2V communications are based on D2D communications defined as part of ProSe services in Release 12 and Release 13 of the specification. As part of ProSe services, a new D2D interface (designated as PC5, also known as sidelink at the physical layer) was introduced and now as part of the V2V WI it has been enhanced for vehicular use cases, specifically addressing high speed (up to 250Kph) and high density (thousands of nodes).”

5G Automotive Association
- AUDI AG, BMW Group, Daimler AG, Ericsson, Huawei, Intel, Nokia und Qualcomm Inc. launched the 5G Automotive Association (5GAA)
- “The association will develop, test and promote communications solutions, support standardization and accelerate commercial availability and global market penetration. The goal is to address society’s connected mobility and road safety needs with applications such as connected automated driving, ubiquitous access to services and integration into smart cities and intelligent transportation”
Cross-Industry Collaboration: 5G Automotive Association

Automotive Industry
Vehicle Platform, Hardware and Software Solutions

Telecommunications
Connectivity and Networking Systems, Devices and Technologies

End to End Solutions for Intelligent Transportation, Mobility Systems and Smart Cities

Connect telecom industry and vehicle manufacturers; work closely together to develop end-to-end solutions for future mobility and transportation services, impact regulation and standardization.

Audi, Daimler, Ericsson, Huawei, Intel, Nokia, Qualcomm, Rohde & Schwarz
Support for V2V Services in 3GPP based on LTE Sidelink

- Enhancing the D2D (PC5) interface
  - In coverage and out-of-coverage

- New transmission modes:
  - TM3: eNB schedules resources
    - Scheduled by DCI format 5A, scrambled with SL-D-RNTI
  - TM4: UE autonomous resource selection

- V2V PC5 uses a dedicated carrier which is only used for V2V communication
  - TR 36.785: (Band 47: 5.9 GHz, not yet in spec)

- Time Synchronization via GNSS possible

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**Configuration 1: D2D Sidelink (PC5), dedicated carrier, distributed scheduling TM4**

- GNSS timing

- PC5

- V2V on fv

**Configuration 2: Dedicated carrier, eNB scheduling, TM3**

- GNSS timing

- MNO1

- Uu

- PC5

- V2V on fv

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**E-UTRA V2X channel bandwidth**

<table>
<thead>
<tr>
<th>E-UTRA V2X Band</th>
<th>1.4 MHz</th>
<th>3 MHz</th>
<th>5 MHz</th>
<th>10 MHz</th>
<th>15 MHz</th>
<th>20 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>47</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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With & without LTE coverage | Dedicated V2X carrier with single / multiple operators | Shared V2X/ LTE on licensed LTE carriers
3GPP Rel. 14 V2X Enhancements: examples

Demodulation reference signal (DMRS) extension
to cope with higher Doppler shift up to 500 km/h

New arrangement of resources into resource pools (RPs)
- RP redesign, control and data packets (channels) are in the same subframe
- New subframe (SF) structure Reducing latency (40ms separated before, now combined in 1 SF, i.e. 1TTI=1ms)

URLLC
LTE latency enhancements: TTI of 2 symbols (2 x 67us) => moved from Rel15 to Rel14 (fix expected summer 2017)
Rohde & Schwarz is supporting the wireless communications industry with the solutions needed to investigate, develop and standardize 5G