Exploring the most challenging radio environments for mission critical IIoT communication

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Rohde&Schwarz
The Triangle of 5G Use Cases

eMBB remains priority 1

**eMBB – the known playground**
- Established ecosystem (operators, manufacturers, certification of devices)
- Evolution from existing technologies (LTE-A, 802.11 ad) and revolutionary additions (cm- / mm-wave)
- It’s all about data (speed and capacity)

**Massive IoT**
- A diverse ecosystem (operators, manufacturers, local authorities, certification only for some technologies)
- Mix of technologies (GSM, Lora, Zigbee, WLAN, Bluetooth, Cat M, NB-IoT, …)
- It’s all about cost efficiency, massive connectivity, battery

**Ultra reliable & low latency communication**
- A significantly enhanced and diverse ecosystem (operators (?), manufacturers, verticals, certification not existing (yet))
- Existing technologies do not provide sufficient performance
- It’s all about reliability and security (data and capacity)
Customer experience, business success and sometimes our life depend on the reliability and availability of any single piece

• The main value add of the Internet of Things comes essentially from application software that relies on real-time sensor data.

• Wirelessly connected devices are just the enabler, but only valuable when connected – secure, reliable and 24/7
“Things” are different: Customer experience

We are somehow “trained” to search for a signal in case of coverage problems.

Quite hard for ‘things’ like smart meters to walk around to search for a signal.
Main idea of channel sounding is to understand the wave propagation characteristics like attenuation, power delay profile, direction of arrival, correlation aspects etc. -> especially for the "higher" frequency ranges
Channel sounding – multipath propagation MPP

Channel impulse response CIR

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

- Path delay
- Path phase
- Path attenuation

Separatibility of MPP components

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

Identify each MPP component.

Minimum measurement duration
Setup for Channel Propagation Measurements

Channel Impulse Response in the time domain

Channel sounding is a process that allows a radio channel to be characterized by decomposing the radio propagation path into its individual multipath components.

Channel Sounding Solution

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

- Fast measurement in time domain
- Support for in- and outdoor sounding
- Very high dynamic range
- Time and frequency reference
R&S Memmingen Factory
Measurement Campaign

Rx 1
Rx 2
Rx 3
Rx 4
Tx 1
Industry 4.0 channel sounding trial

Position: Tx1 Rx4 (NLOS)

Frequencies: 38 GHz, 28 GHz, 5.8 GHz

Bandwidth: 500 MHz

Plateau effect due to reflections

38 GHz
28 GHz
5.8 GHz
Industry 4.0 trial: Street in Factory Hall, Moving Vehicle
Setup Description, R&S factory in Memmingen

Movement

Tx 2
Movement

Rx 5

Movement

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Industry 4.0 trial: Street in Factory Hall, Moving Vehicle R&S factory in Memmingen: Time-Delay Domain

Positions:
Tx2 Rx5

Frequency:
5.8 GHz

Bandwidth:
500 MHz
Industry 4.0 trial: balcony scenario:
LOS and Rx is moved around a corner
Corner Effect
Industry 4.0 trial: power delay profile vs. time

Positions: Tx4 Rx7

Frequency: 5.8 GHz

Bandwidth: 500 MHz
Industry 4.0 trial
power delay profile vs. time

Positions:
Tx4 Rx7

Frequency:
38 GHz

Bandwidth:
500 MHz
V2X Channel Propagation Measurements at 5.9 GHz (24.11.2016)
MAN Truck2Truck (Project RoadArt / Platoon)

Transmit antennas on Tx Truck
Receive antenna on Rx Truck

Signal generator
Tx
Rx

2x8 MIMO channel measurement
V2X Channel Propagation Measurements at 5.9 GHz
Various drive Scenarios (highway, intersection, roundabout, tunnel) with 3 trucks
Tunnel Scenario
Typical CIR measurement between moving vehicles

- Direct outcome of measurement
- Line-Of-Sight Path (LOS) and reflected components (multipath contributions: MPC)
- Channel length: 1µs
- Large-scale fading of MPCs due to RX movement
Multipath Component Tracks
Study of individual wideband MPCs and their temporal behavior

power versus time of single Multi path components: time variant scenario

delay shift versus time of single Multi path components: time variant scenario
## Characteristics of URLLC and how to achieve ...

<table>
<thead>
<tr>
<th>URLLC</th>
<th>How</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low user plane latency</td>
<td>Air Interface structure (TTI) - PHY</td>
</tr>
<tr>
<td>(Ultra) high reliability</td>
<td>Improved HARQ procedures, duplex schemes (FDD, TDD)</td>
</tr>
<tr>
<td>(related to latency)</td>
<td>Specific channel coding</td>
</tr>
<tr>
<td></td>
<td>Architecture: redundant links</td>
</tr>
<tr>
<td></td>
<td>Reliable links</td>
</tr>
<tr>
<td></td>
<td>Improved PHY / HARQ procedures</td>
</tr>
</tbody>
</table>
### 5G New Radio (NR) numerology:

<table>
<thead>
<tr>
<th>Subcarrier Spacing [kHz]</th>
<th>-2</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol Length [μs]</td>
<td>266.7</td>
<td>66.7</td>
<td>33.3</td>
<td>16.7</td>
<td>8.33</td>
<td>4.17</td>
<td>2.08</td>
<td>...</td>
</tr>
<tr>
<td>Subframe Length [ms]</td>
<td>4</td>
<td>1</td>
<td>0.5</td>
<td>0.25</td>
<td>0.125</td>
<td>0.0625</td>
<td>0.03125</td>
<td>...</td>
</tr>
</tbody>
</table>

But TTI length depends on the number of symbols

\[
TTI = \text{# of symbols} \times \text{symbol length}
\]
Air Interface structure (TTI) – PHY (2)

Subcarrier Spacing → Symbol length → TTI → Subframe

Scalable Transmission Time Interval (TTI)

Scalable TTI for diverse latency and QoS requirements

- Shorter TTI for low latency and high reliability
- Longer TTI for higher spectral efficiency

Efficient multiplexing of long & short TTIs to allow transmissions to start on symbol boundaries\(^2,\)\(^3\)

- 1 ms subframe with 14 symbols of SCS\(^4\) = 15 kHz
- 500 µs TTI with 14 symbols of SCS = 30 kHz
- Short TTI with 2 symbols of SCS = 15 kHz
- Short TTI with 8 symbols of SCS = 60 kHz

Source: Qualcomm
FDD / TDD duplex schemes - improved HARQ procedures

FDD
Fewer (variable) interlaces for HARQ

FDD: Retransmission possible after 2 TTI

TDD
Self-contained design reduces RTT

Flexible TDD switching (betw. DL and UL)

TDD: Data and ACK in the same TTI

Source: Qualcomm

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RTT: Round Trip Time
## Channel Coding

Different Channel Coding Strategies possible for different use cases

<table>
<thead>
<tr>
<th>High Efficiency:</th>
<th>Low Complexity:</th>
<th>Low Latency:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Focus on data throughput</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Large block sizes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- eMBB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Focus on throughput</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Parallelized coding?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- eMBB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Focus on time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Efficient encoding / decoding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- URLLC</td>
<td></td>
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</tr>
</tbody>
</table>

Not finalized yet → more investigations on channel coding expected for mission-critical and also Massive IOT
How to achieve Ultra High Reliability?

Definition:
Reliability: Success probability of transmitting a certain amount of data within a certain time

Network Architecture topics:
- Simultaneous redundant links (to infrastructure – also multiple technologies)
- Reliable device-2-device links

5G NR topics:
- Improved PHY / HARQ procedures
  → lower BLER required (impact on capacity)

BLER: Block Error Rate
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Topic</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment scenarios</td>
<td>Urban grid for connected car</td>
<td>highly densely deployed vehicles in urban area (high network load and high UE density)</td>
</tr>
<tr>
<td>KPI</td>
<td>User plan latency</td>
<td>URLLC: 0.5ms in DL and 0.5ms in UL (no DRX restrictions)</td>
</tr>
<tr>
<td></td>
<td>Reliability (success probability)</td>
<td>URLLC: 99.999% (1-10^-5) for 32bytes with 1ms user plane latency eV2X: 99.999% (1-10^-5) for 300bytes with relaxed user plane latency</td>
</tr>
<tr>
<td></td>
<td>Mobility interruption time</td>
<td>0ms for user plan between UE and any BS (for all intra-NR mobility)</td>
</tr>
<tr>
<td>Supplementary-Service related</td>
<td>V2X communication</td>
<td>V2X communication via infrastructure and sidelink (road side unit)</td>
</tr>
<tr>
<td>requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operational requirements</td>
<td>V2X communication</td>
<td>NR V2X shall complement and interwork with LTE V2X</td>
</tr>
<tr>
<td></td>
<td>High Availability</td>
<td>Availability of a BS = X% of the time. URLLC services shall not be compromised by energy efficiency functions, system reconfigs, SW updates!</td>
</tr>
</tbody>
</table>
Conclusion

Is 5G just the next generation? No: It is a paradigm shift!

- Approach in industry:
  - UMTS: 1: define a technology for data transmission, 2: for what? / “what is the killer app?”
  - LTE (3GPP: e-UTRA): 1: define a better technology than UMTS, 2: use case (mobile web)
  - 5G: 1: define use cases, 2: requirements, 3: elaborate technologies / solutions
- From cell-centric (2G - 4G) to user-centric / application-centric in 5G (beamforming)
- From link efficiency (2G - 4G) to system efficiency in 5G (RAT defined per app)
- From antenna connectors (2G - 4G) to Over-the-Air testing in 5G (antenna arrays, beamforming)
- Increasing demand for security / high reliability in 5G (up to mission- and safety-critical use cases)

Rohde & Schwarz offers all essential capabilities to support the wireless communications industry with solutions needed to investigate, standardize, develop and rollout 5G
“If you want to go fast, go alone. If you want to go far, go together!”

African proverb