5G Outlook
Test and Measurement Aspects

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Rohde & Schwarz

Turnover (FY 12/13): EUR 1.9 billion

R&D: 15% of turnover

9300 employees

In over 70 countries
Our world: receiving, measuring, analyzing, generating and transmitting wireless signals

We create the basis for fully utilizing the radio frequency range.
Four business fields

Test & Measurement

Broadcasting

Secure Communications

Radiomonitoring and Radiolocation
Mobile Data Traffic Growth and Trends

Mobile Video / Global Forecast by Region

- Mobile video will grow at a CAGR of 69 percent between 2013 and 2018
- Mobile video will generate 69.1% of the mobile traffic by 2018

Asia Pacific and North America account for 61% of mobile traffic by 2018

Ref : CISCO VNI mobile 2014
Worldwide Research Activities and Initiatives
Overview (chronological order)

- NYU Wireless: US research center conducting massive work on propagation characterization at mm-wave frequencies since 2012
- 5GNOW: Non Orthogonal Waveforms (started in Sept 2012)
- METIS: Mobile and wireless communications Enablers for the Twenty-twenty Information Society (started in Nov 2012)
- MiWEBA – Millimetre-Wave Evolution for Backhaul and Access (June 2013)
- IMT-2020 / Future Forum*: China 5G organizations (Feb 2013)
- 5G Forum*: Korean industry-academy-R&D cooperation system established in May 2013
- 2020 and Beyond Adhoc: In Japan ARIB established a new AdHoc working group in Sep 2013
- 5G Innovation Centre*: 5G research in the UK started in Nov 2013
- Horizon 2020: EU Research and Innovation program (2014 - 2020)
- NGMN 5G Initiative* (started at MWC 2014)
- 5G Lab Germany* (TU Dresden, opened in Sept 2014)
5G has not been defined yet!

Discussed Scenarios & Requirements

- Is a one fit’s all technology realistic in order to address all use cases / requirements?
5G Scenarios and Requirements

Very dense crowd of users

- High data rates combined with high capacity needs in a limited area
- Energy consumption in the network and battery life time remains important
- Security requirements depend on specific use cases
5G Scenarios and Requirements
Internet of Things (robots, emergency communication, …)

- Low latency in combination with reliability/resilience is key
- Security requirements are generally very high
- Data rate/capacity requirements depend on specific use cases

Very high data rate
Low latency
Massive number of devices
Energy consumption, battery life time
Mobility
Very high capacity
Reliability, Resilience, Security

Picture: Siemens Healthcare
Picture: ETH Zürich/ Golem.de

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Picture: ETH Zürich/ Golem.de
5G Scenarios and Requirements
Internet of Things (sensors, leisure applications, …)

- The envisaged number of devices/things will place new requirements
- Battery life time requirements in the order of years rather than hours
- Data rate/capacity requirements depends on specific use cases
5G has not been defined yet!

Discussed Technology Options

- More virtualization (cloud-based networking)
- mm-wave (much higher bandwidths possible, but propagation characteristics force small cells)
- Massive MIMO / beamforming, active antennas
- Device2Device communication
- New air interfaces are in discussion (non-orthogonal; more spectrally agile waveforms; full duplex, new frame structures)
- Splitting control/user plane and/or decoupled DL/UL
- Light MAC and optimized RRM strategies
R&S impact from 5G Technology Options

**Mm-Wave frequencies**
- High absolute frequency bands / wider bandwidth
- New channel models reflecting different propagation conditions

**Massive MIMO**
- Significantly increased number of Tx / Rx elements
- Over the air measurements become essential

**New air interface technology / New protocols**
- Multiple air interface candidates analyzed in research
- Obvious impact to the complete test portfolio

**Cloud based network architecture**
- Centralized base station baseband with high number of distributed radio units ideally connected with no latency (fiber); SDN and NFV
- Traffic analytics and security will gain importance
5G Spectrum Outlook

High bandwidth is only possible at high frequencies

**Available spectrum**

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>Spectrum Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>470 – 694</td>
<td>226 MHz</td>
</tr>
<tr>
<td>694 – 790</td>
<td>96 MHz</td>
</tr>
<tr>
<td>1300 – 1700</td>
<td>400 MHz</td>
</tr>
<tr>
<td>2025 – 2100</td>
<td>85 MHz</td>
</tr>
<tr>
<td>2200 – 2290</td>
<td>80 MHz</td>
</tr>
<tr>
<td>2700 – 3400</td>
<td>700 MHz</td>
</tr>
<tr>
<td>3400 – 5000</td>
<td>1600 MHz</td>
</tr>
<tr>
<td>5350 – 5470</td>
<td>120 MHz</td>
</tr>
<tr>
<td>5850 – 6425</td>
<td>575 MHz</td>
</tr>
</tbody>
</table>

**Used spectrum:**
- ~ 700 - 900: ~ 20 – 100 MHz
- ~ 1500/1600: ~ 40 – 70 MHz
- ~ 1800/1900: ~ 120 MHz
- ~ 2100: ~ 120 MHz
- ~ 2300: ~ 100 MHz
- ~ 2600: ~ 140 MHz
- ~ 3600: ~ 200 MHz

**Additional spectrum:**
- Junk of 3 – 7 GHz!
The Impact from Using mm-Wave Frequencies
Propagations characteristics – new channel modeling is needed!

Different propagation; may require redesign

Significantly different propagation
- Transmission through most objects is reduced but reflection is amplified.
- Foliage loss is severe.
- High pathloss component requires massive MIMO / beamforming technologies using active antennas.

Disruptive technology likely

Known characteristics: LTE-A evolution possible

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Potential of mm-Wave Frequencies

- Recent research results demonstrate the feasibility using mm-Wave
  - Transmission links were established for a distance of up to 200–300 m with path loss exponents in the range of 3.2 – 4.58 for NLoS and 1.68 – 2.3 for LoS environments
- However realizing massive MIMO / beamforming gains is a must!

➢ Over the air test methods will be required since RF connectors will not be available anymore!

The small wavelengths of mm-Wave frequencies facilitate the use of a large number of antenna elements in a compact form factor to synthesize highly directional beams corresponding to large array gains

Source: Millimeter-Wave Beamforming as an Enabling Technology for 5G Cellular Communications: Theoretical Feasibility and Prototype Results; IEEE Communications Magazine • February 2014
Massive MIMO / mm-Wave MIMO

Beamforming is one important aspect

- Massive MIMO characterized by
  - Very large (in terms of number of Tx elements) antenna array at the base station
  - Large number of users served simultaneously
  - TDD allows channel estimation without UE feedback
  - Leveraging the multiplicity of (uncorrelated) propagation channels to achieve high throughput

- mm-Wave MIMO characterized by
  - Very small (in terms of dimensions) antenna arrays possible
  - Highly directional transmission is needed to compensate severe path loss (beamforming used at Tx and Rx)
  - Dynamic beam adaptation is essential

► Over the air measurements will become much more important
► Dynamic beamforming verification requires enhancement of the existing test procedures
New 5G air interface?

- The air interface of LTE can not efficiently meet all 5G requirements
  - Cyclic Prefix is considered overhead and causes latency
  - Other means needed to avoid inter-symbol-interference (ISI) and inter-carrier-interference (ICI)

- A filtered multicarrier approach is being studied to achieve synchronous/asynchronous traffic types, with loss of orthogonality in some cases

- Different techniques are discussed
  - **FBMC**: Filter-Bank Multi Carrier
  - **UFMC**: Universal Filtered Multi Carrier
  - **GFDM**: Generalized Frequency Division Multiplexing
  - **Full Duplex

Discussion ongoing…
LTE-Advanced Rel12

Rel12 Building Blocks

- Network-Assisted Interference Cancellation
- Dynamic TDD Traffic Adaptation
- Joint FDD-TDD Operation
- Coverage Enhancements

- Small Cell enhancements incl. dual layer connectivity (macro and pico)
- D2D Proximity service detection and communication
- M2M Support for low cost devices
- WiFi offloading Selective traffic offload
- 3D MIMO Support for active antenna systems

Additionally:
5G
What can be expected

- LTE/LTE-A gradual evolution will not be sufficient, if the number of devices (M2M) and data consumption will increase as forecasted and if latency needs to be reduced significantly.
- Obvious that higher bandwidth and higher frequencies will play a role
- Potential new air interface(s), which would also allow to satisfy tight latency requirements
- Integration of potential disruptive technologies with LTE/LTE-A (2G/3G/WLAN) will be key!

“Horizon2020”
R&S Test Solution
Signal Generation / Signal Analysis

- Signal Generation up to 20 GHz (one or two RF out)
- Signal Analysis up to 67 GHz
- Channel bandwidth up to 160 MHz / 500 MHz (without / with external ARB)

R&S®SMW200A Vector Signal Generator
Internal BW of 160 MHz
RF 100 kHz to 20 GHz

R&S®AFQ100B IQ Modulation Generator
1Gsample, 528 MHz RF bandwidth

R&S®FSW Signal and Spectrum Analyzer
Analysis up to 67 GHz in a single instrument...
500 MHz BW today
R&S Test Solution
Signal Generation / Signal Analysis

- Signal Generation up to 20 GHz (one or two RF out)
- Signal Analysis up to 67 GHz
- Channel bandwidth up to 2GHz (external baseband)

R&S®SMW200A Vector Signal Generator
- RF 100 kHz to 20 GHz
- Internal BW of 160 MHz

R&S®FSW Signal and Spectrum Analyzer
- Analysis up to 67 GHz in a single instrument...
- 500 MHz BW today

R&S®RTO1044 Digital Oscilloscope
- Wideband IF

Load your “5G” waveform onto the AFQ100B or any baseband generator

...any Wideband ARB generator
R&S Test Solution

Signal Generation / Signal Analysis - mmWave

- Signal Generation / Analysis up to 67 GHz
- Channel bandwidth options remain the same as on previous slides

R&S®FSW Signal and Spectrum Analyzer
Analysis up to 67 GHz in a single instrument...

R&S®SMW200A Vector Signal Generator

IQ modulator

Two path up to 20 GHz each, e.g. $f_{LO}=15$ GHz and $f_{IF}=4$ GHz

Harmonic mixer using the 4th multiple of LO

mm-wave reference plane
DUT is inserted here

RPG HM4 50-75

2 GHz

RF

i.e. 64 GHz
R&S Test Solution
Signal Generation / Signal Analysis - mmWave

- Signal Generation / Analysis above 67 GHz
- Channel bandwidth options remain the same as on previous slides

- Signal Generation / Analysis above 67 GHz
- Channel bandwidth options remain the same as on previous slides

R&S®FSW Signal and Spectrum Analyzer
Analysis up to 67 GHz in a single instrument...

R&S®SMW200A Vector Signal Generator
2 GHz IQ modulator

Two path up to 20 GHz each, e.g. f_{LO}=17 GHz and f_{IF}= 4 GHz

RPG HM4 50-75

Harmonic mixer using the 4_{th} multiple of LO

R&S®FSZ75/90/110 Harmonic Mixer

mm-wave reference plane
DUT is inserted here

RF

i.e. 72 GHz

Analysis up to 67 GHz in a single instrument...
R&S Test Solution - High frequency / high bandwidth

Summary: Signal Generation / Signal Analysis

Signal Generation:
- SMW: No up-conversion needed up to 20GHz
  (up-conversion worsen the signal quality – phase noise!)
- Signal Generation > 20GHz using external mixer
- Signal Bandwidth up to 2GHz (using external generator via analog I/Q)
- SMW200A with 2 RF out (no additional LO generator needed for up-conversion), additionally 2 analog I/Q and 6 digital I/Q outputs

Signal Analysis:
- FSW alone up to 67 GHz and 500MHz BW in continuous measurement
- FSW: No down-conversion needed up to 67 GHz
- Signal Analysis with FSW up to 100+ GHz (using external mixer)
- Signal Bandwidth up to 2GHz (using R&S oscilloscope RTO)
R&S Test Solution

mm-Wave Component Characterization

R&S ZVA Millimeter Wave Setup

Characterize e.g. High-Pass filter

Characterization of a high-pass filter
Insertion loss vs. frequency
R&S Test Solution

Generation of Phase Coherent Signals

- Testing of Active Antenna Systems (AAS)
- Stimulus generation for Over-The-Air (OTA) tests
- Beamforming simulation
- MIMO simulation
- SMW + SGT: up to 6 GHz

- LO distribution across instruments
- Phase coherent and phase stable RF
- Synchronized baseband signals
- SGT100A directly controlled from SMW100A
- Scalable solution
R&S Test Solution

Generation of Phase Coherent Signals

- The two path SMW + SGS/SGU allows to generate 4 RF paths per set
- Sets can be cascaded by LO distribution across instruments, which creates coherent and phase stable RF
- Phase relations are set via baseband of SMW
- SMW + SGS: up to 6 GHz
- SMW + SGS + SGU: up to 20 GHz
- Complete setup is controlled from the GUI of the SMW

Example: Two sets provide 8 phase coherent signals
Parallel measurements

The R&S®ZNBT8 is the first multiport vector network analyzer offering up to 24 integrated test ports. The instrument can simultaneously test multiple DUTs or measure one DUT with up to 24 ports.

Frequency range from 9 kHz to 8.5 GHz
R&S Test Solutions
Using Vector Analyzers to Characterize e.g. Antenna Arrays

- The R&S®ZNB analyzer features high measurement speed, outstanding precision and exceptional ease of operation
- Frequency range from 9 kHz to 40 GHz

- The R&S®ZVT8/R&S®ZVT20 is the first true eight-port/six-port vector network analyzer with a frequency range from 300 kHz to 8 GHz / 10 MHz to 20 GHz

- For two or four-port R&S®ZNB, configuration of up to 48 test ports possible
- Frequency range from 9 kHz to 8.5 GHz
SK Telecom and Rohde & Schwarz join hands to develop next-generation antenna technologies

Munich and Seoul, Aug 23, 2013 - SK Telecom and Rohde & Schwarz plan to build a test bed for active antenna systems (AAS), a smart antenna system developed as part of SK Telecom’s strategy to promote a concept known as SUPER Cell. The aim is to create a stable mobile environment that allows customers to experience faster speeds by enhancing traffic management efficiency through smart antenna systems.

SK Telecom (NYSE: SKM), Korea’s largest telecommunications company, and Rohde & Schwarz announced on Tuesday that they have signed a memorandum of understanding (MOU) on joint research and development of next-generation antenna technologies.

Under the MOU, SK Telecom and Rohde & Schwarz will work together to create a test bed for AAS, a core technology in next-generation antenna systems, for performance verification. Under this agreement, the two companies will also conduct research and development for next-generation antenna system equipment. Rohde & Schwarz will provide SK Telecom with signal generators (R&S SMW200A, R&S SGS100A) and a radio network analyzer (R&S TSMW).

As part of an initiative by SK Telecom to enhance the performance of its LTE Advanced/LTE network, the company has currently been focusing on promoting network evolution through small cell technologies. In particular, it has suggested a differentiated technology concept called SUPER Cell to expand network capacity and improve data quality.

Moreover, in line with its SUPER Cell concept, SK Telecom has been focusing on research and development of next-generation antenna systems since 2011 to dramatically improve data speeds. In particular, AAS is a comprehensive antenna technology that can be applied to all types of networks, including LTE-Advanced. It is also capable of increasing the number of radio channels between a base station and handset by several to tens of times.

AAS will allow customers to experience high-quality service even in areas of high data traffic, since the antenna can coordinate the amount of radio signals to be sent from the base station.

“We are pleased to join hands with SK Telecom, the world’s top LTE service provider, to research and develop next-generation antenna technologies,” said Christian Leicher, President and COO of Rohde & Schwarz. “We hope that our joint efforts will serve as a basis for developing the most innovative network technologies that will drive further evolution of telecommunications network.”

“Joint research and development between SK Telecom, a mobile operator, and Rohde & Schwarz, a manufacturer of T&M equipment for communications networks, will generate synergies in the development of next-generation network technologies. And with these technologies, we will continue to provide our customers with high-quality services,” said Choi Jin-sung, Head of the ICT R&D Division at SK Telecom.
A potential timeline for 5G
Comparison with LTE

- **2005**: Development of R&S 1st commercial LTE test solutions
- **2010**: 1st commercial LTE network
- **2012**: Research on 5G
- **2015**: You are here
- **2020**: Development of commercial test solutions, commercial networks

**Rel**:
- Rel8
- Rel10
- Rel12
- Rel13
- Rel14
- Rel15
5G – Take away

- Significant 5G research has started (strong global momentum), but we are still at the research and educational level

The most significant T&M impact is expected from

- Use of mm-wave frequencies, R&S anticipates a stepwise approach:
  - Phase 1: Use everything up to 6 GHz. “Explore the known playing field!”
  - Phase 2: “5G” systems that support potentially up to 30 GHz.
  - Phase 3: “5G” hits frequencies above 30 GHz.
- Support for high number of devices (IoT / M2M) and D2D communication
- New physical layer, C/U splitting and optimized MAC/RRM

R&S has rich RF experience and contributes to ongoing 5G research activities
Thank you for your attention!