mmWave Multi-Antenna/MIMO techniques for 5G NR

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5G – first 22 months in numbers

140
Global Live
5G networks
(Ericsson May 2021)

703
5G devices
available
(GSA April 2021)

25%
Population covered
by the end of 2021
(Ericsson April 2021)

26 GB
Monthly mobile
data traffic per sub
South Korea (Mar 2021)

50%
of traffic on the
5G network
South Korea (Mar 2021)

mmWave rollout is happening too

175 operators in 48 countries/territories have been investing in 5G mmWave (testing, trialling, planning, acquiring licences, deploying, or operating networks)

- 26/28 GHz
- 37-40 GHz
- 47-48 GHz
- Plus historically some trials at 15 GHz, 18 GHz, 66-76 GHz and 81-86 GHz

- Strong mmWave device vendor ecosystem
  - 52 vendors have announced mmWave devices
  - mmWave in 19% of all announced 5G devices

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
<td>14.3%</td>
</tr>
<tr>
<td>MIFI/hotspot</td>
<td>9.8%</td>
</tr>
<tr>
<td>Industrial CPE</td>
<td>2.7%</td>
</tr>
<tr>
<td>Laptop</td>
<td>3.6%</td>
</tr>
<tr>
<td>Other</td>
<td>2.6%</td>
</tr>
<tr>
<td>Phone</td>
<td>29.5%</td>
</tr>
<tr>
<td>Indoor CPE</td>
<td>26.8%</td>
</tr>
<tr>
<td>Outdoor CPE</td>
<td>10.7%</td>
</tr>
</tbody>
</table>

Source: Global mobile Suppliers Association, (GSA) February 2021
5G is here – supporting a world where everything connects

An innovation platform for digital transformation
Agenda

- mmWave Multi-Antenna / MIMO techniques for 5G NR
- Main Challenge for Deployments of 5G and Beyond
- 5G NR Key Design Concepts
- 3GPP Spectrum Region Allocations
- 5G NR Spatial Processing Support & Management
- RF Front-End challenges Spectrum Outlook Beyond 5G
- Key Takeaways
Deployment Main Challenge

Global mobile data traffic (EB per month)

Channel Capacity [bit/s]

\[ C = B \cdot \log_2 \left(1 + \frac{S}{N}\right) \]

Bandwidth [Hz]

Signal to Noise (& Interference)

Source: Ericsson Mobility Report, November 2020

Claude Shannon (1916-2001)
What is the range of mmWave?

Let’s exemplify by assume the following:

- 28GHz carrier, Bandwidth 400MHz
- 64QAM, 3/4 coding rate, BER $10^{-3}$

Required Ideal Detector $SNR_{min} = 22.8$ dB

Source: G. Hueber, A. M. Niknejad,
“Millimeter-Wave Circuit Design for 5G and Radar”, Cambridge University Press, 2019

- Device receiver Noise Figure of 10 dB

\[
P_{RX, min} = 10 \log_{10}(kTB) + NF_{10dB} + SNR_{min} = -55dBm
\]

\[
P_{TX, max} = 30dBm \ (SNR_{TX} = SNR_{min} + NF_{RX} \approx 33dB)
\]

- Isotropic antennas

\[
L_{Path, max} = 85dB = 20 \log_{10} \left( \frac{4\pi d}{\lambda} \right)
\]

15m range – @ 28 GHz using isotropic antennas
Path-Loss – Frequency Dependency

- Free space path loss (PL) between isotropic antennas increases with $20 \times \log_{10}(f)$

<table>
<thead>
<tr>
<th>$f$ [GHz]</th>
<th>0.7</th>
<th>1</th>
<th>2</th>
<th>3.5</th>
<th>28</th>
<th>39</th>
<th>47</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta PL$ [dB]</td>
<td>~ 3</td>
<td>6</td>
<td>~ 5</td>
<td>~ 18</td>
<td>~ 3</td>
<td>~ 1.5</td>
<td></td>
</tr>
</tbody>
</table>

- Antenna directivity: $\sim$area in $\lambda^2 \rightarrow \sim 20 \times \log_{10}(f)$

- Propagation between fixed area antenna and isotropic antenna exactly balances free space path loss → Frequency independent propagation

- Propagation between two fixed area antennas → Frequency dependent propagation $\Delta 20 \times \log_{10}(f)$
5G NR Key Concepts

Wide spectrum range

Multi-antenna

Ultra-lean

Forward compatibility

Low latency

5G New Radio benefits creating a game-changing technology enabling innovative use cases
5G Spectrum – More Bandwidth

- Sub-GHz Regular cellular macro deployments
- mmWave – opportunity based scenarios
- High band – more bandwidth boost throughput and capacity
- Multi-antennas and Coverage layer important
5G Spectrum – High Band

Good Coverage, Low BW  |  Medium/Good Coverage, Good BW  |  Less good Coverage, Extreme BW

Mainly FDD  |  Mainly TDD

1 GHz  |  3 GHz  |  10 GHz  |  30 GHz  |  100 GHz

5G identification
- Global
- Per country

Spectrum status
- Available
- Planned
- Considered
- Unlicensed

Frequency bands
- Specified
- Work item

3GPP

International Microwave Symposium
6-11 June 2021, Atlanta, GA

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5G Licensing – 24.25-29.5GHz mmWave Band

- High Bands mmWave licensing global momentum building
  - 105 licensed (including local/regional assignments)
  - Of which 25 deploying/deployed
- Leading countries/territories licensing mmWave in addition to mid and low bands

Source: Global mobile Suppliers Association, (GSA) February 2021
5G NR – Beamformed Transmissions

Beam-centric NR design
- “Beam mobility” – Mobility between beams rather than nodes
- System plane matched to beamformed user plane

Self-Contained Transmissions
- All information needed to detect and decode contained within the transmission itself
  - Scheduling assignments
  - Reference signals for demodulation
⇒ Joint beamforming of data and all associated transmissions

To enable capacity, data rate and coverage needed in the 5G era
5G NR support – Multi-Antenna techniques

Support all type of multi-antenna implementations (and combinations thereof)
- Time-domain beamforming
- Frequency-domain beamforming

Benefits supported
- Adaptive Beamforming → Enhanced Coverage
- Spatial Multiplexing → Enhanced Capacity

Mechanisms and management motivated by time-domain beamforming
- “Transmit/Receive in one single direction (beam) per OFDM symbol”
- Dynamic beam indication to update TX/RX beam pair at mobility use cases
- Measurements to identify beams
- Beam management procedures: gNB P1/P2/P3; UE U1/U2/U3
- Beam recovery procedures
5G NR Beam Management

DL beam management procedures
- P1: Tx beam establishment (can be coarse)
- P2: Tx beam sweep for Tx beam refinement and beam tracking
- P3: UE Rx beam sweep for Rx beam refinement

UL beam management analogous procedures
- U1,U2,U3

How to connect – when to transmit Random Access
- Synchronize downlink and uplink beam-sweeping
- Derive random-access timing from received synchronization block timing
Raising the bar: RF Front-End
Industrialization – Dependent on high integration

High band is a new business
Addressable market in volumes small, but expanding rapidly
RF Front-End (FE) expensive technology
KEY – Deployability, Performance, low cost

Some challenges (non-exhaustive):
• Good coverage → EIRP, EIS
• Energy Efficiency
• Product variants: many power classes, many frequency bands, RF-filtering, and common solutions
• Building practice – scalability, modularity, size, power and heat
• Test without contacting the dies, OTA (Over-The-Air) measurements maturity

Selected areas of technology challenges:
• High EIRP and EIS with scalable EIRP with good fundamental power efficiency
• Linearity, dynamic range, EVM – DPD
• Modularity with flexible array sizes
• High integration with low loss routing, and good cooling capability
• Efficient wideband solutions (OpBW, IBW, OBW) – RFIC, antenna design, radome – covering multiple bands
• RF filtering and cost – integration, spurious emission, out of band emission
Outlook: Future wireless access – Timeline (tentative)

- **2016**: Initial 5G/NR
- **2018**: WRC ‘19
- **2020**: 5G/NR evolution
- **2022**: WRC ‘23
- **2024**: 6G systematization research projects
- **2026**: WRC ‘27
- **2028**: Technical standardization
- **2030**: WRC ‘31
- **2031**: Commercialization

- **Research on 6G technology components**

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**Tech. trends & vision document**
**Requirements & evaluation criteria’s**
**Specification**
Extension to higher frequencies – ”THz”

Outlook:
• Further extension to “THz” as part of longer-term radio-access evolution
  – “THz” is often used without a clear definition, frequently meaning ~ 100-300 GHz
  – Addressed use-cases unclear

• Re-evaluation of basic air-interface as implementation challenges differs
  – “single carrier”, e.g. DFTS-OFDM, attractive beyond ~100 GHz
  – Current NR design a good choise below ~70 GHz
Key Takeaways – mmWave
Multi-Antenna/MIMO techniques for 5G NR

5G is switched on

Commercial mmWave deployments live
An innovation platform for digital transformation

Multi-Antennas
5G NR Key Concept

Beam-Centric Design
5G NR – Beamformed Transmissions & Beam Management

RF Front-End Challenges

Industrialization – Dependent on high level of integration Modularity Key
Acknowledgments

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