Hans-Peter Mayer
Nokia Bell Labs
WSA 2017
A GAP

Can be a risk

Or a an opportunity
The Future Wireless Challenges

SEEMINGLY INFINITE CAPACITY
Data and Control Plane
Anywhere, Any Device

PERFORMANCE OPTIMIZED
Low Latency
High Reliability

ENERGY EFFICIENT
Device And Network
The ideal 5G world
... view of 5G PPP
METIS-II:

five 5G use cases

in three use case families: xMBB, mMTC and URLLC
2020: A New Networking & Connectivity Era
The world is changing...

Pre-Internet Era 1st Discovery Era (Browsers) 2nd Discovery Era (Search) 1st Sharing Era (Personal Content) 1st Commerce Era (Video & eGoods) 2nd Sharing Era (Personal Context) 2nd Commerce Era (Everything)

1.0 ZB/Yr
Connected Everything +
Contextual Automated Experiences

2.6 ZB/Yr
8K Video +
Cloud Hosting
User-Generated Content

4.3 ZB/Yr

Source: Bell Labs Consulting
Performance gaps

Ideal system – Shannon limit

Ideal system – with real world constraints
time, causality, protocols, measurement accuracy, users and traffic stats.

Limit of 5G NR Rel.15, 16, 17 implementation

Limit of LTE Rel. 14, Rel.15 implementation

Application – specific KPIs!

Widening, as we understand impairments better and better

Narrowing:
Standard and system will continue to evolve

Narrowing Gap in mid term:
LTE with 32 antenna ports (Rel 14)
LTE-NB (Rel13)
LTE-M (Rel 13)
LTE Latency reduction (Rel 14)
Essential to maintain forward compatibility
To assure evolution over Rel. 16+

NR use cases focus:
- eMBB
- URLLC

NR WIs fixed:
- NOMA
The Internet and broadband world
The Performance Challenge
Data Rates

Dramatic Increase in User Experienced Rates to Drive Demand

Faster Downloads
Virtual Reality with 360 degree views
Fixed Wireless replacement

Dramatic Increase in User Experienced Rates to Drive Demand
Meeting the Capacity Challenge
The Wireless Triangle of Truth

MIMO and Small Cells (with high band spectrum) offer the best potential for increasing capacity.

The dominant direction for investment changes:
- 2006-2010: MIMO
- 2010-2014: Small cells
- 2015-: (M)MIMO
- .....: a combination?
Exploiting the Spatial Dimension: Network Densification
Small Cells for High Capacity

Source: David-Lopez Perez, Bell Labs
New Spectrum Bands
Challenges and Opportunities

- Other services
- 33 GHz of spectrum under study by ITU for either licensed or managed shared use
- In use, unlicensed

0 - 100
0
20
30
40
50
60
70
80
90
100
<6 GHz

20-30 dB higher path loss

Higher Penetration Loss

2.6 GHz
28 GHz
Wall

Large Arrays using RFICs

Monolithic Microwave Integrated Circuit
Exploiting Spectrum Dimension

Gbps Throughputs

Outdoor 100 m Range
NLOS
8 dBi per element
16 AP TX, 10 degree beam
2 UE RX, 50 degree beam

28 GHz, 1 GHz BW

2 GHz, 10 MHz BW

10x
## 5G Frequency Bands

<table>
<thead>
<tr>
<th>Spectrum availability</th>
<th>90 GHz</th>
<th>30 GHz</th>
<th>10 GHz</th>
<th>6 GHz</th>
<th>3 GHz</th>
<th>10 cm</th>
<th>300 MHz</th>
<th>1m</th>
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<tbody>
<tr>
<td>Spectrum</td>
<td>~N×1GHz carrier bandwidth</td>
<td>~N×100 MHz carrier bandwidth</td>
<td>~N×10 MHz carrier bandwidth</td>
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<tr>
<td>Multi-Antenna Technology</td>
<td>Analog/RF array Hybrid</td>
<td>Hybrid RF/Digital</td>
<td>Fully Digital Array</td>
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<tr>
<td>Waveform</td>
<td>Single-Carrier</td>
<td>OFDM 60/120/240 kHz spacing</td>
<td>OFDM (in-band mask) 15/30/60 kHz spacing</td>
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</table>

### Low band (<6 GHz, in cellular bands)
- Provides coverage, performance, long battery life, capacity
- Multi-service support

### High band (>20 GHz)
- cmWave / mmWave
- Provides massive capacity for users in dense urban areas
- Requires beamforming

“Low” and “high” band 5G work together.
The First Use Case...
Fiber to the Home

1 Gbps peak rates, 100 Mbps DL BW, < ~5 ms latency
The First Use Case...
Wireless Fiber to the Home

1 Gbps peak rates, 100 Mbps sustained, < ~5 ms latency

CO
Feeder route

mmWave

Height 9m

Cell range

ISD

fiber distribution point
Ray Tracing Study
Sub-Urban Morphology

- 1 W Tx Power, 0 dBi receiver antenna gain
- Tilt is set for each beam as a function of street width, transmitter height and azimuth angle
- 15° horizontal and vertical beam width, 25 dBi gain

Receivers placed inside within 3 m from front and back window

4 out of 24 beams active simultaneously 250 mW each
Performance Simulations
28 GHz Only System is Insufficient

Poor performance in more than 30% of the homes

Peak Throughputs in Excess of 1 Gbps

12 Active Users per Site, 228m ISD, 250 MHz
Performance Simulations
Combined 28 GHz and 3.5 GHz System

Integrated Low Band and High Band Solution Provides Significantly Better Performance

95% Reference
756 Mbps

Median Reference
202 Mbps

5% Reference
99 Mbps

Self-backhaul:
Trading spectrum for coverage

(3GPP RP170217)
Self-backhaul:
Trading spectrum for coverage

Flow rates with 1 GHz spectrum
(28GHz band, Umi channel, 50m ISD)

Improvement
- 4 relays nodes vs. 2
- dynamic TDD vs. static

IEEE Workshop on Next Generation Backhaul/Fronthaul Networks - BackNets 2015
Frame structure: Slot types

- **NR supports four slots**
  - Bi-directional slot with DL data
  - Bi-directional slot with UL data
  - DL only slot
  - UL only slot

- **Bi-directional slot needed in TDD mode facilitates:**
  - Link direction switching between DL and UL
  - Fully flexible traffic adaptation between DL and UL
  - Opportunity for **low latency**, provided that slot length is short enough.

- **Different slot types can be concatenated in a fully flexible manner**

![Slot structure diagram]

Four slot types provide the basic support for both TDD and FDD modes
“5G has a significant potential for reducing energy compared to LTE by using sleep modes at low load - up to 50-60 percent gains at the base station level when networks operate at 10 percent average load, and up to 30-40 percent gains at 20 percent average load.”

**Figure 5. Base station power reduction potential at low loads in LTE and in 5G**

WP is available online in: [https://networks.nokia.com/innovation/5g](https://networks.nokia.com/innovation/5g) - under ‘5G Potential ‘ section

Direct link: [https://pages.nokia.com/2396.5G_Network_Energy_Efficiency.html](https://pages.nokia.com/2396.5G_Network_Energy_Efficiency.html)

**Lean Design: 5G minimizes must-be-present-signals (e.g. CRS)**

→ Sleep modes allow for strong energy reduction
Massive Machine type and ultra-reliable/low latency
The Massive MTC Challenge
Opportunity to Expand into Verticals

Massive Scalability
Extended Range
Battery Life
Device Cost
MTC Traffic Handling
LTE is Connection Oriented

Traffic Pattern optimal for Connection Oriented Service

Traffic Pattern optimal for Connectionless Service

LTE is optimized for large bursts and NB-IoT is starting to address short bursts
Models and parameters
Protocols

**4G**
- MS: Preamble, RAR, Msg. 3, SR, Grant, Data, ACK
- BS: *

**enhanced 4G**
- MS: Preamble, RAR, Msg. 3, SR, Msg. 4 + Grant, Data, ACK
- BS: *

**5G 2-step**
- MS: Preamble, RAR, Msg. 3 + Data, ACK
- BS: *

**5G 4-step**
- MS: Preamble, ACK
- BS: Data, ACK

NACK path with random backoff time

*) In spite of successful Msg. 4, resource for data packet may be unavailable. This is considered by dynamic or static split of PUSCH resources for Msg. 3 and for data.

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Contestion Based or Scheduled Access

Scheduled Access in Better

Cross-over payload depends on overheads

Contestion Based Access in Better

2020: Latency Matters...
Performance Optimized

Latency Requirements in Milliseconds

- High Frequency Trading (HFT): < 0.240 ms
- Vestibulo-Ocular Reflex (VOR): 7 ms
- VR Gaming: 7 - 13 ms
- Screen-to-Brain Propagation: 80 ms
- Cloud assisted car driving: 10 - 90 ms
- AR - Nongaming: 10 - 90 ms
- 4K video click-to-start: 10 - 1900 ms
- Hi-res Cloud Gaming (FPS): 20 - 90 ms
- Sprint Start: 120 ms
- Blink: 150 ms
- VoIP / Video Conf (1-way): 150 ms
- Web page 1st fold load: 150 ms
- IM Chat: 150+ ms

Max tolerable network delay
Max expected application delay for processing / buffering / display etc.
Human neurological response times (for reference)

After Nokia Technology Vision 2020

Only Feasible in Edge Cloud
Metro Cloud May be Possible
Centralized Cloud Implementation Viable

Human neurological response times (for reference)
Ultra Reliability and Low latency in 5G (URLLC)

URLLC will be an integral part of the 5G system

- Classify use cases along their requirements
- Two camps: wide area (Car2X) and local (Industry)
  - Support low latency
    - By short signals
    - Protocols
  - Support high reliability
    - By exploiting diversity
  - Control E2E system properties
  - Spectrum: mainly licensed, unlicensed for support

(see TS22.261, Mar. 2017)
Ultra Reliable and Low Latency

Diversity matters

- Multi-RAT
- Multi-Link
- Multi-antenna
- Multi-point
- Coding
- H-ARQ

Diversity techniques can be combined
Reliability gains depend on correlation
- Spatial diversity to fight shadowing
- Time and frequency diversity to deal with channel and interference
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# The race towards maturity

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| BB ecosystem                   |                           |                   |
| mMTC ecosystem                 |                           |                   |
| URLLLC ecosystem               |                           |                   |
Closing the gaps

• Use cases - seem to be almost complete
  – The ecosystem has to come up
• 3GPP is going fast
  – Not much time to identify optimal solutions
  – Evolution will go over time (and releases)
• The ends of the scale will matter
  – Wide area coverage (at cost) still is a huge point
  – Integration of body area?
• Maintaining forward compatibility will be extremely important
Acknowledgement

Work supported by the

The 5G Infrastructure Public Private Partnership

FANTASTIC

5G

NORMA

METIS

mmMAGIC

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$100K  
1st prize

$50K  
2nd prize

$25K  
3rd prize

...and the opportunity of collaborating with the world-renowned Bell Labs
Active in shaping and aligning the global 5G end-to-end ecosystem

**COLLABORATION**
- Technical manager
- Chairing association
- Project lead
- Project lead
- 5G expert group lead

**RESEARCH**
- Holistic systems research, prototyping & development

**REGULATORY & STANDARDS**
- ITU-R
- LTE Evolution

**POLICY**
- Supporting right technology related policies

**ALIGNMENT**
- Bringing together industry, academia & regulators