The Path to 6G: Performance Targets and Technology Enablers

Dr Alain Mourad
Outline

• **6G: The Why, What and How?**
  • Why do we need 6G?
  • What performances shall we target?
  • How do we get there?

• **Insights from EMPOWER B5G Roadmap Consultation**
  • KPIs Evolution
  • Technology Trends

• **Take-aways**
6G: The Why (1/2)

• Political view: Far more powerful, faster, and **smarter**
  • Many governments already launched 6G research agendas (e.g. EU, USA, Japan, China, South Korea).

• Societal view: Greener, **smarter** and sustainable
  • United Nations (UN) already announced 17 global sustainable development goals towards 2030.

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6G: The Why (2/2)

- **Economical view: Growth through smarter all-digital economy**
  - Digital transformation agendas including Artificial Intelligence (AI) underpin growth strategies in various sectors of the economy.

- **Technological view: Innovation continues to always do better and smarter**
  - This isn’t to say that 5G is broken and we need to fix it. This is rather the engineering instinct to create, innovate and continuously advance the state of art.
6G Vision

A Smarter Generation fusing Wireless and AI in support of 2030’s Global Societal and Economical Goals

The generation with a sixth sense!
Towards 6G – Use Cases (1/2)

A constant **expansion** of the USER and VERTICAL use cases towards a **blend of extreme** requirements

- **eMBB**
- **5G**
- **mMTC**
- **URLLC**

**2020**: Short-term EVO

**2022**: Mid-term EVO

**2025**: Long-term EVO (6G)

**2030**
Towards 6G – Use Cases (2/2)

1. Volumetric media streaming
2. Multi-sensory extended reality and haptics
3. Connected industries and automation
4. Autonomous vehicles and swarm systems
5. Aerial and satellite networks and platforms
Towards 6G – Key Requirements (1/2)

- **Spectrum** with **leap jumps above 100 GHz** all the way up to THz
- **Bandwidth** expansion from 500 MHz today **up to 10 GHz**
- **Peak data rate** moving to a few 100s of Gbps
- **User data rate** scaling up to a few Gbps
- **Connections density** doubling to 2 devices per sqm

[Source: EMPOWER – www.advancedwireless.eu]
Towards 6G – Key Requirements (2/2)

- **Reliability** gradually increasing to reach highs of **up to 9 nines**
- **U-plane latency** down to a fraction of millisecond
- **Energy efficiency** (both network and terminal) improving towards 100% gains vs 5G today
- **Positioning** accuracy to **few cms**
- **Mobility** up to **1000 km/h**

[Source: EMPOWER – www.advancedwireless.eu]
Towards 6G – Technology Trends

1. **Circuits and devices** at nanometers level with node scaling targets of Power-Performance-Area-Cost (PPAC) breaking through the limits of Moore’s Law

2. **Radio transceivers** supporting extreme requirements at Tbps data rates, sub-ms latency, and sub-mWatts power

3. **Radio system** expanding to integrate (un)licensed, (non)terrestrial, and (non)comms sub-systems, in a 3-D space with fluid topologies

4. **Network protocols** catering for the requirements of next generation internet including determinism, time-sensitivity, and automation

5. **Data** (small and big) driven E2E optimizations with pervasive collaborative **intelligence** distributed across terminals, edge, fog and cloud
Towards 6G – Enabling Technology (1/3)

<table>
<thead>
<tr>
<th>SEVO: Short-Term Evolution</th>
<th>MEVO: Medium-Term Evolution</th>
<th>LEVO: Long-Term Evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transceivers at frequencies up to 250GHz</td>
<td>Transceivers at frequencies up to 500GHz</td>
<td>Transceivers at frequencies up to 1THz</td>
</tr>
<tr>
<td>Massive MIMO with arrays of 256 elements</td>
<td>Massive MIMO with arrays of 512 elements</td>
<td>Massive MIMO with arrays of 1024 elements</td>
</tr>
<tr>
<td>Multi-RATs integration across licensed and unlicensed spectrum</td>
<td>Energy efficient waveforms and modulations for low and high spectrum</td>
<td>Cognitive Multi-WATs access across cellular and non-cellular (WiFi/LiFi)</td>
</tr>
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### Towards 6G – Enabling Technology (2/3)

<table>
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<tr>
<th>SEVO</th>
<th>MEVO</th>
<th>LEVO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended support of NR-light (mid-range) devices</td>
<td>Support of UAVs/drones as UEs, gNBs, and relays</td>
<td>Support of intelligent swarms of heterogeneous devices</td>
</tr>
<tr>
<td>Support of Non-Terrestrial Networks</td>
<td>Integration of Terrestrial and Non-Terrestrial Networks</td>
<td>Support of Massive VLEO satellites and HAPs</td>
</tr>
<tr>
<td>Device and network power savings enhancements</td>
<td>Ultra-low energy devices supporting energy harvesting</td>
<td>Battery-less devices and nodes supporting wireless power transfer</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>SEVO</th>
<th>Communication-based positioning accuracy &lt;30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Data Collection from the core, RAN and UE</strong> to enable fusion with AI/ML</td>
</tr>
<tr>
<td>MEVO</td>
<td>Joint sensing and communication including position accuracy &lt;10 cm</td>
</tr>
<tr>
<td></td>
<td><strong>Wireless Fusion with AI/ML limited to C-plane and higher layers in the U-plane</strong></td>
</tr>
<tr>
<td>LEVO</td>
<td>Integrated sensing and communication including position accuracy &lt;1 cm</td>
</tr>
<tr>
<td></td>
<td><strong>Wireless Fusion with AI/ML in every plane and every layer including PHY</strong></td>
</tr>
</tbody>
</table>
Insights from EMPOWER B5G Roadmap Consultation
H2020 EMPOWER B5G Roadmap Consultation

- Public consultation on 5G evolution towards 6G open from 03 Feb. 2020 until 20 Mar. 2020
- Targets gathering the wireless research community feedback towards a B5G roadmap including:
  - KPIs evolution
  - Technology trends
  - Experimental challenges

Have your say, it is still open for more responses!
Demographic of the Respondents so far

- So far, the consultation collected some **60+ views from experts in the Industry and in Academic Research**
- Respondents have the choice to either **stay anonymous** or **share their affiliations**
- Nearly half of the respondents (34) have chosen to **share their names and affiliations**
  - A good mixture of Industry (14 respondents) and Academic research (20 respondents)
  - A good geographic distribution from Europe, UK, Norway, USA, Canada, China, Taiwan
- Extrapolating to all respondents, a **good mixture of stakeholders** (≈ 40% Industry – 60% Academia) and geographic distribution across **Europe, North America, and South East Asia**
Insights on KPIs Evolution
**Insights – Spectrum**

- **Spectrum** will evolve over the next 10 years to reach THz frequencies?
  - Majority (53%) think we will break the cap of 100 GHz and evolve up to the limit of 500 GHz
  - Going above 500 GHz has a limited support (<20%)
  - A minority (10%) think we will not break the bar of 100 GHz
Insights – User Data Rate

• **User data rate** will evolve over the next 10 years to reach a few Gbps in downlink and uplink?

  • 98% of responses think the user data rate will range from **few 100s Mbps (48%)** to a few Gbps (50%)

  • No one think it will stay below 100 Mbps as in 5G today
Insights – Density

- **Density** will evolve over the next 10 years to reach above 2 million devices per km² (= 2 devices per sqm)?
  - Majority (56%) think it will reach **way above 2 devices per sqm**
  - A third (33%) think it will evolve but to less than 2 devices per sqm
  - Almost no one think it will stay below 1 device per sqm (5G target)

![Density Evolution Chart]

- Percentages:
  - Neutral: 7.41%
  - Below 1 sqm: 3.70%
  - Up to 2 sqm: 55.56%
  - Above 2 sqm: 33.33%

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Insights – Reliability

- **Reliability** will evolve over the next 10 years to reach 9 nines?
  - Majority (67%) think reliability will improve **up to 8 nines**
  - A few (11%) think it might go as high as 9 nines
  - Very few think it will stay below 6 nines (like 5G today)
Insights – Latency

- **Latency** will evolve over the next 10 years to reach 0.1 ms in U-plane?
  - Majority (62%) think latency will need to go **below 0.5 ms**
  - A quarter (25%) think it might evolve to less than 0.1 ms
  - Almost no one think it will stay in the 1 ms (5G target)
Insights – Energy Efficiency

• **Energy Efficiency** will evolve over the next 10 years and reach 100% improvements compared to today’s figures both in the network and in the terminal?

  • Majority (91%) think it will improve compared to 5G with (60%) seeing gains from 30-70% and (31%) seeing gains above 100%

  • Almost no one think it will stay or decrease vs 5G today
Insights – Positioning Accuracy

• **Positioning Accuracy** will evolve over the next 10 years to reach below 1 cm?
  
  • Majority (63%) think positioning accuracy will improve to **below 10 cm**
  
  • Nearly a quarter (24%) think it will go as low as below 1 cm
  
  • Almost no one think it will stay below 100 cm (5G target)
### Insights – Target KPIs Refinement

<table>
<thead>
<tr>
<th>KPI</th>
<th>5G NR (today)</th>
<th>Target KPI in 6G (2030’ish) from EMPOWER</th>
<th>Reference [DOCOMO’s 6G Vision Whitepaper]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum</td>
<td>52.6 GHz</td>
<td>Up to 500 GHz</td>
<td>Up to 500 GHz</td>
</tr>
<tr>
<td>User data rate</td>
<td>100 Mbps</td>
<td>Above 1Gbps</td>
<td>NA (Peak data rate &gt;100 Gps vs. A few 100 Gbps from EMPOWER)</td>
</tr>
<tr>
<td>Density</td>
<td>1 device per sqm</td>
<td>Significantly above 2 devices per sqm</td>
<td>10 devices per sqm</td>
</tr>
<tr>
<td>Reliability</td>
<td>5 nines</td>
<td>Above 8 nines</td>
<td>Up to 7 nines</td>
</tr>
<tr>
<td>U-plane latency</td>
<td>&lt;1 ms</td>
<td>&lt;0.5 ms</td>
<td>&lt;1 ms</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>NA</td>
<td>50%-100% gains vs 5G (Rel.16)</td>
<td>Qualitative: Extreme low power including alternative charging</td>
</tr>
<tr>
<td>Positioning accuracy</td>
<td>&lt;1 m</td>
<td>&lt;10 cm</td>
<td>NA</td>
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</table>
Insights on Technology Trends
Insights – Massive MIMO

- **Massive MIMO** will evolve over the next 10 years to include many more antenna elements utilizing AI-based beamforming enabling significantly higher spectrum utilization?

- Nearly 90% majority see Massive MIMO using some form of **AI-based beamforming**, with antenna array sizes from **a few hundreds (47%) to the thousands (43%)**

- Very few (8%) think it will have limited improvements compared to 5G today
Insights – Waveforms

• During the next 10 years, the transmitted waveform will adapt to the propagation scenario and application in real-time with short latencies?
  
  • Majority (47%) think it will continue to be OFDM-based with evolved numerology
  
  • Nearly a third (34%) think there will be new agile waveforms
  
  • No one think that the waveform will not evolve in some sort
During the next 10 years, **Integrated Access and Backhaul** will be the preferred transmission concept in wireless networks?

- Majority (64%) think there will be **some use of IAB**, but it will remain complementary (not dominant)
- A minority (18%) think IAB will mature and be widely used
- Very few (3%) think that IAB will not gain momentum
Insights – Power consumption/saving

- Battery-less **low power** devices and sensors will in 10 years be supported together with significant advances in **power saving**?
  - Majority (56%) think **ultra-low power devices using energy harvesting** will be supported
  - A third (31%) see more disruptive **battery-less devices** including support for **wireless power transfer**
  - No one see only limited improvements in power saving
Insights – Multi-Connectivity

- **Multi-connectivity** across cellular and non-cellular technologies will reach maturity in 10 years and be implemented in networks and devices?

  - Majority (82%) see multi-connectivity widely supported with _some level of integration_ across wireless accesses

  - A third (30%) see _fully integrated multi-access_ using cognitive schemes

  - No one see multi-connectivity continuing to be limited to within cellular multi-RATs only

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**Multi-connectivity Evolution**

- Full integrated access using cognition: 30.36%
- Limited to cellular multi-RATs: 0.00%
- Some level of integration between Multi-RAT and WiFi: 51.79%
- Neutral: 17.86%

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Insights – Non-Terrestrial Networks

- **Non-Terrestrial Networks (NTN)** like low-orbit satellites (LEO) and high-altitude platforms (HAP) will in 10 years be operational and integrated and supported?

  - Majority (75%) foresee **NTNs integrated with terrestrial networks** either partially (44%) or fully (31%)

  - Almost no one (2%) think that NTNs will continue to be segregated from terrestrial networks
In 10 years, **Wireless AI fusion** based on data collection and analytics from the core, RAN and UE will be pervasive?

- Majority (83%) see **wireless AI fusion happening**, with (50%) foreseeing it will be **pervasive in every plane and every layer including PHY**, whereas (33%) foreseeing it will be **limited to C-plane and U-plane higher layers**.

- Almost no one (2%) think that Wireless AI fusion will be limited to some data analytics in Core and RAN.
Insights – Sensing and communications

- In 10 years, wireless networks will integrate **sensing, imaging and radar** to improve tracking, monitoring and positioning?
  - Majority (91%) think **sensing will be integrated in the network in some form, limited (48%) or full (43%)**
  - Almost no one (2%) think sensing will not be a function or service embedded in the network
### Insights – Top 10 technology trends

1. **Wireless AI fusion (18%)**
2. **Sub-THz technology (14%)**
3. **Ultra-low power (12%)**
4. **Multi-access (10%)**
5. **Flying UEs/Nodes (8%)**
6. **Positioning (7%)**
7. **Holographic MIMO (7%)**
8. **IAB (6%)**
9. **Sensing and Comms (5%)**
10. **Advanced waveforms (5%)**

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#### Technology Trends by Popularity

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<tr>
<th>Technology Trend</th>
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<td>Advanced waveforms</td>
<td>5%</td>
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Take-aways
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• The journey of 5G evolution has already begun in 3GPP!

• Visions for 6G are being laid out, performance targets and technology trends are emerging

• Consensus emerging on 6G targeting extreme KPIs vs 5G today (e.g. 500 GHz spectrum, 100s of Gbps peak rate, Gbps user rate, 0.5 ms latency, 8 nines reliability, etc.)

• Technology trends are emerging with noticeable popularity to Wireless-AI fusion, Sub-THz, and Ultra-low power

• As ITU-R finalizes its IMT-2020 recommendations this year, it may be timely to kick start ITU-R IMT-2030 planning now with the aim to set a global vision and requirement for 6G by 2023
Key References

1. EMPOWER project, www.advancedwireless.eu


Acknowledgment to our Partners

www.advancedwireless.eu

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UNIVERSITY OF Southampton
Thank You – Q&A

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