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ICT - Information and Communication Technologies

Deliverable D2.2
First technology roadmap for advanced wireless

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Executive Summary

This second deliverable D2.2 outlines the first EMPOWER technology roadmap for advanced wireless based on the technology trends captured in the first deliverable D2.1 [1].

The following list summarizes the key points/achievements from this deliverable:

1. A 7-steps roadmap methodology is presented, and the progress is elaborated on for each step, except of step 7 on recommendations and risk analysis due in the final roadmap release in 2021.
2. A comprehensive roadmap is presented for the KPI targets in the short, medium, and long -term evolution of 5G.
3. A baseline wireless technology roadmap is presented with a 3GPP-centric view. This baseline roadmap is compiled based on the prioritization of the Top-5 wireless technology trends in each evolution phase following the capturing of the Top-10 trends in each phase.

Being predictive in nature, we acknowledge that the roadmap may not be complete or may be missing some key trends. In order to ensure that the roadmap is most representative of the EU-US wireless community views, our next step will be to carry out a consultation soliciting the feedback of the community. The results of such consultation will then drive the update of the EMPOWER roadmap in its next release.

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Introduction

The EMPOWER project has been following closely all the developments around 5G evolution, from the shorter term to the longer term, with the aim to develop a comprehensive advanced wireless technology roadmap. The first public deliverable D2.1 [1] of the EMPOWER project presented the emerging wireless technology trends. This second deliverable D2.2 builds on D2.1 and attempts an initial roadmap for advanced wireless technologies. The purpose of the roadmap is two-fold:

- Build a common knowledge for the EU-US wireless R&D communities on the future wireless research directions.
- To help define areas of priority for EU-US to co-work on ahead of worldwide competition for B5G standards.

The methodology adopted to develop the roadmap followed the proven Semiconductor Industry Roadmap process [2]. The seven steps below were followed:

1. Identify roadmap team & agree need/use
2. Define scope & boundaries for the technology roadmap
3. Identify technology areas for the roadmap
4. Determine the requirements/KPIs for area of focus and define corresponding targets
5. Specify major technical solutions pertinent to the target KPIs
6. Roadmap technologies towards targets
7. Issue recommendations on areas of priority including analysis of risks

In accordance with the above methodology, this deliverable is structured in two main chapters:

- Chapter 1 presents the methodology steps 1-4
- Chapter 2 presents the methodology steps 5-6

Step 7 is left for the final release of the EMPOWER technology roadmap.

1. Roadmap Team, Scope, Areas and KPIs

1.1 Roadmap Team

The roadmap team has been launched with the authors of this deliverable, namely: Alain Mourad (InterDigital), Per Hjalmar Lehne (Telenor), and Antonio De La Oliva (UC3M).

The above core team has been supported directly or indirectly by various EU and USA experts through the various forums and actors the EMPOWER consortium has been engaging with, as reported in D2.1 [1]. Following on the release of this initial roadmap, and the planned consultation that will follow, it is anticipated that a call will be issued for experts outside EMPOWER to engage further in the future releases of the roadmap, with various engagement options such as:

i. Direct participation in developing the roadmap
ii. Reviewing the roadmap prior to its public release
iii. Direct participation in designing the roadmap consultation
iv. Responding to the roadmap consultation
v. Direct participation in the roadmap consultation workshop
vi. Promoting the roadmap to relevant forums and organizations

1.2 Roadmap Scope

The roadmap scope is set on wireless technology advances that are pertinent to the evolution of 5G new radio (NR) over the next decade 2020-2030. Figure 1 below illustrates the evolution of cellular technology and highlights the focus of our roadmap on 5G evolution (IMT-2020) towards 6G (IMT-2030) from the perspective of the radio interface. Such an evolution is driven by an expansion of the verticals targeted and a pervasiveness of intelligence everywhere into the system design.

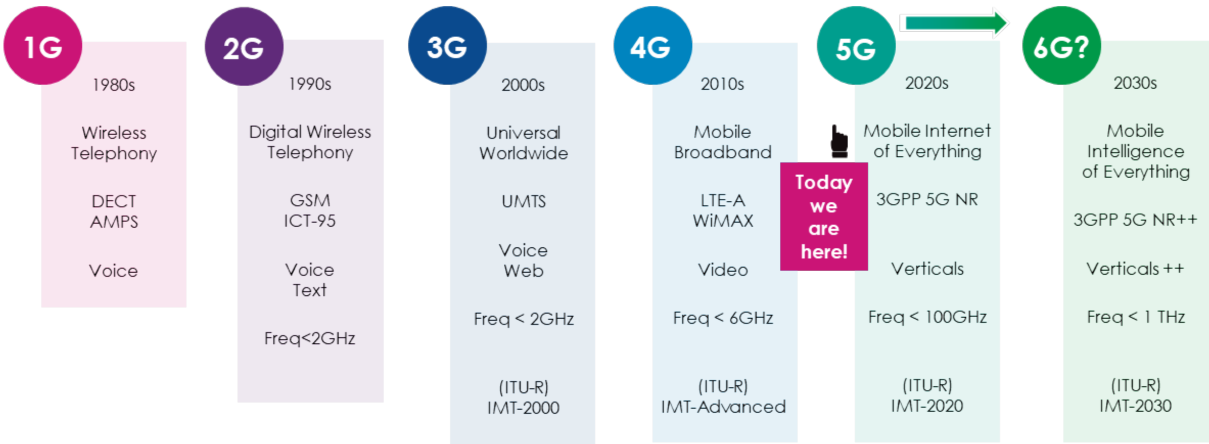

Figure 1: EMPOWER Roadmap Scope.

1.3 Roadmap Technology Areas

The roadmap team identified five technology areas that will influence the 5G evolution towards 6G. These are: i) Circuits and devices; ii) Radio transceivers; iii) Radio systems; iv) Network protocols; and v) Data and intelligence. The evolution trends for each of these technology areas are depicted in Figure 2.

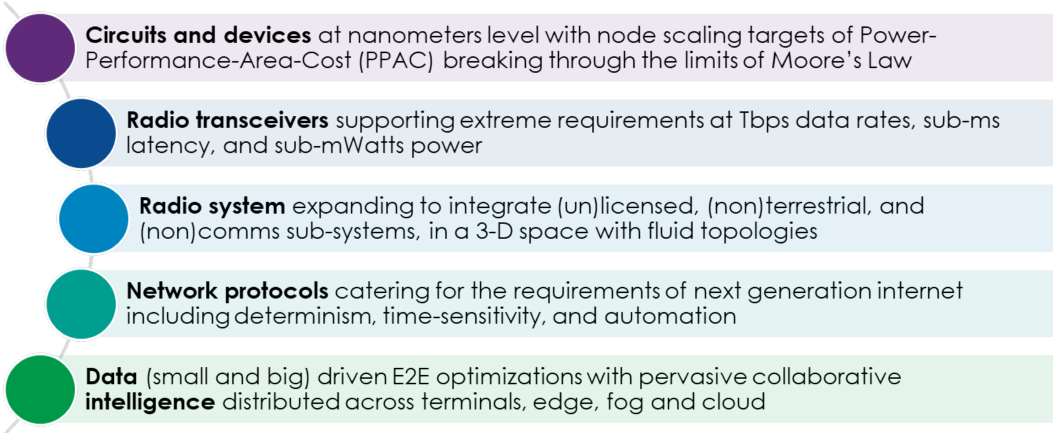

Figure 2: Technology Areas Evolution Trends.

Each of the above technology areas deserves its own roadmap for the evolution over the next decade. With the aim to focus our efforts in the baseline roadmap, the roadmap team elected to focus on the areas of radio system and transceivers which are typically the area of focus of ITU-R IMT systems. This is anticipated to provide a comprehensive roadmap consolidating the views from the radio research community, 3GPP and IEEE 802 standards, and radio spectrum forums.

1.4 Roadmap KPIs

1.4.1 Emerging Use Cases and Requirements

With the aim to motivate the evolution of 5G KPIs, we start here by capturing some trends in emerging use cases and their requirements. We acknowledge that predicting all future use cases and deriving their requirements is mission impossible at this stage, especially for the next 5-10 years. We therefore attempt to only focus on the trends to support our prediction of the 5G KPIs evolution in the next section 1.4.2.

Several use cases are emerging both in the end user applications space and in the vertical applications space. Below we listed five examples spanning both the end user and vertical applications:

- Volumetric media streaming
- Multi-sensory extended reality and haptics
- Connected industries and automation
- Autonomous vehicles and swarm systems
- Aerial and satellite networks and platforms

The above use cases and any future cases are anticipated to continue to require the same kind of 5G KPIs but with: i) new target values (e.g. higher data rate, lower latency, better reliability, etc.); and ii) new hybrids cutting across the three basic 5G service types, eMBB, URLLC, and mMTC, in the famous 5G services triangle.

Let's start first with the user space. The forecast for the user average monthly data consumption in 2024 is approximately 20 GB compared to approximately 6 GB today [3]. The most consuming user applications in 2024 are anticipated to continue to be video streaming based, which in total are forecasted to reach a staggering 15 GB in user average monthly data consumption compared to 3.5 GB today. The top video streaming user applications contributing to this dramatic increase in 2024 include: i) 1080p Full HD (1920x1080); ii) 360° Video – 720p HD; iii) Virtual Reality (VR) Full HD; and 4K UHD (3840x2160). Beyond 2024, it is envisioned that there will be more demanding video streaming applications which will take the user traffic to new levels such as: i) 8K UHD (7680x4320); and ii) Volumetric media streaming. The forecast gives therefore an increase of approximately 5 times in 5 years until 2024, which if extrapolated linearly to 2030 would lead to an increase factor between 20 and 30 times the user's traffic today. These growth factors are used as references in our prediction of 5G KPIs evolution noticeably spectrum, bandwidth, data rates, and area traffic capacity, in section 1.4.2.

Moving next to the vertical space, which is one of the main differences between 5G and its evolution compared to previous generations, various forums such as 5GACIA and 5GAA have been active in defining their use cases and corresponding requirements, and channeling these into 3GPP for support in 5G and its evolution. This is clearly evidenced through the introduction and growing importance of NR-light in 3GPP, where NR-light includes various device types many encountered in vertical applications such as smart cities, smart roads, smart factories, smart farms, smart enterprises, smart homes, etc.

It is widely acknowledged that the vertical space is diverse and heterogeneous and is characterized by a very large number of different use cases and applications, with sometimes very diverse requirements. Taking manufacturing as an example vertical domain, which is forecast in 2026 to be one of the largest and fastest growing market accounting for approximately 234 billion USD of 1,200 billion USD in digitalization revenues from 5G and its evolution [4][5], there are several use cases and applications which are mostly spread all along the side of the 5G services triangle joining the eMBB and URLLC vertices, as depicted in Figure 3 [4][5].

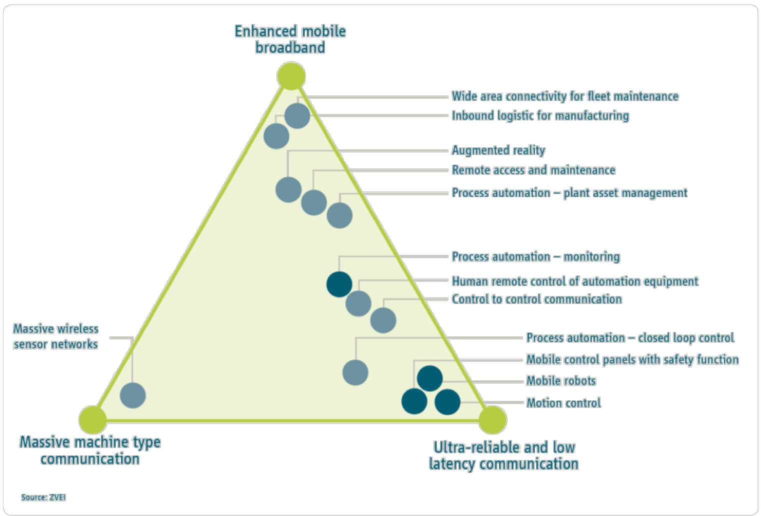

Figure 3: Selected manufacturing use cases and their positioning on the 5G services triangle [4][5].

To appreciate the diverse requirements of the above exemplary manufacturing use cases, Table 1 provided a sample of the KPI requirements extracted from [4][5]. As reported in Table 1, the requirements vary drastically for each KPI with stringent values including down to 0.5 ms latency, up to 8 nines reliability, and down to 20 cm positioning accuracy. These requirements are used as references in our prediction of 5G KPIs evolution noticeably for reliability, latency, density, and positioning, in section 1.4.2.

Table 1: Sample of KPI requirements from the manufacturing vertical use cases [4][5].

KPI	Requirement [4][5]
Data rate	Up to several Gbps
End-to-End latency	Varies from 0.5 ms to 500 ms
Time synchronicity	Down to 1 us
Reliability/Availability	Varies from 3 nines up to 8 nines
Positioning	Varies from 0.2 m to 10 m

1.4.2 *Trends for KPI targets evolution*

Table 2 summarizes the targeted KPIs based on the requirements captured in D2.1 [1] for the short (SEVO), medium (MEVO), and long (LEVO) -term evolution of 5G, compared to the KPIs targeted in today's 5G New Radio. Some of the requirements from D2.1 [1] have been updated in line with the evolution of trends as captured in the research and standardization forums. Below are some guidelines on how the evolution of the different KPIs has been derived for the short, medium and long terms. It is noteworthy that all the KPIs below are not new, but their target values are envisioned to evolve in the various phases of the evolution of 5G.

- **Spectrum:** The current 3GPP 5G NR releases (Rel-15 and Rel-16) operate in a spectrum below 52.6 GHz. This cap is already lifted in the upcoming Rel-17, but there hasn't been yet an agreement on the new cap, whether it will be 100 GHz or 250 GHz. We therefore set the target threshold of the spectrum in SEVO reasonably to 250 GHz, especially as there is already standardization work in this space both in IEEE and ETSI. As we referred in D2.1 [1], a study on the spectrum band 275-450 GHz will be discussed at this year's WRC-19 in October 2019. This is anticipated to underpin the MEVO target. For the 5G LEVO, we extrapolate the MEVO target next to 1000 GHz (1 THz) in line with the active research interest in sub-THz communications detected in the wireless research community.
- **Bandwidth:** The bandwidth was derived in accordance with the Spectrum KPI and it represents a single channel bandwidth thus does not include any aggregation. Today in 3GPP 5G NR, the channel bandwidth may go up to 0.5 GHz (to be precise 400 MHz = 0.4 GHz) in the FR2 spectrum below 52.6 GHz. We therefore anticipate the bandwidth to multiply by 5 to up to 2.5 GHz in the 5G SEVO in line with bandwidth availability in the 50-250 GHz spectrum range. This 2.5 GHz target channel bandwidth comes also in line with what exists in standards today such as in IEEE 802.11ay, where the single channel bandwidth is 2.16 GHz in the 60 GHz spectrum. Further on, the single channel bandwidth is envisioned to go up to 5 GHz in the 250-500 GHz spectrum, and further up to a staggering 10 GHz in the 500-1000 GHz (THz) spectrum. It is noteworthy that in our target bandwidth setting in SEVO, MEVO, and LEVO, we have kept the ratio of frequency/bandwidth constant to approximately a factor of 100 ($\approx 52.6/0.5 \approx 250/2.5 \approx 500/5 \approx 1000/10$). This prediction aligns with the growth in average user data consumption outlined in section 1.4.1 where it is forecast a growth factor of approximately 5-10 times, 10-20 times, and 20-30 times in 2023-2024, 2025-2027, and 2027-2030, respectively.
- **Peak Data rate:** The peak data rate is obtained simply by scaling linearly with the bandwidth KPI. In 5G SEVO, by multiplying by 5 the bandwidth from 0.5 GHz to 2.5 GHz, we anticipate the peak data rate to also multiply by 5 to 100 Gbps and 50 Gbps, respectively for downlink and uplink, up from 20 Gbps and 10 Gbps in 5G NR today. These targets come in line with what is achievable today for example in IEEE 802.11ay where a peak data rate of about 70 Gbps in downlink is achievable in 2.16 GHz channel. In 5G MEVO, as the bandwidth multiplies by up to a factor of 2 compared to SEVO, the peak data rate is anticipated to scale accordingly reaching 200 Gbps and 100 Gbps, in downlink and uplink respectively. Further on, for 5G LEVO, the bandwidth is further multiplied by 2 compared to MEVO, and so the target peak data rate is scaled accordingly to 400 Gbps and 100 Gbps in downlink and uplink respectively.
- **User Data rate:** Similar to the peak data rate above, without channel aggregation, the user data rate is assumed to scale linearly with the bandwidth. It is therefore envisioned to go up from (DL: 100 Mbps; UL: 50 Mbps) today in 5G to (DL: 500 Mbps; UL: 250 Mbps) in 5G SEVO, and next to (DL: 1 Gbps; UL: 0.5 Gbps) in 5G MEVO, and further next to (DL: 2 Gbps; UL: 1 Gbps) in 5G LEVO. This prediction aligns with the requirements outlined in section 1.4.1 for the end user video streaming applications and some of the exemplary manufacturing use cases.
- **Peak spectral efficiency:** The evolution of the peak spectral efficiency from today's 5G targets is derived based on the assumption of an approximately 30% improvement in average every 3 years, in line with the historical evolution from 2G to 3G to 4G to 5G. Starting from today's 5G targets of (DL: 30 bps/Hz; UL: 15 bps/Hz), the targets are envisioned to go up to (DL: 40 bps/Hz; UL: 20 bps/Hz), (DL: 50 bps/Hz; UL: 25 bps/Hz), (DL: 60 bps/Hz; UL: 30 bps/Hz), in 5G SEVO, MEVO, and LEVO, respectively.
- **Density:** The evolution of the density from today's 5G target of 1 device per sqm is primarily driven by the proliferation of connected sensors and objects including flying objects such as drones. It is not straightforward to project the density in the volumetric space (per cubic meter) so we opted to stick to the density as defined today per sqm, and any flying object would be accounted for through its 2-D

footprint projection. This is also justified by the forecast that the UAV market is expected to be significantly smaller in terms of number of devices (e.g. <10M units annual by 2026 according to ABI research). Based on recent forecasts [4], around 34 billion connected devices are forecast by 2024, of which about 22 billion will be related to the IoT. Connected IoT devices include connected cars, machines, meters, sensors, point-of-sale terminals, consumer electronics and wearables. The forecast in [4] assumes a growth of approximately 10% year on year. We therefore applied an increase factor of 30%, 70% and 120% in 5G SEVO, MEVO, and LEVO, respectively, leading to target densities of 1.3 devices per sqm, 1.7 devices per sqm, and 2 devices per sqm, respectively.

- **Area traffic capacity:** The evolution of the area traffic capacity is assumed to scale linearly with the peak data rate but also with the network densification. As we move high in frequencies, the distance range is anticipated to shrink, and further network densification would be expected. The deployment environment (e.g. indoor, outdoor) and the types of devices and their density are also anticipated to influence the area traffic capacity targets. For the sake of simplicity, we assumed a network densification growth factor of approximately 30% every three years, in line with the above assumptions for growth in peak spectral efficiency and devices density. We then took this network densification growth factor in conjunction with the bandwidth growth factor and started from today's 5G target of 10 Mbps per sqm. This led to the following targets of approximately 70 Mbps per sqm, 170 Mbps per sqm, and 450 Mbps per sqm, respectively for in 5G short, medium, and long -term evolutions.
- **Reliability:** The target for reliability today in 5G NR is 5 nines for the URLLC profile. This target is anticipated to evolve gradually to new highs especially as new time-sensitive verticals are considered. Ultimately the vision here is for wireless to replace fiber or cable in these time-sensitive and mobile use cases, in the same way the vision has been for wireless to deliver fiber-like Gbps data rates. We therefore envision the reliability target to reach 9 nines in the long term. The evolution of the reliability target is therefore derived by assuming a gain of 1 nine every 3 years, leading to 6 nines for 5G SEVO, 8 nines for 5G MEVO, and 9 nines for 5G LEVO. This prediction aligns with the requirements outlined in section 1.4.1 for exemplary manufacturing use cases.
- **U-plane latency:** Today in 5G NR, the URLLC target for U-plane latency is 1ms. Similar to reliability, we envision more and more time-sensitive vertical use cases to drive the evolution of the latency KPI. Without knowing the requirements of the use cases, it is hard to come up with precise target figures for the latency. We therefore use the following reasoning in our derivation; as the bandwidth increases, there is potential for the symbol duration to decrease accordingly. Thus, especially through concepts like the mini-slot in 5G NR, one might consider relating the achievable latency with the symbol duration. We therefore base our derivation of the future user-plane latency targets by following the bandwidth scaling factors of 2, 5 and 10, for 5G SEVO, MEVO and LEVO, respectively. This leads to a target of 0.5 ms, 0.2 ms, and 0.1 ms, for 5G SEVO, MEVO and LEVO, respectively. These targets also align with the latency targets in time-sensitive fronthaul (few 100 usec) which are already achievable today using millimeter-wave wireless fronthaul over a few hundred meters distances. This prediction also aligns with the requirements outlined in section 1.4.1 for manufacturing use cases where the most stringent latency requirement was set to less than 0.5 ms.
- **C-plane latency:** Control plane (C-plane) latency is typically measured as the transition time from different connection modes, e.g., from idle to active state, in such a way that the U-plane is established. The target C-plane latency in IMT-Advanced was less than 100 ms when the U-plane latency target was less than 10 ms. In IMT-2020, the target C-plane latency was less than 20 ms and encouraged to go below 10 ms when the U-plane latency target was below 1 ms (URLLC). There are several factors that impact the C-plane latency, such as the distance between the UE and the gNB, and processing delays at both the UE and gNB. Since the distance between the UE and the gNB is anticipated to shrink as the 5G spectrum evolves towards 100s of GHz, and that the processing power of devices and nodes is anticipated to expand, one could easily see the potential for the C-plane latency to reduce further and further. Starting from 20 ms (ideally 10 ms) C-plane latency target in 5G today, the targets for 5G SEVO, MEVO, and LEVO are envisioned to go below 10 ms, 4 ms, and 2 ms, respectively. This represents a reduction factor in 5G LEVO of 5-10 times compared to 5G today, which is inline with the reduction factor of 5-10 times in IMT-2020 (10-20 ms) compared to IMT-Advanced (100 ms).

- **Network energy efficiency:** There is no quantitative target for network energy efficiency in 5G today. The target is more qualitative and aims at minimizing the radio access network energy consumption in relation to the traffic capacity provided. Similar to the spectral efficiency, we derived the target network energy efficiency based on the assumption of an approximately 30% improvement in average every 3 years. This improvement is enabled by various mechanisms such as higher sleep ratios, switch on-off gNBs, energy harvesting, etc.
- **Terminal energy efficiency:** Similar to the network energy efficiency there is no quantitative target for the terminal energy efficiency in 5G today. The target is qualitative and aims at minimizing the power consumed by the device modem in relation to the traffic characteristics. We have therefore adopted the same assumption of an improvement of 30% every 3 years for the terminal energy efficiency, where such improvement is enabled by various mechanisms such as higher sleep ratios, zero-energy companion transceivers, energy harvesting, etc.
- **Mobility:** The targeted mobility in 5G today is up to 500 Km/h. This already covers most of the connected objects including flying objects such as drones. We therefore anticipate this target to remain unchanged at least for the 5G SEVO and 5G MEVO. For the longer term however, there is the assumption that in the future we will have flying objects travelling in excess of 500Km/hr (e.g. UAVs, airplanes) which might need to be supported, hence the target of 1000 Km/h envisioned for 5G LEVO.
- **Positioning accuracy:** There is no target today in 5G for positioning accuracy, despite 3GPP trying to achieve <3 m level accuracy to improve 5G NR location awareness. Several vertical use cases however especially in industrial control require below 1 m-level (down to below 200 cm) positioning accuracies as outlined for the manufacturing use cases in section 1.4.1. This comes in line with the targets set in IEEE 802.11az (next generation positioning) to go down to less than 100 cm in the next few years. In current discussions on enhanced positioning 3GPP Rel-17, there is mention of 10 cm to 30 cm accuracy for several use cases. The move to higher frequencies and wider bandwidths is anticipated to increase the positioning accuracy. Furthermore, cm-level accuracy is achievable today through sensing mechanisms (e.g. LiDAR). It is therefore our view that the evolution of 5G will ultimately in the long-run try to achieve this cm-level accuracy mainly thanks to higher spectrum with integrated sensing and communication. The target accuracy is therefore envisioned to improve to below 30 cm, 10 cm, and 1 cm, in 5G SEVO, MEVO, and LEVO, respectively.

Table 2: Targeted KPIs for the short, medium, and long -term evolution of 5G NR.

Target KPI	Target in 5G [6][7]	Target in 5G SEVO	Target in 5G MEVO	Target in 5G LEVO
Spectrum	<52.6 GHz	<250 GHz	<500 GHz	<1000 GHz
Bandwidth	<0.5 GHz	<2.5 GHz	<5 GHz	<10 GHz
Peak Data Rate	DL: >20 Gbps UL: >10 Gbps	DL: >100 Gbps UL: >50 Gbps	DL: >200 Gbps UL: >100 Gbps	DL: >400 Gbps UL: >200 Gbps
User Data Rate	DL: >100 Mbps UL: >50 Mbps	DL: >500 Mbps UL: >250 Mbps	DL: >1 Gbps UL: >0.5 Gbps	DL: >2 Gbps UL: >1 Gbps
Peak Spectral Efficiency	DL: >30 bps/Hz UL: >15 bps/Hz	DL: >40 bps/Hz UL: >20 bps/Hz	DL: >50 bps/Hz UL: >25 bps/Hz	DL: >60 bps/Hz UL: >30 bps/Hz
Density	>1 device/sqm	>1.3 device/sqm	>1.7 device/sqm	>2 device/sqm
Area Traffic Capacity	> 10 Mbps/sqm	>50 Mbps/sqm	>100 Mbps/sqm	>200 Mbps/sqm
Reliability	URLLC: >5 nines	>6 nines	>8 nines	>9 nines

U-Plane Latency	URLLC: <1 ms	<0.5 ms	<0.2 ms	<0.1 ms
C-Plane Latency	<20 ms	<10 ms	<4 ms	<2 ms
Net. Energy Efficiency	Qualitative	>30 % gain	>70 % gain	>100% gain
Term. Energy Efficiency	Qualitative	>30 % gain	>70 % gain	>100% gain
Mobility	<500 Km/h	<500 Km/h	<500 Km/h	<1000 Km/h
Positioning accuracy	NA (<1 m)	<30 cm	<10 cm	<1 cm

2. Technology Trends and Baseline Roadmap

2.1 Technology Trends

The first deliverable D2.1 [1] captured various technology trends emerging in the wireless research, standardization, and spectrum forums and organizations. These trends were classified into short, medium, and long -term evolution of 5G depending on their maturity timelines. All these trends target the fulfilment of the KPIs listed previously in step 4 of the roadmap methodology from Chapter 1.

With the aim to derive a baseline roadmap to drive a wider discussion, Table 3 provides a list of top 10 wireless technology trends, for the short, medium and long -term evolution of 5G.

The details of which KPIs is targeted by which technology trend listed, and what are the anticipated gains, trade-offs, and maturity lines, of a given technology trend towards meeting or exceeding the targeted KPIs, is not addressed in this deliverable and left for future work. It is our intention to collect the views of the different experts in these areas to shed light on these questions in more details. This will be a key aspect of our consultation which will follow the release of this document.

Table 3: Top-10 wireless technology trends for 5G SEVO, MEVO and LEVO.

No	5G SEVO Trends – Top 10	5G MEVO Trends – Top 10	5G LEVO Trends – Top 10
1	Transmission schemes at mmWave frequencies above 52.6GHz up to 150GHz	Transmission schemes at mmWave frequencies above 150GHz up to 500GHz	Transmission schemes at mmWave frequencies above 500GHz up to 1THz
2	Massive MIMO with antenna arrays of up to 512 elements	Massive MIMO with antenna arrays of up to 1024 elements including distributed arrays	Massive MIMO with antenna arrays of thousands of elements (dubbed Holographic MIMO)
3	PHY/MAC enhancements to support lower latency (<1 ms) and us-level synchronization	Highly energy efficient waveforms and modulations in low and high frequency ranges	Cognitive selection of advanced modulation, coding, and waveforms
4	Unlicensed spectrum and dual-connectivity across licensed-unlicensed spectrum	Multi-connectivity composing from multiple RATs in licensed and unlicensed spectrum	Cognitive integrated access across cellular and non-cellular evolutions of NR, WiFi, and LiFi
5	Integrated Access and Backhaul (IAB) enhancements	In-band full duplexing for gNB and some UE categories	Cognitive dynamic duplexing and carrier aggregation
6	Extended support of NR-light (mid-range) devices	Support of UAVs/drones as UEs, gNBs, and relays	Support of swarms of different devices and device types
7	Device and Network Power Savings Enhancements	Ultra-low energy devices and networks supporting energy harvesting capabilities	Battery-less devices and networks providing support of wireless power transfer
8	Support of Non-Terrestrial Networks (NTNs)	Integration of Terrestrial and Non-Terrestrial Networks	Support of Massive VLEO satellites and HAPs
9	Data Collection from the core, RAN and UE to enable fusion with AI/ML	Wireless Fusion with AI/ML limited to C-plane and higher layers of stack in the U-plane	Wireless Fusion with AI/ML in every plane and every layer of stack including PHY
10	Communication-based indoor positioning accuracy <30 cm	Joint sensing and communication	Integration of communication, sensing, imaging and radar

2.2 Baseline Roadmap

This baseline roadmap aims at driving discussions and collecting feedback from the community to help flesh out the future release of the EMPOWER technology roadmap. In order to draw a baseline roadmap based on the above technology trends, we shortlisted Top 5 technology trends and mapped them to the 5G SEVO, MEVO and LEVO, respectively. We also provided as a benchmark the Top 5 technologies in current 5G NR based on Rel-15 and Rel-16. This initial is depicted in Figure 4. The timeline of the 3GPP releases is only speculative.

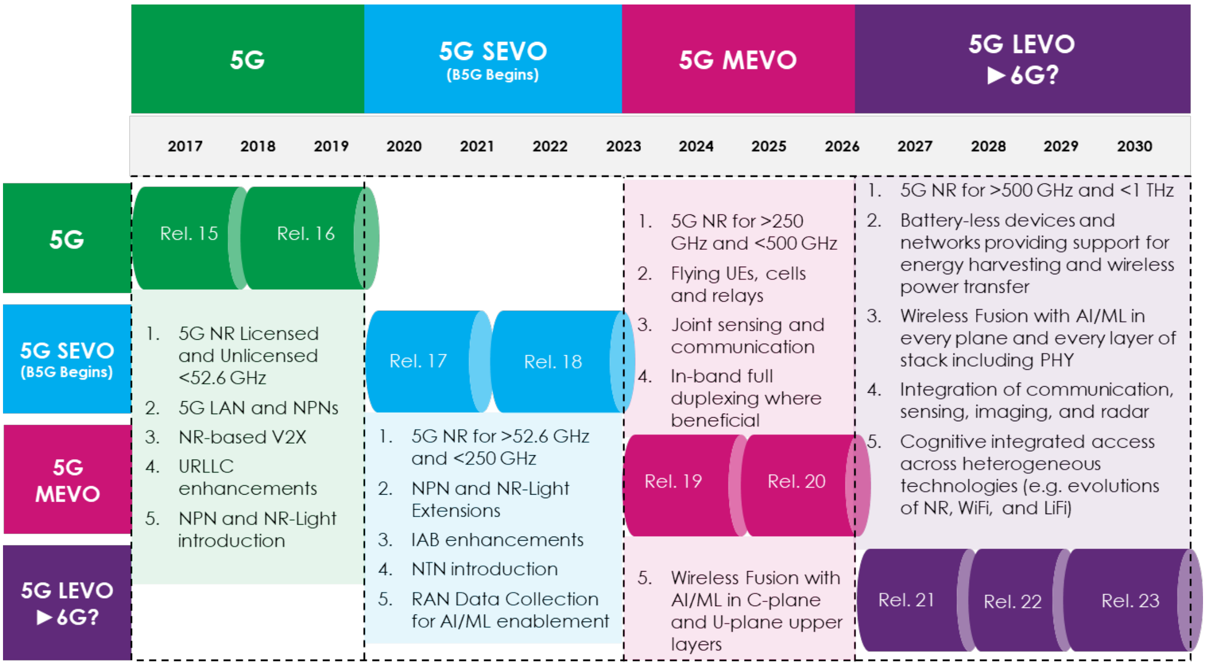

Figure 4: EMPOWER Baseline Technology Roadmap from a 3GPP-Release perspective.

The selection of the Top 5 technologies to appear in the roadmap is done based a qualitative assessment of the potential impact the new technology will bring compared to previous releases. However, for the avoidance of doubts, the roadmap in Figure 4 is always best read in conjunction with the Top 10 technology trends listed in Table 3 above. We also acknowledge that the roadmap in Figure 4 may not be complete or some missing trends in the Top 5 might be more disruptive than trends now listed. Our approach to fix these potential shortcomings and refine the roadmap is to carry out a consultation and update the roadmap based on the feedback received from the different research, standardization and radio spectrum communities.

Conclusions and Next Steps

This deliverable presented a baseline EMPOWER roadmap for the evolution of 5G NR in the short, medium and longer terms towards 6G. A 7-steps roadmap methodology was presented in the introduction following the proven semiconductors technology roadmapping process.

Chapter 1 then followed and presented the progress on the first 4 steps, namely, the roadmap team, scope, technology areas, emerging use cases and requirements, and target KPIs. An explanation was provided for the reasoning behind the KPI targets set in the short, medium, and long -term evolution of 5G.

Chapter 2 followed next on steps 5 and 6 of the methodology, first by listing the Top-10 wireless technology trends in the short, medium, and long -term evolution of 5G. These technology trends are deemed key to meet the KPI targets from Chapter 1. Following on these Top-10 trends, a further shortlisting was attempted for the Top-5 deemed of significant potential impact at every evolution stage. It is noteworthy that step 7 of the methodology which is focused on issuing recommendations of priority areas and risk analysis has been left for the final release of the EMPOWER technology roadmap in 2021.

The roadmap presented in Chapter 2 is based on the roadmap team's best judgment of the trends captured. Being predictive in nature, we acknowledge that the roadmap may not be complete or may be missing some key trends. In order to ensure that the roadmap represents the wider community vision and consensus, our next immediate step will be to carry out a consultation soliciting the feedback from the different research, standardization and radio spectrum communities. The results of this consultation will then drive the update of the EMPOWER roadmap for the future release.

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