**ANNEXES**

**Annex 1 – Technical capabilities and innovating technologies in 5G context**

* *network slicing*

Since not all the 5G capabilities (see Table no. 2 above) are compatible with each other, they cannot be achieved simultaneously. Therefore, defining each category of uses (mobile Internet, fixed Internet, machine-type/M2M communications and mission-critical communications) requires a compromise between different capabilities. This is why network slicing has been introduced and stands as an operating principle – concept introduces the concept of differentiated network administration, by which each "slice" (segment) is a distinct virtual sub-network that benefits from dedicated resources and delivers its own set of performance indicators, corresponding to the needs of each use case/category[[1]](#footnote-1). Sub-networks can separate infrastructure resources from the physical network to create independent virtual networks, with features tailored according to specific needs (for example, an optimized segment for connected IoT objects, another segment for mission-critical communications with special security and quality requirements, such as for public safety government services).

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It should be noted that network slicing also provides a model for network infrastructure sharing at the very level of equipment using radio frequencies: for example, a single network of transmitters can be used by more than one operator, for example as a short-term solution to reduce costs.

* *software and virtualization*

Efficiently achieving the various compromises needed to simultaneously provide different use categories implies a high level of network agility. Thus, the simultaneous use of multiple generic, reconfigurable and high-performance components instead of those permanently dedicated to achieving predefined tasks ensures the flexibility and dynamism of networks by enabling massive and fast adjustment and configuration of network slices to service demand.

This evolution of a significant number of network components is possible through **Software Defined Networking** (SDN) and **Network Function Virtualization** (NFV).

A functionality evolved from Software Defined Networking (SDN) is **cloud RAN**[[2]](#footnote-2), or **centralized RAN**. This type of radio access network has a very different architecture from the currently used one, mainly due to the fact that base station signal processing units are not on the base stations, being centralized upstream, in the cloud network.

Centralization based on cloud computing allows for a complete view on all the base stations (2G, 3G, 4G, and 5G), therefore coordinated signal processing and the management of interference between cells and devices can be achieved almost instantly and with increased efficiency.

Intelligent administration also enables dynamic allocation of network resources in time or real-time automated capacity adjustments based on demand peaks for specific segments (for example, capacity can be allocated to an office building during business hours and to information gathering from sensors, at night) or based on the instantaneous capacity change (a network of surveillance cameras permanently transmits low-resolution images, but when sensors detect activity within their range, the resolution increases to the maximum).

* *antenna technologies*

Currently, mobile networks are typically congested in areas with a high density of users, a situation that diminishes the bandwidth available to customers, reduces the speed of internet services, and may sometimes lead to the connection failure. Beyond increasing the amount of radio spectrum, a possible remedy enabled by 5G only is the use of a frequency spectrum that has not been used for mobile communications before - the **millimetre waves**. Widely used for point-to-point communications[[3]](#footnote-3), the use of millimetre waves in mobile communications for the capacities listed in Table no. 2 above will require very large bandwidth frequency channels (100 MHz and above, per user). On the other hand, coverage will be limited, and the signal will not penetrate buildings or obstacles. Consequently, the operators will radically transform the architecture of existing networks by installing thousands of miniature base stations - the so-called small cells. Miniaturization of base stations allows targeted and more efficient use of the frequency spectrum.

Furthermore, the new antenna technologies contribute substantially to increasing spectrum efficiency. Other technologies, currently in the trial-research phase, will help reduce latency - a critical requirement for 5G.

Two antenna technologies are critical to materializing 5G performance: by aligning tens of radiating segments (intelligent micro-antennas) on the same panel, **massive MIMO** can increase simultaneous transmission capacity even 22 times or more, compared to existing capabilities. The productivity of this technique is enhanced by **beamforming**, which allows base station antennas to direct the signal to a particular area/zone, instead of radiating it omnidirectionally. Directional signals make it possible to increase the connection capacity between the base station and the connected terminal while being much less susceptible to interference and ensuring a significantly larger radius/distance from the base station. Thus, the base station's ability to simultaneously serve more users for higher traffic per connected device increases considerably.

If massive MIMO substantially contributes to increasing spectrum efficiency, a new technology, called **full duplex**, is currently in the trial-research phase. In classical systems, transmission and reception are achieved either in different frequency bands (FDD mode) or at different moments in time (TDD mode, in the same frequency). In Romania, the vast majority of frequencies used by mobile networks are in FDD mode. Full duplex technology allows the transmission and reception of information simultaneously, on the same frequency and at the same location, therefore - in principle - it could double the capacity of the network using the same spectrum resources.

Ensuring the expected performance of 5G wireless networks also involves providing upstream capabilities, in order to connect cells to networks. Widely used in backhaul networks today, current radio relay links will not be enough in the 5G perspective, the unanimously recognized solution for meeting the capacity and latency requirements is the massive migration to connecting cells to the network using fiber optic. However, network deployment experience shows that point-to-point radio relay links can be efficient for traffic concentration/transport, and for ensuring other connectivity scenarios, such as machine-type communications, given the less stringent capacity requirements, or even for the fronthaul segment (up to the first point of traffic concentration). Very high frequency bands (e.g. 70-80 GHz) are suitable therefor, as they provide sufficient bandwidths, spanning hundreds of MHz, and even 1 GHz.

* *mesh networks*

In a mesh network, all objects/nodes are connected to each other without a central hierarchy, forming a mesh topology, so that each node could receive and transmit data and information.

In addition to avoiding critical points whose failure isolates part of the network, mesh networks have multiple benefits in the 5G context, especially for machine-type communications between connected objects:

* through dynamic routing, equipment connected to a mesh network is able to look for the fastest and the most secure route for data exchange;
* effective solutions can be offered for covering remote areas (agriculture, forestry), since if a single object in a network of connected objects lies within the coverage of the parent network, it will act as a point of interconnection for the entire network of objects.

**ANNEX 2 – Methodology**

This strategy has been drawn up within an inter-institutional working group (GLI-5G)[[4]](#footnote-4) under the coordination of the Ministry of Communications and Information Society, consisting of members from ministries and public administration institutions in Romania, as well as of representatives from institutions within the national defence, public order and national security system, respectively of invited participants - organizations of county councils, municipalities, towns and communes. The technical secretariat of the GLI-5G was ensured by ANCOM.

Since its inception, the GLI-5G has worked in various formats and with different involvement degrees, depending on the analysed issues: documenting and individual work, bilateral or multi-lateral consultations, plenary sessions organized at different levels (experts, decision-makers). Moreover, the GLI-5G resorted to specialists in the field in order to substantiate some points of view, to outline trends or to highlight some challenges. In this respect, it is worth noting that:

* providers of public mobile communications networks active in Romania presented their opinions and views to GLI-5G on two occasions;
* global equipment manufacturers presented their views on 5G challenges and opportunities in Romania to GLI-5G, based on their international experience;
* outlining the 5G challenges and opportunities has allowed the permanent involvement of ATU cooperative organizations at GLI-5G plenary sessions.

Furthermore, MCSI and ANCOM allocated human and financial resources to support the drafting of the strategy.

In drafting the 5G Strategy for public consultation, GLI-5G organised 9 plenary sessions: 2 at the decision-making level, on 18 June 2018 and on 19 November 2018, respectively 7 at expert level on 12 July, 21 August, 30 August, 6 September, 18 October, 25 October and 31 October 2018.

The public consultation on the draft 5G Strategy, foreseen for the period 21 November - 21 December 2018, will allow an even greater involvement of the stakeholders and decision-makers in improving this strategic planning. Contributions to public consultation can be sent to GLI-5G@ancom.org.ro.

**Annex 3 – Acronyms and abbreviations**

**3GPP** (The 3rd Generation Partnership Project) – association of telecommunications standard development organizations

**4K** – approximately 4000 pixels resolution

**5G-PPP** – European 5G Infrastructure Public Private Partnership

**8K** – approximately 8000 pixels resolution

**AI** – artificial intelligence

**CAGR** – Compound Annual Growth Rate

**CPS** – cyber-physical systems

**CTIA** – Cellular Telecommunications Industry Association

**DSRC** – dedicated short range communications

**eMBB** – enhanced Mobile Broadband

**FDD** – Frequency Division Duplexing, communications network technology

**FWA** – Fixed Wireless Access, wireless communications technology

**Gbps** – Gigabits per second

**GSM** – Global System for Mobile Communications, mobile communications standard

**IMT 2000** – International Mobile Telecommunications for the year 2000, a family of mobile communications standards

**IMT 2020** – IMT for 2020 and beyond, a family of mobile communications standards

**IoT** – Internet of Things

**ITS** – Intelligent Transport Systems

**UIT** – International Telecommunications Union

**kbps** – kilobit per second

**LoRa** – Long Range low power wireless technology

**LTE** – Long-Term Evolution, typically 4G mobile communications standard

**Mbps** – Megabit per second

**MPGT** – General Transport Masterplan of Romania

**MIMO** – multiple-input and multiple-output (radio antenna technology for mobile communications)

**mMTC** – massive Machine Type Communications, a mobile communications specification

**NB-IoT** – Narrowband IoT, a wireless communications standard

**NGN** – Next Generation Network

**NFV** – network function virtualization – communications network architecture concept

**NMT** – Nordisk MobilTelefoni, the first fully automated system of cellular mobile telephony

**OECD** – Organisation for Economic Co-operation and Development

**OTT** – over-the-top, a generic name for internet applications (e.g. SKype, Facebook, NEtflix)

**PPDR** – [Public Protection and Disaster Relief](https://www.cept.org/ecc/topics/public-protection-and-disaster-relief-ppdr)

**RAN** – radio access network

**RSPG** – Radio Spectrum Policy Group, high-level advisory group that assists the European Commission in the development of radio spectrum policy

**SDN** – software defined networks, a communications network technology

**SigFox –** wireless communications technology, developed for connecting objects

**TEN-T** – Trans-European Transport Networks

**TIC** – Information Technology and Communications

**TDD** – time division duplexing, a communications network technology

**UMTS** – Universal Mobile Telecommunications System, a typically 3G mobile communications standard

**URLLC** – Ultra Reliable Low Latency Communications

**V2I, V2P, V2V, V2X** – vehicle-to-infrastructure, vehicle-to-person, vehicle-to-vehicle, vehicle-to-everything (technology developments for self-driving and connected vehicles)

**Wi-Fi** – a technology for wireless local area networking

**WiGig –** Wireless Gigabit Alliance, developing multi-gigabit per second speed wireless communications technology

**WRC** – World Radiocommunications Conference

1. e.g. viewing high-resolution media content (4K, 8K, 3D, VR) require spectrum efficiency, maximum data rates and ensuring the data rate over a certain area, which can be achieved at the expense of other capabilities, such as latency or connection density; on the other hand, simultaneously connecting a large number of objects requires concentrating resources to the detriment of spectrum efficiency and latency [↑](#footnote-ref-1)
2. RAN - Radio Acces Network [↑](#footnote-ref-2)
3. de exemplu, pentru conectarea stațiilor de bază la rețea [↑](#footnote-ref-3)
4. mandated by the MoU adopted in the Government working session of 16 May 2018 no. 20/9022/A.I.L [↑](#footnote-ref-4)