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5G WHITE PAPER 2

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5G White Paper 2

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Executive Summary

Since the publication of the first NGMN 5G White Paper, the first phase of 5G standards has been completed, initial 5G services have been launched, and much more is underway to increasingly realise the potential of 5G. Whilst the initial standards and launches have mostly focused on enhanced Mobile Broadband, 5G is expected to increasingly enable new business models and countless new use cases, in particular those of massive Machine Type Communications and Ultra-reliable and Low Latency Communications. These capabilities, along with such features as virtualisation, cloudification, edge computing, network slicing and autonomic management, will provide the flexibility, agility and resilience needed to deliver solutions for a wide range of industry segments, or Verticals.

These new and evolving technology paradigms and building blocks enable a great number of user and application scenarios with a broad variety of requirements. The cloud native 5G system will involve automated platforms with exposure of capabilities and value. It will provide dedicated and shared network slices dynamically as required by the use cases and Verticals, all the way to the edge. Furthermore, network disaggregation and openness will provide flexibility and scalability, and enable a broad ecosystem and choice.

To realise the full benefits of virtualisation, cloud, and edge computing, the industry must avoid fragmentation by adopting global standards with open, interoperable interfaces and application programming interfaces, thereby delivering the promise of agility and scalability. A common Operator Platform architecture is desired in order to allow edge computing to be used on a global scale.

5G creates diversity and flexibility in business models, enabling a variety of roles. Partnerships will form the end-to-end ecosystem, with Mobile Network Operators having a unique and expanded role to provide networks and services, creating and distributing value to the Verticals within a dynamic and adaptive ecosystem. They will leverage their networks and services to provide dedicated and customised solutions for enterprises, who can thus benefit from economies of scale and the operators' experience in providing and operating these networks and services.

Mobile Network Operators are uniquely placed to provide a fully integrated solution that encompasses networks, clouds and platforms, with dynamic customisation, partnerships, end-to-end management, carrier-grade security and efficient spectrum use. Mobile Network Operators and Verticals should increase their engagement to develop meaningful, mutually-beneficial partnerships and business models in order to fully deliver the 5G potential.

5G is therefore expected to continue to empower and enrich the digital gigabit society and economy, and this must be delivered with social responsibility. Telecommunication networks have been shown to be, and will continue to be, vital for society during disaster and emergency situations; in the future they will be fundamental for the personal and professional life of citizens worldwide. Our objective is to enable and contribute to prosperity and productivity, with significant energy and resource efficiency, sustainability, social wellbeing, trust, and inclusion.

Increased focus needs to be given to significantly improving energy efficiency, sustainability, social wellbeing, trust, and to digital inclusion. We encourage studies about quantifying the general societal benefits of networking technologies, the investigation of solutions to reduce end-to-end environmental footprint, and an analysis of the sustainability vs societal / environmental / economic benefit of the current innovation cycles, which imply renewing and manufacturing equipment regularly.

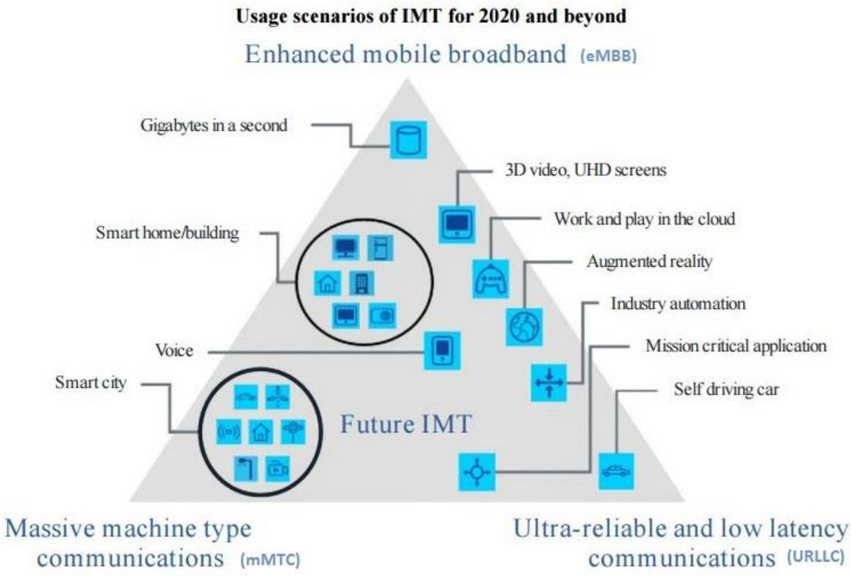
Finally, NGMN acknowledges and welcomes research starting on the future evolution of wireless systems.

The operators of NGMN suggest to the worldwide research community to focus on the societal and environmental requirements, challenges and opportunities that future wireless systems can help address. Research on new technologies and future network architectures should be prioritised towards addressing the challenges and opportunities beyond the full realisation of NGMN's 5G vision.

Contents

1 INTRODUCTION

NGMN published its first 5G White Paper in 2015 [1], providing an operator vision of 5G and serving as a guideline for 5G definition and design. Since then, the White Paper has been referenced by standards development and industry organisations when producing 5G specifications and promoting the 5G ecosystem. In June 2019, 3GPP[1] completed Release 15, which included the first phase of 5G specifications, targeting the usage scenarios and requirements for IMT-2020 specified by the ITU and summarised by the diagram below [2]:



In June 2020, 3GPP completed Release 16, including the second phase of 5G specifications which provide capabilities for massive IoT (mMTC) and critical communications (URLLC). Subsequent releases will further expand the capabilities for mMTC and URLLC, providing solutions for different industry segments (also referred to as vertical industries, or Verticals) such as automotive, transport, industry and health. Coupled with the introduction of capabilities such as network function virtualisation, cloudification, edge computing, network slicing and autonomic management, 5G will deliver the flexibility and agility to address a wide range of Verticals' needs.

The first NGMN 5G White Paper provided a 5G vision, describing the business context and identifying several use cases and business models. It defined detailed requirements based on this vision, reviewed technology trends, identified potential technology building blocks and proposed an architecture for the 5G system. Finally, the White Paper provided recommendations on spectrum and IPR. This second White Paper builds on the first 5G White Paper, extending the vision, use cases and enablers with an increased focus on the vertical industries that 5G will serve.

This second 5G White Paper begins with a review and expansion of the vision in the first 5G White Paper. It then highlights some of the vertical industries that 5G will progressively support, showing how mobile network operators can provide both network and services to meet the varied requirements of the different markets. A high-level description is provided of key technology enablers that have matured or been identified since the first 5G White Paper, and that are required to meet the Verticals' requirements. Specific consideration is given to sustainability, the latest considerations and recommendations on IPR and spectrum are provided, and we conclude with some key messages and actions to industry. Sections listing abbreviations, definitions and references then complete the document.

[1] The global initiative specifying cellular communications technologies, www.3gpp.org

2 THE 5G VISION

The first NGMN 5G White Paper outlined the 5G vision, along with diverse classes of use cases, requirements, building blocks and design considerations, to position for 2020s and enable digital transformation. Much progress has been made since then, including formulation of detailed requirements and phases of standardisation, spectrum acquirement, ongoing innovations, tests and commercial launches.

A number of areas need further work at this stage, particularly in the context of new and emerging paradigms in 5G business enablement and service enablement, and delivery with inclusion and social responsibility.

2.1 Business Context

5G is expected to further enable socio-economic transformation, smart environments, and automated industries. There will be a vast heterogeneity in number of use cases, diverse requirements, end devices of all kinds, and ecosystem players.

Furthermore, the 5G vision is about a cloud-native business model, architecture, and operation. The evolution of operator cloud may involve a hybrid cloud model consisting of flexible arrangements of private clouds and public clouds, for example in partnership with one or more hyper-scale cloud providers. This is accompanied with new paradigms such as service-based architecture and open interfaces, disaggregation and distribution of intelligence all the way to the edge of the network, separation of control and user planes and software-defined networking, containerisation of micro-services, automation and AI-based operation, orchestration and network slicing.

Mobile Network Operators (MNOs) will thus enable a new business environment, within a large and growing ecosystem. This dynamic ecosystem, particularly in relations to Verticals and cloud providers, will create and demand a large variety of flexible business and operational models with great diversity in the value chain.

2.2 Service Enablement

Several new and evolving technology paradigms and building blocks enable a vast number of use cases in the full 5G vision, particularly related to the wide range of Verticals. The service enablement is surely about much greater service capabilities and possibilities, but also about full agility, flexibility, resilience, and resource efficiency.

The cloud native 5G system with service-based architecture will be software-based and programmable, with separation of planes and RAN functions, network disaggregation and openness, distributed intelligence, composable core and hybrid clouds. This path will involve automated platforms with exposure of capabilities and value, leveraging machine learning and context awareness. It will provide dedicated network slices dynamically as required by the use cases and Verticals, all the way to the edge of the network.

The enablement of the vast variety of services and value creation and delivery, with agility, efficiency and social responsibility, drive 5G to have an open, intelligent, green and software-based network and ecosystem. 5G will facilitate openness through open architecture and interfaces, open source software and open reference design components. It will leverage big data machine learning for network operation, management and promotion, to accelerate automation with embedded network intelligence. With the design principle of significant energy-efficiency, 5G will further construct the need for a comprehensive green framework. The MNO cloud journey will continue to exploit virtualisation and container technologies, softwarisation and cloudification towards an open and automated Network-as-a-Service (NaaS).

The 5G core will be capable of integrating fixed and/or mobile, terrestrial and/or non-terrestrial, unicast, broadcast and/or multicast, and local- or wide-area access networks. This should allow common services across different mechanisms providing service ubiquity, continuity and coverage, and scalability for countless number of use cases.

The number of end devices of various types will also be limitless, with possibilities of physical and virtual interfaces, sensors, robots, unmanned aerial vehicles, autonomous vehicles of various kinds, wearables, media and gaming sets, virtual CPEs, smartphones, and others, within human-to-human, human-to-machine, and machine-to-machine interactions.

The transformation in the end-to-end service enablement brought about by these enablers will greatly influence the business and operational models, the creation and distribution of value, the relationships in the new ecosystem, and the overall social responsibility.

2.3 Business Models

The 5G business context, and the associated transformation in service enablement to create and deliver value to a vast number of use cases, inherently demand great diversity and flexibility in business and operational models. These evolving and new models, with agility, adaptability, trust and efficiency, relate and adapt to the diversity in 5G ecosystem, with wide range of new service scenarios, socio-economic patterns, partnerships, user experiences, and devices, many unimagined today.

The different service scenarios potentially have their own value chain and 5G will affect and shape this ecosystem. 5G is a game changer in the business ecosystem, enabling all players to differentiate and enrich their service portfolio and to play different business roles beyond their traditional ones, covering a wider segment in the value chain.

The MNOs will be in unique position to create and distribute value. They will provide a fully integrated solution that encompasses networks, platforms and services, with dynamic customisation, end-to-end management, carrier-grade security and efficient spectrum use. The softwarisation, orchestration and exposure of network functions enable an efficient and real time allocation of network resources and capabilities. The role as a connectivity provider enhances with a variety of partnerships to provide services to end users. The strength in providing a customized service enabling platform with intelligence all the way to the edge and lifecycle management is delivering value to Verticals, while integrating telco services, including security, knowledge, context and others. The dedicated network-as–a-platform will give the MNOs the ability to form and contribute to a variety of different business models and partnerships, including cloud providers and the Verticals.

The new service enablers and increased flexibility may lead to changes in relationships between local/national MNOs, and their global counterparts; which in turn would require deeper engagement between various parties, to ensure outcomes which would be mutually beneficial to all. Additionally, closer relationships between different stakeholders may be extremely valuable in order to effectively cope with an ecosystem enabled by more open and articulated infrastructure; where non-traditional players (e.g. Over-the-Top Hyperscalers and MVNOs, Neutral Hosts, etc.) may be interested to leverage potential new opportunities.

It is therefore envisioned that 5G creates diversity and flexibility in business models enabling a variety of roles and the ability to dynamically change and reposition. Partnerships will form the end to end ecosystem, with MNOs having a unique and expanded role to provide networks and services, creating and distributing value to the Verticals within a dynamic and adaptive ecosystem, supporting different use cases and scenarios. They will leverage their networks and services to provide dedicated and customised solutions for enterprises, who can thus benefit from economies of scale and the MNOs' experience in providing and operating these networks and services.

2.4 Social and Environmental Responsibility

The MNOs, working together with the entire ecosystem, focus on and drive 5G requirements, design principles, standards, and ultimately deployments and service delivery to empower and enrich the digital transformation.

The increasingly mobile and connected society, socio-economic transformation, and automated industries of this decade, outlined in the first NGMN 5G White Paper, pose great demands to which we respond with social responsibility. Countless number of use cases, many unimagined today, with diverse requirements, and vast level of heterogeneity, traffic volume, and connection density, are enabled by 5G and its evolution, through significant technological, operational, and business transformation.

Digital inclusion is a primary objective. The minimisation of digital divide has been an ongoing trend, which should take significant step towards inclusion, in the early years of this new decade, through providing broadband connectivity and services everywhere. Service continuity, ubiquity and scalability, as indicated earlier, serve this goal, with coverage, capacity, and capabilities.

Telecommunication networks provide vital support in emergency and crisis situations, for the management of the emergency as well as to ensure business continuity, education, and in general to allow citizens to stay connected and continue to carry out their activities to the greatest possible extent. This has been demonstrated during the recent COVID-19 outbreak, where MNOs have responded to unpredicted demand and continued to provide reliable services enabling society and companies to maintain communications and interact in different ways. In this context, from a capacity, performance and agility perspective, 5G will be instrumental in enabling telecommunication networks to cope with the lasting consequences of global health crises, both in personal and professional domains.

The 5G value provided to enterprises is about innovative services and business models, on virtually dedicated networks offered as a customised and private agile platform. The value creation and delivery should inherently include trust and security, from design, through lifecycle, and security as a service as needed. The dedicated platforms offered to Verticals will enable new opportunities, high levels of productivity, and social health and well-being. Examples such as 5G for remote care, health monitoring and mobile clinics, environment protection, resource management, road safety, smart education, smart factories, smart cities, precision agriculture, intelligent transportation, tracking, supply management, and smart inventory utilisation demonstrate this. Use of unmanned vehicles such as those in construction, ports, mining, public safety and others contribute to productivity but also safety in many hazardous situations.

As such, 5G is expected to continue to empower and enrich the digital gigabit society and economy, and the value provided by the MNOs is aimed to be developed and delivered with social responsibility. The objective is to enable and contribute to prosperity and productivity, with resource efficiency and sustainability, and social welfare, trust, and inclusion. Ongoing and emerging initiatives to make future networks more energy efficient and to have lower carbon footprint are presented in Chapter 5.

3 VERTICAL INDUSTRIES

In the 5G era, network operators, whether in the mobile or fixed access space, will focus on both the consumer market and vertical industries. MNOs will not only provide communication products to individual customers, but also provide a variety of integrated ICT solutions for enterprise customers, with e.g. enhanced radio performance, dynamic customisation, end-to-end flexibility and management, and carrier-grade security.

This end-to-end flexibility will come largely from the introduction of enablers and technologies such as edge computing, telco cloud, Software-Defined Networking (SDN), Network Functions Virtualisation (NFV) and autonomic management and control. Furthermore, the 5G network can be logically partitioned (i.e. network slicing) to provide customised solutions for different market and business scenarios.

To avoid fragmentation with spectrum allocation for each Vertical, to deliver value provided by the MNOs, and in order to keep the right investment momentum, MNOs will leverage on their public network creating physical and virtual private extensions, customizing network features on the needs of different industries. Vertical industries will be able to use network slicing to build an operator-supported business system which manages customer operations, employees and assets. Vertical industries can be seen as specific case of the hybrid cloud model, where network MNOs and Hyperscale Cloud Providers can cooperate to meet Vertical's requirements. 5G will provide vertical industries with the possibility of intelligent cognition allowing it to push the right data, information, and knowledge to the right people or devices at the right time and place to achieve real-time intelligent services. With the inclusion of big data and AI, 5G realises the process from perception and cognition to prediction for vertical industries.

In order to cope with the Verticals' different requirements, the standardisation, testing and construction of a 5G network requires participation of vertical industries to achieve deep integration and large-scale applications. MNOs will cooperate with enterprises in the vertical industry to build various business platforms (such as cloud platforms and IoT platforms). In this way, MNOs and Verticals will together realise a 5G ecosystem including Verticals, equipment manufacturers, chip suppliers, MNOs and application and platform providers.

Although Verticals represent particular industries and market segments with distinct requirements, culture, operation and management, a number of building blocks and specific use cases have commonalities and therefore synergies. Examples are intelligent remote operations, robotics, supply management, tracking, etc.

Furthermore, in digital society and economy, 5G enables opportunities that leverage several use cases from across the Verticals and 5G application scenarios. A distinct and significant example is the well-being of society and economy, particularly at the time of crisis (such as the COVID-19 global experience). A wide range of use cases, for example, involving intelligent and virtual/remote health, robotics, automated operations / industries, AR/VR, virtual smart offices, virtual education, supply management, media, retail, finances, unmanned vehicles, public safety, multi-access service continuity, etc. will have high relevance.

This chapter provides a non-exhaustive list of vertical industries for which 5G will provide a variety of integrated solutions and services. It then stresses the importance of engagement between MNOs and Verticals.

3.1 Vertical Industry Examples

The first NGMN 5G White Paper [1] identified several vertical industry use cases that will be supported or enabled by 5G. This section re-iterates some of those, and introduces other use cases, to demonstrate the varied industries and requirements that 5G can support. In all these vertical industries, MNOs are uniquely placed to provide and integrate networks, clouds, and platforms to deliver end-to-end managed solutions encompassing security and trust, so becoming key partners of the Verticals.

Manufacturing Industry

The global manufacturing industry requires high-quality, time-sensitive, automated, intelligent and flexible industrial control, so that materials, products and processes can be monitored, optimised and controlled in real time.
Currently, most factories use wired connections, which satisfy the technical performance requirements, but they are complex and inflexible for reconfiguration purposes. 5G will provide more flexible and convenient wireless connections, which will meet industry requirements. The 5G system will enable monitoring, automation and optimisation by providing, amongst others:

- low-latency, high-reliability and high-availability connectivity, mobility and precise positioning of all the devices (e.g. sensors and actuators) for real-time monitoring and control of processes, and end-to-end logistics and asset tracking;
- connectivity and local processing for real-time video capture and video-based applications;
- connectivity of massive numbers of sensors, and platforms for collation and processing of large amounts of data;
- augmented reality to optimise and improve maintenance tasks.

Construction Industry

It is very important for the construction industry to deliver construction projects within planned timescales and budgets, whilst ensuring the highest level of employee safety and working conditions. For this reason, remote management of the vehicles used, autonomous operation, safe operation of machines, and synchronisation between the vehicles used will be very important in the future. The 5G system will support an autonomous smart system for construction projects by providing, amongst others:

- low-latency, high-reliability and high-availability connectivity for sensors and controllers, with a high density in a given geographical area;
- high-quality real-time video transmission;
- high-precision location of equipment and humans;
- local (edge) computing resources for controlling e.g. movement of vehicles.

Transport

The road transportation industry expects to provide efficient, safe, environmentally-friendly and comfortable transportation, especially by exploiting the potential of artificial intelligence, to achieve connected and automatic driving through perception, decision and control. The 5G system will enable this by supporting, amongst others:

- transmission of high quality video or images of road condition and roadside facilities to help navigation, remote and automatic driving, as well as identification of blind zones and other vulnerabilities for vehicles;
- real-time communication among vehicles and road infrastructures, coupled with precise vehicle positioning and local (edge) computing capabilities, enabling identification of potential dangers, which can help decision-making including route planning and updating, emergency braking, and intelligent car collision avoidance;
- connectivity of sensors and collection of data from vehicles and roadside infrastructure, supporting building models of the road environment and business application such as advanced road-use charging;
- remote maintenance through download of software updates to vehicles and the reporting of status information to vehicle manufacturers.

Health

The health industry requires a balanced allocation of medical resources, portable and intelligent medical equipment, improved medical vehicle treatment capabilities, and the transformation of surgical operations from the operating room to multiple regions. Most hospitals currently use wired connection medical equipment, which is reliable but complex and inflexible. There is also an increasing need to provide remote health assistance, in particular to assist the fragile and elderly or to manage emergency situations. 5G can provide more flexible and convenient wireless connections, which can meet most health industry application scenarios, for example:

- wide-area continuous coverage for ambulances, including sending live high quality video and patient vital signs in real time to the command centre in the hospital;
- sensors collecting vital signs from the wearable devices of patients or the elderly, wherever they are, helping remote medical staff make timely treatment decisions and administer medication remotely;
- sensors monitoring and collecting vital information for all in-hospital patients within a unified manner, and performing management on a unified platform;
- a dedicated reliable communication channel between, for example, hospitals, enabling remote surgery and guidance;
- managing and monitoring of medical equipment and hospital assets and personnel.

Smart Cities and Communities

Smart cities and communities expect to further the networking space for intelligent urban infrastructures, to enhance information collection and processing capabilities, to improve urban security governance capabilities, to integrate various intelligent applications for communities, and to improve government efficiency and the quality of life. For smart cities and communities, 5G will enable:

- high quality video transmission, positioning and tracking to improve security monitoring efficiency;
- networked intelligent sensors, including video, to realise urban environmental monitoring, supporting enhanced integrated city management and various citizen services such as traffic and transport management, and resource management and planning.

Education

Communication technologies enable new educational models and applications, which in turn address the imbalance in the availability of general education and education resources. Education approaches can be tailored to specific educational endeavours using a mix of teaching modes (e.g. online and offline).
For the education industry, the 5G system will enable:

- virtualised and augmented teaching, using virtual reality and augmented reality services to enhance and animate traditional approaches
- virtualised and augmented experiments which provides virtualised devices and equipment that the student can interact with, especially for the experiments associated with expensive devices or extreme dangers;
- remote interactive teaching, delivering a synchronous experience and remote interaction between teachers and students from different schools, as well as the inclusion of children who would not otherwise be able to attend school
- management of school personnel, assets and monitoring of the school environment, which helps in safeguarding of people and resources.

Tourism

The tourism industry can use new 5G network capabilities to deliver more immersive, interactive and exciting experiences and provide much more in-depth knowledge about the visited region, and its sites, attractions and facilities. Tourist spots tend to be much more crowded than other locations: thanks to higher data throughput and capacity of 5G networks, large numbers of visitors can benefit from, amongst others:

- Augmented reality, offering, for example, a 3D virtual reconstruction of archaeological sites, thematic tours in museums, and annotated city tours enhancing the experience of a city with architecture and historical information;
- Automatic transfer of high quality video and photos to the cloud;
- Smart crowd flow management.

Agriculture

Smart farming constitutes a revolution in the field of agriculture providing a tremendous productivity improvement. The enhanced capabilities of the 5G system support several enablers of smart farming, including:

- Agricultural robots (AgBots) such as driverless tractors, precision seeders, automated weed and pest controllers and automated harvesters, which will make it possible to produce more and higher quality crop with less manpower;
- UAVs or drones providing a bird's eye view for imaging, planting and crop spraying to help optimise land and crop management;
- Sensors for real time monitoring of health of crops, health and location of livestock, and environmental and climate conditions;
- Communication between all the machines and sensors, and with networks for real-time processing, decision making and streamlining operations related to land, crop, livestock, logistics and machinery.

Finance

The finance industry requires a secure, reliable and widely adopted platform to enable advanced financial services. 5G will provide such a platform and accelerate the digital transformation for banks, boosting ubiquitous banking operations and delivering better customer service. 5G offers an array of capabilities that can be matched with the finance industry's needs, including:

- gigabit data rates that enable collection of a vast amount of high-frequency stock market data for fast analysis;
- ultra-reliable and low latency communication that enables fast response and control on high-frequency mobile trading, and ensures time-critical buying and selling transactions take place at the edge of the mobile network by using multi-access edge computing technology;
- robust connectivity using vast numbers of devices to accelerate the ability of devices to share data and provide personalised payments and micro-payments over ubiquitous connected devices. These numbers of devices and connectivity could lead the development of a new era of finance services;
- enhanced security, that will significantly improve security and trust of banking operations for both banks and customers, thereby helping to ensure authenticity of transactions and preventing fraud.

3.2 Engagement

The new technical capabilities addressed in this White Paper are key to driving new use-cases and opening up new commercial opportunities, however, these are not sufficient for MNOs and Verticals to capitalise on the emerging commercial opportunities: **Systematic engagement is required between the MNOs and various industry partners** in order to discuss, explore, identify, and exploit these new capabilities towards a mutual benefit.

Besides discussions between the MNOs and other industry partners, there is also a need to support **development of open ecosystems** which will encourage the emergence of new (perhaps unforeseen) use-cases.

This is not a technical challenge, but an organisational one. To make 5G a commercial success, systematic mechanisms to engage with vertical partners, both from a global (top-down) as well as local (bottom-up) perspective, are required. This will help to:

- ensure MNOs understand the business environment, culture, and requirements of the various Verticals, and deliver appropriate solutions and value, and
- demonstrate the unique value MNOs can bring to benefit the Verticals.

NGMN and MNOs are already engaging with many different vertical industries from a global (top-down) perspective, for example:

- Automotive

  Automotive is an important Vertical for 5G and NGMN has been actively engaging with key industry players in this area. As part of this engagement NGMN signed a cooperation agreement with the 5G Automotive Association (5GAA[1]). The focus of this cooperation has been to review initiatives in both organisations and align strategy as appropriate. In addition NGMN has supported 5GAA's policy on spectrum use for C-V2X. Direct engagement of NGMN members in 5GAA and with the automotive industry in general include supporting spectrum policy to be used for C-V2X, developing C-V2X safety use cases, harmonizing C-V2X requirements to testing and trialling of various C-V2X interoperability scenarios. NGMN plans to continue collaboration with the automotive industry as 5G gets deployed by its members.

- Industry Automation

  Industry and factory automation is also a significant Vertical for 5G. NGMN has signed a co-operation agreement with the 5G Alliance for Connected Industries and Automation (5G-ACIA[2]) for deeper exchange and joint activities. NGMN members also engage directly with 5G-ACIA, industrials and the operational technology (OT) industries to ensure that the interests and particular aspects of the industrial domain are adequately considered in 5G standardisation and regulation, and that the ongoing 5G developments are known by and transferred to the industrial domain.

- Satellite industry

  NGMN signed a cooperation agreement with the EMEA Satellite Operators Associations (ESOA) and joined forces to foster a closer co-operation in the area of integration of satellite solutions in the 5G ecosystem. ESOA representatives have been participating in the NGMN project on Extreme Long-Range Communications for Deep Rural Coverage and contributed to NGMN's position paper on Non-Terrestrial Networks.

At the local (bottom-up) level, many MNOs are attempting to engage directly with Verticals, with varying degrees of success. New mechanisms of engagement need to be formulated to foster meaningful partnership between the MNOs and the members of the different Verticals, with support and endorsement of the NGMN.

In order to fully address the 5G potential, NGMN intends to extend its engagement with vertical industries, exploring further opportunities for engagement and supporting its members. NGMN and its members are open to and encourage cooperation with different vertical industry sectors in various ways, either as MNOs or as NGMN. This cooperation can cover several aspects, such as information exchange, joint development of new capabilities and requirements, trials and testing.

[1] 5GAA Automotive Association: https://5gaa.org

[2] 5G-ACIA 5G Alliance for Connected Industries and Automation: https://www.5g-acia.org/

4 ENABLERS

The 5G system is expected to evolve in the coming years to further enable the full 5G vision. This path continues to involve pushing the performance envelope, including throughput and latency, while evolving towards a highly agile, flexible and efficient platform as a service, to enable value provided by MNOs in a cloud native architecture.

The continuing trends broadly consist of a decomposition of software and hardware, separation of control plane and user plane, virtualisation, distribution, and decentralisation. Virtualisation of the network through the use of cloud-native models in a service-based architectural framework is an integral aspect of advances in the 5G system. Flexible provisioning of network slices is necessary for delivering service value at the edges of the network through multi-access edge computing. This requires an ongoing coordination and cooperation among SDO's, and ecosystems in general, in the progress towards automated platforms, with the appropriate exposure of capabilities.

Furthermore, the 5G core is expected to be access-neutral, integrating fixed and/or mobile, terrestrial and/or non-terrestrial, unicast, broadcast and/or multicast, and local- or wide-area access networks.

This chapter builds on the foundations of the first NGMN 5G White Paper [1], by describing prominent emerging enablers that enable different and flexible business and operational models, including support for a wide range of Verticals' use cases.

4.1 Network Telco Cloud

MNOs have continued to evolve and expand telecommunication operations towards a diverse assortment of services, beyond mobile connectivity, voice, and messaging services. This direction has continued with an adoption of virtualisation, which serves as a foundation for flexible and rapid time-to-market services, while simultaneously optimizing the utilisation of network resources. Virtualisation is fundamental for satisfying the demands of flexibility and adaptability for MNOs and is being adopted to meet the emerging demands of the service paradigm. The introduction of VNFs (Virtual Network Functions) within the NFVI (Network Function Virtualisation Infrastructure) framework provides separation between the functions rendered in software and the generalised hardware platforms over which the VNFs are executable. This introduces an integration challenge, hence support for interoperability and onboarding of VNFs in a multi-vendor environment is a critical benefit for MNOs. This is being addressed in the Cloud iNfrastructure Telco Task Force (CNTT[1]), whose objective is to ensure that the required VNFs are supported, in an interoperable manner, with consistent behaviours in an emerging multi-vendor environment.

Adoption of virtualisation in the telecommunications industry is evolving towards a cloud-native paradigm, where network functions are realised as cloud-native VNFs hosted by cloud infrastructures, which are amenable to distribution, decentralisation, and localisation, in terms of edge computing arrangements. Cloud native evolution is expected to provide several benefits such as a reduction in Total Cost of Ownership (TCO), further reduced time-to-market, business agility, faster innovation and flexibility to enable services more dynamically and on demand.

This approach of Platform-as-a-Service (PaaS) is being built on top of Infrastructure-as-a-Service (IaaS) environments already deployed in MNO data centres. The telco cloud spans all the layers of MNO networks, from central data centres to the edge of the network in order to support edge computing services. An autonomic framework cooperates with the telco cloud from a system wide perspective to facilitate optimised system performance and end-user experience.

The telco cloud may involve hybrid clouds, with public clouds offered by the Hyperscale Cloud Providers (HCPs), equipped with the capabilities of seamlessly realizing compute, storage, and network resources required to scale effectively to meet the diversity, dynamism, and volume of services, in a distributed and multi-access technology

[1] https://cntt-n.github.io/CNTT/

environment. This would enable the MNO Cloud to provide different service levels based on customer requirements, e.g. private coverage and traffic isolation with on-premise deployment, low latency services with edge deployments. In a hybrid cloud model, MNOs, HCPs and developers, may cooperate through open interfaces, application programming interfaces (APIs) and shared technologies to create innovative digital services and support the diverse requirements of Verticals.

Furthermore, MNOs will define a common platform architecture to aggregate individual platforms, allowing edge computing to be used on a global scale and inspiring a global community of developers. A common platform guarantees replication of business models, uniformity in the deployment of applications, uniformity of available APIs, and service continuity models between different platforms. The global community of developers will benefit from a common operator platform which complements the current HCP offerings of capabilities. GSMA [8] and NGMN [9] have announced initiatives to deliver this platform, and GSMA has published a White Paper on the concept of an operator platform [10].

4.2 Edge Computing

The diversity and number of end-user services and equipment that characterise the nature of a forward-looking 5G ecosystem demand location of resources at the network edge, through decentralised and distributed network architectures.
Localised processing at the network edge, in coordination with the user-equipment facilitates, new service-enabling capabilities that deliver a customised, contextual, and performance optimised service experience for the end-user.

Edge computing and telco cloud also enable hosting of MNO and 3rd party applications at the MNOs' network edge nodes. Applications can be hosted on dedicated platforms (owned by the MNO or by a 3rd party), and benefit from local breakout of traffic and from network APIs exposed by the MNO [5]. This allows applications to run closer to the customer, with benefits such as ultra-low latency, high reliability and off-loading processing from end-user equipment, and provides opportunities for new partnerships and associated business models.

Cryptographically strong encryption and privacy controls, provide the tools to mitigate and minimise the risk for information compromise, which is complemented by decentralised and distributed architectural arrangements that are aligned with the concept of edge computing, where a compromised segment of the system can be isolated without affecting the system as a whole.

Precise positioning techniques [4] are indispensable at the network edge for providing location and context aware capabilities for a variety of use cases such as for IIoT (Industrial IoT). The most challenging IIoT uses cases require accuracy of the order of centimetres, with very low-latency and a position fix which is of a continuous nature. Several other Verticals' use cases require precise positioning, for example autonomous vehicles and relative positioning between nearby user equipment, etc.

The network edge with flexible levels of distribution requires an enabler for automating the service experience, such that the time-to-market is reduced, and the overhead of intermediaries or brokers is reduced, while trust, security, and privacy are preserved. The Distributed Ledger Technology (DLT) [6] enabler provides these capabilities in the form of a distributed database. A permissioned flavour of DLT consists of known participating entities, where a common method of identification of these participating entities is utilised. The realisation of agreements between communicating parties, in a permissioned distributed ledger can be automated via smart contracts, which is a simple rules engine for a cryptographically assured business logic used for the execution and transfer of service value. Smart contracts are protocol based and automatically facilitate, verify, execute and enforce the terms of a commercial agreement. Examples of smart contract uses include roaming and service verticals across the 5G ecosystem of service categories.

4.3 Open and disaggregated radio access network

Conventionally, networks, in particular the radio access network, have been realised mostly by single-vendor solutions, where equipment and software were provided by and restricted to a single vendor on an area-by-area basis. This imposes limitations for MNOs in constructing their network, especially as deployment scenarios (e.g. macro cells, outdoor small cells, indoor solutions, etc.) and frequency bands diversify. Furthermore, disaggregated radio access networks are complementary for multi-access edge computing.

To improve the situation, MNOs are demanding disaggregation of network platforms through open interfaces, and promoting multi-vendor interoperability efforts. Disaggregation and openness, together with virtualisation, provide flexibility, efficiency, agility, scalability, a broad ecosystem and choice. Open, interoperable interfaces and multi-vendor RAN allow innovative, best-of-breed solutions from different vendors to be utilised. Furthermore, individual vendor will not have to deliver all solutions required by MNOs, leading to a competitive and vibrant vendor ecosystem, and more cost-effective network construction. This is ever more important for the 5G era with further diversifying scenarios and requirements.

Multi-vendor RAN is not only a vision: open, interoperable interface specifications (building on the 3GPP RAN) are being delivered by the O-RAN Alliance (Open RAN Alliance), and working multi-vendor implementations are available and being tested. Together with the Telecom Infra Project (TIP), this enables flexible arrangements of the radio access network and facilitates features and capabilities that are beneficial for innovative services provided by Verticals.

4.4 Autonomic Management and Control

Realisation of the full benefits of virtualisation, cloud and edge computing requires the adoption of an autonomic management and control framework. 5G networks can support more diverse service scenarios and applications while also creating the challenge of increasing complexity in network management, which requires the adoption of autonomic management functions, encompassing both autonomous and automatic behaviours. An autonomic management framework is an important enabler for innovative business models. It represents not only a benefit for MNOs but also enables customers to dynamically request and negotiate services and preferences for service customisation and personalisation. The telco cloud is expected to be programmable end-to-end, where the customer service requirements are supported by an appropriate underlying network slice with the necessary and sufficient allocation of compute, storage, and network resources. Cognitive and programmable capabilities enable 'zero-touch' operation and maintenance of the network through automation for network and service planning, deployment, maintenance and optimization phases, delivering self-CHOP (Configuration, Healing, Optimisation, and Protection) qualities in a forward-looking system. The network and user equipment operate cooperatively within the autonomic management and control framework for closed-loop automation and optimisation of system performance and behaviours, while allowing in-deployment flexibility. Isolation, facilitated by underlying automated network slicing procedures, provides for improvements in security, privacy and fault tolerance, which are aligned with the self-CHOP characteristics of an end-to-end autonomic management and control framework.

The characteristics of a self-CHOP enabled system reflect a fundamental shift from the relatively cumbersome silos of manual operational and configuration procedures, to agile, programmable, and autonomic capabilities for automating system operation for performance and service optimisation, in real-time or near real-time. Self-CHOP brings other benefits, for example:

- **Zero-touch, personalised self-service experience:** End-to-end intuitively attractive, open, well-defined, and uniquely customizable interfaces, with personalised style choices.

- **Network insight and inference enablement:** Use of a local and global scope for continuous mining and derivation of system-wide insights and inferences, for an optimised system performance and customer experience.

To gradually achieve the goal of an autonomic management framework, a hierarchical architecture for the self-CHOP enabled system needs to be ensured. A more upper-layer and centralized deployment location indicates a larger data volume, raises computing power requirements, and is more suitable to perform cross-domain self-CHOP capability which does not have real-time requirements, while at a lower-layer and closer to the network edge, the domain-specific or entity-specific self-CHOP capability is suitable for meeting real-time performance requirements. To ensure optimal performance and minimize the complexity of integration between layers, there must be a clear definition of the layered self-CHOP framework, with standardised, open interfaces between layers.

4.5 Artificial Intelligence (AI) and Machine Learning (ML)

Cognitive capabilities embedded within an autonomic management and control subsystem are realised in terms of the various modes of AI. AI and ML offer a variety of extensible methods to meet the connectivity, coverage, capacity, spectrum efficiency, energy efficiency and service demands of a virtualised, decentralised, distributed 5G system.

AI and ML are broadly viewed as a class of computer and algorithm assisted intelligence modalities that mimic human intelligence at a task level, characterised by analysing a given set of data or observations, while determining an optimised solution to meet a desired objective. Deep Learning (DL) is an augmentation of ML rendered through the use of multilayer neural network algorithms to flexibly handle a diverse array of complex use cases, associated with structured or unstructured data.

- **Structured data:** Consists typically of formatted, clearly defined and easily readable data types, such as names, geolocation, address etc.
- **Unstructured data:** Consists typically of qualitative information that cannot be easily searched, analysed or processed, such as mobility patterns, free text, audio, video, satellite images etc.

The functions across any layer of the core network, radio access network, the user equipment as well as the management and orchestration level are potential reference points to serve as a source of data (and events) or as a target for control, behaving as an input or an output respectively for a given ML function. The ML function optimises the operation of a particular entity in the 5G system, a larger part of the network or an associated service. The application of a specific learning model, hinges on the nature of the optimisation problem in the 5G system. A common framework of architectural building-blocks that are technology neutral is beneficial for harnessing a given ML function and its related interfaces, for technology-specific realisations.

Examples of technology-specific realisations include edge computing, fixed-mobile convergence, beam correspondence, spectrum and network resource utilisation, service experience and personalisation, autonomic management and control, among several other forward-looking and emerging features, across eMBB, mMTC and URLLC categories of service offerings. An example use case is automatic adaption of video QoS based on the number of users, so the service is always optimised to the best available quality,

4.6 Access Network Convergence

The expectation for ubiquitous service availability from any geographic location is fundamental and underscores the support for convergence across multiple access technologies. Examples of such scenarios include mobile broadband, fixed broadband, non-terrestrial access, and proximity access. The adoption of various methods of connectivity in the 5G ecosystem promises a convergence of different methods of connectivity through convergent and access neutral architectural models. These complementary methods of connectivity consist of a variety of access technologies that include terrestrial network and Non-Terrestrial Network (NTN) access for supporting a diverse variety of 5G services [3]. Initially, convergence will focus on re-using the 5G Core Network for “trusted non-3GPP access network”, and “wireline 5G Access Network”, facilitating synergies with 3GPP access. Typically, for example, a customer wireless LAN may re-use the same core infrastructure as the operator’s 5G radio network. Beyond this, connectivity provided by NTN access as part of the multi-access technology landscape is a valuable mode of connectivity in 5G, where multiple types of access could be leveraged for higher system availability, as well as for coverage in remote underserved areas and in emergency or disaster recovery situations.

Beyond the initial phase of 5G specifications in 3GPP, it is anticipated that future specifications will harness NTN access to enrich and enhance the service experience, and enable optimisations, across different categories of the 5G service paradigm. The integration of non-terrestrial networks in 5G will provide enhanced opportunities for network slice management, inter-technology access hand-over, and dual connectivity across all access technologies as well as connections to fixed or moving cells using NTN-based integrated access and backhaul capabilities.

A major advantage of NTN integration into the 5G ecosystem is to broaden service delivery choices, especially to unserved or underserved areas. Direct access to handheld devices is expected to complement and extend cellular networks for 5G eMBB and mMTC services with direct or indirect satellites line of sight use cases, where indirect would imply the use of relays in the cases where it can further improve service to users (note that direct NTN access is likely to be unavailable for dense urban coverage, in the absence of an unimpeded line of sight access).

NTN access encompasses radio access provided by different spaceborne and airborne vehicles such as low earth orbiting satellites, high altitude platform systems (HAPS), drones etc. Spaceborne and airborne access networks in 5G are vital for reliably serving passengers on board moving platforms and serving populations in rural areas; supporting flexible and fast network restoration, e.g., in the context of public protection, disaster relief or other emergency situations; and in sustaining audience access to content via efficient broadcast/multicast capabilities, combined with edge-caching techniques thereby optimizing core server and network loads.

These and other technological advances in spaceborne and airborne vehicles are likely to provide significant yet cost effective performance enhancements, in addition to improved capacity/coverage flexibility. A complete convergence of terrestrial and NTN access within the 5G standards suite is expected to enable MNO service provisioning and delivery to meet the customer requirements for experientially attractive services with high availability, reliability and system resiliency.

4.7 Harmonisation

The harmonisation of capabilities associated with technology enablement is vital for managing complexity, scalability, performance optimisation, and deployment flexibility. In particular, the commercial availability of emerging 5G devices on a global scale, hinging on technology advancements and standardisation, requires the support for multi-mode (multiple access technologies) and multi-band (multiple frequency bands) 5G devices for enabling the global roaming of these devices.

With the growing global demand for spectrum and higher bandwidths to meet demands of future services, there is a corresponding increase in the number of standardised radio frequency bands and their combinations. The support for a large number of radio frequency bands and their correspondingly large number of combinations translate into increasing levels of device implementation complexity. The harmonisation of a minimum set of commonly utilised global radio frequency bands in multi-mode and multi-band device configurations is essential for managing device complexity and global roaming. To that end, mandatory and recommended features for 5G devices, including the support for radio frequency bands to enable global roaming, are documented in [7]. The harmonisation of globally utilised radio frequency bands would also be beneficial in terms of flexible deployment choices, in terms of both Non Stand-Alone (NSA) and Stand-Alone (SA) 5G system configuration options. Furthermore, from a network perspective, the harmonisation of APIs is fundamental for supporting a variety of Verticals and the developer ecosystem, for managing complexity and for enabling automation.

4.8 Sustainable Trust

Trust represents a belief in the ability of a system to act reliably and dependably with respect to interactions among two or more entities and the system in a mutually congruent manner. In the emerging virtualised, decentralised, and distributed ecosystem of networks, user equipment, and machine-type devices, the establishment of trust is foundational. The flexible and customizable service paradigm of 5G demands adaptive models for trust that are secure-by-design and adopt security best-practice. The types of relationships between interacting entities provide the context for configuring an appropriate trust model for a given use case scenario. The notion of sustainable trust includes both security and privacy to adaptively and dynamically maintain the system performance and the user experience.

While earlier generations of trust models in telecommunication systems were generally based on centralised methods of authentication, authorisation, and accounting, the inclusion of decentralised trust models is pivotal for supporting a widespread adoption of 5G systems. For example, in the case of a centralised trust model, the security credentials are known a priori to an MNO or an SP. On the other hand, in the case of a decentralised trust model a dynamic verification scheme is suitable for trust establishment. A decentralised trust model is expected to support and enable the virtualised, distributed, dynamic, and cloud-native nature of a 5G service-based architecture.

Autonomic management and control of the 5G system, embedded with distributed AI and ML-enabled virtual functions, will provide cognitive building blocks, including anomaly detection, to proactively mitigate and manage threat scenarios. This will enable the necessary automation for trust sustainability, in the presence of an increased exposure of attack surfaces and vulnerabilities, resulting from higher levels of flexibility and distributed deployments, including edge computing.

5 SUSTAINABILITY PRINCIPLES

Faced with the challenge of climate change, minimizing the carbon footprint of networks and devices is essential in the design of digital technologies and equipment. Recently, GSMA operators have adopted the target to be carbon-neutral by 2050[1]. Earlier, a fundamental 5G requirement has been the significant increase needed in energy efficiency, as explicitly stated in the first NGMN 5G White Paper [1]. This chapter presents the technical solutions, life cycle and energy sourcing actions to be implemented to make future networks more sustainable. The 5G paradigms and building blocks (such as operator cloud), standardisation, innovations, deployments and operations should address this goal.

5.1 Energy Efficiency

The optimisation of energy efficiency is fundamental to delivering green objectives. The 5G energy efficiency requirements put forward, amongst others, by the first NGMN 5G White Paper, have been continuously addressed in 5G design and definition (for example [13]). Virtualisation, disaggregation and cloudification contribute to reducing the energy consumption of network infrastructure and terminals, along with features such as efficient coding, low-power wide-area networks, spectrum management technologies, transmission on demand, and sleep modes and dormancy [14]. Intelligent operation combined with network as service, and fully flexible and dynamic configurability, lead to significant energy efficiency improvements. However, this is a significant and stringent requirement that needs to be continuously and further improved, and remains a target in the next phase.

As such, the heterogeneous coverage footprints of the 5G system, with converged and complementary access capabilities provide opportunities for an optimisation of energy consumption, while managing the energy requirements for ubiquitous connectivity and advanced service demands. The role of autonomic management and control capabilities augmented by AI and ML is critical in the enhancement of energy efficiency, while meeting the increasing energy requirements associated with corresponding increases in capacity and coverage demands. These advanced cognitive capabilities provide an optimisation of energy efficiency, by autonomously, dynamically, and selectively scheduling capacity and coverage based on changing demands.

5.2 Renewable energy and energy harvesting

Renewable and clean energy sources depend on environmental conditions, and their availability tends to be intermittent depending on the location and the type of resource (e.g. wind, solar etc.), which imply that energy storage is required to maintain a relatively uniform availability. Energy-free devices (sensors, trackers) that make use of ambient energy harvesting or sustainable energy further reduce the energy demands and dependence on batteries.

The harvesting of energy from the environment provides an eco-friendly source of renewable energy, which when integrated with the smart grid provides energy efficiency improvements and cost savings. This, combined with the measurement processing of large datasets and analytics in the network, using AI and ML, provides strategies for MNOs to optimise network planning and operation in order to optimise energy efficiency and reduce carbon footprint.

5.3 Equipment environmental footprint

Beyond the consumed energy, we also need to minimise the environmental impact of building equipment, both for the infrastructure and user equipment. This impact is in terms of needed energy, but also in terms of materials usage and how they are sourced. To this end, network equipment manufacturers should provide information on which materials are the most critical regarding the Abiotic Resource Depletion indicator (ARD) as well as their critical raw materials content based on the life cycle assessment (LCA) method [12]. Even if 5G equipment inherently requires scarce and critical raw materials for their manufacture, most of those materials are already commonly used in other ICT equipment (e.g., gold, silver or cobalt). Thus, the question ahead would be how these materials are extracted and how well equipment is designed to ensure an efficient material use.

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[1] https://www.gsma.com/betterfuture/mobile-creating-a-better-future-climate-action

In order to continue advancing towards more sustainable networks, as a first step we encourage studies on quantifying the general environmental impact of networking technologies, including the positive impacts they have on other sectors of the society. We also encourage the investigation of solutions to facilitate recycling and upcycling of materials. Finally, we believe our ecosystem should start an analysis about the sustainability versus the societal, environmental and economic benefit of the current innovation cycles, which imply renewing (and manufacturing) equipment regularly. Indeed, the advent of virtualisation and AI may offer new ways to upgrade existing infrastructure and terminals equipment in the future.

6 SPECTRUM

NGMN acknowledges the important mission of the International Telecommunication Union (ITU) to harmonise globally and regionally suitable frequency ranges for the next generation of mobile services. This has a significant impact on the timing and success of adopting 5G, reduce the deployment costs and facilitate border coordination between countries. In addition to bands already identified for IMT below 6GHz, the mobile community will need to access new spectrum bands in order to fulfil the 5G promise. The characteristics of these bands (e.g. large contiguous bandwidths, short wave lengths) make them particularly suitable for the 5G ecosystem.

6.1 Conclusion in WRC-19

The 2019 World Radiocommunication Conference (WRC-19) identified 17.25 GHz of additional frequency bands above 24 GHz (mmWave) for International Mobile Telecommunications (IMT), including IMT-2020. Most of these bands were globally harmonised - the 24.25-27.5 GHz, 37-43.5 GHz, and 66-71 GHz bands - while the 45.5-47 GHz and 47.2-48.2 GHz frequency bands were identified in specific countries. These new identifications facilitate diverse usage scenarios for enhanced mobile broadband (eMBB), massive machine-type communications (mMTC) and ultra-reliable and low-latency communications (URLLC).

6.1.1 Additional spectrum bands for 5G

WRC-19 has also defined the agenda items to be studied for WRC-23 including the possible identification of the frequency bands 3300-3400 MHz, 3600-3800 MHz, 6425-7025 MHz, 7025-7125 MHz and 10.0-10.5 GHz for IMT globally or regionally. NGMN highlights the role this can play in opening new opportunities for the developing and expanding the 5G ecosystem, with any appropriate technical conditions, as required, to ensure fair coexistence with other services already allocated to this spectrum.

In this regard, NGMN believes that the potential of the following frequency bands should be further explored:

- 6425-7125 MHz: given the relative lack of large bandwidth allocations below 6 GHz and the coverage challenges associated to bands above 24GHz, this band is a good choice for the future 5G ecosystem, especially for the vertical markets. Incumbent services, including fixed services potentially used for wireless backhaul in 5G systems, should be protected and/or relocated to other bands yet to be identified, in which case associated costs have to be evaluated and taken into account.

- 3400-3800 MHz: This band is viewed as a core global 5G band and thus its IMT identification is key. Within this band, the frequency range 3600-3800 MHz is currently considered for a possible upgrade of the mobile service allocation to a primary basis in Region 1 (Europe, Middle East and Africa), which is a step in recognising the global importance of the band for 5G, while it is also key not to impact current 5G deployments[1].

- 3300-3400 MHz: This band is particularly attractive for future 5G deployments due to the vicinity to the aforementioned 3400-3800 MHz band.

- 10-10.5 GHz: this band is also attractive for Fixed-Wireless Access service, with a better propagation than 26/28 GHz, especially in near or non-Line of Sight

[1] 3600–3800 MHz is already allocated by ITU-R to the mobile service on a primary basis in the other Regions.

6.2 Spectrum Management Options

6.2.1 Continuing Need for licensed Spectrum

Spectrum should normally be made available on a national basis with exclusive licences assigned to MNOs, to enable quality of service to be managed. This needs to be harmonised on a global or regional basis to the greatest extent possible to support global roaming and generate economies of scale. Exclusive licensing regimes should remain the main and preferred solution for accessing core spectrum. The way to create sustainable consumer benefits and increased competition should start by creating regulatory and legal certainty in the market.

License-exempt spectrum can be used to complement use of licensed spectrum, for example in a license-assisted mode for offloading traffic, However, licensed spectrum is preferred as stated above.

6.2.2 Giving priority for use of public network

MNOs have extensive experience in deployment, operation and maintenance of networks and services. The 5G system capabilities such as network slicing and PaaS will assist MNOs using their public networks to provide dynamically customised (and private/isolated) services for vertical markets in a cost efficient way and by efficiently using spectrum. The use of large-scale public network deployments in this way leads to the scale effect, reducing the cost of the service provision and promoting the maturity of industry. Compared with the large-scale public network, private network deployments are in a scattered state with higher cost of production and operation[1]. NGMN therefore believes the spectrum regulators should continue to give priority for public networks when allocating spectrum in order to minimise spectrum fragmentation and associated complexity, and optimise its use over wide areas.

[1] Vodafone have published a report that analyses industrial 5G spectrum policy for Europe [11]

7 RECOMMENDATIONS FOR PROMOTING A SUSTAINABLE 5G LICENSING ECOSYSTEM

In line with the Business Objectives of Chapter 7 of the NGMN White Paper, 2015, the following recommendations are made related to Intellectual Property Rights (IPR) [1].

7.1 Promote a licensed 5G ecosystem

NGMN recommends that 5G products and applications on the market are adequately licensed and that appropriate measures are considered to enable the ecosystem to distinguish between licensed and unlicensed products. NGMN urges the 5G industry to rely on sound commercial IPR licenses and good-faith licensing negotiations so as to avoid unnecessary litigation as much as possible.

7.2 Improve the transparency of SEP declarations

NGMN recommends that 5G SDOs consider requiring each patent holder member to declare, in a timely manner, to the SDO its potentially essential patents (Standard Essential Patents, SEP) and at least to declare the member's licensing position for its SEP, and that the SDO makes these received declarations publicly available not later than upon publication of the adopted standard, and in any case shortly after receiving them. NGMN recommends that 5G SDOs consider implementing the 4 NGMN Recommendations[1] (echoed by regulators, e.g. European Commission[2]) in order to improve the transparency of their SEP declarations.

7.3 Build trust in SEP declarations to 5G SDOs

NGMN emphasises that one important aspect of declaration of a SEP is to build a certain level of trust among the industry players. This may be achieved if a SEP is subject to some kind of essentiality check(s) before being reported with its declaration, which may be updated afterwards. NGMN will engage into further activities related to essentiality checks of declared SEP, e.g. with the European Commission[3].

7.4 Adapt and expand the patent pooling governance and services for 5G

NGMN recommends patent pool administrators to pursue a dialogue with the SEP holders, prospective licensees, representatives of the various regulators, and themselves in order to explore and build new ways of providing sustainable patent pooling services that seek to address and benefit the 5G ecosystem. NGMN will continue to provide with its IPR Forum a platform where the likely concerned parties - possibly including SDO and patent offices - may anticipate and address the potential issues in an open and inclusive manner.

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[1] NGMN IPR Forum Recommendations to Improve SEP Declarations, 20/02/2017, available at https://www.ngmn.org/publications/annex-ngmn-ipr-forum-recommendations-to-improve-sep-declarations.html

[2] Communication from the Commission to the Institutions on Setting out the EU approach to Standard Essential Patents, 29/11/2017, available at https://ec.europa.eu/docsroom/documents/26583

[3] Call for tender: http://www.iprhelpdesk.eu/news/pilot-project-essentiality-checks-standard-essential-patents

8 CRITICAL SUCCESS FACTORS

As shown in the first NGMN 5G White Paper and this paper, 5G will provide services for new market segments, leveraging new technologies and technological enablers to deliver bespoke and agile solutions to a wide variety of customers. Drawing from the previous chapters, this chapter identifies a number of key success factors and actions needed across the ecosystem to ensure successful delivery of these technologies and enablers in order to realise the full 5G potential for all types of customers, whilst bringing significant social benefit.

Vertical industries

Success factors:

- 5G creates diversity and flexibility in business models enabling a variety of roles. Partnerships will form the end to end ecosystem, with MNOs having a unique and expanded role to create and distribute value to the Verticals within the dynamic and adaptive ecosystem for different use cases and scenarios.
- MNOs will leverage their public networks to operate dedicated networks for enterprises. Enterprises can thus benefit from economies of scale and the MNOs' experience in providing and operating these networks and services.
- MNOs are uniquely placed to provide a fully integrated solution that encompasses networks, clouds and platforms, with dynamic customisation, partnerships, end-to-end management, and carrier-grade security.

Actions:

- Spectrum regulators should continue giving priority to the MNOs for public networks when allocating spectrum in order to minimise spectrum fragmentation and associated complexity, and optimise its use over wide areas.
- MNOs and Verticals should increase engagement to develop meaningful, mutually-beneficial partnerships and business models in order to fully deliver the 5G potential.

Cloud, Automation, Openness and Edge

Success factors:

- The cloud native service-based 5G architecture will exploit automated platforms with exposure of capabilities and value, offering NaaS, creating a 5G service-enabling platform.
- Network disaggregation and openness, together with virtualisation, provide flexibility, efficiency, agility, scalability, a broad ecosystem and choice. Open, interoperable interfaces and multi-vendor RAN allow innovative, best-of-breed solutions from different vendors to be utilised, and relieves individual vendors from having to deliver all solutions required by MNOs, leading to a competitive and vibrant vendor ecosystem.
- Edge computing provides local context and low latency, enabling new capabilities and

Actions:

- The industry must ensure global standards with open, interoperable interfaces to deliver the flexibility and scalability promise.
- MNOs must work towards realizing multi-vendor RAN, especially by avoiding fragmentation of multiple related efforts and by driving actual validation and interoperability testing activities with vendors.
- MNOs will define a common operator platform architecture to aggregate individual platforms allowing Edge Computing to be used on a global scale, in order to attract the global community of developers. The operator platform needs to guarantee: replicable business models,

applications and enhanced and customised Verticals' service experience.

- Network slices will respond to the Verticals' requirements, with customised QoS and SLAs being deployed dynamically 'on-demand' all the way to the edge of the network.

uniformity in the deployment of applications, uniformity of available APIs, service continuity models between different platforms. The global community of developers will benefit from an operator platform which complements the current HCP offerings.

Convergence

Success factors:

- The 5G system is expected to include different access networks, with different access capabilities, allowing the user equipment to steer traffic across types of available access flexibly, to suit capacity, coverage and service demands.

Actions:

- NGMN and relevant standards organisations and industry associations (for example, 3GPP, BBF[1], WBA[2]) should continue to cooperate to enhance solutions for wireless-wireline convergence and integration of different access networks in the 5G system.

Need for global roaming capability of devices

Success factors:

- While entering the stage of 5G commercialisation on a global scale, the maturity of 5G device supporting multi-mode multi-band becomes critical to ensuring global roaming and consistent 5G services for customers. Given the number of 5G frequency bands and band combinations existing in 3GPP, it is unlikely that all the bands or band combinations will be supported in one 5G device.

Actions:

- Support of global roaming bands, and both Stand-Alone and Non Stand-Alone modes, to enable the global roaming capability, is key to 5G success on a global scale.

Social responsibility

Success factors:

- 5G is expected to continue to empower and enrich the digital gigabit society and economy, and the value provided by the MNOs is to be developed and delivered with social responsibility. Telecommunication networks provide vital support in emergency and crisis situations, and in future will be fundamental for the personal and professional life of citizens worldwide.

Actions:

- Increased focus needs to be given to significantly improving resource and energy efficiency, sustainability, social wellbeing, trust, and focus on digital inclusion.
- As a first step, we encourage studies about quantifying the general environmental impact of networking technologies, including the positive impacts they have on other sectors of the

[1] Broadband Forum, https://www.broadband-forum.org/

[2] Wireless Broadband Alliance https://wballiance.com/

- Minimizing the carbon footprint of networks and devices is essential in the design of digital technologies and equipment. However, beyond the consumed energy, we also need to minimise the environmental impact of building the equipment, both for the infrastructure and user equipment. This impact is in terms of needed energy, but also in terms of materials usage and how they are sourced.

society. We also encourage the investigation of solutions to facilitate recycling and upcycling of materials. Finally, we believe our ecosystem should start an analysis about the sustainability versus the societal, environmental and economic benefit of the current innovation cycles, which imply renewing (and manufacturing) equipment regularly.

Spectrum

Success factors:

- In addition to bands already identified for IMT below 6GHz, the mobile community will need to access new spectrum bands, recognising that different frequency ranges provide different opportunities particularly in terms of coverage and capacity.
- In particular MNOs are starting to take advantage of the new millimetre wave bands (above 24 GHz) which were identified by the ITU at the WRC-19. These will enable new opportunities for much wider channels, providing much higher data rates within hotspots to meet higher user demands, in addition to enabling innovative services that require larger bandwidths for high reliability and ultra-low latencies.

Actions:

- Exclusive licensing regimes should remain the main and preferred solution for accessing core spectrum, made available on a national basis assigned to MNOs, to enable end to end quality of service.
- Participate in WRC activities to ensure that sufficient spectrum will be made available to assist in realizing the full potential of 5G.

9 CONCLUSION

Since the publication of the first NGMN 5G White Paper, the first phase of 5G standards has been completed, initial 5G services have been launched, and much more is underway to increasingly realise the potential of 5G. The initial standards and launches have mostly focused on eMBB, while the full 5G is expected to enable countless number of use cases, many unimagined today, including those of mMTC and URLLC. A vast number of the 5G use cases relate to the wide range of Verticals.

New and evolving technology paradigms and building blocks enable this great number of user and application scenarios with broad variety and variability in requirements. The service enablement is about much greater service capabilities, but also about full agility, flexibility, resilience, and resource efficiency.

The cloud native 5G system will involve automated platforms with exposure of capabilities and value, leveraging machine learning and context awareness. It will provide dedicated and shared network slices dynamically as required by the use cases and Verticals, all the way to the edge. Network disaggregation and openness provide flexibility, efficiency, agility, scalability and broad ecosystem and choice. Edge Computing provides local context and low latency, enabling new capabilities, applications, and enhanced and customised Verticals' service experience.

The 5G core will be capable of integrating fixed and/or mobile, terrestrial and non-terrestrial, unicast, broadcast and multicast, and local- or wide-area access networks. This should allow common services across different mechanisms providing service ubiquity, continuity and coverage, and scalability for countless number of use cases.

The number of end devices of various types will also be limitless, with possibilities of physical and virtual interfaces, sensors, robots, unmanned aerial vehicles, autonomous vehicle of various kinds, wearables, media and gaming sets, virtual CPEs, smartphones, and others, within human-to-human, human-to-machine, and machine-to-machine interactions.

5G creates diversity and flexibility in business models enabling a variety of roles. Partnerships will form the end-to-end ecosystem, with MNOs having a unique and expanded role to provide networks and services, creating and distributing value to the Verticals within a dynamic and adaptive ecosystem, supporting different use cases and scenarios. They will leverage their networks and services to provide dedicated and customised solutions for enterprises, who can thus benefit from economies of scale and the MNOs' experience in providing and operating these networks and services.

Spectrum regulators should continue giving priority for public networks when allocating the spectrum, minimising spectrum fragmentation and allowing the realisation of the high-performance and cost-effective end-to-end customised solutions. In addition to bands already identified for IMT below 6GHz, the mobile community will need to access new spectrum bands, recognising that different frequency ranges provide different opportunities.

5G is therefore expected to continue to empower and enrich the digital gigabit society and economy; and the value provided by the mobile network operators is aimed to be developed and delivered with social responsibility. Telecommunication networks will be vital for society during disaster and emergency situations, and in the future they will be fundamental for the personal and professional life of citizens worldwide. The 5G objective is to enable and contribute to prosperity and productivity, with significant energy and resource efficiency and sustainability, social wellbeing, trust, and inclusion.

Orchestration of the entire ecosystem is a critical requirement and success factor. NGMN promotes engagement with the wider ecosystem to fully address the 5G potential and the realisation of its full vision. For example, increased engagement between MNOs and Verticals is required to exploit 5G capabilities for mutual benefit and value generation. Additionally, regulators have a significant role in creating an environment for development of the 5G ecosystem and this role is becoming broader with the introduction of new enablers such as AI. NGMN has advocated positions to regulators and other relevant authorities on behalf of MNOs, and will look to further increase the advocacy and engagement, both as NGMN and in cooperation with other organisations.

Research has started about the future evolution of wireless systems. The operators of NGMN suggest to the worldwide research community to focus on the societal and environmental requirements, challenges and opportunities that future wireless systems can help address. Research on new technologies and future network architectures should be prioritised towards addressing the challenges and opportunities beyond the full realisation of NGMN's 5G vision.

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
AI	Artificial Intelligence
API	Application Programming Interface
CHOP	Configuration, Healing, Optimisation, and Protection
CPE	Customer Premise Equipment
DLT	Distributed Ledger Technology
eMBB	enhanced Mobile Broadband
GNSS	Global Navigation Satellite Systems
GSMA	GSM Association
HCP	Hyperscale Cloud Provider
ICT	Information and Communications Technology
IIoT	Industrial Internet of Things
IMT-2020	ITU term for International Mobile Telecommunications for 2020 and beyond
IaaS	Infrastructure-as-a-Service
ITU	International Telecommunications Union
ML	Machine Learning
mMTC	Massive Machine Type Communications
MNO	Mobile Network Operator, providing both connectivity and services
MVNO	Mobile Virtual Network Operator
NaaS	Network-as-a-Service
NFV	Network Function Virtualisation
NFVI	Network Function Virtualisation Infrastructure
NTN	Non-Terrestrial Network
PaaS	Platform-as-a–Service
QoS	Quality of Service
RAN	Radio Access Network
SDN	Software-Defined Networking
SDO	Standards Development Organisation
Self-CHOP	Self-Configuration, Self-Healing, Self-Optimisation, and Self-Protection
SEP	Standard Essential Patent(s)
SLA	Service Level Agreement
SP	Service Provider
URLLC	Ultra-reliable and Low Latency Communications
VNF	Virtual Network Function
WRC	World Radiocommunication Conference

DEFINITIONS

A collection of terms used in the main body of the White Paper is defined in this section.

Autonomic Network

This refers to a network consisting of network elements that exhibit autonomics, encompassing both autonomous and automatic behaviours, which are characterised in terms of cognitive capabilities, and realised through feedback control loops. These cognitive capabilities are embedded in Network Functions (NFs), within Network Elements (NEs).

Edge Computing

This refers to a localisation of computing, storage, and network resources for rendering services close to an end-user or a device.

Self – Configuration, Healing, Optimisation, and Protection (Self-CHOP)

Self-CHOP qualities enable the automation of system planning, integration, deployment, and life-cycle management. These aspects are expected to be facilitated through various modalities of cognitive intelligence (e.g. artificial intelligence, machine learning), which are pivotal technologies to enable preventive and predicative optimisations, with limited or no human intervention.

Supervised Learning

This ML category is useful for utilizing structured data and a known pattern to learn a suitable rule or a transfer function. Examples of an application of this ML category, include optimisation for a variety of radio layer aspects, such as channel estimation, handover, signal processing, spectrum utilisation, among others, where a known model is available. This type of learning is also relevant for upper layer aspects, such as quality of service, end-user behaviours, mobility enhancements, among others, using established models of discovery and learning.

Unsupervised Learning

This ML category is useful for utilizing unstructured data, where an appropriate model is discovered and inferred heuristically from the data to learn a suitable rule or a transfer function. Examples of an application of this ML category include optimisation for a variety of heterogeneous network deployments, coexistence of different radio access technologies, fault detection, anomaly detection, end-user behaviours and preferences, intrusion detection, among others.

Reinforcement Learning

This ML category is useful for learning about an environment, using a feedback control system methodology, where the learning is dynamic and iterative, based on an action and reward sequence to converge towards a suitable rule or transfer function for a given environment. Examples of an application of this ML category include optimisation for a variety of probabilistic scenarios, in a wireless and mobile network environment, where conditions are not known a priori. Such examples include dynamic resource allocation for network slicing, channel access conditions, decentralised and distributed resource allocation for edge computing, dynamic spectrum sharing, beam correspondence, dual connectivity and carrier aggregation, autonomic management and control, network and user equipment resource cooperation and coordination, among others.

Non-Terrestrial Network (NTN)

This refers to a network that provides connectivity augmentation through spaceborne or airborne entities. Airborne entities include Unmanned Aerial Vehicles (UAV)s (e.g. drones, balloons etc.), and High Altitude Platforms (HAPs), Medium Altitude Platforms (MAPs), Low Altitude Platforms (LAPs) that enable the augmentation of connectivity and coverage for rendering diverse services for remote regions where terrestrial access is not available, or requires capacity or availability enhancement to meet appropriate service KPIs. Spaceborne entities are characterised in terms of the type of orbit and other characteristics. A high-level description of airborne and spaceborne entities is provided in Table 1.

Spaceborne[1]/Airborne vehicle type	Altitude [km]	Max propagation delay contribution [ms.]	Description
GEO	35,786	541.46	A Geostationary Earth Orbit satellite orbit appears motionless for ground observers
MEO	7000 – 25000	93.45 @ 10000 km	Non-Geostationary (Medium Earth Orbit and Low Earth Orbit) satellites are constellations of multiple satellites in orbit that utilise handover management for providing service continuity, over a given terrestrial coverage area.
LEO	500 – 2000	25.77 @ 600 km	
HAP (High Altitude Platform)	20	< 1	A HAP is an airborne vehicle hovering over a given terrestrial area, providing wide and continuous coverage. LAPs and MAPs are of the same type functioning at different altitudes – low altitude and medium altitude respectively.

Table 1 : Characteristics of spaceborne and airborne entities

Vertical

This refers to an industry segment that addresses a specific set of unique customer needs, which collectively could also be referred to as a vertical market, in contrast with generalised customer needs, such as a ‘mass market’ or a horizontal market. Examples of ITU-T referenced vertical markets include health care, transport, energy, financial services, etc.

[1] Satellites are spaceborne vehicles that utilise either an amplified non-regenerative payload (functions as a signal repeater) or a regenerative payload (functions as a signal regenerator).

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