5G White Paper - Executive Version

by NGMN Alliance

Version:	**1.0**
Date:	**22nd December 2014**
Document Type:	**Final Executive Version**
Confidentiality Class:	**P - Public**

Project:	**NGMN 5G Initiative**
Editor / Submitter:	**REH/JE**
Contributors:	**5G Initiative Team**
Approved by / Date:	**NGMN Board, 19th December 2014**

Commercial Address:
ngmn Ltd.,
Großer Hasenpfad 30 • 60598 Frankfurt • Germany

Phone +49 69/9 07 49 98-04 • Fax +49 69/9 07 49 98-41

Registered Office:
ngmn Ltd.,
Reading Bridge House • George Street • Reading • Berkshire RG1 8LS • UK
Company registered in England and Wales n. 5932387,
VAT Number: GB 918713901

NGMN 5G Initiative White Paper	
Leadership	Rachid El Hattachi (Deutsche Telekom) *Initiative Leader and Chairman of the Steering Committee* Javan Erfanian (Bell Mobility) *Co-leader of the 5G Initiative*
Editors	Javan Erfanian (Bell Mobility) *Chief editor* Brian Daly (AT&T) *Co-editor*
Work stream leaders	Armando Annunziato (Telecom Italia) Kevin Holley (Telefonica) Clark Chen (China Mobile) Eric Hardouin (Orange) Lou Feifei (China Mobile) Mikio Iwamura (NTT DoCoMo) Ralf Irmer (Vodafone) Stefan Apetrei (Orange) Chris Cheeseman (BT) Alex Tame (Vodafone)
Contributors	NGMN Members
PMO	Walter Grethe (Deutsche Telekom) Philipp Deibert (NGMN) Klaus Moschner (NGMN)
Steering Committee	Luigi Licciardi (Telecom Italia) Huang Yuhong (China Mobile) Takehiro Nakamura (NTT DoCoMo) Remi Thomas (Orange) Luke Ibbetson (Vodafone)

This document contains an Executive Version of NGMN's 5G White Paper. It has been produced to enable NGMN's Partners and stakeholders to engage in the development of the 5G White Paper and to enable planning and focus of future 5G industry activities (e.g. standardisation).

Commercial Address:
ngmn Ltd.,
Großer Hasenpfad 30 • 60598 Frankfurt • Germany

Phone +49 69/9 07 49 98-04 • Fax +49 69/9 07 49 98-41

Registered Office:
ngmn Ltd.,
Reading Bridge House • George Street • Reading • Berkshire RG1 8LS • UK
Company registered in England and Wales n. 5932387,
VAT Number: GB 918713901

TABLE OF CONTENT

1 ABSTRACT

The fifth generation of mobile technology (5G) is positioned to address the demands and business contexts of 2020 and beyond, that is, to enable a fully mobile and connected society and to empower socio-economic transformations in countless ways many of which are unimagined today, including those for productivity, sustainability and well-being. The demands of a fully mobile and connected society are characterized by the tremendous growth in connectivity and density/volume of traffic, the required multi-layer densification in enabling this, and the broad range of use cases and business models expected.

Therefore, in 5G, there is a need to push the envelope of performance to provide, *where* needed, for example, much greater throughput, much lower latency, ultra-high reliability, much higher connectivity density, and higher mobility range. This enhanced performance is expected to be provided along with the capability to control a highly heterogeneous environment, and capability to, among others, ensure security and trust, identity, and privacy.

While extending the performance envelope of mobile networks, 5G should include by design embedded flexibility to optimize the network usage, while accommodating a wide range of use cases, business and partnership models. The 5G architecture should include modular network functions that could be deployed and scaled on demand, to accommodate various use cases in an agile and cost efficient manner.

In 5G, there could be a need to develop a new radio interface driven by use of higher frequencies, specific use cases such as Internet of Things (IoT) or specific capabilities (e.g., lower latency), that goes beyond what 4G and its enhancements can support. However, 5G is not only about the potential development of a new radio interface. NGMN envisions 5G as an end-to-end system that includes all aspects of the network, with a design that achieves a high level of convergence and leverages today's access mechanisms (and their evolution), including fixed, and also any new ones to be defined.

5G will operate in a highly heterogeneous environment characterized by the existence of multiple types of access technologies, multi-layer networks, multiple types of devices, multiple types of user interactions, etc. In such an environment, there is a fundamental need for enablers to achieve seamless and consistent user experience across time and space.

Business orientation and economic incentives with foundational shift in cost, energy and operational efficiency should make 5G feasible and sustainable. 5G should also enable value creation towards customers and partners through the definition and exposure of capabilities that enhance today's overall service delivery.

NGMN has had a central role in the definition of operator requirements which has contributed significantly to the overall success of LTE. In the meantime, LTE has become a true global and mainstream mobile technology, and will continue to support the customer and market needs for many years to come. While accelerating the development of LTE and its evolution, NGMN has been developing the 5G requirements. This is outlined by the operators, in close interaction with NGMN partners, in a White Paper, to address the needs of customers and markets beyond 2020. The NGMN White Paper serves as a guideline for 5G definition and design, and also insight into areas of further exploration by NGMN and other industry stakeholders.

The NGMN White Paper will be published at the MWC in March 2015 and will be presented and discussed at the NGMN Industry Conference & Exhibition 24-25 March 2015. This executive version of the NGMN 5G White Paper is published in advance of the full version to enable NGMN Partners and other industry stakeholders to consider NGMN's 5G requirements at this early stage. This executive version outlines a summary of the 5G outlook and vision. It then defines end-to-end requirements to make this vision successful. An initial perspective on the overall 5G design principles and end-to-end architecture is offered. The high level requirements with respect to spectrum, IPR and the 5G development timelines are also provided as part of this paper.

2 5G OUTLOOK

2.1 Business Context

Driven by technology developments and socio-economic transformations, the 5G business context is characterized by changes in business, technology, and operator contexts.

Consumer

Significant recent technology advancement is represented by the advent of smartphones and tablets. While smartphones are expected to remain as the main personal device and further develop in terms of performance and capability, the number of personal devices will increase driven by new classes of user devices such as wearables or sensors.

Supported by cloud technology, these devices will extend their capabilities to various applications such as high quality (video) content production and sharing, payment, proof of identity, cloud gaming, mobile TV, and in general supporting smart life. They will have a significant role in health, security, safety, and social life applications, as well as controlling home appliances, cars and other machines. To support customer trends such as multi-device and multi-access, a comprehensive view of the 5G consumer is required.

Enterprise

Many of the trends in the consumer segment apply to future enterprises as well. The boundaries between personal and enterprise usage of devices will blur. Enterprises will look for solutions to address security and privacy challenges associated with this hybrid type of usage.

For enterprises, mobility will be one of the main drivers for increased productivity. In the next decades, enterprises are expected to make all enterprise applications available on mobile devices. The proliferation of cloud technology will enable application portability and will offer major opportunities for enterprises. At the same time the cloud imposes challenges to enterprises that have to be managed properly (e.g., security, privacy, performance).

Verticals

The next wave of mobile is to mobilize industries and industry processes. This is widely referred to as machine communication and the IoT. Tens of billions of smart devices will use their embedded communication abilities and sensors to act on their local environment and use remote triggers based on intelligent logic. These devices differ in terms of requirements with respect to capabilities, power consumption and cost. IoT will also have a wide range of requirements on networking such as reliability, security, performance (latency, throughput), etc. The creation of new services for vertical industries (e.g. health, automotive, energy) will not be limited to connectivity but can require enablers from cloud computing, big data management, security, logistics and other network-enabled capabilities.

Partnerships

In many markets today, telco players have already started to leverage partnerships with over-the-top (OTT) players to deliver packaged services to end users. OTT players will move to deliver more and more applications that require higher quality and lower latency and other service enhancing capabilities (e.g., proximity, location, QoS, authentication) on demand and in a highly flexible and programmable way.

Infrastructure

Breakthrough technology advancements of the recent years, such as Software-Defined Networking (SDN), Network Function Virtualization (NFV), Big Data, and all-IP, will change the way networks are being constructed and managed. Those changes will enable the development of a highly flexible infrastructure that enables cost-efficient development of networks and associated services as well as increased pace of innovation. Operators will continue developing own services, but also expand their business reach through partnerships for both the infrastructure as well as the application development aspects.

Services

From a services perspective, a global business model evolution of mobile operators' services will include the evolution of current services as well as the emergence of new ones. Currently the most common services provided by mobile operators include point-to-point personal communication and (best effort) data services. These services will evolve to improve both in quality as well as in capability. Personal communication will include high quality IP multimedia and rich group communication as a baseline. Data services on the other hand, will be possible from multiple integrated access technologies and be ubiquitous and characterized by performance consistency. Data traffic will be dominated by video and social media.

New services will emerge which may cover new market segments such as automated industries and smart user environments, public safety and mission critical services, big data, proximity and geo-community services, and many others.

2.2 5G vision

As outlined above, NGMN expects that the business context beyond 2020 will be notably different from today and will see the emergence of new use cases and business models driven by the customers' and operators' needs and enabled by the maturity and emergence of key technologies. Therefore, NGMN has formulated the following vision for 5G that serves as an inspiration to develop the requirements and the related technology and architecture guidelines:

"5G is an end-to-end ecosystem to enable a fully mobile and connected society. It empowers value creation towards customers and partners, through existing and emerging use cases, delivered with consistent experience, and enabled by sustainable business models."

NGMN 5G Vision

Use cases

In addition to supporting the evolution of the existing use case of mobile broadband, 5G will support countless emerging use cases with a high variety of applications and variability of their performance attributes: from delay-tolerant video applications to ultra-low latency, from high speed entertainment applications in a vehicle to mobility on demand for connected objects, and from reliable applications to critical ones such as health. Furthermore, use cases will be delivered across a wide range of devices (e.g., smartphone, wearable, machine module) and across a heterogeneous environment. NGMN has developed twenty four use cases for 5G, as representational examples, that are grouped into eight use case families. The use cases and use case families serve as an input for stipulating requirements and defining the cornerstones of the 5G architecture. The use cases are not meant to be exhaustive, but rather act as a tool to ensure that the level of flexibility required from 5G is well captured. The following diagram shows the eight use case families with one example use case given for each family:

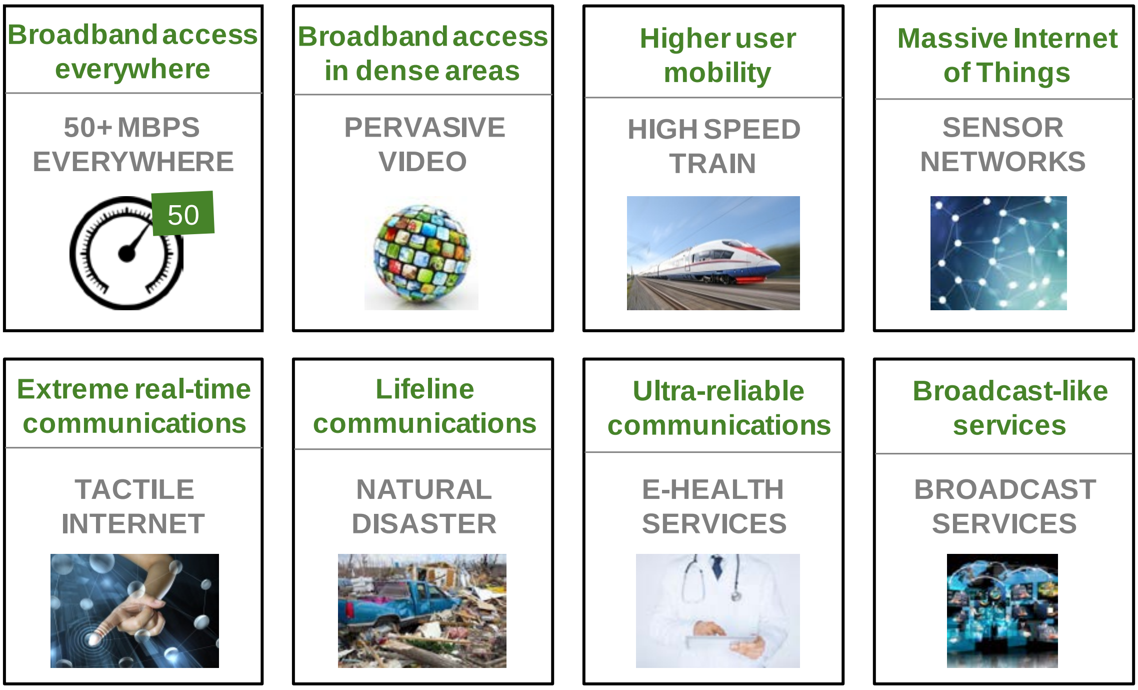

Figure 1: 5G use case families and related examples

Business models

To support the evolution of the current business models, 5G will expand to new ones and will support different types of customers and partnerships. Operators will support vertical industries and contribute to the mobilization of industries and industry processes. Partnerships will be established on multiple layers ranging from sharing the infrastructure, to exposing network capabilities as a service end-to-end, and integrating partners' services into the 5G system through a rich and software oriented capability set. There is a need for flexibility and embedded functionality to enable these. The following diagram shows examples of models that have to be supported by 5G:

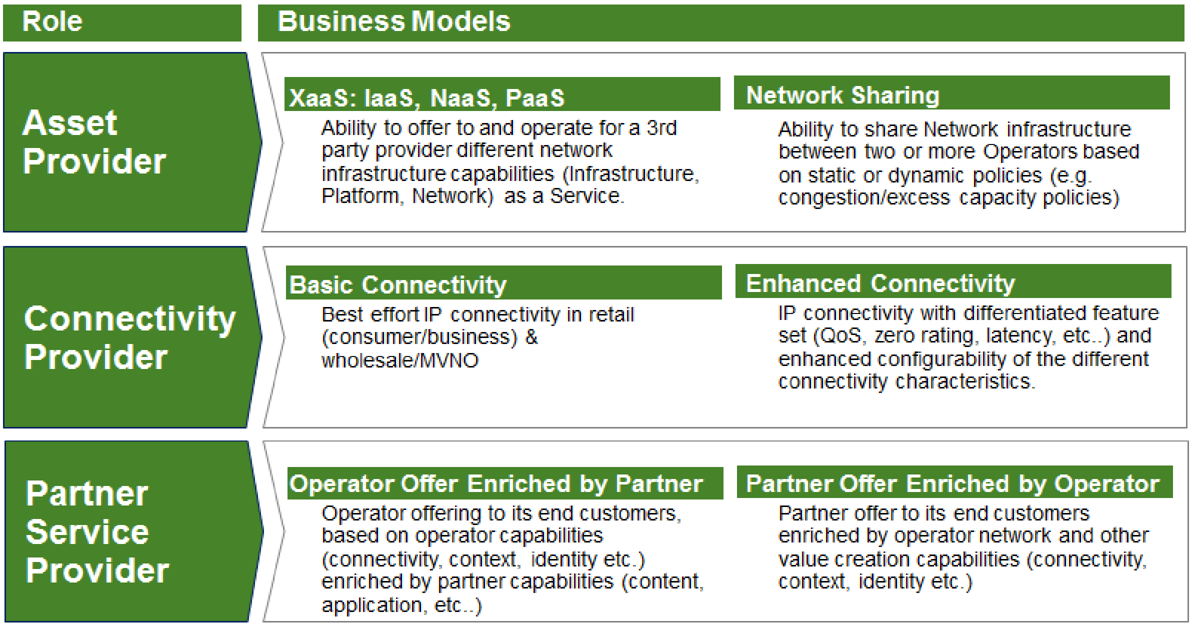

Figure 2: 5G business models - Examples

The key requirement for 5G will be to support the business models at a very low cost and provide the flexibility to enable the business models on demand.

Value creation

5G will bring multiple propositions to all customers and at the same time provides an enhanced and unique proposition tailored to each of them. The definition of the customer is not limited to the consumers and the enterprises as in today's environment but will include verticals and other partnerships. The propositions that are expected to be offered across all services and customer segments are:

- Services are available anywhere, anytime
- Services are delivered with consistent experience across time and space
- Services are accessible on multiple devices and access technologies
- Services support multiple interaction types
- Services are delivered seamlessly and transparently across access technologies
- Services are delivered in a contextual and personalized fashion
- Services are enabled by secure and trusted communications
- Services are supported by a highly reliable and resilient network
- Services are delivered in a responsive and real-time fashion

Operators' value creation propositions will be enabled by capabilities that are flexibly integrated into the 5G system and easily exposed through Application Programming Interfaces (APIs) to foster innovation and reduce time to market. This will be of much benefit of all customers as it will allow for tailored and differentiated capability offering, enablement of new services, faster time to market and cost-efficient design. On top of network connectivity, the following capabilities are expected to be embedded in the 5G design from the start, and designed for exposure to enable fast service development. Moreover, the delivery of these services is expected with consistent user experience, provided with trust.

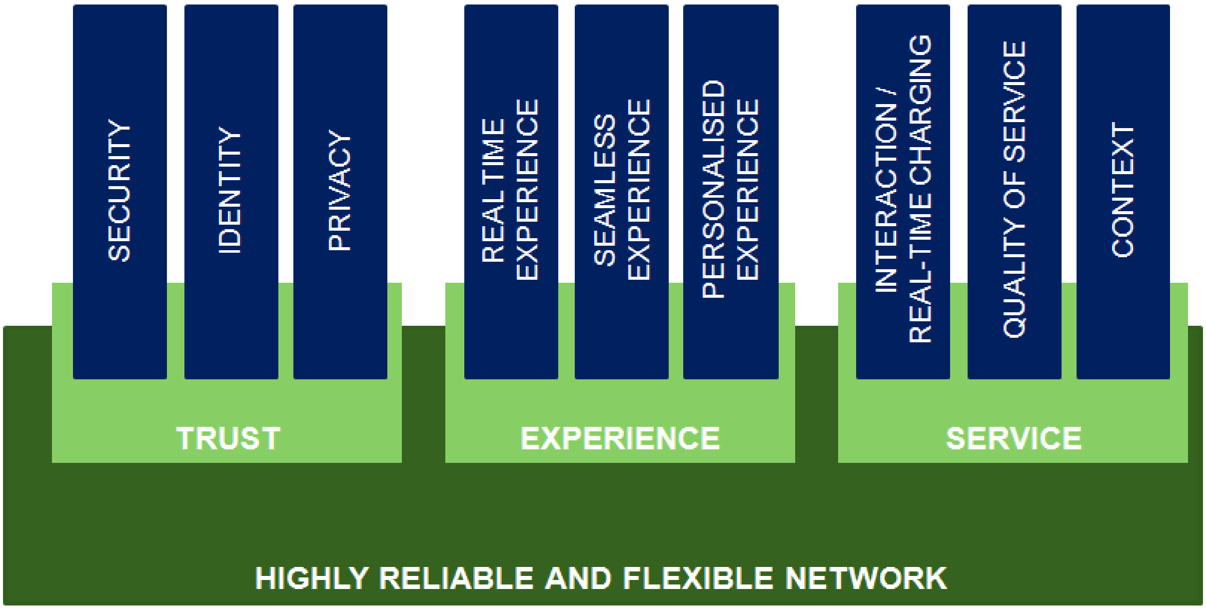

Figure 3: 5G Value creation capabilities

Therefore, the capabilities cover trust, experience and service related attributes. Trust includes capabilities such as security, identity management and privacy. Experience of services will be seamless and personalized across technologies, devices, time and location. From a service perspective, capabilities such as quality of service, context, and a responsive interaction and real-time charging design will enable a differentiated service offering to customers and other service partnerships.

3 REQUIREMENTS

The 5G requirements are inspired by NGMN's vision of the potential use cases and business models. Furthermore, NGMN believes that the requirements should also satisfy the value creation that NGMN intends to deliver to the different types of customers and partners. The NGMN vision leads to requirements that are grouped in six categories shown below:

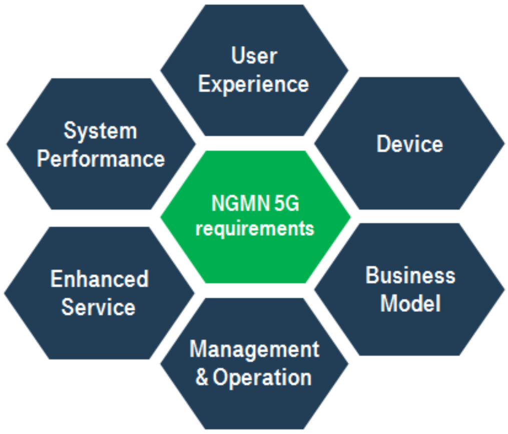

Figure 4: 5G requirements categories

The 5G use cases demand very diverse and sometimes extreme requirements. It is anticipated that a single solution to satisfy all the extreme requirements at the same time is potentially a case of over-specification and costly. Nevertheless, several use cases are anticipated to be active concurrently in the same operator network, thus requiring a high degree of flexibility and scalability of the 5G network.

3.1 User Experience

The 5G system should be able to deliver a consistent user experience over time for a given service everywhere the service is offered. Consistent user experience is defined by service-dependent minimum KPIs (e.g. data rate, latency) being met over the service coverage area, with a level of variation configurable by the operator.

- Use case specific data rates up to 1 Gb/s should be supported in some specific environments, like indoor offices, while at least 50 Mb/s shall be available everywhere at a reasonable cost. Use case specific data rate requirements are specified in terms of the data rates that should be available to at least 95% of the location and time in the considered environment (i.e. at “cell-edge”).
- E2E latency of 1 ms should be provided for the use cases which require extremely low latency.
- Mobility on-demand should be supported, ranging from very high mobility, such as high-speed trains/airplanes, to low mobility or stationary devices such as smart meters.

3.2 System Performance

The network should be able to serve a massive number of human and Machine-Type Communication (MTC) devices. In the extreme cases:

- Data rates of several tens of Mb/s should be supported for tens of thousands of users in crowded areas, such as stadiums or open-air festivals.
- 1 Gb/s to be offered, simultaneously, to tens of workers in the same office floor.
- Up to several 100,000s simultaneous connections per square kilometre to be supported for massive sensor deployments.

- Spectral efficiency should be significantly enhanced compared to 4G in order for the operators to sustain such huge traffic demands under spectrum constraints, while keeping the number of sites reasonable.
- Coverage should be improved to allow the high 5G data rates in rural areas with the current grid of macro sites.
- Signalling efficiency should be enhanced, so that signalling and energy consumption are adapted efficiently to the application needs.

3.3 Device Requirements

Smart devices in 5G era will grow in capability and complexity as both hardware and software, and particularly the operating system will continue to evolve. They may also in some cases become active relays to other devices, or support network controlled device-to-device communication.

- 5G terminals should have a high degree of programmability and configurability by the network.
- Human type devices (smart devices) should be able to support multiple bands as well as multiple modes.
- 5G terminals shall support aggregation of flows from different technologies.
- Flexible and dynamic UE capability handling should be assured.
- Dedicated, low cost MTC devices should be supported without the need to support additional (aforementioned) capabilities.
- Battery life shall be significantly increased: at least 3 days for a smartphone, up to 15 years for a low-cost MTC device.

3.4 Enhanced Services

In the 5G environment, services should be enhanced with the following capabilities:

- The user application should be seamlessly and consistently connected to the Radio Access Technologies (RATs) and/or access point(s) providing the best user experience without user intervention.
- Network based positioning should be supported, with accuracy from 10 m to <1 m at 80% of occasions, and better than 1 m for indoor deployments.
- Network security for highly heterogeneous environments and usages should be enabled.
- User identity and protection of the users' trusted information should be assured.
- Resilience and high availability will be essential, to ensure minimal service is available to critical infrastructures or service providers in case of disaster.
- Packets should be delivered successfully within a maximum delay to be defined by the operator, up to an ultra-high reliability rate of 99.999% or higher for specific use cases.

3.5 New Business Models

5G should enable creation of new business models in a programmable manner without having architectural impact. 5G should be designed from the beginning such that network operator is able to create large variety of relationships between its network infrastructure and customer/service provider. With respect to the business model examples mentioned earlier, the following requirements are formulated

- Connectivity provider model: Modular network architecture capability needs to be exposed to the provisioning/configuration system of 5G so that network operator/service provider is able to configure data flows. Here only necessary network functions will be used and configured to optimize operational and management costs.
- Partner service provider and XaaS asset provider model: This requires creation of open API layer that allows service provider to configure its own policies and the way its data packets are processed in the network. At same time, for the operator, freedom to control, manage and evolve the network is ensured.
- Network sharing model: It requires technical functionalities from design to maximize the overall synergies of network sharing agreements and enable flexible business models that can change dynamically over time.

3.6 Network Deployment, Operation and Management

It is fundamentally essential to ensure that operators will be able to provide 5G services in an economically sustainable way. 5G should be designed with the objective to minimise the Total Cost of Ownership (TCO) of the network infrastructure and the cost of devices, for any given service offering.

- Energy efficiency of the networks is a key factor to minimize the TCO, along with the environmental footprint of networks. 5G should support a 1,000 times traffic increase in the next 10 years (or less) timeframe, with half of the typical consumed energy, compared to today, over the whole network.
- The technology should allow native flexibility for the operator to configure trade-off between energy efficiency versus performance where justified.
- 5G should provide efficient, flexible and fast ability for introduction of new services and future technical evolutions (including inserting new RATs into the network).
- Ease of deployment to reduce planning, configuration and optimization efforts.
- Flexibility and scalability should be provided, in particular through on-demand resource utilization.
- Fixed and mobile convergence should be supported for seamless user experience and unified subscriber management.
- Operational efficiency should allow trusted, simplified, flexible and reduced-cost management and operations, using standard and open interfaces
- Options should be offered to allow ultra-low cost deployments for very low Average Revenue Per User (ARPU) areas and/or use cases.

4 TECHNOLOGY AND ARCHITECTURE

When the baseline 4G system (which in here is considered to be LTE Release 12) is compared against the 5G requirements, improvements are needed particularly to enable consistent user experience, flexibility (along with trust, reliability, and security), efficiency, ease of innovation, and also pushing the envelope (/ limit) of performance attributes and network capabilities.

4.1 5G Design principles

Considering emerging technology trends and the requirements as stipulated above, NGMN believes that the 5G system should be designed based on the following design principles:

Leverage spectrum – Higher frequencies (e.g., centimetre and millimetre waves) and licence-exempt spectrum should be exploited to complement endeavours to use any spare bandwidth at lower frequencies and as a complement to the available mainstream licensed spectrum resource (allocated for mobile communication). Due to different properties of different spectrum, optimized use of various spectra should be considered, leading to concepts such as Control/User (C/U)-plane path split and Uplink/Downlink (UL/DL) split. This implies that simultaneous connections to multiple access points need to be supported.

Enable cost-effective dense deployments – To make densification economically viable, new deployment models, such as integration of third-party / user deployments as well as multi-operator / shared deployments are necessary. The system should be able to cope with unplanned, chaotic deployments, drawing out maximum performance even given such conditions. The network should hence self-manage interference and load balancing.

Coordinate and cancel interference – Massive Multiple-Input Multiple-Output (MIMO) and Coordinated Multi-Point (CoMP) technologies will be essential to improve the achievable Signal-To-Interference Ratio (SIR) in the system, thereby improving QoS consistency and overall spectrum efficiency. Non-orthogonal multiplexing schemes could be introduced, exploiting advanced receiver capabilities to mitigate interference.

Support dynamic radio topology – Devices should be connected through topologies that minimize battery consumption and signalling. Wearable devices could connect through a smartphone as well as directly to the network if the smartphone battery runs short. Extended use of tinted glass on vehicles as well as large scale sensor deployment makes hub devices highly relevant. In some cases, device-to-device communications could be exploited to offload traffic from the network. Thus, the radio topology should be able to change dynamically based on the context. A unified frame design, together with radio-topology-agnostic design of identities, authentication and mobility procedures, is essential to support this.

Simplify the core – The system design should move away from the 4G monolithic design optimized for mobile broadband. The mandatory functions should be stripped down to an absolute minimum (if possible none in the U-plane), and C/U-plane functions should be clearly split with open interfaces defined between them to support flexible function utilization and scalability, so that they can be employed on demand. The current means of supporting mobility using tunnelling should be reassessed with the aim of routing more directly based upon SDN-like principles. Legacy interworking should be minimized, for example by removing the interworking with the circuit switched domain in 2G and 3G.

Embrace flexible functions and capabilities – Network slices should be created utilizing the same infrastructure to support various use cases. That is, network / device functions and RAT configuration should be tailored for each use case, leveraging the NFV and SDN concepts. To improve robustness of such virtualized system, state information should be split from functions and nodes, so that contexts could be easily relocated and restored even in failure events.

Support new value creation – Big data analytics and context awareness are deemed essential to optimize network usage, and at the same time to provide added value to the end-user. In addition, various capabilities of the network should be exposed to facilitate XaaS businesses.

Build in security and privacy – Security is an essential value proposition of the 5G system and must be a fundamental part of the system design despite paradigm shifts like extreme densification, dynamic radio topology, and flexible function allocation. In particular, user location and identity must be protected from unlawful disclosure.

Simplify operations and management – Expanded network capabilities and flexible function allocation should not imply increased complexity on operations and management. Procedures should be automated as far as possible, with well-defined open interfaces to mitigate multi-vendor interworking problems as well as interoperability (roaming) issues. Use of dedicated monitoring tools should be avoided and network functions (software) should be embedded with monitoring capabilities. Carrier-grade network cloud orchestration is needed.

4.2 5G Architecture

Based on the design principles, NGMN envisions an architecture that leverages the structural separation of hardware and software, as well as the programmability offered by SDN and NFV. As such, the 5G architecture is an SDN/NFV native architecture covering all aspects ranging from devices, (mobile/fixed) infrastructure, network functions, value enabling capabilities and all the management aspects to orchestrate the 5G system. APIs are provided on the relevant touch points to support multiple use cases, value creation and business models.

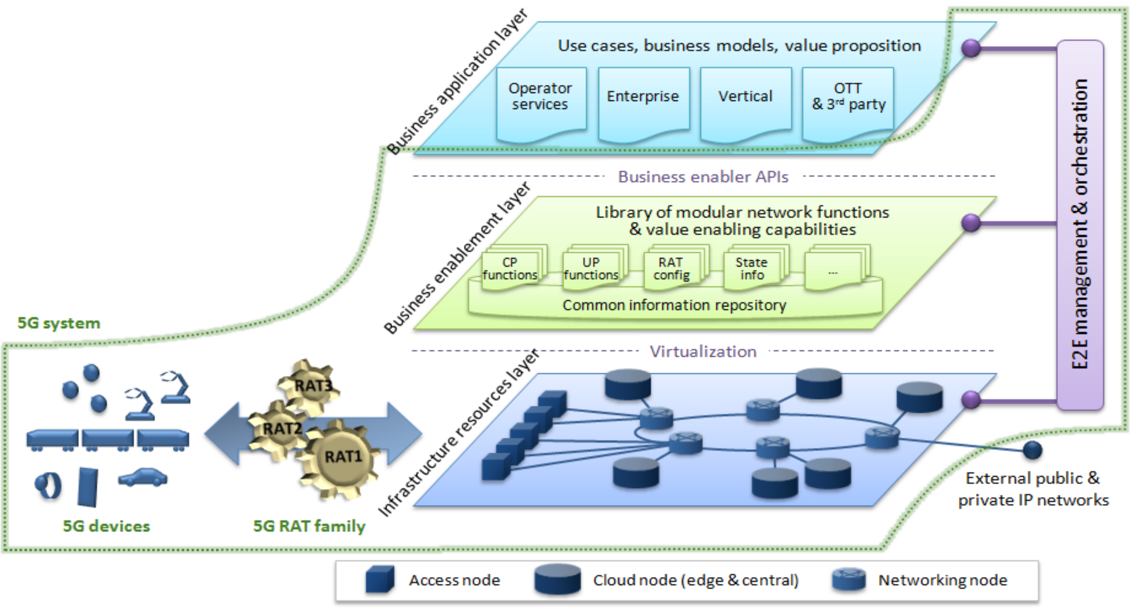

Figure 5: 5G architecture

The architecture comprises of three layers and an E2E management and orchestration function:

1. **Infrastructure resource layer** – The physical resources of a fixed-mobile converged network, comprising access nodes, cloud nodes (which can be processing or storage resources), 5G devices, networking nodes and associated links. The resources are (a) abstracted, so that they can be exchanged without affecting the upper layer, and (b) become virtualized, so that they appear as multiple instances and become reusable in different usage scenarios
2. **Business enablement layer –** Library of all functions required within a converged network in the form of modular architecture building blocks, including functions realized by software modules that can be retrieved from the repository to the desired location, and a set of configuration parameters for certain parts of the network, e.g., radio access. Those functions and capabilities are called upon request by the orchestration entity, through relevant APIs.
3. **Business application layer** – Specific applications and services of the operator, enterprise, verticals, or third parties that utilize the 5G network.

E2E orchestration and management plays a central role in this architecture, and has the capability to manage such a virtualized network end-to-end, in addition to providing the traditional OSS and SON automation capabilities. Orchestration and management serves as the contact point to translate the use cases and business models into actual network functions and slices. It defines the network slices for a given application scenario, chains the relevant modular network functions, assigns the relevant performance configurations, and finally maps all of this onto the infrastructure resources. It also manages scaling of the capacity of those functions as well as their geographic distribution. In certain business models, it could also possess capabilities for third parties (e.g., MVNOs and verticals) to create and manage their own network slices, through APIs and XaaS principles. Data-aided intelligence will be utilized to optimize all aspects of service composition and delivery.

Figure 6 illustrates an example of multiple 5G slices concurrently being operated on the same infrastructure. For example, a 5G slice for typical smartphone use can be realized by setting fully-fledged functions distributed across the network. For a 5G slice supporting automotive use case, security, reliability and latency could be critical. For such a slice, all the necessary (and potentially dedicated) functions can be instantiated at the cloud edge node, including the necessary vertical application due to latency constraints. To allow on-boarding of such vertical application on a cloud node, sufficient open interfaces should be defined. For a 5G slice supporting massive machine type devices (e.g., sensors), some basic C-plane functions can be configured, omitting, for instance, any mobility functions, with contention-based resources for the access.

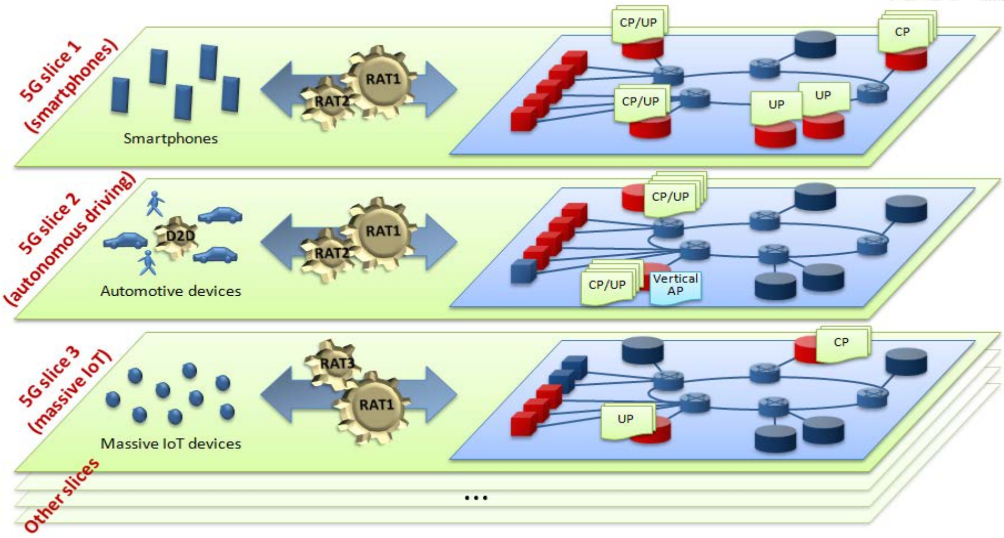

Figure 6: 5G network slices implemented on the same infrastructure

Irrespective of the slices to be supported by the network, the 5G network should contain functionality that ensures controlled and secure operation of the network end-to-end and at any circumstance.

5G Radio Access Technology

Given the wide spectrum of capabilities that need to be delivered, 5G will most likely be comprised of more than one RAT, each optimized for certain use cases and/ or spectrum, hence comprising a “5G RAT family”. A new RAT could be motivated by higher carrier frequencies (e.g., bands above 6GHz), lower latency, and specific use cases. Nevertheless, to achieve economies of scale, the number of RATs should be minimized as far as possible, ideally down to one. Even if multiple RATs are to be introduced, commonality should be achieved to the largest extent possible. For example, the protocol stack above layer 2 could be harmonized, and the same control functionality could be applied, thereby making the different RATs rather different modes of operation of a single RAT. Then, even if a new RAT is introduced, carrier aggregation with LTE-Advanced is deemed essential, especially in the early phases of deployment for migration.

5G Interfacing Options

There are several options to interface the access technologies, all with their advantages and disadvantages. In one option recommended by NGMN, all 5G components of the 5G RAT family are supported by the new 5G functions (5GFs) design. Other RATs (e.g., Wi-Fi) and the fixed network may also be supported through the new 5GFs design. This will allow parallel deployment of Evolved Packet Core (EPC), for legacy devices, and 5GFs, for new devices, using existing RAT deployments, hence providing a sound migration path.

In order to facilitate migration towards 5G, NGMN recommends that LTE/ LTE-Advanced and Wi-Fi, as well as their evolution, are to be supported by the new 5G network design. Thus, the access-agnostic network functions should accommodate any new RATs, as well as LTE/ LTE-Advanced, Wi-Fi, and their evolution. This way, the network function design can fully benefit from the new technologies without backward compatibility constraints, and still would allow operators to benefit from the new design using existing radio deployments. This will also minimise the need for interworking functions between the 5GFs and the legacy networks.

Regardless of the architecture option pursued, harmonizing different identity and authentication paradigms in cellular networks, (wireless) local access networks, and fixed networks will be essential to enable convergence of different access types, and also to facilitate the realization of different business models. The architecture must also facilitate further convergence of fixed and mobile networks in a manner that efficiently addresses the needs and requirements originating from regulators.

5 SPECTRUM

Evolving today's Smartphone use cases and expanding into a wide range of new ones with significant traffic growth will require far more spectrum than is currently allocated to mobile broadband. Ensuring the availability of the right amount of spectrum, considering relevant spectrum bands and spectrum management, is key to providing the required consistent user experience across different use cases.

Spectrum Bands

As indicated, the timely availability of suitable spectrum bands with suitable spectrum management regimes will be a critical factor in the successful implementation of 5G. A fundamental requirement is that operators must be free to "re-farm" their existing mobile spectrum holdings for 5G as well as being able to gain timely access to spectrum that is already harmonised for mobile but is not yet assigned and additional spectrum that may be identified at the ITU World Radiocommunication Conference 2015 (WRC-15).

5G will require access to a range of spectrum bands with differing characteristics in order to address a wide range of requirements for coverage, throughputs and latency in the most cost efficient manner and to make effective use of the spectrum

NGMN anticipates that 5G will be integrated within the umbrella of "IMT" within the ITU and will look to ITU for global spectrum identification and harmonisation. NGMN has identified potential new requirements for 500-1000MHz of spectrum located above 6 GHz to support very high data rates and shorter-range connectivity and believes that this should be studied and if appropriate addressed at the conference after WRC-15.

Whilst in a 5G context access to additional spectrum above 6 GHz is of interest, it should be emphasized that in general low frequency spectrum (below 6GHz), especially sub-1GHz, is absolutely essential for an economical delivery of mobile services and this holds true for existing systems as well as future 5G systems. Therefore, priority must be put on how to make more spectrum in those low bands available, and how to use that spectrum much more efficiently.

Depending on the outcome of WRC-15, there may be a need for a future conference to consider additional spectrum for coverage and capacity (e.g. for the period beyond that considered by WRC-15). Spectrum below 1 GHz is useful for coverage (rural and indoor) and spectrum above 6 GHz is useful for very high data rates and shorter-range connectivity. It should be further noted that backhaul requirements for 5G may include wireless solutions and need suitable spectrum.

Spectrum Management

A key point to emphasize is that exclusive licensing regimes should remain the preferred solution for access to core spectrum for 5G – ideally nation-wide spectrum that is globally harmonised to enable guaranteed QoS and support global roaming.

Supplementary spectrum, made available on a shared basis, will be required to deliver extra capacity where needed, for example additional licensed spectrum made available by an incumbent governmental / public user within a defined geographic area and/or defined time. Access to licence-exempt spectrum as a useful supplement for certain applications and may be seamlessly integrated into the 5G platform.

Spectrum flexibility can bring benefits of spectral efficiency gains, examples include: increasing exclusive spectrum with emphasis on improving regional/global harmonisation; smart carrier aggregation to use spare frequencies; spectrum trading; and managing fair access to supplementary shared spectrum.

6 IPR

NGMN is developing guidelines towards a more transparent and predictable IPR regime across the mobile industry that will support the commercial implementation of 5G technologies and will ensure the business case for 5G is sustainable.

One of the business objectives is to make 5G connectivity affordable for all types of devices from the high end smartphones and tablets down to the low end MTC devices such as smoke detectors and sensors. This is to ensure the IP royalties paid for connectivity are distributed fairly across patent holders, and are established at a reasonable level to ensure the sustainable and successful mass deployment of MTC devices to support the Internet of Things (IoT).

This will be outlined in the NGMN White Paper to be published in March 2015.

7 WAY FORWARD

The roadmap, milestones and steps to be taken towards the final deployment are essential prerequisites for the overall success of 5G. NGMN has defined a 5G roadmap that shows an ambitious time-line with a launch of first commercial systems in 2020. At the same time it gives reasonable time for all the industry players to carry out the required activities (such as standardisation, testing, trials) ensuring availability of mature technology solutions for the operators and attractive services for the customers at launch date. The key milestones are as follows:

- Commercial system ready in 2020
- Standards ready end of 2018
- Trials start in 2018
- Initial system design in 2017
- Detailed requirements ready end of 2015

The launch of 5G will happen on an operator and country specific basis. Some operators might plan to launch in 2020 – others will plan for a later deployment. The roadmap represents the baseline planning from an NGMN perspective and milestones might be shifted in the course of the 5G development due to external factors (e.g. standardisation process, etc.). The detailed roadmap is shown below:

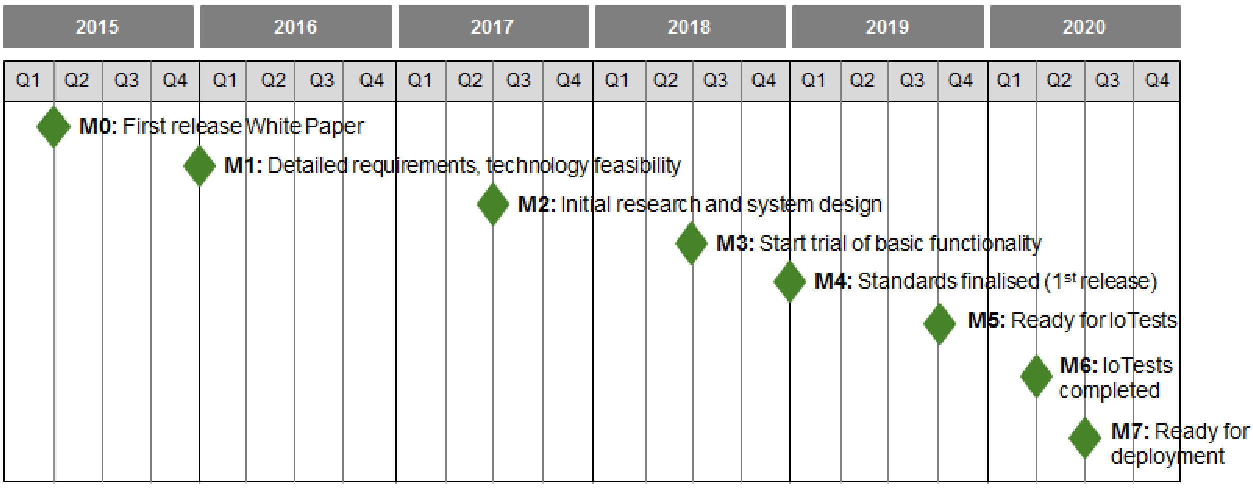

Figure 7: NGMN 5G Roadmap

M0: First release (v1.0) NGMN 5G White Paper, NGMN Industry Conference: Vision, requirements, architecture, spectrum, IPR
M1: Detailed requirements available, technology feasibility and options explored
M2: Initial research and system design done, first prototypes ready, study and recommendation for standardisation available, standardisation starts
M3: Trial of basic functionality starts **M4:** Standards finalised (1st release)
M5: Infrastructure and terminals ready for interoperability tests. Start of friendly customer trials
M6: Infrastructure and terminals interoperability tests completed
M7: First commercial infrastructure. Services and terminals ready for deployment

8 CONCLUSIONS

5G is expected to have countless use cases, many unimagined today. In this executive version of the NGMN White Paper, examples of use case families have been provided, showing extensive variety and variability and need for wide range of attributes and capabilities. These have provided guidance to definition of requirements and associated architecture.

The requirements cover the end to end considerations including user, system, enhanced service, management and operation, device and business model requirements. It is particularly important to keep improvements in the following areas in focus:

- **Network capability:** To cope with the diversity of use cases, the capabilities of the network need to be expanded to support e.g., higher data rates (>10x on average, >100x at cell edge), lower latency (>10x improvement) and higher connection density (>100x improvement). Nevertheless, not all capabilities need to be supported at the same time for the same user/use case. Thus, a flexible and scalable system that can steer those capabilities on demand is necessary.

- **Consistent customer experience:** Customer experience in 5G is defined by a set of customer-perceived and service-dependent experience metrics delivered consistently across time and service footprint.

- **Flexibility:** Supporting a wide range of use cases and business models requires 5G to provide a high degree of flexibility by design, along with trust, reliability and security. This applies for the level of modularity of the system as well as the granularity level for scaling the system on demand and as per need. Network resources and capability will be provided and allocated dynamically, on demand, per context, and in near real-time.

- **Efficiency:** 5G should show foundational shifts in cost and energy efficiency, and device power consumption, while supporting the expected traffic growth and the use cases. Sustainability and efficiency in deployments and management of potentially ultra-dense and multi-layer deployments is fundamental to the 5G eco-system.

- **Innovation:** The 5G eco-system is an open eco-system that enables innovations at a fast pace, involving many partners. 5G should provide the capabilities to allow this, with value creation for the operators and the market as a whole. Programmability of the network, availability of 5G value enabling capabilities (e.g. location, QoS, identity, security) and the related APIs are needed to make this happen.

Enabling 5G use cases and business models require the allocation of additional spectrum for mobile broadband and needs to be supported by flexible spectrum management capabilities. In addition, an IPR regime needs to be developed to further enable innovation and unlock the potential associated with some of the use cases described in this paper.

The commercial introduction of 5G will vary from operator to operator; however, NGMN encourages the ecosystem players to work towards a plan that would deliver globally and commercially available solutions by 2020.