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Abstract

The main goal of 5G NORMA is to propose a multi-service mobile network architecture that adapts the use of the mobile network resources to the service requirements, the variations of the traffic demands over time and location, and the network topology. In this context, the purpose of this deliverable is to identify, alternatively to define, use cases that, with their related requirements, help on the definition of the 5GNORMA architecture, as well as proposing scenarios combining several uses cases that, all together, challenge the key innovations that 5G NORMA claims. In this sense, it provides the foundations for the work of the other WPs in the 5G NORMA project in charge of developing the end to end 5G network architecture.

Keywords

5G, Network Architecture, Use Cases, Requirements, Design Principles, Scenarios, Key Performance Indicators

[1] CO = Confidential, only members of the consortium (including the Commission Services)

PU = Public

Executive Summary

This deliverable provides the foundations for the work of the other WPs in the 5G NORMA project in charge of developing the end to end 5G network architecture. In this sense, it has identified, from a set of relevant use cases, the functional and performance requirements that the network architecture solutions proposed should address, as well as the scenarios that should be used for the validation of the solutions.

We defined 12 uses cases building on those developed by NGMN, METIS and 3GPP. The idea is not to present an exhaustive collection of use cases but identify a set of them that may have impact on the definition of the architecture. In this sense, the use cases were selected carefully on a number of criteria including the **potential business case**, responding to **societal needs** and the **inability of legacy technologies** to meet the requirements. The use cases are diverse and span a wide range of requirements. The selected use cases are:

- Industry Control,
- Enhanced Mobile Broadband,
- Emergency Communications,
- Vehicle Communications,
- Sensor Networks Monitoring,
- Traffic Jam,
- Real-time Remote Computing,
- Massive Nomadic Mobile Machine Type Communications,
- Quality-aware Communications,
- Fixed-Mobile Convergence,
- Blind Spots,
- Open Air Festival,

Each use case is source of a high number of requirements and therefore, for the purpose of facilitating the analysis by the 5G NORMA WPs that will define the network architecture, the following **groups of requirements** have been defined:

- Fast network reconfiguration within a network slice
- Fast network reconfiguration between network slices
- Device duality
- Separation and prioritization of resources on a common infrastructure
- Multi-connectivity in access and non-access part of the 5G system
- Massive scalability of protocol network functions
- Highly efficient transmission & processing
- QoE/QoS awareness
- Adaptability to transport network capabilities
- Low latency support
- Security

In terms of performance, these requirements can be grouped around three axes: **very low latency and reliability** for critical machine type communications; **high throughput** (compared to legacy networks) for massive broadband communication and the ability to support **high volumes of devices** for massive machine type communication.

The next step has been to analyse how the use cases and requirements map onto the **key innovations of 5G NORMA** which are the driving forces of our work. The first two innovations we classify as **innovative functionalities**:

- Multi-service- and context-aware adaptation of network functions,
- Mobile network multi-tenancy.

We classify the next three innovations as **innovative enablers**, i.e. they enable the innovative functionalities above:

- Adaptive (de)composition and allocation of mobile network functions,
- Software-Defined Mobile network Control,
- Joint optimization of mobile access and core network functions.

On top of this, in order to guide the transition from requirements to realization, 5G NORMA has also adopted a number of **design principles**, based on the collective experience and expertise.

Finally, to validate that there is a real need for the proposed innovations, a **scenario framework and several exemplary scenarios** for how the use cases might play out together in real world deployments have been proposed. The focus for these scenarios has been to help in the validation of the multi-service and context aware adaptation of network functions and mobile network multi-tenancy innovations, and for his reason each of them encompass more than one use cases. These scenarios should be refined and adopted by the WPs that are developing and validating the proposed 5G NORMA innovations.

The outcomes of this deliverable will guide the future work in 5G NORMA

- Other WPs in the project will work on the **design of a 5G network architecture** which meets the **functional and performance requirements** that we have defined for all the use cases. The transition from requirements to architectural solutions will be guided by the **design principles** identified. The architecture design will also take into account the physical environment and demand which have also been defined for each use case as reported in the deliverable.

- The **scenarios** described in this document will inspire and be used as reference for the **validation work of the 5G NORMA architecture**.

- The detailed descriptions of the use cases will also feed into the **assessment of the economic and social benefits of 5G NORMA** in relation to legacy networks. It will allow us to identify the relevant users, the type of benefits both from economic and the wider societal perspective and will provide a basis for identifying the business model(s) for each use case.

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List of Acronyms and Abbreviations

Term	Description
3GPP	3rd Generation Partnership Project
5G PPP	5G Infrastructure Public Private Partnership
AAA	Authentication Authorization Accounting
API	Application Programming Interface
ARPU	Average Revenue Per User
CAPEX	CAPital EXpenditure
CCTV	Closed Circuit TeleVision
CN	Core Network
C-RAN	Centralized or Cloud-based Radio Access Network
D2D	Device-to-Device
DL	DownLink
D-RAN	Distributed Radio Access Network
DRSC	Dedicated Short Range Communications
DSL	Digital Subscriber Line
EC	European Commission
ETWS	Earthquake and Tsunami Warning System
EU	European Union
FMC	Fixed Mobile Convergence
FTTH	Fiber To The Home
H2020	Horizon 2020
HD	High Definition
ICT	Information and Communication Technologies
KPI	Key Performance Indicator
Lx	Layer x (L1=Layer 1, L2=Layer 2 L3=Layer 3, L4=Layer 4)
MBB	Mobile BroadBand
METIS	Mobile and wireless communications Enablers for the Twenty-twenty Information Society
MME	Mobility Management Entity
MNO	Mobile Network Operator
MTC	Machine-Type Communication
NFV	Network Functions Virtualisation
NGMN	Next Generation Mobile Networks Alliance
NLoS	Non-Line of Sight
OPEX	OPerational EXpenditure
OTT	Over The Top (player)

Term	Description
PCRF	Policy and Charging Rules Function
P-GW	Packet Data Network GateWay
PPDR	Public Protection and Disaster Relief
QoE	Quality Of Experience
QoS	Quality Of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RG	Requirements Group
RSU	Road Side Unit
SDMC	Software-Defined Mobile network Control
SDN	Software Defined Networking
S-GW	Serving GateWay
SON	Self Organising Networks
TC	(METIS) Test Case
TCP	Transmission Control Protocol
UHD	Ultra High Definition
UICC	Universal Integrated Circuit Card
UL	UpLink
USIM	Universal Subscriber Identity Module
V2I	Vehicle to Infrastructure
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
V2X	Vehicle to X (Vehicle/Pedestrian/Infrastructure)
VRU	Vulnerable Road User
WLAN	Wireless Local Area Network
WP	Work Package
XaaS	X as a Service (Network/Platform/Infrastructure/Software/…)

1 Introduction

1.1 Objective of the document

The main goal of 5G NORMA is to propose a multi-service mobile network architecture that adapts the use of the mobile network resources to the network situation in a wide sense, encompassing the service requirements, the variations of the traffic demands over time and location, and the network topology, among other factors.

The main purpose of this document is to identify, alternatively to define, use cases that, with their related requirements, help on the definition of the 5GNORMA architecture, as well as proposing scenarios combining several uses cases that, all together, challenge the key innovations that 5G NORMA claims.

1.2 Structure of the document

The document is structured in the following way:

The chapter “Brief overview 5G NORMA concept” presents the essence of the 5G NORMA project outlining the key innovations the project is built on, namely:

- Adaptive (de)composition and allocation of mobile network functions,
- Software-Defined Mobile network Control,
- Joint optimization of mobile access and core network functions,
- Multi-service- and context-aware adaptation of network functions,
- Mobile network multi-tenancy,

The following chapter entitled “Terminology and methodology” presents the methodology to be used by the project for the development of the 5G network architecture. Definitions of terms such as requirement, scenario or network slicing are introduced in this chapter.

The chapter “Representative 5G use cases” introduces the state of the art for the 5G representative use cases. The focus is set on the use cases issued by “Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society” European research project, the “Next Generation Mobile Networks” alliance and the 3rd Generation Partnership Project” standards organization.

The next chapter, “Selection of 5G NORMA use cases and requirements” is the core chapter of this document. The first part of the chapter presents the 5G use cases selected for the scope of 5G NORMA. The idea is not to present an exhaustive collection of use cases but identify a set of them that may have impact on the definition of the architecture, either because they cannot be supported with legacy technologies or because they can benefit of the introduction of new architectural solutions. The selected use cases are:

- Industry Control,
- Enhanced Mobile Broadband,
- Emergency Communications,
- Vehicle Communications,
- Sensor Networks Monitoring,
- Traffic Jam,
- Real-time Remote Computing,
- Massive Nomadic Mobile Machine Type Communications,
- Quality-aware Communications,
- Fixed-Mobile Convergence,

- Blind Spots,
- Open Air Festival,

and analyse use cases' corresponding requirements.

Each use case is source of a high number of requirements and therefore, for the purpose of facilitating the analysis by the 5G NORMA WPs that will define the network architecture, the following groups of requirements are defined in the chapter:

- Fast network reconfiguration within a network slice
- Fast network reconfiguration between network slices
- Device duality
- Separation and prioritization of resources on a common infrastructure
- Multi-connectivity in access and non-access part of the 5G system
- Massive scalability of protocol network functions
- Highly efficient transmission & processing
- QoE/QoS awareness
- Adaptability to transport network capabilities
- Low latency support
- Security

Finally, the second part of the chapter outlines how the use cases addressee the aforementioned group of requirements and the 5G NORMA innovations.

In order to guide the transition from requirements to realization, in chapter 6 the deliverable collects a number of design principles, based on the collective experience and expertise.

As two of the key 5G NORMA innovations, more specifically the multi-service and the multi-tenant innovations cannot be addressed by a use case independently, scenarios addressing these innovations have to be defined. Just before the conclusion of this deliverable the 'Initial specification of scenarios" chapters introduces the frameworks for defining "multi-service" and multi-tenant scenarios based on the selected use cases.

2 Brief overview 5G NORMA concept

The main goal of 5G NORMA is to propose a **multi-service mobile network architecture** that adapts the use of the mobile network (RAN and CN) resources to the service requirements, the variations of the traffic demands over time and location, and the network topology (including the available front/back-haul capacity).

The key idea behind 5G NORMA for achieving the above objective is to **decompose the mobile network functions** (including access and core functions) and **adaptively allocate** them to the access network or central cloud, depending on (i) the specific service and its requirements, e.g., bandwidth and latency; and (ii) the transport network capabilities (e.g., available front/back-haul capacity). This adaptive allocation of functions brings several advantages:

- When service requirements and backhaul capacity allows **centralizing** the functionality in the network cloud, better scalability and pooling gains can be obtained from moving all the functionality to the cloud.
- When services have special requirements that require moving part of the functionality to the access, or backhaul constraints do not allow full centralization, gains can be obtained by using a **fully or partially distributed configuration**. Achievable benefits are lower latencies, enabling autonomous operation of edge clouds, and offloading the backhaul.

To implement the above adaptive (de)composition and allocation of network functions, the architecture applies concepts from Software-Defined Networking (SDN) and Network Functions Virtualization (NFV). With the resulting paradigm, which we refer to as **software-defined mobile network control**, the functionality executed in the cloud is designed following a software-defined approach: it relies on well-defined, 'programmable' interfaces with the access node that allow to flexibly adapt the network behaviour only by modifying the centralized functionality.

As a result of the flexible allocation of functions in the access and cloud, the separation between Radio Access Network (RAN) and core network (CN) is blurred. Indeed, with the proposed architecture, RAN and CN functions can be executed in the same location, either the access or the cloud. Thus, 5G NORMA opens the opportunity to **jointly optimize access and core functions**, taking advantage of the fact that these functions are no longer separated in different locations but may be executed next to each other.

In addition to adapting the network functions to the different services, the above technologies also serve as an enabler for **mobile network multi-tenancy**, i.e., to flexibly share the network infrastructure among different operators. Indeed, 5G NORMA treats the network elements as a pool of resources that can not only be adaptively assigned to different services but also to different operators.

It follows from the above explanation that the 5G NORMA architecture relies on five key innovations, three of which can be considered as **innovative enabling technologies**: (i) adaptive (de)composition and allocation of mobile network functions, (ii) Software-Defined Mobile network Control (SDMC); and (iii) joint optimization of mobile access and core network functions; while the other two can be considered as **innovative functionalities**: (iv) multi-service and context-aware adaptation of network functions; and (v) mobile network multi-tenancy.

2.1 Innovative Enablers

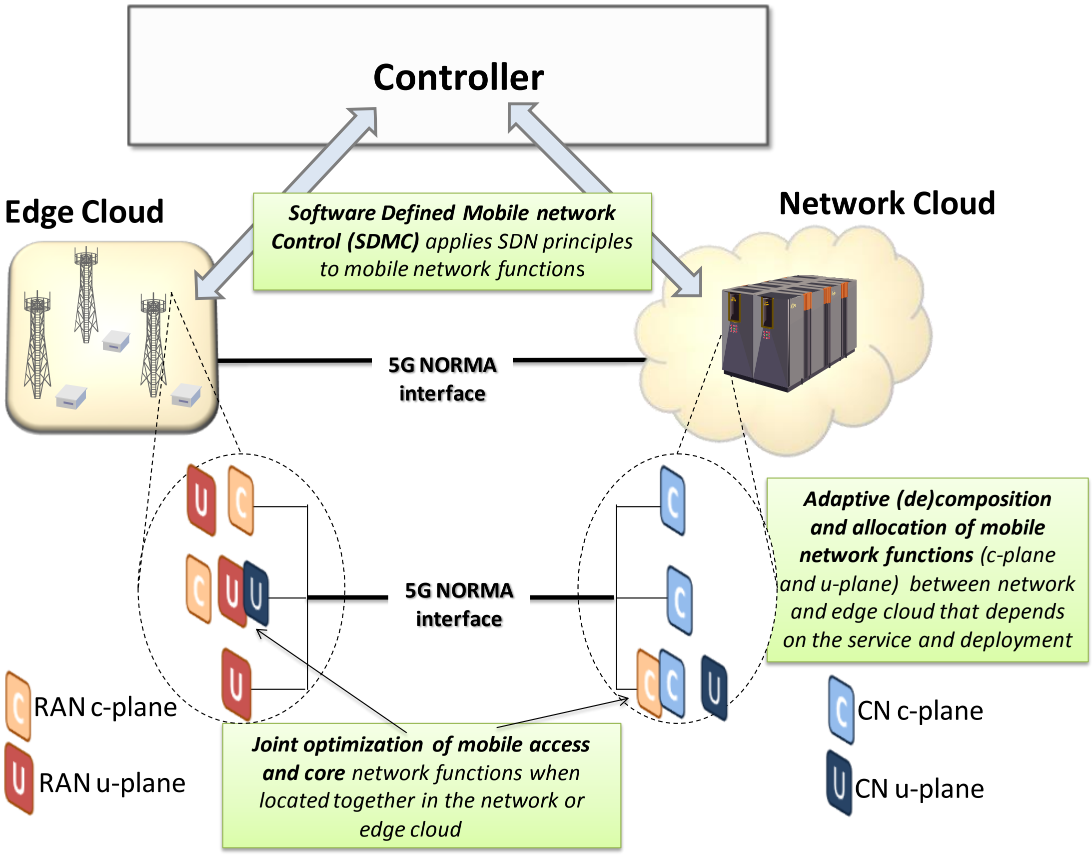

Figure 2-1: 5G NORMA concept based on the “3” innovative enablers.

Figure 2-1 illustrates the fundamental blocks of the 5G NORMA architecture: (i) the **edge cloud**, which is the integration of base stations and distributed servers at the radio or at the aggregation sites [2], (ii) the **network cloud**, which consists of servers at central sites, and (iii) the (centralized) **controller**, which is responsible for controlling the functions executed in the edge and network clouds and is usually co-located in the network cloud. Along with these blocks, the figure also illustrates the “3” enabling technologies of 5G NORMA (i) **adaptive (de)composition and allocation of mobile network functions** between the edge and the network cloud depending on the service requirements and deployment needs; (ii) **Software-Defined Mobile network Control (SDMC)**, which applies the SDN principles to mobile network specific functions; and (iii) **joint optimization of mobile access and core network functions** localized together in the network cloud or the edge cloud. As we can see from Figure 2-1, different services (three examples are illustrated in Figure 2-1) use a different allocation of RAN and CN functions (both user- and control-planes): while for some services most of the functionality may be located in the edge cloud, for others it may be located in the network cloud. In the following, the key concepts behind the three innovative enablers of 5G NORMA are explained in more detail.

2.1.1 Adaptive (de)composition and allocation of mobile network functions

Centralized RAN architectures have recently attracted considerable attention as a technology that leverages cloud techniques to centralise the computational resources of the mobile network. However, current centralized RAN solutions have been designed with the assumption that the backhaul is composed of fibre links and hence mobile network functions location is static, which is unlikely to hold in future very dense deployments relying also on wireless, bandwidth-limited, backhaul links.

5G NORMA develops a virtualization of mobile network functions which allows for a **flexible decomposition of mobile network functions between the radio access and the network cloud infrastructures**, supporting fully distributed, partially distributed, and fully centralized deployments. The decision of the degree of centralization (i.e. allocation of Network Functions) takes into account computational requirements, existing or required backhaul deployments, service and application requirements, and costs. This decision is driven by the optimization of metrics such as latency, QoE, resource utilization, energy efficiency, etc., and it is further dependent on the spatial and temporal characteristics as well as traffic fluctuations of the RAN. For instance, for latency-critical services we may allocate functions in the radio access to minimize delay, while we may allocate them in the central cloud for other services for efficiency reasons. This is especially important given the widening range of applications for 5G.

The decomposition and allocation of mobile network functions can be (broadly) based on the service requirements and backhaul deployment. For instance, we may choose different configuration settings as a function of the backhaul characteristics, i.e., the transport network connection to the antenna site, e.g., a fully distributed configuration, a fully centralized one and an intermediate one. The network rate and network latency are key in the selection of the configuration to be used, since (i) the more centralized the configuration is, the more information needs to be sent to the network cloud, and hence the larger the rate required, and (ii) the interaction between the lower layers of the protocol stack have very strict timing requirements, and hence splitting these lower layers between the edge and the network cloud is only possible when fronthaul/backhaul latency is sufficiently low. In addition to the backhaul deployment, the decomposition and allocation of functions also depends on the service requirements (see Section IV).

2.1.2 Software-Defined Mobile network Control (SDMC)

Current Software-Defined Networking (SDN) implementations focus mostly on wired networks to separate routing control (which decides how to handle the traffic) from forwarding (which routes traffic according to decisions by the control plane).

5G NORMA applies these same principles to wireless functions beyond routing, where benefits of this technology are even more significant than for wired networks, as the control functionality of wireless networks include many more **wireless related functions than just routing control** [3]. This includes time critical functions (such as scheduling control, modulation and coding scheme selection and HARQ processing) and other less time critical (like Radio Resource Control, power control and handover decision and execution). With the SDMC concept, all these functions can be implemented more easily by a programmable central control, which provides very important benefits for the flexible operation of the wireless edge network.

2.1.3 Joint optimization of mobile access and core network functions

Today, the physical separation between mobile access and core network functions limits the interaction between RAN and CN functions requiring the specification of complicated interfaces between those functions, which in turn delays innovation and technology uptake.

The adaptive (de)composition and allocation of mobile network functions described above may pool – in the edge or in the network cloud processor – functions that were located in the RAN in traditional architectures with other functions that were located in the CN. This not only blurs the separation between access and core network, but also provides new opportunities to jointly **optimize the operations of mobile access and core network functions** which previously were dealt with separately because of their different locations.

2.2 Innovative Functionality

The objective of the three innovative enablers described in the previous section is to enable the two innovative functionalities of 5G NORMA, namely (i) **multi-service- and context-aware adaptation of network functions**, and (ii**) mobile network multi-tenancy**.

The two innovative functionalities of 5G NORMA are illustrated in Figure 2-2. The figure shows three examples of services that would probably be served with different configurations in terms of the decomposition and allocation of functions:

- **Vehicular communications**, which requires very low latency and hence would be better served by moving all the functionality into the edge so that delays are minimized; since this kind of services typically consist of separate packets that do not require session continuity, even CN c-plane functions can be (partially) moved to the edge in this case;
- **Tactile communications**, which also requires very low latencies and (like in the previous case) would better be served by moving all the functionality to the edge; however, in this case session continuity is required and hence CN c-plane functions need to stay in a central location;
- **Internet access**, which does not have any stringent latency requirements and hence can be served by moving all the functionality to the cloud, which provides efficiency gains.

Of course, the specific design of the optimal allocation for each of these services is something that needs to be carefully designed and the purpose of the above examples is no other than illustrating the variety of possible configurations that may be used.

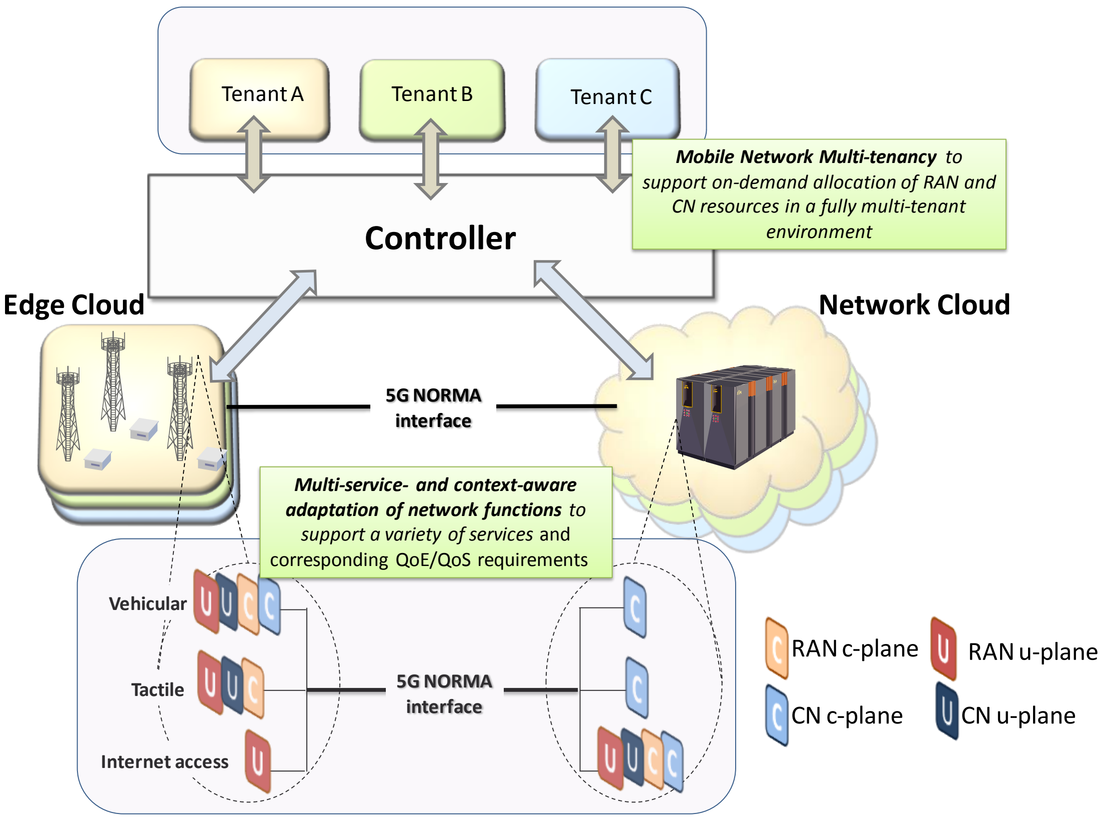

Figure 2-2: Multi-service and multi-tenancy architecture.

The figure also shows the **multi-tenancy** feature of 5G NORMA. As it can be seen in the figure, multi-tenancy is supported by placing the different operator modules ('tenant') on top of the controller, which is the responsible module for adaptively allocating the mobile network resources to the different 'tenants' or operators.

2.2.1 Multi-service- and context-aware adaptation of network functions

Although current network architectures and concepts already support a variety of service classes and respective QoE/QoS, network functions typically cannot be reallocated nor adapted to service classes. Current architectures are based on a pre-defined set of bearers, support only limited variations of the topology, and, thus, prevent the networks from efficiently supporting new and dynamically changing service classes.

In contrast to this, 5G NORMA considers fully adaptive, programmable network functions that might – depending on their usage context – be reprogrammed and even relocated. The latter option **allows for a dynamic relocation of network functions between the edge of the network and a centralized cloud infrastructure, thereby enabling low latency communication** and global optimisation.

2.2.2 Mobile network multi-tenancy

Infrastructure sharing is a key business model for mobile operators (tenants) to reduce deployment and operational costs, driven by the capacity requirements forecasted for future mobile networks as well as the decreasing operators' benefits margin. While passive and active sharing solutions are partially used and standardized today, these sharing concepts are based on fixed contractual agreements with mobile virtual network operators (MVNOs) on a coarse granularity basis (monthly/yearly).

5G NORMA introduces the unprecedented no-human intervention (signalling-based) dynamic sharing concept referred to as **Mobile Network Multi-tenancy** building on the 3GPP SA1/SA5 infrastructure sharing enhancements efforts towards on-demand capacity brokering. Our concept supports classical (e.g. mobile operators) and non-classical tenants, e.g. YouTube, Netflix, utility companies (energy), etc. In our vision, **5G NORMA Multi-tenancy does not only consider RAN resources but a range of other scarce network resources, including backhaul and core network capacity**.

2.3 Security natively built into the network architecture

Security is an essential requirement for future 5G mobile networks and can only be achieved if 5G networks are designed with security in mind from the outset. Indeed, the design of the overall 5G architecture cannot be separated from the security mechanisms and architecture. Consequently, 5G NORMA will drive the architectural decisions with the respective security considerations, including the potential threats and protection measures, and thus **security considerations will influence architectural decisions**.

While general security issues (such as vulnerable software, vendor made backdoors, distributed DoS attacks etc.) obviously apply to 5G networks, the focus of 5G NORMA will rather be on those specific security issues that are related to the architecture design. Thus, the **security risks associated to new concepts** and procedures proposed by 5G NORMA (such as the use of virtualized environments, the design of software-defined mechanisms or the new multi-tenant interfaces) will be assessed and mitigated with the suitable security measures.

It is an explicit goal of 5G NORMA to investigate and provide more **flexible security measures** (as compared to current LTE networks) that can be adapted to the needs of specific services. For instance, a service doing its own, service-specific, traffic protection should not be strained by an additional layer of radio interface encryption enforced by the network. Of course, this flexibility to allow service-specific security measures does not imply that the network does not have to provide user plane security with (at least) the security level available in today's LTE networks.

2.4 Socio-economic analysis

The socio-economic analysis – closely interacting with the use case analysis – conducts an analysis of the benefits of 5G NORMA innovations to determine the value both to the wireless industry and to the users in society. The logical interaction between this work and the wider project is illustrated in Figure 2-3. The key tasks planned are:

- Identification of the changing market drivers (increases in demand, economic pressure, market consolidation and other changes) associated with several vertical markets, such as public safety (PPDR), consumer mobile usage, transportation, energy generation & distribution etc.
- Identification of shortcomings in the expected capabilities of 4G LTE by around 2020 based on the requirements of the expected future service demands (e.g., deep indoor coverage, stand-by time of machine-type devices, energy efficiency in both networks and devices, ultra-low latency to support tactile internet applications, flexibility to rapidly create a wide range of services, and support for direct mode/isolated network operation);
- Derivation of 5G requirements based on the 4G shortcomings;
- Analysis of the business impact of candidate mobile network concepts under discussion for 5G by translating technical KPIs to business KPIs of relevance to each sector, such as cost efficiency, return on investment, reduction in service creation time, etc.

The result of this work will enable 5G NORMA to identify the relative value of each planned 5G NORMA innovation, and to direct the technical work to focus on the innovations with the most opportunity to create overall value. In parallel with this we will identify the benefits to the wider society, aligned with EU policy priorities, including:

- those related to Innovation Union's requirements for smart sustainable & inclusive growth and jobs;
- those related to the EU Digital Agenda on social and economic potential and sustainable economic and social benefits – particular pillars of relevance include the Digital Single Market, Interoperability and Standards, Fast and ultra-fast internet access and ICT-enabled benefits for EU society.

Towards the end of the project, 5G NORMA will repeat the business analysis to account for the actual outcome of performance of each 5G NORMA innovation and the synergies of those different innovations working together.

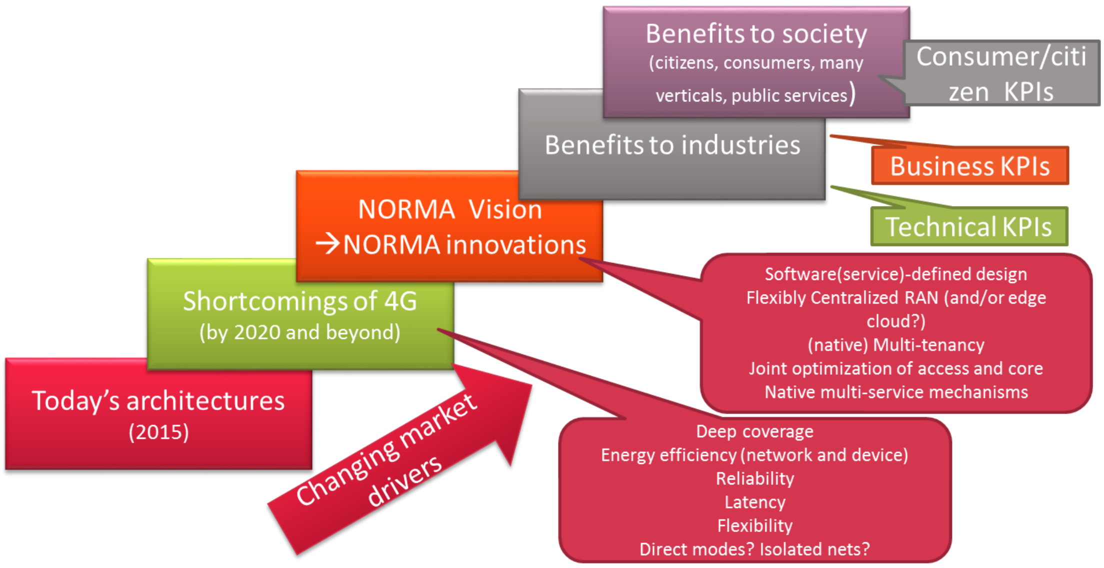

Figure 2-3: Relation between business case and society/economic value analysis and overall 5G NORMA activities.

3 Terminology and methodology

In this chapter, the methodology to be used by the project for the development of the 5G network architecture is presented. The methodology is based on the identification of relevant use cases, which are analysed in order to identify the requirements that should be considered in the network design. In addition to the requirements identified from the use cases, the project also considers other design requirements, which are design principles that guide the transition from requirements to realization, and which reflect the collective experience and expertise.

Due to the fact that different terminology is used by different sources (e.g., METIS vs. NGMN), we first introduce the terminology used by the project.

3.1 Terminology

Use case: A use case defines a goal-oriented set of interactions between external actors and the system under consideration. It is a description of how an end user (which may be a human being or a machine) uses a system that exercises that system's deployment of 5G. A use case includes one or more applications in a deployment environment with details regarding the user activity and both sides of the link.

Requirement: This is a description of what the network must do in order to support a given use case, which provides the foundation for the design. In the context of 5G NORMA, we distinguish different kinds of requirements:

- Functional requirements: these identify the kind of functionalities that are required to be supported by the network in order to support each use case.
- Performance requirements: they indicate values or range of values for network performance parameters that are consistent with achieving a good user experience of the use case under normal operational conditions.
- Other requirements: these are requirements associated with the operation of the network that are not associated with the user experience or with the measurable network performance. For example, the requirement that a use case must be supported even if the network infrastructure required is owned by different actors would fall into this category, as would happen with requirements on energy efficiency.

Design principles: The design principles are derived from the collective experience and expertise in order to guide the transition from the requirements to the realization of the network architecture.

Scenario: This is an instance of one (or more) use case(s), defined by the set of conditions that describe how the use case (or a set of use cases) takes place.

- Pre-Conditions: Initial conditions before the use case begins.
- Applications: A source and/or sink of wireless data that relates to a particular type of user activity.
- Environment: The type of place or physical setting in which the network of the use case is deployed, such as home, outdoor, hot spot, enterprise, metropolitan area, rural, etc.
- Traffic Conditions: General background traffic or interference that is expected while the use case steps are occurring.

System: This is a set of components that work together to support or provide connectivity, communications, and services to users of the system. Generically speaking, components of the system include applications, devices and networks.

User: This is the party outside the system that interacts with the system in order to get communication services. It may be a person or a process in a machine.

Network Slice: It is a set of 5G network functions and associated device functions (incl. radio interface) set up within the 5G system tailored to support a communication service to a particular type of user [NGM15]. The target of NW Slicing is to provide dedicated logical NWs with customer specific functionality, without losing the economies of scale of a common infrastructure**.**

3.2 Methodology

The proposed methodology for defining the 5G NORMA architecture is composed for several steps:

- Collect use cases from relevant sources, including (but not limited to) NGMN, 3GPP, 5G PPP, ITU, etc. The main sources used by the project are resumed in chapter 4. Each use case has been profiled using the same template:
    - Use case Description
    - Vertical sectors it addresses
    - Physical environment and traffic demand patterns
    - End-user devices involved
    - Benefits 5G brings to this use case compared to legacy networks
    - End to end business model in 5G
    - Functional and performance requirements and KPIs
    - Sources for this use case
- Ensure that the use cases selected map into all the technical innovations proposed by the project. If not, look for additional use cases that may be used to validate the proposed innovations.
- Derive technical requirements for each set of use cases. Requirements have been classified into functional, performance and other. The requirements associated to each use case are collected in Annex A.
- Group requirements into sets that present a high degree of commonality. These sets are identified in section 5.3. The grouping facilitates their consideration in the network architecture definition and helps requirement management.
- Define the design principles that will be used in the design of the network architecture solutions. These are based on the current state of technology and operational constraints and are further detailed in Chapter 6.
- Defining scenarios that combine use cases running simultaneously in a given physical setting to capture the flexibility and ability of 5G to support multiple service chains. These are introduced in Chapter **¡Error! No se encuentra el origen de la referencia.** and further detailed in Annex B. These scenarios will be used as inspiration and reference for the validation of the 5G NORMA architecture.

The proposed methodology is represented in the following figure.

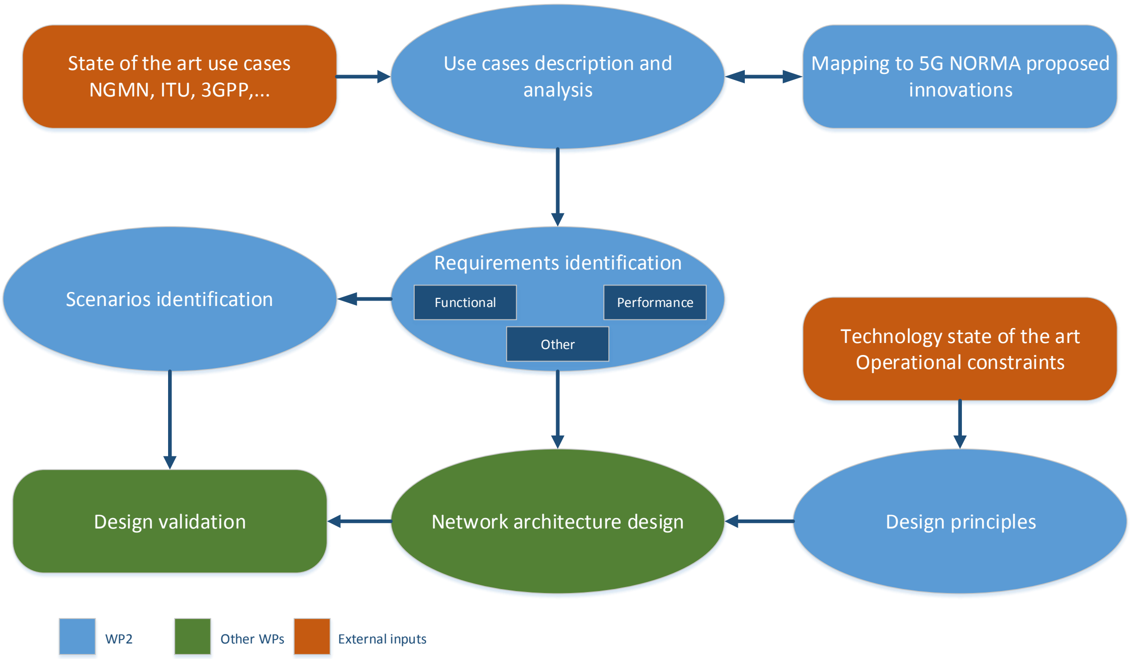

Figure 3-1 : Requirements identification methodology

4 Representative 5G use cases

This section describes main representative 5G use cases provided by other R&D projects and by standardization and industry forums. Due to high overlap of use cases the description focuses on the outcome of METIS, NGMN and 3GPP only as the most prominent ones.

As part of the 5G PPP initiative in Europe there are activities ongoing in the *5G PPP Vision and Requirements Working Group* with particular focus on requirements for vertical markets. 5G NORMA project is involved in this working group. The outcome will be captured in the next project deliverables.

4.1 EU project METIS

The METIS project [MET_Web] has defined 5 scenarios each representing a specific challenge according to overall technical goals identified for a 5G system [MET13-D11][2]:

- "**Amazingly fast**": Provisioning very high data rates for users to experience instantaneous connectivity without perceived delays.
- "**Great service in a crowd**": Provisioning reasonable mobile broadband experience even in crowded areas such as stadiums and open air festivals.
- "**Ubiquitous things communicating**": Efficient handling of a very large number of devices with widely varying requirements (sensors, machines, etc.).
- "**Best experience follows you**": Provisioning end users on the move, e.g. in cars or trains, with high levels of service experience.
- "**Super real-time and reliable connections**": Provisioning new applications with low latency and high reliability related to vertical industries, like traffic safety and mission-critical control in industrial processes.

In addition to scenarios, METIS created so-called test cases (TCs) to address the needs in the beyond 2020 information society and to enable testing of the technology components and the architectural approach for 5G derived within the project:

- TC1 "Virtual reality office",
- TC2 "Dense urban information society",
- TC3 "Shopping mall",
- TC4 "Stadium",
- TC5 "Teleprotection in smart grid network",
- TC6 "Traffic jam",
- TC7 "Blind spot",
- TC8 "Real-time remote computing for mobile terminals",
- TC9 "Open air festival",
- TC10 "Emergency communications",
- TC11 "Massive deployment of sensors and actuators",
- TC12 "Traffic efficiency and safety".

The defined 5 scenarios and 12 TCs are depicted in Figure 4-1.

[2] It has to be noted that according to the definition applied for a scenario in 5G NORMA (see Sec. 3.1 of this deliverable) the meaning is different to the approach applied in METIS.

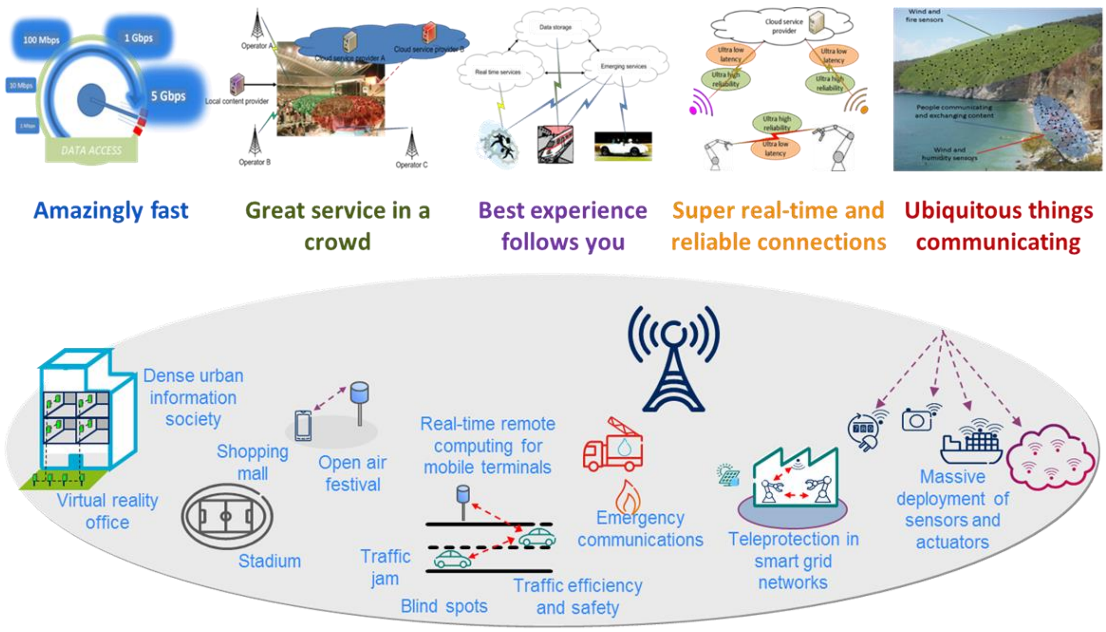

Figure 4-1: Overview of METIS scenarios and test cases [MET13-D11]

Each TC derives a set of assumptions regarding requirements, a set of constraints, and key performance indicators. As a TC may address several challenges, it may also belong to several scenarios. The mapping of TCs to scenarios is shown in Figure 4-2 with scenarios represented by bubbles.

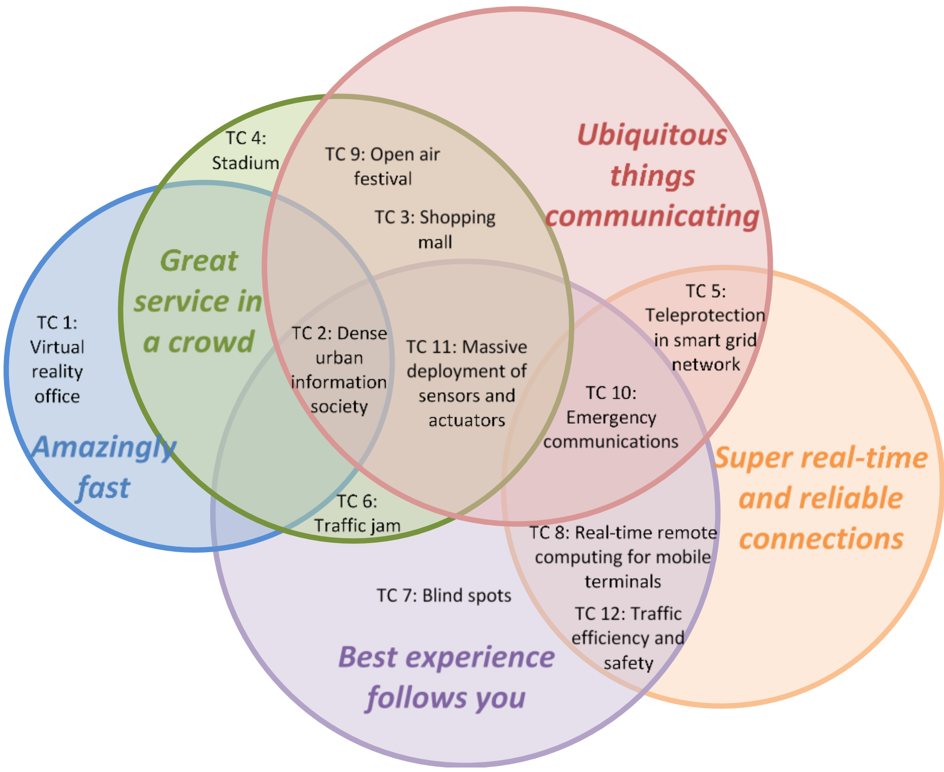

Figure 4-2 : Mapping of METIS test cases to scenarios [MET13-D11]

Finally, the METIS project broadened its scope by collecting diverse feedbacks from vertical industries, not limited to telecom communities, like industrial automation, automotive and energy industries as well as media sector. Conclusions are given w.r.t. to requirements raised by verticals. In addition 9 use cases (in contrast to TCs a description of requirements in terms of concrete values or ranges is missing) were described extending the range already spanned by the TCs. Examples are “Cloud gaming”, “Remote tactile interaction”, and “Unmanned aerial vehicles”. More details on attained results from verticals and on use cases can be found in [MET15-D15].

4.2 NGMN

During the Mobile World Congress 2015, the Next Generation Mobile Networks (NGMN) Alliance published their 5G White Paper [NGM15], providing consolidated 5G operator requirements intended to support the standardisation and subsequent availability of 5G for 2020 and beyond. NGMN outlines in the white paper its vision for 5G empowering value creation through new use cases and being enabled by sustainable business models. Therefore, the capabilities of the network need to be expanded to support much greater throughput, lower latency and higher connection density. To cope with a wide range of use cases and business models, the 5G system has to provide a high degree of flexibility and scalability by design. In addition, it should show foundational shifts in cost and energy efficiency. On the end-user side, a consistent customer experience across time and service footprint will be a key requirement for the 5G system. NGMN envisages a 5G eco-system that is truly global, free of fragmentation and open for innovations.

NGMN developed 25 use cases, as representative 5G use case examples, which were grouped into eight use case families. The use cases and use case families are intended to serve as an input for stipulating requirements and defining the building blocks of the 5G architecture. The use cases were not meant to be exhaustive, but rather as a tool to ensure that the level of flexibility required in 5G is well captured. The following diagram shows the eight use case families with one example use case given for each family [NGM15].

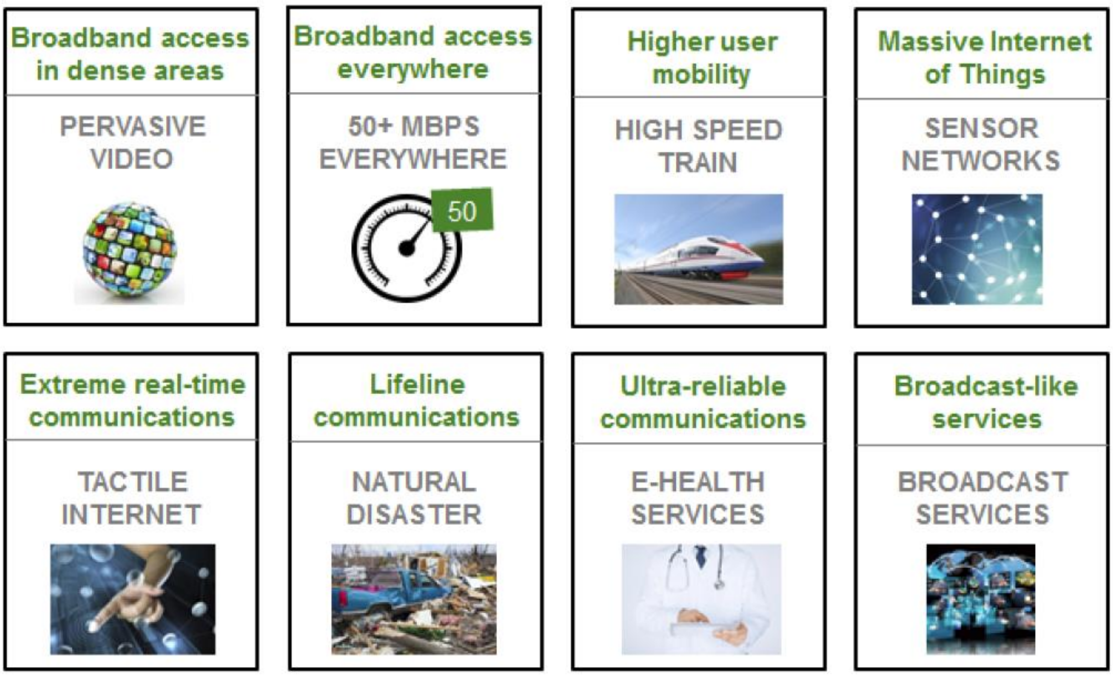

Figure 4-3 : 5G use case families and related examples identified by NGMN [NGM15]

NGMN also considers that 5G will expand to new business models to 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 specific network capabilities as an end-to-end service, and integrating partners' services into the 5G system through a rich and software oriented capability set.

The 5G requirements are derived out of NGMN's vision of the potential use cases and business models, and are intended also to satisfy the value creation that operators expect to deliver to the different types of customers and partners. In summary, the NGMN vision leads to requirements that are grouped along the six dimensions shown below.

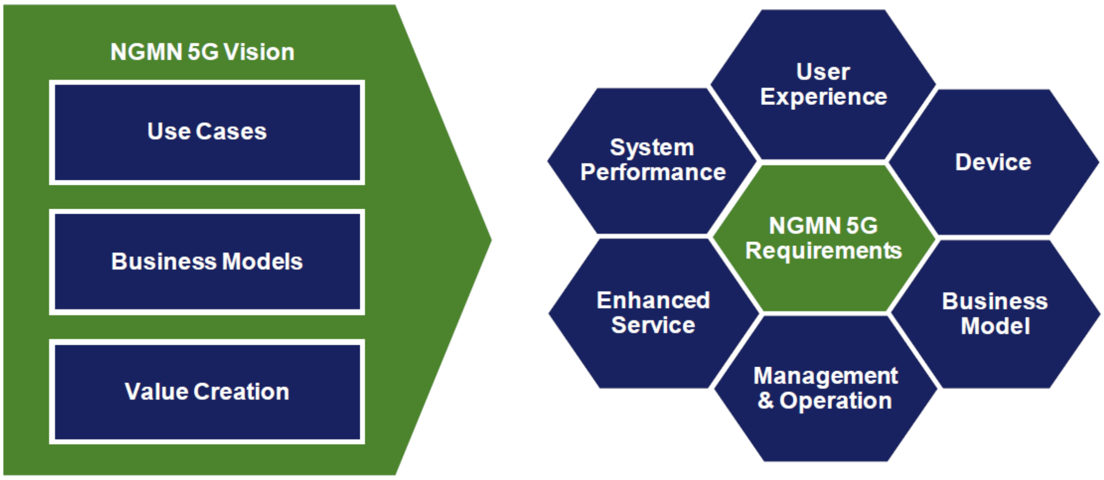

Figure 4-4: NGMN 5G requirements dimensions [NGM15]

In order to reflect their use case dependency, the requirements are specified according to the "use case categories" defined in the figure below. For each use case category, one set of requirement values is given, which is representative of the extreme use cases(s) in the category. As a result, satisfying the requirements of a category leads to satisfying the requirements of all the use cases in this category.

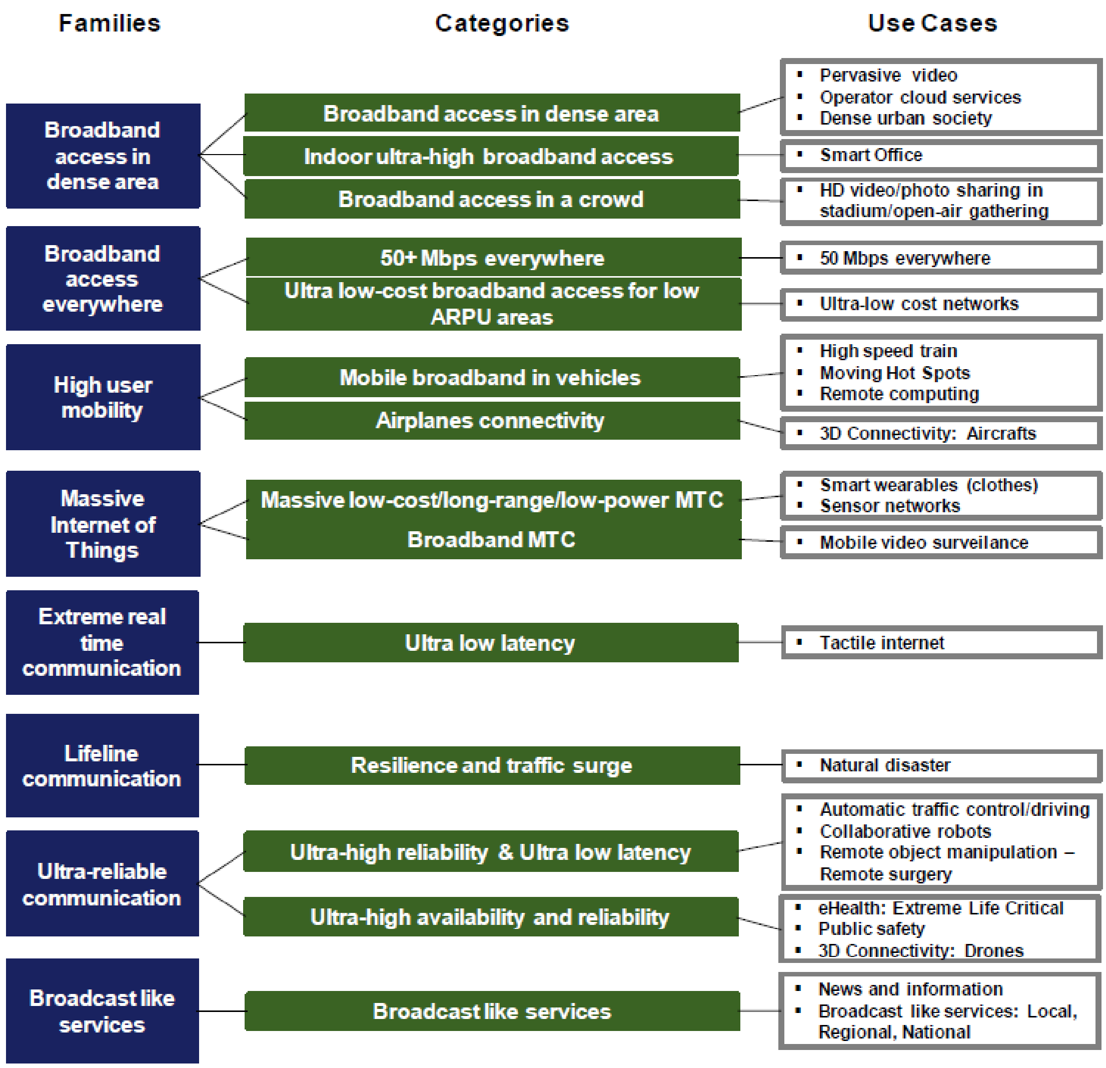

Figure 4-5 : Use cases categories identified by NGMN [NGM15]

NGMN considers that 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 use case dependent minimum KPIs (e.g. data rate, latency) being met over the service coverage area, with a level of variation configurable by the operator. In the following Table 4-1 the main user experience related KPIs values for each use case category proposed by NGMN are collected.

Table 4-1 : User experience requirements defined by NGMN [NGM15]

Use case category	User Experienced Data Rate	E2E Latency	Mobility
Broadband access in dense areas	DL: 300 Mbps UL: 50 Mbps	10 ms	On demand, 0-100 km/h
Indoor ultra-high broadband access	DL: 1 Gbps, UL: 500 Mbps	10 ms	Pedestrian
Broadband access in a crowd	DL: 25 Mbps UL: 50 Mbps	10 ms	Pedestrian
50+ Mbps everywhere	DL: 50 Mbps UL: 25 Mbps	10 ms	0-120 km/h
Ultra-low cost broadband access for low ARPU areas	DL: 10 Mbps UL: 10 Mbps	50 ms	on demand: 0-50 km/h
Mobile broadband in vehicles (cars, trains)	DL: 50 Mbps UL: 25 Mbps	10 ms	On demand, up to 500 km/h
Airplanes connectivity	DL: 15 Mbps per user UL: 7.5 Mbps per user	10 ms	Up to 1000 km/h
Massive low-cost/long-range/low-power MTC	Low (typically 1-100 kbps)	Seconds to hours	on demand: 0-500 km/h
Broadband MTC	See the requirements for the Broadband access in dense areas and 50+Mbps everywhere categories		
Ultra-low latency	DL: 50 Mbps UL: 25 Mbps	<1 ms	Pedestrian
Resilience and traffic surge	DL: 0.1-1 Mbps UL: 0.1-1 Mbps	Regular communication: not critical	0-120 km/h
Ultra-high reliability & Ultra-low latency	DL: From 50 kbps to 10 Mbps; UL: From a few bps to 10 Mbps	1 ms	on demand: 0-500 km/h
Ultra-high availability & reliability	DL: 10 Mbps UL: 10 Mbps	10 ms	On demand, 0-500 km/h
Broadcast like services	DL: Up to 200 Mbps UL: Modest (e.g. 500 kbps)	<100 ms	on demand: 0-500 km/h

On top of this, NGMN has also defined the system performance requirements, which were defined as the system capabilities needed to satisfy the variety and variability of users and use cases. In this sense, NGMN identifies requirements on connection density, traffic density, spectrum efficiency, coverage, resource and signalling efficiency. In the following Table 4-2 the values for the main system performance requirements proposed by NGMN are presented.

Table 4-2 : System performance requirements defined by NGMN [NGM15]

Use case category	Connection Density	Traffic Density
Broadband access in dense areas	200-2500 /km^2	DL: 750 Gbps / km2 UL: 125 Gbps / km2
Indoor ultra-high broadband access	75,000 / km^2 (75/1000 m^2 office)	DL: 15 Tbps/ km2 (15 Gbps / 1000 m2) UL: 2 Tbps / km2 (2 Gbps / 1000 m2)
Broadband access in a crowd	150,000 / km^2 (30.000 / stadium)	DL: 3.75 Tbps / km2 (DL: 0.75 Tbps / stadium) UL: 7.5 Tbps / km2 (1.5 Tbps / stadium)
50+ Mbps everywhere	400 / km^2 in suburban 100 / km^2 in rural	DL: 20 Gbps / km2 in suburban UL: 10 Gbps / km2 in suburban DL: 5 Gbps / km2 in rural UL: 2.5 Gbps / km2 in rural
Ultra-low cost broadband access for low ARPU areas	16 / km^2	16 Mbps / km^2
Mobile broadband in vehicles (cars, trains)	2000 / km^2 (500 active users per train x 4 trains, or 1 active user per car x 2000 cars)	DL: 100 Gbps / km^2 (25 Gbps per train, 50 Mbps per car) UL: 50 Gbps / km^2 (12.5 Gbps per train, 25 Mbps per car)
Airplanes connectivity	80 per plane 60 airplanes per 18,000 km^2	DL: 1.2 Gbps / plane UL: 600 Mbps / plane
Massive low-cost/long-range/low-power MTC	Up to 200,000 / km^2	Non critical
Broadband MTC	See the requirements for the Broadband access in dense areas and 50+Mbps everywhere categories	
Ultra-low latency	Not critical	Potentially high
Resilience and traffic surge	10,000 / km^2	Potentially high
Ultra-high reliability & Ultra-low latency* (*) the reliability requirement for this category is described in Section 4.4.5	Not critical	Potentially high
Ultra-high availability & reliability* (*) the reliability requirement for this category is described in Section 4.4.5	Not critical	Potentially high
Broadcast like services	Not relevant	Not relevant

NGMN has also proposed device requirements, as well as network deployment, operation and management requirements. Details can be found in [NGM15].

On top of the use cases and requirements, the NGMN 5G White Paper also proposes some design principles to be applied in the definition of the 5G architecture:

- Network: create common composable core
  - Minimize number of entities and functionalities
  - C/U-plane function split, lean protocol stack
  - No mandatory U-plane functions
  - Minimize legacy interworking
  - RAT-agnostic core
  - Fixed-mobile convergence
- Embrace flexible functions and capabilities
  - Network slicing
  - Function variance
  - Flexible function/service/application allocation

  - Leverage NFV/SDN
  - State-disintegrated functions
  - Graceful degradation
- Support new value creation
  - Exploit big data and context awareness
  - Expose radio and network APIs
  - Facilitate XaaS

4.3 3GPP standardization

In March 2015, 3GPP adopted a study on New Services and Markets Technology Enablers (SMARTER) [22.891].

The study aims to develop high-level use cases and identify the related high-level *potential requirements* to enable 3GPP network operators to support the needs of new services and markets. The analysis has been made on which legacy services and requirements from the existing 3GPP systems need to be included, if fallback mechanisms to them need to be developed, or if they are not necessary. The main focus will be to develop high level use cases and identify the related high-level potential requirements for the 5G system.

The work flow in 3GPP is as follows:

- Step 1: Develop several use cases covering various scenarios and identify the related high-level potential requirements.
- Step 2: Identify and group together use cases with common characteristics.
- Step 3: Select a set of use cases (or group of use cases with common requirements) for further development.
- Step 4: Start new individual building block study items for each use case or group of use cases identified in Step 3. First normative requirements are expected by March 2016 in Release 14.

The step 1 is already finalized and the outcome has been published in TR 22.891 [22.891] and presented in the last 3GPP workshop held in Phoenix, USA, in September 2015.

More than 50 use cases have been identified and described. For each a set of *potential service requirements* and *potential operational requirements* has been derived.

Approximately, 70 % of use cases came from major industry white papers, i.e. are already covered to a great extent by [IMT14], [NGM15], [4GA14] and [MET15-D15].

The

Table 4-3 below summarizes the different use cases covered in TR 22.891.

Table 4-3: Use cases considered by 3GPP in TR 22.891

Category (Market driver)	Use Cases
Internet of Things	▪ Environmental monitoring ▪ Smart transportation ▪ Smart building ▪ Smart home ▪ Smart agriculture ▪ Smart metering ▪ Remote surgery ▪ Moving ambulance and bio-connectivity ▪ Vehicular internet/infotainment ▪ Internet of vehicles ▪ Forest industry on remote control ▪ Sports & fitness ▪ Sensor networks ▪ Smart wearables
Broadband access in dense areas	▪ Pervasive video ▪ Pervasive wireless ▪ Video immersion ▪ Immersive service ▪ Smart office ▪ HD video/photo sharing in stadium/open air gathering
Broadband access everywhere	▪ 50+ Mbps everywhere ▪ Media on demand, high capacity ▪ Ultra-low cost networks ▪ Teleworking available anywhere ▪ Access availability in larger remote areas
Extreme video, virtual reality, and gaming applications	▪ Online gaming
Mobile internet	▪ Augmented reality ▪ Virtual reality ▪ UHD 3D video ▪ Mobile cloud/desktop cloud ▪ Holograms ▪ Pervasive wireless ▪ Immersive service
Extreme real time communications	▪ Tactile internet
Public Safety	▪ Mission critical voice
Lifeline communications	▪ Natural disaster
Higher user mobility	▪ High speed train ▪ High speed moving scenarios ▪ Moving hot spots ▪ 3D connectivity: Aircraft
Ultra reliable communications	▪ 3D connectivity: Drones ▪ Collaborative robots: A control network for robots ▪ Industrial control/factory automation ▪ Logistics & tracking
Broadcast-like services	▪ News, information broadcasting

Among the 59 use cases listed in TR 22.891, some of them actually represent features of a future 5G system that will empower it to support the envisioned set of very heterogeneous and diverse use cases: network slicing, flexibility and scalability, and on-demand networking. Flexibility and scalability means that the system can meet changing signalling and U-plane demand by adjusting up/downlink assigned resources geographically and over time. As potential operational requirement as little as 5 minutes lead time is stated, the typical time after which call attempts surge after a disaster. On-demand networking is similar, but more planned/predictable, targeting different QoS depending on connection density. As potential service requirement a downlink rate of 300 Mbps and uplink rate of 50 Mbps at 200–2500 /km^2 connection density is claimed, for users entering a hot spot area a downlink rate of 50 Mbps and uplink rate of 25 Mbps at 2000 /km^2 connection density shall be maintained.

Two additional studies have been launched in 3GPP to cover specific use cases for Vehicle to Anything (V2X) and the mission critical video communication (MCVideo). These two specific use cases types are already included in the set of 3GPP use cases given in

Table 4-3. They target the evolution of LTE standard and should be considered for 5G system design.

The V2X use cases are described in TR 22.885 [22.885]. Its scope is to identify the set of use cases and potential requirements to support V2X services over an LTE-based transport in the 3GPP system. 24 use cases over three types of V2X links have been identified: Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I) and Vehicle to Pedestrian (V2P).

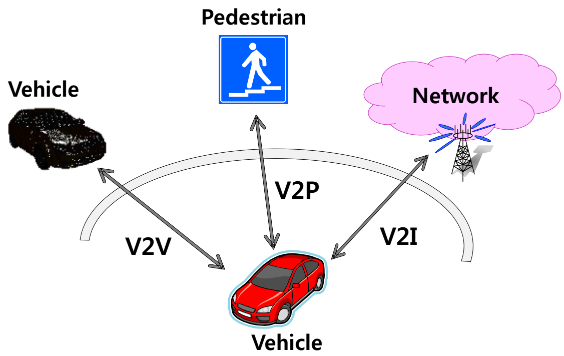

Figure 4-6 : Types of V2X use cases [22.885]

The study is not yet finalized. Here a collection of the identified use cases:

- Forward collision warning
- Control loss warning
- V2V use case for emergency vehicle warning
- V2V emergency stop
- Cooperative adaptive cruise control
- V2I emergency stop
- Queue warning
- Road safety services
- Automated parking system
- Wrong way driving warning
- V2V message transfer under MNO control
- Pre-crash sensing warning
- V2X in areas outside network coverage
- V2X road safety service via infrastructure
- V2N traffic flow optimisation
- Curve speed warning
- Warning to pedestrian against pedestrian collision
- Vulnerable Road User (VRU) safety
- V2X by UE type Road Side Unit (RSU)
- V2X minimum QoS
- Use case for V2X access when roaming
- Pedestrian road safety via V2P awareness messages
- Mixed use traffic management
- Enhancing positional precision for traffic participants

The second complementary study covers the mission critical video communication service (MCVideo). The different use cases and potential requirements for operation are described in TR 22.879 [22.879]. The MCVideo service can be used for public safety applications and also for general commercial applications (e.g., utility companies and railways) which already referred in

Table 4-3.

5 Selection of 5G NORMA use cases and requirements

In this chapter, we firstly identify, from different sources, the use cases that the project has selected, according with the criteria established, in order to derive requirements. The detailed description of the use cases can be found in the Annex A. From the set of use cases selected, the different kinds of requirements are identified. The requirements describe what is expected from the network in order to support the use cases selected with an adequate quality of experience in reasonable operational conditions. In order to facilitate their consideration in the network architecture definition, they are clustered into eleven groups that collect the main implications in terms of functionalities required. Lastly, the mapping between use cases, requirements and the technological innovations proposed by 5G NORMA is carried out.

5.1 Criteria for the selection of use cases and requirements

In the methodology used by the project, the main objective of the use cases is to help in the identification of the requirements. The requirements intend to capture the expected behavior of the system, expressed as services or functions the system is required to perform. For 5G NORMA, the requirements that are relevant are those that have an impact on the network architecture.

5G NORMA has started considering the use cases that have been identified previously by different sources. As it is not possible to analyse all of them in order to derive requirements, a selection has to be carried out. In this sense, the use cases need to fulfil a number of criteria in order to be significant for 5G NORMA:

- The use cases are meaningful either from an **economic viewpoint** (i.e., there is a potential business case to support the use case) or from a **societal viewpoint** (the use case responds to a society need).
- The use cases **cannot be supported by 4G technology**, or they can be supported in a much more efficient way when introducing 5G technology.
- The use cases result in requirements that are **relevant for the design of the 5G network architecture**.
- The use cases correspond to the use of the mobile networks to attend the **needs of different market segments and verticals**.

From the use cases selected, requirements are derived. For each use case, the potential implication on the network architecture, both in terms of functionality required and performance expected, has been identified. In order to have a manageable number of requirements, rather than grouping use cases in generic ones (the approach adopted by, e.g., 3GPP), 5G NORMA has grouped use case specific requirements into sets that are more generic. Finally, the correspondence between the use cases selected and the technological innovations proposed by 5G NORMA (through the associated technical requirements) is established.

5.2 Use cases selected

The detailed description of the use cases selected for 5G NORMA project is presented in Annex A. This section briefly presents the selected use cases with their most significant requirements.

Industry Control: This use case focuses on the industrial process monitoring and control services which currently are provided via wired or proprietary wireless network solutions.

Enhanced Mobile Broadband: This "classical" use case covers the scenario in which users can ubiquitously connect to the mobile network which provides extremely high data rates, significantly above those provided in 4G networks. It shows that mobile network performance increases exponentially over time in order to satisfy the increasing demand of users who quickly rate the most recent and advanced technology as an expected state of the art.

Emergency Communications: This use case addresses those cases in which, due to a natural disaster (e.g., earthquake, tsunamis, floods, and hurricanes), part of the network infrastructure are destroyed. Under these circumstances users need the network to communicate their situation, contact family members,… Rescue teams use the network to coordinate their activities. As the natural disaster may have affected the power grid, the energy consumption of both terminals and network infrastructure must be low. The network may be used for locating victims and broadcast alerts. Users' devices battery life should be extended as much as possible.

Vehicle Communications : Cars, trucks and other vehicles use 5G communications to improve traffic safety, to assist drivers with real-time information about road and traffic conditions, and to support the mobility of emergency vehicles (e.g., ambulances, fire trucks), among other applications. For these purposes, transport entities, such as vehicles, roadside infrastructure, and pedestrians, collect knowledge of their local environment (e.g., information received from other vehicles or sensor equipment in proximity) to process and share that knowledge with each other using 5G communication services.

Sensor Networks Monitoring: The main service covered by this use case is monitoring a wide area for a particular measured property. The measured property may be, but is not limited to, temperature, motion, vibration, air quality, moisture, or radiation. The need may have been planned (e.g. due to building construction or bridge maintenance) or unplanned (e.g. as a result of a forest fire or other natural/man-made event).

Traffic Jam: The challenge taken by this use case is providing public cloud services (e.g. video streaming, web browsing and file downloading) for users inside vehicles during the occurrence of traffic jams. In this case the capacity demand is suddenly increased and, like immediately after landing at airports, a huge volume of signaling messages is expected (signaling storm). The main goal is keeping the QoE of the provided services, in particular in areas where the deployment of network infrastructure does not have an adequate density to satisfy the non-stationary capacity variation.

Real-time Remote Computing: Remote computing/real-time remote computing can be thought as a generic container for a variety of future applications such as: cloud computing for UEs, remote gaming, remote device control, tactile internet, etc. These services need network latencies below 10 ms which cannot be offered in current 4G networks. Cloud computing (apps running in the edge/core cloud rather than in the mobile terminal) enables first a variety of resources-hungry applications that would run on remote servers rather than on terminals, keeping resources requirements for the UEs lower and battery life longer.

Massive Nomadic Mobile Machine Type Communications: In contrast to use case "Sensor networks monitoring" which is related to sensors placed statically in a certain environment this use case is relevant for sensors or actuators that are physically mounted on nomadic and mobile objects

Quality-aware Communications: Quality-aware communications take place when the network knows about and reacts according to the quality of the services that it is providing to the end-users, both in terms of QoS and QoE. This use case considers both the objective service quality and subjective end-user perceptions – which in turn is affected by the corresponding user and context factors - to study novel and advantageous quality-based resource allocation and control mechanisms in future mobile networks, which in turn pose new functional, performance and architectural requirements that current mobile networks are not capable of providing

Fixed-Mobile Convergence : In its 5G White Paper the NGMN Alliance stated that 5G services should be delivered via a converged access-agnostic core (i.e., where identity, mobility, security, etc. are decoupled from the access technology). Different technologies based on wireless as well as on wired types (FTTH, xDSL …) can be applied for the customer access providing always the optimal network capabilities to the end user. FMC will ensure a seamless customer experience within the fixed and mobile domains (e.g., a unified user authentication) and will allow the operators to process a customer independently of his access type for authentication and billing, via a unified customer data base and information system across the different domains. In addition service and/or device characteristics might be adapted when changing between domains because of different capabilities.

Blind Spots: Modern users expect high data rate services, accessible anywhere they go. Providing those kinds of services with high Quality of Experience (QoE) in blind spots will be challenging and is the main aspect addressed by his use case.

Open Air Festival: The context of this use case is defined by a remote and small rural area receives tens of thousands of visitors for a multi-day open air music festival. The mobile network here has few sparsely deployed nodes. The user and device density is extremely high, and the data traffic demands are orders of magnitude higher than the usual situation for that particular remote area. Using the current technologies, network overload occurs frequently, causing poor QoE or outright service outages. Each visitor wants to use location and map services, and share HD videos and photos in social networks, usually in the interval between performances. Given the contact, the underlying challenge of this use case is providing users with a fast, reliable and highly available network access.

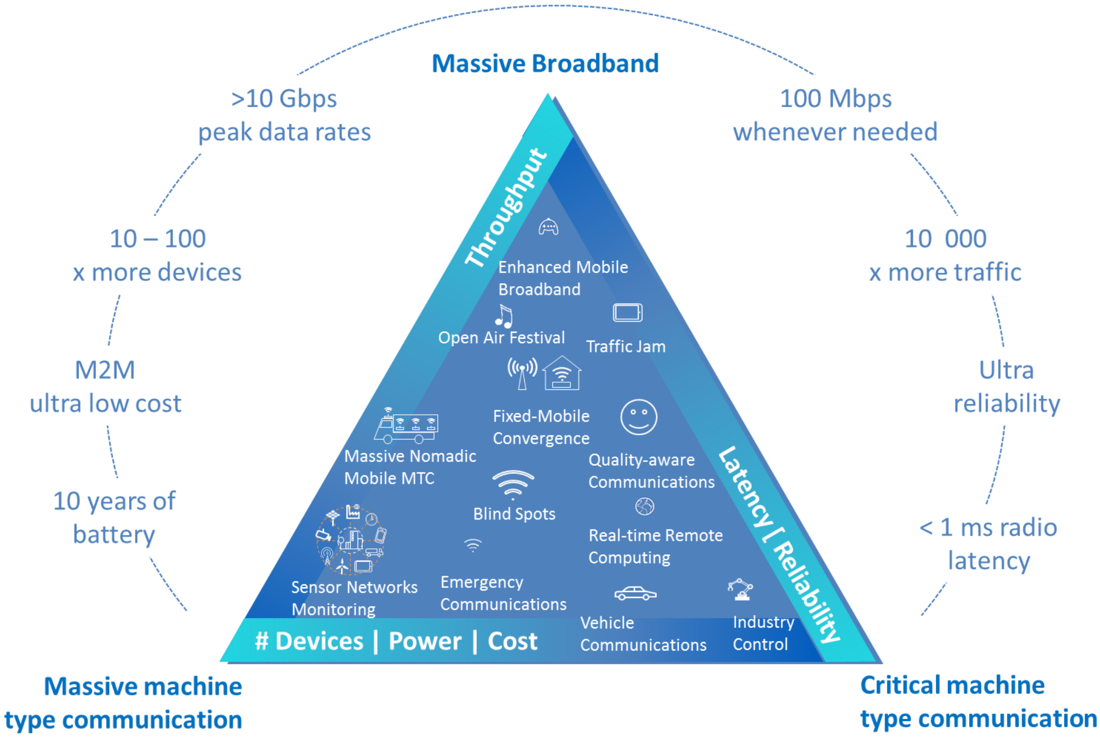

Figure 5-1 : 5G NORMA Use cases in the 5G ecosystem

The figure above presents the topology of the 5G NORMA selected use cases with regards to the 5G network evolution axes and their related requirements.

5.3 Requirements

For each of the use cases listed in Sec. 5.2 three kinds of technical requirements were considered in the detailed description (see Annex A):

- **Functional requirements**: Functionalities that should be provided by the network in order to make the use case possible.
- **Performance requirements**: Performance that should be provided by the network in order to fulfill the specific service demand(s) covered with the use case.
- **Other requirements**: Requirements that do not fit into the two categories above.

The identified requirements are associated to technical goals of each use case and are described in a precise way so that it is possible to validate or refute the claim that a given architectural realization satisfies each goal – while the current architectural solutions fail to support them.

The functional requirements listed in the use case descriptions have been clustered into eleven groups given in the following table:

Table 5-1 : Identified groups of functional requirements

Requirement group	Group name
RG#1	Fast network reconfiguration within a network slice
RG#2	Fast network reconfiguration between network slices
RG#3	Device duality
RG#4	Separation and prioritization of resources on a common infrastructure
RG#5	Multi-connectivity in access and non-access part of the 5G system
RG#6	Massive scalability of protocol network functions
RG#7	Highly efficient transmission & processing
RG#8	QoE/QoS awareness
RG#9	Adaptability to transport network capabilities
RG#10	Low latency support
RG#11	Security

The idea for the Requirement Groups is to facilitate the design process, so requirements that are similar enough, or that can be addressed with the same technological solutions, are not considered separately.

The different **Requirement Groups (RGs)** are defined as follows:

- **RG#1:**

  This group covers functional requirements which are related to a **fast reconfiguration of the network and its NW functions, respectively, within a dedicated NW slice** during running operation. Fast reconfigurations may happen e.g. in case of failures on NW elements or on the links between the elements belonging to the same slice instance.

- **RG#2:**

  In contrast to RG#1 this group covers functional requirements which are related to a **fast reconfiguration of NW and NW functions between different slices** (i.e. in a multi-tenancy operation). Slices are – from a logical perspective – independent virtual networks, but as they will be operated onto a common infrastructure layer changes in one slice may have impact onto other slices (e.g. w.r.t resource utilization).

- **RG#3:**

This group is related to functional requirements addressing aspects of **device duality** in a future 5G system. Device duality means that a device can act both as “usual” end user device (incl. sensor types) and as a network node extending the infrastructure part of the system [MET15-D64]. Examples are e.g. devices acting as cluster head for sensor nodes in their neighborhood or devices acting as relays for other devices covering also self-backhauling functionalities with radio resource sharing (not for P2P). Also requirements related to D2D communication aspects belong to RG#3 (both for NW controlled D2D and D2D without impact from infrastructure, e.g. V2V communication outside the radio cell coverage or links via several devices in emergency situations).

- **RG#4:**

RG#4 addresses functional requirements w.r.t. **separation and prioritization of resources on a common infrastructure**. A 5G system architecture based on SDN/NFV concepts allows a flexible management of network, storage, and computing resources, but has to consider the separability of the resources for operational and security purposes, e.g. running different slice instances in parallel. In addition to separation the resource usage has to be prioritized according to needs of the different services/slices, so a joint resource management is expected to be implemented with further differentiation on available infrastructure layers.

- **RG#5:**

This group covers functional requirements related to **multi-connectivity in access and non-access part of the 5G system**. Multi-connectivity via different radio access technologies (RATs) or via different links of the same RAT (e.g. via different sites and/or frequency bands) will result in better performance (e.g. data throughput) and/or increased reliability for services to be offered within 5G. This is also true for the non-access part, e.g. utilizing the redundancy in transport network links.

- **RG#6:**

RG#6 is related to functional requirements for **massive scalability of protocol NW functions**. The 5G system has to support different services with strongly diverging demands. To fulfill those demands on a common infrastructure the NW functions in the communication protocol stacks have to be flexibly scalable and adaptable.

- **RG#7:**

This group covers functional requirements which are related to **highly efficient transmission & processing** of data. Examples for that feature are realizations of NW functions inside the radio protocol stack allowing e.g. fast access of devices for mMTC with extremely low overhead in C-Plane signaling.

- **RG#8:**

RG#8 addresses functional requirements for **QoE/QoS awareness**, i.e. the adaptability of the NW and its NW functions, respectively, to the demands of the services offered to the customers. This covers not only the processing during NW operation, but also during instantiation of slices as QoE/QoS demands of associated services limits flexible placement of NW functions on available elements of the NW infrastructure.

- **RG#9:**

Functional requirements related to the **adaptability to transport network capabilities** are covered by RG#9. The set-up and operation of virtual NWs (slices) has to take care of the available transport NW capabilities between NW elements. Different deployment scenarios w.r.t. the RAN can be addressed dependent on suitability of transport capabilities for ideal or non-ideal backhaul/fronthaul, resulting in distributed or centralized placement of radio NW functions (D-RAN, C-RAN) [MET15-D64].

- **RG#10:**

In RG#10 all functional requirements are collected related to the **support of low latency** service creation. They are addressing architectural solutions like mobile edge computing, i.e. placement of NW functions and their operation nearest to the access link.

- **RG#11:**

This group covers all functional requirements which are related to **security aspects** in a 5G system, i.e., to all aspects of how to secure the network and the traffic in it against cyber attacks.

The following table provides an overview of which use cases require which requirement groups. A 3-level priority approach was applied with the level indicating the importance of the corresponding requirement group for the use case. Please note: "Low" does not mean, that e.g. a low level of security (RG#11) is sufficient for the corresponding use case, but only that this RG is not in the main focus of the use case. RGs marked by "High" cover the main functional aspects behind the use case.

Table 5-2 : Importance of requirement groups for the selected use cases

Requirement groups	**Use cases**											
	Industry control	Mobile broadband	Emergency communications	Vehicle communications	Sensor Networks Monitoring	Traffic Jam	Real-time remote computing	Massive nomadic/mobile machine type communications	Quality-aware communications	Fixed-Mobile Convergence	Blind Spots	Open Air Festival
RG#1: Fast NW reconfig. within a slice	H	M	L	M	L	H	H	M	L	M	M	M
RG#2: Fast NW reconfig. between slices	M	L	L	M	L	M	L	L	L	M	M	M
RG#3: Device duality	L	L	H	H	M	L	L	H	L	L	M	L
RG#4: Separation & prioritization of resources on a common	M	H	L	M	L	M	H	L	H	H	M	H

Requirement groups	**Use cases**											
	Industry control	Mobile broadband	Emergency communications	Vehicle communications	Sensor Networks Monitoring	Traffic Jam	Real-time remote computing	Massive nomadic/mobile machine type communications	Quality-aware communications	Fixed-Mobile Convergence	Blind Spots	Open Air Festival
infrastructure												
RG#5: Multi-connectivity in access & non-access part	H	H	L	H	L	M	L	M	M	H	H	M
RG#6: Massive scalability of protocol NW functions	H	L	H	H	M	H	L	H	L	M	M	L
RG#7: Highly efficient transmission & processing	L	L	M	M	H	M	H	H	L	L	M	M
RG#8: QoE/QoS awareness	H	M	M	H	M	M	M	M	H	M	M	M
RG#9: Adaptability to transport NW capabilities	L	H	L	L	L	M	M	L	L	M	H	H
RG#10: Low latency support	H	L	L	H	L	L	H	L	L	L	L	L
RG#11: Security	H	M	H	H	M	L	M	H	L	M	L	L

The table entries reflect the diverging functional requirements addressed by the use cases. This is primarily caused by the different demands from the services covered in the use case descriptions. Finally, the distribution of different assessment levels shows the need for the 5G architecture to be flexible and scalable enough to address all those requirements on a common infrastructure.

5.4 Mapping of use cases into 5G NORMA proposed innovations

5G NORMA aims to develop a **novel mobile network architecture** that provides the necessary **adaptability in a resource efficient way** able to handle fluctuations in traffic demand resulting from heterogeneous and dynamically changing service portfolios and to changing local context. For these purposes, **5 key innovations** have been **already identified as promising components of a potential solution** that will be developed, optimized and integrated in the context of the project. They are:

- Adaptive (de)composition and allocation of mobile network functions
- Software-Defined Mobile network Control (SDMC)
- Joint optimization of mobile access and core network functions
- Multi-service- and context-aware adaptation of network functions
- Mobile network multi-tenancy

and described in chapter 2.

Table 5-3 : 5G NORMA Use cases and the innovations which are involved

5G NORMA key innovations		Use cases											
		Industry control	Mobile broadband	Emergency communications	Vehicle communications	Sensor Networks Monitoring	Traffic Jam	Real-time remote computing	Massive nomadic/mobile MTC	Quality-aware communications	Fixed-Mobile Convergence (FMC)	Blind Spots	Open Air Festivalolor
KI-1	Multi-service- and context-aware adaptation of network functions	L	H	H	H	M	H	H	M	H	M	H	H
KI-2	Mobile network multi-tenancy	L	H	H	H	H	L	M	L	L	M	L	L
KI-3	Adaptive (de)composition and allocation of mobile network functions	L	H	H	H	M	H	H	M	M	M	H	H
KI-4	Software-Defined Mobile network Control (SDMC)	L	H	H	H	M	M	H	M	H	H	M	M

5G NORMA key innovations		Use cases											
		Industry control	Mobile broadband	Emergency communications	Vehicle communications	Sensor Networks Monitoring	Traffic Jam	Real-time remote computing	Massive nomadic/mobile MTC	Quality-aware communications	Fixed-Mobile Convergence (FMC)	Blind Spots	Open Air Festivalolor
KI-5	Joint optimization of mobile access and core network functions	H	H	H	H	H	H	H	H	M	H	H	H

The use cases selected by 5G NORMA can be grouped and classified as follows:

- **Service – Application related Use Cases**: Industry control, Mobile Broadband, Emergency communications, Vehicle communications, Sensors Network Monitoring, Real Time Remote computing, Massive nomadic-mobile MTC and Fixed-Mobile Convergence
- **Coverage – Capacity related Use Cases**: Blind Spots, Traffic Jam, Open Air-festival
- **Performance related Use Case**: Quality aware communication

The various use cases benefit from the 5 key innovations in a different way; Table 5-3 shows the related relevance per use case, High, Medium or Low.

The High-Medium-Low relevance reflects the following principles:

- **Industry Control** is a very specific use case with very tight real time (and security) requirement. This is the reason why KI-5 is classified as High. However such a service demands a ‘dedicated and isolated sub-network’ and flexibility given by KI-1 through KI-4 are not very significant thus classified as Low.
- **Mobile Broadband (MBB)**: this use case benefit very much from all KI components. KI-1 gives the flexibility of adapting network functions to user context, KI-3 to have the best network configuration in all deployment scenarios (e.g. depending available front-haul) and KI-4 enables user plane programmability through SDMC. By means of KI-5 the efficiency in terms of signalling is maximised and finally KI-3 gives the right tools for network sharing.
- **Emergency Communications**: it requires extreme and fast reconfiguration of the network, as well as multi-tenancy since emergency services must always be provided, independently on which operator is providing service. All KIs are important and classified as High.
- **Vehicle Communication: KIs same as MBB.** KI-1 allows to adapt network functions depending on user context, e.g. change from V2V to V2I (or vice-versa) or from the access to a local server (e.g. for traffic control) to another local or to a common one (e.g. located at an aggregation point in the operator’s network). KI-2 is necessary since vehicles need to rely on full coverage (thus benefit from multiple operators). KI-4 and KI-5 have same motivation of MBB and emergency services.

- **Sensor Network Monitoring:** due to the static nature of such devices, KI-1, KI3 and KI-4 are less important than MBB. However KI-5 is very relevant since very simple and lean signalling is extremely important for low end machines (for battery saving). KI-2 is also important since part of the network can be shared with other operators (e.g. RAN).
- **Massive nomadic/mobile MTC: the** main difference with MBB is that, instead of high throughput, those devices transmit small packets. However mobility may be very similar to MBB since wearable devices (may) follow the user resulting in high speed if the user jumps in a car. However, due to the nature of the traffic, adaptability of network functions is less relevant than MBB: KI-1 through KI-4 are classified as Medium.
- **Real Time Computing:** benefits from KIs are same as MBB.
- **Fixed to Mobile Convergence**: KI-4 and KI-5 are the most relevant, thus classified as High.
- **Traffic Jam, Blind Spot and Open Air Festival**: being coverage and capacity use cases, they all benefit from KIs which provide high degree of flexibility. Less important is multi-tenancy, i.e. KI-2.
- **Quality-aware communications**: being a performance related use case it benefits mainly from context awareness adaptation of network functions, that is KI-1, and SDMC, KI-4, to provide the best user plane configuration for best QoE.

6 Design principles

In order to guide the transition from requirements to realization, 5G NORMA adopts a number of design principles, as listed in the following. A design principle is a philosophical stance that is informed by collective experience and expertise, so it is both subjective and subject to debate. For example, a design principle that the current mobile network architecture embodies well is the "end-to-end principle". A design principle that the current mobile network architecture does not embody well is "isolation of control and data" or "minimalism".

The following design principles have been identified for 5G NORMA:

Network architecture design principles:

- The network architecture design will be built on the network function virtualization (NFV) and software defined networking (SDN) paradigms.
- The network architecture design will support infrastructure sharing and multi-tenancy.
- The network must be designed in a way that allows to secure the network, its users and their traffic effectively against cyber-attacks, and may provide flexible security mechanisms that can be tailored to the needs of the different use cases that are supported.
- The network architecture will support the concept of dedicated slices, understood as the allocation of dedicated network resources to serve a defined business purpose, customer, or use case. The network should be able to support a fast allocation of the resources needed by the specific network slice.
- The 5G architecture will provide for the support of fixed-mobile convergence resulting in seamless change of connectivity between both domains based on selectable policies.

Operation design principles:

- The network will be able to support the definition and operation of subnetworks (local area networks, closed user groups, …).
- The network will support multi-connectivity to achieve high reliability and availability levels, multi-hop communication across several devices , as well as fast data path rerouting on network elements.
- The network will be implemented by self organizing network (SON) procedures and will be able to self-configure and self-heal in case of failure.
- The network will support the provision of mobility on demand (e.g. no mobility required for stationary/nomadic sensors).
- The network will expose its capabilities to other parties through a set of open APIs, allowing different provider business models to be implementable (e.g. XaaS). The network will implement application awareness for OTT.
- The support of critical applications, like vehicle and emergency communications, will be reliable enough and be able to survive loss of energy supply for a reasonable period of time.
- The design of the 5G system will aim to preserve the compatibility with LTE network features like PROSE, ETWS, MCPTT,…, as well as facilitate the reuse of the available infrastructure from legacy networks, as far as possible (i.e., when it does not result in the need to break with other design principles).

Design principles associated to the control of the network:

- The network will support building up a hierarchical and reconfigurable control plane, that will allow operators to manage their network in a flexible way and supporting the flexible allocation of the network functionalities.
- The 5G architecture will support the network function decomposition, i.e. RAN and core network functions can be adaptively placed to different locations within the network infrastructure.
- The network will be able to introduce a joint optimization of access and core.
- The network will support real-time coordination between base stations.
- The network will be able to offer a lean control signaling.
- The network will provide for common ID management, authentication, and billing for fixed and mobile domains.

7 Scenario framework for 5G NORMA architecture validation

A scenario is a combination of use cases that allows to demonstrate the need of 5G NORMA enhanced functionalities. The purpose of the scenarios is to fix the conditions for validating that the proposed architectural solutions meet the identified requirements, both in terms of functionality and performance. The idea is to define a limited set of scenarios where at least one of them considers the support of more than one use case. The reason for this is to ensure that the flexibility that is being promoted by 5G NORMA architecture is validated.

In these sections we present how to build scenario frameworks to evaluate respectively the multi-service support and the multi-tenancy capability of the 5G mobile network architecture developed in 5G NORMA project. In Annex B instance examples are provided on scenarios where multi-service and multi-tenancy capability can be evaluated.

7.1 Multi-service scenario framework

This scenario focuses on one of the key innovations of 5G-NORMA: multi-service and context-aware adaptation of network functions. That is, adapt or relocate network functions on a service class basis, a functionality which legacy networks do not support (although they already support a variety of service classes and respective QoE/QoS). 5G NORMA considers fully adaptive and programmable network functions that can be reprogrammed and relocated (between edge and central clouds) depending on their usage context, thereby enabling low latency communication and global optimization. An example for this scenario can be found in Annex B.1.

7.1.1 Justification

Purpose of this scenario is to demonstrate the capacity of the 5G NORMA network to be aware of different service classes and to adapt to each specific service class and usage situation (context-awareness).

The rationale for considering this scenario in the context of the project is based in the 5G-NORMA's objective of developing an adaptive and flexible 5G network architecture which provides the flexibility to dynamically adapt to the changing traffic demand of different service classes that can be deployed over the architecture.

5G-NORMA's network architecture will allow the delivery of other service types than the basic ones provided by today's networks (mainly voice and broadband access). An example of one of the new services may be the different machine type traffic (M2M), where the LTE's "always on" principle is certainly not efficient for this new type of communications which need to be "almost always off".

All the new services will have different requirements in terms of mobility, latency, traffic volume, security, power consumption etc. Within this scenario, the network will consist of different architectural instantiations to serve different services, implementing customized functions tailored to the specific requirements of the corresponding service and applying a different decomposition of network functions and their allocation to the network elements.

One of the key features that enable the multi-service principle is the enhanced knowledge of UE capabilities and UE context awareness. Distinguishing among the different services and understand their requirements along the whole delivery chain will allow to support of different types of services in a more cost- and energy-efficient way.

7.1.2 Use cases

This scenario comprises number of the 5G-NORMA's use cases. These use cases are characterized by the fact that the network adapts dynamically to different types of services, also considering contextual information (or other information concerning the end-user, context, terminal, etc.) to provide an optimal service deployment and delivery.

The use cases that are highly related to this scenario are the following.

- **Enhanced Mobile broadband** – Users ubiquitously connect to the mobile network which provides extremely high data rates. Users use multiple services and the network (service-aware) adapts accordingly.
- **Vehicle communications** – Vehicles connect using 5G communications technologies. The network provides multiple services to improve traffic safety, to assist drivers with real-time information about road and traffic conditions, etc.
- **Emergency communications** – The network can be destroyed due to natural disasters. In this scenario the network adapts to the emergency service requirements, prioritizing the emergency services, minimizing energy consumption, etc.
- **Traffic Jam** – In traffic jam a high concentration of people use different services. The network reconfigures and adapts on a service basis to deliver the appropriate quality to each end-user.
- **Real-time remote computing** – The remote execution of computing tasks allows the alleviation of computing load at the UE, thus improving battery lifetime and allowing the possibility of providing a faster service. For that, the specific service requirements have to be taken into consideration, adapting and allocating the computing load accordingly.
- **Quality-aware communications** – To offer an optimal service quality, the network must be aware of the specific requirements of each service type. Contextual information also enables optimal quality delivery to end-users.
- **Blind Spots** – Areas lacking of radio resources and/or low coverage caused by insufficient network deployment pose challenges such as the satisfaction of high traffic demands and the impact of propagation losses in battery lifetime. To effectively cope with this, service-awareness allows optimizing the service delivery in this areas.
- **Open Air Festival** – As in the traffic jam use case, high concentration of people requires the network to adapt and configure accordingly on a service basis to deliver a proper quality.

The other use cases that are medium or low related to the scenario are:

- Industry control
- Sensor Networks Monitoring
- Massive nomadic/mobile machine-type communications
- Fixed-Mobile Convergence (FMC)

7.1.3 Applications

A wide range of applications fit within this scenario. As the scenario is multi-service oriented, a myriad of applications, running over all the different services that 5G-NORMA's network support, are considered within this scenario. This includes traditional applications already provided by legacy networks such as voice, video calls, multimedia streaming etc.; along with new applications enabled by the new architecture such as M2M applications, V2X applications, etc.

7.2 Multi-tenant scenario framework

Multi-tenancy is another key innovations of 5G-NORMA architecture. This key innovation is based on the idea of the sharing of the same infrastructure among different tenants (participant operators, vertical market player, etc.). It should be noted that sharing network resources between different operators need to be transparent to end-user devices. Examples for those scenarios are in Annex C.2 and C.3.

7.2.1 Justification

With this scenario we intend to demonstrate the capacity of the 5G NORMA network solutions to support simultaneously up to five different use cases, which present significantly different requirements. The use cases are characterized by the fact that network resources are needed on-demand in a flexible way for a particular time periods. A hosting operator can share by autonomous means some designed portion of its RAN infrastructure with other virtual market players. In this way, the hosting operator can monetize the excess resource in a more efficient manner with network sharing providing a way for Return of Investment (RoI) creating additional revenue.

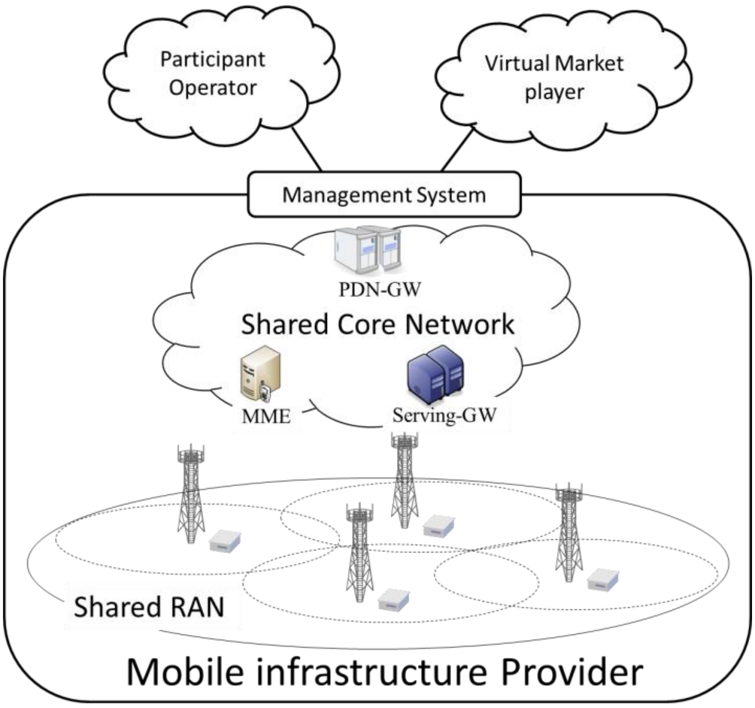

Figure 7-1 : Multi-tenant scenario

This scenario, however, can also accommodate other use cases where resources can be shared flexibly on-demand, e.g. in case of a participating operator. The hosting infrastructure provider should support API to expose resources and receive request from participant operator and vertical market players (including authentication) and should be able to configure/release resources allocated to different participant operators or vertical market players (also referred to as tenants) on-demands via signaling means.

The rationale for considering this scenario in the context of the project is based in the following points:

- Creation of a resource slice for a particular tenant allows customization of resource considering the service level requirements of the participating tenant, e.g. enhanced bandwidth, low latency, resiliency, etc.
- Creation of a resource slice for a particular tenant can ensure service isolation that can guarantee resources for different tenants, including vertical market players like sensors based monitoring and control, as well as ensure on-demand resource enhancement to accommodate situations like traffic jams and open air festivals that need resources for short time durations.
- Resource utilization efficiency, enabling the mobile infrastructure provider to make the most out of their resources by the means of sharing.
- Energy efficiency by allowing operators to share resources and power-off or scale-down in terms of power consumption particular network equipment.
-

7.2.2 Use cases

The proposed scenario can be considered as a validation of the capabilities of the 5G network for supporting some of the main flexible resource allocation and on-demand resource enhancement use cases, including:

- **Industry control-** involving monitoring and control services offered by the wireless network. Multi-tenancy can enable an on-demand network infrastructure provision assuring isolation/security, while being able to scaling in and out the resource needed in order to accommodate the required SLA for industry control.
- **Vehicular Communications –** is concerned with a number of difference services including safety, traffic conditions, etc. in where multi-tenancy can ensure a flexible network resource associated with each supported type of service.
- **Sensor Network Monitoring –** involves information monitoring and control in where multi-tenancy can be used to provide network infrastructure on-demand accommodating service isolation/security requirements and specified SLAs.
- **Traffic Jam** – focuses in situations where a high number of concentrated users consume a variety of different services at the same time. The use of multi-tenancy can help increasing the allocated resource towards certain a mobile network operator when needed addressing particular QoS/QoE requirements.
- **Open Air Festivals** – involves scenarios in where a high network capacity is needed at particular locations on-demand to accommodate a densely populated area. The use of multi-tenancy, can enable mobile network operators to enhance their capacity or share an network infrastructure dedicated for this particular occasion being able to accommodate particular QoS/QoE requirements

7.2.3 Applications

Several applications are considered in this scenario, where we distinguish between those supported by machine type communications including vehicular and resource provision.

In the case of machine type communications we distinguish between vehicular and stationary, and among them between critical and non-critical.

- Vehicular communications would require a resource slice with a higher flexibility since the allocated resources are required within the areas that the vehicles move.
- Stationary cases like monitoring and control have more relaxed requirements in terms of resource allocation following a movement.

In both cases it is significant to consider critical and non-critical situations that impose different Service Level Agreements (SLA) on the allocated slices. Critical communications for vehicles require high responsiveness, while for industry control the notion of critical is perceived as accuracy and resiliency. Non critical communications for both vehicular and sensor network monitoring can also acquire a resource slice with more relaxed timing and resource requirements.

For providing additional network resources on demand, i.e. in case of traffic jam and open air festivals, we distinguish between the one that aim at enhancing QoE due to concentration of many user in a certain location and the one that focuses on providing resources in a location where there is a lack of resources.

The use case proposed can take place both in an urban and rural environment, raising different resource sharing requirements.

- In urban environments, infrastructure sharing focuses on QoE enhancement and resource provision for vertical market players that have no network infrastructure.
- In rural environments, infrastructure sharing most aims cases for providing infrastructure focusing mainly on coverage for both participating carriers and for vertical market players that have no network infrastructure.

8 Conclusions and next steps

This deliverable provides the foundations for the work of the other WPs in the 5G NORMA project in charge of developing the end to end 5G network architecture. In this sense, it has identified, from a set of relevant use cases, the functional and performance requirements that the network architecture solutions proposed should address, as well as the scenarios that should be used for the validation of the solutions.

We defined 12 uses cases building on those developed by NGMN, METIS and 3GPP. The use cases were selected carefully on a number of criteria including the **potential business case**, responding to **societal needs** and the **inability of legacy technologies** to support them. The selected use cases are:

- Industry Control,
- Enhanced Mobile Broadband,
- Emergency Communications,
- Vehicle Communications,
- Sensor Networks Monitoring,
- Traffic Jam,
- Real-time Remote Computing,
- Massive Nomadic Mobile Machine Type Communications,
- Quality-aware Communications,
- Fixed-Mobile Convergence,
- Blind Spots,
- Open Air Festival,

Due to their diversity, the use cases span a wide range of requirements, which have been classified into functional, performance and other requirements. For the purpose of facilitating the analysis by the 5G NORMA WPs that will define the network architecture, the functional requirements have been collected into a set of **groups of requirements**:

- Fast network reconfiguration within a network slice
- Fast network reconfiguration between network slices
- Device duality
- Separation and prioritization of resources on a common infrastructure
- Multi-connectivity in access and non-access part of the 5G system
- Massive scalability of protocol network functions
- Highly efficient transmission & processing
- QoE/QoS awareness
- Adaptability to transport network capabilities
- Low latency support
- Security

The mapping of each individual requirements into requirements groups is provided in the description of the use cases in Annex A.

These requirements can also be grouped, in terms of performance, around three axes: **very low latency and reliability** for critical machine type communications; **high throughput** (compared to legacy networks) for massive broadband communication and the ability to support **high volumes of devices** for massive machine type communication.

The next step in our work has been to analyse how the use cases and their associated requirements map onto the **key innovations of 5G NORMA** which are the driving forces of our work. The first two innovations we classify as innovative functionalities:

- Multi-service- and context-aware adaptation of network functions,

- Mobile network multi-tenancy.

We classify the next three innovations as innovative enablers, i.e. they enable the innovative functionalities above:

- Adaptive (de)composition and allocation of mobile network functions,
- Software-Defined Mobile network Control,
- Joint optimization of mobile access and core network functions.

To validate that there is a real need for these innovations, it was essential to construct **scenarios** for how the use cases might play out together in real world deployments.

Hence, we specified 3 initial scenarios, representing feasible combinations of use cases, each set in specific physical environments, such as urban, suburban, rural etc. These scenarios characterise the combined performance and functional requirements for the use cases. Our analysis has established that the key 5G NORMA innovations will bring benefits compared to legacy networks in meeting these combined requirements.

The scenarios focused on the *multi-service and context aware adaptation of network functions* and *mobile network multi-tenancy* innovations.

The Multi-Tenant Scenario combining vehicle communications and massive MTC communications use cases in an urban environment shows that the multi-service capability (and context-aware network function adaptation) is required to support the delivery of a diverse range of services within the two use cases (as well as each use case greatly differing from the other) over the same network infrastructure. This is in stark contrast to the separate, dedicated networks which would be required using legacy technologies. Moreover, legacy technologies might not have the necessary functionality to support the use cases. The 5G NORMA architecture will deliver similar benefits compared to legacy networks Flexible Service Scenario which combines the vastly different use cases of real-time remote computing and enhanced mobile broadband communications.

The Traffic Jam Caused by Open Air Festival Scenario also shows the need for multi-service capability. While the network traffic in the traffic jam situation will comprise mostly data and video, and will require network function reconfiguration and dynamic reallocation of resources to deal with the demand increase, the festival itself will have a diverse set of requirements (video, voice, data, machine, broadcast and multicast). This means that network functions will have to be highly adaptable to deliver the appropriate quality to each end-user.

The scenarios also show that the mobile network multi-tenancy innovation may also offer significant benefits. In the combined real-time remote computing and enhanced mobile broadband communications scenario the potential benefits of multi-tenancy arise from the heterogeneity of the two use cases and the possibility that there may be different providers of the various network components as well as in content provision.

Multi-tenancy has been shown to be important for both urban and rural environments. It enhances cost effectiveness, enabling a host operator’s spare capacity to be shared with other participant operators and vertical market players and to be managed on-demand. Software defined mobile network control is also necessary to manage the distribution of resources on-demand to provide network slices.

Next Steps:

Based on the outcome of the present deliverable 5G NORMA will design the specifics of a 5G architecture which meets the functional and performance requirements that we have defined for all the use cases. The transition from requirements to architectural solutions will be guided by the design requirements identified. The architecture design will also take into account the physical environment and demand which have also been defined for each use case as reported in the annex.

The scenarios described in this document will inspire and be used as reference for the validation work of the 5G NORMA architecture.

The detailed descriptions of the use cases will also feed into the assessment of the economic and social benefits of 5G NORMA in relation to legacy networks. It will allow us to identify the relevant users, the type of benefits both from economic and the wider societal perspective and will provide a basis for identifying the business model(s) for each use case.

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Annex A. Use cases description

A.1. Industry Control

Use case Description:

Traditionally industrial control applications have relied on wired connections, or proprietary or tailored wireless solutions. A wired connection may not be applicable for every machine because physical wires are subject to tear and wear, and because wiring impacts the mechanical design of the machines to be controlled. Proprietary wireless solutions may suffer from the high prices due to the lack of mass production, and from the lack of globally available frequency bands.

Figure A-1: Industry Automation

Vertical Sectors:

- Industrial process monitoring and control
- Emerging and future haptic communications

Physical Environment and Demand:

- Limited physical area where industry control communication needs to be provided
- Controlled environment which leads to partial determinism
- Integration of heterogeneous communication technologies
- Varying density from very dense (mainly focusing very short range communication) to dense (communication between entities and controller)

End-user Devices:

- Robots, actuators, and sensors. Those may use technologies like Industrial Ethernet, WirelessHART or ZigBEE
- Field equipment for Indoor Mobility and Traffic Control (PAN or LAN)
- Terminals for manufacturing Operation & Control
- Terminals-equipment for Supply / Value Chain
- Sensors, displays, smartphones and tablets

Benefits Relative to Legacy Networks:

- A wired connection may not be applicable for every machine because physical wires are subject to tear and wear, and because wiring impacts the mechanical design of the machines to be controlled.
- A variety of proprietary solutions exists but proprietary wireless solutions may suffer from the high prices due to the lack of mass production standards;
- Legacy mobile network solutions (IEEE 802.16 or 3GPP LTE) cannot satisfy requirements
- Increased safety for citizens.
- Increased security against intended attacks to the communications infrastructure

End to End Business Model:

- Provision of connectivity in factories.
- Provision of managed services for the factories.
- Sensors-actuators-equipment and connectivity belong to the factory, operators may provide the IT infrastructure (e.g. IaaS) and/or data collection and pre-processing (PaaS or SaaS)

Functional and Performance Requirements and KPIs:

- Functional Requirements
    - The network should be resilient, reconfigure fast upon a failure, and have fast failover to redundant links in case of a primary link interruption **(H – RG#1, #2).**
    - The system shall support both efficient multiplexing (e.g. network slicing) of mission critical traffic and nominal traffic **(H – RG#4, #6, #8, #10).**
    - Very high network availability and therefore superior robustness against attacks, in particular DoS attacks, is required. This includes strong authentication between devices and network in order to prevent unauthorized communication. Moreover, integrity protection and encryption is required for the signaling traffic and – unless the applications build on application layer security mechanisms – also for the user plane. Security mechanisms must be robust against loss of network nodes; security mechanisms must be available also in RAN parts that are isolated from central components. Security aspects are of high importance for the use case. **(H – RG#11)**
    - Self-configuration: the network should be able to self-configure; in particular discover the topology of the networks established between the devices **(H – RG#1, #3, #6, #9)**
    - The system shall support the integration of heterogeneous radio technologies to enable the connectivity of machines, robots and further devices on production sites. **(H – RG#5, #6)**
- Performance Requirements
    - The network should support very low latency, in the order of less than 1ms (250µs-1ms)
    - The network should enable stable latency within defined tolerance limits on a low total latency level (e.g. between 5 and 15 ms)
    - The system shall support high uplink data rate (tens of Mbps per device in a dense environment)
    - The network should support very high reliability, with error rates down to 10^{-9}
    - The network should be able to re-establish connectivity seamlessly (which depends upon latency requirements)
    - The network should be able to support large user densities

    - The network should provide highly accurate information about the position of devices/objects: 1 m (finding of objects) down to 1 cm (augmented reality)
- Key Performance Indicators
    - Latency
    - Reliability
    - Number of connected devices
    - High uplink data rates

Sources:

- NGMN 5G WP 3.2.1 [NGM15]
- METIS Use Cases “Remote Tactile Interaction”, “eHealth”, and ”Forest industry on remote control” [MET15-D15]
- 3GPP WG1 SMARTER SI
- 4G Americas 5G White Paper : smart grid, public safety [4GA14]

A.2. Enhanced Mobile Broadband

Use case Description:

This “classical” use case covers the scenario in which users can ubiquitously connect to the mobile network which provides extremely high data rates, significantly above those provides in 4G networks. It shows that mobile network performance increases exponentially over time in order to satisfy the increasing demand of users who quickly rate the most recent and advanced technology as an expected state of the art. This continuously drives the expectations towards mobile network operators to provide faster services, at higher quality, at any place, and at any time – even when the user density is extremely high. Due to this constant development, the requirements and demands will change over the next year and the introduced 5G network architecture is expected to keep pace with this development.

Figure A-2: MBB for Virtual Office

Vertical Sectors:

- Telecommunication providers

Physical Environment and Demand:

- Typical urban, sub-urban, and rural areas with different physical properties in terms of buildings, mobility, streets, or indoor coverage
- Spatial and temporal traffic distribution is highly varying
- Traffic type: mainly human. This type of traffic is not deterministic but driven by human behaviour

End-user Devices:

- Smartphones
- Laptops and tablets
- Integrated devices, e.g. in cars or buildings

Benefits Relative to Legacy Networks:

- Higher per-user data-rates and higher user densities to enable novel services when a member of a group (family or friend) wants to share experience (e.g. event like a concert). One example is virtual office, where the participants feel like they are sitting on the same meeting table while being physically far. This would save energy and time since people are not force to drive or flight to same location
- HD video can be transmitted e.g. for medical consultation when a patient is far from main hospital

End to End Business Model:

- New models may be explored such as provision of high data-rate connectivity by telecommunication providers and/or advanced services with high QoE and quality connection (in addition to flat tariff where quality may be offered as best effort).

Functional and Performance Requirements and KPIs:

- Functional Requirements
  - Application awareness **(H – RG#8)**
  - Multi-layer and multi-RAT connectivity (for TP and coverage) **(M – RG#8)**
  - Efficient backhaul **(H – RG#9)**
  - User privacy and security is required at least at the level provided in LTE, and should be enhanced by options for even better protection (e.g. “IMSI-catching” protection). While security is important for mobile broadband, it is not in the main focus of this use case. (**M – RG#11**)
  - Capacity for uplink and downlink can be flexibly allocated and optimized on cell and sector level based on just-in-time user requirements and used applications **(H – RG#5)**
- Performance Requirements
  - Peak bit rate (indoors and outdoors 10s of Gbps)
  - Low latency, e.g. for interactive video conferencing (a few 10s ms)
  - Traffic density (indoors and outdoors at least Tbps/km^2)
  - High mobility with bit rates and latency (500 km/h, 10 Mbps, 10 ms)
- Key Performance Indicators
  - Peak, System, and Cell edge throughput
  - Number of connected devices
  - Cell and user density
  - Coverage, indoors and outdoors
  - Mobility performance
  - Cost efficiency
  - Energy efficiency
- Other Requirements
  - Power efficiency in the infrastructure and terminal shall be an essential element

Sources:

- METIS Test Cases TC1, TC2, TC3, TC4, and TC9 [MET13-D11]
- NGMN 5G WP [NGM15]

- 3GPP WG1 SMARTER SI
- 4G Americas 5G White Paper : smart grid, public safety [4GA14]

A.3. Emergency Communications

Use case description:

Due to a natural disaster (e.g., earthquake, tsunamis, floods, hurricanes) part of the network infrastructure is destroyed. Users need the network to communicate their situation, contact family members, find rescue shelters, etc. Rescue teams use the network to coordinate their activities. As the natural disaster may have affected the power grid, the energy consumption of both terminals and network infrastructure must be low. The network may be used for locating victims and broadcast alerts. Users' devices battery life should be extended as much as possible.

Based on operator's policy, the system shall be able to define minimal services necessary in case of disaster or emergency that are conditional on e.g. subscriber class (i.e. access class), communication class (i.e. emergency call or not), device type (i.e. Smart phone or IoT device), and application. Examples of those minimal services are communications from specific high priority users, emergency calls, and a disaster-message-board type of application that helps people reconnect with friends and loved ones in the aftermath of disasters.

Vertical Sectors:

- Governments: local, regional, state.

Physical Environment and Demand:

- Communications will be carried in a scenario with limited resources both in terms of infrastructure, energy availability, physical access to equipment, etc.
- Urban environment

End-user Devices:

- Ordinary 5G devices re-commissioned for safety purposes.
- Ordinary 5G devices operating in emergency mode.
- Specialised devices for emergency communications.
    - Police, fire and ambulance crew with handheld radios or wearable cameras.
- Cellular small cell mounted on emergency vehicles.

Benefits Relative to Legacy Networks:

5G networks, as proposed by 5G NORMA, may prove significantly advantageous with respect to legacy networks thanks to the additional flexibility provided by software defined networking capabilities and a less hierarchical infrastructure. This will translate into:

- Faster decision-making and response time for safety supporting groups (police, firefighters…)
- Lower costs for public bodies, since they can rely on the commercial infrastructure.
- Increased safety for citizens.
- Increased security against intended attacks to the communications infrastructure.

End to End Business Model:

- For this use case, there is not a clear business model, in the sense that it is very unlikely that anyone is paying any extra for emergency communications and in the best potential conditions, the use case should never be implemented. However, this is one use case where the societal benefits are most apparent, allowing for minimizing the damages caused by natural disasters and other events. Also, the enhanced capabilities supported by 5G may help to accelerate the recovery from a disastrous event.

Functional and Performance Requirements and KPIs:

- Functional Requirements
    - The network should be able to reconfigure itself with the network elements available. The network should be able to evaluate its own status in order to determine which the best configuration in order to provide the functions expected **(H – RG#1, #6)**
    - The network should be able to prioritize the communication services for certain groups, like rescue teams. At the same time, it should be possible to block users to prevent that they make the network unusable .**(H – RG#4, #8)**
    - The network should be able to seize resources (e.g., frequency channels) from other operators or systems to support the operation. **(H – RG#1, #4)**
    - The network should support broadcast mechanisms to disseminate alerts with enough flexibility in terms of selecting areas or user groups where location-specific alert information can be directed. **(H – RG#4, #7)**
    - The network should be able to discover the topology of the networks established between the devices. **(M – RG#3, #6)**
    - It should be possible for the network to activate the safety capabilities of devices without the users' intervention . **(H – RG#3,#6, #11)**
    - Very high network availability and therefore superior robustness against attacks, in particular DoS attacks, is required. This includes strong authentication between devices and network in order to prevent unauthorized communication. Moreover, integrity protection and encryption is required for the signaling traffic and – unless the applications build on application layer security mechanisms – also for the user plane. Security mechanisms must be robust against loss of network nodes; security mechanisms must be available also in RAN parts that are isolated from central components. Security aspects are of high importance for the use case. **(H – RG#11)**
    - The network should be able should be able to provide intrinsic security mechanisms if the security infrastructure (e.g., HSS/AuC, MME in LTE) is not accessible. **(H – RG#11)**
    - The network should provide protection against attacks that may intend to disrupt the network operation (e.g., in terrorist attacks). **(H – RG#11)**

- Performance Requirements
    - The network should be able to re-establish connectivity in less than 60 seconds.
    - The network should be able to support more than 1000 simultaneous connections per cell and MHz of spectrum available.

- Key Performance Indicators
    - High number of simultaneous users supported by cell and MHz (up to 1000).
    - Low time to recover connectivity (60 s for basic connectivity services).
    - Location accuracy supported.

- Other Requirements
    - The network should be able to survive in emergency mode without access to external energy for a period of 1 week.

Sources:

- METIS Test Case 10 [MET13-D11]

- 3GPP REOPS (Resilient E-UTRAN Operation for Public Safety) [22.897]
- NGMN Lifeline Communication use case [NGM15]

A.4. Vehicle communications

Use case description:

Cars, trucks, motorcycles, bicycle and other vehicles use 5G communications to improve traffic safety, to assist drivers with real-time information about road and traffic conditions, and to support the mobility of emergency vehicles (e.g., ambulances, fire trucks), among other applications. For these purposes, transport entities, such as vehicles, roadside infrastructure, and pedestrians, collect knowledge of their local environment (e.g., information received from other vehicles or sensor equipment in proximity) to process and share that knowledge with each other using 5G communication services. Most of the interactions are activated without the driver intervention, but are intended for her to act on them. Examples of such interactions are:

- Warnings: Emergency Vehicle / Road Worker / Construction Zone / Slow or Stopped Vehicle / Traffic Jam Ahead / Curve Speed Limit Ahead / …
- Information: Road Conditions / Exceptional Weather Conditions / Remote Diagnosis of Vehicles
- Media Sharing: Infotainment

These applications require not only a vehicle to vehicle (V2V) or vehicle to infrastructure (V2I) communication, but also communication with vulnerable road users such as pedestrians and cyclists (V2P).

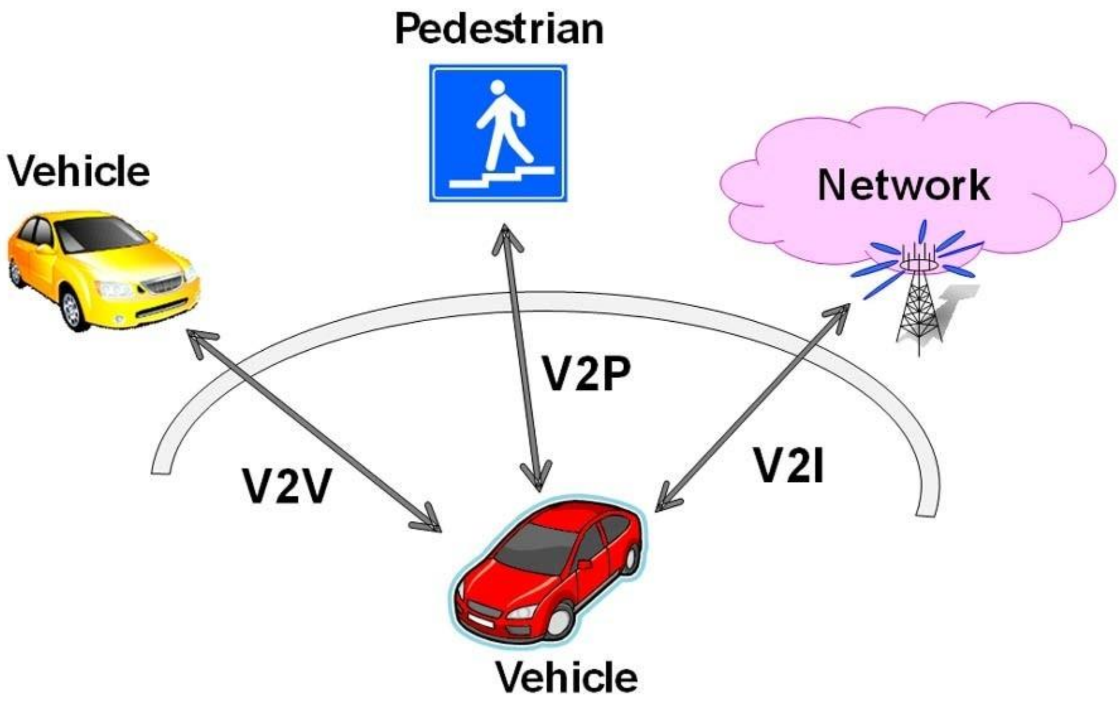

Figure A-3: Different types of V2X communications

Ultimately, V2X will be one of the main enablers for autonomous vehicles. Since human lives are directly affected highest security has to be fulfilled to avoid any malfunction or manipulation.

Vertical Sectors:

- Automobile industry.
- Road authorities

- Car / Traffic related Service Providers
- Developers of applications tailored for the vehicular environment (infotainment, insurance, navigation support,…)

Physical Environment and Demand:

- Services will be provided in roads and highways.
- Flows of up to 1500-2500 vehicles per lane can be expected.
- Up to 10% of the vehicles may have incorporated communication devices to support V2X communications.

End-user Devices:

- Infotainment devices integrated in the vehicle structure.
- MTC devices incorporated into the vehicle.
- End-user devices that connect to the vehicle internal communications system and provide it connectivity.

Benefits Relative to Legacy Networks:

Although some V2X services may be supported with LTE, there are a number of applications that require extremely low latency that cannot be supported with legacy networks. Also, geographical addressing cannot be supported by LTE networks.

End to End Business Model:

Different actors may be involved in the E2E service provision:

- Vehicle manufacturers will support the installation of supporting devices as a way to make their vehicles more attractive, especially for customers who value safety.
- City councils and other governmental entities will expect some significant benefits from the generalization of V2X services like:
    - Increased road safety.
    - Lower commuting time.
    - Reduced energy consumption

  In this way, it would be very likely that incentives and facilities for infrastructure deployment will be offered by them.
- New service providers and developers may be willing to take advantage of the V2X capabilities to offer new services and applications.

Functional and Performance Requirements and KPIs:

Both in terms of functionality (e.g., new routing mechanisms) and performance (e.g., ultra low latency), the support of this use case implies requirements that probably cannot be addressed with legacy technologies. The most important ones that have been identified are the following:

- Functional Requirements:
    - The network should be able to create ad-hoc subnetworks, linking specific nodes and allowing for local access. Ad-hoc networks may support geographical addressing and geographical routing between network elements (i.e., GeoNetworking). **(H – RG#1, #3, #4, #5, #6)**
    - The system should guarantee the coexistence of safety and non-safety vehicular applications operating over the same scenario. **(H – RG#4, #5, #8)**
    - The system should provide the fast, targeted dissemination of safety messages. **(H – RG#4, #5, #7, #8)**
    - The system should allow the retrieval of network information to be processed by external applications (e.g., for traffic levels estimation). **(M – RG#8)**
    - The system should be able to keep track of devices’ precise location without incurring in signaling overloads. **(H – RG#8)**

  - The system should be able to discover the topology of V2V networks established, even if links have been established using non 5G links (e.g., Bluetooth, 802.11p). **(L – RG#3, #6)**
  - The system should be able to support content discovery for certain types of information (e.g., traffic conditions in the roads). **(L – RG#8)**
  - The system should enable optimizations for control plane and data plane functions such as optimal routing and handover minimization in the ad-hoc, vehicle supporting subnetworks. **(M – RG#3, #6, #8)**
  - The system should be able to predict its own reliability against changing traffic conditions or other factors. **(H – RG#8)**
  - Very high network availability and therefore superior robustness against attacks, in particular DoS attacks, is required. This includes strong authentication between devices and network in order to prevent unauthorized communication. Moreover, integrity protection and encryption is required for the signaling traffic and – unless the applications build on application layer security mechanisms – also for the user plane. Security mechanisms must be robust against loss of network nodes; security mechanisms must be available also in RAN parts that are isolated from central components. Security aspects are of high importance for the use case. **(H – RG#11)**
  - The network should be able to provide intrinsic security mechanisms and protection against attacks. To increase security the network should be able to combine data from different sources for redundancy and consistency checks. **(H – RG#11)**

- Performance Requirements
  - The network should ensure the transmission of critical messages related to safety (e.g., collision avoidance) with a latency of 1 - 5 milliseconds.
  - The network should support a high number of active connections, being able to trade off the capacity per connection to the number of connections supported.

- Key Performance Indicators
  - Very low latency (1 to 5 milliseconds end-to-end latency) for critical services and applications.
  - High reliability (nearly 100%) for critical services and applications.
  - Very high mobility (absolute speed more than 200 km/h while relative speed more than 400 km/h).
  - High positioning accuracy (0.1 to 1 meters).
  - High density of connections for vehicles up to 10000 per square kilometer in scenarios with multiple lanes and multiple levels and types of roads).

- Other Requirements
  - The network should be able to cooperate with other existing Vehicular Ad Hoc NETworks (VANETs), e.g., those based on ITSG5/IEEE 802.11p.
  - The system should be able to expose its reliability prediction to third parties through and open API.

Sources:

- METIS Test Case 12 “Traffic Efficiency and Safety” [MET13-D11]
- NGMN Automated Traffic Control and Driving use case [NGM15]
- 3GPP SA1 SMARTER Study Item/V2X Study Item
- ETSI Intelligent Transport Systems (ITS) [ETSI-ITS]

A.5. Sensor Networks Monitoring

Use case Description:

More and more use cases arise related to monitoring a wide area for a particular measured property. The measured property may be, but is not limited to, temperature, motion, vibration, air quality, moisture, or radiation. The need may have been planned (e.g. due to building construction or bridge maintenance) or unplanned (e.g. as a result of a forest fire or other natural/man-made event).

To describe the interest of the use case for our society and our future life, we select the example of agriculture. Today, almost every piece of agricultural equipment has sensors and controls. Sprayers now have sensors that sense whether plants are nutrient deprived or not, and sensors dragged across the field show the textural variation in the soil. The farmer 2.0 uses these precision technologies to be more efficient, and reduce the environmental impacts such us reducing water use or the amount of farm chemicals in water.

Figure A-4: Sensor monitoring for precision Agriculture (source: sourcetech411)

One can think that the satellite navigation is the best technology to support this need, which is partly true for an ideal environment where there is just open space, rolling hills, and flat land. However, many other areas blocks the satellite signals due for example to high trees. The use of sensors with wireless network connectivity is the best solution to develop the precision agriculture.

As the area to be monitored is “wide” in the sense that it is remote and/or large enough, we use sensors which are low cost and low powered devices. Sensors become manually or automatically activated when they are deployed in the area to be monitored.

Upon activation, each sensor identifies itself with the network and registers with the sensor monitoring service/application.

Periodically thereafter, each sensor wakes up and transmits it registration information, location, and measured data value. Additionally, the sensor alarm may be triggered either due to an event (e.g. vibration, motion) or threshold crossing (e.g. temperature, air quality). Total message size should be ~100 bits. The sensor monitoring service verifies the device registration information and forwards sensor data to the application at the location specified. The service may correlate and/or further aggregate sensor information before forwarding.

Vertical Sectors:

- Agriculture
- Weather
- Air quality supervision

- Earthquake monitoring
- Logistic/Transportation

Physical Environment and Demand:

- Depending on the situation, the sensors could be deployed in large numbers in a given area, varying from stationary and dense (e.g., in a warehouse) to wide-spread and mobile but locally dense (e.g., delivery trucks).
- During the majority of time the traffic will have low data throughput and a low duty cycle.
- The NGMN expectation was to have a sensor connection density of up to 200.000 /km^2 the 5G system should be able to handle, but this number includes also fully static devices.
- Periodically or due to an event (e.g. a measured property threshold crossing), the sensor will wake up and transmit a message to the network.
- In most cases, especially for stationary and low mobility sensors, it is expected that the sensor coverage area would be limited to a few cells.
- The devices might have line-of-sight connections and distances among devices might not be large.

End-user Devices:

- The devices are expected to be low cost and battery powered sensors.
- The Universal Subscriber Identity Module (USIM) could be hardcoded into the device, e.g. during manufacturing, instead of on a Universal Integrated Circuit Card (UICC) and thereby considered non-transferrable.

Benefits Relative to Legacy Networks:

- Currently, we have many different systems (RIFD, short-range communications techniques, UWB, Blue-Tooth, etc.) to make the sensors connected. This could be a problem in the future if we talk about a bigger picture like monitoring a wide area or in a more general sense of building the smart city. A unified framework for seamless connection is required.
- To enhance the system performance in terms of energy consumption and throughput, many signalling messages can be saved to support sensors compared to 4G. In a 5G system, we target to have a not “connected” sensors which able to transmit messages to all nodes capable of hearing them. Therefore, many mechanisms could be saved like handover requests, RRC reconfiguration, inter-node data forwarding, or path switching.
- The signalling required establishing a connection is reduced through using “connectionless” access. Each individual sensor would be connectionless in that they would not need to establish individual bearers and no L1/L2 connection state information for individual devices would need to be maintained by the network. This improves the scalability of the system to support a large numbers of devices.
- Wireless sensor networks have the potential for tremendous societal benefit by enabling new science, better engineering and improved productivity.

End to End Business Model:

- Most likely, the sensors in a given area will be owned by the same entity. This latter pays for connectivity from the network provider.
- A set of charging models could be supported (overall data volume, pay per use, flat rate for the service …)

Functional and Performance Requirements and KPIs:

To support this use case for wide area sensor monitoring which addresses the challenge of communicating with large numbers of low-throughput devices within a coverage area, a set a requirements should be fulfilled by 5G system.

In order to support the usual operation of the sensors (periodically waking up and transmitting its registration information, location, and measured data value), a set of functional requirements have been derived.

- Functional Requirements
    - The 5G system should support appropriate authentication for low power devices/sensors. Security is not in the main focus of this use case **(M – RG#7, #11).**
    - The 5G system should be able to accept unsolicited information from large numbers of sensor devices without the need for bearer establishment or mobility signaling (mobility signalling is not required because it is not "connected" to any particular node) **(H – RG#7, #8)**.
    - The system should support an infrequent uplink data transfer in a "non-connected" mode **(H – RG#7, #8)**.
    - The system should be able to deactivate the service and sensors, possibly for future use **(L – RG#7, #8)**.
- Performance Requirements

  Most of use cases related to sensors monitoring face the challenges in relation to connectivity, which should be available when the sensors have to interact with the network. The typical use case of precision agriculture requires reliable radio communication between the base station and the rover over long distances and uneven terrain. Therefore, one can extract the following performance requirements:
    - The 5G system should offer 100 % geographic coverage.
    - The 5G system, typically RAN, should be able to accept unsolicited information from sensor devices.
    - The network should support highly reliable communication and prioritization but does not have stringent latency restrictions.
- Key Performance Indicators
    - Number of connected devices
    - Energy efficiency
    - Coverage/availability

Sources:

- METIS Test Case 10 "Massive deployment of sensors and actuators" [MET13-D11]
- NGMN 5G White Paper section 3.2 [NGM15]
- 3GPP WG1 SMARTER SI
- GSMA Understanding 5G Paper: M2M [GSMA14]

A.6. Traffic Jam

Use case Description:

An increased demand of public cloud services will be a consequence of the high diffusion of mobile devices (smartphone, tablets…), even while travelling by cars, buses or immediately after landing at airports. This kind of users will require services like video streaming, web browsing or file downloading with their personal devices and the vehicle's infotainment systems.

The challenge will be providing public cloud services inside vehicles during the occurrence of traffic jams. In this case the capacity demand is suddenly increased and, like immediately after landing at airports, a huge volume of signalling messages is expected. This phenomenon is referred to as signalling storm, a well-known issue nowadays [Nok12].

Figure A-5 : A traffic jam

The main goal is keeping the QoE of the provided services, in particular in areas where the deployment of network infrastructure does not have an adequate density to satisfy the non-stationary capacity variation.

Vertical Sectors:

- Operators
- Transportation industry
- OTT Players

Physical Environment and Demand:

- Connection density: 4000 users/Km^2 (Source: METIS, where a 6-lane highway of length 1 [km] suffering a traffic jam is considered [MET13-D11]).
- Total volume traffic per user: 53 GB per hour (considering as worst case 120Mbps DL + UL per each user, Source: METIS [MET13-D11]).
- These figures apply on both urban and rural environment.
- Traffic type: mainly human.

End-user Devices:

- End-users: mainly smartphones and tablets.
- In-vehicles connected devices (e.g. LCD displays, audio streaming equipment).

Benefits relative to legacy networks:

- Transportation companies may offer new advanced services (e.g. in-vehicle infotainment) in every traffic condition.
- OTT players may offer their services to their customers that require a broadband connection also in a traffic jam condition (e.g. HD video streaming: Netflix, Hulu; Cloud services: MS Office Online).
- The above-mentioned opportunities are potential new revenues for operators. Moreover, any further deployment of infrastructure should be avoided, exploiting the 5G NORMA architecture flexibility, improving efficiency then reducing CAPEX and OPEX for operators.
- Wider social benefits:

  - Traffic jam scenarios are really stressful for the involved people. Having the support of a traffic jam proof network may help people living in cities where traffic jam are pretty common or commuters that spend a lot of time on cars, buses, etc...

End to End Business Model:

- Wireless services provided by cellular operators to transportation companies or directly to end users.
- Transportation companies pay to operators for having IP connectivity on their buses and cars.
- End-users do not directly pay for the service as they always expect a stable QoE. Moreover they may not pay directly for in-vehicle infotainment service and in-vehicle Wi-Fi which uses 5G NORMA as backhaul.

5G NORMA provides:

- A network that can handle non-stationary capacity variation.
- An alternative to deploy additional infrastructure compare to legacy 4G networks.

Functional and Performance Requirements and KPIs:

The main goal is keeping the QoE of the provided services, in particular in areas where the deployment of network infrastructure does not have an adequate density to satisfy the non-stationary capacity variation. In 4G LTE network the QoE is usually heavily affected by a traffic jam-like situation. The missing expected QoE is reducing revenues for operators and OTT players.

- Functional Requirements
  - The network should be able to evaluate and react to a sudden significant increase of access requests. **(H – RG#1, #2, #6, #7, #8)**
  - The network should support a sudden high volume of C-plane messages for calls setup/handovers (signalling storm). **(H – RG#1, #6, #7, #8)**
  - The network should be able to deploy locally and temporarily a high U-plane capacity without stringent latency requirements (infotainment type of traffic). **(H – RG#1, #2, #4, #8)**
  - The network should implement a mechanism of resources decommissioning. **(M – RG#1, #2, #4, #8)**
- Performance Requirements

  As reported in METIS each user should be able to experience a data rate of at least 100 [Mbps] in downlink and 20 [Mbps] in uplink with an E2E latency lower than 100ms. Hereinafter a differentiation among all the different applications (voice, video, public cloud services) within the use case is proposed.

  - Voice, 21-320Kbps per call, E2E one-way latency < 150ms (ITU G.114 standard).
  - Video, 100Mbps DL (up to 3D 4K/8K quality) and 20Mbps UL, E2E one-way latency depending on the video application's buffering capabilities, less than 300ms for videoconference (ITU G.114 standard).
  - Public cloud services, 100Mbps DL and 20 Mbps UL, E2E latency (RTT) < 100ms.
  - A typical macro-cell handles 100 attach attempts/second, in the traffic jam scenario the system shall be able to handle 10 times more.
- Key Performance Indicators

  Reliability of services

- # user connected/[km2]
- # of successful accesses / Total # of accesses

Quality of service

- Min throughput per user
- Peak traffic/mean traffic

Sources:

- METIS Test Case 6 [MET13-D11]
- 3GPP Feasibility study on New Services and Markets Technology Enablers (On-Demand networking) – TR 22.891 [22.891]
- NGMN Moving Hot Spots [NGM15]

A.7. Real-time remote computing

Use case Description:

Remote computing/real-time remote computing can be thought as a generic container for a variety of future applications such as: cloud computing for UEs, remote gaming, remote device control, tactile internet, among others. These services need network latencies below 10 ms [Nok14].

In current 4G networks the latency is not low enough to provide these kind of services. The only pure RAN U-plane latency is about 4 ms (one-way) [ITU11]. Another aspect to consider is the transition from idle to active mode, which has to be fast especially in M2M communications, while in the existent network is around 50 ms [ITU11].

Cloud computing (apps running in the edge/core cloud rather than in the mobile terminal) enables a variety of resources-hungry applications that would run on remote servers rather than on terminals, keeping resources requirements for the UEs lower and battery life longer. It also enables emerging paradigms such as "software as a service", where the software is centrally installed, run and maintained, and the user is charged on a service basis rather than on a license basis.

Remote device control/tactile internet allows the end user to remotely control a variety of devices through the network, enabling applications such as remote control of industrial/construction equipment, healthcare/surgery applications, online collaboration/gaming. This kind of applications requires extreme low device-to-device latency and high communication availability and reliability.

Figure A-6: Smart car windscreens that provide real-time information to drivers (Source: Autoglass 2020 Vision)

Vertical Sectors:

- Operators
- Automotive and transportation industry
- OTT Players

Physical Environment and Demand:

- Connections density [MET13-D11]:
    - Cars in highway: 500 users /Km^2
    - Bus: 50 user devices simultaneously active
    - Train: 300 user devices simultaneously active
- Total volume traffic per user (DL + UL): 53 GB per hour (considering as worst case 120Mbps DL + UL per each user [MET13-D11]).
- These figures apply on both urban and rural environment.
- Traffic type: human and machine.
- User speed up to 350 km/h.

End-user Devices:

- End-users: head-mounted displays, smartphones and tablets.
- In-vehicles connected devices (e.g. augmented reality windscreen, electronic control units in vehicle).

Benefits relative to legacy networks:

- New revenue stream for operators supporting stringent latency needs of clients.
- Automotive and transportation industry may offer easier vehicle maintenance and new services with reduced time-to-market.
- OTT players may offer services that require a very low latency (e.g. real-time cloud services, 3D virtual reality).
- Wider social benefits:
    - 5G Norma enables remote healthcare/surgery applications.

End to End Business Model:

- Wireless services provided by cellular operators to:
    - Car manufacturers that pay directly to operators.
    - Over-the-top player's customers. The OTT will offer cloud applications and software as a service that require very low E2E latency to its customer using the 5G network. OTT's customer may or not may pay directly for the enhanced network service.
    - Public and private healthcare.
- 5G NORMA provides:
    - A network that provide extreme low E2E latency and high communication availability and reliability.
    - In current 4G networks the latency is not low enough to provide these kind of services.

Functional and Performance Requirements and KPIs:

- Functional Requirements
    - The network should be able to identify low-latency service requests. **(H – RG#8, #10)**
    - The network should be able to create efficient user plane paths between service end points. **(H – RG#1, #4, #5, #7, #10)**
    - The network should be able to prioritize the resources allocation for these type of UEs with minimal/no C-plane intervention. Reducing control signalling

overhead is also proposed by the 5G-PPP project Fantastic 5G [MWB+15]. **(H – RG#4, #7, #10)**
    - The system shall support mobility scenarios (handover). **(M – RG#1, #4, #6, #8)**
    - Security mechanisms must not introduce significant additional latency. Security is not in the main focus of this use case. **(M – RG#11)**
- Performance Requirements
    - Real-time voice and video communications needs network latencies between 100 and 170 ms [Nok14].
    - PR2: Advanced apps like remote execution of application, augmented reality, virtual office, tactile, remotely controlled vehicles require latency below 10 ms, and even lower for ultra-low-latency services [Nok14].
    - The experienced user throughput should be of 100 Mbps in downlink and 20 Mbps in uplink.
    - The system shall support the mobility at very high speed (up to high speed train).
    - Availability 99%.
    - Reliability 95%.
- Key Performance Indicators

  Reliability of services

    - Availability
    - Reliability

  Quality of service

    - Latency
    - Min throughput per user

Sources:

- METIS Test Case 8 [MET13-D11]
- 3GPP Feasibility study on New Services and Markets Technology Enablers (Flexible Application Traffic Routing) [22.891]
- NGMN Remote computing [NGM15]

A.8. Massive nomadic/mobile machine type communications

Use case Description:

In contrast to use case “Sensor networks monitoring”, which is related to sensors placed statically in a certain environment, this use case is relevant for sensors or actuators that are physically mounted on nomadic and mobile objects enabling smart services like metering/monitoring, alerting or actuating also during movement. It is not assumed that there is a need to have direct long distance links from the sensors to a wide-area cellular radio network, but the communication can be also handled via a local radio network (e.g. in a production line in a factory) or via mobile gateways (“cluster heads” or aggregators) which might be again connected to a cellular network (e.g. a gateway/mobile router on a harvester collecting data from sensors related to positioning, maintenance status, etc.). Also a smartphone may act as a cluster head, e.g. for connecting wearables at the human body to an application server for eHealth purposes, or even other sensors can take that role via D2D and/or meshed communications. The local air interface type for the connection between sensors as well as between sensor and cluster head are assumed to be part of the 5G air interface family and should be managed and controlled by the network (only exception in case of out of coverage situations).

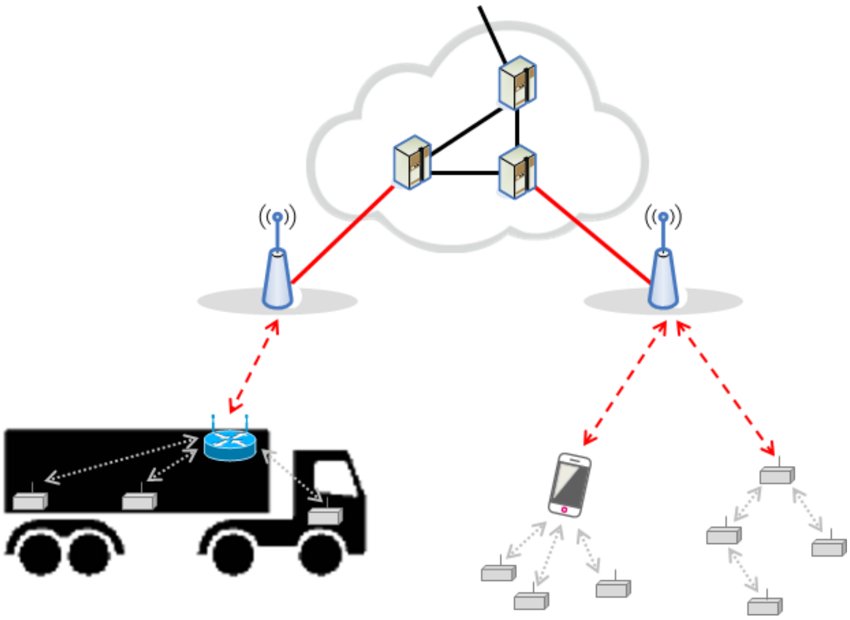

Figure A-7: Massive nomadic/mobile MTC

In general the data payload per message transmitted by the considered sensor types is typically small, e.g. 20 to 125 byte, and also the latency requirements are often very moderate, e.g. up to one second or higher dependent on the application (broadband services like video surveillance and ultra-reliable/-low latency applications are not considered here, as they are covered by other use cases). For nomadic and mobile usage the frequency of messages might be higher compared to a static low-cost sensor, i.e. several messages per minute down to about 1 per second. Nevertheless, there is no need to support features like session continuity during movement of sensors.

It is expected that except of usual unidirectional sensor communication (i.e. uplink only for lowest cost devices) also bidirectional communication has to be supported for some sensor types (for configuration purposes or event triggers which results in higher cost for such a device class).

The key challenge is the overall management (incl. identity and addressing in case of bi-directional communication) of the high number of sensors as well as the small data chunks for applications associated with these devices. Mobile gateways or local radio networks with small cells reduce the volume of sensors connected to a single radio node, but nevertheless the efficient transfer of the short data packets may still be a problem (partly traffic characteristic is changed by data collection/multiplexing in a gateway).

As the applications behind the sensor links may have different requirements, the network is expected to provide different classes of QoS as well as security and authentication mechanisms for the sensor links.

Vertical Sectors:

In general most vertical industry sectors are addressed by the use case, especially:

- Production industry
- Logistics/Transportation
- Agriculture

- Health
- Automotive industry

Physical Environment and Demand:

- As the focus is on nomadic/mobile usage the physical environment covers the range from dense urban areas to rural areas.
- In addition the usage can be differentiated between indoor and outdoor dependent on the object movement (e.g. wearables at a human body, sensors at goods within a storage depot or also on track within a container).
- Therefore the density of such devices in an area will also strongly fluctuate, e.g. from a high density within a storage depot (especially if the depot is located within an industrial city environment) down to a lower density for sensors mounted on goods within a container transported by a truck on a country lane (but in this case still locally dense due to concentration on one vehicle).
- The NGMN expectation was to have a sensor connection density of up to 200.000/km^2 the 5G system should be able to handle, but this number includes also fully static devices.
- The communication type would be predominately in the UL direction with a typical volume for a sensor message in the range of 20 to 125 byte. Its occurrence is dependent on usage type and business purpose. Current assumption is between several messages per minute down to about 1 per second.
- Against the network infrastructure the traffic type may change by involvement of cluster heads which can act against the network both as separate end user device (e.g. a smartphone), but also as a network radio node (device duality within Dynamic RAN approach for 5G [MET15-D64]). Dependent on the number of sensors connected to the cluster head and their message triggering and timing requirements, an aggregation of messages in a single one can happen in the cluster head, resulting in larger data chunks.
- Dependent on a dedicated environment a resulting traffic model including cluster heads can be derived based on message statistics described in Test Case 10 of METIS [MET13-D11].
- The reception of sensor messages at infrastructure radio nodes should be possible in an efficient way up to high velocities in the range of 500 km/h (with or without usage of cluster heads; cluster heads may have more sophisticated Tx/Rx functionalities).

End-user Devices:

- Sensor devices with uni- or bidirectional communication modules. Bidirectional communication required e.g. to activate such devices remotely triggered by an event and to provide a light weight configuration.
- Lowest cost as possible and small form factor is expected, which requires a simple RF part with low number of antennas (in most cases only a single one). Due to operation in varying environment some of the devices may be equipped to support several frequency bands with corresponding radio access technologies / air interfaces.
- Sensor devices should have usually low power consumption allowing battery operation until up to 15 years (dependent on usage scenario).
- Addressing of sensor devices should be possible by different ways dependent on underlying business model (usual SIM card approach for high number of device groups of a customer may be too complex and expensive).
- To be considered for the use case: Interconnection of sensors to network infrastructure flexibly via nearby positioned gateways (cluster heads, aggregators, or sensor mesh networks) and/or direct local- to wide-area links (dependent on device class).

Benefits Relative to Legacy Networks:

- The 5G system will avoid unnecessary network attachment and bearer management signalling overhead as it is required in today’s 3GPP systems. In this way network resource utilization is minimized which allows to efficiently handle connections to several thousands of sensors per km^2.

- High availability related to 5G network coverage in combination with efficient transmission schemes for low packet data chunks will allow high reliability for sensor-based applications.
- Therefore enhancements w.r.t. following exemplary application areas expected:
    - Process optimization in production facilities and transportation of goods based on real-time information (material and inventory management).
    - Industrial system adjustments and predictive maintenance.
    - Remote eHealth applications.

End to End Business Model:

- Reliable connection from/to sensors (incl. also configuration dependent on device types) to be offered by network operators to players in different vertical markets (see information provided before).
- SDN/NFV approach in combination with configurable sensor devices will simplify future service offerings resulting also in cost reduction.
- Charging for sensor services can be performed by different approaches (number of devices, number of messages, overall data volume, security type …).

Functional and Performance Requirements and KPIs:

- Functional Requirements
    - The protocol stack (access/core) should allow the management of a massive number of devices w.r.t. ID management and addressing. **(H – RG#7)**
    - The access network should handle the network resources in C-Plane and U-Plane in a highly efficient way, it should especially only require a low signaling overhead. **(H – RG#7, #8)**
    - The system should support the use of sensors-type devices with very low cost and long battery lifetime. **(H – RG#7, #8)**
    - Depending on device type the network access should be applicable via dedicated RATs and frequency bands or in a flexible way. **(M – RG#4, #5)**
    - The mobility management should support stationary, nomadic, and highly mobile devices and should consider also roaming across network boundaries. **(H – R#1, #4, #6, #7, #8)**
    - Connectivity to a radio network shall be provided directly in case of local radio networks or via relay of other devices in surrounding (gateways, cluster heads). **(H – R#3, #4)**
    - The network should support direct device-to-device (D2D) connectivity between sensors as well as connection of a sensor to intermediate gateways (cluster heads or aggregators). The local links should be manageable and controlled by the network. **(H – RG#1, #4, #6, #7, #8)**
    - The system should support both unidirectional as well as bidirectional communication between sensors and other radio nodes. **(M – RG#5, #6, #7)**
    - The network should provide flexible security and authentication procedures for mMTC as well as means for easy security credential provisioning for massive number of devices. Such security aspects are of high importance for the use case. **(H – RG#7, #11)**
- Performance Requirements
    - The network should be able to handle small data payloads in the order of 20-125 bytes per message of sensor-type devices with often moderate latency requirements in the range of one second.
    - The reception of those messages should be feasible for velocities of up to 500 km/h of objects the sensors are mounted on.
    - The devices shall be highly energy efficient (long battery lifetime up to 15 years) and low cost.

  - The network should be able to handle a density of up to 200.000 active sensor connections per /km^2.
- Key Performance Indicators
  - Connection density
  - Energy efficiency
  - Protocol efficiency
  - Coverage/availability

Sources:

- METIS Test Case 11 “Massive deployment of sensors and actuators” [MET13-D11]
- NGMN use case family “Massive Internet of Things” [NGMN15]
- 3GPP SA1 SMARTER use cases “Wide area sensor monitoring and event driven alarms”, “ Light weight device configuration”, “IoT Device Initialization”, “Bio-connectivity”, “Wearable Device Communication”, “Low mobility devices”, “Materials and inventory management and location tracking”, “Massive Internet of Things M2M and device identification” [22.891]

A.9. Quality-aware communications

Use case Description:

Quality-aware communications take place when the network knows about and reacts according to the quality of the services that it is providing to the end-users, both in terms of QoS and QoE.

Two main aspects to be considered in quality-aware communications, especially when we refer to QoE, are the user (personal peculiarities) and its context. “Context” can be understood as any information that characterizes the situation of an entity. In mobile networks the term context refers to the environmental background that surrounds the end-user that may include the user’s location, activity (working, resting at home, jogging, etc.), time of the day, etc. Thus, context-awareness in mobile networks refers to the consideration of these (user-centric) context factors in network management and operation. In turn, user-awareness refers to the consideration of user diversity by means of user-specific factors that determine user’s personal and individual characteristics. User factors may be for example the user’s emotional state, knowledge/skills, expectations, likings, etc.

This use case considers both the objective service quality and subjective end-user perceptions – which in turn is affected by the corresponding user and context factors - to study novel and advantageous usage situations in future mobile networks, which in turn pose new functional, performance and architectural requirements that current mobile networks are not capable of providing.

In contrast with the other use cases this use case does not deal with the allocation of high amounts of capacity, but with the allocation (in an intelligent manner) of just the needed capacity (and no more) for a given purpose, which is to maintain the end-user satisfied. In this way optimal resource allocation (s.t. QoE) is achieved, which leads to energy and cost savings, also leaving potential free resources to be used by further users. In addition, operators also reduce churn and increase long-term revenue, since further users will be attracted by the good word of mouth of the satisfied customers.

Driving paradigms

An important aspect to consider in forthcoming 5G networks is that as the densification level in mobile networks increases, the access network accounts for the major energy consumption share

[Auer11]. In addition to that, an important result of research work on energy efficiency is that in this scenario a moderate reduction in the data rates can lead to large energy (and therefore costs) savings [And14]. This use case focuses on these aspects considering user- and context- aware solutions for an optimal trade-off between the allocated resources and the users' quality perception (i.e. minimizing resource utilization without damaging users' satisfaction).

Another key driving paradigm is the Webber-Fechner law (WFL) of psychophysics [Rei10]. As depicted in Figure A-8**¡Error! No se encuentra el origen de la referencia.**, the WFL relates the physical stimulus that a person receives with the subjective perceived intensity in a logarithmic manner. The subjective perception is comprised of discrete noticeable intervals (horizontal dashed lines) within which the user perceives the same subjective intensity. Some research work [Frie10] has used the WFL considering network QoS parameters as physical stimuli and the perceived intensity as the QoE. The driven paradigm for this use case can be seen comparing points A and B of Figure A-8**¡Error! No se encuentra el origen de la referencia.**. In the AB interval the subjective perception of the user is the same, while the upper part of the interval (point B) involves up to twice as much of resources as the lower part (point A). The conclusion is that to achieve the same user perception, moving away from point A involves a waste of resources and therefore, energy.

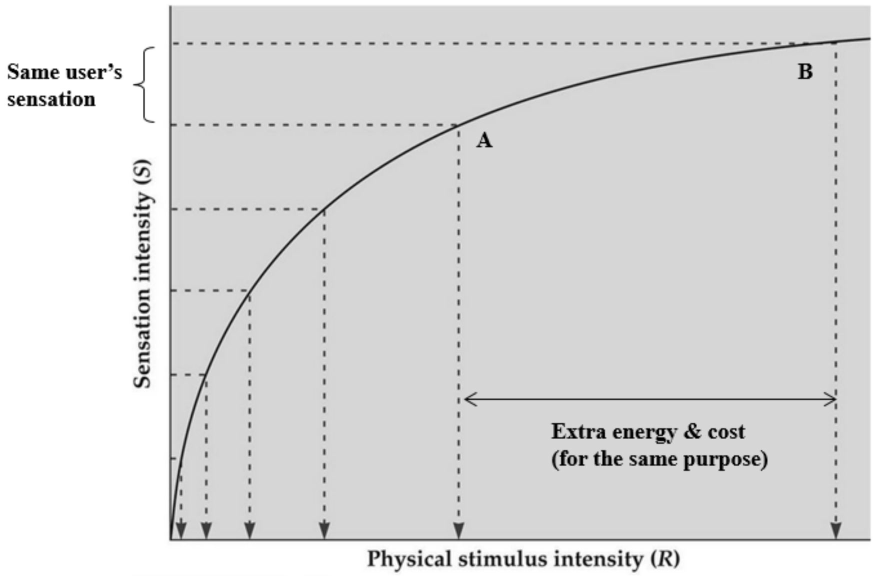

Figure A-8: Webber-Fechner law of psychophysics

Vertical Sectors:

Among others, the main vertical markets that may benefit from the application of the technologies addressed in this use case are:

Automotive – Car manufacturers can offer advanced communication services focused on UX, while reducing costs and being energy efficient.

Media – Delivery of media content is high resource consuming, thus leveraging user- and context-aware solutions allows to serve users in a more efficient way. This includes multimedia broadcast (TV/radio), video streaming services, video games, etc.

Telecom – Network providers (MNOs, ISPs, etc.) can provide better services, assuring user satisfaction and reducing costs.

Transportation and travel – Transportation services can offer better connectivity (in terms of UX) to large groups of moving persons. Public transport services, airlines, trains, ships, cruises, etc., can benefit offering communication services to their travellers in a more cost-effective manner, also ensuring the proper satisfaction level of the provided services.

Physical Environment and Demand:

Quality-aware communications are envisaged to take place in any environment in the future 5G scenario. Urban, rural, corporate, indoor/outdoor, etc. deployments can benefit of a more efficient resource usage. Ideally, the best scenario to show the quality-aware communication capabilities is the one that comprises the following characteristics:

- Dense deployment of BSs (street and public places, work, home, etc.)
- High number, density and variety of users (kids, workers, old people, etc.)
- Different context situations (work, resting at home, practicing sports, etc.)
- Variety of resource hungry services/applications (multimedia, augmented reality, etc.)
- High user mobility (and different user mobility patterns)

Any challenging situation in the propagation environment which translates in low capacity availability (mountainous areas, operating in factories with metalized windows blocking RF signals, etc.), can benefit from the optimal resource utilization provided by a quality-aware solution for the communications. Furthermore, challenges with the users' disposition (high user density, high mobility patterns, etc.) and application requirements (high bandwidth and tight latency demands) can benefit in the same way.

Quality-aware communications can take place with any traffic type. For human to human (H2H) or human to machine (H2M) traffic, the QoE dimension of the quality (i.e. the subjective perceived quality) takes the major role. While for M2M communications (or V2V), the only dimension of the quality that is relevant to be considered is QoS.

In any physical environment and under any traffic demand, the objective of quality-aware communications is to provide an optimal resource allocation minimizing the resources utilized for a given quality purpose.

End-user Devices:

The end-user device is particularly important for quality-aware communications since it determines in a high degree the quality of the service that is delivered directly to the end-user's senses. In other words, the end-user does not experiment the same quality perception if he watches a video on a big TV screen or in a smartphone screen.

In the same way, the end-user device can limit the performance of the service delivered. For example, an ultra-high definition video cannot be reproduced with fidelity in a non-compliant resolution screen (e.g. a laptop screen). And the other way around, a low definition video may be perceived very badly by a user with a high definition screen in its terminal.

For quality-aware communications, the monitoring of the end-user device becomes critical. In this way the waste of resources can be avoided if the user's terminal is not compliant with high definition/quality services. And in the same way, when a user has a high level terminal, high quality services can be properly delivered for the user's satisfaction.

End-user devices that are relevant for this use case are all kind of mobile devices the user may carry with him, for example smartphones, tablets, smart watches and any other kind of wearable devices that may allow context data gathering.

Benefits Relative to Legacy Networks:

Current quality assurance mechanisms are mainly based on QoS management approaches such as Differentiated Services (DiffServ) and Integrated Services (IntServ). For example, the Policy and Charging Control (PCC) architecture, component of LTE and specified by the 3rd

Generation Partnership Project (3GPP), supports differentiated service quality mapping service flows to different logical bearers based on the service QoS requirements.

The utilization of QoE-aware approaches allows the following benefits not achievable with today's networks:

- Monitor the satisfaction of the end-users. Ensure that the end-users are satisfied and detect when a user is experiencing a low perceived quality (regardless of the QoS provided) which can be caused by external (context) factors instead of the QoS of the communication.
- To allocate to each user the necessary resources (and no more) to keep them satisfied. This leads to the reduction of both energy consumption and costs.
- To minimize the quality impact of network handovers, for example prioritizing handover-sensitive services. QoE prediction mechanisms can also be used if quality degradation events can be foreseen (e.g. predictable handovers) so that performing proactive resource (re)allocation in advance can reduce the quality degradation when the said event occurs. Moreover, 5G aims to provide seamless mobility upon heterogeneous network handover (i.e. maintaining ongoing connections when mobility occurs between separate network domains with different wireless technologies), which can be greatly improved using quality-aware mechanisms.
- QoE-based approaches may also allow to dismiss counterproductive management actions and resource adaptations, since frequent adaptation of the transmission might not improve the overall QoE; quite the contrary. Thus, reducing the management effort while improving scalability.

End to End Business Model:

Quality-aware communications are not a specific service that end-users contract and pay for it. Instead, it is a new capability of 5G networks that allow operators to optimize the resources allocated for their services, reducing the energy consumption and costs.

At the end of the day, end-users will experience benefits in terms of satisfaction, since quality-aware communications ensure that they perceive a proper subjective service quality (QoE) regardless of the underlying QoS parameters.

In turn, operators will increase their revenue stream in terms of the following points:

- Moderate reductions in data rates can lead to large energy (and therefore costs) savings [And14]. Operators will reduce the costs associated to the services they provide since they will allocate fewer resources to provide the services to their customers, thus reducing the associated energy expenditures.
- Optimizing resource allocation leaves potential free resources to be used by further users which otherwise could not be allocated due to overloads of the system. In this way, operators may serve a larger number of users with the same resource utilization, therefore allowing increases in revenue.
- Operators can also reduce churn and increase long-term revenue, since further users will be attracted by the good word of mouth of the satisfied customers, which will remain with the respective operator's services. In other words, current customers will stay while potential customers will come.

Functional and Performance Requirements and KPIs:

Requirements are classified according to its High (H), Medium (M) or low (L) relevance for the use case.

- Functional Requirements
    - Users' QoE should be monitored/estimated with the appropriate granularity and accuracy **(H – RG#6, #8)**
    - The QoE management function should be able to

- Monitor the QoE: user factors, context factors, terminal factors. **(H – RG#4, #8)**
  - Context factors: location, identity, activity and time; user & role, process & task, location, time and device. Context related to physical environment is structured into three categories: location (absolute position, relative position, co-location), infrastructure (surrounding resources for computation, communication, task performance), and physical conditions (noise, light, pressure, air quality), etc.
  - User factors: Information on the user (knowledge of habits, emotional state, biophysiological conditions), the user's social environment (co-location of others, social interaction, group dynamics), and the user's tasks (spontaneous activity, engaged tasks, general goals), etc.
  - Terminal factors: screen size, screen resolution, audio characteristics, battery level, etc.
- Map QoS to QoE (and vice-versa) **(H – RG#4, #8)**
- Perform the corresponding configuration actions over the RAN and CN functions **(H – RG#4, #8)**

- RRM should allow configuration actions from the QoE management function **(M – RG#4, #5, #6, #8)**
- The architecture should support (a kind of) dynamic/QoE-driven QoS bearers per service and per user. **(H – RG#4, #5, #6, #8)**
- RRM should notify to the QoE management function/centralized monitoring system the necessary QoS parameters (and other data if needed). **(M – RG#4, #8)**

- Performance Requirements
  - The system should be fast / efficient enough to handle changing conditions (mobility, etc.)
  - The system should be highly scalable (in terms of computing and storage) to handle a high number of users simultaneously.

- Key Performance Indicators
  Quality-aware communication strategies can be evaluated by means of the following Key Performance Indicators:
  - Overall end-user satisfaction – A successful employment of quality-aware communications will lead to a high overall user satisfaction.
  - Energy savings – A successful employment of quality-aware communications will lead to energy savings for a given service usage situation.
  - Cost savings – In the same way as the above point, a successful employment of quality-aware communications will lead to cost savings for a given service usage situation.

Sources:

- No sources have been identified for this use case. This use case has been developed integrally within 5G-NORMA.

A.10. Fixed-Mobile Convergence (FMC)

Use case Description:

In its 5G White Paper [NGM15] the NGMN Alliance stated that 5G services should be delivered via a converged access-agnostic core (i.e., where identity, mobility, security, etc. are decoupled from the access technology). Different technologies based on wireless as well as on wired types (FTTH, xDSL …) can be applied for the customer access providing always the optimal network capabilities to the end user.

FMC will ensure a seamless customer experience within the fixed and mobile domains (e.g., a unified user authentication) and will allow the operators to process a customer independently of his access type for authentication and billing, via a unified customer data base and information system across the different domains. In addition service and/or device characteristics might be adapted when changing between domains because of different capabilities.

One example:

> During driving to his office/home, a travelling salesman replied to a voice call. He answered to the call via head-set (e.g. he might receive a video conference on a side-zone of his augmented reality glasses). The call is received via the mobile network of the operator he has a contract with.
>
> When arriving at office/home and entering the building, the communication will be transferred to the local WLAN or future 5G RAT still using the same device. This local area network might be managed by the same operator or by another operator (federation is needed). Alternatively (e.g. based on pre-selected policies), the communication can be also transferred to a locally installed device with a high-resolution display. In that case the service characteristic may change from pure telephony to a HD video call. Such a session transfer has also a huge impact on the service performance requirements (e.g. data rate).

In addition to a path switching for data flows between fixed and mobile infrastructure the flows can also be jointly transferred across both infrastructures (so-called hybrid access) dependent on selected policies based on user or operator criteria (e.g. cheapest pipe first). In contrast to higher layer solutions like Multipath TCP the 5G system is expected to support a joint resource management also on lower layers.

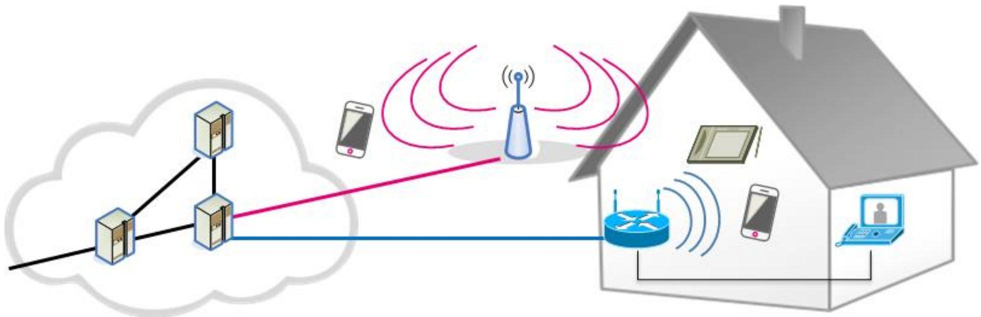

Figure A-9 : Fixed-mobile convergence

Vertical Sectors:

- The use case does not address vertical, but usual communication market with following players:
  - Operators with both fixed and mobile networks (integrated operators)
  - Enterprise and local area network operators

Physical Environment and Demand:

- The environment covers all buildings (residential, enterprise …) equipped with a fixed access line which lay additionally inside a mobile radio coverage area.
- The use case does not address any specific end user service. Typical applications which can be considered in a scenario description are internet and streaming services as well as voice/video communications.

End-user Devices:

- Smart phones, tablets or similar devices equipped with different radio access technologies incl. at least one for local area purposes (e.g. legacy WLAN or future 5G local area air interface).

Benefits Relative to Legacy Networks:

- Convergence of network functions for both fixed and mobile networks resulting in simplified network operation (e.g. for AAA, ID management, billing), so lowering OPEX.
- Enhanced QoE w.r.t. latency and availability based on joint resource management across mobile and fixed domains (optimized link selection or bundling/aggregation of available links for seamless connectivity) which are targeted to be implemented on lower layer functions instead of today's higher layer solutions like Multipath TCP.

End to End Business Model:

- More or less a usual business model between network provider and end customer.
  - Customer pays integrated network provider for convergent service offer.
  - Inter-operator payments in case of different operators for residential and mobile domain.
- With 5G the flexibility for inter-operator partnering and operation of virtual networks on the infrastructure provided by different players will be simplified.

Functional and Performance Requirements and KPIs:

- Functional Requirements
  - Access environment might be managed by the own operator or by another operator in case of a visit (federation is needed). **(M – RG#1, #3, #4)**
  - Management of the access network might end at the residential (office/home) gateway or will cover the whole residential network. **(M – RG#1, #3, #4)**
  - The 5G system shall provide a common C-Plane across the fixed and mobile domains. **(H – RG#5, #6)**
  - The common C-Plane should allow a joint access resource management across the fixed and mobile domains allowing both link switching and link bundling (so-called hybrid access) according to demand and/or given policies. **(H – RG#4, #5, #6, #8)**
  - Demand and/or policy driven selection of the communication link between the mobile device and a local infrastructure in case of handover to local office/home network. **(H – RG#3, #4)**
  - Flexible QoS management across different access domains supporting dynamic adaptation of service characteristics, e.g. change or service type according to access bandwidth availability or utilizing other context information (assuming that the access is the bottleneck). **(H – RG#4, #8, #9)**
  - Security mechanisms are required that fit in with the goal of a seamless end user experience (e.g. a unified user authentication). Security is not in the main focus of this use case. **(M – RG#11)**
- Performance Requirements
  - Fast and seamless handover between wireless technologies as well as between mobile and fixed access domains to guarantee well-received QoE for all relevant customer services.
- Key Performance Indicators
  - User experienced data rate
  - Protocol efficiency
  - Handover efficiency

Sources:

- NGMN 5G White Paper [NGMN15]

- 3GPP SA1 SMARTER use case "Multi access network integration" [22.891]

A.11. Blind Spots

Use case Description:

Modern users expect high data rate services, accessible anywhere they go. Providing those kind of services with high Quality of Experience (QoE) in blind spots will be challenging. Blind spots are areas with a lack of radio resources and/or low coverage caused by insufficient network deployment, such as rural areas with sparse network infrastructure or deeply shadowed urban areas. In these cases, higher data traffic demands correlate with the higher number of vehicles and users in the proximities. This property should be taken into account. Another important aspect to be considered is that areas with low coverage have an impact on the battery consumption of UEs, since higher propagation losses have to be compensated. Increasing cell density is a potential solution for boosting service capacity in urban areas, but rural and heavily shadowed areas require a more flexible and energy and cost efficient solution.

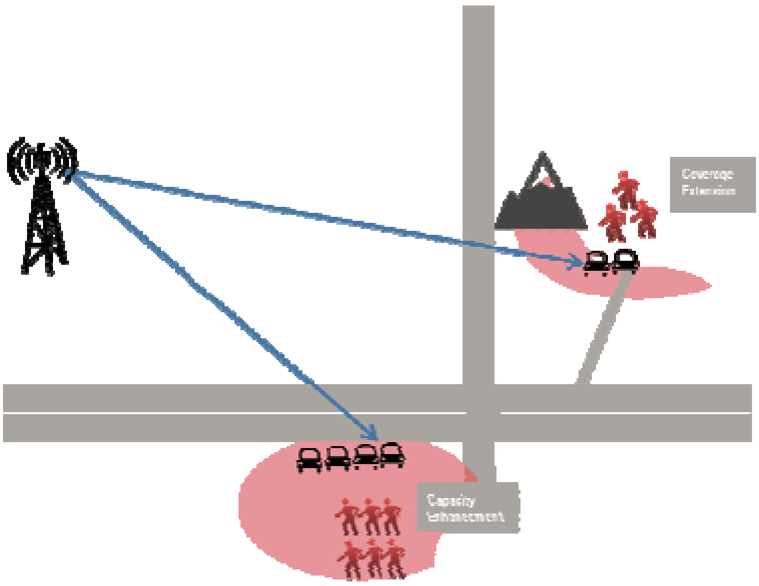

Figure A-10: Blind Spots (Source: METIS Deliverable D1.1 [MET13-D11])

Vertical Sectors:

- Operators

Physical Environment and Demand:

- The environment for this use case will be a remote open rural areas with sparse network infrastructure or deeply shadowed urban areas
- Traffic volume density: 12 Gbps/km^2 in rural areas, 120 Gbps/km^2 in urban areas
- Traffic volume per user: 53 Gbytes per device per hour
- Connection density: 100 users per km^2 in rural areas, 10 times more in urban areas

- Traffic type:
    - Human: HD video, internet access

End-user Devices:

- End-user devices (smartphones, tablets, laptops, …)

Benefits Relative to Legacy Networks:

- Efficient energy consumption.
- Operators can offer services with high QoE even in areas with bad or no coverage
- The current solution using 4G technologies include increasing the cell density, but this is not flexible, or energy and cost efficient.
- Wider social benefits:
    - As data and voice services become integral to everyday life, allowing people in rural areas or shadowed urban areas access to reliable and fast connections is of great importance.

End to End Business Model:

- Wireless services provided by cellular operators to
    - End users
- End-users do not pay more than the usual rates for network access

Functional and Performance Requirements and KPIs:

- Functional Requirements
    - All locations of the service area should be provided with reliable network access with high data rates. **(H – RG#5, #8, #9)**
    - Energy consumption for users and the infrastructure should be minimized. **(L – RG#7)**
    - The network should be able to identify areas with insufficient radio resources and/or low coverage, and adjust to provide better services. **(M – RG#1, #2, #4, #5, #8)**
- Performance Requirements
    - Data rate of at least 100 Mbps in downlink and 20 Mbps in uplink.
    - End-to-end latency below 100 ms.
    - Availability must be as high as 95% in blind spots
    - Reliability must 95% in blind spots
- Key Performance Indicators
    - Availability and Reliability in blind spots
    - End-to-End latency
    - Minimal data rate per user in blind spots

Sources:

- METIS Test Case 7 “Blind Spots” [MET13-D11]

A.12. Open Air Festival

Use case Description:
A remote and small rural area receives tens of thousands of visitors for a multi-day open air music festival. The mobile network here has few sparsely deployed nodes. The user and device density is extremely high, and the data traffic demands are orders of magnitude higher than the usual situation for that particular remote area. Using the current technologies, network overload occurs frequently, causing poor QoE or outright service outages.

Each visitor wants to use location and map services, and share HD videos and photos in social networks, usually in the interval between performances. Users expect a fast, reliable and highly available network access.

The festival organization sets up a whole infrastructure in the area, comprise of garbage collection, waste management, provision of food, security guards, paramedics, and video surveillance, all of which will use devices and sensors that rely on wireless communication. This means a diversity of requirements from users (smartphone, tablets) and infrastructure (machines, sensors). Besides that, the organizers would like to provide useful information to the visitors (map of the event, schedule of performances, location of emergency services, live streams, among others). Broadcast and multicast capabilities would allow that type of information to be quickly distributed.

Figure A-11: Open air festival (Source: trueamsterdam.com)

Vertical Sectors:

- Operators
- Entertainment industry

Physical Environment and Demand:

- The environment for this use case will be a remote open rural area, which will have to deal with 1000 times more devices and users during the festival
- Number of user devices is over 100.000, and number of machines and sensors is up to 10.000
- Traffic volume density: 900 Gbps/km^2
- Traffic volume per user: 3.6 Gbytes, during busy period
- Connection density: up to 4 user per m^2
- Traffic type:
    - Human: video sharing, internet access, voice services
    - Machine and sensor communication

End-user Devices:

- Smartphones, tablets and laptops
- Sensor and machine devices
- Surveillance cameras
- Police, fire and ambulance crew with handheld radios

Benefits Relative to Legacy Networks:

- Maximization of advertisement for the event, since users can share their experience online
- Guarantee of a smooth, safe and fulfilling visitor/user experience
- Operators can offer users and festival organizers many services without incurring high deployment or energy consumption costs
- Current solutions, like mobile eNodeB, do not provide the required end-user throughput and latency.
- Wider social benefits:
    - Festivals can be amazing experiences for the attendees, and boost local business by allowing them to serve thousands of people. They can also be dangerous, since any big congregation of people can get out of hand, and providing emergency services with good wireless communication helps prevents any disasters.

End to End Business Model:

- Wireless services provided by cellular operators to
    - End users
    - Local businesses and festival organizers
    - Emergency services
- End-users do not pay more than the usual rates for network access
- Local businesses and festival organizers may pay extra for the increased capacity necessary, for connecting all of their sensors and machines to the network, and for extra services like broadcast and multicast services.
- Emergency services have to be notified by festival organizers, and may come to an agreement with operators for access to the network.

Functional and Performance Requirements and KPIs:

- Functional Requirements
    - The network should detect and react to the increase in demand **(H – RG#1, #2, #4)**
    - The network should adapt to the different delay requirements **(H – RG#4, #5, #8, #9, #10)**
    - The network should support resources decommissioning **(L – RG#1, #2, #4, #8)**
    - The network should support Broadcast / Multicast mode on the air interface to allow provision of content even to an extremely high number of users in that location in a most efficient way. **(M – RG#4, #7, #8)**
- Performance Requirements
    - Data rate of 30 Mbps per user
    - End-to-end latency of less than 1 second for 99% machine/devices
    - Delivery of delay tolerant data in less than 10 minutes with 95% probability
    - Outage probability should be less than 1%
    - Availability for users of 95%
    - Availability for sensor applications of 100%
- Key Performance Indicators
    - Availability
    - End-to-End latency
    - Average data rate per user
    - Traffic capacity up to 900 $Gbps/km^2$

Sources:

- NGMN 5G White Paper “HD Video/Photo Sharing in Stadium/Open-Air Gathering” [NGM15]
- METIS Test Case 9 “Open Air Festival” [MET13-D11]

Annex B. Scenario examples

As indicated in the methodology section, a scenario is an instance of one or more use cases. The scenarios are defined by the set of conditions that describe how the use cases take place, to be able to evaluate e.g. through simulations against a set of target KPIs. In the following, three example scenarios are described. Each combines a different set of use cases from Annex A so that all scenarios together cover a broad subset of all the use cases.

B.1. Multi-tenant scenario: V2X + massive MTC communications in urban environments

B.1.1. Justification

With this scenario we intend to demonstrate the capacity of the 5G NORMA network solutions to support simultaneously two different use cases, which present significantly different requirements in a multi-tenancy environment. The use cases are characterized by the fact that the services and applications the 5G network support are not (mainly) human beings but machines and embedded devices. This scenario, however, can also accommodate other use cases where people use the 5G network to communicate. In more general terms, the proposed scenario can be considered as a validation of the capabilities of the 5G network for supporting some of the main smart city applications, like those intended to help driving (including the potential support of self-driving cars) and those for connecting sensors for regulating traffic, parking assistance, pollution control, etc.

The rationale for considering this scenario in the context of the project is based in the following points:

- While sensor based communications may require very limited or no mobility support, V2X communications should support not only mobility but also some location capabilities to control the destination devices in V2V communications.
- Different RATs can be used for the support of the communications, as well as different frequency bands. Sensor based communications may be supported using low frequency bands in order to maximize coverage, while V2V may be based on high frequency bands (e.g., 5.9 GHz spectrum for DRSC).
- The scenario also requires different levels of centralization/distribution of processing functionalities depending on the kind of application supported.
- It also requires the support of different connection topologies, including D2D communications, one to one, one to many etc.
- The scenario also can consider the option of supporting multi-tenancy, as parts of the network may be owned by different partners, especially governmental institutions like city councils and regional and national governments in charge of road safety.

B.1.2. Applications

Several applications are considered in this scenario, where we distinguish between those supported by V2X communications and those associated to sensors networks.

In the case of V2X communications, we distinguish between critical and non-critical applications:

- V2X critical communications: these applications are associated to events that require a very quick action from the vehicle. For these kind of communications. direct exchange between the vehicle and other entities, without:
    - V2V (Vehicle to Vehicle) communications to exchange information (position, speed, acceleration,…) leading critical actions (e.g., collision avoidance).
    - V2P (Vehicle to Person) communications to exchange information leading to running over pedestrians avoidance.
    - V2I (Vehicle to Infrastructure) communications to assist drivers in critical procedures like e.g., stop sign and turn left assistance, which may not be supported by V2V communications due to NLoS propagation.
- V2X non critical communications:
    - V2V communications, established in order to exchange information about vehicle capabilities (e.g., if they support automatic collision avoidance procedures or not) or non-critical events (e.g., presence of a broken down vehicle down on the road).
    - V2I communications to exchange information regarding operating conditions that may help to an improvement of vehicle traffic conditions (optimal route selection information, emissions control …).
    - V2P communications in order to support traffic and weather information distribution, infotainment applications …

Sensor based communications can be applied for a number of applications that may have different requirements.

- Non-critical event driven communications, related to changes in the state of the parameters that are being measured. E.g., when a parking lot is occupied, the sensor sends a message in order to inform of this circumstance, or when a limit in a value being measured is being exceeded (e.g., level of N_2O, CO_2 …).
- Critical event driven communications, related to events that may have an implication in terms of safety (e.g., when a vehicle does not respect a red light in a semaphore) or to help (e.g., stop sign and turn left assistance). This application may be considered complementary to critical V2I communications.
- Periodic communications, in order to inform of the status of a set of parameters that are being measured. E.g., the number of vehicles circulating in a given segment of a street.
- Commands sent to actuators to activate/deactivate some functionality (e.g., commands sent to streetlights to be turned on or off or to the traffic lights to change their periodicity).

B.1.3. Simulation model

B.1.3.1. Deployment and channel model

The scenario proposed takes place in an urban environment, which is more easily modelled assuming a Manhattan-like grid of streets. For sake of simplicity, all the communicating devices will be located outdoors, for both the V2X applications and the sensor based communications.

Consider a city grid with square blocks with:

- Fixed block edge length in the order of hundred meter
- Fixed inter-block distance in the order of tens of meters
- A number of lanes
- A number (a few tens) of parking slots per block edge
- A number (a few tens) of lampposts per block edge
- A number (a few) of CCTV cameras per block
- A number (typically two) of semaphore lights per block edge

The following figure collects the most important aspects of the scenarios' environment including example lengths and numbers:

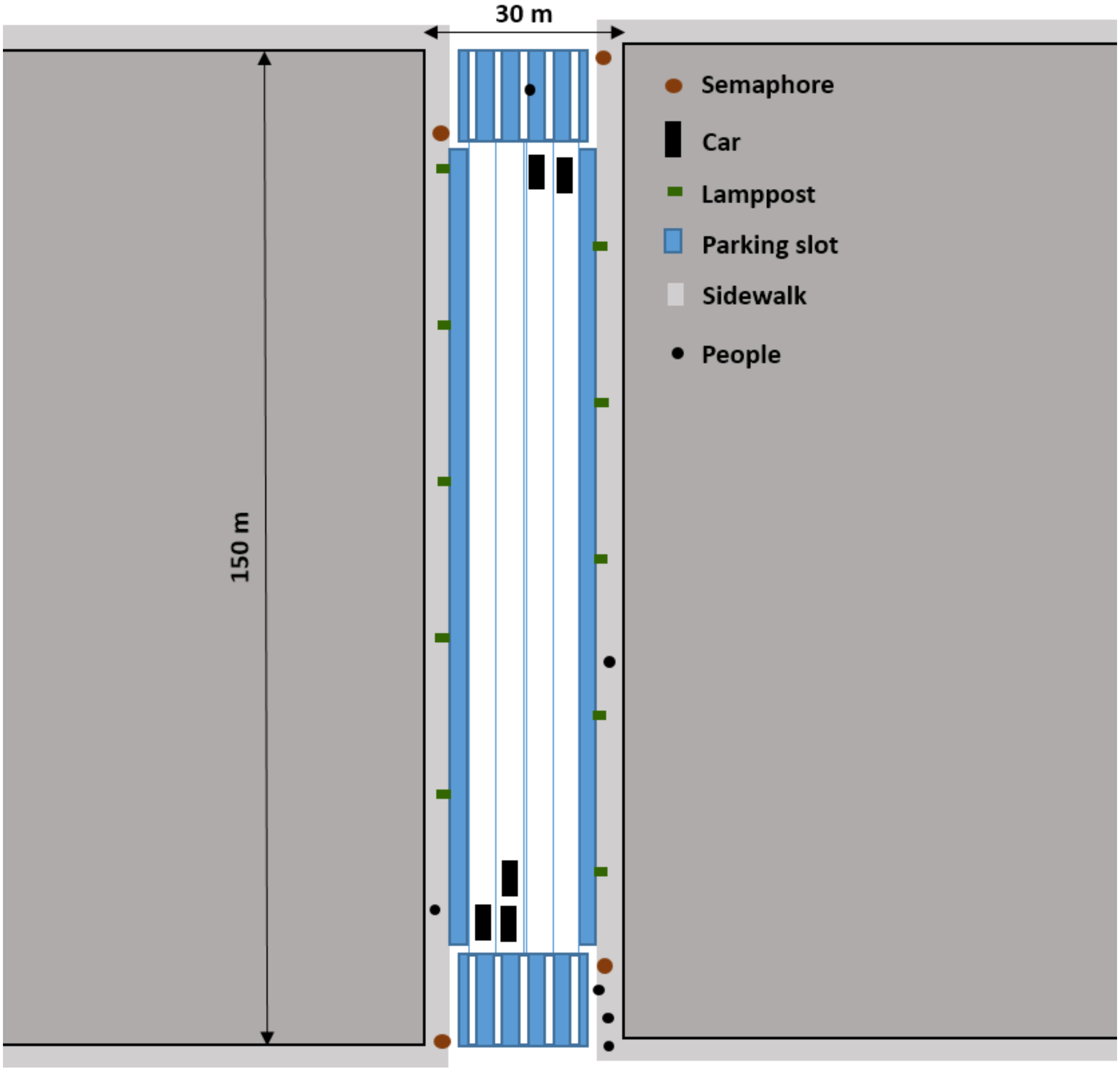

Figure B-12 : Environmental conditions for the scenario

The complete scenario for simulation purposes could be composed by a square of e.g. six building blocks per side, as represented in the following figure:

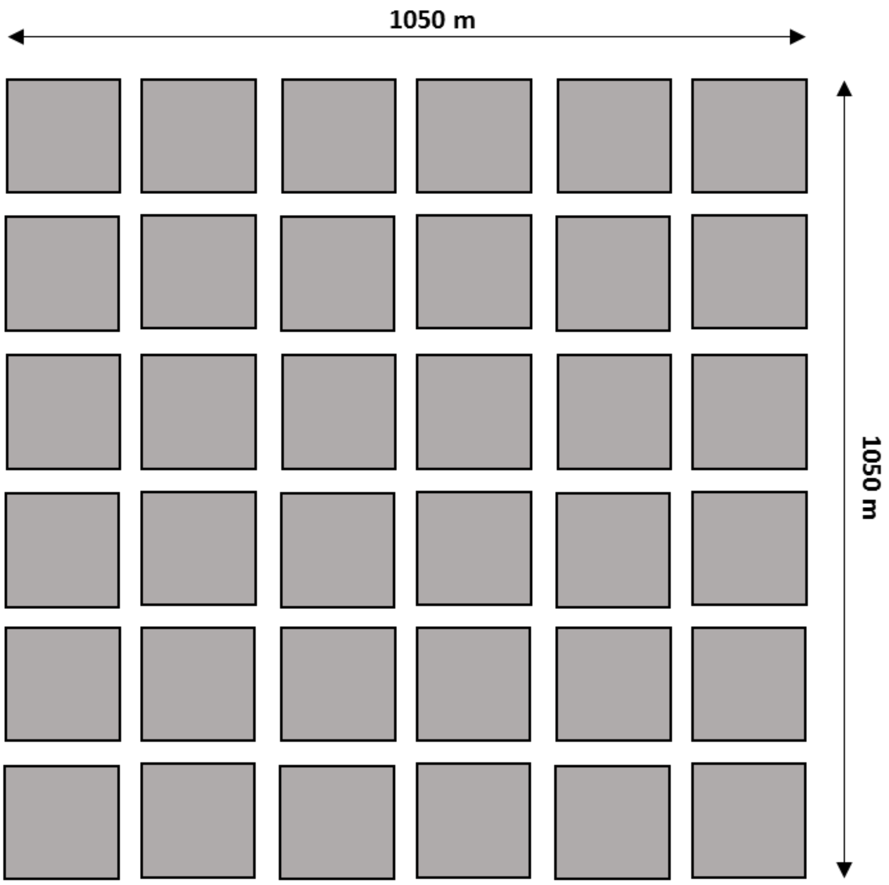

Figure B-13: Simulation framework for the scenario.

B.1.3.2. Traffic model

Traffic conditions in the scenario proposed are dependent on a number of environmental factors that were defined in the previous section:

- Number of vehicles and persons that circulate in the scenario, as well as those that are parked.
    - A number of moving vehicles per block , depending on the traffic conditions, heavy, medium and light, respectively.
    - A number of parked vehicles per block edge
    - A number of persons per block edge
- Vehicle and people speed and mobility patterns, which can also be affected by traffic lights and signs as well as by the pedestrians' behaviour.
    - Average vehicle speed depending of traffic conditions
    - Average people speed is typical pedestrian (a few km/h)
- Number of devices supporting services.
    - Infrastructure devices:
        - Critical V2I device: typically one per lamppost.
        - Non critical V2I device: typically one lamppost per block edge
    - User devices:
        - A fraction (a few tens of percent) has Critical V2X device
        - A fraction (a few tens of percent) has Non-Critical V2X device
        - Typically one user smartphones per person
        - A fraction (a few tens of percent) of users ha personal IoT devices (either integrated in the smartphone or in an independent device).

The following table provides a first attempt to characterize the main traffic parameters to be used for the evaluation of the scenario. However, these values should be refined in the interaction with other project's WPs.

Table B-1 : Example traffic characterization parameters

	V2X critical services			V2X non critical services			Sensor based			
	V2V	**V2P**	**V2I**	**V2V**	**V2P**	**V2I**	**Non critical event driven**	**Critical event driven**	**Periodic**	**Commands**
Nº active devices per scenario	72	576	1140	72	576	1140	360		720	2000
Nº of packets per second	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd
Cardinality	One to few	One to few	One to one	One to many	One to many	One to many	One to one	One to few	One to one	One to many
Proximity level	Hyperlocal	Hyperlocal	Local	Local	Local	Wide area	Wide area	Local	Wide area	Wide area

B.1.3.3. Performance metrics

The following table provides a first attempt to characterize the main traffic parameters to be used for the evaluation of the scenario. However, these values should be refined in the interaction with other project's WPs.

Table B-2 : Example latency targets

	V2X critical services			V2X non critical services			Sensor based			
	V2V	**V2P**	**V2I**	**V2V**	**V2P**	**V2I**	**Non critical event driven**	**Critical event driven**	**Periodic**	**Commands**
Maximum latency	1-5 ms	1-5 ms	1-5 ms	1-10 s	1-10 s	1-10 s	10-100 s	10-50 ms	10-100 ms	10-100 s

In terms of characterization of the performance, for the different applications there are a number of parameters that should be defined.

- Throughput required in the exchange of information between the different actors in the scenario.
- Latency: maximum delay that is consistent with the objectives of the application that is being supported
- Cardinality: whether the communication is intended one to one, one to few, one to many,…
- Proximity: whether the communications are hyperlocal (e.g., to the closest vehicle in the road), local (e.g., to those vehicles within a given distance) or wide area.

B.1.4. Relevance of 5G NORMA innovations

This scenario is expected to be used to validate the two main 5G NORMA technical innovations:

- Multi-service- and context-aware adaptation of network functions: this functionality is required to allow for the support of both use cases considered in the scenario with the same network infrastructure. In other words, while the actual 4G technologies for massive MTC and V2X (although it is not clear that 5G V2X requirements can be met with LTE V2X), in order to coexist, the only solution possible would be the use of overlay networks, each one dedicated to each of the use cases or applications.
- Mobile network multi-tenancy: in the scenario proposed several operational frameworks are possible, including those that imply different kinds of multi-tenancy, like having different operators for parts of the radio access network or for the backhaul (e.g., using city council internal transport network).

B.2. Flexible Service

In this scenario a user switches between two vastly different services, namely between use cases real time remote computing and enhanced mobile broadband.

B.2.1. Justification

Both use cases represent different trade-offs: While real time remote computing needs to ensure low latency on the application layer, while data rates are rather low, so that resource efficiency is less important. In contrast, the latter is of utmost importance to enhanced mobile broadband, which can very well tolerate significant jitter and latency. This latency tolerance also allows to use multiple carriers and antenna sites, because the incurred added latency to reroute packets between antenna sites and/or additional latency for packet reordering can be tolerated.

B.2.2. Applications

As an example application, a mobile user that first does online video gaming, which falls under real time remote computing, decides to switch to watching a movie in HD, i.e. to enhanced mobile broadband, or vice versa.

B.2.3. Simulation model

B.2.3.1. Deployment and channel model

- Heterogeneous urban macro, several small cells per macro, equipped with mm-wave
- Both indoor and outdoor users, indoor being stationary/pedestrian (3 km/h), outdoor a mixture between vehicular and pedestrian
- Variable load split between online gaming and video streaming, with an emphasis on video streaming

B.2.3.2. Traffic model

- Video streaming
  - high data rate, adaptive rate
  - latency tolerant with soft deadlines in the order of hundreds of milliseconds
- Online gaming
  - low data rate, fixed rate
  - low latency with hard deadline in the low tens of milliseconds

The user density is typically in the order of tens of (active) users per cell.

B.2.3.3. Performance metrics

The minimum rates and packet loss events determine objective technical quality (QoS), while the CDFs may help to derive the subjective user perceived quality (QoE).

- Video streaming
  - minimum rate as averaged over buffer size worth of data (determines minimum quality)
  - CDF of rates as averaged over buffer size worth of data
- Online gaming
  - frequency and/or fraction of loss events (a loss event is a burst of lost or late packets)

CDF of loss events

B.2.4. Relevance of 5G NORMA innovations

Both multi-service adaptation and multi-tenancy are needed for best support:

- Multi-service- and context-aware adaptation of network functions: this functionality is required to allow for the support of both uses cases considered in the scenario with the same network infrastructure. In other words, were the actual 4G technologies (although it is not clear that online gaming requirements can be met with tem), in order to coexist the only solution possible would be the use of overlay networks, each one dedicated to each of the use cases.
- Mobile network multi-tenancy: in the scenario proposed several operational frameworks are possible, including those that imply different kinds of multi-tenancy, like having different operators for parts of the radio access network, e.g. mm-wave small cells vs. macro coverage layer, as well as for providing content, e.g. OTT as Netflix, Amazon, Hulu for video streaming vs. the user’s default (virtual) mobile network operator for online gaming.

B.3. Traffic Jam caused by Open Air Festival

B.3.1. Justification

This scenario combines use cases that deal with unusual increases in demand, and how the network should adapt and reconfigure itself to handle them. The open-air festival will bring 100.000 people to a remote rural area, most likely causing traffic jams on the nearby cities. Traffic jams require short-term dynamic reconfiguration, while a festival represents planned reconfiguration with a diversity of end-users and devices. One of the main goals of 5G will be to have the capacity to serve “1000 times higher mobile data volume per geographical area”, “100 times more connected devices” and “100 times higher typical user data rate” [5GPPP]. All of those new performance requirements come into play with these use cases.

B.3.2. Applications

The applications considered in this scenario are:

- Customers stuck in the traffic jam want to access infotainment options, either on their end-user devices (smartphones, laptops, tablets) or on in their internal vehicle multimedia system.

- Traffic jams also lead to an increase in calls, as people stuck in traffic will notify other people about their situation.
- People attending the festival use their smartphones to access the Internet, check social networks, get information about the festival, and upload photos and videos of the event.
- The festival organizers can use broadcast and multicast services to inform the attendees about the schedule of different performances, give out safety tips, and promote sub events and opportunities that will occur throughout the festival.
- Local businesses and event organizers set up a supporting infrastructure, consisting of garbage collection, waste management, food and beverages, security and emergency personnel, all of which use different sensors and machines to provide their services.
- Emergency and security services require good and reliable wireless communications to be able to provide a safe experience for the attendees. This means sensors, surveillance cameras, surveillance drones, and handheld radios are going to be use during the festival.

B.3.3. Simulation model

B.3.3.1. Deployment and channel model

In order to provide more details about the scenario being described here, models for the traffic jam and the open-air festival are given in this section.

A traffic jam can be modelled as the number of cars in a segment of a city avenue for a certain period. Let us assume a city block with a typical length in the order of hundred meters, a multi-lane avenue, a typical car length of a few meters, and a separation between cars in the order of one meter. During a traffic jam, each block edge will have several tens of cars. For an avenue of one kilometre, accordingly several hundreds of cars are going to be stuck. Each vehicle has a number of users.

The environmental conditions for the open-air festival as a whole are:

- Location: A remote open rural area
- Size: in the order of a square kilometre
- Number of attendees in the order of hundreds of thousands of people
- Duration: a few days
- Event Type: multi-stage music festival

As a model for this part of the scenario, a section of the festival can be modelled:

- A small stage
- In the order of one thousand square meters in front of the stage for the audience
- A few thousand people watching a show
- 3 surveillance cameras
- A number of support crew, consisting of a number of paramedics and security guards (in the order of ten in total)
- An area with food and beverage stands, portable toilets and bins. This area will have sensors and machines

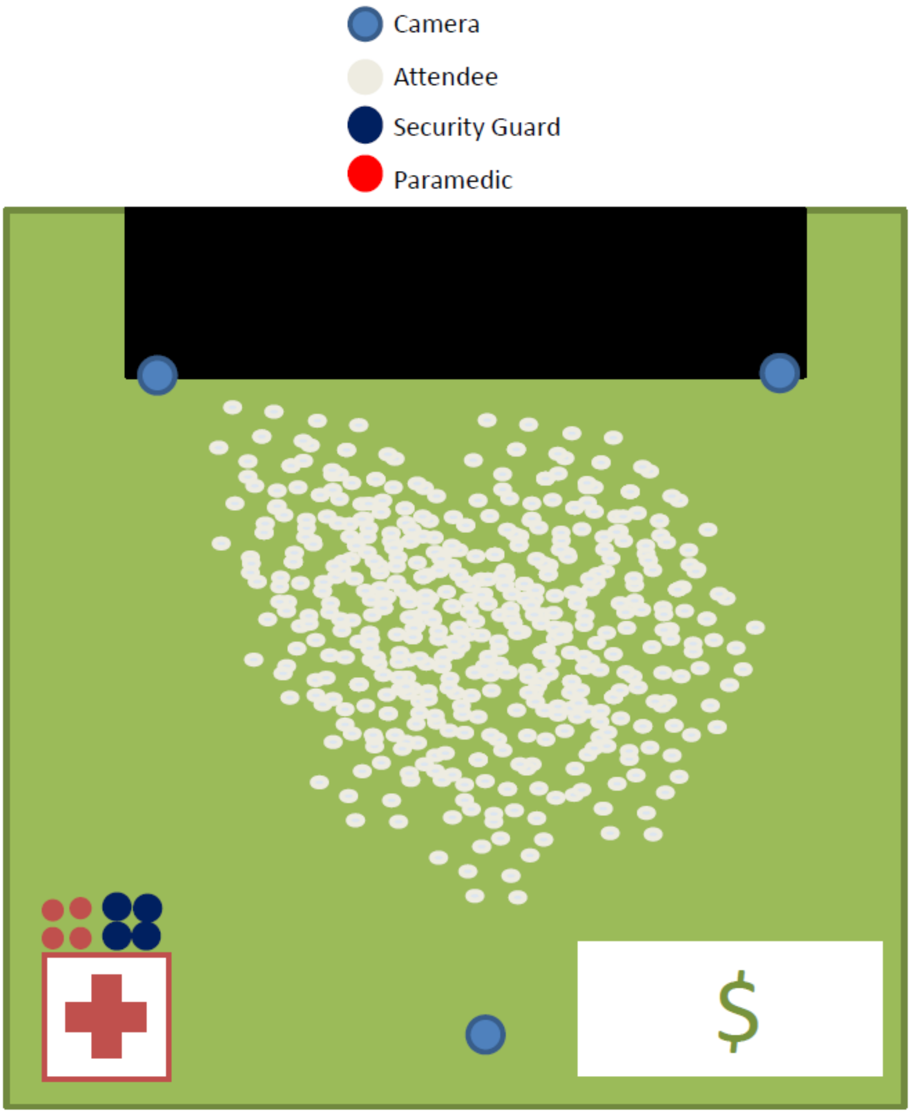

Figure B-14: Example scenario model.

B.3.3.2. Traffic model

In this section, the network traffic conditions will be detailed. Coupled with the previous section, this should give an overview of the scenario, especially in terms of the demands the network will have to meet.

For the traffic jam, the traffic conditions are:

- Connection density is typically lower than of one per square meter
- A few thousand users, one device per user
- Very low (at most a few km/h) user mobility
- Traffic type is human, i.e. video stream, internet access, voice services
- High data rate but latency tolerant (a few hundreds of milliseconds)

Traffic conditions for the festival model are:

- Connection density and number of user devices are similar to the traffic jam conditions
- Several tens of machines and sensors: per several tens of users
- User Mobility: static or very low

- Traffic type is human, i.e. video stream, internet access, voice services, additionally machine and sensor communication
- High data rate (tens of Mbps) per user

B.3.3.3. Performance metrics

- End-to-end latency should be below one second for most machine/devices
- Delivery of delay tolerant data in less than in the order of ten minutes with high probability

B.3.4. Relevance of 5G NORMA innovations

As it pertains to 5G NORMA innovations, the reasons behind this scenario are as follows:

- Multi-tenancy can be supported by this scenario, especially in the open-air festival. Multiple operators maybe come together to offer their services to the crowd. The event organizers and local businesses can use the network to give the attendees a better experience. Finally, emergency and security services can guarantee the safety of everybody in the festival using the network infrastructure deployed for the event.
- Multi-service- and context-aware adaptation of network functions is fundamental for supporting both of these use cases. Traffic jams will require reconfiguration of network functions, and dynamic reallocation of network resources to deal with the demand increase. Network functions will moved to the edge of the network, since meeting the delay and bandwidth demands of the traffic jam and the festival will not be possible if services are only offer by the network cloud. While the network traffic of the jam will focus mostly in data and video, the festival will have a variety of different traffic requirements (video, voice, data, machine, broadcast and multicast). This means that network functions will have to be highly adaptable.