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Abstract

This deliverable continues reporting on use case and requirements definition. Requirements and key performance indicators selected for 5G NORMA have been compared with those defined for use cases in other 5G PPP projects and consistency has been checked. We describe an evaluation framework for use case validation and architecture design verification within which work package overarching activities shall contribute to a final proof of concept of 5G NORMA key innovations. This report also summarises the results of our initial network cost model based on a non-virtualised 5G RAN in a single- and multi-tenant scenario for enhanced mobile broadband services. We set out the progress we have made in developing the set of scenarios and inputs for the fully virtualised 5G network cost model, including network design requirements, spectrum availability, spectrum efficiency, back-/fronthaul requirements, unit costs and service requirements such as latency, reliability and throughput. We also present our progress on assessing the economic benefits of 5G in relation to the use cases defined in Deliverable D2.1, including a full qualitative analysis of business models and initial revenue predictions for a limited set of services.

Keywords

5G, Socio-economic Benefits, Economic Validation, Network Cost Modelling, Scenarios, Business Models, Network Elements, Network Design Requirements, Performance Requirements, Services, Revenues, Demand, Use Case Validation, Architecture Design Verification

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

PU = Public

Executive Summary

This document reports on the current progress on the economic and social analysis in 5G NORMA. It covers the analysis of use cases, potential business models and the services within them, that require the new capabilities that 5G networks can provide and whose performance requirements the 5G NORMA architecture will aim to meet. Deliverable D2.1 [5GN15-D21] first reported on use cases and requirements and here we provide our final results in this area.

Within 5G NORMA, a methodology for use case validation and architecture design verification has been established. In order to assess the different business models that can benefit from a 5G NORMA architecture so-called evaluation cases are developed in this document. These will be the basis of a consistent methodology that can be used across different work packages within the 5G NORMA project. In a two phase approach we evaluate network economics on the benefits of architectural alternatives which come up with the approach considered in 5G NORMA. In Phase 1 analysis described in this deliverable in detail we consider the savings a multi-tenant 5G NORMA architecture delivers over a number of single-tenant networks serving the same level of traffic demand based on an evolved LTE network architecture with enhanced sharing capability. For Phase 1 we take into account predicted increases in spectrum availability and spectrum efficiency to the year 2030 and trying to capture as much of the essence of a 5G NORMA RAN architecture as possible. This report demonstrates that the RAN costs for four operators sharing one 5G network are 41% less than that for four identical single-tenant networks, each carrying 25% of the traffic of the shared network. The cost saving is lower, but still substantial at 27%, when only 2 operators share a network. Phase 2 analysis will consider additional benefits when more flexibility of the 5G NORMA architecture is assessed.

In addition, this document sets out the evaluation cases that are proposed to assess the benefits of 5G NORMA architecture innovations, in future analysis, and which will be used as the basis of the functionality of the network cost model which is currently being developed. A set of evaluation cases is proposed for use in subsequent economic evaluations of the 5G NORMA architecture. These will be used to define multi-service scenarios to be used in future 5G networks and economic modelling in the 5G NORMA evaluation. We present an approach (for Phase 2) to model the network infrastructure for the 5G NORMA architecture, including approaches to accommodate the different air interface and network infrastructure (virtual) utilisation at different network nodes between antenna sites and core network.

As a preliminary analysis, this deliverable presents our initial evaluation of potential 5G network costs and revenues (which will be expanded in Deliverable D2.3) and a qualitative assessment of potential social benefits. This and upcoming results of economic analysis will be part of a comprehensive use case analysis verifying KPIs from user perspective and architecture design verification from a network point of view.

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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
A/D	Analogue to Digital
AI	Air Interface
API	Application Programming Interface
AR	Augmented Reality
ARM	Advanced RISC Machines
ARPU	Average Revenue Per User
ARPS	Average Revenue Per Subscriber
BS	Base Station
BBU	BaseBand Unit
BMS	Broadcast Media Service
CAGR	Compound Annual Growth Rate
CAPEX	CAPital EXpenditure
CCTV	Closed Circuit TeleVision
CDN	Content Distribution Network
cmW	Centimetre Wave
CN	Core Network
CP	Control Plane
CPRI	Common Public Radio Interface
C-RAN	Centralized or Cloud-based Radio Access Network
D2D	Device-to-Device
D/A	Digital to Analogue
DL	DownLink
D-RAN	Distributed Radio Access Network
DRSC	Dedicated Short Range Communications
DSL	Digital Subscriber Line
DSP	Digital Signal Processor
E2E	End-to-End
EC	European Commission
EM	Element Manager
eMBB	Enhanced Mobile BroadBand
EMC	Electromagnetic Compatibility
ETSI	European Telecommunications Standards Institute

ETWS	Earthquake and Tsunami Warning System
EU	European Union
FCAPS	Fault, Configuration, Accounting, Performance, Security
FD	Full Dimension
FFT	Fast Fourier Transform
FMC	Fixed Mobile Convergence
FPGA	Field-Programmable Gate Array
FTTH	Fiber To The Home
GDP	Gross Domestic Product
H2020	Horizon 2020
HD	High Definition
HW	HardWare
ICT	Information and Communication Technologies
IMS	IP Multimedia Subsystem
InP	Infrastructure Provider
KPI	Key Performance Indicator
LTE	Long Term Evolution
Lx	Layer x (L1=Layer 1, L2=Layer 2 L3=Layer 3, L4=Layer 4)
MANO	MANagement & Orchestration
MBB	Mobile BroadBand
METIS	Mobile and wireless communications Enablers for the Twenty-twenty Information Society
MIMO	Multiple Input Multiple Output
M-MIMO	Massive MIMO
MME	Mobility Management Entity
mmW	Millimetre Wave
MNO	Mobile Network Operator
MTC	Machine-Type Communication
mMTC	Massive Machine Type Communication
MVNO	Mobile Virtual Network Operator
NBI	NorthBound Interface
NEM	Network Element Manager
NF	Network Function
NFFG	Network Function Forwarding Graph
NFV	Network Functions Virtualisation
NIST	National Institute of Standards and Technology
NGMN	Next Generation Mobile Networks Alliance
NLoS	Non-Line of Sight
NPV	Net Present Value
NS	Network Service

NW	NetWork
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	OPerational EXpenditure
ORI	Open Radio equipment Interface
OSS	Operations Support System
OTT	Over The Top (player)
PA	Power Amplifier
PCRF	Policy and Charging Rules Function
P-GW	Packet Data Network GateWay
PNF	Physical Network Function
PoC	Proof of Concept
PoP	Point of Presence
PPDR	Public Protection and Disaster Relief
QoE	Quality Of Experience
QoS	Quality Of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
RG	Requirements Group
RISC	Reduced Instruction Set Computing
RRU	Remote Radio Unit
RSU	Road Side Unit
SBI	SouthBound Interface
SDM-C	Software-Defined Mobile network Control(-ler)
SDM-O	Software-Defined Mobile network Orchestrator
SDM-X	Software-Defined Mobile network Coordinator
SDN	Software Defined Networking
SDO	Standards Developing Organization
SINR	Signal to Interference plus Noise Ratio
S-GW	Serving GateWay
SLA	Service Level Agreement
SON	Self Organising Networks
SW	SoftWare
TC	Transport Class
TCO	Total Cost of Ownership
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TTM	Time to Market
UHD	Ultra High Definition

UICC	Universal Integrated Circuit Card
UL	UpLink
uMTC	Critical Machine Type Communication
UP	User Plane
USIM	Universal Subscriber Identity Module
V2I	Vehicle to Infrastructure
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
V2X	Vehicle to X (Vehicle/Pedestrian/Infrastructure)
VIM	Virtual Infrastructure Manager
VNF	Virtualized Network Function
VoIP	Voice over IP
V-RAN	Virtualized Radio Access Network
WAN	Wide Area Network
WLAN	Wireless Local Area Network
WP	Work Package
WRC	World Radio Conference
XaaS	X as a Service (Network/Platform/Infrastructure/Software/…)
xMBB	Extreme Mobile Broadband

1 Introduction

This document reports on the current progress on the economic and social analysis in 5G NORMA. It covers the analysis of the use cases, potential business models and the services within them, that require the new capabilities that 5G networks can provide and whose performance requirements the 5G NORMA architecture will aim to meet. The 5G NORMA Deliverable D2.1 [5GN15-D21] first reported on use cases and requirements and here we provide our final results in this area.

In this document we also evaluate some network economics on the benefits of different sharing possibilities of an evolved 4G network architecture. The output of that evaluation will be the basis for comparison of the 5G NORMA architecture with the current LTE network in future reports (IR2.2 and D2.3).

This document also establishes the evaluation cases that can be used to assess the benefits of 5G NORMA architecture innovations, in future analysis, and which will be used as the basis of the functionality of the network cost model which is currently being developed. As a preliminary analysis, this deliverable presents our initial evaluation of potential 5G network costs and revenues (which will be expanded in future deliverables) and a qualitative assessment of potential social benefits. This analysis will be used both for the economic validation of some of the innovations of a 5G NORMA architecture (as has been discussed in Deliverable D3.1 [5GN15-D31] which sets out the overall validation and architecture verification framework) and an economic validation of the use cases / potential for 5G services – a quantitative and qualitative assessment of the potential economic and social benefits. Given the level of uncertainty around future 5G services, our quantitative assessment will be indicative, however we believe it will be possible to get a good assessment of the scale of the potential economic and social benefits of 5G, in particular the incremental impact in relation to the status quo (i.e. if 5G were not introduced) and how the economic and social benefits compare to the estimated costs of a 5G NORMA architecture.

1.1 Objective of the document

The objective of this document is to present the framework for the socio-economic analysis and the initial results of our network cost and economic benefits modelling based on an evolved 4G network architecture. Deliverable D2.1 provided the foundations for the work of the other work packages (WPs) in the project in order to develop the end-to-end (E2E) 5G network architecture. In this document we present the approach proposed to perform the network cost modelling of a network architecture able to evaluate the innovations being developed within 5G NORMA.

2 Final results on use cases and specification of requirements

In developing the E2E architecture, this project adopted the usual top down approach methodology, also employed by other projects and Standards Developing Organizations (SDOs), of identifying relevant use cases, and deriving requirements to initiate the network architecture design process. In this sense, it has identified, from a set of twelve 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.

The twelve uses cases defined by 5G NORMA in D2.1 build on those developed by NGMN, METIS and 3GPP. The idea has not been to present an exhaustive collection of use cases but to 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 a 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 functional 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,
- Quality of experience/quality of service (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 (MTC); **high throughput** (compared to legacy networks) for massive Mobile BroadBand (MBB) communication and the ability to support **high volumes of devices** for massive MTC (mMTC).

One of the objectives of the current deliverable is the consolidation of the use cases and the functional requirements that are used for the definition of the architecture, as well as the performance requirements that will be used for the validation of the 5G NORMA architecture. For these purposes, the requirements and key performance indicators (KPIs) from other relevant projects have been analyzed. Since 5G NORMA D2.1 was released, different 5G PPP projects have produced deliverables where they collect the use cases and requirements that they are using for the development of the different technological solutions they are addressing. Although other projects have also been considered (e.g., 5G-CrossHaul), we have focused in the analysis of four projects, namely mmMAGIC, FANTASTIC-5G, METIS-II and 5G-XHaul. In the next section, we briefly present their main results in this area. Then, in section 2.2 we analyse them in order to assess whether there are use cases and requirements that they have considered that may affect the 5G network architecture and that have not been taken into account by 5G NORMA up to now. In section 3 we describe the evaluation framework, including the methodology for use case validation and architecture design verification which build the pillars for a final PoC for 5G NORMA key innovations. More details on the technical part can be found in Deliverable D3.1 [5GN15-D31] and the upcoming Deliverable D3.2.

2.1 Review of the approach from other relevant projects

In this section we present a brief review of the work carried out by other 5G PPP projects regarding use cases, requirements and KPIs. We have chosen not to focus on projects that aim to develop the components of the network architecture, but rather on those that will provide the inputs in terms of the functionalities and performance that the network should provide. In this sense, we have chosen the two main projects dealing with the definition of the new radio interface for low frequencies (FANTASTIC-5G) and high frequencies (mmMAGIC), one of the projects devoted to the convergence of fronthaul and backhaul (5G-XHaul), and the METIS-II project, which aims to define the Radio Access Network (RAN) design for 5G. This selection, is influenced by consistency in the project methodology and whether the relevant deliverables are public or not.

It should be noticed that not all the projects share the same terminology, so we have tried to provide the definitions of the terms used and the potential equivalences with the terms employed by 5G NORMA.

2.1.1 mmMAGIC

The mmMAGIC project’s main objective is to develop and design new concepts for mobile radio access technology (RAT) for deployment in the 6-100 GHz range.

Although the methodology adopted is quite similar to the one used by 5G NORMA, it should be highlighted that the terminology used by the mmMAGIC project is different from the one of 5G-XHaul. A use case is defined as a “general account of a situation or course of actions that may occur in the future. It is described from end-user perspective and illustrates fundamental characteristics. In order to have a more concrete description, the challenges are described by means of representative use cases that contain a set of assumptions, constraints, and requirements.” For mmMAGIC, a KPI is a “quantifiable measurement that reflects the critical success factors of a proposed solution; it reflects the goals captured by each use case. The KPIs are related to the use case in order to link the proposed solutions with the usage driven test cases.” On the other hand, a requirement is defined as the quantified need for each KPI. For example: If the KPI is delay the requirement could be 10 ms.

In its internal report IR3.1 [mmM16-IR31], the mmMAGIC project considers four families of use cases, with several use cases associated with each family. A total of eight individual use cases has been analysed.

- Broadband access in a dense area:
  - Use Case 1: Media on demand,
  - Use Case 2 Cloud services,
  - Use Case 3: Dense urban society with distributed crowds,
  - Use Case 4: Smart offices,
  - Use Case 5: Immersive early 5G experience in targeted coverage.
- Broadband access everywhere:
  - Use Case 6: 50+ Mbps everywhere.
- High mobility users:
  - Use Case 7: Moving hot spots.
- Extreme real time or ultra-reliable communication
  - Use Case 8: Tactile Internet, remote surgery

For each individual use case a number of KPIs have been identified including:

- User data rate in uplink/downlink (UL/DL),
- Connection density,
- Traffic density,
- Mobility,
- Availability,
- Latency.

For each use case the requirement is the value defined for each KPI. In the following table, the main challenges (characterized as the most critical KPI) for the use cases selected are provided:

Table 2-1: Use cases of mmMAGIC project and main challenges addressed

Use Case	Main Challenge (most critical KPIs)
Media on demand	Peak connectivity density (4000 users/km^2)
Cloud services	DL traffic density (up to 750 Gbps/km2), mobility (up to 100 km/h)
Dense urban society with distributed crowds	Connection density (30,000, up to 150,000 users/km^2), traffic density (7,500 Gbps/km^2), sufficient bandwidth
Smart offices	DL user data rate (1Gbps), traffic density (15000 Gbps/km^2)
Immersive 5G early experience in targeting hot spots	Data rate (x10 average, x20 peak) and cell densification (25 small cells / hotspot area)
50+ Mbps everywhere	Coverage
Moving hot spot	Mobility (up to 500 km/h)
Tactile internet / video augmented robotic control and remote control manipulation surgery	Availability and reliability (99.999%), low latency (1ms)

By analysing it in a critical way, the advantages and the challenges of using millimetre Wave (mmW) frequency bands to address the described KPIs are derived as well as some directions to be followed in order to design a common technology.

2.1.2 FANTASTIC-5G

The objective of FANTASTIC-5G is to develop a new multi-service Air Interface (AI) for below 6 GHz through a modular design. To allow the system to adapt to the anticipated heterogeneity, the pursued properties are: flexibility, scalability, versatility, efficiency and future-proofness.

In IR2.1 [F5G15-IR21], from an initial set of 24 use cases based on the output from different sources, like NGMN and METIS/METIS II, the project has identified a reduced set of seven use cases:

- Use Case 1: 50 Mbps everywhere MBB,
- Use Case 2: High speed train MBB + Vehicle to Anything (V2X),
- Use Case 3: Sensor networks MTC,
- Use Case 4: Tactile Internet MTC,
- Use Case 5: Automatic traffic control / driving MTC + V2X,
- Use Case 6: Broadcast like services: Local, Regional, National Broadcast Media Service (BMS),
- Use Case 7: Dense urban society below 6 GHz MBB.

It should be noted that the selection of the use cases is affected by other factors beyond the interest to address only 5G representative applications. These include e.g. the fact that use case simulations can be carried out using simulators that are available in the framework of the project.

The project has also selected a set of KPIs:

- KPI 0: User experienced data rate,
- KPI 1: Traffic density (to achieve high system capacity),
- KPI 2: Latency,
- KPI 3: Coverage (to provide ubiquitous access),
- KPI 4: Mobility,
- KPI 5: Connection density,
- KPI 6: Reliability/availability,
- KPI 7: Complexity reduction,
- KPI 8: Energy efficiency.

For each of the use cases, FANTASTIC-5G has set the corresponding values for the KPIs and has also characterized them in terms of User Experience KPIs (0, 2, 3, 4, 6 in the list above) and System Performance KPIs (1, 5, 7, 8). The User Experience KPIs directly impact the QoS and the overall QoE for the user of a given service, whilst the System Performance KPIs mostly relate to the service delivery efficiency from the mobile network operator’s (MNO’s) perspective.

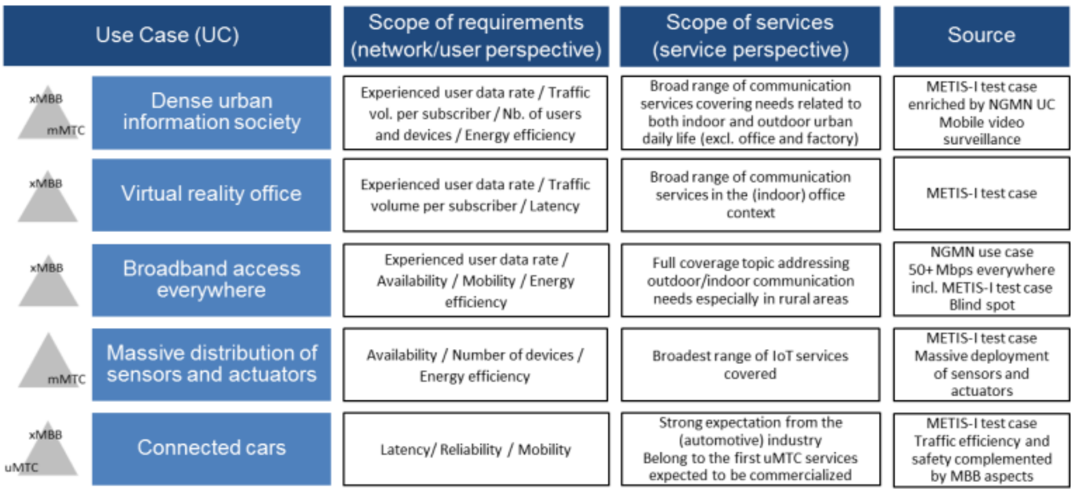
The project has also classified the KPIs for each use case in terms of relative importance as primary, secondary or tertiary.

2.1.3 METIS-II

Three use case families are considered as the corner stones, where each use case addresses at least one use case family. These three use case families are contained in the system concept of the METIS project (and are referred to as generic services). In [MET15-D66] they are e.g. described as follows:

- Extreme Mobile BroadBand (xMBB) provides both extreme high throughputs and low latency communications, and extreme coverage improving the QoE by providing reliable moderate rates over the coverage area.
- Massive Machine-Type Communications provides wireless connectivity for dozens of billions of network-enabled devices (in the order of 100 000 per access point). Scalable connectivity for an increasing number of devices; wide area coverage and deep indoor penetration are prioritized over peak rates as compared to xMBB.
- Ultra-reliable Machine-Type Communications (uMTC) provides ultra-reliable low-latency and/or resilient communication links for network services (NSs) with extreme requirements on availability, latency and reliability, e.g. V2X communication and industrial control applications.

However, METIS-II considers that only a common RAN that accommodates all three service types is an economically and environmentally sustainable solution. For this reason, the METIS-II RAN design is performed specifically towards a set of 5G use cases that typically combine multiple service types. More precisely, the project has performed an analysis of the 5G use cases considered by various entities, classified them into families considering the special characteristics of these (e.g., covered services, mobility, and/or number of users, infrastructure, etc.), and chosen five use cases that are seen as most representative of these different families. Figure 2-1 provides an overview of the complementary requirements and service scopes addressed by each use case and thus describes the motivation for selecting each of them [MII16-D11].



Use Case (UC)		Scope of requirements (network/user perspective)	Scope of services (service perspective)	Source
xMBB mMTC	Dense urban information society	Experienced user data rate / Traffic vol. per subscriber / Nb. of users and devices / Energy efficiency	Broad range of communication services covering needs related to both indoor and outdoor urban daily life (excl. office and factory)	METIS-I test case enriched by NGMN UC Mobile video surveillance
xMBB	Virtual reality office	Experienced user data rate / Traffic volume per subscriber / Latency	Broad range of communication services in the (indoor) office context	METIS-I test case
xMBB	Broadband access everywhere	Experienced user data rate / Availability / Mobility / Energy efficiency	Full coverage topic addressing outdoor/indoor communication needs especially in rural areas	NGMN use case 50+ Mbps everywhere incl. METIS-I test case Blind spot
mMTC	Massive distribution of sensors and actuators	Availability / Number of devices / Energy efficiency	Broadest range of IoT services covered	METIS-I test case Massive deployment of sensors and actuators
xMBB uMTC	Connected cars	Latency/ Reliability / Mobility	Strong expectation from the (automotive) industry Belong to the first uMTC services expected to be commercialized	METIS-I test case Traffic efficiency and safety complemented by MBB aspects

Figure 2-1: METIS-II 5G use cases and scopes in terms of requirements and services (from [MII16-D11]).

The main KPIs and requirements of the METIS-II use cases [MII16-D11] are given in the following table:

Table 2-2: Use cases of METIS-II project and main requirements (KPIs) addressed.

Use Case (UC)	Key Performance Indicator (KPI)	Requirement
UC1 Dense urban information society	Experienced user throughput	300 Mbps in DL and 50 Mbps in UL at 95% availability and 95% reliability
	E2E RTT latency	Less than 5 ms (augmented reality applications)
UC2 Virtual reality office	Experienced user throughput	5 (1) Gbps with 20% (95%) availability in DL 5 (1) Gbps with 20% (95%) availability in UL both with 99% reliability
UC3 Broadband access everywhere	Experienced user throughput	50 Mbps in DL and 25 Mbps in UL at 99% availability and 95% retainability
UC4 Massive distribution of sensors and actuators	Availability	99.9%
	Device density Traffic volume per device	1 000 000 devices/km^2 From few bytes per day to 125 bytes per second
UC5 Connected cars	E2E one-way latency	5 ms (traffic safety applications)
	Experienced user throughput	100 Mbps in DL and 20 Mbps in UL (service applications) at 99% availability and 95% reliability
	Vehicle velocity	Up to 250 km/h

These use cases, along with their key requirements, are illustrated in Figure 2-2 [MII16-D11]:

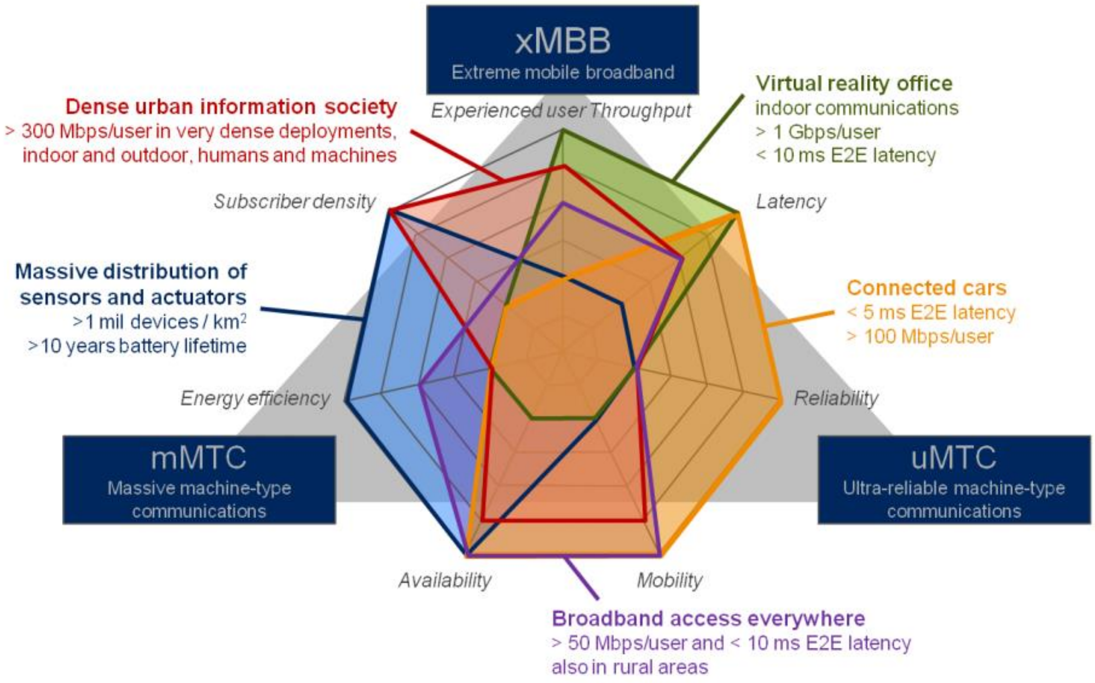


Figure 2-2: The METIS-II 5G use cases and their mapping to the 5G services (from [MII16-D11]).

METIS-II is continuing working on 5G business models, with a quantitative techno-economic feasibility assessment and the proposal of cost and profit sharing strategies between the different 5G RAN actors.

2.1.4 5G-XHaul

In their Deliverable D2.1 5G-XHaul [5GX15-D21] established the basis for the design process of the 5G-XHaul solution, based on identifying relevant use cases, and deriving requirements to start the network architecture design process. However, given the characteristics of 5G-XHaul, which is focused on the transport infrastructure of 5G networks, two kinds of use cases have been identified, namely **end-user use cases** and **operator use cases**. In the former, the actor that plays the role of the user is the end-user consuming 5G services (either a human being or machine), whereas in the latter, the role is adopted by the operator, service provider or enterprise that obtains connectivity services from the transport infrastructure and uses the services developed and provided by 5G-XHaul. For both kinds of use cases the associated requirements have been identified, which help to identify the functionalities that must be supported by the 5G-XHaul transport infrastructure as well as the performance expected from the system in terms of capacity, latency and jitter. The distinction between the two use case classes is illustrated in the following figure:

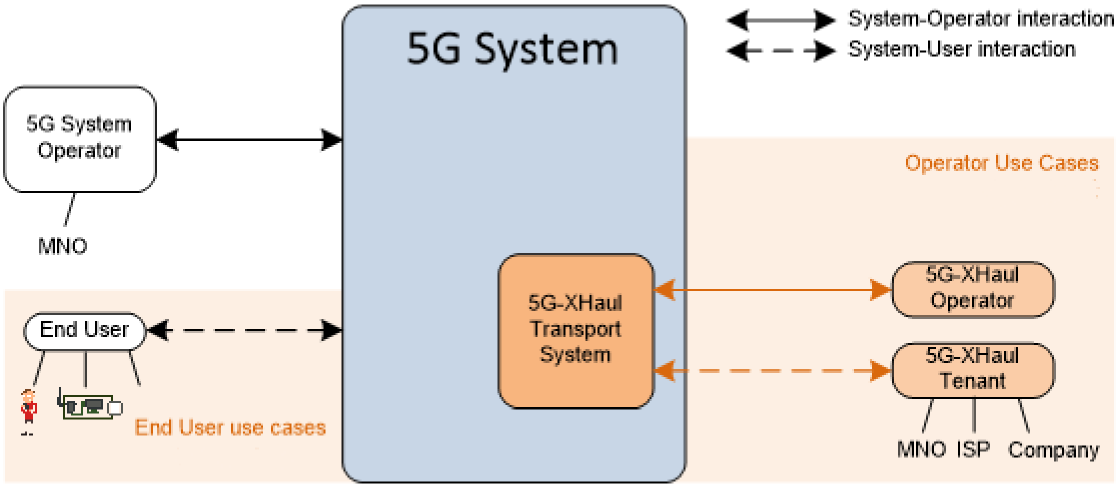


Figure 2-3: Actors involved in the different kinds of 5G-XHaul use cases (from [5GX15-D21]).

In terms of performance to be supported by the transport network, it should be noticed that the requirements for 5G-XHaul will not only arise directly from the end-user use cases and the operator use cases, but also from the physical layer requirements, such as latency, jitter, and overall capacity, that will be defined by the proposed RATs for 5G systems, currently being designed by other 5G PPP projects. In addition, it should be noted that the transport network limitations may become a critical factor when deciding how the network functions are distributed or centralised in the network architecture in order to support different use cases. For this reason, several potential 5G RATs technologies (like the use of massive MIMO or mmW) have been analysed, both from a single transport link perspective as well as from an aggregation transport network point of view. From these requirements, important guidelines for the overall design of the 5G-XHaul transport network have been identified.

5G-XHaul has adopted the following list of use cases, as most relevant. Even though these use cases are not the only ones to challenge the key innovations of the 5G-XHaul solution they lead us towards the system architecture design through the elaboration of the widest possible range of system and user requirements:

1. Cloud Service offerings, including heavy data storage, retrieval, sharing, e.g. mobile/smart office data/services for business users, personal content (Ultra High Definition (UHD) videos, photos) for individuals.
2. High Speed Train and Vehicular data services (e.g. internet/infotainment).

3. Intelligent Transport Services, focusing on safety applications to drivers.
4. Large Number of Sensors and Actuators with relatively low data traffic requirements, e.g. smart cities applications such as environmental monitoring, smart transportation & traffic monitoring systems, smart building/ home/agriculture/metering, smart wearables.
5. Medium Number of Sensors with high data traffic requirements, e.g. surveillance for buildings, nature protected areas, remote facilities including mobile Augmented Reality (AR) applications.
6. On-line Gaming.
7. Tactile Internet, e.g. precisely controlling a drone in a windy environment.
8. Communications Support in case of Natural Disaster Occasions (e.g. earthquakes, tsunamis, floods).
9. Public Safety Communications including critical video applications support.
10. m-Health Applications, including remote surgery, health care remote monitoring, remote diagnosis/virtual visit.
11. Industrial Control and Factory Automation.
12. UHD Video/Photo Sharing in Heavily Crowded Spots (e.g. stadium, concerts).
13. TV Programs Broadcasting over 5G offering UHD experience.
14. Distributed Virtual Orchestra, meeting the musicians' requirements when performing a musical piece, each residing at different remote locations.

On top of these end-user use cases, 5G-XHaul has identified the following operator use cases:

- Op-UC1: Transport Capacity as a Service. This use case describes the ability of a 5G-XHaul tenant to dynamically set the capacity/QoS being provisioned by the 5G-XHaul system, according to foreseeable/planned or unforeseeable events.
- Op-UC2: Multi-Tenancy. A 5G-XHaul operator should be able to sell transport connectivity services to various 5G-XHaul tenants, e.g., MNOs, content distribution companies, large enterprises with dispersed branches/offices, etc.
- Op-UC3: Transport Network Slicing. A 5G-XHaul operator should be able to create slices of his transport network that can be directly controlled by a 5G-XHaul tenant. A 5G-XHaul transport slice is composed of a virtual representation of (a subset of) the physical network elements composing the 5G-XHaul transport network.
- Op-UC4: Multiple-split RAN implementation support. The main goal of 5G-XHaul operator will be to provide connectivity services to MNOs, which may use a heterogeneous set of RAN technologies (2G/3G/4G/5G). In particular, different MNOs may implement different functional splits, where a functional split defines the functionality implemented in a Remote Unit (RU) deployed in the field and a Centralised Unit (CU) centralised in a Data Centre, and possibly virtualised.
- Op-UC5: Seamless Integration with legacy transport technologies. A 5G-XHaul operator should be able to deploy 5G-XHaul network components in a gradual manner, and these components should integrate to legacy transport network components

In order to identify what we call performance requirements, 5G-XHaul has carried out an analysis of the impact of the expected new functionalities to be incorporated in the new 5G RATs on the transport infrastructure. This analysis takes into account different functional splits that may be required to support different use cases. Based on values obtained in this analysis, 5G-XHaul has come up with the identification and definition of a set of Transport Classes (TCs) that may facilitate the support both of the convergence between fronthaul and backhaul as well as the new physical layer requirements from 5G RATs. These TCs are considered a first step in the definition of a network architecture that provides the expected functionalities and performance without incurring unnecessary complexity and cost.

2.2 Consolidation of 5G NORMA requirements, scenarios and KPIs

The objective of this section is to ensure that the requirements coming from other projects are consistent with those defined by 5G NORMA, so the network architecture proposed is able to meet their expectations, both in terms of functionality and performance.

In terms of use cases, the set selected by 5G NORMA covers most the applications of 5G that are considered by other projects – or have similar requirements. In other words, no use case identified by these four projects analysed includes requirements that are not covered by those selected by 5G NORMA. The use cases are also consistent with those considered by 3GPP [3GPP-22891] and ITU-R [ITU-2083].

With respect to the functional requirements posed on the network infrastructure, 5G NORMA shares some basic principles with other 5G PPP projects regarding the need to support multi-tenancy, network slicing and the flexible allocation of functionalities at different network levels. At this point in time it is premature to say that the 5G network architecture is able to support all functional requirements that are associated to the radio interface and transport solutions proposed (given the level of detail available in their description hitherto), but no inconsistency has been identified so far. There are even some potential synergies with some of the solutions proposed by the projects analysed. The introduction of the concept of TCs in 5G-XHaul D2.1, for example, may help to support the adaptability of the transport network capabilities requirement that has been identified by 5G NORMA. The main issue that may arise from the fact that there may be incompatibilities in the specific solutions proposed in terms of, e.g. architecture, protocols, topology.

The performance requirements and KPIs defined by the projects analysed can be classified into two different groups:

- **KPIs associated with the characteristics of the radio interface proposed.** These KPIs translate into requirements for the network infrastructure. Given the spectral efficiency of the AI and the spectrum availability (among other factors), it is feasible to derive the capacity requirements that the network could fulfill. The same reasoning can be applied to other KPIs like latency. It should be however noted, that the values indicated are, so far, targeted objectives to be achieved with the solution proposed.
- **KPIs associated with the expected usage patterns of the different use cases.** These KPIs translate into deployment options that must be feasible from both technical and economic viewpoints. For example, in some of the projects analysed, KPIs for traffic densities of the order of Gbps per square kilometre are proposed. For supporting these traffic densities, a high capillarity/high capacity cell deployment will be necessary, and the transport network should be able to support it in a cost affordable/sustainable way. For these purposes, it is necessary to ensure consistency in the evaluation scenarios used for the validation of the different solutions.

The main conclusions from the analysis carried out are the following:

- The set of use cases that 5G NORMA has selected is adequate, covering the main uses expected in the context of 5G. There is no need to extend the set of use cases to be considered by the project.
- Functional requirements and functional requirement groups identified in 5G NORMA are consistent with those coming from other projects referring to the network architecture (although there are functional requirements that are not relevant to 5G NORMA). However,

this does not guarantee necessarily that the solutions proposed will eventually be compatible – although the fact that the technical approaches adopted exhibit similarities (e.g., adoption of software defined networking (SDN) and network function virtualization (NFV) architectural frameworks to provide flexibility) will certainly help in avoiding potential compatibility issues.

- The consistency in terms of performance requirements and KPIs must be assessed during the validation process. However, the KPIs defined by other projects may help to define 5G NORMA KPIs, as well as orientate the techno-economic evaluation.
- With respect to scenarios, every project has to address the trade-off between what ideally should be validated by simulations or other means (e.g., proof of concept (PoC)) to ensure the project objectives are properly achieved and what is feasible with the resources that are available. In addition, regarding a potential homogenisation of the scenarios between the different projects, it should be noticed that evaluation scenarios for, e.g., radio interface projects may not be adequate for evaluating the network architecture.

3 5G NORMA evaluation framework

Economic evaluation is part of a project wide evaluation framework aiming at a proof of concept for 5G NORMA key innovations. As assumptions should be consistent for evaluations from technical as well as economic point of view, in this section, we introduce a work package overarching methodology including a limited number of evaluation cases that allow for inspection of all relevant evaluation criteria. Evaluation cases in this sense are to be distinguished from use cases and scenarios defined so far as they parametrise and specify evaluation conditions and assumptions. Based on three evaluation cases we have defined first the expected outcome of economic evaluations. Concrete steps for evaluations from technical point of view and expected outcomes will be described in upcoming deliverables of WP3.

3.1 Methodology

It is important that project outcomes are mature and can be handed over to next step realization activities. Therefore, the fulfilment of end user requirements is checked by a comprehensive use case validation and the fulfilment of technical and economical requirements is checked by architecture design verification.

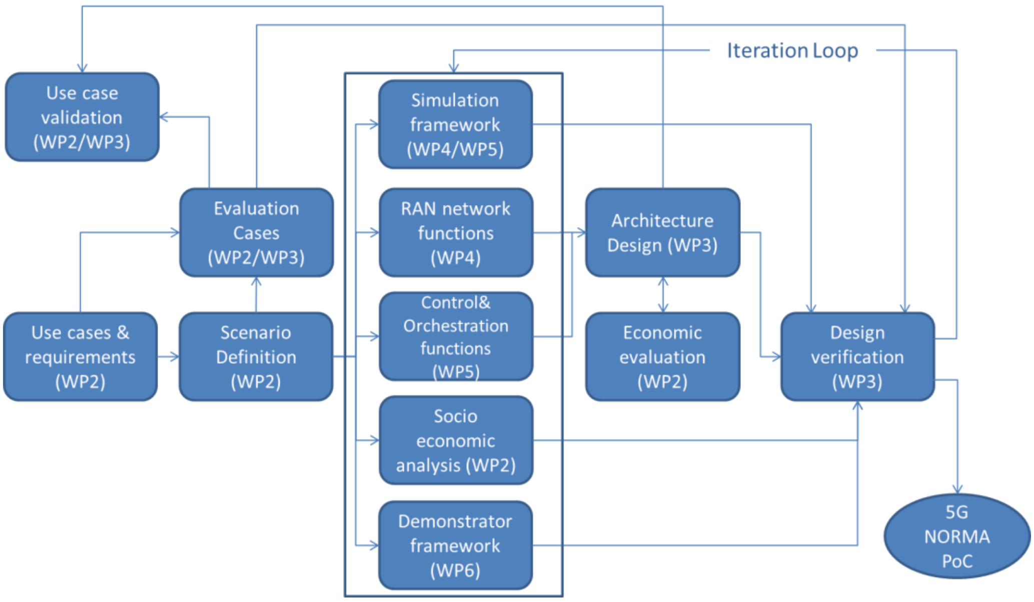


Figure 3-1: Methodology for use case validation and architecture design and design verification.

The interrelation of activities to be carried out by the different WPs is depicted in Figure 3-1. As can be seen these evaluation activities are WP overarching and include technical as well as economic aspects. Based on use case and scenarios definitions from Deliverable D2.1 [5GN15-D21] evaluation cases compiling sets of concrete evaluation assumptions have been described in Section 3.2 and Annex C. This common evaluation cases shall ensure that all evaluations are based on unique assumptions and contribute to a consistent PoC of 5G NORMA key innovations.

Results of architecture design will be provided by WP3 as output of a twostep iteration loop. Use case validation checks for the fulfilment of end user requirements defined by the selected use cases (Annex A). Architecture design verification investigates evaluation criteria from network point of view depicted in Figure 3-2. In the following technical evaluation criteria are described as much as needed to give an overview. More details can be found in upcoming deliverables of WP3.

Figure 3-2: 5G NORMA evaluation criteria.

Partner simulation results as well as 5G NORMA demonstrations will contribute to a check of performance requirements. As 5G NORMA is focussing on the architecture aspects, some of performance related information especially in context with novel air interfaces will be taken from other R&I projects. Functional requirements defined in Deliverable D2.1 are to be checked by tools like protocol and protocol overhead analysis, but most of the comparisons are to be executed by qualitative analysis. The same applies for operational and security requirements defined in Deliverable D3.1. The topic "Soft KPI" will include:

- Check for manageable network complexity;
- Check for feasibility of multi-vendor networks (feasible standardisation effort);
- Check for scalability of centrally arranged management functions.

Economic evaluations and the methodology for verification of economic feasibility are detailed in the remainder of this deliverable. The results of the economic modelling will be abstracted so that key trends derived from the modelling will be used to support a web-based GUI as part of the demonstrators for the project.

3.2 5G NORMA evaluation cases

In order to establish a work package overarching verification framework, the definition of evaluation cases is proposed. These evaluation cases build a common basis for checking the fulfilment of functional, operational and performance requirements as well as economic feasibility. Based on the scenario definitions from Deliverable D2.1 [5GN15-D21] two evaluation scenarios have been identified in Deliverable D3.1 [5GN15-D31] that allow for checking the majority of use cases and network related requirements. As the project has progressed, in addition to these scenario definitions, evaluation cases have been introduced that specify evaluation parameters and combine differentiating elements of business models, deployment scenarios and architecture options[2]. The most important differentiators are compiled in Figure 3-3.

[2] For clarification: Use case and scenario definitions were developed to provide the basis for the qualitative and quantitative evaluation and assessment of 5G NORMA key innovations. Evaluation cases extend these by including the impact of different business models and associated network deployment options as well as definition of evaluation parameters.

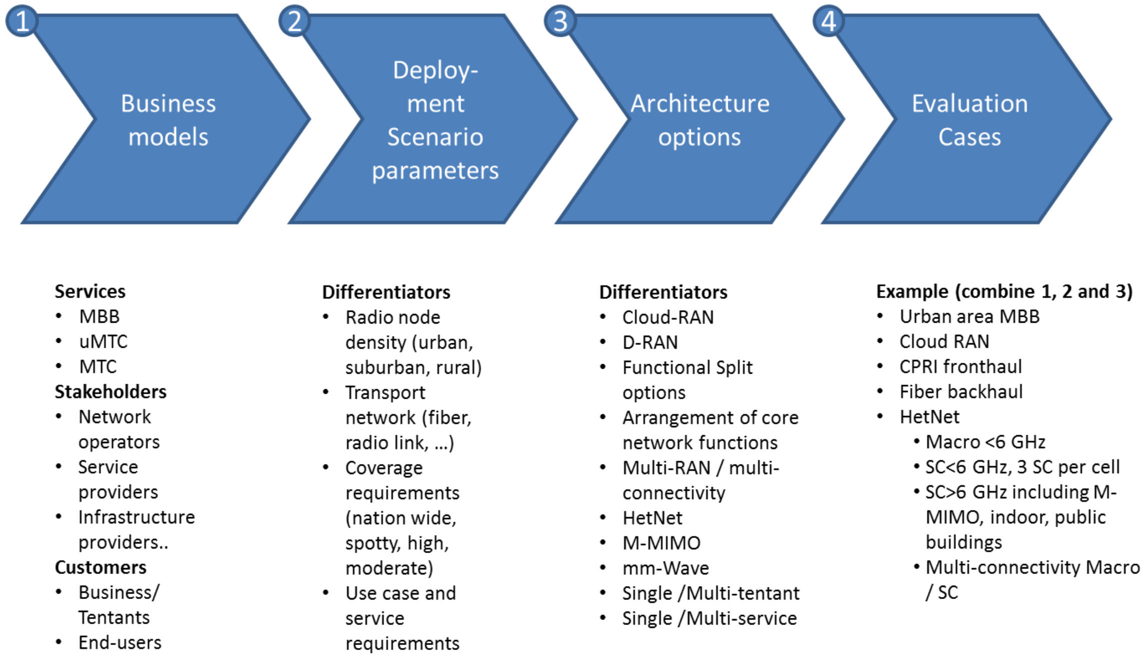


Figure 3-3: Differentiators for definition of evaluation cases.

Business models are distinguished by the services provided, stakeholders included and customer types.

5G generic services MBB, MTC and ultra-reliable MTC (uMTC) have been selected as service differentiators. These services and related use cases can be characterized by specific modelling requirements leading to respective network dimensioning rules that are needed in order to enable meaningful modelling of network costs. The most important requirements are compiled in Table 3-1.

Table 3-1: Requirements to cost modelling caused by generic 5G services

Generic Service	Requirement
MBB	• Mapping of air interface traffic and coverage requirements to antenna sites (base station) density • Mapping of throughput, latency and capacity demand to transport (back-/fronthaul, wide area) and network elements
MTC	• Mapping of increased coverage requirements to antenna site density or demand for multi-connectivity (resilience)
uMTC	• Mapping of increased coverage requirements to antenna site density or demand for multi-connectivity • Increased cost for provisioning of low latency and/or ultra-reliability (edge cloud density, resilience, multi-path linkage)

KPIs for MBB are peak throughput, capacity (data volumes per area), coverage probabilities for indoor and outdoor and mobility performance. In our evaluations, mapping of traffic and coverage requirements to base station density is mostly done by utilization of existing realistic scenarios where in urban areas base station density is mostly coverage driven. Deployment scenarios have to be adapted to growing capacity and coverage demand. Capacity extension may be realized by applying base station densification, technology upgrades (increased spectrum efficiency) or spectrum extension. Basically per site there is a limitation of radiated power for Electromagnetic Compatibility (EMC) reasons. In the multiple operator case, these share the available spectrum but even in this case not all available operator specific spectrum may be deployed at a single site. Moreover as explained later on in this section, for coverage and reliability reasons it would be favourable to deploy frequency band specific site grids. For capacity extension macro site densification can be realized by increased sectorisation. We assume that up to 6 sectors per site can be deployed where increased sectorisation can be realized using active antennas that are standardized in context with the 3GPP study item on full dimension (FD) MIMO [3GPP-36897]. As further macro site densification may be limited by technical (interference) and economic reasons (site cost) small cell (SC) layers will play an important role. First roll out of SCs is assumed to be at frequency bands below 6 GHz. For interference reasons the number of SCs per macro sector should be limited to ≤5. SCs should be favourably deployed at frequencies around 3.5 GHz where part of this spectrum can also be deployed at macro sites. SCs are deployed below rooftop where sectorisation in most cases is not favourable[3]. Outdoor wall mounted SC deployments could benefit from FD-MIMO application especially with horizontal beamforming[4] [3GPP-36897].

In order to provide future multiple Gbps MBB peak data rates SCs at frequency layers > 6 GHz will play a major role. The new radios may enable indoor and outdoor coverage at traffic hot spots in public and residential domains. Massive MIMO (M-MIMO) will enable multi-user (MU) separation and may be economically feasible at public hot spots (indoor and outdoor). These SCs may be mainly operated by network operators whereas femto cells operated at higher frequency layers in residential indoor environments may be subscriber owned and may be excluded from cost modelling.

Transport networks in form of backhaul, fronthaul as well as wide area networks connecting network cloud infrastructures will play a most cost sensitive role in future network architectures. Hence careful assumptions have to be made during our evaluations. Sensitivity analysis for these assumptions could help to get a feeling of the impact on final costs.

mMTC will require the network to be able to connect to huge number of devices and provide increased coverage probability. In 5G networks huge number of devices will be enabled by deployment of novel connectionless / connection oriented lean protocols whereas increased coverage probabilities may be provided in the first instance using robust transmission and access schemes facilitated owing to the decreased per unit data volumes typical of sensor communications. Furthermore, in a first approach it can be anticipated that interference will play a minor role, hence coverage criteria can be checked in link budgets by defining minimum received power levels. One means for increased coverage in case of mMTC can be base station densification especially at lower frequency layers. This would also apply to legacy networks based on 3GPP NB-IoT [NB-IoT, 3GPP_RP-151621]. Alternatively, even introduction of dense SC layers may contribute to increased coverage. All such potential deployments are subject to there being a sound business case. Methodologies for estimating cell coverage probabilities in our evaluation may be taken from the literature.

A means to increase coverage probability in case of uMTC may be the introduction of diversity by multi-connectivity. This can be realized by deployment of frequency layer specific site grids enabling that at every location within the network multiple statistically independent links are available. Deployment of frequency layer specific site grids anyhow appears to be straight forward as for EMC reasons the number of frequency bands per base station site is to be restricted. In addition to increased coverage probabilities uMTC services will require low latency and/or ultra-reliable links. The first requirement will demand network functionalities to be placed at network edge (edge clouds) and sufficient edge cloud density whereas the later will force the need for improved network resilience or increased effort due to multi-path linkage. Both aspects (i.e. improved coverage probability and reduced packet latency) could be realized by multi-connectivity and will be matter of investigation in 5G NORMA WP4. Hence economic

[3] Some deployments (e.g. at open places) may allow for sectorisation.

[4] Feasibility of CPRI/ORI fronthaul [CPRI13] [ORI14] connecting to bare metal edge clouds to be checked.

efforts may be estimated by network dimensioning rules derived from simulation results. In addition, a literature search may be needed in order to enable the estimation of the increased effort for establishing uMTC services like V2X.

The 5G NORMA architecture will enable different stakeholder relationship scenarios. In these scenarios stakeholders owning different parts of the network (asset cases) are combined with multi-tenant service types that determine responsibilities for management and orchestration (MANO). The mobile service provider is offering a network slice to the tenant. It is worthwhile to mention that 5G NORMA network slices correspond to fully operational end-to-end virtual networks running telecommunication services offered to end-users.

Stakeholders are entities, individuals or organizations, supervising or making decisions that affect how the 5G NORMA ecosystem operates and evolves. Various stakeholders are involved in 5G NORMA, each with their characteristics and interests.

The mobile Internet/telecommunication service provider (in the following shortened as mobile service provider) is represented by the entity/company that provides Internet connectivity and communication services to end users. In 5G NORMA's context, it is also the entity that provides network slice services to its tenants.

The infrastructure provider is the entity/ company that owns and manages parts of or all infrastructure of the network. It can be further refined in RAN infrastructure provider and datacentre or cloud infrastructure provider. The former owns the physical infrastructure such as the antenna sites, the HW equipment for the antenna and RRHs (Remote Radio Heads), monolithic base stations, etc. The latter is represented by the collapsed roles of entity/company that owns and manages local and central datacentres. Within 5G NORMA, there are two types of datacentre operators, infrastructure providers acting on small/medium size datacentres (in terms of resources to be deployed and geographical presence) and big players (like Amazon) having big datacentres deployed world-wide.

The mobile network operator is the entity that operates the mobile network, i.e. it merges the roles of mobile internet/communication service provider and infrastructure provider into a single business stakeholder.

The user in 5G NORMA is divided in two types:

- The tenant, that is a business user, buys and leverages on 5G NORMA network slice services to expand their business. It can be a mobile virtual network operator, an enterprise or a vertical market player (e.g. industrial company).
- The subscriber is an individual who purchases 5G NORMA Internet connectivity and telecommunication services for the purpose of entertainment, communication, etc.

Regarding asset cases 5G NORMA distinguishes between:

1. Infrastructure ownership case #1: The mobile network operator owns all physical & cloud infrastructure. It owns all needed infrastructure from the physical infrastructure for hosting its bare metal nodes to the data centre(s) for hosting its edge and central nodes. The mobile service provider controls the VIMs.
2. Infrastructure ownership case #2: The mobile service provider owns (parts of) the RAN infrastructure for deploying its bare metal nodes but relies on Service Level Agreements (SLAs) with multiple cloud providers to host its edge nodes and central nodes. It has to provision virtual resources rented from virtual infrastructure providers to serve SLAs with its tenants. Cloud infrastructure providers control the VIMs.
3. Infrastructure ownership case #3: The mobile service provider owns (parts of) the RAN infrastructure for deploying its bare metal nodes and its edge nodes but relies on SLA with cloud infrastructure provider for hosting its central nodes.
4. Infrastructure ownership case #4: The tenant is providing parts of the infrastructure. E.g., it is a special situation of infrastructure ownership case #2 and infrastructure

ownership case #3 as well, where the tenant owns (parts of) the virtual infrastructure. In another example, the tenant owns parts of the RAN.

Multi-tenant service types can be described as

- Service Type 1:
    - The mobile network operator provisions and operates the network service on behalf of the tenant.
    - The tenant uses network services for its business service/applications towards its customers.
    - Example: energy provider uses mMTC service from service provider to run its telemeter service.
- Service Type 2:
    - The mobile network operator provisions the network service.
    - The tenant orchestrates the network service (compose, create/delete instances) for her own business.
- Service Type 3:
    - The mobile network operator provisions the network service (provision NFs, MANO-F, ... and infrastructure resources).
    - The tenant orchestrates the network service (compose, create/delete instances) and orchestrates/control the NFs (MANO-F and SDM control) belonging to the operator for its own business.
- Service Type 4:
    - The tenant has his own set of VNFs, MANO-F customized/ certified for its business needs.
    - The mobile network service provider provisions the virtual resource from cloud infrastructure provider.
    - The tenant orchestrates the network service (compose, create/delete the NS instance) and orchestrates/control the NFs (MANO-F and SDM control) belonging to the operator for its own business.
- Service Type 5:
    - The tenant has his own set of VNFs, MANO-F customized/ certified for its business needs.
    - The mobile operator provisions and operates the network service on behalf of the tenant.
    - The tenant uses network services for its business service/applications towards its customers (e.g., energy provider uses mMTC service from mobile network operator to run its telemeter service).

Basically each combination of asset cases and service types should be feasible but in order to limit evaluation effort, WP3 partners generate priorities for evaluation as shown in Table 3-2.

Table 3-2: Highest score combinations of asset cases and service types.

Asset case	Service Type	Remarks
1	1	"Conventional/legacy" scenario; baseline scenario for evaluation purpose
1	2	Typical ”vertical use case" scenario for big mobile service provider reluctant to rely on external cloud provider for the support of network functions
2 or 3	1 or 2	Typical “vertical use case" scenario for big/SME mobile service provider ready to rely on external cloud provider for the support of network functions
3	3 or 4	Extreme scenarios, in order to test the full flexibility and capabilities of 5G NORMA architecture, but very unlikely to be deployed

Finally there exist different architecture options like e.g. cloud (C-RAN) and distributed RAN (D-RAN) that influence network cost modelling. The arrangement of functional split between RAN protocol layers depend on several influencing factors. In our evaluations we concentrate on the traffic, user density and demand for multi-connectivity. In order to restrict the options for our evaluations we later on will introduce a limited number of split options that guaranty comprehensive evaluation dimensions. It is to be assumed that fibre based transport technology is needed in order to connect edge clouds with bare metal sites if part of the radio protocol stack is centralized. Highest benefit due to this centralization is to be expected in terms of multiplexing gains due to fluctuating traffic demand in multiple cells. But centralization of RAN VNF might also be motivated by latency requirements in context with multi-connectivity. Distributed operation of RAN VNF might be useful if a lot of antennas are operated (e.g., M-MIMO) or if the traffic demand in an area is rather low. At sites hosting a huge number of antennas and also in the case of HetNet deployments, the operation of edge clouds at bare metal sites makes sense (see Figure B-4).

Two of the key innovations introduced by 5G NORMA are multi-service and multi-tenancy. Hence showing the benefit of these architecture options appears essential. The most important cost saving mechanism enabled by both options can be seen as the introduction of traffic demand diversity that can be utilized in multi-service and multi-tenant networks and will reduce the cost of this variant compared to single stovepipes dramatically. The tools required for these comparisons are listed in Table 3-3.

Table 3-3: Requirements to cost modelling from multi-tenant and multi-service architectures.

Option	Requirements
Multi-tenant architecture	Estimation of gain of multi-tenant network sharing
Multi-service architecture	Estimation of gain of multi-service network sharing

An estimation of these diversity gains will be not easy to accomplish. Hence it will be important to use these cost influencing factors primarily as a dimension for sensitivity analysis. This also applies to the diversity gains achieved in C-RANs.

Three different evaluation cases are specified in Annex C. Economic evaluations will contribute to the final PoC by:

- Evaluation case C.1: Baseline evaluation case
    - Provisioning of Baseline Reference for MBB
    - Comparison of 5G networks economics with that of evolved legacy networks in case of MBB provisioning
    - Rules for C-RAN functional split selection
- Evaluation case C.2: Multi-tenant evaluation case for MBB
    - Comparison of single and multi-operator networks
    - Identification of multi-tenant network cost benefits compared to single operator networks
    - Impact of different stakeholder roles
    - Impact of # of tenants
    - Impact of spectrum use
    - Impact of multi-tenant traffic diversity
- Evaluation case C.3: Multi-service evaluation case
    - Comparison of single and multi-service networks
    - Identification of multi-service network cost benefits compared to isolated service specific network stovepipes
    - Impact of multi-service traffic diversity
    - Cost impact of demand for increased coverage, reliability and latency

4 Key metrics for economic validation of 5G NORMA architecture

This section describes the metrics we intend to use for the economic validation of the 5G NORMA architecture. We have chosen a set of profit and cost based metrics which will enable us to carry out this economic validation. These metrics map onto the evaluation cases described in chapter 3. The table below shows the relationship between the evaluation cases and metrics.

Table 4-1: Relationship between evaluation cases and metrics

Evaluation Case	Profit based metric	Cost based metrics
Baseline	Metric A	Metric D
Multi-tenancy	Metric A	Metric B
Multi-service	Metric A	Metric C

4.1 Description of metrics

4.1.1 Metric A

Description

This metric measures the incremental profit (or loss) from deploying the 5G NORMA architecture (including variants or alternative architectures) compared to the counterfactual (or status quo). The counterfactual varies according to the evaluation case. In this subsection, we explain how Metric A would work when the relevant counterfactual is the “comparator” 4G network as described at the end of this chapter (i.e. in the baseline evaluation case).

We define the incremental profit as the difference in revenue minus the difference in cost between the 5G NORMA architecture and the comparator 4G network. Costs include operating (OPEX) and capital (CAPEX) expenses. The incremental profit should be measured over a suitable period, say 10 years, so that captures the fact that operators need a suitable period of time to recover their investment in the new assets they deploy.

A net present value (NPV) should be calculated so that we can express the value of future revenues and costs in today’s terms. I.e. a promise to pay €1 in two years’ time is worth less than being given €1 today because today’s €1 could be invested and will earn a return so the total will be greater than the €1 promised in two years’ time. For example, if a firm’s discount rate – the rate at which it can get access to new funds – is 10% – the NPV of €1 in two years’ time is equal to 1 / (1 + r) ^2 – €0.83 – where r is the discount rate of 10%.

We may consider two alternative bases for deployment of the 5G NORMA architecture: brownfield and greenfield. The brownfield deployment assumes that 5G deployment would make use of any existing parts of the legacy 4G network that were appropriate. The greenfield deployment assumes that none of the existing legacy network – at least the radio access network, if not the core network – would be re-used, thus increasing the cost of deployment.

Importance of the metric

This metric is different from the other metrics in that it is based on profitability and not cost. This is important because profitability is the ultimate test of whether an operator would invest and deploy a new network or continue with the comparator network, which would not necessarily be standing still either. The metric can be used to assess the value of the key innovations of the 5G NORMA architecture.

As a sensitivity check, we may also assess whether the existence of social benefits from 5G could have an impact on the overall economic case for 5G. In the event that social benefits might tip the balance in favour of deploying 5G from the economy's perspective (as opposed to the operator's perspective) it would raise interesting questions on the need for government subsidy and ability of governments to intervene successfully in this way (e.g. estimating how much subsidy is required and giving operators the right incentives to deploy the optimal 5G architecture).

4.1.2 Metric B

Description

This metric measures the difference in cost between delivering one or more 5G services (based on the multi-tenant evaluation case) over the a multi-tenant 5G NORMA architecture compared to delivering the same 5G services over several single tenant networks.

The single-tenant 5G network will have to be consistent with the 5G NORMA architecture. We would first model a single tenant network for providing enhanced mobile broadband services which is common to all the three evaluation cases. Then we would model an equivalent multi-tenant network. In the evaluation case, tenants are taken to be other MNOs, in theory we could also model tenants as mobile virtual network operators (MVNOs), over-the-top (OTT) providers or customers from vertical industries. The key issue would be to identify how the network of an MNO would differ from that of another type of service provider or vertical user.

Similarly to metric A, we measure operating and capital costs over a period of years related to the typical time needed to earn a return on the network assets and calculate the cost in NPV terms. We may also look at modelling the 5G networks in a brown field and greenfield situation.

Importance of the metric

This metric provides an illustration of whether one of the key innovations of 5G NORMA, multi-tenancy, is likely to be cost effective. A metric solely based on costs is a useful complement to the profit based metric A, because costs are likely to be much less uncertain than revenues (and hence profits). Therefore, cost based metrics should be less prone to error than revenue or profit based metrics.

It specifically identifies whether the multi-tenancy innovation in 5G NORMA brings an economic benefit, however it does not measure the wider context assessed by metric A, i.e. whether 5G NORMA is beneficial compared to the legacy 4G network.

4.1.3 Metric C

Description

This metric measures the difference in cost between delivering a set of 5G services (based on the multi-service evaluation case) over a multi-service 5G NORMA network infrastructure compared to delivering each service over a separate single-service network.

Metric C is similar to Metric B, with the key differentiator being the multi-service dimension as opposed to the multi-tenant architecture, and it follows the same logic.

In, particular we note that this metric would focus on the multi-service evaluation case. The single-service 5G networks should be consistent with the 5G NORMA architecture and we would identify the features specific to multi-service networks only and to each hypothetical single-service 5G network.

Importance of the metric

Like Metric B, Metric C is a cost based metric. Metric C complements the profit based Metric A and its advantages and disadvantages are similar to Metric B.

Multiple service or product business can often generate substantial benefits for companies through economies of scope. These arise from sharing costs between services that would otherwise be duplicated if each service were provided separately. One of the indicators of whether this is likely to be the case for 5G NORMA will be the extent to which there are common costs (i.e. costs shared between services) in the 5G NORMA infrastructure.

4.1.4 Metric D

Metric D relates to the baseline evaluation case. It can be thought of as a simplified version of Metrics B and C since it measures the costs for a single-service and single-tenant network. However, whereas Metrics B & C compare 5G networks, this measure compares the costs of an LTE-A Pro and a 5G network.

Importance of the metric

This metric captures the benefits of the 5G NORMA network which arise simply from 5G per se (such as the 5G air interface) rather than the specific 5G NORMA innovations mentioned above.

4.2 Comparator for calculating operator costs

In order to assess metric A, the incremental profit (or loss) associated with 5G NORMA network architectures, we need to compare it against a "counterfactual" – i.e. the network that a mobile operator would deploy if it did not rollout a 5G network.

We will model as a comparator network an expected future LTE network of 2020. It is reasonable to assume that LTE networks will continue to develop between now and the advent of 5G in 2018-2020. In particular, we note that NFV is already being discussed in the LTE context and LTE-A Pro and its evolutions are expected to address MTC, V2X services and improved transmission capabilities. Hence this allows us to compare the 5G NORMA architectures to the networks that we would reasonably expect to be in place where 5G not to be introduced and it will be very important to capture the differences between LTE-A Pro and 5G NORMA. This type of comparison is commonly used in the financial appraisal of new projects and could be said to represent an organisation's decision whether to invest in a new project.

We will need to make some assumptions to define this comparator and will focus on assessing which of the new 5G NORMA technologies might feasibly be incorporated in the future LTE network. This can be captured in the evaluation case as we develop it during the rest of the project.

We will also consider modelling an additional point of comparison: today's LTE network. This would freeze the LTE network at the level of today's technology and no further development. It would allow comparison of the 5G NORMA architecture with an existing network rather than a future LTE network about which there is some uncertainty because such networks have not yet been built. However, the estimation of revenues will have to take into account that today's LTE network will not be able to support many of the services we expect 5G networks to support.

5 5G NORMA cost model

This chapter outlines a methodology for establishing the cost of a network that can support the 5G NORMA architecture. Developing a network cost model that can accommodate the full flexibility is challenging and so provisional results based on an evolved 4G architecture (Phase 1) and the approach for a more comprehensive analysis (Phase 2) are described. The main sections of this section are:

- Section 5.1: This provides an overview of the 5G NORMA architecture. Though much of this is extracted from [5GN15-D31], but this provides the context for the rest of this section.
- Section 5.2: This section identifies the methodology and parameters used for Phase 1 modelling to provide provisional economic metrics on the potential for 5G NORMA networks to save costs.
- Section 5.3: This section presents the results for the Phase 1 modelling
- Section 5.4: This section describes the key functionality needed to be modelled in Phase 2 to reflect the range of options and capability of a 5G NORMA network. Key elements are described and a methodology to address innovative architecture aspects is identified.

5.1 Overview of the 5G NORMA architecture

Within the 5G NORMA project the first description of a preliminary 5G architecture framework based on SDN and NFV principles was given in Deliverable 3.1 “Functional Network Architecture and Security Requirements” [5GN15-D31].

The architecture framework leverages on five main pillars, three innovative enablers:

(i) the adaptive (de)composition and allocation of mobile network functions (NFs) between the edge and the network cloud depending on the service requirements and deployment needs,
(ii) the Software-Defined Mobile Network Control and Orchestration (SDM C+O), i.e., applying the SDN principles to mobile NFs, and
(iii) the joint optimization of mobile access and core NFs localized together in the central or edge clouds;

and two innovative functionalities:

(iv) the multi-service and context-aware tailoring of NFs used to support a number of services and their associated QoE/QoS requirements, and
(v) the mobile network multi-tenancy to support on-demand allocation of radio and core resources in a full multi-tenant environment.

The architecture developed in 5G NORMA builds these main pillars by applying network (NW) slicing and NW programmability concepts. A high-level overview is given in Figure 5-1.

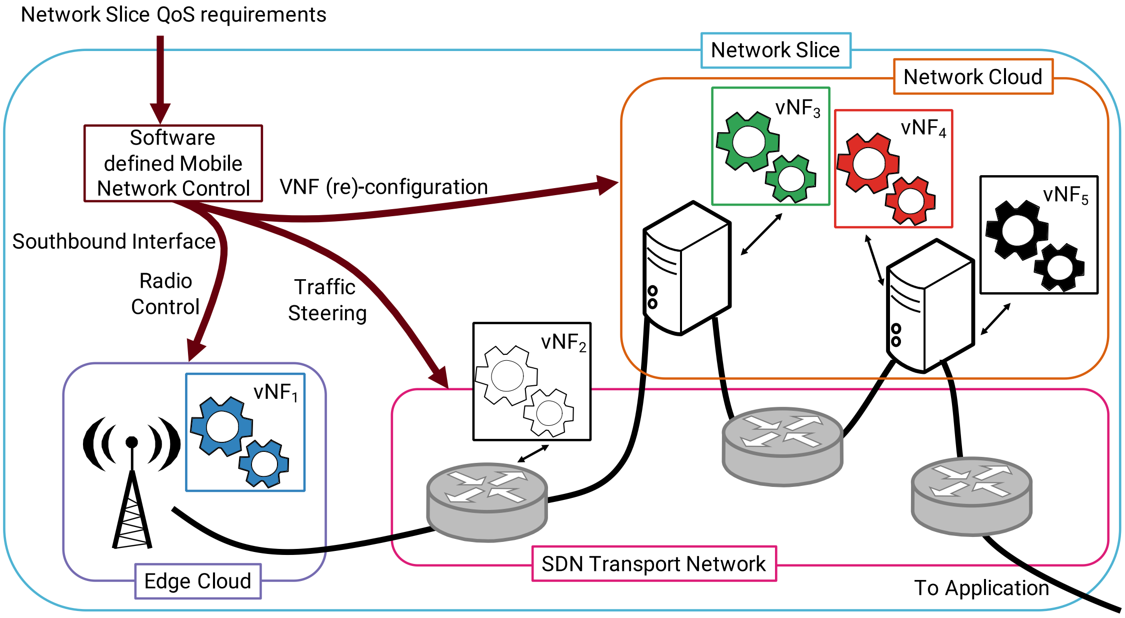


Figure 5-1: High-level overview about 5G NORMA architecture to address network slicing and programmability (from [5GN15-D31])

This framework supports delivery of multiple services with diverging characteristics and requirements across a single infrastructure platform, which additionally allows to be shared by different stakeholders or tenants each operating his own logical network via slicing on top of the platform.

The 5G NORMA architecture can be described in more detail by four different views as shown in Figure 5-2 and shortly described in the following. Please note that this approach was also taken as a basis for the description of the 5G architecture published by the 5G PPP Architecture Working Group in their 1st White Paper (see [5GP16-AWG]).

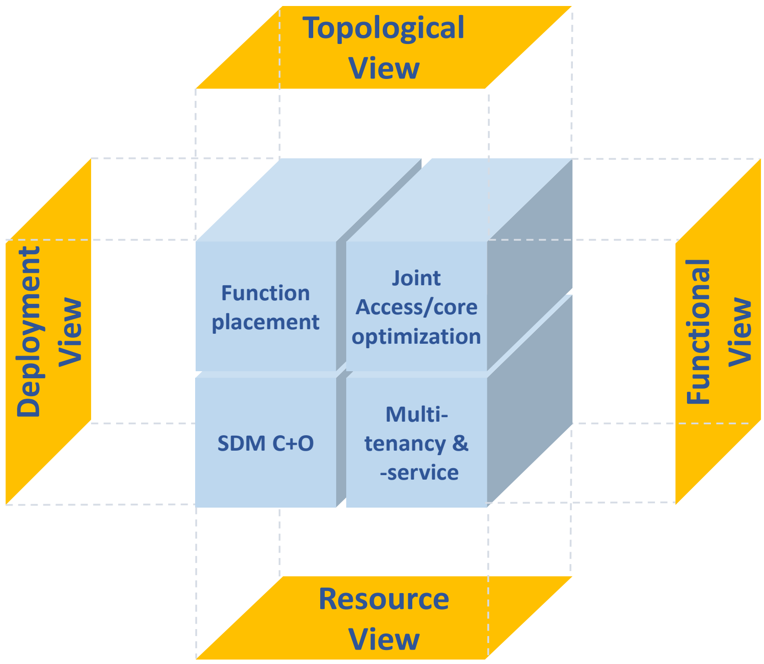


Figure 5-2: The four different views of the 5G NORMA architecture (from [5GN15-D31]).

Resource view: It represents resources that different NW components make use of. This includes physical and virtual resources, along with repositories for NFs and NW slice blueprints.

Functional view: It shows functional blocks and functional interfaces that deliver the system´s overall functionality, regardless of each function block's deployment location within the NW infrastructure and regardless of the resources used (i.e., a pure logical view).

Deployment view: It depicts different possible deployment locations of functional blocks, so defining the mapping of functional blocks to the physical environment in which the system is intended to run. This also includes the possibility that a functional block may be deployed in different locations. In the same way, NW slices may also be represented in this view showing different deployment locations of functional blocks based on the service(s) provided in each slice.

Topological view: It shows the network topology, so differing from functional view in that it depicts the way in which physical respectively virtualized NW resources are interconnected (including networking, processing, storage, and memory), while the functional view depicts the interconnections between functional blocks. The topological view includes the notion of distance respectively latency, which in 5G NORMA determines the main difference between edge and central cloud. It may also depict bandwidth of transport media between distinct instances of resources in contrast to the deployment view that shows only the generalized class of resources such as edge and central cloud.

More details about the different architectural views as well as a description of NW element classification and possible topological placement to be applied for techno-economic evaluations can be found in Annex B of this deliverable. In the following only a short summary based on the analysis of the initial 5G NORMA architecture is given; for details please refer to Annex B.

Three main types of deployment nodes (NW elements) were identified (see section B.1):

- Bare Metal Nodes,
- Edge Cloud Nodes,
- Central Cloud Nodes.

These 3 node types rely on different hardware (HW) resource categories:

- Server HW (based on x86, ARM, RISC or other architectures) suitable for Edge and Central Cloud Nodes,
- Programmable or non-programmable, purpose-built HW (relevant for Bare Metal Nodes, but also for Edge Cloud Nodes (programmable only)).

The nodes are hosting user plane (UP) and control plane (CP) related NFs, both of physical and/or virtualized type (PNF, VNF). In addition they are also hosting software-based functional blocks relevant for the operation and maintenance of the 5G system (see section B.2):

- Software-Defined Mobile network Controller (SDM-C),
- Software-Defined Mobile network Coordinator (SDM-X),
- Software-Defined Mobile network Orchestrator (SDM-O),
- Virtual Infrastructure Manager (VIM) and VIM Agent, respectively,
- VNF Manager,
- Operations Support System (OSS) and Element Manager (EM).

The deployment nodes and their related PNFs/VNFs and functional blocks are mapped on sites of the operator's network. Three main site types are distinguished (see section B.3):

- Antenna sites (placement of Bare Metal Nodes only or combinations of Bare Metal and Edge Cloud Nodes),
- Edge cloud sites,
- Central cloud sites.

For techno-economic evaluation of NW scenarios also the cost of the data transport network between the sites as well as any HW installation (power supply, antenna, etc.) and cabling (power, data, RF, etc.) at the sites have to be considered.

5.2 Inputs for Phase 1 network cost model

The Phase 1 network to be modelled is required to assess the baseline evaluation case. This is restricted to MBB services. The network architecture is based upon an anticipated evolved 4G network, anticipating that enhanced sharing can be permitted.

5.2.1 Location

The selected location is central London – specifically the areas of Westminster, City of London, Kensington and Chelsea. The population is assumed to increase at an annual rate of 0.6% [World2016].

Traffic was distributed to residential and commercial addresses. The residential population was assumed to be 2.3 x the number of residential addresses. Traffic is distributed between residential and commercial locations on 3 busy hours, chosen to assess different peak traffic demands in different location types, using the methodology of [CAP2012].

Figure 5-3: Modelled Traffic distribution, Central London

5.2.2 Demand

The recent Cisco VNI report [Cisco_2016] anticipates mean mobile data demand to be 4.6GB/Month/user in 2019, rising with a Compound Annual Growth Rate (CAGR) of 45%. This represents a traffic increase by a factor of 41 over the 10-year study period from 2020 to 2030.

5.2.3 Spectrum availability

Spectrum availability in mobile bands below 6GHz, has included the planned release of spectrum by the UK regulator, Ofcom. The release of spectrum above 6GHz (in practice, above 24GHz) was discussed during World Radio Conference 2015 (WRC15) and identified several bands for review to for further discussion at WRC19.

For the purposes of modelling the coverage available at different frequencies, 4 different spot frequencies have been used to characterise broad spectrum bands. These groupings and the spot frequencies are identified in Table 5-1.

Table 5-1: Band categorisation and spot frequencies for radio propagation of mobile bands

Band Categorisation	Spot Frequency (MHz)	Band Allocations (MHz)
Sub 1GHz	700	700, 800, 900
Low	1 400	1427 - 1452, 1452 - 1492, 1492 - 1518, 1800, 2100
Med	2 800	2310 - 2390, 2600
High	24 250	24 250 - 27 500, 31 800 - 33 400, 40500 - 42 400

We further anticipate that the macro layer will only use spectrum below 6GHz, and that the higher frequency bands will be used to support Time Division Duplex (TDD) mode. In practice, many of the narrowband allocations in lower frequencies are not supported in today's mobile networks – and we anticipate that these relatively narrowband assignments will be less attractive to deploy if high bandwidth harmonised spectrum can be released in higher frequencies.

As part of this discussion, within Europe, Radio Spectrum Policy Group (RSPG[5]) are investigating the feasibility of making some spectrum available to assist the early development of 5G (the "pioneer bands"). We have assumed that limited spectrum will be released from this initiative until mid-2025, where we anticipate that 440MHz of spectrum will be released by 2025 in the 24GHz band. A bandwidth of 100MHz for each operator has been assumed – and 90% of this is assumed for use in the DL direction. Though some frequency will be released in higher frequencies (66-76GHz band) we do not anticipate widespread mobile operator use in the timeframe of this study.

This means that the following spectrum availability is anticipated for a representative operator on their macro and small cell layers is as shown in Figure 5-4.

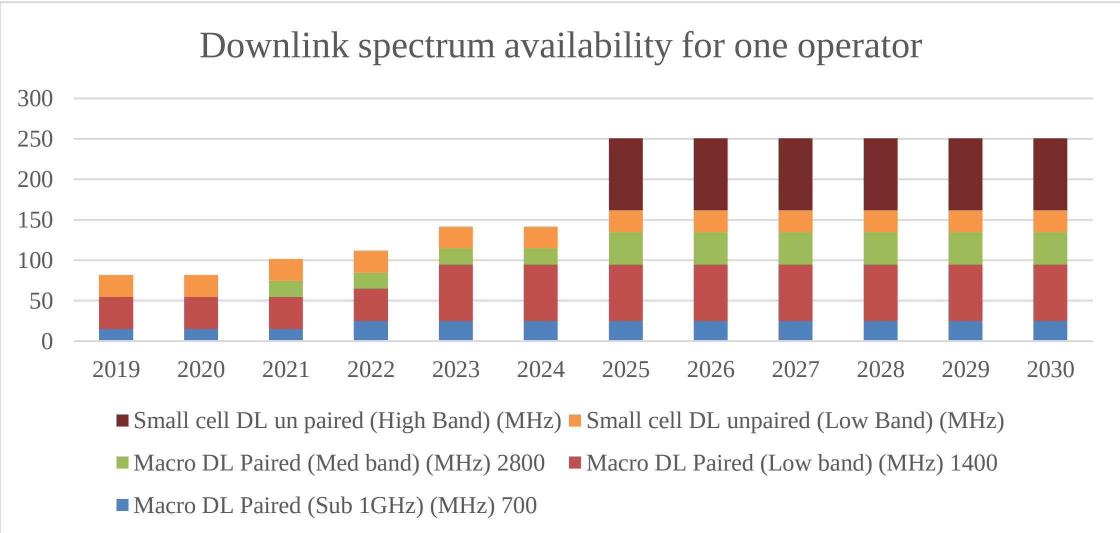


Figure 5-4: Assumed spectrum used by each operator (in the DL direction)

[5] The RSPG is the European Commission's high level advisory group that provides assistance in the development of EU spectrum policy.

5.2.4 Spectrum efficiency and user throughput

The spectrum efficiency achievable in real devices is approaching the Shannon bound. Marginal improvements in reducing the guard bands and signalling overhead can yield useful, though small, improvements. They would require a new air interface and may form part of the 5G air interface definition.

In the interim the key improvements in achievable throughput are likely to be driven by higher order MIMO methods. This becomes difficult to achieve in small devices, with lower frequencies or when supporting an increased number of frequency bands.

For Phase 1, we have adopted the assumed improvements in average spectrum efficiency based on a blended use of additional antennas in both devices and base stations as described in [CAP2012].

The anticipated average spectrum efficiencies are shown in Figure 5-5.

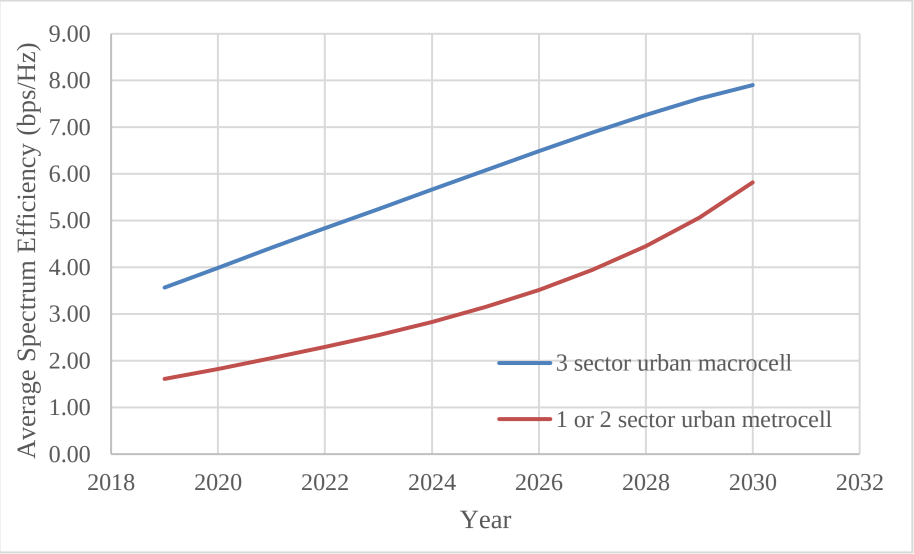


Figure 5-5: Anticipated average spectrum efficiencies, macro cell and small cells

5.2.5 Phase 1 site types and costs

It is understood that in representative urban areas, normal practice is for operators to deploy 6 sector macro sites where possible. This trend is unlikely to reverse.

Only two site types have been considered for Phase 1:

- 6 sector macro sites
- Small cell sites.

The OPEX costs for these different site types has been based on a variety of reports. In general, we see OPEC prices as remaining stable – rental and rates value increases are likely to be offset by backhaul cost reductions. Licensing costs will depend upon the capacity of the macro cell site deployed.

Table 5-2: OPEX values used for 6 sector macro cells and small cell sites.

	6 sector macro site (k GBP)	Small cell site (k GBP)
Site rental	4.00	0.35
Rates and utilities	3.90	0.35
Vendor services and maintenance	2.10	0.25
Licensing and maintenance[6]	1.0 (for a 2x2 MIMO, 2x20MHz capacity)	(included above)
Backhaul	7.80	1.0
Total	**18.8**	**1.95**

The CAPEX costs for the different infrastructure elements deployed at different sites is made up as shown in Table 5-3.

Table 5-3: Assumed capital costs and yearly cost change for different infrastructure elements.

	Capital Costs (k GBP 2016 values)	Year on year cost variation
Mast	10	0%
Cabinet	2.2	-3%
Cooling	2	-3%
Site civil works	18	0%
Backhaul CAPEX	8.8	0%
2x2 Antenna_feeder/band (6 sector)	6.8	-3%
RF front end (2x2, 20MHz)	7.5	-3%
Base band (2x2, 20MHz)	2.5	-3%
Small cell (2x2, 1 band)	13.3	-3%
Small cell (active equipment only)	2.5	-3%

Small cells are assumed to be replaced every 5 years, and macro cells are assumed to be replaced every 10 years. This means that the small cells have an upgrade cost during the study period.

Where additional spectrum is deployed on a macro cell, additional active electronic equipment (RF front end and base band processing) is required. Additional MIMO capability requires additional RF front end and processing and antennas – but does not require any additional civil works. Similarly, it is assumed that all active equipment and civil works can be shared in the event of assessing the benefits of sharing infrastructure, but the additional capacity do need to be met with additional active equipment.

The macro cells are assumed to be above rooftop level and only use frequencies below 6GHz, and have a 10-year useful life.

Small cells are assumed to be deployable on street furniture – such as lampposts and bus stops, available several meters above street level, and to be replaced after 5 years of first deployment. These small cells are assumed to be able to process one frequency band only. We anticipate that

[6] This figure is based on 10% of the capital cost of the RF front end and baseband processing with an assumed capital cost reduction of these items of 3.0% per year.

M-MIMO would support multiple independent spatial streams from the one site – for Phase 1 we have approximated this by allowing small cells to support multiple sectors at the additional cost of additional small cell active equipment.

5.3 Phase 1 model results

In this section we summarise the results of our initial economic validation analysis of the 5G NORMA architecture. This is based on the Phase 1 network cost model which models an access network (including backhaul) that is capable of delivering the performance necessary to support the type of 5G services outlined in our use case analysis. The model takes account of expected developments over the 2020-2030 modelling time period in spectrum efficiency and spectrum availability. The cloud based management and orchestration (MANO) layer is not considered in the Phase 1 model, but will be covered in Phase 2. The cost of the core network is also not considered in the results we present here.

We have only applied Metric B for the economic validation with these Phase 1 model results. Metric B assesses the savings a multi-tenant 5G NORMA network delivers over a number of single tenant networks serving the same level of demand.

Potential cost savings from multi-tenancy will be one of the core drivers of the network operator business case for deploying a network based on 5G NORMA architecture. If these cost savings are significant, then there will be strong incentives to invest regardless of the potential for delivering new and innovative services with 5G. This is important because, although our initial research does suggest considerable scope for innovation, uncertainty over future demand and revenues is a lot higher than for costs. As a result, if cost savings are high, the riskiness of investing in 5G infrastructure will be lower because the benefits to operators will not depend solely on the (more uncertain) revenue potential from new services.

The reasons for only considering Metric B for this phase of the modelling are as follows. The Phase 1 model only considers enhanced mobile broadband services, so we cannot analyse the implications of multi-service networks – upon which Metric C is based. We cannot apply Metric A, which considers the incremental profitability of a 5G NORMA network, either. This is because the model only covers network costs relating to access and not those of the core network or MANO layer. Therefore, if we were to consider profitability, the results would be misleading. In Phase 2, however, we do intend to consider in metrics A and C (described in section 3.2 above).

We estimate the costs of three different network-tenant relationships below which illustrate the degree of benefit from 5G NORMA multi-tenancy capability:

- 4 operators / tenants not sharing, i.e. each with their own network
- 2 pairs of operators / tenants with each pair sharing a network, i.e. two shared networks
- 4 operators / tenants sharing one single network.

The cost we estimate is the net present value of cash flow (the sum of operating and capital expenditures) over the period 2020-2030. As explained in the previous chapter, the area modelled is Central London comprising, Westminster, the City of London, Kensington and Chelsea. This area has a population. Using population statistics from the UK's Office of National Statistics, this population of this area is predicted to grow from 414,000 in 2020 to 439,000 in 2030. It has an area of 37 square kilometres.

The Phase 1 model estimates the additional network (number of macro cell and small cell sites) needed to meet increases in traffic demand over the period 2020-2030. In addition to this, the model estimates the existing network in force prior to that period, i.e. for 2019. This is necessary because the pre-existing sites need to be replaced over the subsequent years. We assume that these sites are halfway through their lifetime on average, hence in each of the coming years, 1 / (equipment lifetime) of the network elements for each site type are replaced.

For macro cell network elements this amounts to 10% a year (equivalent to a 10-year lifetime) and for small cell network elements 20% a year.

Table 5-4: Implications of multi-tenancy on network elements

	Network element	Varies with number of tenants?
Macro Cell	Mast	No
	Cabinet	No
	Cooling	No
	Site civil works	No
	Backhaul CAPEX	No
	2x2 antenna feeder / band (3 sector)	No
	RF front end (2x2, 20MHz)	Yes
	Base band (2x2, 20MHz)	Yes
Small Cell	Small cell sites	No
	Small cell processing units	Yes

As detailed in section 5.2, we model the network costs at the level of the network elements in Table 5-4. Hence we model the number of network elements required by site type and the cost of those network elements. This way we can isolate those network elements, and hence costs, that vary according to whether the network is single or multi-tenant.

Table 5-5 below shows the headline results of our comparison. Multi-tenancy capability delivers an impressive cost saving compared to a single tenant network, suggesting that there is could be a strong business case for deploying 5G NORMA architectures. The RAN costs for four operators sharing one 5G network are 41% less than that for four identical single tenant networks, each carrying 25% of the traffic of the shared network. The cost saving is lower, but still substantial at 27%, when only 2 operators share a network.

Table 5-5: Access network costs, Central London, single and multi-tenant cases

	NPV of network costs[7] (2020-2030)	NPV as % of not sharing case
4 x1 operators not sharing	£292 million	100%
2x2 operators sharing	£212 million	73%
1x 4 operators sharing	£172 million	59%

Table 5-6 below shows the model output, in terms of the number of site types and related network elements, on which the access network cost figures are based. It shows the substantive benefit for multi-tenancy versus single tenancy networks in terms of a large reduction in network element volumes as a result of the sharing framework enabled by multi-tenancy. Clearly, the number of sites (macro cell or small cell) is 4 times higher in the case of 4 operators not sharing a network than in the case where all four operators share a network (assuming as

[7] Operating and capital expenses

stated above that the amount of traffic carried by the networks is the same in each case. The approach used to derive the requirements for the traffic sensitive network elements is described in section 5.2. There are some economies from sharing the traffic sensitive macro cell network elements, but these are much smaller in scale than the site sharing economies.

Table 5-6: Network element volumes, Central London, single and multi-tenant cases

	4 x1 operators not sharing		2x2 operators sharing		1x 4 operators sharing	
	2020	2030	2020	2030	2020	2030
Mast	496	776	248	388	124	194
Cabinet	496	776	248	388	124	194
Cooling	496	776	248	388	124	194
Site civil works	496	776	248	388	124	194
Backhaul CAPEX	496	776	248	388	124	194
2x2 Antenna_feeder/band (6 sector)	1,500	3,512	750	1,756	375	878
RF Front end (2x2, 20MHz)	2,408	11,072	2,256	9,756	2,034	9,362
Base band (2x2, 20MHz)	2,408	9,976	2,256	9,740	2,034	9,362
Small cell sites	1,188	11,648	594	5,824	297	2,912
Small cell processing units	1,432	68,240	2,026	74,064	2,323	76,976

Table 5-7 and Figure 5-6 show the year-by-year projected CAPEX for the different sharing options modelled. Table 5-8 and Figure 5-7 show the projected OPEX figures for these scenarios. The CAPEX reduction in 2030 results from a low number of replacement small cells being required. OPEX increases gradually over the period as more equipment needs to be maintained and licensed.

Table 5-7: RAN CAPEX, Central London, single and multi-tenant cases (£ million)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
4 x1 operators not sharing	2.54	3.48	4.23	5.80	6.52	8.81	9.26	10.72	11.57	15.50	6.49
2x2 operators sharing	3.63	5.47	6.61	8.60	9.79	13.54	14.26	17.05	18.87	25.55	9.69
1x 4 operators sharing	5.59	8.99	11.15	15.77	16.21	22.82	24.18	29.58	33.41	45.64	16.24

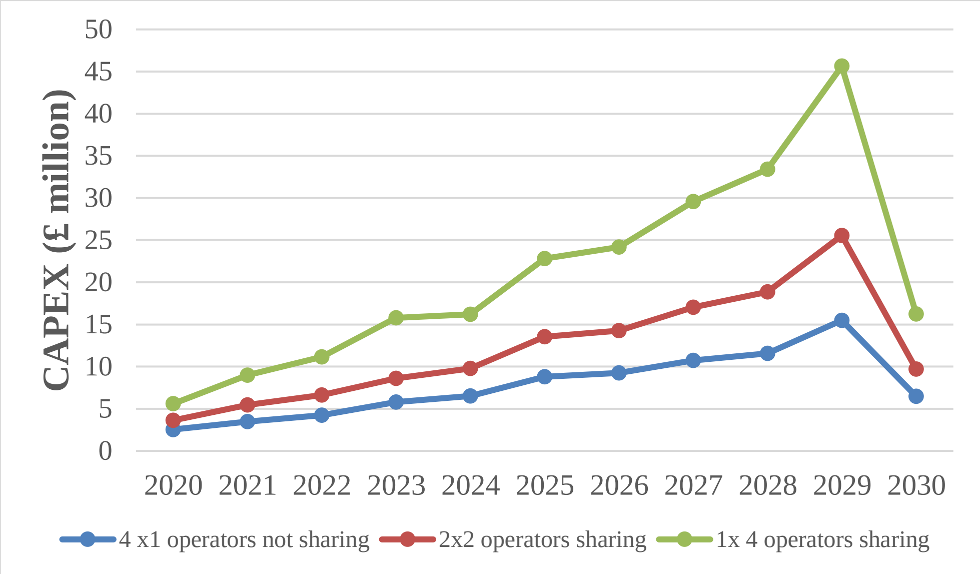


Figure 5-6: Projected RAN CAPEX for different sharing scenarios in the study period.

Table 5-8: RAN OPEX, Central London, single and multi-tenant cases (£ million)

Sharing scenario	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
4 x1 operators not sharing	2.74	2.84	2.98	3.30	3.41	3.50	3.58	3.68	3.96	4.40	5.26
2x2 operators sharing	3.21	3.40	3.65	4.12	4.29	4.46	4.53	4.66	5.00	5.55	6.64
1x 4 operators sharing	4.01	4.36	4.85	5.81	6.12	6.43	6.51	6.69	7.16	7.98	9.57

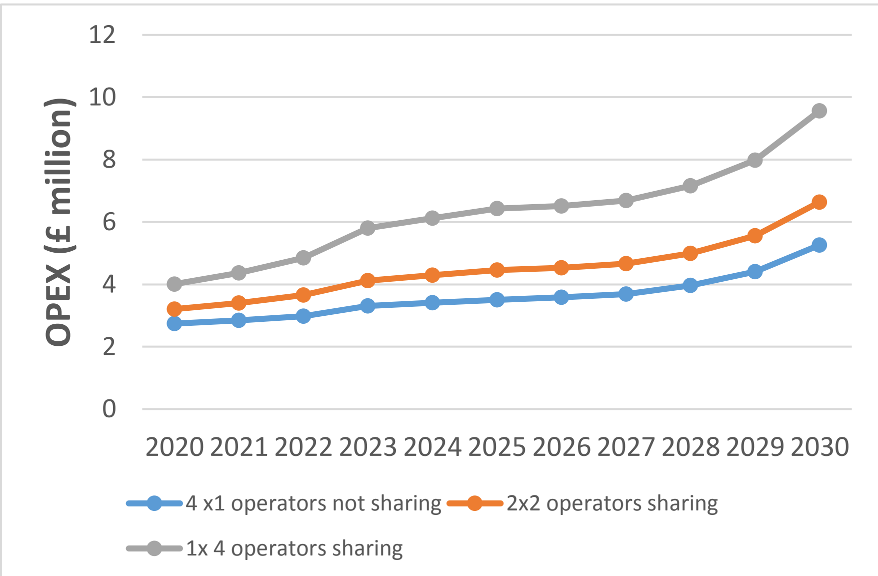


Figure 5-7: Projected RAN OPEX for different sharing scenarios in the study period.

5.4 Phase 2 capability

In the following, the key functionality required to emulate 5G NORMA features and innovations is assessed and the approach to be adopted in the modelling is identified.

5.4.1 Multi-service aspects

Multiple services will be supported in subsequent phases of the study – in particular the services to be supported will incorporate mMTC and uMTC as well as MBB services.

Support for these different services has an impact on several aspects on how the services are supported by the network:

- mMTC: MTC communications is likely to have a different geographical distribution to MBB traffic and to use reduced capability terminals in order to satisfy the long life-time and low battery consumption of some embedded devices. This has the following impact on how MTC should to be modelled over the lifetime of the study period:
  - The terminal capability is unlikely to evolve over a long time period (possibly up to 20 years) – we will therefore need to consider that the terminal capability (supported band, antenna configuration, spectrum efficiency) will not change for a defined period after initial deployment.
  - mMTC devices may need to be distributed within buildings (such as meter readers), or at particular areas of high demand (road junctions) where communicating machines will be located. Several device types can be used to allow differentiation between some key mMTC devices, with representative penetration values used to differentiate between their environments.
  - Short message durations will increase the effective overhead needed to transmit such communications, which will impact the effective spectrum efficiency that can be supported.
- uMTC: Ultra-reliable MTC will be achieved using low latency and/or multiply connected radio paths (diverse paths). This will impact the spectrum efficiency with which the traffic can be supported (lower scheduling efficiency), require overlapping coverage between the base stations and impose a traffic load at more than one site. Since the uMTC traffic volume is likely to be small compared to other sources, it is For Further Study [FFS] as to whether this will be explicitly modelled, or if approximations to reflect these additional overheads can be implicitly taken into account.
- MBB: Whilst mobile broadband is anticipated to evolve as users demand faster data connectivity in more places, the fundamental service paradigm to user is not anticipated to change. Operators will continue to seek to offload MBB where it is possible to do so – particularly for indoor users. We propose to restrict the network modelling of MBB traffic to the proportion of MBB traffic that is outdoors.

5.4.2 Multi-tenant aspects

As described in section 3.2, 5G NORMA seeks to evaluate different multi-tenancy arrangements, spanning a range of asset cases and service types.

The 5G NORMA architecture will enable different stakeholder relationship scenarios. In these scenarios stakeholders owning different parts of the network (asset cases) are combined with multi-tenant service types that determine responsibilities for management and orchestration (MANO). The mobile service provider is offering a network slice to the tenant. It is worthwhile to mention that 5G NORMA network slices correspond to fully operational E2E virtual networks running telecommunication services offered to end-users.

Regarding asset cases 5G NORMA distinguishes between different infrastructure ownership cases – currently four different ownership cases and five different service types are defined in section 3.2. In general, the degree of ownership reduces from ownership case 1 to ownership case 4; the degree of responsibility for service management reduces from service type 1 to service type 5.

The costs that would be borne to purchase different levels of infrastructure or service management will depend upon the contractual relationship between the relevant stakeholders involved in the E2E service provision and will change over time.

For the purpose of being able to provide accounting metrics as an output of the cost model, the model is required to gather metrics which can assess the utilisation that each service and operator demand to support their traffic. This is complicated since different services will impose a different network load for the same data rate or traffic volume depending upon the service characteristics; different traffic mixes will generally result in aggregate peak load that may not correspond to the peak demand of any one service provider. In addition, it is important to assess what services, or service providers stress the network dimensioning. This knowledge may be able to adjust prices to encourage utilisation adjustment.

To capture these aspects the model will gather the following utilisation metrics for the following groups in order that suitable costs can be allocated:

- For each service class, busy hour and service provider supported:
    - The level of utilisation (dimensioning) of the different physical and virtual elements of the network infrastructure (see section 5.4.4) between the antenna site and the central cloud.
- For each service class and busy hour:
    - The aggregate level of utilisation (dimensioning), of all service providers, of the different physical and virtual elements of the network infrastructure (see section 5.4.4) between the antenna site and the central cloud.
- For each service provider and busy hour:
    - The aggregate level of utilisation (dimensioning), of all service classes, of the different physical and virtual elements of the network infrastructure (see section 5.4.4) between the antenna site and the central cloud.
- For each busy hour:
    - The aggregate level of utilisation (dimensioning), of all service providers and service classes, of the different physical and virtual elements of the network infrastructure (see section 5.4.4) between the antenna site and the central cloud.

The utilisation metrics will identify:

- The air interface bandwidth occupied in each frequency band
- The bandwidth of the transport network occupied between network nodes (including front-/backhaul)
- The processing burden for different network nodes.

5.4.3 Back-/fronthaul issues

Key issues to consider in back-/fronthaul are the bandwidth and latency requirements and the latency imposed by different solutions [SCF2015]. Typically, any managed leased line has a latency in the order of 30ms, whereas CPRI/ORI based solutions (which digitise the received signals at each antenna port) imposes a delay associated with the RF front end A-D conversion and the fibre transfer time travelling close to the speed of light. This would suggest that only CPRI/ORI-based solutions can achieve the 5G NORMA performance targets – and these only when the processing is performed close (few tens of km) to the antenna site.

In reality not all 5G NORMA services require to achieve the lowest 5G NORMA latency target, or can achieve low latency by use of locating upper layer protocol functions at the edge. In general, processing these protocol layers remote from the antenna node relaxes the backhaul performance requirements.

Typical latency performance and bandwidth requirements to process a 2x2 MIMO transceiver with a bandwidth of 20MHz are shown in Table 5-9.

Table 5-9: Representative latency and bandwidth performance requirements when the received signal is processed at different protocol layers (from [SCF2015]).

Protocol split	Maximum One-Way Latency	DL Bandwidth	UL Bandwidth
CPRI/ORI	250 µs	2457.6 Mbps	2457.6 Mbps
MAC/PHY	2 - 6 ms	187.5 Mbps	62.5 Mbps
PDCP/RLC	30 ms	187.5 Mbps	62.5 Mbps
S1/D-RAN	30 ms	187.5 Mbps	62.5 Mbps

The price paid for the reduced CPRI latency is a large increase in the bandwidth required. This motivates shifting upper protocol processing to the edge for low latency services and accepting some small delays to gain from backhaul bandwidth reduction when physical layer and L2 can be processed at the antenna site.

Increasing the bandwidth and/or MIMO order would scale the back-/fronthaul bandwidth linearly until the location where the L2 (or higher layers) are processed and combined. Hence, processing 2x80MHz would require the bandwidths as shown in Table 5-10. In practice CPRI/ORI can only achieve the very low levels of latency and support the high data transfer rate using dark fibre.

Table 5-10: Backhaul bandwidth throughput to support DL with 80 MHz of spectrum

Protocol split	2 x 2 MIMO	4 x 4 MIMO	8 x 8 MIMO
CPRI/ORI	9.8 Gbps	19.7 Gbps	39.3 Gbps
MAC/PHY	0.8 Gbps	1.5 Gbps	3.0 Gbps
PDCP/RLC	0.8 Gbps	1.5 Gbps	3.0 Gbps
S1/D-RAN	0.8 Gbps	1.5 Gbps	3.0 Gbps

Managed fibre solutions are an alternative to the use of infrastructure operators providing their own fibre or using dark fibre. Typically, managed fibres products available today are ethernet-based supporting rates of typically 100 Mbps and up to 10 Gbps. Within the UK, BT Openreach provides managed fibre solutions to MNOs, such as the Ethernet Access Direct. It is understood that managed fibre SLAs, typically in place today, only guarantee latencies between 10 and 20ms, though latencies closer to 5ms are typical and available for some premium services.

Based on today's prices, and assuming a 5% year on year price erosion, the 10 year Total Cost of Ownership (TCO) of different managed and dark fibre solutions is shown in Figure 5-8. The cost of using higher data rates with dark fibre (differences in the terminal equipment) is modest. It is evident that there is still a price penalty for high data rate managed fibre, but that the cost of lower data rate managed fibre is close to that of the TCO of dark fibre. It is therefore anticipated that, in future, competition and availability of higher data rate managed services will also be available at a price comparable to that of dark fibre. This assumption will be used when costing dark fibre going forward.

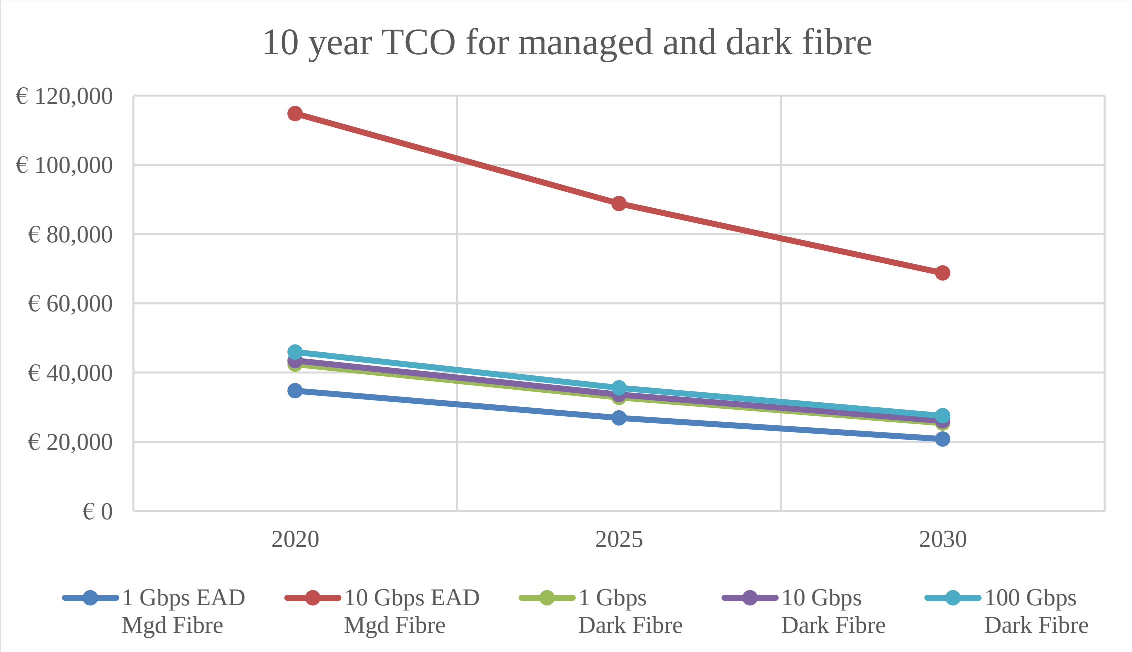


Figure 5-8: 10 Year TCO of different fibre solutions available in London, based on 2016 prices.

5.4.4 Site chains and multi-site connectivity

The 5G NORMA site types are described in [5GN15-D31] (see also Annex B). Supporting services on a 5G NORMA architecture requires additional considerations compared to existing 4G architectures:

- Virtualisation allows the processing to be performed at different locations – and hence the model needs to maintain a track of the resources used at different network elements to support the traffic. In this sense the linkage between a site (the site chain) rather than the radio access sites needs to be considered.
- Different sites have performance capabilities that can limit or permit the ability to support different services – for example a site with an edge node may be able to support uMTC with low latency that would not be possible from a site without an edge node and a high latency backhaul link to the core network.
- Some services will require connectivity from multiple sites to allow diversity connection to support high availability and reliability of some uMTC traffic. This will impose a traffic overhead on multiple sites and require sites to have overlapping coverage areas.

The flexibility in processing different features at different locations means that there are a large number of different configurations that can support 5G NORMA architecture. We propose to investigate 3 key different configurations to assess if there are fundamental differences in the network capability and/or cost. These options span the range of 5G NORMA virtualisation capability. Additional configurations may be used to supplement these initial types.

5.4.4.1 Frequencies for use at different antenna sites

The spectrum available to different operators will, in general vary and how this spectrum will be used by different operators, may vary according to the spectrum holding, and enthusiasm to split traffic into different quality categories. The network model will support the following constraints to reflect primary patterns of spectrum use. This approach will be reviewed, but the following is proposed:

- Spectrum allocations held by operators may be shared or not (in which case different active equipment would be needed, though passive equipment could be shared).
- Macro layers may support different traffic:
    - Lower frequencies may be used to support some services (such as some mMTC applications and control layer) with other traffic supported on higher licensed or licence-exempt frequencies.
    - Only higher antenna power classes (e.g. macro layer) can support fast moving traffic sources (cars).
- Spectrum use by antenna power class: Some spectrum allocations may be sufficient to allow small cells to use different spectrum to macro cells – other allocations may not allow the separation of these different power classes – resulting in lower spectrum efficiency availability in both layers.

5.4.4.2 Configuration 1 – classical base station variant

In this classical base station variant, the antenna site can connect direct to the central cloud or via a more local edge cloud site if preferred. The full radio protocol stack is supported on the antenna site – but not higher protocol layers.

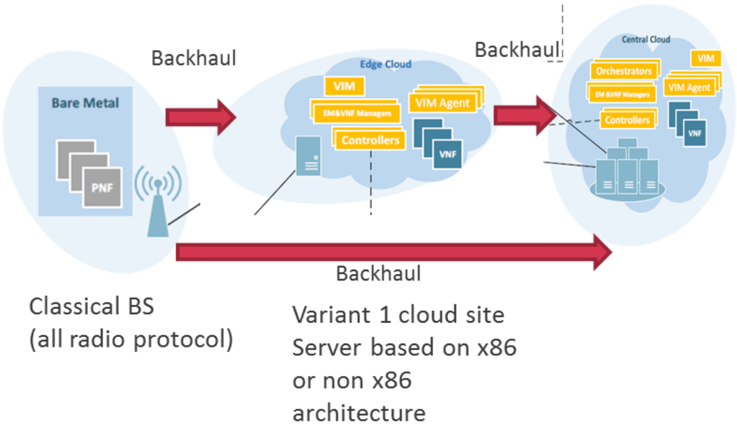


Figure 5-9: Configuration 1 - classical base station variant

Service feature and constraints of this variant:

- This site will not be able to support traffic that requires higher layer protocol functions to be performed at the edge.

Management features and constraints of this variant:

- This site has programmable HW located at the radio site and will be configurable to adjust sharing, etc. and upgrades

Higher layer aspects could be supported at the edge cloud or at the central cloud. Using central cloud may impose some additional delay – but allow more pooling of resources and be less expensive. Processing of these higher layer functions will therefore be performed as centralised as possible, as long at latency targets can be satisfied. Using the intermediate edge cloud serves as an aggregation point for the backhaul, reducing the backhaul requirements towards and at the central cloud.

In order to implement the least possible number of different configurations, whilst examining the full range of different solutions, we will restrict this configuration to the variant that processes all higher layers in the central cloud. Other options may be reviewed during this project.

5.4.4.3 Configuration 2 – remote radio head variant

This variant consists of a bare metal node at the antenna site with no programmable HW elements such as DSPs and FPGAs. This type of site provides the functionality of a radio remote unit and communicates with the rest of the network via a CPRI/ORI connection. This chain requires the use of an intermediate edge cloud site where the radio protocol stack processing will be performed.

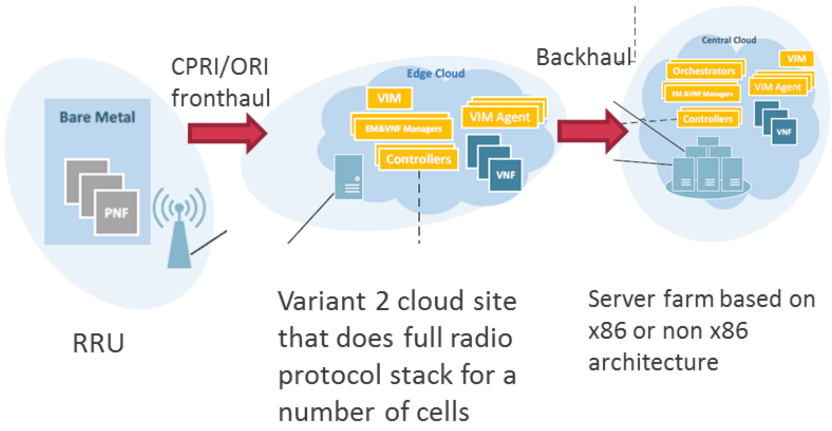


Figure 5-10: Configuration 2 - remote radio unit with CPRI/ORI variant

Service features and constraints of this variant:

- This site will be able to support low latency traffic since all higher layer protocol aspects can be processed locally and with a low latency fronthaul connection. Multi-site decoding is possible at the edge cloud.

Management features and constraints of this variant:

- HW at the antenna site is inflexible and difficult to upgrade. Replacement more likely.
- Use of CPRI requires high bandwidth backhaul connectivity.

Processing up to L3 will be performed at the edge cloud. Higher layer processing for low latency traffic could also be performed at the edge cloud. Higher layer processing for delay tolerant traffic will be more efficiently supported in the central cloud. Initially, we will restrict the range of functionality to assume that all higher layer processing is performed at the intermediate edge cloud.

5.4.4.4 Configuration 3 – Integrated edge capability

This variant consists of an antenna site base station which contains programmable HW, supports processing the radio protocol stack and has cloud capability to support higher layer protocol functions at the edge.

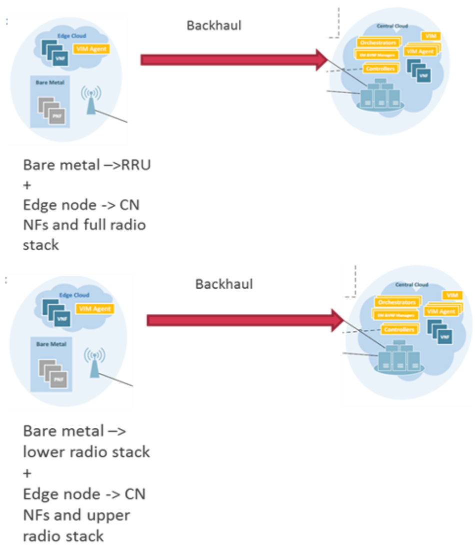


Figure 5-11: Configuration 3 – Edge cloud capability at the antenna site

Service features and constraints of this variant:

- This site will be able to support low latency traffic since all higher layer protocol aspects can be processed locally. Multi-site decoding is not possible.

Management features and constraints of this variant:

- HW at the antenna site is flexible.

Processing up to L3 will be performed at the edge cloud. Higher layer processing for low latency traffic will also be performed at the edge cloud. It would be possible for some of the higher layer protocol functions to be performed at the central cloud. Initially, we will restrict the range of functionality to assume that all higher layer processing is performed at the intermediate edge cloud.

5.4.4.5 Configuration type comparison of the proposed sites for analysis

The variants of the different configuration types that are proposed to be developed initially for Phase 2 have the attributes summaries in Table 5-11.

Table 5-11: Comparison of the different configuration types proposed for initial use in network modelling for economic analysis

Configuration type	Key features
Configuration 1	"Classical" with Central Cloud handling of higher layers
Configuration 2	Remote radio unit with locally separated (Intermediate) Edge Cloud handling of higher layers
Configuration 3	Antenna site with programmable flexibility and Edge Cloud capability.

5.4.4.6 Power amplifier classes

The above 3 configurations represent the range of virtualisation capabilities – and these can be available in different power amplifier classes.

We will focus on two key power amplifier classes – macro and small cell types. These different types would have the following properties:

- Macro types:
    - These cells would primarily operate in the spectrum below 6GHz, and be located on masts or above roof height. These types would be able to support a range of spectrum bands, from multiple different operators, as long as the radiation is within permissible limits. Radiated power will be determined at each cell to check conformance with ICNIRP limits [ICN2010].
- Small cells types:
    - Initially, it is intended that these cells would support only one band. However, depending upon the capability of the configuration, multiple operators would be able to share this cell type. Radiation would be checked to conform to permissible limits.

5.4.4.7 Computational load at different network elements

Virtualising the network allows different functions to be performed in different locations. The computational load of the active equipment is divided into three categories:

- Processing: This is primarily related to the physical layer and lower protocol layers.
- Storage: This is related to the need for different network nodes to store information.
- Networking: This is the processing burden required for inter network element connectivity.

A key issue in 5G architecture is the appropriate handling of C-plane and U-plane data: in general the additional co-ordination and management functions will require an increase in the C-plane. We propose to base the cost estimation on the volume of the U-plane traffic since this will dominate both the processing load and is easier to relate directly to the traffic being supported.

5.4.4.7.1 Processing burden

The processing burden of the physical layer and lower protocol layers will scale as more bandwidth is processed or more antenna elements are used. We will baseline the costs of processing using a basic unit of 2x20MHz bandwidth, with 2x2 MIMO. This baseline used for comparison to the 5G NORMA computational burdens is the level of processing required to support a 4G D-RAN base station, transitioning through a backhaul aggregation node before terminating in the 4G EPC. The processing burden (processing, storage and networking) for a 5G NORMA network with antenna sites, intermediate edge cloud and central clouds will be compared to this baseline.

The cost of front end RF processing is a significant driver of existing base station costs, and so we can anticipate costs to increase rapidly as higher order MIMO is deployed. After combination of the different antenna channels, the data rate to be supported back to the core is reduced to the user data rate with overheads. Prior to this combining, the processing burden will be approximated at the cost of the basic unit scaled linearly with the bandwidth and the MIMO order increase above the basic unit. We define MIMO_f, the MIMO_factor, to be the MIMO dimension deployed / baseline MIMO factor, i.e. MIMO_f = MIMO_Dimension_deployed/2. Similarly, we define the bandwidth factor (BW_f) as the bandwidth used / baseline bandwidth, i.e. BW_f = bandwidth(MHz)/20[8].

[8] The use of the BW_f for all utilisation metrics from section 5.4.2 is still to be fully clarified. For the purpose of assessing the processing load on a given service the bandwidth occupied by that service (considering the spectrum efficiency and the datarate requirement) is likely to be a better proxy for the processing load required.

5.4.4.7.2 Storage

Storage capability needs to be located at all network nodes where processing or buffering will occur. We will assume that the storage costs will rise linearly with the capacity being handled by different elements. Hence we propose to assume that the storage required will scale with the volume of the data being transferred through each network node.

5.4.4.7.3 Networking

The networking processing is assumed to increase linearly with the capacity being processed. Hence this will scale with the raw data rate being exchanged between nodes.

5.4.4.7.4 Site chain dimensioning metrics

Based on analogous cost elements identified for the Phase 1 analysis, we can split the key components along the site chain and examine how the processing burden would scale, based on the following categories:

- Antenna feeder elements
- RF front end
- Base band
- Front-/backhaul from antenna site to intermediate edge cloud
- Backhaul from intermediate edge cloud to central cloud

Based on the above discussion, we can approximate how the processing burden will scale relative to a standard unit of capacity (i.e. 20MHz of 2x2 MIMO) and identify scale factors. These factors indicate how this processing burden (processing, storage and networking) will scale along the chain for the different site configurations as shown in Table 5-12.

Table 5-12: Relative processing burden compared to a basic unit of capacity for the site chains for different configurations

Attribute		Configuration 1	Configuration 2	Configuration 3
Antenna site	Processing	MIMO_f *BW_f	-	MIMO_f *BW_f *(1+ α)
	Storage	MIMO_f * BW_f	-	MIMO_f * BW_f * (1+ β)
	Networking	BW_f	MIMO_f * BW_f * 12	MIMO_f * BW_f
Intermediate edge cloud	Processing	BW_f	MIMO_f *BW_f * (1+ α)	BW_f
	Storage	BW_f	MIMO_f * BW_f * (1+ β)	BW_f
	Networking	BW_f	MIMO_f * BW_f * 12	BW_f
Central edge cloud	Processing	BW_f *(1+ α)	BW_f	BW_f
	Storage	BW_f * (1+ β)	BW_f	BW_f
	Networking	BW_f	BW_f	BW_f

From Table 5-12, the actual processing burden required to process the data changes primarily as the bandwidth of the data being handled. However, the cost of processing will reduce as this processing load is performed closer to the central cloud. It remains for further study to determine approximate metrics for this cost reduction that will be applied to the estimated processing burden to be performed at these nodes. Applying the above simple metrics will demonstrate how the processing burden can be aggregated across the different site configuration changes and ensure that satisfactory dimensioning is in place to handle the load at all points in the network for the traffic offered.

5.4.5 Spectrum efficiency

Modulation and coding developments over the past 40 years have dramatically improved the efficiency with which information can be transferred in mobile networks, and the Shannon Limit can now be reasonably approached for some physical layer transfers. However, there are other constraints and overheads that limit the overall ability to communicate data for a general purpose wireless communication system. In addition, advances in multiple antenna technology allows improvements in the data rate – dependent upon the capability at both the transmitter and receiver. In general, we anticipate the capability to evolve over time as both infrastructure and terminals are replaced – however this may not be possible for some long life terminals. The range of site deployments across future networks will be highly diverse – some with M-MIMO mmW arrays and others providing connectivity but with lower peak data rate capability. In another complication, some services will make less efficient use of the air interface resource in order to achieve lower latency services or diverse communication links. For these reasons, we have sought to develop an adequate approximation that can be used to represent the wide range of different capabilities that are likely to be present over the duration of the project.

For implementation simplicity, we seek to parameterise a method that can estimate the data throughput achievable. This method is an extrapolation of the approach used by 3GPP TR36.814 [3GPP-36814].

We can represent the Spectrum Efficiency as a function of time, the service to be supported, the MIMO configuration and the deployment. Hence we can approximate the achievable Spectrum Efficiency (in bits/s/Hz) as:

$$SE(t, service, MIMO, deployment) = CSH * OverheadGain * MIMOFactor * NetworkLoadingFactor * ServiceFactor * FrequencyFactor * CellGeometryFactor * JointProcessingEfficiencyFactor,$$

and the user throughput (in Mbps) as:

$$T'put\ (t, service, MIMO, deployment, Bandwidth) = Bandwidth * SE,$$

where the parametric dependence of the parameters has not been shown to simplify the notation.

Each of the parameters will now be described in turn, before considering how these different factors will evolve over the lifetime of the study period.

- CSH: The ability of communication waveforms to approach the Shannon bound, i.e. achievable single channel raw spectrum efficiency.
- OverheadGain: Reductions in overheads via more efficient waveforms or control traffic reductions.
- MIMOFactor: Gains via different orders of MIMO.
- NetworkLoadingFactor: In practice, base stations and realisable schedulers do not operate at 100% utilisation.
- ServiceFactor: Changes in spectrum efficiency for different services due to low latency performance or smaller packet sizes and hence higher overheads.
- FrequencyFactor: Changes in spectrum efficiency with frequency band.

- CellGeometryFactor: This is a value to indicate cell geometry efficiency gain compared to traditional urban macro cell.
- JointProcessingEfficiencyFactor: This is a value to indicate spectrum efficiency gain resulting from joint processing (e.g. for interference cancellation) resulting from joint processing of signals from multiple antenna sites.

We will establish a baseline value for spectrum efficiency for a nominal case and examine how the different factors will moderate the achievable spectrum efficiency.

5.4.5.1 Baseline spectrum efficiency

The baseline spectrum efficiency is based upon 2x2MIMO LTE in an urban environment.

Spectral efficiency evaluations have been carried out for LTE systems and can be found in 3GPP TR36.814 [3GPP-36814], which reports the average cell spectral efficiency values for different cases, i.e., including various antenna configurations, duplex mode (FDD/TDD).

For the baseline spectral efficiency values we refer to the 2x2 Single User (SU) -MIMO FDD case, which is given in Table 5-13. Note that the spectral efficiency values refer to 3GPP Case 1, which is defined as urban macro-cell scenario, pedestrian users and with 500 m inter-site distance. Note also that the MU-MIMO SE figures reported in Table 5-13 are obtained as an average of several values from different sources [3GPP-36814 – Tables 10.1.1.1-1, 10.1.1.2-1].

Table 5-13: SE for baseline 2x2 MIMO-LTE

Antenna configuration	Average cell spectral efficiency [bps/Hz]
2x2 SU-MIMO Rel. 8 - FDD	2.23
2x2 MU-MIMO Rel. 8 – FDD	2.62
2x2 SU-MIMO Rel. 8 – TDD	2.17
2x2 MU-MIMO Rel. 8 – TDD	2.88

We will consider the value for 2x2 SU-MIMO FDD (highlighted in Table 5-13) as the baseline for the spectral efficiency in the following, as a broadly conservative estimate.

5.4.5.2 Overhead Gain

The air interface waveforms and implementation considerations to simplify decoding impose overheads that become tied in to any standards-based communication system.

5G is expected to adopt new waveforms that will possibly replace OFDM, which is currently used in 4G. The main reasons to propose new waveforms are the following [Farhang14]:

- OFDM suffers from high out-of-band emissions.
- OFDM offers low spectral efficiency, due to large required guard bands and overhead (e.g., usage of Cyclic Prefix (CP)).
- OFDM has high Peak-to-Average Power Ratio.
- OFDM is sensitive to frequency and time offset.

To cope with the issues listed above, several waveforms have been proposed. This subsection does not aim at discussing the pros and cons of different waveforms, but rather has the goal of identifying the gain in term of spectral efficiency (SE) that 5G will benefit from. These benefits will only arrive with a new standard – that is not anticipated to be available until 2020.

It is worth pointing out that, at the moment, no waveform has been chosen yet as the candidate for 5G, hence it is not possible to know exactly what spectral efficiency gain will be experienced in 5G due to the introduction of new waveforms. To this end, in the following we present an attempt to estimate this potential SE gain, which will arise from the overhead and from the guard band reduction.

One of the candidate waveforms for 5G is Filter Bank Multi-Carrier (FBMC) [Farhang14a], which makes it possible to remove the Cyclic Prefix – currently part of the OFDM, as per the LTE standard – as a requirement to combat the Doppler effect and multi-path fading. Moreover, FBMC has lower out-of-band emission compared to OFDM, which allows the operator to shrink the guard-band among transmissions on different bands; this translates into an improved overall spectral efficiency, as the guard band is effectively not used to transmit information.

5.4.5.2.1 Gain due to overhead reduction

Cyclic Prefix length in OFDM can be set to various lengths, in order to adapt to different propagation environments. In the common setting (i.e., urban scenario), the length of the Cyclic Prefix represents 11.7% of the symbol length. Hence, removing the CP from the waveform yields a 13% over the spectral efficiency of current OFDM in 4G.

5.4.5.2.2 Maximum gain due to lower out-of-band emissions

To estimate the SE gain enabled by lower out-of-band emissions, one would need to compare the spectrum emissions of new waveforms with those of OFDM. It is important to notice, though, that the emission requirements – which are necessary to estimate the spectral efficiency gain – are band specific, meaning that several band configurations should be taken into account to evaluate the average gain provided by out-of-band reduction. Moreover, it is not always possible to find references with the spectrum masks of FBMC for all the cases of interest.

This can be estimated, for instance, by considering the case of carrier aggregation. The guard bands between adjacent component carriers (CCs) is specified by the 3GPP TR36.912 [3GPP-36912]. The upper bound of the spectral efficiency gain is obtained simply by removing the guard band and computing the related gain. With reference to [3GPP-36521, Section 5.4.2A], the band spacing between adjacent Component Carriers (CCs) is 1.8MHz for the case of 20MHz CCs. By removing the guard band, the gain is found to be 9.9%, which can be approximated as 9%.

5.4.5.3 MIMO Factor

Multi-antenna techniques are a key enabler of improving future spectrum efficiencies. LTE enables several MIMO configurations [Holma2009] and MIMO schemes can now be considered conventional. As well as the conventional MIMO methods, in future M-MIMO antenna arrays will be deployed, which can support multiple independent streams [Larsson14].

5.4.5.3.1 Conventional MIMO

Among the different MIMO configurations, those for which the spectral efficiency values are openly available (either on the 3GPP standards or on scientific papers) are the following:

- 4x2 SU-MIMO and MU-MIMO
- 4x4 SU-MIMO and MU-MIMO
- 8x2 SU-MIMO and MU-MIMO
- 8x8 SU-MIMO

The cell spectral efficiency improvement for these MIMO configurations are shown in Table 5-14. We note that FBMC is not fully compatible [Farhang14] with conventional MIMO, hence the SE gain values shown may not apply to FBMC. There are some apparent inconsistencies, which arise by trying to compare spectrum efficiency values from multiple sources (see the footnotes for the source of these values). However, these values are broadly indicative of the anticipated gains achievable with MIMO developments.

Table 5-14: Conventional MIMO spectral efficiency improvements

Antenna configuration	SU/MU-MIMO	Cell Spectral efficiency [bps/Hz]	MIMO gain factor compared to baseline 2x2 SU-MIMO FDD[9]	Source
4x2	SU-MIMO	2.53	1.13	3GPP36.814 - Table 10.1.1.1-2
	MU-MIMO	3.43	1.53	3GPP36.814 - Table 10.1.1.1-2
4x4	SU-MIMO	3.41	1.52	3GPP36.814 - Table 10.1.1.1-3
	MU-MIMO	4.69	2.10	3GPP36.814 - Table 10.1.1.1-3
8x2	SU-MIMO	2.82	1.26	[Holma2012, Figure 6.10]
	MU-MIMO	4.23	1.9	[[10]]
8x8	SU-MIMO	6.82	3.06	[[11]]

5.4.5.3.2 Deriving an average conventional MIMO gain

The data in Table 5-14 show that a range of different MIMO gains are possible depending upon the MIMO dimension and if single or multiple users are to be supported. Typically multi-user MIMO benefits are higher and the difference between lower and average values is in the range 15-20% of the mid value. The mid value is therefore not an unreasonable estimate.

Thought the antenna configuration at each site will be modelled, there is uncertainty over the capability of the population of terminals that will be served. For mobile broadband, we can assume that equipment replacement cycle will mean that capability will evolve over time; this is not the case for some MTC devices, and even some uMTC terminal that may be place in vehicles with a long replacement (or no replacement) cycle.

We will propose a method of how to blend terminal capability for the range of services as the scenarios are developed further in order to take this into account in the network modelling.

[9] Here the "MIMO gain factor" is calculated as the ratio between the cell SE with M-MIMO transmission and the 2x2 SU-MIMO FDD SE given in table Table 5-13.

[10] The SE value for 8x2 MU-MIMO SE was initially taken from [Holma2012, Figure 6.10] and was 3.12 bps/Hz. However, it appears that there is some inconsistency between the 8x2 MU-MIMO SE value and the 4x2 MU-MIMO case, as the latter is surprisingly higher than the SU-MIMO above from [Holma2012]. This is due to the fact that the SE values are obtained from different sources and, thus, with different simulations settings. To help comparison, we recalculated the SE value for 8x2 MU-MIMO as follows: (i) we compute the SE increase of 8x2 MU-MIMO (3.124bps/Hz) compared to 4x2 MU-MIMO (2.533bps/Hz) from the same source [Holma2012, Figure 6.10]. This is 23.3%. (ii) The final value reported in the table is computed by adding the above gain of 23.3% to SE value for 4x2 MU-MIMO taken from [3GPP36.814 - Table 10.1.1.1-2].

[11] The spectral efficiency of 8x8 SU-MIMO is computed as: "(maximum SE of SU-MIMO 8x8) * (average SE of SU-MIMO 4x4) / (maximum SE of SU-MIMO 4x4)", where the "maximum SE of SU-MIMO 8x8" and the "maximum SE of SU-MIMO 4x4" are 30bps/Hz and 15 bps/Hz, respectively [Holma12].

5.4.5.3.3 Massive MIMO

M-MIMO exploits a large number of antennas (e.g., in the order of 100) to achieve high spectral efficiency. The rationale behind M-MIMO is based on the following principles:

- A large number of antennas makes it possible to use beamforming methods. The signals from individual antennas can add coherently at the intended recipient.
- Due to the large number of paths (originated by several transmit antennas), the signal received by a device which is not the intended receiver would be the sum of several low power and uncorrelated signals, whose sum results in very low power.

Hence using a large number of antennas can considerably reduce the interference from the base station to unintended devices, resulting in an SINR benefit. Deploying a large array of elements where the wavelength is large is problematic – initially we plan to model M-MIMO capability only in the frequency bands above 6GHz.

According to [Hoydis13], [Bjornson15], [Larsson14], [Nordrum2016], the spectral efficiency gain of M-MIMO is mainly due to the following reasons:

- **SINR boost**: As a result of high received signal power and low inter-cell and intra-cell interference.
- **Multi-user gain**: thanks to the highly directive antennas arrays in M-MIMO, multiple users can be served in a Spatial Division Multiple Access fashion. This yields a substantial multiplexing gain.

It is worth noticing that, in the studies presented in [Hoydis13], [Bjornson15], [Larsson14], [Nordrum2016], it is assumed that user' terminals only have one antenna. This means that the spectral efficiency gain in M-MIMO is not obtained as a result spatial multiplexing, like in conventional MIMO. Although it is not possible to exclude that spatial-multiplexing will be extended to M-MIMO in the future releases, its earliest versions – such as those presented in [Hoydis13], [Bjornson15], [Larsson14], [Nordrum2016] – leverage different principles to achieve spectral efficiency gains (see points above). We anticipate that combining conventional gain within each spatial beam is likely to be achievable in the lifetime of this study.

As an example of the dramatic improvements that are anticipated with M-MIMO we can use the results of [Bjornson15], as shown in Figure 5-12. These results are for a multi-cell scenario, in which several cells transmit with M-MIMO. Therefore, this study accounts for inter-cell interference, which is a common issue in dense urban networks. The authors present the results for different number of users, which demonstrates that the SE varies tends to increase with the number of users served. Spectrum efficiencies in the order of 50 to 120bps/Hz are feasible.

There are many factors which will implement the achievable spectrum efficiency for M-MIMO. For simplicity in the model implementation, we propose to assume that a M-MIMO array, where deployed, assuming at least 64 elements, will be capable of supporting 8 independent streams, and each stream will take the characteristics of conventional 4x4 MIMO spectrum efficiency. This would result in 8 streams, with an aggregate SE of 32.3 bps/Hz (i.e. 8 streams of 4x4 (with an average gain of MIMO_factor of 1.81) and a baseline SE of 2.23 bps/Hz). Though it is noted that this is less than some quoted values for SE, this value is significantly more than today's figures. The number of independent streams able to be supported by different sized arrays can be reviewed in future, but we believe 8 independent streams is reasonable for this phase of the modelling.

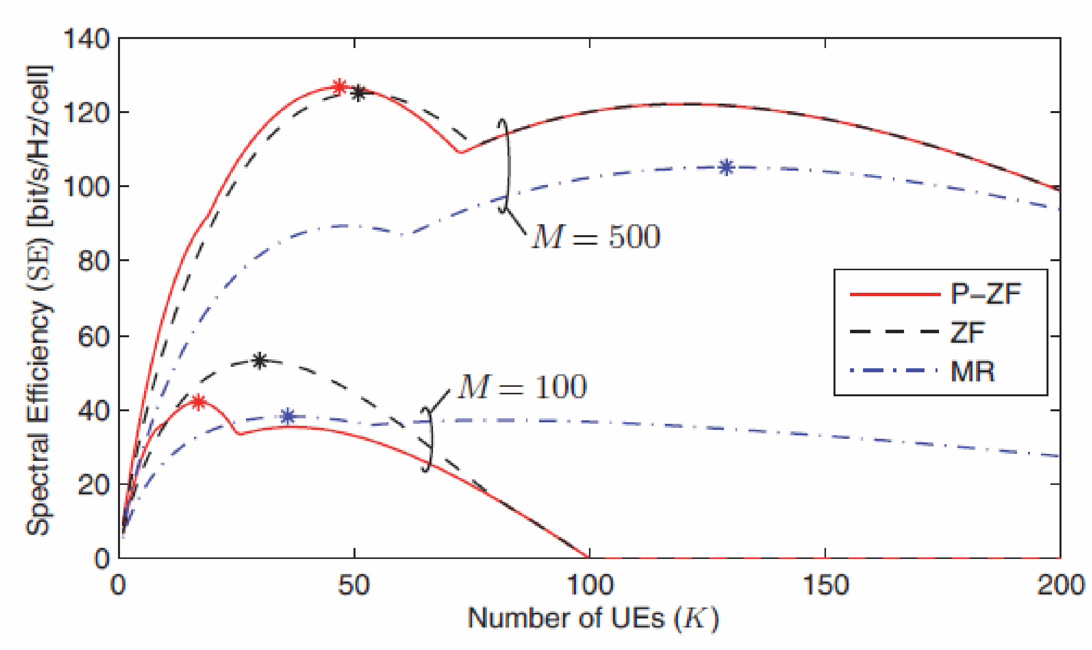


Figure 5-12: SE per cell as a function of the number of scheduled users [Bjornson15, Figure 11]

5.4.5.4 Network Loading

In practice networks do not utilise 100% of the air interface capacity. This would result in excess delay for some packets and inflexibility in scheduling. In previous studies for MBB traffic, Real Wireless have assumed a Network Loading of 85% [CAP2012]. As discussed elsewhere in this section, the actual utilisation of the air interface capacity efficiency is likely to vary between different generic services.

Since MBB is likely to occupy a large quantity of the air interface capacity, we propose to use a nominal network loading of 85%, and adjust from this nominal loading value with differences in the service factor parameter for other services.

5.4.5.5 Service factor

As discussed in section 5.4.5, different services will be able to utilise the air interface less efficiently than others, for reasons such as the following:

- Low latency: This will impose scheduling inefficiencies
- Higher Link reliability: Methods to achieve this can include diversity operation (requiring capacity utilisation from more than one base station to transmit the same information), or increased coding and/or lower order modulation;
- High overhead traffic: Some traffic, such as some MTC communication, has a high proportion of signalling overhead compared to the payload to be transmitted.

Estimates of these service factor gains (they will typically be losses, or have gains less than one) will be examined as the specific traffic is developed for the use cases. For now, it is sufficient to recognise that different service classes will have representative service factors and to incorporate this flexibility into the network costing model.

5.4.5.6 Frequency factor

mmW communications enable new opportunities to exploit larger and unused bandwidths. Due to the different nature of the signal propagation, the spectral efficiency figures at mmW can be substantially different from those at lower frequencies. In the following, we report two different factors that can influence the SE values in the mmW regime.

- Different small-scale fading statistics at mmW are likely to affect the signal propagation. This implies that the coding techniques and antenna schemes, which are designed to exploit transmission diversity, will experience different performance at mmW compared to lower frequencies. For instance, this could result in a lower richness of the propagation environment, which could potentially affect the spectral efficiency or large MIMO systems [Bai2014].
- Different shadowing characteristics: For example, signal blocking of mmW can disrupt the (primarily) Line of Sight propagation path resulting in the catastrophic received signal power reduction.
- Directive antennas are needed to counterbalance the high signal attenuation occurring at high frequencies. This changes the interference scenario, as each user will perceive less overall interference from adjacent cells. The network is expected to operate in the so-called "noise-limited" regime, unlike in sub 6GHz frequencies, where the networks are "interference-limited". The SINR will be affected by the noise, rather than by the interference and then the average cell spectral efficiency at mmW may be different from that at lower frequencies.

In the timescales of this first version of the cost model we assume the same SE values for all frequency bands but may revisit this assumption later in the project particular if new information from complimentary EC projects emerges.

5.4.5.7 Cell geometry factor

This is a value to indicate cell geometry efficiency gain compared to traditional urban macro cell. Within the 5G NORMA consortium we have identified that small cell geometries should have, on average, a SE improvement of 1.2 compared to urban macro cells. Other factors will be identified for use in other environment types – but this flexibility will be incorporated into the network cost model.

5.4.5.8 Joint processing efficiency factor

In theory, joint processing of the information from multiple antenna sites at a common site should allow interference reduction to be performed. Though computationally intensive this multi-site processing could yield performance gains. In practice, this capability is not being deployed in practice. This flexibility will be incorporated into the network cost model, but we will assume a nominal value of 1 (i.e. no benefit) and will review if new information arises.

5.4.5.9 Summary of spectrum efficiency parameters

The different spectrum efficiency factors will evolve over the course of the study period. The spectrum efficiency can be altered by a large range of different factors. In this section we propose a mechanism that allows for these different attributes to be combined to derive estimates of the achievable spectrum efficiency for an arbitrary deployment. It is expected that this approach is sufficiently robust and flexible to accommodate the range of services, site configuration and network deployment that is needed to be modelled to capture the economic impact.

A summary of these factors and the time at which they can reasonably be assumed to be available is shown in Table 5-15. Some of these factors will be updated during the process of defining the traffic scenarios where more details of the service characteristics will be reviewed.

Table 5-15: Baseline spectrum efficiency parameters

Parameter	Source of gain	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Overhead Gain	Cyclic Prefix	1	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
	Guard band removal	1	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
MIMO factor	4x4	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
	8x8	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06
	Massive MIMO (# streams)	1	1	1	1	1	1	8	8	8	8	8	8
Network Loading Factor		[0.85]	[0.85]	[0.85]	[0.85]	[0.85]	[0.85]	[0.85]	[0.85]	[0.85]	[0.85]	[0.85]	[0.85]
Service Factor		[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]
Frequency Factor		[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]
Cell Geometry Factor	Macro	1	1	1	1	1	1	1	1	1	1	1	1
	Small cell	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Joint Processing Factor	Unlikely	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]

6 Socio-economic benefits analysis

In this section we set out our progress so far on the analysis of the economic and social benefits in relation to the economic validation of the 5G NORMA network and the assessment of the use cases.

We begin by looking at the use cases in more detail to clarify the potentially most interesting services within those use cases from an economic perspective. Since it is impossible to be comprehensive about future 5G services, as the number of potential applications is large and uncertain, we focus instead on those services we can identify which may have a significant economic and/or social impact (noting that the selection process will not be fully objective). In the next phase of our work we intend to make a qualitative and quantitative assessment of the economic and social impact of the leading services that we identify.

We also present the results of our revenue assessment for enhanced mobile broadband (eMBB) services. eMBB is a key service in one of the evaluation cases for the economic validation of the 5G NORMA network. These revenue forecasts will be used in combination with results of the cost modelling in the metrics for the economic validation. In the next phase of our work we intend to produce similar revenue forecasts for services for the evaluation cases that relate to MTC and uMTC generic service categories.

Finally, we set out our approach to assessing social benefits, and how that will build on the initial description of potential social benefits contained in Annex Aon use case business models.

6.1 Selecting potential 5G services from the use case business models

The table on the following page sets out a matrix of use cases against end users (verticals and consumers). We have identified, as far as is possible given the uncertainties over 5G developments, a representative range of 5G services within this matrix. It is necessary to delve into the use cases and focus on specific services because users purchase services rather than use cases, hence services drive revenues and social benefits. We have drawn the list of services from the business model analysis of the use cases, presented in Annex A of this document, and from desk research on the evolution of mobile communications, IoT and related areas.

We took this approach because it is too early to derive, with any certainty, an exhaustive list of future 5G services. The matrix of use cases, identified in 5G NORMA Deliverable D2.1, and users – verticals and consumers – provides a framework for identifying which services are likely to be important for 5G (about which there is a fair degree of consensus). Looking at users and use cases gives us a wider perspective than otherwise if we were to focus only on use cases.

Table 6-1: Matrix of user types and use cases

	Users							
	Tenants							**Subscribers**
Use Cases	Manufacturing	Agriculture	Healthcare	Emergency Services	Automotive	Transport	Utilities	Consumers (content)
Industry Control	Wireless control & automation of machinery						Automated control e.g. street lighting	
							Automated load balancing (electricity)	
Enhanced Mobile Broadband			Patient monitoring					Tiered packages for consumer content
								VR Gaming
Emergency Communica-tions			Remote care in ambulance	Secure voice & data for the emergency services				
				Natural disaster resilience				
Vehicle Communica-tions					Municipal traffic management			
					Assisted driving & safety			
					In-car infotainment			
Sensor Networks Monitoring	Wireless automation of machinery	Semi-automated crop management	Patient monitoring			Train flow optimisation	Remote diagnostics: fleet & infrastructure	

		Livestock tracking	Wearable personal sensors			Remote fleet diagnostics	Fleet management	
		Farm equipment tracking					Smart metering	
Traffic Jam								High user density eMBB performance
Real-time Remote communica-tions			Remote procedures & training:					VR gaming
			Remote diagnosis					
Massive Machine Type Communica-tions						Train flow optimisation	Remote fleet diagnostics	
						Fleet load optimisation		
						Remote fleet diagnostics		
Quality-aware Communica-tions								
Fixed-Mobile Convergence								Integrated fixed & mobile connectivity
Blind Spots								Extended coverage
Open Air Festival								High user density eMBB performance
								Multicast services to festival-goers

The next step is to identify a limited subset of the above services for further analysis of the potential revenues and social benefits. We want to identify the services which are going to have the greatest potential impact on the economy and wider social welfare.

This is no easy task and we have to rely on qualitative reasoning to tease out reasons why some services may be more important than others. Our main criteria are taken from two key 5G NORMA innovations, multi-tenancy and multi-service capability.

These innovations are relevant because they suggest that at least part of the value from 5G will be driven by the potential economies of sharing (e.g. multiplexing gains and economies of scope) in 5G networks and part by the underlying value of the services. Hence, services whose demand is geographically coincident with other services are more likely to benefit from economies of sharing and more likely that network will be built to serve those customers. This is an important consideration because the industry verticals we consider operate in fairly distinctive locations, unlike, say, consumer eMBB which is much more widely dispersed (though there are areas of very concentrated and low-density consumer demand too).

The services which will have the greatest potential for generating sharing economies are those whose users are most widely distributed and hence most likely to overlap other users. The following hypotheses arise from applying this criterion to the various vertical user types:

- Vehicle communications services (V2X) require a network that is widely deployed in cities and suburban areas. Hence sharing possibilities are likely to be relatively high for these types of services. On arterial routes between towns and cities, the opportunities for sharing with other services may be less. However, there will be a demand for consumer mobile broadband, from vehicle passengers, which may still generate significant economies of scope between eMBB and vehicle communication services.
- Transport has significant potential to generate economies of scope because it shares similar drivers, in terms of the required network, to V2X communications.
- For healthcare and emergency service applications, potential sharing opportunities are also substantial. For example, healthcare institutions are typically widespread and reflect the general spread of the population. Hence the overlap with consumer MBB is likely to be high.
- For utilities, such as energy and rail, the potential for sharing is lower than health and V2X communications services, since infrastructure is often routed to avoid areas of population where possible. However, in areas such as train stations, or local energy distribution networks there will be sharing opportunities and utility networks do cover such areas.
- Manufacturing, industry control applications are quite diverse, and therefore difficult to generalise. Heavy industry may be located away from population centres. Large manufacturing sites may also be fairly self-contained with limited other activity in the vicinity. Lighter or smaller scale industry may be more integrated with population centres with greater possibilities. We also note that the type of industry will vary significantly between countries, e.g. countries such as Germany will have a much higher proportion of large scale industry than some other EU Member States.
- Finally, we expect the potential sharing opportunities for communications services in agriculture to be limited, because it will not coincide with most other users. In addition, performance requirements for agricultural uses, e.g. throughput, are expected to be relatively low. However, there could in principle be some opportunities for sharing 5G infrastructure with consumer eMBB which could reduce the cost of extending mobile network coverage in rural areas (not a primary driver for 5G more widely).

The diagram below provides a stylised representation of the propensity for economies of scope from the geographic overlap from serving different categories of user.

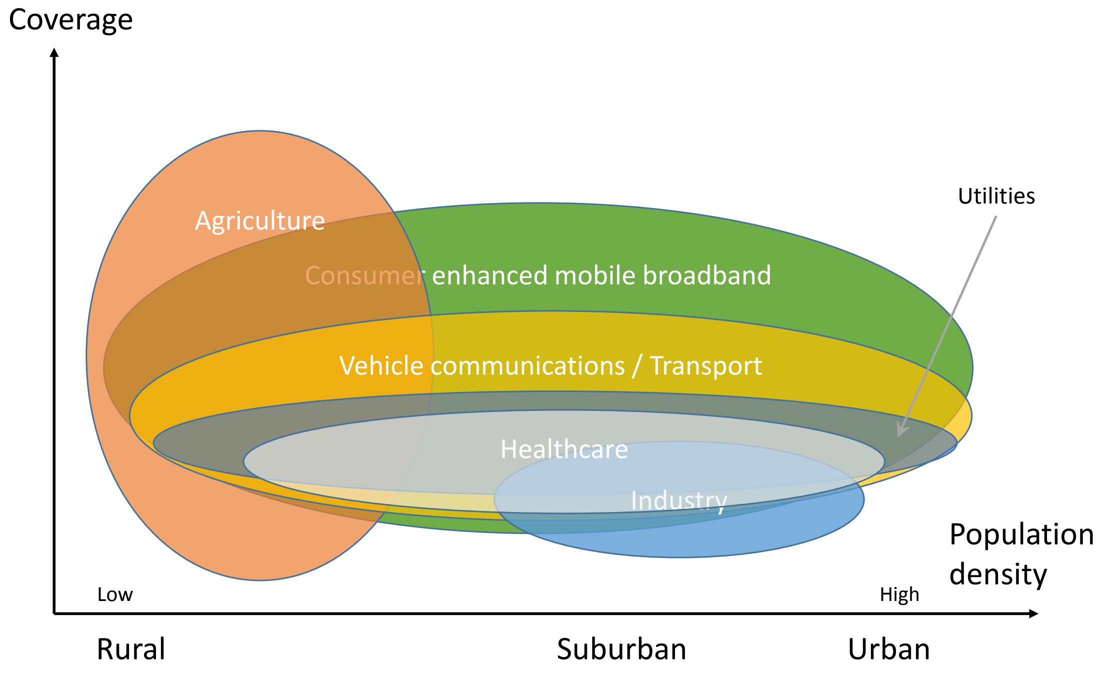


Figure 6-1: Overlap between user types

The next step in deriving a more focused list of services from which to make forecasts is to group them into clusters according to how markets for end user services might develop. For example, consumer broadband might encompass a range of packages priced according to performance and adapted to different combinations of content, information and virtual reality services that could be used in the home, in a traffic jam scenario or for in car entertainment, plus blind spots. I.e. the consumer eMBB service may cross over several other use cases. Other services can be seen as segments of the same market such as municipal traffic management and assisted driving may rely on common resources in the network (in terms of specific infrastructure}.

The clusters are set out in the table below, which also arranges the clusters according to the likely propensity to generate economies of scale (through sharing) discussed above.

Table 6-2: Clusters of services listed by potential impact on economies of scope

Service or service cluster	Cluster across user segments	Cluster across use cases
Consumer content, tiered packages for	High res video; VR gaming; in-car services; fitness & health monitoring; FMC; blind spots; traffic jams.	Includes eMBB, Traffic Jam, FMC, blind spots
Vehicle communications	Traffic management; assisted driving; consumer infotainment	
Transport – fleet management, remote diagnostics	Freight; rail	Note transport and utility fleet management could also be seen as segments of the same market
Utilities – reliable and resilient sensor	Fleet management / load balancing / remote diagnostics /	Note transport and utility fleet management could also be seen as

Service or service cluster	Cluster across user segments	Cluster across use cases
network	smart metering	segments of the same market
Secure emergency service communications	Secure communications; disaster relief mode services	
Healthcare – remote procedures, monitoring	At hospital; ambulance; home; wearables	
Industry – wireless control & automation of machinery		Industry control; sensor networks monitoring; uMTC
Agriculture	Crop management; livestock & equipment tracking	

6.2 Initial revenue analysis for eMBB

In this section we present our revenue analysis for eMBB. Revenues for other services will be calculated according to the same methodology, adapted where necessary. This revenue analysis forms part of the economic validation of the 5G NORMA architecture in combination with the cost modelling described in the section 5. Combined, the revenue and the cost side of the analysis enable us to look at the impact of 5G NORMA on profit and other financial measures. As in the network cost analysis, we project forward revenues over the period from 2020-2030.

This section only examines the impact of providing eMBB with sharing benefits assumed to be available with 5G NORMA vs LTE Advanced Pro. In future reports we intend to consider the impact of two more services falling within the vehicle communications and mobile nomadic MTC use cases.

6.2.1 Approach and key assumptions for eMBB

We begin by breaking down the market into market segments in order to capture the demand for this generic service from different types of users in the market. We chose four market segments for enhanced mobile broadband:

- Pre-pay users
- Post-pay users:
    - Early adopters
    - Mainstream
    - Laggards.

For each of these market segments we identify:

- the number of potential users in each market segment
- service take-up of eMBB, under both 5G and LTE-Advanced Pro
- ARPU for each market segment for both 5G and LTE-Advanced Pro

We note that some operators are already beginning to market services delivered over LTE Advanced Pro as 5G services. However, in this project by 5G we mean services delivered over true 5G networks.

In the case of eMBB, we assume that 5G allows higher performance in terms of faster average throughput and higher associated usage in terms of volumes of data transmitted. However, there is no consensus as yet over how much better 5G may be than LTE Advanced Pro. For that reason we have developed three projections, an optimistic, a central and a pessimistic projection. It may not be possible to deliver some 5G services at all over LTE-Advanced Pro (e.g. for very low latency remote real-time applications). In these cases, unlike eMBB, LTE-Advanced Pro take up would be zero.

We use these data and assumptions to estimate the difference between revenues for eMBB over a 5G NORMA and LTE Advanced Pro network.

6.2.1.1 Customer segments

We separate pre-pay from post-pay eMBB users because these two forms of pay-plan attract quite distinctive types of user. Pre-pay users are very price sensitive and have substantially lower ARPU than post pay users (£5 vs. £25 /month in the UK).

We take Ofcom's Communications Market Review, 2015, [Ofcom2015] as a source for the proportion of pre-pay subscribers – 40%. For the post pay market segments, we follow the classic literature on technology diffusion, e.g. Rogers, 1962, "Diffusion of Innovations" [Rogers62], and noted in the table below. Early adopters are likely to overlap significantly with heavy / intensive users that relatively insensitive to price. The mainstream we take as being close to the typical or average user and laggards may be fairly representative of light users who are not as price sensitive as pre-pay users.

Table 6-3: Proportion of subscribers by market segment

Market segment	Proportion of total market
Pre-pay	40%
Early adopter	9.6% (16% of post-pay)
Mainstream	40.8% (68% of post-pay)
Laggard	9.6% (16% of post-pay)

6.2.1.2 Service take-up by segment

We model service take-up for each of the four market segments described in the previous section. We would expect take-up to be faster in areas with above average income, such as central London, than for the UK as a whole. However, in order to simplify the analysis we assume that service take-up is the same for Central London as for the UK as a whole.

Table 6-4: Service take-up by market segment

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Early Adopters	11%	21%	29%	36%	42%	49%	57%	66%	77%	90%	96%
Mainstream	0.5%	3%	11%	21%	29%	36%	42%	49%	57%	66%	77%
Laggards	0%	0%	1%	3%	11%	21%	29%	36%	42%	49%	57%
Pre-pay	0%	0%	1%	3%	11%	21%	29%	36%	42%	49%	57%

5G post-pay service take-up is modelled on the historical and predicted penetration of 4G (as a % of all subscribers). This data is taken from GSMA, Mobile Economy Europe 2015, (http://gsmamobileeconomy.com/europe/) and is fitted to the mainstream market segment. We assume the early adopter market segment is 2 years in advance of the mainstream and that the laggard market segment lags the mainstream by 2 years.

5G pre-pay take-up is assumed to be the same as the laggards.

6.2.1.3 ARPU by Market Segment

Average revenue per subscriber is modelled for eMBB instead of ARPU. This is because statistics on consumer mobile typically measure subscribers not users, and it is easier to follow the same basis.

We assume that ARPS for LTE-Advanced Pro services will be the same as current ARPS, taken from Ofcom, Communications Market, 2015. ARPS has been relatively stable in recent years in the UK and we consider that LTE-Advanced Pro would not change that trend, even though it allows higher performance. The post-pay assumptions, shown in the table below, have been chosen so that the weighted average is equal to that observed by Ofcom of £23 per month.

However, we assume that ARPS for 5G services will increase and our assumptions are shown in the table below. We have created three scenarios, low, central and high because of the uncertainty over the extent to which true 5G services are going to be differentiated from those available over LTE Advanced Pro.

For pre-pay services, we assume no difference across the three cases. For post-pay services we make the following assumptions. In the low case, we assume that ARPS will be just enough higher than for LTE Advanced Pro to signify a difference and we assume this is 10%. The medium case is the average of the low and high cases. In the high case, we make a number of specific assumptions:

- Early adopters will derive a similar benefit to a current superfast fixed broadband connection (including line rental) and will be willing to pay a similar price.
- Mainstream segment pays a significant premium for better performance (which leads to an ARPS similar to that observed 5 years ago in the UK for 3G post pay subscribers)
- Laggards will pay a moderate premium for better performance compared to LTE Advanced Pro – 20%
- Pre-pay ARPS is the same as for LTE Advanced Pro, since these subscribers are the most price sensitive.

Table 6-5: Monthly ARPS by market segment

	5G Low	5G Central	5G High	LTE Advanced Pro
Pre-pay	£5	£5	£5	£5
Early adopter	£33	£36.5	£40	£30
Mainstream	£27.5	£28.75	£30	£25
Laggard	£11	£11.5	£12	£10

6.2.2 Initial eMBB revenue forecast

We present below the results of our projection of eMBB revenues for the central case. The results are for the UK as a whole (i.e. applied to the UK population) since this is easier to compare with existing statistics for the mobile market in the UK. However, we have also produced revenue forecasts for the same Central London area as covered by the network cost model.

The tables below show the increase in revenue for eMBB delivered over a true 5G network compared to eMBB delivered over an LTA Advanced Pro network. We present here results for the UK and Central London populations, in both cases just the central case.

To put these figures in context, we note that UK mobile retail revenue in 2014 was £15.3 billion, according to Ofcom. Hence, our forecasts indicate a significant, but modest increase compared to today’s UK mobile market of just over 15% per year by 2030.

Table 6-6: Increment in eMBB revenues due to 5G (mio £), Central Case, UK

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Early Adopters	80	153	209	262	311	365	427	500	585	684	736
Mainstream	9	54	198	379	518	649	772	906	1,060	1,240	1,449
Laggards	0	0	1	5	19	36	49	62	73	86	101
Pre-pay	0	0	0	0	0	0	0	0	0	0	0
Total	88	206	407	646	848	1,051	1,249	1,468	1,718	2,010	2,285

Table 6-7: Increment in eMBB revenues due to 5G (mio £), Central Case, Central London

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Early Adopters	0.5	0.9	1.3	1.6	1.9	2.3	2.6	3.1	3.6	4.2	4.5
Mainstream	0.1	0.3	1.2	2.3	3.2	4.0	4.8	5.6	6.5	7.6	8.9
Laggards	0	0	0	0	0.1	0.2	0.3	0.4	0.5	0.5	0.6
Pre-pay	0	0	0	0	0	0	0	0	0	0	0
Total	0.5	1.3	2.5	4.0	5.3	6.5	7.7	9.1	10.6	12.4	14.1
% increase due to 5G	21%	19%	18%	17%	16%	16%	15%	15%	15%	15%	15%

6.3 Approach for assessing wider economic and social benefits

Some services, such as accident and emergency services, may generate social benefits in addition to or instead of revenues from end-users. For example, emergency communications services at the time of a natural disaster will bring significant benefits in terms of reduction of injury, loss of life and damage to property. Because end-users, including emergency services providers, will not pay for these services on a direct usage or event based tariff, it is not appropriate to calculate potential service revenues. Instead, we intend to estimate these potential social benefits.

Another example is vehicle communications which feed into traffic management systems providing city authorities and drivers with real time information on traffic conditions. This could generate significant benefits for society as a whole through improving traffic flow which reduces pollution and greenhouse gases and reduces travel times for drivers. These benefits to society accrue in parallel to the revenues end-users pay for vehicle communications services and should be considered as an additional economic benefit for society.

The business case analysis in Annex A sets out an initial view on the social benefits that may arise in each use case and we will flesh this out further in the formal assessment of the wider economic and social benefits which we intend to present in the next WP2 deliverable.

Social benefits will be specific to the nature of each benefit. For example, the vehicle communications use case could help improve traffic flow, reducing accidents and pollution. Governments produce estimates of the costs of treating people involved in traffic accidents and the impact on societies of fatalities. The benefits of reduced pollution can be estimated from the impact on public health. Governments routinely cost the impact of major environmental issues such as pollution (or greenhouse gases), particularly where they have to justify intervention in order to regulate environmental impacts. For the benefits of emergency communications, we will look at the impact of 5G emergency communications services on increasing capability and effectiveness in responding to emergencies and the impact on society: lives saved and damage mitigated. These effects are over and above the direct economic effects for emergency services which might lie in reduced costs and increased performance.

In general, we can identify some common elements to the approach. First we will identify the link between the communications service and the wider economic and social benefits, e.g. V2X services and reduced travel times (plus concomitant impact on pollution) and reduced accidents. Second, we will produce estimates of the value per unit of these additional benefits using publicly available statistics, e.g. the value of leisure time to commuters per hour, the cost of nitrogen oxide pollution per cubic tonne emitted or the average cost of a road traffic accident/ value of a life lost. Finally, we will estimate the extent to which 5G services can reduce the incidence of these effects. This will be the most uncertain part of the analysis, as in many cases it will not be easy to identify the direct link between 5G use and the social benefit. We will build on existing work in this area such as the EU research project SMART “Identification and quantification of key socioeconomic data for the Strategic Planning of 5G introduction in Europe” [SMART15] project which has addressed some of these issues at a high level.

Finally, there is the question of how the wider economic and social benefits should be used in our economic analysis. In the economic validation of the 5G NORMA innovations, one possible outcome is that the evaluation case is not negative if only the (incremental) revenues and costs accruing to mobile service providers are considered, *but*, is positive when wider economic and social benefits are included. I.e., there would be a clear benefit to society from the 5G NORMA innovation, in this hypothetical situation, but there would not be a financial incentive for the market to invest. Governments would then have to consider whether subsidising networks in some manner (e.g. public commissioning of infrastructure, public private partnerships, credits to bidders in an auction) could incentivise service providers to deliver the innovations and be a good use of public funds.

7 Conclusions

This document reports progress on the economic and social analysis in 5G NORMA. It covers the analysis of use cases, and the services within them that require the new capabilities that 5G networks can provide and whose performance requirements the 5G NORMA architecture will aim to meet. Deliverable D2.1 first reported on use cases and requirements and here we provide our final results in this area.

In addition, a brief overview on planned project wide evaluation activities is given. In order to provide a common ground for technical as well as economic evaluation contributing to a proof of concept of 5G NORMA key innovations three evaluation cases have been proposed. These evaluation cases parameterise and specify evaluation conditions and assumptions. A clear identification of expected results from economic evaluation will guide the development of economic modelling and will be used providing the basis of the functionality of the network cost models. A set of evaluation cases is proposed for use in subsequent economic evaluation of the 5G NORMA architecture. These will be applied to define the multi-service and multi-tenant scenarios to be used in future and in the economic modelling of the 5G NORMA architecture.

In this Phase 1 network cost analysis we consider the savings a multi-tenant 5G NORMA network delivers over a number of single-tenant networks serving the same level of demand (Metric B) for an evolved LTE network architecture with enhanced sharing capability. This report demonstrates that the RAN costs for four operators sharing one 5G network are 41% less than that for four identical single-tenant networks, each carrying 25% of the traffic of the shared network. The cost saving is lower, but still substantial at 27%, when only 2 operators share a network. These sharing benefits establish a lower bound on the level of saving that is anticipated for a 5G network architecture. In addition, we propose a methodology to develop a network cost model to capture the 5G NORMA architecture flexibility consistent with the evaluation cases.

As a preliminary analysis, this deliverable presents our initial evaluation of potential 5G network costs and revenues (which will be expanded in future deliverables) and a qualitative assessment of potential social benefits. Extrapolating from the UK-based study area, this analysis identifies that the eMBB services within 5G NORMA are anticipated to yield a modest, though significant, increase of 15% growth in the UK mobile retail revenue.

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Annex A. Use case business models

This Annex examines the business models for the use cases described in the prior deliverable D2.1. Our aim is to delve further into the use cases in terms of the services provided, the roles of the key service providers, the interactions between service providers and both other providers and consumers, the potential positioning of the services and models for charging end-users and, in outline, possible welfare effects from use of the services.

This material is intended to inform subsequent economic forecasts of the market potential for the leading use cases and qualitative analysis of the potential benefits and barriers to the development of markets for these services.

A.1. Industry Control

Service Providers

- Telecommunications Operators
  Operators can participate by providing network connectivity within the factories, meaning here NaaS on top of the network infrastructure (IaaS)

- Wireless Technology Companies
  Robots, actuators and sensors may use different radio technologies to connect to the network, like Industrial Ethernet, Bluetooth, WirelessHART, ZigBEE, and maybe in the future even unlicensed bands or 5G radio technologies. Displays, smartphones, tablets and control terminals may use WiFi and 4G/5G networks. Factories in the future will use a mixture of local wireless solutions with larger operators’ networks. The goal here is to integrate all these technologies in a safe and efficient manner.

Communication Services Provided

- High speed network access for terminals
  One of the advantages of using wireless control is that it allows workers in the factory floor to carry around smartphones and tablets, as well as accessing touch displays. A more dynamic and responsive control is possible then, with information about the machines and the different processes available at the worker’s hands. All these devices will need access to high speed radio networks, covering the whole factory.

- Low-latency and reliable wireless control
  When using 5G communication services, the factory operators want to be able to program and control their machines reliably and effectively. This means not only that the messages will arrive at their destinations, but they will arrive within a certain strict window of time. Safety is critical in an industrial scenario. A shutdown command cannot be lost or take too long to arrive.

Target Customers and Service Provider-Consumer Interactions

Factories and industrial complexes are the main target for this business case. They will use all the communication services to control their machines and processes.

The current wired communications have many disadvantages: they will wear over time, and their use affects the design of the machines, as well as their placement. Using proprietary wireless solutions is not the best alternative, since they incur high costs. The goal would be to have a wireless and open solution to industrial control, in order to reduce costs, and increase flexibility and safety.

The interaction between industrial plants and telecom operators will change significantly. As 5G networks move into the factory, better coordination and integration between them will be necessary. Security, safety and reliability are critical for industrial plants, so any service provided by operators will have a strict SLA. Network slices for industrial companies have to be created that may cover infrastructure of more than one operator and probably of the company itself (e.g. local networks at premises).

Companies offering new wireless technologies will interact with industrial plants, providing them with new ways of connecting their machines. From the point of view of operators, these technologies should have standard and open interfaces, in order to integrate and interact with them if necessary.

Charging

Telecommunications operators and factories will have to establish some form of agreement. The services provided have to follow strict policies, since the industrial environment requires reliable and low latency communication. This agreement will most likely be based on a fixed and regular sum the factories will pay for the service.

Service Proposition to End-Users and Other Providers

- Capability provision:
  Capabilities can be tailored to specific classes of users; for example, by defining and generating specific 'network slices' addressing different needs. While slicing enables specific features like prioritisation, availability, low latency, service bandwidth etc. the feature set of a specific slice may become a specific service bundle provided to tenants interested in that set of features. The feature set may be a part, or on top of the basic connectivity / service provision for (office) company communications needs. New 5G network functionalities, such as slicing, should be more efficient than alternative methods of achieving these effects. Hence, the efficiency gain for industry should, in turn, be higher. Since the slicing framework for different industries or even companies may vary, a more solution- and situation-based pricing scheme may apply reflecting the technical capabilities of the service as well as the basic cost of its provision.

- Combination / integration of different networks / access networks:
  Different existing fixed and mobile networks, potentially based on different standards, have to be combined to achieve a comprehensive system for all elements. The infrastructure parts may be delivered by different infrastructure providers depending on existing deployments, local pre-conditions, different (best-in-class) vendors etc. The challenge for an Internet/telecommunications service provider in this industry control use case for a specific customer is to integrate all the necessary parts and to provide itself or to buy, from adequate infrastructure providers, those parts not already available.

Potential Welfare Effects

An up-to date production infrastructure realising benefits from industrial internet can be the driver for economic growth with related effects on employment, efficiency and productivity, and positive effects on the environment. An increase in employee wage levels and corporate tax receipts for government may also generate positive income effects.

Indicators for increase in social welfare:

- Economic growth figures; in particular in industrial production; investments in industrial production methods/equipment.
- Number of start-ups working on developments in this context.

A.2. Enhanced Mobile Broadband

Service Providers

- Telecommunications Operators
  Operators will aim to provide services at any place, in any situation, e.g. in more remote locations or those with higher user densities compared to the coverage and availability of existing mobile networks. At the same time, eMBB is expected to provide significantly higher quality than 4G in terms of user throughput, volumes of data transmitted and consistency of the user experience (e.g. more consistency all the way to the cell edge).

- MVNOs
  It is difficult to say whether MVNOs will have a wider role to play in 5G services than they do today. On the one hand, as purchasers of wholesale mobile network capacity, they may benefit if 5G enables greater competition in this market (as discussed below). On the other hand, 5G does not of itself change the dynamics of the retail market for enhanced mobile broadband.

- Verticals: self-provision
  Verticals may self-provide capacity for eMBB services to their employees who fall within the coverage of their network footprint (whether they own the network or it is provided through a telecoms operator). Ideally, consumers would need to be able to switch between service providers easily e.g. through soft-SIMs, dual SIMs etc.

- OTT Service Providers
  The advantages for OTT service providers of bundling their services with eMBB at a retail level appear weak, therefore the incentives for them to retail eMBB connectivity are also weak. However, they will benefit significantly from the improved performance of eMBB.

Communication Services Provided

- New information and entertainment services
  Video is the key driver, but also virtual reality voice, messaging, data upload and download.

  Next generation TV Services (NGTV): Very High Definition resolution video services up to 8k resolution combined with additional features such as 3D, time shifting and interactivity will define future TV quality. This embraces live TV and Video on Demand (VoD) in any form. Furthermore NGTV is designed for static, nomadic and mobile consumptions, optimising the video stream for the used device and in line with available capabilities of the access network.

  Virtual Reality Experiences (VR): In principle similar to TV services, VR represents the provision of content to a special class of devices. However, given the need to provide a holistic perspective for user to get the full experience, the bandwidth needed is at least that for TV, and probably higher in order to provide the full VR experience.

  Augmented Reality Experience (AR): While VR embraces the entire view of the user, AR combines a real world view with additional experiences and information provided in conjunction with activities and situations happening around the user.

Gaming: In particular for online gaming, high bandwidth and low latency represent crucial aspects for a good gaming experience. With photorealistic graphics, the bandwidth demanded may come close to TV.

However, although we have set these out separately, these aspects can also be combined, particularly with VR as a device through which to enjoy NGTV and gaming.

Target Customers and Service Provider-Consumer Interactions

The consumers for this use case will be private consumers and businesses. Private consumers may be more focused on video and entertainment. Business consumers may be more focused on flexible working, shared access to files / information for collaborative working. Both are likely to involve substantially more down and uploading data to cloud storage services than today.

A major question is how much this eMBB use will be driven by content owners / providers – especially for the private consumer segment. The more consumers are spending on OTT and third party services the less scope there may be for traditional mobile operators to increase the underlying average spend per user on broadband connectivity from today's level (though demand for new applications may increase the overall demand for broadband connections).

If mobile network operators are unsuccessful in increasing average spend per broadband user, they may try to extract revenue from content owners for the delivery of their content to end-users (pre-supposing that some discrimination between different sources of traffic is permitted by regulation).

The market for wholesale mobile network capacity may become more competitive leading to cheaper access for MVNOs. Network slicing should make it easier to provide MVNO access and easier to switch from supplier. In addition, the increased scope for other players, such as verticals, to become 5G service providers and to resell spare capacity also widens the pool of potential suppliers of wholesale mobile capacity to MVNOs.

Charging

Network operators and virtual network operators. Some overlap with other use cases, e.g. consumers will use eMBB in vehicles, traffic jam situations, at open air events etc. The monthly subscription charge for an eMBB package may cover providing general connectivity in a range of different situations (as opposed to specialised services, e.g. access to a site specific network and content at an open air festival or similar event).

Operators may choose to offer a range of different packages with different levels of service depending upon the applications supported. For example, a basic package that still provides high speed and reliable access compared to today, alongside a set of premium packages that allow better quality of experience e.g. for ultra-high speed / low latency services such as virtual reality games (note the overlap with the real-time remote computing use case).

Service Proposition to End-Users and Other Providers

- Capability Provision:
  Bandwidth may be a precondition for specific "bandwidth hungry" applications. High bandwidth can be provided to subscribers as a specific service class enabling faster transmission rates than subscriptions without such an add-on, regardless of and how the service is used by the subscriber. Equally, high bandwidth with guaranteed QoS levels can be provided to Internet/telecommunication services providers to enable them to provide high performance services to end-users.

Potential Welfare Effects

While bandwidth as such may not generate social benefits on its own, the services and applications that higher bandwidth levels will enable may generate social welfare effects. These could go in very different directions.

Indicators for increase in social welfare:

- To be related to the specific market segment in this use case focused on high (guaranteed) service data rates.

A.3. Emergency Communications

Service Providers

- Telecommunications Operators
  Operators provide secure, resilient and highly reliable communications services for emergency service users both in everyday emergencies and in disaster situations.

- Specialist service providers
  Emergency service providers may want to use specialist sub-contractors rather than buying a standard communications service from a network operator, because secure communications are very important. In the past, this has traditionally meant deploying a separate, private mobile communications network. In the UK, EEs commercial network is planned to be used to support Emergency Services as well as commercial traffic. In future, with 5G appropriately configured network slices would simplify the ability to overlay emergency communications needs (including security, priority and pre-emption, terrestrial routing).

Communication Services Provided

- Resilient, secure and reliable wireless services
  Emergency service users will require voice, data and video services (possibly including VR displays) with high resiliency, security and reliability. Services will need to support a high density of simultaneous connections (1000 per cell per MHz) in localised situations, and very high network availability. Very high data rates may also be necessary in certain situations, e.g. where control room decisions depend upon real time high quality video information from emergency service workers.

  The ability to better adapt network resource availability in the 5G NORMA architecture should allow better prioritisation for emergency service users than is possible in 4G networks. In addition, energy efficiency, for both the network and devices, will be important in disaster situations where power facilities may be affected. For example, a low energy survival mode may be required, though this will be accompanied by a corresponding and significant reduction in data rates.

Target Customers and Service Provider-Consumer Interactions

Emergency service providers are the primary target customer. Most likely they will buy wholesale mobile connectivity as a network slice, but it is also possible that less critical communications needs could be fulfilled through the mobile operator’s retail services. Other organisations with a potential role in disaster mitigation such as local authorities, traffic management, environmental and waterways agencies etc. may also be potential customers.

Emergency services should benefit from lower costs due to being able to use public mobile communications infrastructure instead of operating their own separate, private communications network with fewer economies of scale than national mobile networks. However, this depends on the public 5G mobile networks being able to meet adequately the security and resilience needs of emergency service users. Use of the public mobile communications infrastructure should also enable emergency services to use more standard terminal equipment further reducing costs.

Charging

If emergency service users purchase wholesale mobile access through a network slice, there are a number of ways in which the service could be charged. These lie on a continuum from *volume* based charges – based on the *volume* of call minutes and / or GBytes of data used per period (with the possibility of volume based discounts on the per unit price) – to *capacity* based charges – where the user pays upfront for a certain amount of *capacity* (with additional charges if the limits are exceeded).

Volume based charging is the easier option from the user/subcontractor perspective because it requires little involvement in running the service, much like the standard MVNO model of today. Furthermore, there is no upfront payment or need to predict capacity requirements.

Capacity based charging on the other hand does require an upfront payment and good traffic forecasting by the user/subcontractor. In theory, it gives the user more flexibility in deciding how to operate the service (e.g. in allocating resources between different uses) than it might have in theory. However, this flexibility might not be so important to emergency service users as long as they can negotiate appropriate service level agreements for performance, security and resiliency.

If emergency service were to use standard more services directly from public mobile network operators, they might pay subscription (and potentially usage based) charges just like any business user. However, emergency service communications may be required by law to have additional capabilities and operators are likely to be able to charge more for functionality such as additional resilience, security and prioritisation.

It is considered unlikely that emergency service and disaster relief organisations (or individuals) pay any extra for communications capabilities specific to disaster situations, although there could be significant benefits for society as a whole.

Service Proposition to End-Users and Other Providers

- Service provision in emergencies:
  Service provision to emergency companies / public utilities may target specific classes of subscribers based on “classic models”: e.g. tariffs addressing specific needs regarding data volumes or usage patterns.

- Capability provision for specific classes of users:
  While slicing enables specific requirements to be met for prioritisation, availability, low latency, service bandwidth etc. the feature set of a specific slice may become a specific service bundle provided to the groups or tenants interested in those features. The feature set may be a part or on top of the standard connectivity / services provided.

- Network sharing/provision in disaster situation:
  In a disaster scenario local telecommunication infrastructure may be affected in different ways with different levels of destruction. In such an environment, all remaining infrastructure should become available to support emergency operations. However, although this does not address a real business model but works towards very pragmatic needs in a special situation, a mechanism will be necessary to facilitate the benefits and share the costs of such operations.

Potential Welfare Effects

Saved lives and a reduced mortality rate, from the first indication of emergency up to successful transportation to and treatment in a fully prepared location, represent the base line for the economic benefit. With 5G, even better treatment such as remote diagnostics including video/scanning procedures becomes possible during patient transport. More graduated this may lead to shorter treatment times and higher rate of full recovery, which results in a higher success rate and shorter time to return to daily life and work. In special situations, prioritising traffic, defining ad-hoc close user groups and dedicating resources, may help to integrate emergency and rescue forces better, to improve effectiveness, to perform more quickly and, ultimately, to increase the chances to save lives.

Indicators for increase in social welfare:

- Lower mortality rates during transport to hospital; faster rescue operations, higher success rates in rescue operations; decrease in health system costs compared to prior levels for the same activity, reduced damage to property, e.g. due to improved fire service response.

A.4. Vehicle Communications

Service Providers

- MNOs or mobile service providers
These providers may view V2X services as an opportunity to capture more of the value chain by providing the communications part of an autonomous / assisted driving service directly. The greater the role that mobile operators play in V2X, the greater the potential synergies in providing services that work for all car manufacturers compared to a situation where car manufacturers each develop their own versions of V2X services.

- Car manufacturers
Car manufacturers may want to become involved in service provision for several reasons. Manufacturers may want to ”own” the customer and provide V2X services to them directly. They can collect remote diagnostic data on their vehicles to improve maintenance services – e.g. problems are detected and corrected faster. Large scale analysis of vehicle performance data may also allow manufacturers to detect systemic problems more easily and lead to design improvements. They may see the ability to integrate V2X services with other features to provide an autonomous / assisted driving service as an opportunity to differentiate themselves from other manufacturers. Or they might consider that they are better placed than MNOs to tailor V2X services to the needs of drivers.

- Municipal self-provision and third party providers of traffic management applications
Some municipal authorities are already investing in traffic management systems using the wireless communications facilities available today. Hence governments, municipal or otherwise, may want to fund infrastructure or even contract out management (perhaps to non-telco specialists), particularly if they feel that telcos will not deliver the performance they need or deliver it quickly enough.

- OTT service providers and application developers
They may provide additional services that depend on V2X connectivity. For example, geographic based infotainment and navigation support services may be facilitated by a V2X network (although the V2X network might not be a necessary condition to provide these services). There may be opportunities to provide services based on intensive analysis of data captured from V2X services, to customers such as insurance companies. Some of the other players mentioned above are also likely to compete in these areas.

Communication Services Provided

- Autonomous and assisted driving services

Autonomous and assisted driving services will vary in the degree of autonomy offered. They improve safety by providing drivers with information to enhance driving performance and reduce the possibility of accidents. Even with limited autonomy, such as collision avoidance systems, velocity management in difficult driving conditions, anticipation of accident blackspots, responding to real time accident information etc. significant safety benefits could be gained.

- Information services on road and driving conditions
  These services can also improve safety in situations where autonomous driving capability is not in place or is not used. By providing real-time information on driving conditions and traffic situations, drivers will be better equipped to respond hence improving driver performance. Drivers may also benefit from reduced journey times where systems provide them with real-time options to avoid traffic hotspots.

- Geographic and navigation services, mapping, journey planning.

- Traffic management services to transport and municipal authorities.

Services which would fall under other use cases are:

- In-car entertainment and information services (e.g. local information on amenities, businesses etc.) are covered under remote real-time applications. Vehicle device costs and recurring monthly service charges for communications could be covered by both V2V and real time remote in-vehicle services.

Target Consumers and Service Provider-Consumer Interactions

There are three different customer types:

- Transport (or municipal) authorities,
- Automotive companies,
- Drivers.

Transport authorities may deploy sensors around in cities and on highways linking cities to improve public safety (e.g. by providing real time information on road conditions, facilitating access for the emergency services), and/or as part of traffic management services (to reduce congestion and pollution). These services may also be introduced by municipal authorities as part of wider smart city developments in the future.

Automotive companies are already embedding safety systems in cars which either have their own communications capability or link to the driver’s own communications device. Automotive industry experts expect that in the future the balance will shift from embedded communications capability to driver provided.

It is conceivable that automotive providers provide a set of core services free at the point of use to the end user. These core services would be linked directly to safety / autonomous driving capability and could be sold to consumers as a premium feature (at least initially). If the volume of data usage is predictable and relatively limited for this core set of uses, it might enable car makers and network operators to strike per device (rather than per usage) tariff structures for mobile connectivity.

Alternatively, all communications could be linked to the account of the registered owner of the car who pays the communications service provider directly. A variation on this is where the car’s systems need to be linked to a driver’s (or passenger’s) mobile device and hence communications charges could be linked to that end-user’s normal account.

For services beyond the core set of safety related services, such as infotainment, the service provider (which could be the network operator or a third party) will have a direct relationship with the end-user.

Charging

Network operators may agree a charging model with automotive companies for a charge per embedded device activated which would cover the connectivity services needed for a core set of services, particularly autonomous driving and safety measures. This could be used as a rental charge to recoup the cost of the coverage network necessary (including road-side sensors and units) for these services to work.

Where the end-user is paying, mobile connectivity may fall within the end-user's overall monthly rental, or there could be a set of tiered pricing to reflect different bundles of services similar to the way in which cable and satellite TV providers have several bundles of services with add-ons for sport and other high value content.

Charges for traffic management applications, to central/municipal government and highway authorities, may be based on network usage in urban / suburban areas assuming that the infrastructure is shared with other communications services. However, the costs of the sensors themselves and system integration are likely to be charged directly to government agencies.

Service Proposition to End-Users and Other Providers

- Service provision to central/municipal government and highway authorities:
  Support for traffic management applications, integrating the sensor network and the communications service. Service providers may position services to drivers as an add-on to their standard subscription package. This may be tenable for embedded V2X systems, particularly for assisted driving. OTT providers may target services to customers' existing devices – e.g. information services. Offering services over a separate slice may fit well with the safety and reliability requirements for assisted driving / safety applications and make it easier to charge for this service as an add-on. Service providers need to consider whether vehicle manufacturers will be willing to pay, to ensure that a defined level of performance is available to their customers. This is complicated, because it is currently not clear where the boundary between the individual driver and the vehicle manufacturer should lie.

- Network sharing:
  A network slice could be provided to each vehicle manufacturer on behalf of its customers, however vehicles from different manufacturers may also want to communicate with each other. Service providers will need to determine the most efficient way of addressing this issue. Communications infrastructure and V2X systems may also need to be shared between government agencies and also between operators, so there is a need to find suitable solutions for this.

Potential Welfare Effects

Assisted driving will reduce accidents, hence saving lives and reducing road traffic injuries. However, the change may be incremental given that assisted driving applications are already being trialled by some manufacturers which use on-board cameras, radar and GPS and do not make use of the existing mobile communications infrastructure.

City level congestion and travel times should also be reduced due to more advanced traffic management and information provided in real-time to drivers and transport agencies. This is likely to generate environmental benefits – although studies show that increases in vehicle speeds above certain level can actually *increase* pollution and greenhouse gases – and to welfare benefits from the time that is freed up by reducing congestion.

Indicators for increase in social welfare:

- Reduced congestion, without an overall increase in vehicle use, would be reflected in a more even distribution of traffic flows (and speed) over the course of the day; reductions in the average journey time per vehicle user; a fall in road traffic accidents (all other things being equal).

A.5. Sensor Networks Monitoring and Massive Nomadic Mobile Machine Type Communications

Service Providers

- Telecommunications Operators
  The main service providers here will be the operators. Both of these use cases deal with sensors.

  One entails different verticals installing sensors in nomadic/mobile objects (freight trucks, factories, wearables, tractors, among others), and then using the network provided by the operators to collect all the data produced by the sensors. In this context, local and wide area networks are considered, as well as locally positioned gateways.

  The other scenario occurs when one entity (agricultural business, weather agency, transportation companies, among others) owns many low cost and battery powered sensors and installs them in an area, with the operator offering connectivity between all the sensors and the entity's network.

Communication Services Provided

- Interconnection of sensors to the network infrastructure
  The verticals will have low cost and low power consumption sensors either in nomadic/mobile objects or spread around a big area. They will interact with the operator's network infrastructure by sending small data packets with a certain regularity or event-driven. For very large number of sensors (the most common case for the static sensor network use case), this can be accomplished by reducing signalling through "connectionless" access. There will be no establishment of individual bearers and no L1/L2 connection state information for individual devices. In general, sensors will transmit messages to all nodes capable of hearing them and allowing sufficiently secure forwarding of data. Connecting with the sensors will occur either through different gateways (cluster heads, aggregators, or sensor mesh networks) and/or local- to wide-area links (dependent on device class). The operator will then link the data gathered by the sensors with the verticals' network.

Target Consumers and Service Provider-Consumer Interactions

A reliable connection from/to sensors will be offered by network operators to different verticals:

- Production industry
  - Deeper monitoring can provide better fine tuning of industrial system adjustments and allow for predictive maintenance
  - Process optimization in production facilities and transportation of goods based on real-time information (material and inventory management).

- Logistics/Transportation
  - Large deployment of sensors will allow for greater efficiency, high loading of goods vehicles, reduce time and distance travelled per delivery due to improvements in coordination made possible by 5G.

- Agriculture
  - Agricultural business nowadays uses sensors extensively: in agricultural equipment, sprayers, soil sensors, among others. Increasing the density of sensors by allowing bigger numbers of sensors can reduce environmental impact, water and pesticide usage, while increasing yields.

- Environmental monitoring like air quality supervision, earthquake monitoring and weather monitoring
  - A very large number of low cost and low energy sensors spread throughout a big remote and/or inaccessible area are necessary for these verticals. A connectionless framework and a data gathering infrastructure can make these deployments more efficient and lower their cost.

- Health
  - Sensors will be used to support remote eHealth applications. In this case the sensor density might not be too high.

The main interactions will be between the operators and these verticals.

Initially, the vertical will acquire and install all the sensors necessary for its operation. This installation could be supported by the operator, but this is optional. After that, the operator will set the data gathering system, assuming all sensors are capable of connectionless access and send data regularly.5G NORMA will simplify network attachment and bearer management signalling, reducing resource utilization and handling 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.

Verticals and operators could share the upfront costs, e.g. if coverage is a problem in low population density areas. Besides that, some pre-existing private networks could be absorbed into the MNO’s network – MNOs have lower upfront cost, the vertical gets better performance and saves on future maintenance and upgrades.

Charging

Some form of long term agreement between a vertical and the operator will have to be reached. The data volume the network will generate depends on the sensor service and its transmission regularity. For larger data volumes, the most likely charging model will be some form of flat rate per month/quarter/year. An alternative charging scheme for smaller data volumes or nomadic/mobile sensor networks would be overall data volume in a certain period.

Service Proposition to End-Users and Other Providers

- Connectivity provision:
  Depending on the location of sensors and other units in an M2M connectivity framework this may already define a challenge to ensure connectivity to all sensors during all times with requested connectivity features in line with demanded task in the M2M construct.

- Capability provision for specific classes of users:
  This may be implemented by defining and generating specific slices addressing different needs. Very similar to other industry use cases a slice or even a specific

network infrastructure may optimize the transport of data packages among different M2M units /remote and centralized units. While slicing enables specific features like priorities, availability, low latency, service bandwidth etc. this feature set of a specific slice may become subject of a specific service bundle provided to interested group of tenants requesting exactly those kind of features. The feature set may be a part or on top of any provision of connectivity or M2M type services

- Combination / integration of different networks / access networks:
  Similar to Industry control: Different existing fixed and mobile networks, maybe based on different standards have to be combined to achieve a comprehensive system for all elements. The infrastructure parts may be delivered by different infrastructure providers depending on existing deployments, local pre-conditions, different (best-in-class) vendors etc. The Internet/telecommunications service provider within such Industry control scenario for a specific customer is challenged to integrate all parts and either to provide or to buy those parts not already available from adequate infrastructure providers, while those deliver parts of the entire solution.

- Related use cases in B2C context:
  Connected devices in home environment and for any kind of supported living may provide additional services to users. This may either be part of an entire separate communication or provided as any other (mobile) communication device and related service.

Potential Welfare Effects

Similar to Industry control: – the next stage of industrial internet use through more intensive M2M solutions and sensor networks can drive economic growth and increase efficiency, for example production managers and operatives may get more accurate and detailed information on how effectively their production processes are working as a result of just-in-time sensor data. This in turn may have spin-off effects on employment and the environment. An increase in employee wage levels and an increase in commercial taxes may also generate positive income effects.

In the public sector, massive sensor networks can support and improve a variety of applications, e.g. more efficient energy use, pollution control and reduction, improved health care, up to disaster warning / prevention.

In the consumer sector, sensor networks, e.g. connected homes operate in a different context. One major benefit is convenience – but they may also improve welfare if they lead to more efficient energy consumption and, as a result, reduced greenhouse gas emissions.

Indicators for increase in social welfare:

- Economic growth figures; in particular in industrial production; investments in industrial production methods/equipment.
- Energy consumption of private households, reduction of burglary numbers/insurance cases by burglary; improved KPI figures on public services and environmental framework conditions.

A.6. Traffic Jam

Service Providers

- Telecommunications Operators

  The main service providers in this use case are operators. They will provide the fast and reliable communication services that will be used by the other providers.

- Transportation Industry
  Transportation companies and car manufacturers may offer in-vehicle infotainment services to the end-users. As the users are stuck in traffic, any content that will help pass the time will be welcomed. Buses, taxis and trucks can use network connectivity to improve their services, using navigation services, traffic information, company records, etc.

- OTT Players
  Cloud-based services and High Definition (HD) multimedia content providers (for instance, Netflix and Hulu) will use broadband wireless services to end-user during traffic jams. In this case, the users would access the content in their smartphones and tablets.

Communication Services Provided

- Reliable Internet access
  The main service that should be provided is the smooth continuous operation of the network during the traffic jam, without outages due to congestion. Sudden increases in demand should not result in noticeable reduction of the Quality of Experience (QoE) for end-users.

- High speed network access for multimedia content and cloud-based services
  Cloud-based applications, HD multimedia content and infotainment services will require low latency, high speed network service to operate. This is an extension of the service mentioned above, since it's more than continuous service, but also enough bandwidth to transmit HD video/audio, as well as low enough latency for cloud-based apps to be able to operate.

- Voice and messaging services
  People stuck in a traffic jam will contact their families, friends and colleagues to notify them of their current situation. This will increase the number of calls and messages sent in the area affected by the jam, during its duration.

Target Consumers and Service Provider-Consumer Interactions

The interaction between the operators and end-users will not change significantly. QoE is expected to be maintained, even in this extreme situation. Voice and messaging services should likewise continue to work as expected.

Consumers will interact with OTT players and cloud-based services by subscribing to their services directly. It's also possible for those services to be offered in a bundle package by the operators to the consumers. Cloud-based services and OTT players would then reach out to operators, making deals to connect with the clients of a certain operator.

Car manufacturers could make agreements with the operators, providing the drivers and passengers a selection of content bundled with the multimedia system of the car.

Charging

No major changes to the charging of end-users by the operators is expected. OTT players and in-vehicle infotainment will be charged following the current models, like monthly or yearly subscriptions, or a fixed price per piece of content.

Service Proposition to End-Users and Other Providers

- Capability Provision:
  The main goal here would be to guarantee a stable and reliable service even during a sudden spike in demand. High bandwidth should be provided and ensured, especially for multimedia content and cloud-based services. The infrastructure provider should answer requests for resources from internet/telecommunications service providers in a timely manner. Since the main cause of service disruption or degradation will be the sheer increase in connections, calls, and bandwidth, not only will the network have to reorganize itself, it will also demand many more resources from the infrastructure. Additional procedures the telecommunications service providers might use to avoid service outages are prioritization or downscaling of e.g. video services.

Potential Welfare Effects

This is an event based use case. The main welfare benefit would come from the reduction in stress experienced by the drivers and commuters. Another benefit for commuters is the possibility of doing some work while in the traffic jam. Reduction of stress for inhabitants close to major streets can also be mentioned.

Indicators for increase in social welfare:

- Decreased number of delay times in commercial transport;
- Increase on productivity from commuters.

A.7. Real-time Remote Computing

Service Providers

- Telecommunications Operators
  Operators will provide high reliability, low latency and high-speed services for a number of different verticals which will be essential to allowing use of remote control and real-time information services.

- OTT Service Providers
  OTT players may offer services e.g. real-time cloud services, 3D virtual reality, that require a very low latency. End-users may want to use these services because it frees up resources on user terminals, prolongs battery life and may reduce technical overheads in operating and maintaining software applications.

Communication Services Provided

- Real-time voice and video services with low latency:
  This could be used to provide end-user applications such as real-time updates for drivers on traffic, local amenities and local businesses on “smart” windscreen displays. It could also be used for gaming and online collaboration requiring low latency, and virtual reality gaming would require high-speed transmission.

- High speed transmission with low latency and high reliability for remote control of equipment physical functions:
  This includes virtual and augmented reality, tactile, and remote control applications which could be used for remote surgery, remotely controlled vehicles or industrial machinery and the virtual office. Low latency and high reliability will be essential for all “remote” applications. Some applications, such as surgery or intricate industrial work may involve very high-definition video and hence require high-speed transmission services to transmit video in real time. Low latency, reliable data transmission for cloud based services:

Cloud computing (apps running in the edge/core cloud rather than in the mobile terminal) would require low latency data transmission to enable resource-hungry applications to run on remote servers rather than on terminals. This would keep resources requirements for the UEs lower and battery life longer. It also enables emerging paradigms such as "software as a service" (SaaS).
Other emerging applications include applications for the financial markets (e.g. high frequency trading). Currently a large volume of trading operations are performed by automated algorithms, and the number is increasing day-by-day.

Target Customers and Service Provider-Consumer Interactions

There are a number of target customers for each of the different communications services that fall into this use case.

The following verticals may all have need for remote applications:

- Healthcare – surgery;
- Manufacturing – remote control of equipment.

Office workers and gamers may use these services for online collaboration / interactive playing. They may purchase software from specialist producers and deal with operators to obtain the appropriate communications package to be able to use online collaboration / gaming effectively.

Drivers are the target end-users for real-time information services in the automotive sector.

Businesses (and perhaps individual users) are the target end-customers for cloud-based services and SaaS applications.

The main interactions will be between the operators and the target customers in the case of remote control applications. This service capability may be bundled in with the standard communications service purchased by businesses in these sectors, or it could conceivably be a separate service.

In the case of real-time information to motorists, we expect the automotive sector to deal with the operators in terms of the requirements for the service and coverage, with devices installed into vehicles on demand. Third party mapping and information service providers may also be involved in providing the facilities for local businesses to publish and update the information provided to motorists.

Third party providers of cloud-based services will interact with both network operators and end-users in providing cloud based services.

Charging

Many of the end-users may not pay directly for a specific real-time remote communications service. Instead it is more likely that the operator will offer a number of packages, as part of its standard range of mobile communications bundles, which allow effective use of real-time remote applications but also provide for all of the end-user's communications needs.

In manufacturing and in healthcare it is possible that customers do purchase bespoke services if they need services with extreme requirements for reliability and/or high quality video transmission.

For cloud-based services, charging could be on a per licence or per user basis, though there could also be a usage based element in terms of amount of data up/down-load per month.

The end-user may pay for automotive real-time information services on a subscription basis, or as for vehicle navigation services a fee for the initial system access and another for periodic updates to the database.

Service Proposition to End-Users and Other Providers

- Capability Provision for Real-time Remote Computing:
  Given the kinds of service demand, specific capabilities may be created in network slices to provide exactly those capabilities. The feature set of a specific slice may become a specific service bundle provided to the groups or tenants interested in those features. The feature set may be a part or on top of the standard connectivity / service provision.

- B2C scenario:
  In a B2C scenario, real-time remote computing may be promoted as a separate commercial service for business users wanting to use such capabilities beyond what they may be able to provide in their own networks.

Potential Welfare Effects

Real-time remote computing can be seen as an enabler for a multitude of services which depend on complex processing operations and benefit from more efficient or powerful computing technology. Accordingly, real-time remote computing as such may not generate social benefits by itself, however, via the services that may arise due to optimized computing power applied. Social welfare effects could go in very different directions as already addressed above with Healthcare and Manufacturing.

Indicators for increase in social welfare:

- To be related to specific services benefiting from remote computing.

A.8. Quality-aware Communications

Service Providers

- Network Providers (MNOs, ISPs, etc.)
  These are the main providers benefitting from this use case. They will be able to offer better service to their customers, increasing satisfaction and reducing churn and costs.

- Automotive Industry
  Cars could offer better communications services, especially for edutainment media. Savings in costs and energy consumption also make this use case attractive to the automotive industry.

- Media
  Services like multimedia broadcast (TV/radio), video streaming services, video games, among others, are very resource consuming. Tailoring their delivery to user experience would represent a great improvement in efficiency.

- Transportation and Travel
  Public transport companies, airlines, train operators, shipping companies, etc., can ensure good satisfaction levels for communication services to their passengers and network operators can provide this capability in a more cost-effective manner. This could result in lower costs for the end-user if it is reflected in lower prices.

Communication Services Provided

- Quality-aware mobile communications
  5G mobile communications would take into account user satisfaction, context and experience when allocating resources, leading to reduction in energy consumption and overall costs. The end-user satisfaction would be monitored, and only the resources

necessary to keep the user satisfied would be used. Management effort would also be reduced, since any transmission adaptation will only come from changes in satisfaction. This could lead to improvement in scalability.

Quality-aware mobile communications are especially suited for services that have variable needs while also requiring high throughput and/or high reliability. One example would be a live stream for a soccer match. For about two hours, there is an increase in demand for HD video and audio, as people follow the game. Resources can be diverted to allow for the capacity necessary to provide a high quality viewing experience, while preserving the integrity of less resource critical services.

Target Customers and Service Provider-Consumer Interactions

The main interactions will be between the different verticals and operators, and the end-users. Services provided will have improved quality of experience and user satisfaction.

Operators will reduce user churn, serve larger number of users, save energy and other operational costs, and attract new users by focusing on better user experience.

When end-users are travelling, they will be looking for ways to entertain themselves by consuming multimedia content. This provides an incentive for the use of quality-aware communication services for all the service providers (communications, content and transport) involved. Providing high-speed network access on the move can be resource intensive, and the better allocation following user satisfaction can represent significant savings.

Charging

It is unclear whether end-users will pay extra for this improvement to mobile communications. The end-user may expect more consistent performance across different environments and be unwilling to pay more. However, there may be customers who are prepared to pay more because they intensively use high performance services such as gaming that particularly benefit from the capabilities provided by quality aware communications.

Service Proposition to End-Users and Other Providers

- Capability Provision regarding Quality Aware Communications:
  These services have to be analysed regarding the aspects that determine the quality level. Given those capabilities in the network or cloud infrastructure, an optimization – e.g. by defining slices to enable these capabilities – can be done.
  Such a feature set can be provided i) to the relevant subscribers (e.g. "gamers") as a higher service class enabling QoS levels beyond a basic subscription and as part of a specific service package (e.g. in cooperation with a game provider); or ii) in general as an option to improve the QoS level of the access link without any particular combined service.

  In a B2B context these services can be provided to Internet/telecommunication service providers to enable those with guaranteed QoS levels to benefit from 5G NORMA's ability to deliver quality aware communications.

Potential Welfare Effects

While quality aware communication may not lead to significant welfare effects in the private or consumer use context, it can have positive effects in all scenarios with enhanced business processes (commuting, (remote) service support, public utility service), which should result in an efficiency increase.

Indicators for increase in social welfare:

- Travel / Logistics: fewer delays.

A.9. Fixed-Mobile Convergence (FMC)

Service Providers

- Telecommunications Operators
  Operators will provide truly converged services across mobile and fixed networks with seamless transition between them. The end-user will not need to be aware of which access technology he is using. Customers will receive unified bills independently of the access networks used.

  Mobile network operators, national and regional fixed network operators, WiFi hotspot and enterprise network operators may be involved.

Communication Services Provided

- This use case does not represent a new functionality per se instead it adds value for end-users by providing convenience and continuity of service through converging fixed and mobile access.

  Services include those already covered in other use cases such as enhanced mobile broadband encompassing voice, data and video streaming services.

Target Customers and Service Provider-Consumer Interactions

The main target group is consumers and verticals are not expected to be strongly involved in this use case.

The mobile operator will need to have a series of agreements with fixed network providers to allow for converged services across their networks. This could cover different types of fixed providers from national fixed network operators to WiFi hotspot operators. The development of heterogeneous networks (HetNets) already promises some degree of integration between cellular mobile and WiFi networks.

However FMC would go beyond what HetNets are likely to deliver, offering improved quality of experience across converged domains and reduced costs e.g. through optimising the use of resources.

Systems for inter-operator payments will have to be established. “Bill and keep” (i.e. the service provider who bills the customer keeps all the revenue) is one model that has been used in telecoms, particularly in providing Internet connectivity, that could be applied. The operator who bills the end-user keeps the revenues. This is easiest to apply when traffic flows between operators are relatively equal in each direction. Alternatively payments could be based on a per volume basis, however negotiations over interconnection rates can be difficult and protracted. Competition authorities may be concerned to ensure that such agreements do not entrench monopoly power, or discriminate in favour of vertically integrated fixed and mobile operators.

Charging

It is likely that consumers would be charged in the same way for converged services as for eMBB services, i.e. there may be a variety of packages based on performance and monthly data allowances. However, since users benefit from integrated fixed and mobile services, they should be willing to pay a premium for the converged service.

Service Proposition to End-Users and Other Providers

- Service provision to subscribers (end-consumers):
  Service provision by selling access / connectivity and other services on top while the fixed and mobile access networks below are integrated, and the service landscape becomes overarching for the consumer regardless of the access environment he is in.

- Network sharing/provision:
  The FMC experience may be delivered by different infrastructure providers depending on local network availability, features, capability etc. The service providers selling FMC communications services to the subscriber might not own all the infrastructure components itself. Therefore, it may buy the missing components from those who are in a position to provide the required infrastructure capabilities and integrate these. Meanwhile, the (third party) infrastructure providers will be able to capture part of the premium from FMC services without necessarily having contact with the subscriber (end-customer).

Potential Welfare Effects

Welfare effects may arise from the possibilities to enhance services for subscribers, i.e. seamless integration between former fixed and mobile applications and increasing the ability to use communications services regardless of being in one or the other environment.

Indicators for increase in social welfare:

- To be related to specific use case benefiting of FMC.

A.10. Blind Spots

Service Providers

- Telecommunications Operators
  Operators extend coverage as far as possible to areas where coverage was previously poor, either because radio resources were limited and/or network infrastructure was sparse – in rural and remote areas or urban/suburban areas in deep shadow situations.

Communication Services Provided

- The main value added by this use case is in extending "coverage" which is a means for end-users to be able to use services such as eMBB rather than an end in itself from the customer's perspective.

Target Customers and Service Provider-Consumer Interactions

Consumers are the target customers. Verticals are not involved, except as users of eMBB. However, the number of new subscribers will probably be significantly less than the increase in the population covered. This is because many consumers living in blind spots (particularly in urban areas) will have subscriptions anyway since they may work in locations which do have good coverage.

Charging

New users, who subscribe because the blind spot has been filled in, should be willing to pay the same as other eMBB users. Usage charges, if applicable, should be uniform across blind spots and normal areas.

There will be social benefits, for blinds spots in rural and peripheral areas – for example enabling economic activity and increasing social inclusion particularly if fixed connectivity is poor. Although these social benefits are not reflected in what individual consumers are willing to pay, governments may be willing to subsidise the extension of coverage as they have in the past with 2G-4G.

Service Proposition to End-Users and Other Providers

- Service provision to subscribers (end-consumers)
  Service provision by selling access / connectivity and other services on top. Once the customer is connected, the entire communications portfolio is available to it, including all existing telco and OTT offerings from Internet/telecommunications service providers.

- Network sharing/provision:
  "Blind spots" are the result of missing economic benefits to do network investments, since expected revenues do not cover the up-front cost. Local network facilities, even beyond traditional telco-networks, may be used to provide connectivity to subscribers in the blind spot, and the local infrastructure provider may then sell these capabilities to overarching infrastructure providers such as telcos and mobile internet/telecommunications service providers who are able to provide services covering the full range of customer processes (accounting, billing, customer care …).

Potential Welfare Effects

As mentioned above; social benefits arise since "Internet connectivity" is seen important to ensure that people as well as companies can take part in the digital world. Reducing "Blind spots" will directly contribute to welfare by including more citizens and companies in the digital economy.

Indicators for increase in social welfare:

- Increase in local rents, ground prices, business / industrial tax in former "blind spot areas".

A.11. Open Air Festival

Service Providers

- Telecommunications Operators
  Operators will provide fast and reliable wireless services to the other stakeholders and consumers. These services are crucial for a well-organized festival, since all others services will use a variety of communication channels.

- Festival Organizers
  These stakeholders are the main force between the creation, organization and coordination of the whole festival. Their goal is to attract as many people and businesses to the festival, guaranteeing an entertaining experience to the former, and a profitable endeavour for the latter.

- Venue Owners
  Some venues may host multiple festivals throughout the summer or the whole year. The venue owners may provide a one-stop shop for a number of services to festival organizers which otherwise fall into the next two categories, e.g. waste management, safety**.**

- Local Businesses and Festival Sponsors
  A whole infrastructure will be installed in the festival location. On one hand, we have services provided by local businesses like waste management, garbage collection, and

provision of food and drinks. On the other hand, the sponsors will set up a booth or stand to interact with the attendees. Their goal is to provide the best service possible, taking the opportunity to increase revenue and visibility through the festival.

- Security and Safety Personnel
  This category comprises both security and medical services hired by the organizers, as well as public emergency services (mainly firefighters and paramedics) that will be in the festival. Many problems can arise in any large gathering of people, and the goal of these stakeholders is to guarantee the security and safety of all attendees.

Communication Services Provided

- High-speed network access
  Fans attending the festival want to have high-speed network access throughout the festival. Providing that access in the remote rural area where the festival is taking place is the main service provided, and the focus of the use case.
- Wireless services for sensors, machines and surveillance cameras
  These are the services related to the infrastructure setting of the festival, as they allow for or improve the services provided by the local businesses, sponsors, and security and safety personnel.
- Broadcast/multicast
  These services allow the organizers to spread information about the festival quickly to a large number of attendees at the same time. Festival organization and promotion benefit from the chance to use broadcast and multicast mechanisms.

Target Customers and Service Provider-Consumer Interactions

There are no specific end-users targeted by any of the services provided. Anyone interested in the performances of the festival will be able to attend and use the services.

There is no immediate change to the end-users in this use case. The use case is about providing the same fast and reliable network access a user is used to also during the festival. Festival organizers could offer and advertise the broadcast/multicast messaging, but that system is already integrated into LTE and will be part of 5G NORMA.

The main interactions will be between the operators and the organizers, sponsors, and security personnel.

Organizers need to notify the operators about the location and duration of the event. While the network will be able to adapt to a rise in demand, the operators will potentially need to deploy extra radio access points. Access to broadcast/multicast will be necessary, and that will require some coordination and perhaps some form of agreement.

Another possibility for deploying portable radio access points would be third party network providers, instead of traditional operators. The organizers could enter an agreement with these providers for access to additional network resources for the duration of the festival. Managing the access points with a cloud-based solution, and guaranteeing rights of access to licensed spectrum, would be tasks left to the third party providers. Unlicensed spectrum might be applicable, via WiFi or Licensed Assisted Access.

Local businesses, sponsors, and security and safety personnel will need support for wireless services that differ from the usual mobile broadband. Sensors, machines, surveillance cameras, and handheld radios have different requirements, and need to be supported by the network.

Charging

End-users are expected to directly pay extra for service during the festival, since many services are already included with the festival ticket. However, event-based charging schemes may apply, which allow visitors to get access to very specific extra content like a live stream from backstage area, interviews with bands or “first row view” or even a “stage view”.

Festival organizers will most likely reach an agreement with the operators, and add the extra cost on the ticket price. Conditions to be negotiated could be: number of access points, coverage area, data volume, and bandwidth provided, among others. This agreement will also include any wireless service that the local business and sponsors need.

Service Proposition to End-Users and Other Providers

- Connectivity Provision:
  Provision of connectivity, especially if a festival takes place in a very remote location; as a specific feature, multicast/broadcast capabilities could be a means to ensure service quality in the downlink for all users requesting specific content at the same time – a mix of connectivity (capacity limits due to large numbers of users in one location) and QoS. In a B2C context, greater connectivity and coverage can be provided either as part of the general service delivered by the telecommunications service provider (without any specific tariffing) or for specific service packages for festival attendees. For B2C/B2B2C, provision of specific premium content related to the festival, maybe even with a sharing model between the festival organizer, the bands/sponsors and the visitor as consumer

- Capability Provision:
  Bandwidth could be an issue, in particular for HD video transmission. High bandwidth can be provided to allow subscribers access to specific class of services enriching their festival/event experience, most likely not marketed as a pure bandwidth but as part of a specific service for the event. Ensuring adequate bandwidth by the infrastructure provider is, in this context, a wholesale service that can be provided to internet/telecommunications service providers, for this event. This may have two different aspects:

  - Capabilities to ensure services for all participants of the event.
  - Capabilities to ensure operational communications for security and emergency services, given the mass participation at the event e.g. overcrowding, evacuation for safety/security purposes.

Potential Welfare Effects

This is very much a situation-based use case; welfare aspects are most likely to arise in the context of avoidance of negative effects possible with such mass events.

Indicators for increase in social welfare:

- The festival should make the attending people happy, and a good indicator for happiness in social context is very hard to find. Indeed, this type of benefit mostly accrues directly to the individual and any additional benefit to society, particularly in relation to 5G use, would be difficult to measure.
- A reduction or amelioration of public safety incidents at open air festivals through improved security communications (though it would be difficult to separate out improvements specific to 5G from things such as better training of personnel and health and safety procedures).

Annex B. Network element classification and possible topological placement

As indicated in section 5 this annex provides an overview of network element classification and possible topological placement of those elements based on analysis of information on initial 5G architecture as described in Deliverable D3.1 [5GN15-D31] and Internal Report IR3.1 [5GN16-IR31]. The overview is oriented to the different architectural views shown in Figure 5-2.

B.1. Hardware/software resources and deployment nodes

The resource view described in D3.1/IR3.1 (see Figure B-1) addresses the different categories of infrastructure resources considered in the 5G NORMA architecture. This includes general-purpose physical and virtual resources, i.e., networking, storage, computing, and memory, as well as dedicated physical network functions (NFs) and legacy monolithic network elements, referred to as "PNFs" or "embedded." Furthermore, blueprint libraries for NFs and network (NW) slices are described. The following list defines the main categories considered:

- **Virtualized resources:**
  - Virtualized resources represent virtualized computing capabilities (vCPU), virtualized memory and storage resources, and virtualized networking capacity to be allocated to virtual network functions (VNFs).
- **Physical resources:**
  - Physical resources include both general purpose and specialized hardware (HW) that comprise memory, compute, storage, networking, and other fundamental capabilities. These physical resources can be made available in either virtualized (see above) or non-virtualized (i.e., PNF) manner.
- **Library of network functions:**
  - Repository of all executable VNF packages including the necessary blueprint and metadata, such as resource requirements, supported interfaces, and reference points as well as orchestration and configuration parameters.
  - Support of creation and management of a VNF, i.e., VNF descriptors, software (SW) images, and metadata files, via interfaces exposed to other management and orchestration entities.
  - In addition repository of PNFs that can be orchestrated to be incorporated in a network slice covering PNF metadata, such as PNF location, connectivity to other NFs, maximum performance (e.g., capacity), configuration parameters, sharing and prioritization rules, etc.
  - Tenants either access a "default" library or have individual, customized libraries.
- **Library of network slices:**
  - Catalogue of all executable NW slices including necessary blueprints and metadata such as QoS parameters.
  - A NW slice template refers to the set of VNFs that should be chained to implement the network service, as well as the NF forwarding graph (NFFG) that specifies how these NFs have to be interconnected in order to provide the service properly. In general, a NW slice blueprint could contain NW service descriptors, link descriptors and connectivity descriptors.

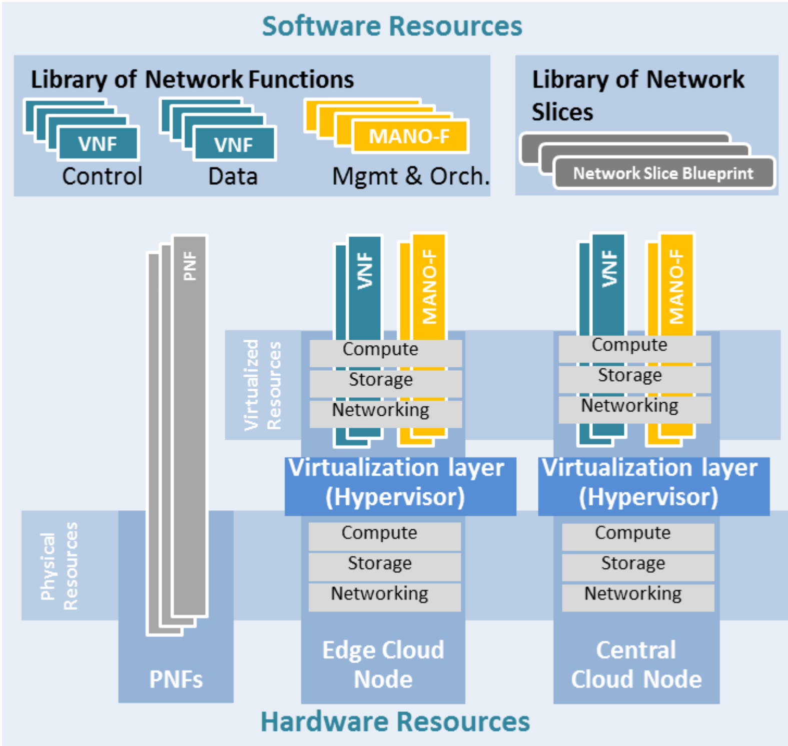

Figure B-1: 5G NORMA resource view [5GN15-D31] [5GN16-IR31]

According to Figure B-1 three main types of **deployment nodes** are defined:

- **Bare Metal Node:**
    - Execution of Physical Network Functions (PNFs) with tight coupling between HW and SW platforms (in many cases SW is even highly embedded in HW).
- **Edge Cloud Node:**
    - Comprises a small, locally placed (i.e., within the access network close to or at radio sites) collection of processing, storage, networking, and other fundamental computing resources.
    - Typically, the number of edge cloud nodes is at least one order of magnitude higher than the number of central cloud instances.
    - Deployment particularly in rather densely populated metropolitan, urban, and sub-urban areas.
- **Central Cloud Node:**
    - Hosting a significantly large collection of processing, storage, networking, and other fundamental computing resources.
    - Typically, only a few of them are found in a nationwide operator network.

The following features are to be considered for both cloud node types:

- Ability to deploy and run arbitrary SW (incl. operating systems and applications; limiting factor is the available processing, storage and/or networking power).
- Provisioning of virtualized resources based on NFV principles in order to execute VNFs, and management and orchestration functions (MANO-Fs).
- Edge cloud exhibits greater heterogeneity than central cloud in terms of utilized HW and hypervisors, geographical deployment, and topological structure.

With respect to HW resources for all three main types of nodes, four main categories can be differentiated:

- **HW based on x86 architecture:**
  - Standard server HW based on the x86 Intel instruction set architecture.
  - Simple portability of executable SW (only minor or even no adaptation).
- **HW based on non-x86 architecture:**
  - Server HW based on other architectures than standard x86, e.g. RISC (Reduced Instruction Set Computing) and ARM (Advanced RISC Machines).
  - Executable SW not easily portable from x86 to other server architectures.
- **Programmable, purpose-built HW:**
  - Tight coupling between HW and SW platform (SW often highly embedded in HW).
  - Based on DSPs (Digital Signal Processors), FPGAs (Field-Programmable Gate Arrays), or dedicated mobile radio base station chipsets (e.g., available from Texas Instruments, Freescale, and Cavium).
  - Completely different programming instruction sets than commonly used x86 processors; moreover, use of different kinds of HW accelerators (for FFT (Fast Fourier Transform), channel decoding etc.).
- **Non-programmable, purpose-built HW:**
  - Built for dedicated processing functions with very limited (or no) configurability.
  - Examples include Radio Frequency (RF) components of mobile radio base stations.
  - Sharing by multiple tenants feasible, e.g. 2 mobile network operators (MNOs) using separate carriers amplified on a shared power amplifier (PA) and transmitted from the same antenna.
  - Virtualization techniques not applicable to this HW category.

Table B-1 shows the possible mapping between deployment node types and the HW resource categories with an "X" indicating which HW resources can be used for which deployment types.

Table B-1: Mapping between deployment nodes and the HW resources

HW resource categories	Deployment node types		
	Bare Metal Node	Edge Cloud Node	Central Cloud Node
HW based on x86 architecture	-	X	X
HW based on non-x86 architecture	-	X	X
Programmable, purpose-built HW	X	X	-
Non-programmable, purpose-built HW	X	-	-

B.2. Functional blocks of 5G NORMA architecture

The functional view of the 5G NORMA architecture (see Figure B-2) includes the main functional blocks for realization of the 5G system.

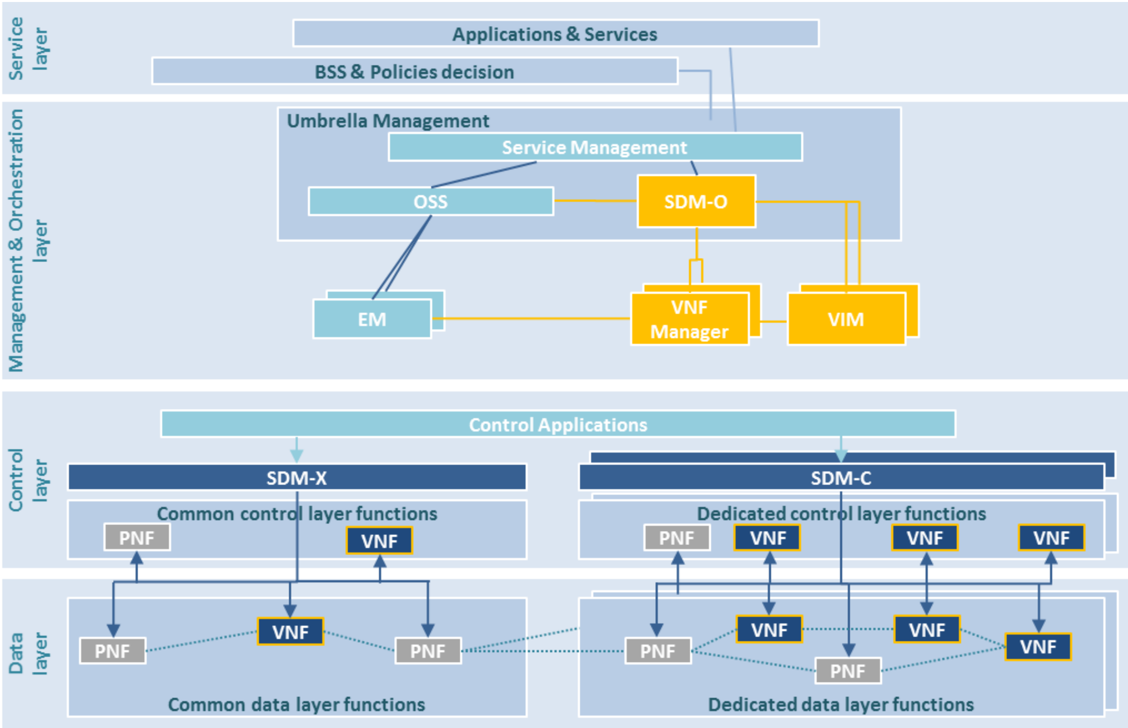

Figure B-2: 5G NORMA functional view [5GN15-D31] [5GN16-IR31]

The functional blocks are arranged in four layers of interaction:

- **Service Layer:**
    - It is comprised of Business Support Systems (BSSs) as well as business-level Policy and Decision Functions. BSSs enable customer-facing business processes in the administrative domain of the mobile service provider as well as the tenants including customer, order, product, and revenue management. Within 5G NORMA, the scope is extended towards business-to-business (B2B) relationships between the tenant (with own subscribers) and the mobile service provider that provides the network slice(s) to the tenant. Policy frameworks ensure automated processes for the business relationship (e.g., seamless service assurance and fulfilment).
    - Further, applications and services operated by tenants reside in the Service Layer. They comprise any software or automated process that interacts with the MANO Layer, in particular with the Application Programming Interfaces (APIs) exposed by the Service Management to onboard, deploy and operate NW slices.
- **Management & Orchestration Layer:**
    - The MANO Layer includes the 5G NORMA MANO functions (MANO-F), the Virtual Infrastructure Manager (VIM), the VNF Manager and the Software-Defined Mobile network Orchestrator (SDM-O) as well as Operations Support System (OSS), Element Manager (EM), and Service Management.
    - The Service Management is primarily an API towards the Service Layer.
    - The VIM is responsible for allocation or release of virtual resources (i.e., processing, storage, and networking) on request of the SDM-O based on full knowledge about all physical resources under its control. The VIM Agent is an optional function which can be logically subsumed under the VIM managing a dedicated part of the overall infrastructure of its operator.
    - The VNF Manager performs lifecycle management for the VNFs in its responsibility domain. There are usually multiple instances of the VNF Manager per slice; the number scales with number of VNF vendors and VNF

instances, as a vendor's VNF Manager typically only operates VNFs of the same vendor and a single VNF Manager manages typically only up to a certain maximum number of VNF instances at a time.

- The SDM-O fulfills NW service orchestration and resource orchestration tasks, within and across NW slices, NW services, and tenants. For this purpose, it is split into three sub-components: Service Orchestrator, Inter-Slice/Tenant Orchestrator and Resource Orchestrator.
  - Major task of the Service Orchestrator is to annotate the NW slice blueprint by the Service Management function. This includes, among others, NF configuration and placement, and is performed by evaluating additional service requirements and key quality indicators as provided by the tenant, taking into account availability constraints of physical and virtual infrastructure resources. In addition, NFV service orchestration tasks are within the scope of the Service Orchestrator including onboarding, instantiating, scaling, and terminating of NW slices, updating NW services by supporting NW service configuration changes of various complexities, as well as creating, deleting, querying, and updating of NFFGs associated to a NW slice.
  - The Inter-Slice/Tenant Orchestrator operated by the service provider has responsibility to not only broker virtualized resources between NW slices but also between tenants. Based on a performance model it determines how much resources (compute, storage) need to be allocated to each NW slice for meeting the QoS requirements as function of the load. Further, by means of modelling the expected load of different NW slices (geographical and temporal distribution), it can decide on the dynamic provisioning of shared resources among slices by combination of different strategies (reactive vs. proactive, fixed reservation vs. fully floating).
  - The Resource Orchestrator provides the overall status of resources present in its administrative domain. It also performs fault and performance management for virtualized resources, thus hiding the according interfaces of the VIMs. In this was it serves as a "proxy gateway" for the VIMs underneath it, therefore providing resource management in "indirect mode", as requests for resources from the slice-dedicated VNF Managers must go through the Resource Orchestrator. The Resource Orchestrator is not able to take decisions based on VNF or NW slice instances. Rather, for any lifecycle management decision, it is instructed by either the responsible VNF Manager or the Inter-Tenant Orchestrator in case of cross-tenant resource pools. There exists at least one Resource Orchestrator per tenant, if required also one per NW slice.
- OSS and EM are legacy functions already present in today's non-virtualized and non-cloudified networks, but they are extended to become VNF-aware and to interface with SDM-O and VNF Manager. With help of the EM the OSS does setup of all NFs that have been instantiated beforehand. After creation and instantiation, resp., the EM instance performs FCAPS (fault, configuration, accounting, performance, security) management for both PNFs and VNFs.

- **Control Layer:**
  - In this layer there are two main controllers: The Software-defined Mobile network Controller (SDM-C) for NFs dedicated to a single NW slice (i.e., one SDM-C instance per slice) and the Software-defined Mobile network Coordinator (SDM-X) for NFs shared between slices. In their respective domains both controller types abstract from specifics of the controlled PNFs and VNFs and use different variants of a southbound interfaces (SBIs) to

control them. Through their northbound interfaces (NBIs), e.g., REST-ful APIs, they interact with control applications that host the centralized control logic of mobile networks, e.g., session management, mobility management, QoS control, policy and charging rules, application-level scheduling, and interference coordination. Moreover, functional blocks from 5G NORMA MANO Layer, such as the SDM-O or EMs, can act as control applications as well. Via the APIs the corresponding NFs in the Control Layer can be customized and parametrized according to the needs of the different NW slice instances.

- **Data layer:**
    - This layer is shown with abstract VNFs and PNFs only. The NFs included here are relevant for data forwarding and processing both in the access (e.g., the user plane (UP) radio protocol stack), transport, and core network parts. Their operation is controlled via corresponding NFs in the Control Layer (e.g., the control plane (CP) radio protocol stack). More details can be found in [5GN15-D31] and [5GN16-IR31], respectively.

By addressing the 5G NORMA deployment view Figure B-3 shows how those main functional blocks listed before can be mapped on different deployment nodes in a multi-tenant, multi-slice environment (exemplary illustrated for tenant T1 with two slices and tenant T2 with a single slice).

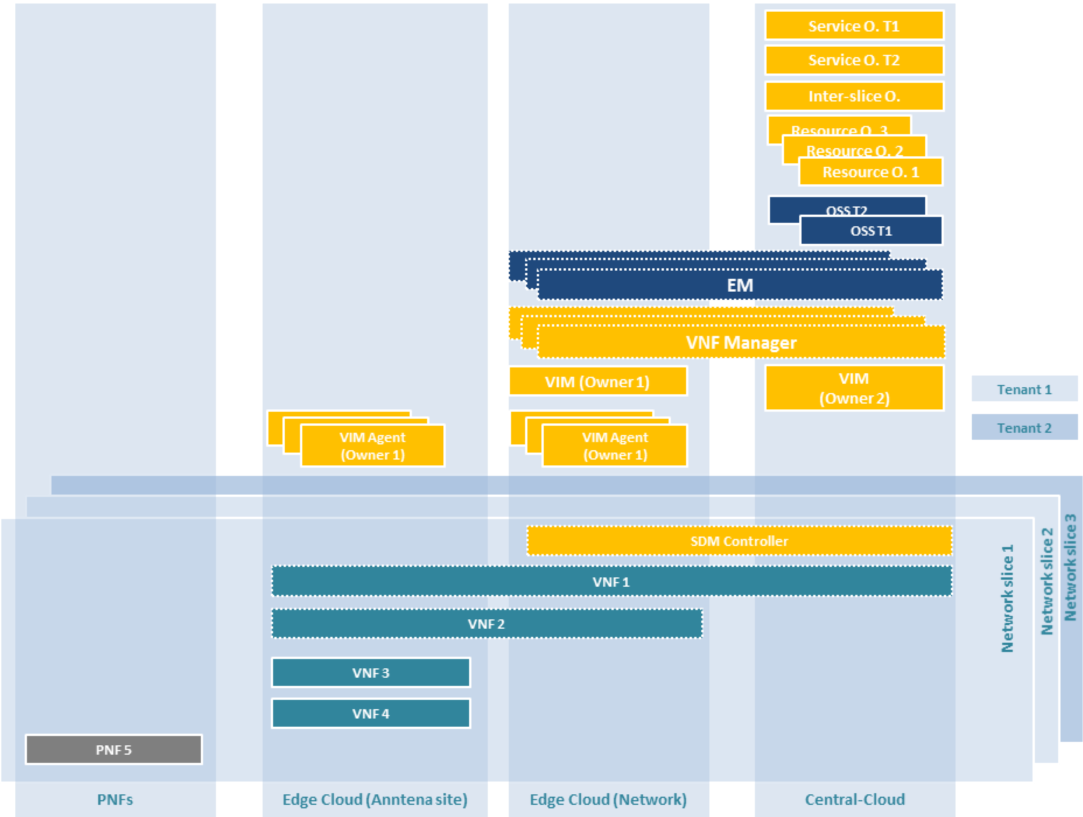

Figure B-3: 5G NORMA deployment view [5GN15-D31] [5GN16-IR31]

B.3. Network topology

The topological view of the 5G NORMA architecture in Figure B-4 shows how main functional blocks and deployment nodes are mapped to sites inside the operator’s network.

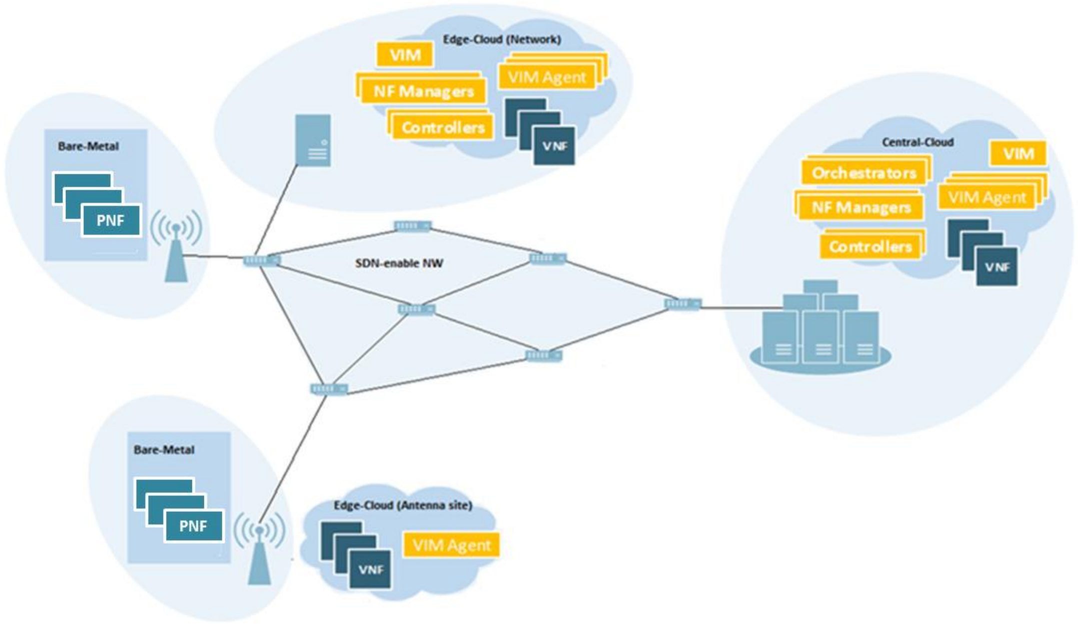

Figure B-4: 5G NORMA topological view [5GN15-D31] [5GN16-IR31]

In case of **antenna sites** two different types of elements to be placed at those sites have to be considered:

- **Type 1: Antenna installation in combination with Bare Metal Node** (see upper left part in Figure B-4)
  - Bare Metal Node:
    - Based on non-programmable, purpose-built HW:
      - Only Remote Radio Unit (RRU) as in today's 4G deployment.
      - Use of CPRI/ORI-like[12] fronthaul input based on I/Q samples with following digital/analog (D/A) and A/D conversion as well as up/down conversion and filtering).

    or

    - Based on programmable, purpose-built HW with following alternatives:
      - "Classical" base station (BS) set-up consisting of Base Band Unit (BBU) and RRU connected together via CPRI/ORI like data interface and BBU via backhaul (fiber, microwave, …) to core network (Edge or Central Cloud Nodes); the BBU is hosting the full radio protocol stack.
      - Combined BBU/RRU with BBU hosting only lower layer functions of radio protocol stack (e.g., parts of PHY layer up to MAC layer); this solution results in modified fronthaul interface ("midhaul") to Edge Cloud (incl. BB processing capabilities via C-/V-RAN).

[12] Common Public Radio Interface [CPRI13]/ Open Radio equipment Interface [ORI14]

  - Cabling to antenna (power supply, signal (dependent on antenna type and Bare Metal Node), …)[13]
  - Antenna type (differentiation according to single/multi-column, single/multi-band, Full-dimension (FD)/M-MIMO, power amplifier class (femto, pico, micro, macro), number of sectors, …)[14]
- **Type 2: Antenna installation in combination with Bare Metal Node and Edge Cloud Node** (see lower left part in Figure B-4)

  Two possible realizations for Bare Metal/Edge Cloud Nodes[15]:

  - **Variant 1:**
    - Bare Metal Node based on non-programmable, purpose-built HW (RRU only).
    - Edge Cloud Node[16] providing additional processing, storage and networking power (e.g. for local "Core Network (CN) (V)NFs"), but especially hosting the full radio protocol stack processing (virtualized BBU; possibly in combination with HW accelerators)[17].
    - Connection between both nodes via CPRI/ORI-like fronthaul ("ideal backhaul"); connection to CN (Central Cloud) via backhaul; optionally also local point of presence (PoP) to Internet.
  - **Variant 2:**
    - Bare Metal Node based on programmable, purpose-built HW (combined BBU/RRU with BBU hosting only lower layer of radio protocol stack (e.g. parts of PHY layer up to MAC layer).
    - Edge Cloud Node[18] providing additional processing, storage and networking power (e.g. for local "CN (V)NFs"), but especially hosting radio protocol stack processing for upper layers above PHY or MAC (virtualized BBU; possibly in combination with HW accelerators in case of upper PHY layer implementation)[19].
    - Connection between both nodes via modified fronthaul ("midhaul") interface; connection to CN (central cloud site) via backhaul; optionally also local point of presence (PoP) to Internet.

  Common to both variants is:

  - Cabling to antenna (power supply, signal (dependent on antenna type and Bare Metal Node), …)[20]

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[13] Please note: These features are common to all antenna sites.

[14] Please note: These features are common to all antenna sites.

[15] A 3rd straight forward realization is feasible by extending a classical BS set-up by an Edge Cloud Node hosting local CN functions only, but this is not seen as primary focus in 5G NORMA architecture.

[16] Edge Cloud Node based on x86 or non-x86 architecture, possibly in combination with programmable, purpose-built HW for acceleration of lower radio protocol stack processing.

[17] Even if an Edge Cloud Node is located directly at one antenna site it can be used also for other antenna sites in near environment, e.g. a macro cell site connected to a number of small cell sites.

[18] Edge Cloud Node based on x86 or non-x86 architecture, possibly in combination with programmable, purpose-built HW for acceleration of lower radio protocol stack processing.

[19] Even if an Edge Cloud Node is located directly at one antenna site it can be used also for other antenna sites in near environment, e.g. a macro cell site connected to a number of small cell sites.

[20] Please note: These features are common to all antenna sites.

  - Antenna type (differentiation according to single/multi-column, single/multi-band, Full-dimension (FD)/M-MIMO, power amplifier class (femto, pico, micro, macro), number of sectors, …)[21]

For the placement of NW elements at **edge cloud sites** (see upper medium part of Figure B-4) three possible realizations w.r.t. Edge Cloud Nodes can be considered:

- **Variant 1:**
  - Server(s) based on x86 or non-x86 architecture.
  - Provisioning of processing, storage and networking power (e.g. for local CN VNFs, covering also services like Content Distribution Networks (CDN), caching etc.).
  - Possible hosting of dedicated control and management functional blocks (e.g., SDM-C/-X, VIM, VNF Manager, and EM).
  - Connection to antenna sites and central cloud site(s) via broadband optical fiber links.
- **Variant 2:**
  - Same as Variant 1, but extended by:
    - Hosting of full radio protocol stack processing for a certain number of cells (virtualized BBU, i.e. C-/V-RAN; possibly in combination with HW accelerators[22]).
  - Connection to antenna sites via CPRI/ORI-like fronthaul ("ideal backhaul"), to central cloud site(s) via broadband optical fiber links.
- **Variant 3:**
  - Same as Variant 1, but extended by:
    - Hosting of radio protocol stack processing for upper layers (above PHY/MAC) for a certain number of cells (virtualized BBU, i.e. C-/V-RAN; possibly in combination with HW accelerators in case of upper PHY layer implementation).
  - Connection to antenna sites via modified fronthaul ("midhaul") interface, to central cloud site(s) via broadband optical fiber links.

The last site type is noted as a **central cloud site** (see right part of Figure B-4). The main differentiation of Central Cloud Nodes placed as NW elements at those sites is only w.r.t. HW volume and implemented SW functions:

- Server farm based on x86 or non-x86 architecture.
- Usually only low number of central cloud sites per operator and country.
- Provisioning of processing, storage and networking power (e.g. for CN VNFs)[23].
- Hosting of dedicated control and management functional blocks (e.g., SDM-C/-X, SDM-O, VIM, VNF Manager, OSS as well as EM).
- Typically co-located PoP to Internet.
- Connection to antenna sites and edge cloud site(s) via broadband optical fiber links (backhaul).

To allow a techno-economic evaluation of different 5G scenarios, detailed information has to be provided w.r.t. HW and SW applied at each site of the underlying network:

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[21] Please note: These features are common to all antenna sites.

[22] Based on programmable, purpose-built HW.

[23] Please note: In principle a central cloud site may also be combined with an antenna site (similar to Type 2 with inclusion of Edge Cloud Node), so a Central Cloud Node as described above may also host radio protocol stack related processing functions similar to the Edge Cloud Node. This case is not considered in the description of D3.1 and therefore is not taken into account in the analysis.

- Hardware:
    - Antenna type;
    - Bare Metal Node type;
    - Edge Cloud Node type;
    - Central Cloud Node type;
    - Intra-site interface/link types (incl. also RF cabling);
    - Inter-site interface/link types;
    - Router/switch type;
    - Power supply type.
- Software (Service Layer not considered):
    - Radio/Core CP (physical/virtualized) NFs;
    - Radio/Core UP (physical/virtualized) NFs;
    - SDM-C/-X;
    - SDM-O;
    - VIM and VIM Agent, respectively;
    - VNF Manager;
    - OSS and EM.

The usability of the different HW and SW categories is dependent on availability at each site. Please note that this list is not exhaustive and can be extended during further work on techno-economic evaluation.

In addition to the four site types mentioned above the **data transport network** between these sites (see middle part in Figure B-4) has to be taken into account. In the following a list is given of most important features for the transport network that have to be noted here in the context of the techno-economic evaluation:

- Central cloud sites usually connected among each other by a wide area network (WAN) based on optical fibers with high capacities of 10 Gbps or more.
- WAN topology may differ significantly according to needs and preferences of operators, e.g.:
    - Multiple hierarchy levels, e.g. long haul links on a high level to interconnect regional and metropolitan NWs on underlying levels.
    - On each hierarchy level deployment of star, ring, tree or chain topologies considering also redundancy.
- Dedicated edge cloud sites usually in the vicinity of antenna sites to allow hosting of radio protocol stack functions (Variants 2 and 3):
    - Distance to be within a range of few 10 kms to keep latency below 200 µs.
    - Use of dedicated point-to-point fiber links (limited use of cmW/mmW links due to bandwidth restrictions); usually no redundancy is applied.
    - Required data throughput dependent on radio signal bandwidth (incl. number of carriers), number of antennas and split in radio protocol stack (CPRI/ORI-like fronthaul, midhaul, backhaul); data throughput at present typically in the range of 1 – 10 Gbps.
- For (ultra-dense) small cells wireless back-/fronthaul (incl. self-backhauling) with novel 5G mmW air interface(s) probably applicable.
- For last hop to small cells newest copper-based solutions like G.Fast also seen as a possible solution.
- Network elements for transport NW (routers, switches, …) to be expected to operate on SDN principles.

Possible reference networks w.r.t. data transport and architectural considerations w.r.t. back-/fronthaul implementation that can be taken into account for the techno-economic evaluation in 5G NORMA can be taken e.g. from the EU FP7 project COMBO (“COnvergence of fixed and Mobile BrOadband access/aggregation networks”), see e.g. Deliverable D3.3 [COM15-D33]. In addition further inputs w.r.t. latest developments in backhaul and fronthaul technologies for 5G are expected by the projects 5G-Xhaul (see http://www.5g-xhaul-project.eu/) and 5G-Crosshaul (see http://5g-crosshaul.eu/) performed within the 5G PPP Phase 1 Framework.

Annex C. Evaluation case definitions

Section 4 of this report identifies the rationale for using particular evaluation cases. This annex summarises the key parameters that are proposed to be used in three key evaluations:

- A baseline case
- Multi-tenant case
- Multi-service case

C.1. Baseline evaluation case

In Table C-2 a set of parameter for evaluation of baseline operator costs for MBB services is compiled. The baseline evaluation case enables comparison of operator costs in case of LTE-A Pro as well as 5G NORMA networks under identical conditions. Most significant parameter deviations appear by introduction of C-RAN for 5G NORMA networks.

Table C-2: Parameters for evaluation of baseline operator costs

Business model parameter	4G / LTE-A Pro	5G NORMA
Services	MBB	MBB
Asset case / Multi-tenant Service Type	1 / 1	1 / 1
Stakeholder / Customers	4 operators / End users	4 single-tenant networks / End users
Deployment Scenario Parameters	4G / LTE-A Pro	5G NORMA
Radio node density	Sites in existing London area + CAGR	Sites in existing London area + CAGR
Increased sectorisation	Up to 6 sectors per macro site	Up to 6 sectors per macro site
Transport network	Backhaul macro + SC: Fibre Aggregation network: Fibre	WAN[24] Network: Fibre Fronthaul: Fibre Backhaul: Fibre
MBB requirements (according to use case A2, Enhanced mobile broadband)	Coverage probability: 95% Capacity demand: according to Cisco VNI report	Coverage probability: 95% Capacity demand: according to Cisco VNI report Peak data rate: 10 Gbps
Indoor / Outdoor traffic demand	80% / 20%	80% / 20%
Traffic offload by indoor SC	80% → tbd	80% → tbd
Spectrum deployment	Max. 100 MHz per site But 4 operators share the whole spectrum (see section 5.2.3).	Max. 100 MHz per site But 4 operators share the whole spectrum (see section 5.2.3).
SE upgrade of macros and	Up to16x4 FD MIMO @	Up to16x4 FD MIMO @

[24] Wide Area Network (WAN) connecting network clouds

SC	macros[25], up to 32x4 FD-MIMO @ SC	macros, up to 32x4 FD-MIMO @ SC
Architecture Options	4G / LTE-A Pro	5G NORMA
C-RAN @ central offices	D-RAN	C-RAN density[26]: (tbd) per sqkm, bare metal nodes including edge clouds for joint SC interference management
HetNet	≤5 SCs @ 3500 MHz[27] per sector Indoor SCs[28] >6 GHz incl. M-MIMO 64 element antennas. 8 spatial streams	≤5 SCs @ 3500 MHz per sector Indoor SCs >6 GHz incl. M-MIMO 64 element antennas. 8 spatial streams
Operator scenarios	4 single-operator networks	4 single-tenant networks

C.2. Multi-tenant evaluation case

In Table C-3 a set of parameter for comparison of single- and multi-tenant architectures are compiled. Most significant parameter deviations for these two cases are the respective network architecture, the asset case and the use of joint site grids and spectrum by an infrastructure provider

Table C-3: Parameters for comparison of single- and of multi-tenant architectures.

Business model parameter	5G NORMA	5G NORMA
Services	MBB	MBB
Asset case / Multi-tenant Service Type	1 / 1	2 / 1
Stakeholder / Customers	2/4 single-tenant networks / End users	2/4 tenants share a multi-tenant platform operated by a service provider / End users
Deployment Scenario Parameters	5G NORMA	5G NORMA
Radio node density	Sites in existing London area + CAGR	Sites in existing London area + CAGR
Increased sectorisation	Up to 6 sectors per macro site	Up to 6 sectors per macro site
Transport network	WAN Network: Fibre Fronthaul: Fibre Backhaul: Fibre	WAN Network: Fibre Fronthaul: Fibre Backhaul: Fibre
MBB requirements (according to use case A2, Enhanced mobile broadband)	Coverage probability: 95% Capacity demand: according to Cisco VNI report Peak data rate: 10 Gbps	Coverage probability: 95% Capacity demand: according to Cisco VNI report Peak data rate: 10 Gbps
Indoor / Outdoor traffic demand	80% / 20%	80% / 20%

[25] Full Dimension (FD) MIMO to be used for horizontal and vertical sectorisation

[26] Apply C-RANs in dense urban, D-RAN in suburban

[27] Part of the spectrum @ 3500 MHz to be used for SC layer

[28] Indoor SC in residential buildings assumed to be subscriber owned, in public buildings operator owned

Traffic offload by indoor SC	80% → tbd	80% → tbd
Spectrum deployment	Max. 100 MHz per site But 4 operators share the whole spectrum (see section 5.2.3).	Max. 100 MHz per site[29] Frequency specific (joint) site grids for 700-900, 1800-2100, 2600-3500 MHz
SE upgrade of macros and SC	Up to16x4 FD MIMO @ macros[30], up to 32x4 FD-MIMO @ SC	Up to16x4 FD MIMO @ macros, up to 32x4 FD-MIMO @ SC
Architecture Options	5G NORMA	5G NORMA
C-RAN @ central offices	C-RAN density[31]: (tbd) per sqkm, bare metal nodes including edge clouds for joint SC interference management	C-RAN density[32]: (tbd) per sqkm, bare metal nodes including edge clouds for joint SC interference management
HetNet:	≤5 SCs @ 3500 MHz[33] per sector Indoor SCs[34] >6 GHz incl. M-MIMO 64 el. 8 spatial streams	≤5 SCs @ 3500 MHz per sector Indoor SCs >6 GHz incl. M-MIMO 64 el. 8 spatial streams
Operator scenarios	2/4 single-tenant networks	Multi-tenant network

C.3. Multi-service evaluation case

In Table C-4 a set of parameter for comparison of single and multi-service architectures are compiled. Most significant parameter deviations for these two cases are the respective network architecture, the Multi-tenant service type, differences in transport technologies, different realization of mMTC and V2X as well as operation of C-RAN in case of 5G NORMA networks

Table C-4: Parameters for comparison of single and of multi-service architectures

Business model parameter	4G / LTE-A Pro	5G NORMA
Services	MBB, V2X (as a more specific uMTC service), mMTC	MBB, V2X (as a more specific uMTC service), mMTC
Asset case / Service Type	1 / 1	1 / 2
Stakeholder / Customers	3 single service networks / End users	Mobile network provider, 3 tenants share (rent) the infrastructure / End users
Deployment Scenario Parameters	4G / LTE-A Pro, LTE-V, NB-IoT	5G NORMA
Radio node density	Sites in existing London area + CAGR	Sites in existing London area + CAGR
Increased sectorisation	Up to 6 sectors per macro site	Up to 6 sectors per macro site

[29] For asset case 2 a single infrastructure provider (=service provider in this case) owning all RAN infrastructure (bare metal nodes), edge & central clouds as well as software

[30] Full Dimension (FD) MIMO to be used for horizontal and vertical sectorisation

[31] Apply C-RANs in dense urban, D-RAN in suburban

[32] Apply C-RANs in dense urban, D-RAN in suburban

[33] Part of the spectrum @ 3500 MHz to be used for SC layer

[34] Indoor SC in residential buildings assumed to be subscriber owned, in public buildings operator owned

Transport network	Backhaul macro + SC: Fibre Aggregation network: Fibre	WAN Network: Fibre Fronthaul: Fibre Backhaul: Fibre
MBB requirements (according to use case A2, Enhanced mobile broadband)	Coverage probability: 95% Capacity demand: according to Cisco VNI report Peak data rate: 10 Gbps	Coverage probability: 95% Capacity demand: according to Cisco VNI report Peak data rate: 10 Gbps
MTC requirements (according to case A.5, Sensor network monitoring and massive nomadic mobile machine type communications)	Coverage probability 99%200.000 active sensors per sqkm[35]	Coverage probability 99% 200.000 active sensors per sqkm[36]
uMTC requirements (according to use case A4, Vehicle communications)	Latency of <10 ms[37], high reliability and coverage of 99%, position accuracy 0.1-1 m, high connection density	Latency of 1-5 ms[38], high reliability and coverage of 99%, position accuracy 0.1-1 m, high connection density
Indoor / Outdoor traffic demand	80% / 20%	80% / 20%
Traffic offload by indoor SC	80% → tbd	80% → tbd
Spectrum deployment	Max. 100 MHz per site But 4 operators share the whole spectrum (see section 5.2.3).	Max. 100 MHz per site[39] Frequency specific (joint) site grids for 700-900, 1800-2100, 2600-3500 MHz
SE upgrade of macros and SC	Up to16x4 FD MIMO @ macros[40], up to 32x4 FD-MIMO @ SC	Up to16x4 FD MIMO @ macros, up to 32x4 FD-MIMO @ SC
Architecture Options	4G / LTE-A Pro	5G NORMA
C-RAN @ central offices	D-RAN	C-RAN density[41]: (tbd) per sqkm, bare metal nodes including edge clouds for joint SC interference management
HetNet:	≤5 SCs @ 3500 MHz[42] per sector Indoor SCs[43] >6 GHz incl. M-MIMO 64 element antennas. 8 spatial streams	≤5 SCs @ 3500 MHz per sector Indoor SCs >6 GHz incl. M-MIMO 64 element antennas. 8 spatial streams
Operator scenarios	3 single-service networks	A mobile network operator

[35] Realized by 3GPP NB-IoT

[36] Realized by 5GN MTC slice

[37] Realized by 3GPP LTE-V

[38] Realized by 5GN V2X slice

[39] For asset case 2 a single infrastructure provider (=service provider in this case) owning all RAN infrastructure (bare metal nodes), edge & central clouds as well as software

[40] Full Dimension (FD) MIMO to be used for horizontal and vertical sectorisation

[41] Apply C-RANs in dense urban, D-RAN in suburban

[42] Part of the spectrum @ 3500 MHz to be used for SC layer

[43] Indoor SC in residential buildings assumed to be subscriber owned, in public buildings operator owned

	realized by legacy technologies owned by 4 network operators	deploys a 5GN multi-service network. 3 independent tenants orchestrate their rented network slices in own responsibility