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5G-MoNArch

Project No. 761445

5G Mobile Network Architecture

for diverse services, use cases, and applications in 5G and beyond

Deliverable D6.2

Methodology for verification and validation of 5G-MoNArch architectural innovations

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Abstract: This document describes the methodology required for the verification and validation of the 5G-MoNArch innovations and technologies. To achieve this objective, three evaluation cases are defined. Each evaluation case contains specific uses cases, simulation assumptions, the baseline deployments, service definitions and key performance indicators that will be used to conduct the corresponding evaluation, as well as a description of the verification tasks. As first step toward sensitivity analyses, the interdependencies between key performance indicators are identified. Furthermore, a methodology for the techno-economic analysis is defined. Finally, first validation results are provided.

Keywords: 5G Network Architecture, KPIs, Service Definitions, Validation, Verification

Executive Summary

The main goal of the 5G-Monarch project is to provide an adaptable and flexible fully-fledged architecture 5G mobile networks that can satisfy the diverse requirements of expected 5G services. To this end, the 5G-MoNArch architecture design combines 5G-PPP Phase 1 concepts (such as virtualisation, slicing and orchestration) with the enabling innovations provided by the project. The devised architecture is being deployed in two testbeds: (i) the *Smart Sea Port*, representative of a vertical industry use case, and (ii) the *Touristic City*, representative of a mobile operator deployment. For each testbed, 5G-MoNArch instantiates the architecture and complements it with a use case specific functionality – the two functional innovations of 5G-MoNArch: (i) *resilience and security*, needed to meet the Smart Sea Port requirements, and (ii) *resource elasticity*, required to make an efficient use of the resources in the Touristic City.

The verification and validation activities are essential to accompany the design and implementation of the 5G-MoNArch key innovations, to ensure that the proposed innovations are technically feasible, economically viable and that they meet requirements and needs of stakeholders. For this purpose, the present document establishes a comprehensive set of evaluation criteria and Key Performance Indicators, which update and extend those that were compiled in 5G-MoNArch deliverable D6.1 [5GM-D61].

Furthermore, a framework is established to steer the verification and validation activities in a project-overarching manner. These activities are focused on the three so-called *evaluation cases (ECs)*. The first two ECs investigate the projects' functional innovations (with resilience and elasticity requirements, respectively) while the third one covers a broader scenario combining a future smart city with industrial and hot spot applications. For each of the ECs, a set of verification elements is specified which include the underlying assumptions and scenario considerations (corresponding to the problem space) as well as the set of enablers being evaluated (which conform the solution space). The ultimate goal of the definition of the ECs is to conduct a technical and economic proof of concept of the corresponding technology enablers. The three ECs have been defined in the Hamburg zone, comprising areas that include the Hamburg sea port as well as other parts of the city.

This document also presents the first steps towards a sensitivity analyses that will be conducted for the envisaged ECs, comprising both the technical and the economical verification. Moreover, the document defines a comprehensive framework that will be the basis for the techno-economic analysis. This framework will leverage to conduct an economical evaluation that compares the costs and benefits provided by 5G-MoNArch technology as compared to a 5G baseline under common assumptions. The evaluation conducted will be provided as feedback on the advantages of the 5G-MoNArch technology to the various stakeholders.

Whereas the verification and validation methodology has been comprehensively specified in the project reporting period covered by this document, the realisation and implementation of the corresponding verification is still ongoing, and some details on the framework still need to be fixed. Final details and results will be published in 5G-MoNArch deliverable D6.3 *"Final report on architectural verification and validation"*, which is due in June 2019.

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List of Acronyms and Abbreviations

2G	2nd Generation mobile wireless communication system (GSM, GPRS, EDGE)
3G	3rd Generation mobile wireless communication system (UMTS, HSPA)
4G	4th Generation mobile wireless communication system (LTE, LTE-A)
5G	5th Generation mobile wireless communication system
3GPP	3rd Generation Partnership Project
5G-MoNArch	5G Mobile Network Architecture
5G PPP	5G infrastructure Public Private Partnership
AMF	Access and Mobility Management Function
API	Application Programming Interface
AR	Augmented Reality
B2B	Business-to-Business
BF	Beamforming
CAGR	Compound Annual Growth Rate
CAPEX	CAPital Expenditure
CCTV	Closed Circuit Television
CN	Core Network
CP	Control Plane
CPRI	Common Public Radio Interface
CU	Centralised Unit
D2D	Device-to-Device
DL	Downlink
DU	Distributed Unit
DOW	Description of Work
EC	Evaluation Case
E2E	End-to-End
eMBB	Enhanced Mobile Broadband
EMF	Extended Electro Magnetic Field
FDD	Frequency Division Duplex
GSMA	Groupe Speciale Mobile Association
HW	Hardware
InP	Infrastructure Provider
ITS	Intelligent Transport System
IOT	Internet of Things
ISC	Intra-Slice Controller
KPI	Key Performance Indicator
LTE	Long Term Evolution
MANO	Management and Orchestration
MBB	Mobile Broadband
MCS	Modulation and Coding Scheme
MIMO	Multiple-Input and Multiple-Output
ML	Machine Learning
mMTC	Massive Machine Type Commination
mmW	Millimetre Wave
mIoT	Massive Internet of Things
MNO	Mobile Network Operator
MSP	Mobile Service Provider
MVNO	Mobile Virtual Network Operator
NE	Network Element
NEO	Network Operation

NF	Network Function
NFV	Network Function Virtualisation
NFVO	Network Function Virtualisation Orchestrator
NFVI	Network Function Virtualisation Infrastructure
NSI	Network Slice Instance
NSSI	Network Slice Subset Instance
N(S)-aaS	Network (Slice)-As-A-Service
NGMN	Next Generation Mobile Networks
OAI	Open Air Interface
OPEX	OPerational EXpenditure
OTT	One-Trip Time
PAN	Personal Area Network
PaaS	Platform-As-A-Service
PDCP	Packet Data Convergence Protocol
PHY	Physical Layer
PNF	Physical Network Function
PRB	Physical Resource Blocks
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RRC	Radio Resource Control
RRH	Radio Remote Head
RRM	Radio Resource Management
RSRP	Reference Signal Received Power
TT	Round-Trip Time
TDD	Time Division Duplex
SA	System Architecture
SDN	Software Defined Network
SDO	Standards Developing Organisation
SDU	Service Data Unit
SE	Spectrum Efficiency
SINR	Signal to Interface plus Noise Ration
SotA	State of the Art
STZ	Security Trust Zone
STZm	Security Trust Zone manager
SW	Software
TDD	Time Division Duplex
TN	Transport Network
TR	Technical Report
TRxP	Transmission-Reception Point
UE	User Equipment
UL	Uplink
UP	User Plane
URLLC	Ultra-Reliable Low Latency Communications
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-everything
VNF	Virtualised Network Function
VISP	Virtualisation Infrastructure Service Provider
VOIP	Voice over IP
VR	Virtual Reality

WP	Work Package
XSC	Cross-Slice Controller

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1 Introduction

1.1 Objectives of verification and validation in 5G-MoNArch

The verification and validation process driven by WP6 establishes a framework for the collaboration of the different Work Packages of 5G-MoNArch. The key objectives are (i) verify that the envisaged innovations are technically and economically feasible, and (ii) validate that proposed use cases and business models meet the stakeholder needs.

This document describes the methodology to instantiate the so-called evaluation cases (ECs) of the project, comprising (i) uses cases, (ii) simulation assumptions, (iii) description of verification tasks and (iv) timelines. The ECs shall demonstrate the benefit of the 5G-MoNArch innovations developed by WP2, WP3 and WP4 from a technical as well as from an economic standpoint.

In particular, the main contributions of the other Work Packages to the verification and validation activities conducted in WP6 are as follows:

- WP2 has developed [5GM-D21] and refined [5GM-D22] an architecture that comprises the project's enabling innovations and provides the basis for deploying of use case specific functionalities developed by WP3 and WP4. In addition, WP2 has also defined enablers on inter-slice radio resource management which improve network efficiency by allowing a more flexible utilisation of radio resources across network slices, and hence contribute to reducing the cost associated to network deployment and operation.
- WP3 is developing network functions (NFs) that provide secure and reliable communication, even in situations where meeting the high requirements on reliability and security is challenging due to poor radio conditions [5GM-D31]. WP3 enablers on RAN reliability and network fault management improve the coverage guarantees, the reliability of the telco cloud as well as the resulting E2E reliability. With this functionality, they pave the way for resilient industrial network slices and novel Business-to-Business (B2B) models.
- WP4 is working on an elastic functional architecture that addresses the three different dimensions: (i) computational elasticity in the design and scaling of NFs, (ii) orchestration-driven elasticity through the flexible placement of NFs, and (iii) slice-aware elasticity via cross-slice resource provisioning mechanism [5GM-D41]. WP4 resource elasticity enablers improve the resource utilisation efficiency and thus allow for cost savings in future networks.
- WP5 is working on the development of prototypes to demonstrate the technical feasibility of the project technology in the two testbeds, one in Hamburg and the other in Turin [5GM-D51]. This will contribute to the verification activities within the project by providing experimental results and practical lessons learned.

The technical and economic evaluations will be based on an emulated network roll-out consisting of a multi-operator infrastructure in a study area around the city of Hamburg that includes the sea port as well as other surrounding areas. The considered study area is depicted in Figure 1-1.

The verification work of the project will focus on the following three ECs:

1. Resilient network slices for industrial applications
2. Elastic network slices enabling local peak performance and
3. Integration of resilient and elastic slices into smart city environments

All evaluations are referenced by technical and economic investigations of EC-specific 5G baseline deployments that are derived from an architecture provided by WP2 in [5GM-D21].

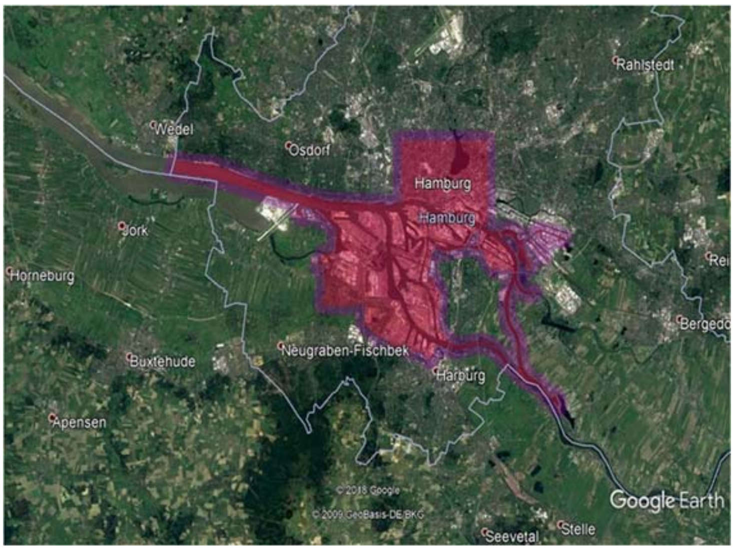

Figure 1-1: Satellite image of the study area in Hamburg

Comprehensive service definitions set the target Key Performance Indicators (KPIs) from the user or service point of view and comprise of a description (narrative), a set of performance benchmarks and radio capacity as well as radio coverage KPIs. They build the basis for the design of service specific network slices.

To verify and validate project results, WP6 elaborated a comprehensive list of requirements and KPIs in Deliverable D6.1 [5GM-D61]. The KPIs identified can be classified in the following categories:

- *Service-related KPIs*: These KPIs result from the service definitions and will be verified by network level simulations.
- *Generic KPIs*: These KPIs reflect the system-related requirements that should be optimised subject to the constraint that the service-related KPIs are met.
- *Techno-economic KPIs*: These KPIs ensure that all stakeholders in the business ecosystem are satisfied. At the same time, these KPI shall also provide an understanding of the commercial and socio-economic drivers of the technology.
- *Use case-related KPIs*: These KPIs allow to evaluate the benefits of the functional innovations covered by WP3 and WP4.
- *Application-specific KPIs*: These KPIs will be validated in the testbeds based on the performance of the running applications.

In alignment with WP2-WP4 most important enablers to be included into verification have been selected and the technical WPs will provide algorithm and tools to demonstrate quantitative improvements of use case related KPI.

One of the challenges that will need to be addressed when bringing together the performance evaluation results obtained by the other WPs (namely, WP2-WP5) will be to ensure that they have been obtained under the same conditions and assumptions and for the same scenario, so that they can be compared and combined. To this end, WP6 will define the so-called verification scenarios, which will set the basis for the evaluation activities conducted by all involved WPs.

In addition, the evaluation activities conducted by the individual WPs, WP6 will also conduct its own evaluations. In contrast to the other WPs, WP6 will not evaluate each enabler individually, but will evaluate multiple enablers simultaneously. To this end, WP6 will develop a framework that allows to combine multiple enablers and evaluate their joint contribution of to a given KPI.

WP6 will also develop the necessary method in order to leverage the experimental results obtained in the testbeds and incorporate them into the overall verification and validation analysis.

Finally, a sensitivity analysis will be performed to understand the generality the results obtained and their variation upon changing some of the input parameters. This analysis will be performed for the service KPIs, the use case related KPIs as well as for the techno-economic KPIs.

1.2 Structure of the document

The rest of this document is organised as follows:

Chapter 2 provides a background and results of verification in 5GPPP phase 1.

Chapter 3 addresses the verification and validation methodology along with the three ECs considered in 5G-MoNArch. This chapter sets the definitions of the essential elements that are needed for the specification of the verification process. Furthermore, it contains a detailed description of the three ECs, comprising their KPIs and their final targets. It also addresses the validation methodology that is established, including (i) the view from verticals on service related requirements, and (ii) the view from service and network providers on economic requirements. The rest of the chapter describes how the technical and regulatory barriers faced from a stakeholder perspective and how possible mitigation scenarios will be identified.

Chapter 4 presents the instantiation of the projects' verification elements. First, the requirements for the different services related to the ECs are identified. Then, information describing the physical location and the infrastructure assumptions of the chosen verification scenario is presented. The rest of the chapter addresses the baseline architecture deployment, enabler selection and first considerations on evaluation concepts. EC specific elements are detailed and, finally, high level information on the verifications tools is presented.

Chapter 5 addresses the steps comprised within the evaluation activities. First, it presents the expected interdependencies between KPIs qualitatively, which provides the basis sensitivity analyses. Furthermore, this chapter describes the potential input that will be provided for the verification activities from WP5 testbeds. It also describes the development of a framework to assess commercial and social benefits resulting from the use cases considered in 5G-MoNArch.

Chapter 6 addresses the steps that will be taken to obtain the validation results. This chapter describes interactions with consortium partners involved in the testbed scenarios to understand the service set, interactions with the 5G-MoNArch advisory board and industry groups to understand requirements for 5G services and a review of user requirements from other sources. Furthermore, a questionnaire that will be used for the validation process with vendors and technical community is presented in detail.

Finally, Chapter 7 provides a summary of the document.

2 Background on verification from 5GPPP Phase 1

A comprehensive architecture design verification that made sure that the design met the requirements of the envisaged use cases and stakeholders has already been conducted especially in the 5G NORMA project [5GN-D33] [5GN-D23] within 5G-PPP Phase 1. For this purpose, use cases and KPIs have been defined in an early project phase [5GN-D21]. The evaluation concept covers a broad range of evaluation criteria checking performance, functional, operational, security, and economic requirements. The original use cases and scenarios proved to be insufficient for testing of the requirements of flexibility and adaptiveness. Hence deployment of single- and multi-tenant networks including a slice for enhanced mobile broadband (eMBB) as well as combined network slices for eMBB, massive machine type communication (mMTC) (such as smart metre services) and ultra-reliable low latency (URLLC) (such as semi-automated driving services as part of a wider vehicle-to-infrastructure (V2I) service set) operated on a joint hardware platform has been emulated in a London sample area.

Similar to [5GM-D61], user related KPIs have been specified by so called service definitions. To make sure that the most valuable services are considered, the final service selection was based on socio–economic evaluations.

Most technical evaluations have been done in a qualitative manner checking feasibility of the elaborated architectural concepts in a simulated network roll-out. The results and lessons learned listed below are structured into a technical part taken from [5GN-D33], an economic part [5GN-D23] and a look ahead on possible migration path [5GN-D33]. Common assumptions for technical and economic evaluations in the London study area proved to be very helpful as they guaranteed integrity of both types of both types of results.

Please note that the terminology used below is specific to the 5G NORMA project. 5G NORMA outcomes are considered in the 5G-MoNArch architecture definition, but their role is extended.

2.1 Results of technical verification of the architecture

Technical evaluations have included performance, functional operational and security aspects [5GN-D3.3]:

- Interaction between the NFV-orchestrator (NFVO), intra-slice controller (ISC) and cross-slice controller (XSC) provides a flexible means of resource management that allows for improved interference management as well as inter-cell resource allocation (spectrum, compute, storage, transport) and hence improves user experience. For economic reasons extreme traffic demand as appearing with new services like outdoor augmented or virtual reality (AR/VR) cannot be realised in an area covering manner but at points of interest where deployment of mmWave small cell nodes will allow for those applications.
- To adapt the network to the emergence of 5G services the transport networks need to provision capacity on demand through automatic connectivity services in a scalable and cost-efficient manner. Those requirements for flexibility and dynamicity across different network domains, along with the need for efficient consumption of resources, reinforces the demand for network programmability that transport networks already face.
- Multi-tenant performance benefits in terms of improved network capacity and user experienced data rates can be achieved by more flexible spectrum deployment and multi-connectivity. However, these benefits may be limited for identical services due to the extent in which traffic is correlated between these services. Hence multiplexing gains with respect to common resources may be more readily achieved across network slices with different traffic behaviour.
- Regarding spectrum sharing, the regulatory status in Europe is quite fragmented. But regulators might be keen to ensure that there are no regulatory barriers that unnecessarily present challenges to the long-term sustainability of the mobile industry. The most important sources for cost savings by multi-tenant networks are:
  - Site cost reduction (passive sharing).
  - Reduction of Operational (OPEX) and Capital Expenditure (CAPEX) due to common Radio Access Network (RAN) functions in edge clouds as well as at antenna sites.

- Postponed capacity extension and acquisition of new sites due to spectrum sharing and multi-connectivity due to lower cell load, shorter air times for elastic services like file transfer and increased virtual spectrum availability caused by traffic multiplexing gains.
- Extended Electro Magnetic Field (EMF) limitations due to the reduced number of antenna planes when sites are shared meaning that safety distance increase if spatial dimension of antennas decrease.
- Reduced number of small cell sites due to higher spectrum efficiency if frequency reuse factor >1 is introduced by small cell spectrum sharing.
- Joint utilisation of transport network (TN), also known as x-haul (back-/mid-/fronthaul) in the RAN.

2.2 Results of socio economic evaluation

Alongside the above technical evaluation of the 5G NORMA architecture a socio-economic evaluation of the proposed architecture in a central London study area considering a smart city deployment was also completed. Results from this evaluation showed [5GN-D23]:

- There is significant risk in the business case, over the 2020 to 2030 timeframe, for today's mobile networks following a strategy of delivering eMBB only services. This level of risk is highly sensitive to the eMBB traffic levels realised in practice with very limited scope for increases in revenue due to high subscriber penetration levels in Europe already existing and subscriptions being close to the limit of consumer willingness to pay.
- The eMBB only business case is not greatly changed by deploying a cloudified RAN (C-RAN) rather than distributed RAN (D-RAN) network. Although there is an initial conversion cost to migrating to a C-RAN network once this has been incurred the total cost of ownership (TCO) of a network in the study area evolving to meet eMBB demand over the period 2020 to 2030 is very similar between C-RAN and D-RAN options.
- Support for multi-tenancy in the 5G NORMA architecture can deliver significant cost savings. For example, a 14% reduction in the TCO between 2020 and 2030 for the eMBB network in the study area was recorded when two existing site portfolios became shared for two MSPs compared with the two infrastructure sets being used independently.
- Support for multiple services on a single network can help to de-risk the long-term business case for mobile networks. A number of smart city services were considered in combination with eMBB in the study area and corresponding costs and revenues calculated over the period 2020 to 2030. This showed an improvement in ROI of up to 10% beyond a baseline eMBB only ROI of 6%.
- There are significant quantifiable social and wider economic benefits that may result from the smart city services considered in the study. This shows that although some services may have commercial risk there may be a case for public private partnerships or partnerships from infrastructure or property owners to help support the roll out of mobile services with significant social and economic benefit.

2.3 Possible migration path

Important results with respect to verification have also been achieved by laying down feasible migration paths showing the transition from a brownfield network towards a virtualised target architecture.

- Deploying a mobile radio infrastructure for end-to-end (E2E) network slicing requires high investments. The same holds for the reconstruction of an existing network.
- As long as only a single service (e.g. eMBB) is provided on a network infrastructure, it is more economical to use a network infrastructure with conventional architecture instead of an architecture that supports network slicing, due to the additional costs for the slicing of the NF and for the corresponding Management and Orchestration (MANO) functions needed to manage the slices. This results in a 'chicken and egg' problem: Without slicing capabilities no further service types (like URLLC or MMTC) with business relevance for new tenants (e.g. from

vertical industries) can be offered on a common infrastructure, and without further services the deployment of a slicing-capable infrastructure might not be economically attractive.

- In summary, this yields the following requirements on the migration approach, taking into account both user and network perspective:
    - Deployment in incremental steps, in-line with the speed at which the new technical possibilities are adopted by end customers and tenants. Additionally, migration of network functionality and infrastructure has to be synchronised with penetration of novel User Equipment (UE) generations adapted to service needs (e.g. sensors).
    - Minimum additional upfront investments per deployment step.
    - Provisioning of maximum benefit for the end customers and tenants by the new technical possibilities of each deployment step.
    - Coexistence of legacy and sliceable network infrastructures.
    - Technical migration steps need to support and match the expected stakeholder model.

3 Verification and validation methodology

In this chapter the methodology that will be employed within 5G-MoNArch verification and validation activities is described in detail. First, the selected KPIs are identified. Then, the different verification elements in the proposed methodology are provided. Next, a high-level description of the ECs is provided. Finally, the validation methodology is exposed.

3.1 KPIs selected for verification

A comprehensive list of KPIs has been defined in D6.1 [5GM-D61]. A subset of these KPIs has been selected for verification based on the verification targets identified in Section 3.3. The subsets of selected KPIs are presented in Table 3-1.

Table 3-1: Definition of the KPIs that have been selected for verification

	KPI	**Description**
Service related	Area Traffic Capacity	Total traffic throughput served per geographic area (in bps/m^2)
	Coverage area Probability	Coverage area probability is the percentage of the area under consideration, in which a service is provided by the mobile radio network to the end user in a quality that is sufficient for the intended application
	User Experienced Data Rate	The achievable data rate that is available ubiquitously across the coverage area to a mobile user/device (in bps)
	End–to-end latency	Latency is measured by time required to transfer a data packet from a source to a destination from the moment it is transmitted by the source until a) the moment of successful delivery (one trip time) or b) acknowledgements are received from the receiving entity (round trip time)
Resilience	End-to-end reliability	The probability that all network components are capable to support a required function for a given time interval
	Reliability of the telco cloud	Probability that a telco cloud component can perform a required function (taken from the set of computation; networking; storage) under stated conditions for a given time interval.
Resource elasticity	Cost efficiency gain	Average cost of deploying and operating the network infrastructure to support the foreseen services
Techno-economic	Incremental revenue per GB	The revenues expected to be received for services on the 5G-MoNArch platform per unit of data delivered
	Incremental revenue per GB	The costs expected to be incurred in delivering services on the 5G-MoNArch platform per unit of data delivered
	Social benefit	A financial assessment of the social benefits achieved through new 5G services from the 5G-MoNArch platform
Application specific	Maximum number of simultaneously active IoT devices	Maximum number of sensors a slice can serve within the given deployment area
	Time on task	Amount of time it takes the user to complete a task, expressed in minutes and seconds
	Task Success Rate	Task success rate is the percentage of correctly completed tasks by users per total number of attempts
	Frame Rate Judder	The percentage of time during a VR application where the framerate was less than 75 frames per second

3.2 Verification elements

This chapter defines the basic elements comprised in the proposed verification framework. Figure 3-1 shows the relation between these elements.

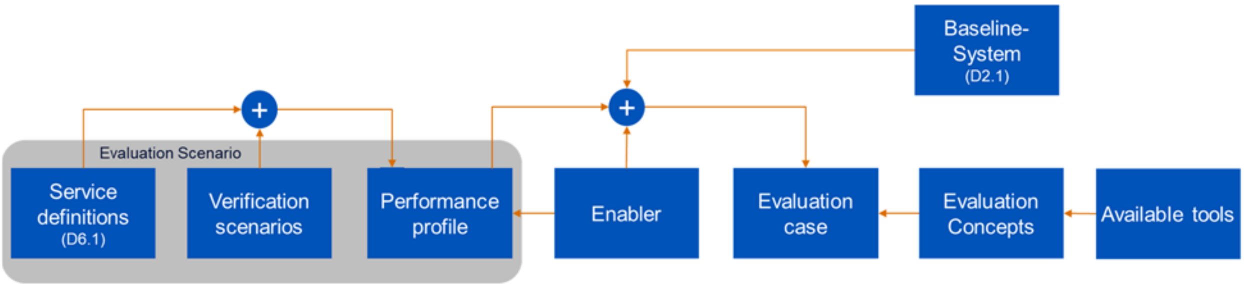

Figure 3-1: Relations between elements in the 5G-MoNArch verification process

In the following, each of the verification elements is described:

Service definitions: Relevant services have been defined in Deliverable D6.1 [5GM-D61] and are further refined in Section 4.1 of this Deliverable. These *service definitions* set the target Key Performance Indicators (KPIs) with respect to service-related KPIs and comprise of a (narrative) description, a set of performance benchmarks, and radio capacity and coverage KPIs.

Verification scenarios: They complement the description of the problem space by adding the geographical physical location information and infrastructure characteristics. A common understanding on the verification scenario ensures that inputs from the evaluation of different innovations are based on consistent assumptions. Verification scenarios comprise the following attributes, see Table 3-2:

Table 3-2: Verification scenario attributes

Physical location	Area name or latitude longitude co-ordinates	
	Boundary and size of the considered area	
	Clutter type of the area (rural, suburban, urban) and description of building types or other physical location characteristics	
Infrastructure	Infrastructure deployment (infrastructure deployed at the beginning, in 2020)	Number, type, and configuration of antenna sites deployed, both macro and small cells
		Number and configuration of edge cloud deployed
		Availability and characteristics of existing site x-haul connections (fibre, wireless, etc.)
	Network migration and evolution rules (to be harmonised between all verification scenarios if applicable)	Spectrum availability over time and support in user devices
		Spectrum efficiency per Multiple Input and Multiple Output (MIMO) antenna configuration and availability of this over time
		Ability of different site types to support particular traffic types (e.g. high velocity traffic on macros only)
		Support of MIMO by different site types and assumed spectrum efficiencies
		Power and antenna assumptions per antenna site
		Rules for dimensioning RAN processing requirements
		Rules for assessing latency contributed by each network element

Performance profiles: They describe the services to be offered by a Mobile Service Provider (MSP) or tenant in a specific verification scenario. While the service definitions describe the range of possible services that can be evaluated, performance profiles select the set of services being considered in a particular verification scenario for a given EC. They also add an extra level of detail to the service definitions by providing the *traffic profiles* which are required for comprehensive modelling. Traffic profiles include:

- Mix of network slices based on services and their respective requirements.
- Density of users (users per km^2) per service.
- Expected spatial distribution of users their timely change of positions and service consumption.
- Forecast on traffic growth out to 2030 for each service.

In addition to the above, the performance profiles also need to capture *business model assumptions* and *implications for network slices*, which are required for the economic modelling. These include:

- Key stakeholders involved in the scenario, i.e., end users, tenants, mobile service providers and infrastructure providers (InP).
- Network slicing requirements to support proposed stakeholder model with interactions and required interfaces between them.

Enablers: 5G-MoNArch enablers are modules, algorithms or schemes to be developed by the project contributing to KPI improvement.

Available tools: For verification of the improvements provided by the enablers, specific tools will be provided by the enabler owners. These are called the available tools.

Baseline system: This includes the extension of an existing (single- or multi-operator) infrastructure for provisioning of the envisaged performance profiles. Baseline deployments are specific to the EC and provide a reference for the assessment of the enabler benefits. They have implications both in the technical as well as in the economical evaluation. A baseline system has been defined in Deliverable D2.1 [5GM-D21]

Evaluation concepts: It is anticipated that part of the verification will be conducted by the enabler owners and another part of the verification results will come from the testbeds. However, these results may not be suitable to be directly combined in a broader verification scenario such as the one considered for technical and economic verification, since in most cases the KPI contributions of multiple enablers cannot be simply superimposed. To address this issue, *evaluation concepts* will be developed by WP6 to:

- Describe how verification results achieved at testbed level may up-scaled to bigger sized scenarios.
- Provide methodologies for estimation of joint KPI contributions in case of multiple enablers are applied at the same time.

3.3 High level descriptions of evaluation cases

In 5G-MoNArch, the verification and validation activities will be based on three ECs. In the following, a high-level description of these three ECs is provided. A more detailed description is provided in Chapter 4 along with the instantiation of the verification elements.

3.3.1 EC1: Resilient network slices for industrial applications

EC1 focuses on delivering secure and resilient industrial services to a Smart Sea Port tenant. It is assumed that an MSP, in addition to maintaining an eMBB slice for existing eMBB services, is providing additional slices to realise an isolated industrial network as needed to serve Smart Sea Port related service requirements. The following performance and economic KPIs for a baseline deployment are compared with those achieved when applying enablers originating from WP3:

- Coverage area probability.
- Reliability of the telco cloud.
- E2E reliability.

- Incremental cost per GB.
- Incremental revenue per GB.

The 5G-MoNArch enablers for RAN reliability are network coding and data duplication. These enablers will improve the coverage area probability. Another group of enablers around network fault management, fault detection, recovery and healing will improve the reliability of the telco cloud.

Whereas improved RAN reliability comes predominantly at the cost of capacity and experienced data rates, the improved reliability of the telco cloud will cause additional expenditures.

Verification activities should give evidence that the 5G-MoNArch functional innovations for resilience enable significant improvements with respect to coverage area probability and E2E reliability and via these will also improve resilience as defined in D6.1 [5GM-D61]. The incremental revenues per GB will have to justify the increased cost caused in the RAN, in the cloud and for extending transport resources.

5G-MoNArch enablers on security threat detection, prevention and reaction contribute significantly to security threat identification and security failure isolation. Both are indispensable features in industrial networks. Hence these enablers are a basic requirement for introduction these new services. As there is so far no mature methodology for the verification of security features available, the incremental revenue benefit of these enablers against incremental cost by Smart Sea Port services will quantify their benefit.

WP3 is expected to provide network dimensioning rules that allow for estimation of additional radio, transport and cloud resources due to all the aforementioned resiliency and reliability measures. The objectives of EC1 are to:

- Instantiate the Smart Sea Port related target performance profile and possible baseline deployments.
- Build a platform for execution of measurements and WP3 related verification.
- Carve out characteristic performance and business aspects of possible use cases for industrial network slices.
- Demonstrate the benefits of 5G-MoNArch enablers with respect to selected KPI.
- Provide network dimensioning rules contributing to traceable cost estimations.
- Quantify the business case for providing resilient network slices for industrial applications based on the observed above technical KPI improvements (with mapping to service improvements and new services) and dimensioning rules associated with the WP3 enablers.

3.3.2 EC2: Elastic network slices enabling local peak performance

EC2 will compose of two verification activities. The first focuses on the Turin Touristic City testbed and observations from this to demonstrate network elasticity working in practice. This concept of network elasticity proven on the Turin Touristic City testbed will then be verified and scaled up in the verification scenario of Hamburg city port in the context of considering an existing mobile network delivering eMBB services and having to cope with temporary eMBB demand hotspots such as those generated by passengers arriving at the sea port terminal from a large cruise ship.

In the simulation activities centring on the Hamburg verification scenario, the following performance and cost KPIs for a baseline deployment are compared with those applying on top elasticity enablers originating from WP2 and WP4:

- Cost efficiency gain.
- Incremental cost per GB.
- Incremental revenue per GB.

Future 5G networks will allow for flexible network reconfigurations enabling local peak performance and at the same time avoiding static oversizing of network elements. Without network elasticity use cases demanding local peak performance for certain periods of times would cause bottlenecks with respect to radio, transport network and cloud resources. 5G-MoNArch network elasticity enablers work at a:

- Computational level by allowing for graceful NF performance degradations.

- Orchestration level by shifting NFs to other cloud locations in case of overload.
- Slice level by demand oriented reassignment of resources to different network slices.

It is to be expected that the footprints of all kinds of resources can be reduced by leveraging these network elasticity enablers. The implementations in the Turin Touristic City testbed will demonstrate the technical feasibility of these innovations. The Hamburg Smart Sea Port testbed shall show that elastic network functions are more favourable compared to network overprovisioning from an economic point of view.

The objectives of EC2 are:

- Instantiate verification elements (performance profiles, baseline deployments, enabler supported deployments) that demonstrate the benefit (performance vs. cost) of network elasticity in a Hamburg verification scenario.
- Build a verification scenario in Turin for conducting WP5 measurements and WP4 related verification
- Demonstrate the benefits of 5G-MoNArch enablers on inter-slice RRM and network elasticity with respect to cost efficiency gain
- Provide network dimensioning rules contributing to a traceable reduction of the minimum resource footprint and cost benefit estimations.
- Integrate measurement results from the testbed in Turin into the WP6 verification framework.

3.3.3 EC3: Integration of resilient and elastic slices into smart city environments

EC3 is executed in the Hamburg verification scenario considering a wider range of tenants than those planned in EC1 and EC2. These tenants now include those for smart city services as well as for the Smart Sea Port services to understand how the benefits of the 5G-MoNArch enablers change for scenarios of different scale and scope of services. In addition, the localised temporary demand hotspots from EC2 are combined in this scenario to understand the economic impact of network elasticity in a multi-service network. In this case, all the performance profiles of the former cases are applied to investigate the benefits of and flexibility introduced due to 5G-MoNArch enablers in a combined scenario.

This EC will consider the KPI contributions to the improvement of:

- Coverage area probability.
- E2E reliability.
- Cost efficiency gain.

3.4 Validation methodology

5G-MoNArch takes developments from 5G-PPP Phase 1 projects closer to implementation and commercial realisation. A key part of this is engaging with the various stakeholders and players in the marketplace [5GM-D12] to ensure that:

- Requirements of stakeholders are correctly captured and interpreted. This includes service requirements but also requirements in other operational areas such as level of control required over the network and its infrastructure, ownership of spectrum, interactions with other stakeholders, current commercial challenges faced etc.
- Thinking on the key benefits of 5G-MoNArch; proposed business models are tested on the market and refined throughout this project.
- Feedback is obtained from stakeholders on the practicalities of migrating existing and deploying new cellular networks to ensure that realistic migration plans are part of the 5G-MoNArch outputs.
- Feedback is obtained from stakeholders on any regulatory barriers to realising the 5G-MoNArch benefits.

This section describes the 5G-MoNArch approach to validation in the above areas.

3.4.1 View from verticals on service related requirements

The purpose of the validation of service requirements is to get feedback on the specifications compiled in deliverable D6.1 [5GM-D61]. The following potential "tenant" groups are foreseen, and corresponding interactions have already been launched:

- Hamburg Port Authority (for Smart Sea Port services).
- Municipality of Turin (for Touristic City services).
- City councils (for smart city services).
- Vehicle manufacturers or industry groups (for vehicular services included under smart city services).

Also included in these discussions will be an assessment of how the ability to achieve service requirements can impact the willingness to pay across the range of services proposed in a given scenario. Furthermore, investigated will be any restrictions from the perspective of potential tenants on the way a service needs to "follow" until it's delivery, i.e., the level of control required over parts of the network infrastructure for security reasons, or the type of relationship envisaged with the end users and service providers, for example.

3.4.2 View from service and network providers on economic requirements

It is expected that the 5G-MoNArch innovations will help to improve the commercial viability of mobile networks and reduce the long-term risks that are currently facing the industry if eMBB-only strategies are followed [5GN-D23]. With this in mind, the project intends to engage with providers of mobile services, sites, network interconnectivity and equipment to understand the commercial challenges facing the industry. The 5G-MoNArch consortium already contains a range of mobile operators and mobile equipment vendors, but the clear aim is to reach stakeholders outside the consortium, to potential new entrants in the infrastructure space in particular.

3.4.3 Technical and regulatory barriers from a stakeholder perspective

To bring 5G-MoNArch and its evaluation closer to reality the goal is to understand the practical deployment challenges faced by industry stakeholders, and to capture early on any barriers perceived to the deployment of techniques envisaged by 5G-MoNArch. Initial thinking in this area has already been presented in deliverable D2.3 of 5G NORMA [5GN-D23]. In this deliverable, are a number of key questions are outlined that arise in relation to proposed more flexible virtualised 5G networks, in particular around multi-tenancy and the emergence of new stakeholder roles, such as:

- Whether any opportunities for anti-competitive behaviour may arise from companies that are vertically integrated across the new stakeholder roles?
- The implications of multi-tenancy for the regulation of shared resources and, in particular, should spectrum pooling and sharing network resources to a level similar to a multi-operator core networks approach (MOCN) as proposed in 4G networks be allowed?
- How do the new stakeholder roles affect existing regulation, e.g., on net neutrality, Quality of Service (QoS) and interference?
- Is there a need for a review of approaches to net neutrality in view of network slicing's ability to differentiate network performance for different sources of traffic?
- Is there a need to ensure that access to fibre for mobile operators is regulated in a way that allows mobile operators to deliver the maximum benefits for consumers and businesses whilst still providing a fair return to fibre network operators?

The above topics will be included in discussions with the previously mentioned stakeholder groups, but in addition the aim is to further discuss these topics with regulators. Even though it is not within the scope of the 5G-MoNArch project to develop solutions for complex regulatory issues as the ones described above, it is necessary to understand and raise any critical regulatory issues that might form significant barriers to deploying the 5G-MoNArch innovations in practice.

3.4.4 Migration scenarios

As a 5G-PPP Phase 2 project it is key that 5G-MoNArch investigates migration paths for the technology and network evolution that it proposes. This work has already been started in 5G NORMA Deliverable D3.3 [5GN-D33] (summarised in Section 2.3) which proposed that 5G NORMA like architectures would not be a complete replacement for existing 4G networks in all areas and scenarios. Rather it proposes that virtualised multi-service networks should be gradually migrated and only in areas where they commercially make sense. In this way the future of mobile networks is likely to contain a mix of both 4G and virtualised 5G networks for some time to come. Therefore, there is a challenge for 5G-MoNArch to clearly articulate how migration to this type of scenario can be reached, considering both the practicalities of migrating infrastructure and equipment and also the time to develop and implement the proposed new ecosystem and stakeholder relationships. It is to be anticipated that network migration will have to be investigated related to the selected performance profiles.

Feedback needs to be obtained from stakeholders on the practicalities of migrating existing and deploying new cellular networks, based on their expectations around infrastructure and networking assets, to ensure that realistic migration plans are part of the 5G-MoNArch outputs. This topic will therefore also be part of the project's discussions with stakeholders.

4 Instantiation of verification elements

To conduct the verification activities, the verification elements defined in Section 3.1 need to be instantiated for each of the specific ECs addressed. This is an ongoing task. In this chapter, the current status of this work is documented.

4.1 Service definitions

To quantify the impact on user experience of performance improvements delivered by 5G-MoNArch and understand the associated dimensioning of network infrastructure, the services of interest for the ECs envisaged in the verification of 5G-MoNArch first need to be defined.

An initial service set has already been defined in deliverable D6.1 [5GM-D61] based on services envisaged in relation to:

- The two testbed scenarios of:
  - An enhanced Touristic City experience.
  - Resilient and secure industrial wireless services for a Smart Sea Port setting.
- A wider smart city scenario which the two above testbed scenarios could be located within. This wider scenario will help with understanding how technical and economic performance benefits change between localised 5G deployments compared with those of wider scale and scope of services.

This section presents an update to this set of services originally presented in D6.1 which have since progressed in further review and analysis within the project drawing on stakeholder feedback, evolved thinking on the testbeds and other public sources on service definitions. It first presents services related to the two testbeds and then the smart city scenario. For each of these the service definitions are split into:

- Performance requirements per service in terms of throughput, latency and reliability, security and resilience
- Indicative capacity and coverage requirements per service and
- User device requirements.

These service definitions are then mapped to the three proposed ECs in the target performance profile described for each EC in Section 4.6.

4.1.1 Touristic City testbed

In this section, the service requirements for the services related to a Touristic City experience are described. These include the services that will be specifically supported on the Turin Touristic City testbed (Anchor services) and also a wider set of services related to tourist attractions and venues but not specifically shown on the testbed. This wider set of services may be useful to consider in the techno-economic assessments to understand the business case and social benefits of such services in a wider more commercial deployment beyond the testbed. Note that not all services in this category explicitly appear in the ECs of the 5G-MoNArch but will be assessed on the testbeds and potentially via further qualitative analysis rather than the full quantitative analysis planned for the ECs.

Service requirements are split into:

- Performance requirements per service in terms of throughput, latency and reliability, security and resilience, see Table 4-1.
- Indicative capacity and coverage requirements per service, see Table 4-2.
- User devices for Touristic City services, see Table 4-3.

Table 4-1: Performance requirements for Touristic City services

Service component	Min. required bit rate	E2E latency	End to end reliability, resilience and security
"Anchor" services – to be shown on Turin Touristic City testbed			
On site VR tour of a remote room of the museum with real time interaction with a guide avatar requiring two services of: • eMBB supporting 360-degree video • Registration, control and VOIP support to VR	10Mbps 16kbps	<100 ms <10 ms	End to end reliability and resilience: Standard – 99.9%. Security: Standard.
High density eMBB hotspot (connectivity for video streaming, voice, emails etc. for large groups of tourists)	10 Mbps	>100ms	End to end reliability and resilience: Standard – 99.9%. Security: Standard
Other Touristic City related potential services			
Mixed-reality enhanced tours or navigation	As for VR tour above	As for VR above	As for VR above
Tourist safety – tracking	Minimum connectivity	>100 ms	End to end reliability and resilience: Standard – 99.9%. Security: Standard.

Table 4-2: Capacity and coverage requirements for Touristic City services

Service component	Data volume per user per day	Number of visitors per km^2 per day (user density)	Coverage area probability
"Anchor" services – to be shown on Turin Touristic City testbed			
On site VR tour of a remote room of the museum with real time interaction with a guide avatar requiring two services of: • eMBB supporting 360-degree video • Registration, control and VOIP support to VR	13.5 GB (assumes typically 3hours usage)	Up to 150k for busiest example tourist attractions but likely located in a dedicated VR area of the attraction. Note: The testbed will not demonstrate this high volume of users directly and in full deployment not all visitors will use VR service.	95% (indoors at testbed area / point of interest)
High density eMBB hotspot (connectivity for video streaming, voice, emails etc. for large groups of tourists)	0.25 GB per day in 2020 growing to nearly 3 GB by 2030, i.e., an approx. 30% CAGR (as per smart city eMBB)	As above – testbed will support a high volume of eMBB traffic alongside the VR experience to demonstrate network elasticity. Verification activities will model the arrival of a cruise ship of tourists to Hamburg to generate a demand hotspot and assess elasticity.	95% (indoors at testbed area / point of interest)
Other Touristic City related potential services			
Mixed- reality enhanced tours or navigation in a Touristic City	As for VR tour above	As for VR above but potentially over a wider service area of the entire building of the tourist attraction or a wider touristic area of a city.	As for VR above

Tourist safety – tracking	200-byte location update every 15 mins	As for anchor services above	95% (indoors at testbed area / point of interest and outdoors around city also)

Table 4-3: User devices for Touristic City services

Service component	**User device description**	**Number of user device antennas**	**Limitations on supported frequency bands**	**Location**
“Anchor” services – to be shown on Turin Touristic City testbed				
On site VR tour of a remote room of the museum with real time interaction with a guide avatar requiring two services of: • eMBB supporting 360-degree video • Registration, control and VOIP support to VR	VR headset	2, 4	Higher frequency bands for wider BWs	
High density eMBB hotspot (connectivity for video streaming, voice, emails etc. for large groups of tourists)	Handheld consumer portable devices	2, 4	All bands likely supported.	Three passenger terminals
Other Touristic City related potential services				
Mixed- reality enhanced tours or navigation	AR glasses	2, 4	Higher frequency bands for wider BWs	
Tourist safety – tracking	Handheld consumer portable devices	2, 4	All bands likely supported.	

4.1.2 Smart Sea Port testbed

In this section, the service requirements for the services related to a Smart Sea Port are described. These include the services that will be specifically supported on the Hamburg Smart Sea Port testbed (Anchor services) and also a wider set of services related to sea ports but not specifically shown on the testbed. This wider set of services may be useful to consider in the techno-economic assessments in particular to understand the business case and social benefits of such services in a wider more commercial deployment beyond the testbed. Service requirements are split into: This wider set of services may be useful to consider in the techno-economic assessments in particular to understand the business case and social benefits of such services in a wider more commercial deployment beyond the testbed. Service requirements are split into:

- Performance requirements per service in terms of throughput, latency and reliability, security and resilience, see Table 4-4.
- Indicative capacity and coverage requirements per service, see Table 4-5.
- User devices for sea port city services, see Table 4-6.

Table 4-4: Performance requirements for Smart Sea Port services

Service component	**Minimum required bit rate**	**E2E latency**	**E2E reliability, resilience and security**
"Anchor" services – to be shown on Hamburg Smart Sea Port testbed			
Connected traffic lights and intelligent traffic signal control (high reliability, low throughput MTC service)	Minimum connectivity	>100 ms	End to end reliability and resilience: High – 99.999%. Security: High.
Environmental sensors - low throughput, high density MTC for environmental data analysis	Minimum connectivity	>100 ms	End to end reliability and resilience: Standard – 99.9%. Security: High.
Augmented reality for port management and maintenance	10 Mbps	<10ms	End to end reliability and resilience: Standard – 99.9%. Security: High.
Other Smart Sea Port related potential services			
Wireless CCTV - eMBB service supporting 4k+ video (high throughput MTC service, but not necessarily low latency)	10 Mbps	<300 ms	End to end reliability and resilience: Standard – 99.9%. Security: High.
Logistics sensors - Low throughput, high density MTC for tracking goods and containers	Minimum connectivity	>100 ms	End to end reliability and resilience: Standard – 99.9%. Security: Standard.
Automated vehicles and port machinery	0.5 Mbps DL/UL	<10ms	End to end reliability and resilience: High – 99.999%. Security: High.
eMBB for cruise ship passengers arriving a port terminal	10 Mbps	>100ms	End to end reliability and resilience: Standard – 99.9% Security: Standard.

Table 4-5: Capacity and coverage requirements for Smart Sea Port services

Service component	**Data volume per user or device per day**	**Number of devices or users per km^2**	**Coverage area probability**
"Anchor" services – to be shown on Hamburg Smart Sea Port testbed			
Connected traffic lights and intelligent traffic signal control (high reliability, low throughput MTC service)	1-byte messages with 1440 messages per day i.e., one per minute [IEEE-2011]	100s of road sensors in the port area. Note testbed will not show this high a volume of sensors.	99.9% (outdoors)
Environmental sensors - low throughput, high density MTC for environmental data analysis	200-byte messages, 100 messages per day i.e., updates every 15 minutes. [GSMA-2016]	100s of environmental sensors in the port area. Note testbed will not show this high a volume of sensors.	95% (outdoors)
Augmented reality for port management and maintenance	13.5 GB (assumes typically 3hours usage)	10s of maintenance staff actively using the service across the area simultaneously. Note testbed will not show this high a volume of users.	95% (indoors at testbed area / point of interest)
Other Smart Sea Port related potential services			

Wireless CCTV - eMBB service supporting 4k+ video (high throughput MTC service, but not necessarily low latency)	1.8 GB (assumes 24-hour video surveillance)	10s of video surveillance points in the port area.	95% (outdoors)
Logistics sensors - Low throughput, high density MTC for tracking goods and containers	200-byte messages, 100 messages per day i.e., updates every 15 minutes. [GSMA-2016]	10s of thousands of containers in the port area per day	95% (outdoors)
Automated vehicles and port machinery	450MB per hour operational per device (many operational 24 hours a day, 365 days per year)	Up to 100 cranes in the sea port across various logistics companies	99.9% outdoors
eMBB for cruise ship passengers arriving a port terminal	0.25 GB per day in 2020 growing to nearly 3 GB by 2030, i.e., an approx. 30%	Up to 4,000 passengers on larger cruise ships	95% (indoors in passenger terminal and outdoors)

Table 4-6: User devices for Smart Sea Port services

Service component	User device description	Number of user device antennas	Limitations on supported frequency bands	Location
"Anchor" services – to be shown on Hamburg Smart Sea Port testbed				
Connected traffic lights and intelligent traffic signal control (high reliability, low throughput MTC service)	Traffic lights and other roadside sensors	1, 2	Sub-1GHz	HPA polygon
Environmental sensors - low throughput, high density MTC for environmental data analysis	Low power sensors	1, 2	Sub-1GHz	HPA polygon
Augmented reality for port management and maintenance	AR glasses	2, 4	All bands likely supported.	HPA polygon
Other Smart Sea Port related potential services				
Wireless CCTV - eMBB service supporting 4k+ video (high throughput MTC service, but not necessarily low latency)	CCTV cameras and central monitoring unit	2, 4	All bands likely supported.	HPA polygon
Logistics sensors - Low throughput, high density MTC for tracking goods and containers	Low power sensors	1, 2	Sub-1GHz	HPA polygon
Automated vehicles and port machinery	Port area operations vehicles and machinery such as container cranes	2, 4	All bands likely supported.	HPA polygon
eMBB for cruise ship passengers arriving a port terminal	Handheld consumer portable devices	2, 4	All bands likely supported.	HPA polygon

4.1.3 Example future smart city scenario

Services in the specific testbed areas would be provided in addition to a wide range of wireless services outside the locality of the testbed areas. Therefore, here the requirements for a busy future smart city scenario as would be expected as the baseline service requirement for future wireless networks are presented.

The services listed earlier for the future smart city scenario example map to the three-main service classes of eMBB, mMTC and URLLC as shown in Table 4-7.

Table 4-7: Categorisation of example services to service classes

Service		eMBB	mMTC	URLLC
eMBB for consumer portable devices	eMBB - 4k+ streaming	X		
	eMBB - AR/VR	X		
Vehicle-to-infrastructure	Infotainment	X		
	Assisted driving		X	
	Semi-automated driving			X
City council and utility services	Environmental monitors, intelligent transport systems (ITS) and waste management		X	
	Smart energy		X	
Logistics	Tracking goods		X	

4.1.3.1 eMBB service requirements

The service requirements for all services envisaged in the future smart city scenario that are classed as eMBB type services are defined in Table 4-8 and Table 4-9 while the user devices are presented in Table 4-10

Table 4-8: Performance requirements for future smart city eMBB services

Service component	Minimum required bit rate for this service	E2E latency	End to end reliability, resilience and security
eMBB – consumer portable devices (driven by video applications)	10 Mbps Downlink (DL)/Uplink (UL) (4k video quality experience)	<150 ms	End to end reliability and resilience: Standard – 99.9% Security: Standard.
V2I – infotainment (eMBB)	10 Mbps DL (4k video quality to at least one passenger)	<150 ms for live conversational video <300ms for buffered video streaming	End to end reliability and resilience: Standard – 99.9% Security: Standard.

Table 4-9: Capacity and coverage requirements for future smart city eMBB services

Service component	Data volume per device per day	Number of devices	Coverage area probability
eMBB – consumer portable devices (driven by video applications)	On average, each device consumes 0.25 GB per day in 2020 growing to nearly 3 GB by 2030, i.e., an approx. 30% CAGR (Considering outdoor demand only which assumed to be 20% of overall eMBB traffic on average)	10s of thousands per km2	95% (outdoors)
V2I – infotainment (eMBB)	On average 1 GB - 25 GB per day per car (2020 - 2030)	100s of vehicles per km	95% (vehicles, outdoors)

Table 4-10: User devices for future smart city eMBB services

Service component	User device description	Number of user device antennas	Limitations on supported frequency bands
eMBB – consumer portable devices (driven by video applications)	Handheld consumer portable devices	2,4	All bands likely supported.
V2I – infotainment (eMBB)	In car infotainment unit	4,8	All bands likely supported.

4.1.3.2 mMTC service requirements

The service requirements for all services in the future smart city scenario that are classed as mMTC type services are defined in Table 4-11 and Table 4-12, while the user devices are presented in Table 4-13.

Table 4-11: Performance requirements for future smart city mMTC services

Service component	Minimum required bit rate	E2E latency	End to end reliability, resilience and security
V2I – Assisted driving (mMTC)	0.5 Mbps DL/UL	< 300 ms	End to end reliability and resilience: Standard – 99.9%. Security: Standard
Environmental monitors, waste management and ITS (mMTC)	Minimum connectivity UL	< 300 ms	End to end reliability and resilience: Standard – 99.9%. Security: High
Smart meters – sensor data, meter readings, individual device consumption (mMTC)	Minimum connectivity UL	< 300 ms	End to end reliability and resilience: Standard – 99.9%. Security: Standard.
Logistics sensor data for tracking goods (mMTC)	Minimum connectivity UL	< 300 ms	End to end reliability and resilience: Standard – 99.9%. Security: Standard.

Table 4-12: Capacity and coverage requirements for future smart city mMTC services

Service component	Data volume per device per day	Number of devices	Coverage area probability
V2I – Assisted driving (mMTC)	On average 50 MB consumed per day per car in 2020 growing to 1700 MB per day per car in 2030 due to growing service uptake (i.e., 40% CAGR).	100s of vehicles per km^2	95% (vehicles, outdoors)
Environmental monitors, waste management and congestion control (mMTC)	On average 230 bytes per day per roadside item (i.e., traffic lights, road signs, bins etc.) in 2020 growing to 1500 bytes per day per roadside item by 2030. This is a CAGR of 20%.	100s of devices per km^2	95% (outdoors)
Smart meters – sensor data, meter readings, individual device consumption (mMTC)	1600 bytes per smart meter per day i.e., 200-byte messages, 8 messages per day	10s of thousands per km^2	99% (indoors) Reflects smart meters likely in hard to reach locations
Logistics sensor data for tracking goods (mMTC)	4 MB per day per equipped vehicle based on 200-byte messages, 100 messages per day (i.e., updates every approx. 15 mins) per sensor and on average 200 items to track per goods vehicle	Up to 10k items to track per km^2	95% (vehicles, outdoors)

Table 4-13: User devices for future smart city eMBB services

Service component	User device description	Number of user device antennas	Limitations on supported frequency bands	Location
V2I – Assisted driving (mMTC)	In car driver information/assisted driving service unit	4,8	Likely all bands supported	Study area streets
Environmental monitors, waste management and congestion control (mMTC)	Low power sensors on buildings, waste bins, street furniture etc.	1,2	Sub 1-GHz band	Study area streets
Smart meters – sensor data, meter readings, individual device consumption (mMTC)	Low power smart meter sensors	1,2	Sub 1-GHz band	Addresses
Logistics sensor data for tracking goods (mMTC)	Low power sensors on goods in transit	1,2	Sub 1-GHz band	Study area streets

4.1.3.3 URLLC service requirements

Finally, here the service requirements for all services in the future smart city scenario that are classed as URLLC type services are defined in Table 4-14 and Table 4-15, while the user devices are presented in Table 4-16.

Table 4-14: Performance requirements for future smart city URLLC services

Service component	Minimum required bit rate	E2E latency	End to end reliability, resilience and security
V2I – Semi-automated driving	0.5 Mbps DL/UL	< 100 ms	End to end reliability and resilience: High – 99.999% Security: High.

Table 4-15: Capacity and coverage requirements for future smart city URLLC services

Service component	Data volume per device per day	Number of devices	Coverage area probability
V2I – Semi-automated driving	On average 50 MB consumed per day per car in study area in 2021 growing to 1500 MB per day per car by 2030, i.e., 45% CAGR	100s of vehicles per km^2	99.9% (vehicles, outdoors) High coverage target reflects high reliability requirement

Table 4-16: User devices for future smart city URLLC services

Service component	User device description	Number of user device antennas	Limitations on supported frequency bands
V2I – Semi-automated driving	In car semi-automated driving unit	4, 8	Likely all bands supported

4.2 Verification scenario

4.2.1 Physical location information

The verification scenario targeted by the simulation based verification activities, as opposed to testbeds, considers a combination of the areas of Hamburg sea port (and specifically the sea port area under the authority of Hamburg Port Authority (HPA)) and a central part the City of Hamburg on the northern side of the river. This verification scenario area is shown in Figure 4-1 and contains a number of locations where tourists can congregate, including cruise ship terminals, creating temporary demand hotspots as envisaged in the verification storylines presented earlier. The clutter database used is CORINE Land Cover 2012 and a clutter map of the verification scenario area is shown in Figure 4-2.

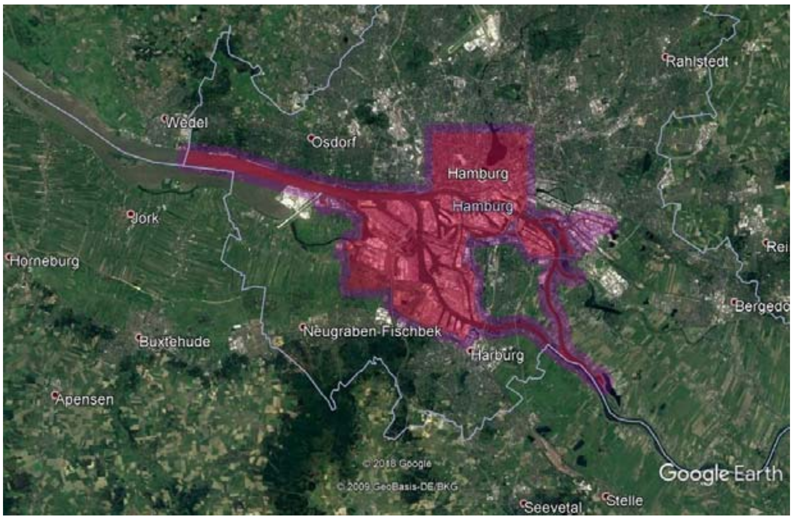

Figure 4-1: Satellite image of verification scenario area

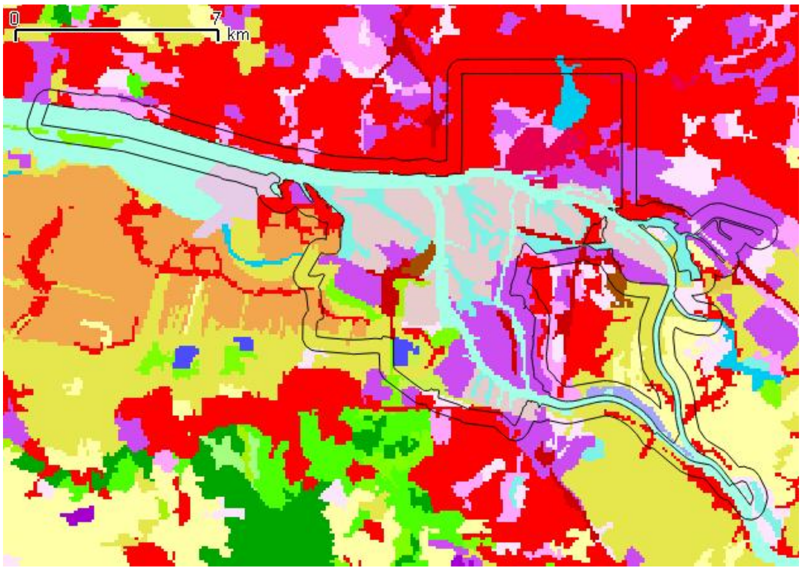

Figure 4-2: Clutter map of verification scenario area

4.2.2 Infrastructure assumptions

In the framework of the 5G-MoNArch ECs a concrete planning of service provisioning based on existing infrastructure will be conducted. This approach allows for the estimation of incremental cost and incremental revenues with and without the innovations developed in the project.

The sourcing of the data sets defined in Section 3.2 is still an ongoing task. The extension of multi-operator infrastructure for the baseline provisioning of service sets as described in Section 4.6 for EC1-EC3 has also yet to be agreed but it will be based on similar assumptions as have been made in the 5G NORMA project [5GN-D32] [5GN-D22] [5GN-D23].

From 2020 onwards, the impact of additional services on the site portfolio will be considered depending on the EC being considered in the project. Edge cloud sites in the verification scenario will be assumed to be located at existing fixed telecoms exchanges in the area as was the case in [5GN-D23].

To achieve comparable testbed measurement results infrastructure assumptions and network configuration within the two testbeds in Hamburg and Turin still have to be aligned at project level.

4.3 Baseline architecture

A baseline architecture based on the service provisioning (performance profiles) of the envisaged EC1-EC3 will provide the reference for evaluations, providing performance benchmarks for service-related, use case related and techno-economic KPIs, against which potential 5G improvements will be measured. In 5G-MoNArch, the enabler benefit will be determined quantitatively by KPI comparison of a 5G baseline system deployment with those of a system deployment extended by 5G-MoNArch enablers as described in Section 4.6. As a baseline, the architecture described in Deliverable D2.1 [5GM-D21] is used. For technical as well as for techno-economic evaluations detailed information on network deployment is required especially when extending available infrastructure for 5G service provisioning (roll-out emulation):

- Kind and number of network slices.
- Required functionality of the different slices.
- Antenna site locations.
- Edge and central cloud locations.
- Topological allocation of network functions.

Each EC has a related performance profile (a set of services in a defined verification scenario). These profiles reveal the service mix and hence the required network slices can already be identified. Work Package 6, in collaboration with WP2, plans to define service specific slice templates that will eventually compile all needed information for slice deployment.

When deploying the baseline architecture, there are some general principles and guidelines that will be used for all ECs. The first principle is that each service defined here for each EC will be deployed as one network slice. The NFs for each service have the possibility to be hosted either in:

- The MNO’s central cloud.
- One of the MNO’s edge cloud.
- In the tenant’s cloud.

It is assumed that tenants (for instance, city councils and port authorities) only have clouds with less capabilities and closer to the edge. Besides that, for all services, the radio stack needs to be hosted in an edge cloud as the delay to the central cloud would be too much for a CPRI (Common Public Radio Interface) connection if it were located there. According to [5GN-D33] M-MIMO deployment will require functional splits at higher RAN layers.

Finally, it’s important to list the criteria used for the placement of network functions (MNO central or edge cloud, tenant edge cloud). In the following the initial proposed criteria are listed.

- Latency is a critical requirement for many services, so the guideline is that any service requiring less that 20ms of latency must be hosted in an edge cloud, unless this latency would not be met by current edge cloud technologies.
- Strategic demands from the tenant can restrict the service to be deployed in a specific cloud.
- High Security requirements do not necessarily indicate where the service must be hosted, however external conditions (legal requirements, Service Level Agreements (SLAs)) can force the service to the deployed in a certain location (especially for data privacy reasons).
- It is assumed that the MNO, both in their edge and central clouds, has bigger processing and storage capability compared to the clouds of the tenant. So, if a service requires the processing and storing of a large amount of data, this favours the deployment on the MNO side.
- Central clouds have more resources and therefore can better explore redundancy, so service requiring higher Cloud Reliability should ideally be placed in the central cloud of the MNO.

4.4 Selection of WP2-WP4 enablers for verification

To support the verification framework the technical work packages WP2-WP4 have described their results in terms of enablers that contribute to KPI improvements. In alignment with these WP's the most important enablers covering all relevant tasks of the project have been selected, see Table 4-17. The selection criteria have been an estimation of the KPI impact and an assessment of the level of novelty.

Table 4-17: Most important 5G-MoNARch enablers

WP/ Task	Enabler	Short description	Type of novelty	Level of novelty	KPI impact
WP2 T2.2	Inter-slice RRM management	Approach to efficiently share radio resource between slices and allow for exploitation of traffic diversity	Enhancement to existing solutions and proposals in current State of the Art (SotA)	High	Cost efficiency gain
WP2 T2.2	Slice-aware RAT selection	Adapting the RAT selection mechanisms such that the proper RAT technology is used to serve UEs according to their associated slice	Enhancement to existing solutions and proposals in current SotA	High	Cost efficiency gain
WP3 T3.1	UL/DL network coding techniques	Network coding based on compute-and-forward method for uplink / network coding based on broadcasting with feedback for downlink	Enhancement to existing solutions and proposals in current SotA	Medium/ High	E2E reliability improvement, Coverage area probability
WP3 T3.1	Data duplication techniques	Contribution towards higher RAN reliability, by duplicating packets across multiple links, thereby reducing the probability that the packet cannot be received correctly	Enhancement to existing solutions and proposals in current SotA	Medium/ High	E2E reliability improvement, Coverage area probability
WP3 T3.2	Network fault management - fault detection and root cause analysis incl. recovery/ healing	Detect the anomaly in network operation along with the root cause. Perform recovery/healing.	Enhancements to existing solutions in SotA and adapting them to slicing context	Medium	Reliability of the telco cloud, E2E reliability improvement
WP4 T4.1	Elastic VNF design	Make the operation of VNF aware of the available computational resources, to allow graceful degradation when shortages happen	Completely novel concept	High	Cost efficiency gain
WP4 T4.2	Elastic NF orchestration using Machine Learning (ML)	Change the location of NF if computational resources become scarce	Completely novel concept	High	Cost efficiency gain
WP4 T4.3	Cross-slice elastic resource allocation; Multi-objective resource allocation	Chance the allocation of compute resources to network slices if computational resources become scarce	Completely novel concept	Medium	Cost efficiency gain
WP4 T4.3	Flexible RAN	Find requirements for a definition of open interfaces among newly designed virtualised RAN functionalities, which enables a higher flexibility in updating and replacing RAN functionalities	Completely novel concept	High	Cost efficiency gain

WP4 T4.3	Machine learning optimisation for RAN functions	The overall target is to derive a design of an algorithm which controls radio and computational resources simultaneously. This enables higher cost efficiency in terms of savings of computational resources.	Completely novel concept	High	Cost efficiency gain

4.5 Evaluation concepts

Technical verification of the enabler benefit in 5G-MoNArch will be done at three different levels:

- The technical work packages WP2-WP4 will provide enabler specific verification methodologies and results that provide evidence for KPI improvements with respect to use case related KPI.
- WP5 will provide testbed measurement results proofing the feasibility of envisaged performance improvements demonstrating the performance of real implementations.
- WP6 will combine groups of enablers in the framework of the described ECs testing their applicability in an up-scaled verification scenario that allows for both technical and economic evaluations.

To estimate joint KPI contributions of multiple enablers and up-scale results achieved at test bed level so called evaluation concepts are needed. These concepts have to be elaborated for each EC. In this section aspects common to all ECs are compiled. Initial technical and techno-economic evaluation plans are described in Section 4.6.

4.5.1 Relation of evaluation concepts and enablers

At high level the enablers compiled in Table 4-17 can be clustered into eight groups that contribute by different means to improvement of use case related KPI

- Coverage area probability.
- Reliability of the telco cloud.
- Cost efficiency gain.

Table 4-18 gives an overview on KPI improvement contributions expected by the enablers selected for verification. As can be seen from the marked boxes, in total six enabler groups contribute to cost efficiency gain in EC2, three groups contribute to coverage area probability (EC1) and only one enabler cluster improves the reliability of the telco cloud which can be combined together with coverage area probability to quantify improvements of E2E reliability in EC1. Respectively it can be deduced that for the technical evaluations two concepts for EC1 and EC2 have to be developed.

Table 4-18: Identifying enablers that contribute to improvements of the same KPIs

Related KPI	**Cost efficiency gain (EC2)**	**Coverage area probability (EC1)**	**Reliability of the telco cloud (EC1)**
Inter-slice RRM - slice-aware RAT selection	X		
UL/DL network coding - data duplication		X	
Network fault management		X	X
Flexible RAN	X	X	
Elastic VNF design	X		
Elastic NF orchestration using Machine Learning	X		
Cross-slice elastic resource allocation	X		
Machine learning optimisation for RAN functions	X		

4.5.2 Input from testbed measurements

Testbed measurement results will contribute to the WP6 verification framework by the following means:

- Measurement results provide achievable performance of real end-to-end implementations dealing with software and hardware constraints.
- The end-users' experience will be captured during the demonstrations (mainly in the Touristic City testbed), providing qualitative insights on how they perceive the capabilities of a 5G network.
- Testbed measurements will feed look up tables for network level simulations executed by WP6.
- The expected output from the testbeds will include both qualitative and quantitative verifications and will feed the discussion on what extent the stakeholders' requirements are met. To this end, for each of the testbeds, the fulfilment of conceptual requirements and the quantification of specific KPIs is foreseen.

Considering all the above, the Touristic City testbed is expected to complement the evaluation concepts related to WP2 and WP4 and it will provide performance measurements related to EC2. The Smart Sea Port testbed, on the other hand, will contribute to EC1.

The Touristic City testbed will put in action a resource elastic network, revealing the potential gains of a system in which (i) the VNFs are designed in a sense that their performance can resist to resource outages, (ii) the infrastructure is shared among multiple network slice instances (NSI) (iii) monitoring mechanisms NSC and orchestration algorithms cooperate to dynamically configure the resource utilisation in VNF, NSI, and System level. The expected quantitative output comprises both service and use case related KPI and includes measurements on *performance degradation (e.g. user throughput), availability, performance degradation, response time, and resource utilisation efficiency.* However, the verification scenario of the Touristic City testbed is yet to be clarified, by following the principles described above and the work that is being conducted in WP5.

The Smart Sea Port testbed, will enable network reliability and resilience to provide and maintain an acceptable quality level for services in case of faults. More precisely, key requirements that are met and assessed in this testbed are the multi-connectivity with data duplication and the integration to the 5G system of the telco cloud. Smart Sea Port testbed measurements still need to be planned.

4.5.3 Techno-economic analysis

As ideas on the technical innovations in the project have now been crystallised in the first half of the project, the techno-economic assessment of these innovations can now be planned and started in earnest. The techno-economic analysis complements the technical verification work by analysing the improvements in business case delivered by the 5G-MoNArch key enablers compared with the baseline system. The techno-economic analysis aims to do this by evaluating the 5G-MoNArch innovations in terms of:

- Setting out opportunities for improvements to relevant stakeholder experience of existing services and the ability to deliver new services beyond today's networks which may increase willingness to pay, unlock new revenue streams and/or deliver social benefits.
- Showing potential to deliver services more cost efficiently than in existing networks.

Combining the above two points will help assess the potential commercial impact of 5G-MoNArch and its potential to de-risk the long-term business case for mobile networks which for providing eMBB services alone is challenging [5GN-D23]. This will build on the techno-economic assessment already started in 5G NORMA for a smart city scenario but with more focus on the verification scenarios and services defined here for 5G-MoNArch. Further thinking on the stakeholder relationships envisaged in the 5G-MoNArch verification scenarios will also be captured so that revenue flows, cost and performance implications against the 5G-MoNArch innovations can be assessed.

Alongside the above commercial assessment there will be research into understanding the social benefits of the service improvements and ecosystem innovation enabled by 5G-MoNArch in the verification scenarios. In cases where the commercial case is less clear this investigation may reveal implications for governments and regulators and potentially show opportunities for public private partnerships. Stakeholder interaction is also desirable to validate this thread of activity (see Section 4.7).

The key groups of 5G-MoNArch innovations that are anticipated to be captured in the ECs are envisaged to map to economic benefits as follows:

- Flexible multi-service architecture – will ideally enable delivery of higher value services than traditional eMBB services and improve revenue whilst utilising economies of scope to deliver these additional services efficiently from a shared network.
- Enhanced security and resilience – will provide access to stakeholder engagements and new revenue streams by improving the quality of experience possible on high security and reliability services from mobile networks. These high security and reliability techniques may come at a higher cost than for baseline services though and so this trade-off between increased revenue and increased cost needs to be assessed.
- Elasticity of resources – will ideally deliver a wide range of services more cost efficiently and in line with a diverse range of demand and user profiles than in a static network.

4.5.4 Qualitative verification

Most of WP6 work in 5G-MoNArch is focussing at quantitative verification and validation of key innovations based on selected KPIs. In addition to KPIs Deliverable D6.1 [5GM-D61] has compiled a comprehensive list of requirements taken from 5G-PPP Phase 1 projects and industry forums like NGMN as well as SDOs like 3GPP and ETSI. The baseline system to be defined for every EC will have to be checked for fulfilment of general requirements. General requirements are to be structured into

- Generic requirements on the overall 5G system.
- Requirements on network slicing.
- RAN-related requirements.
- Requirements w.r.t. capability exposure.
- Security requirements.
- For the different evaluation of use case specific systems, the following requirement groups must be checked in addition.
- Resilience and security requirements.
- Resource elasticity requirements.

In addition, results of a gap analysis conducted by WP2 will be compared with status of architecture design at the end of the project. The check of fulfilment of all these requirements will be done in a qualitative manner documenting potential gaps and proposals for improvement.

The test bed implementations will allow gaining practical experience. Stakeholder requirements can be compared against these "lessons learned" which will add valuable practical aspects to the final project results.

4.6 Evaluation cases

4.6.1 EC1: resilient network slices for industrial applications

4.6.1.1 Performance profiles

EC1 has the target performance profile shown in Table 4-19 below. This represents the use case of an existing eMBB MSP in the Hamburg area starting to offer industrial mobile services to a Smart Sea Port tenant like HPA.

Table 4-19: Performance profiles for Smart Sea Port tenant

Performance Profile: Providing secure and reliable industrial applications to a Smart Sea Port tenant	
Physical location	Hamburg study area (see Section 4.2.1)
Infrastructure assumptions	As per Section 4.2.2.
Traffic profile	eMBB for consumer portable devices, see Table 4-8.Table 4-8 All Smart Sea Port services except for "eMBB for cruise ship passengers arriving a port terminal", see Table 4-4.
Business model assumptions	HPA as tenant with existing MNO acting as the MSP and InP

The existing eMBB traffic forecast will be based on Cisco VNI MBB forecasts applicable to Hamburg. The traffic profiles for the Smart Sea Port services will be based on the demand per device levels given in Table 4-20 with more specific device volumes, usage patterns and service uptake under development.

Table 4-20: Smart Sea Port services parameters

Service component	**Uniformness of traffic**	**Mobile traffic hourly pattern**
Connected traffic lights	All traffic lights generate equal amount of daily traffic	A traffic light generates equal amount of data in each hour of the day
Environmental sensors	All sensor poles generate equal amount of daily traffic	An environmental sensor generates equal amount of data in each hour of the day
AR for port management and maintenance	It is assumed that some locations within the HPA polygon are associated with heavier AR use-requests, e.g. AR at berth, AR at container storage	An AR session lasts an hour and may coincide with the busiest hour for mobile networks around 17:00-18:00
Mobile wireless CCTV	It is assumed that some locations within the HPA polygon are associated with heavier mobile wireless CCTV use-requests, e.g. a mobile CCTV is needed at berth for a day	A wireless CCTV generates equal amount of data in each hour of the day
Logistics sensors – container	All container sensors generate equal amount of daily traffic	A container sensor generates equal amount of data in each hour of the day
Automated vehicles	It is assumed that some locations within the HPA polygon are associated with heavier automated vehicle use-requests, e.g. automated vehicles are needed at berth	An automated vehicle generates equal amount of data in each hour of the day, i.e. 24 hr operation
Automated port machinery	Same as above	Same as above

4.6.1.2 Baseline architecture deployment

In this section, first considerations on baseline deployment is described. The service definitions and respective performance profiles described above provide information on the required network slices. If the verification scenario is more detailed the locations of central and edge clouds as well as the antenna sites included for the different services / slices can be added.

Figure 4-3 provides a deployment view with following information:

- Architecture layer hosting in the clouds (grey box)
- Service hosting in the clouds (green boxes)
- Cloud infrastructure provider (colour code blue = MNO, colour code grey = tenant)

The required network slices are listed below. The slices were grouped according to the categories shown in Figure 4 3 (all enhanced mobile broadband services go under "eMBB slices", for example). For each service, there is an explanation for its proposed hosting location.

eMBB slices

- *eMBB for consumer portable devices:* Since this service requires support for 4K+ video and tolerates higher latency, it should be placed in the MNO central cloud.
- *Wireless CCTV:* Since this service requires support for 4K+ video and tolerates higher latency, it should be placed in the MNO central cloud.
- *Augmented Reality and Virtual Reality service for Port Management and Maintenance:* This service requires very low latency (below 10ms), with a 10Mbps minimum required bit rate. An MNO's edge cloud appears to be the only location with the required latency and capability.

URLLC slices

- *Intelligent Traffic Signal Control and Connected Traffic Lights:* Service with minimum connectivity required, not data intensive, high latency allowed, however high E2E reliability required. This service doesn't have a strict placement requirement, so for this proposed deployment, the MNO's edge cloud will be chosen.
- *Automated Vehicles and Port Machinery:* This service requires very low latency (below 10ms), the required bit rate is not high, and the E2E reliability requirements is high. The proposed placement is in the MNO's edge cloud.

mMTC slices

- *Environmental Data Analytics:* Minimum connectivity required, no high E2E reliability, no high requirement for data processing and storage, high latency tolerated, this service could be hosted by the tenant's edge cloud.
- *Cargo Tracking:* Same characteristics from the service above, so it could also be hosted in the tenant's edge cloud.

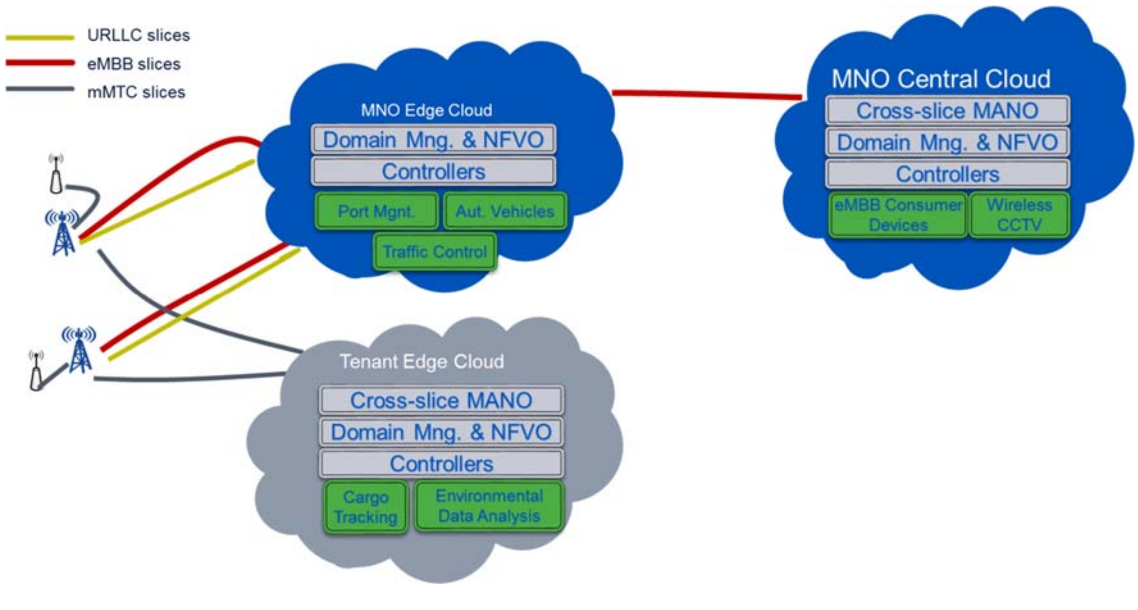

Figure 4-3: Deployment view for the EC1

4.6.1.3 Resilience and security enablers under test

A network slice supporting URLLC services needs to fulfil high resilience, reliability and security requirements. In 5G-MoNArch such specific network characteristics with stringent requirements are provided through the set of *resilience and security enablers*. Those may have different domains of operations, e.g. RAN and core but aim at joint fulfilment of E2E resilience requirements.

Hereby the main specialised network functions and methods are discussed, which are needed for enabling high reliability, resilience and security, i.e., resilience and security enablers:

- ***Multi-connectivity*** (data duplications) is a technique used to maximise the correct reception of the data. It applies to the cases, where the UE is connected to two or more access points, located considerably far away from each other such that the wireless links can be independent. By sending duplicated packets between UE and the access points the level of reliability of data reception is increased. An exemplary implementation of the data duplication enabler is provided in Figure 4-4. Such implementation applies to a Heterogeneous Network deployment that involves the so-called central unit (CU) – distributed unit (DU) architecture. In such architecture, the upper layers of the protocol stack are executed at a centralised location, while the lower layers of the protocol stack at a location closer to the access.

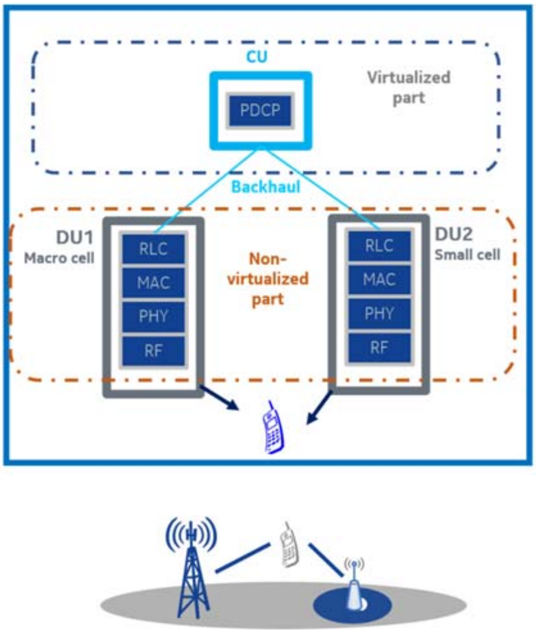

Figure 4-4: Exemplary implementation of the data duplication enabler

- ***Network coding*** is a technique for improving the performance and throughput of networks. However, in the 5G-MoNArch context this technique is used to improve reliability. As such, a particular implementation of network coding is studied, which is tailored for providing higher levels of reliability. This technique enables intermediate nodes to perform operations, where they combine their received packets and forward these combinations to their destinations. Such packet combinations are decoded at the receiver. 5G-MoNArch studies network coding approaches for uplink and downlink separately. An illustration of the concept of network coding for uplink and downlink implementations is provided in Figure 4-5.

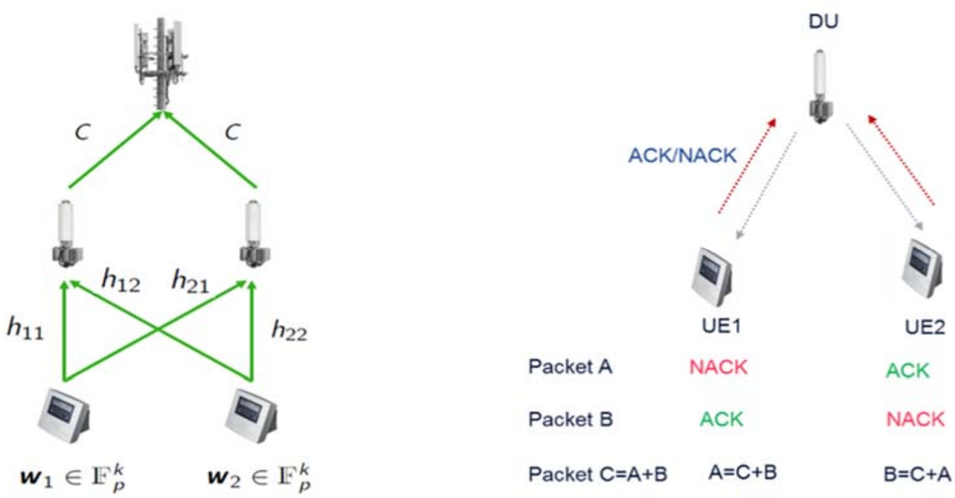

Figure 4-5: Examples for uplink (left part) and downlink (right part) implementation of the network coding enabler

To improve the telco cloud resilience, the focus of the solution is on fault management aspects of the telco cloud. Fault management has been selected due to its capability to monitor the network states and to act against the unexpected network problems, thus improving the network resilience. The fault management functions developed within 5G-MoNArch have as a target resolving the network issues in 5G virtualised networks by jointly handling the faults coming from virtualised and physical infrastructure. Furthermore, the fault management techniques studied in 5G-MoNArch aim at high level of automation and cognition going beyond traditional SON (Self-Organising Network) solutions, by learning from network operation and adapting their processes accordingly. By considering network slice requirements, agreed SLAs as well as characteristics of individual network functions, e.g. in terms of their criticality and deployment options, the fault management techniques developed in 5G-MoNArch are suitable for supporting dynamic and customisable nature of network slices. Furthermore, the fault management techniques developed within 5G-MoNArch take into account the layered deployment of mobile network, where instead of monolithic structure the three deployment layers are to be considered, i.e. physical, virtual and logical as illustrated in Figure 4-6.

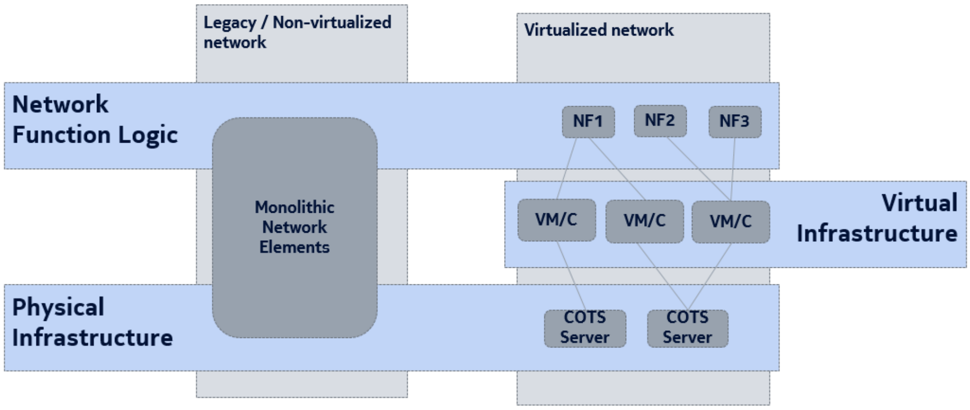

Figure 4-6: Network deployment layers, i.e. physical, virtual and logical considered by the fault management

As security is of high importance for ultra-reliable services, a set of specialised network functions for improving the level of security needs to be deployed in order to achieve the required level of service reliability. Security Trust Zone (STZs) is a logical area of infrastructure and services where a certain level of security and trust is guaranteed, see Figure 4-7. Security level corresponds to a certain amount of assurance of being protected against threats, whereas trust provides certain expectations of being protected against security threats during a defined period of time. The main features of STZ are detection, prevention and reaction which describe the capabilities of the STZ to achieve the promised security and trust levels. 5G-MoNArch aims at deployment of different STZs all over the network slice based on the defined targeted security level. Furthermore, the function that coordinates the activity of Security Trust Zones (STZm – Security Trust Zone Manager) deployed across network slices needs to be present.

It is worth mentioning that the resilience and security enablers can be regarded as a set of network functions, which can be on demand, dynamically instantiated and configured based on the actual network context, resilience requirements as well as agreed SLAs with the slice tenant. As the deployment, activation and management of such NF implies increased operational cost, the presence of such functions needs to be carefully planned and needs to be in line with the slice and tenant needs. In such a way, unnecessary network costs can be avoided by a proper, common management of the resources associated with the resilience and security enablers. Such common resource management of resilience and security is illustrated in the upper right corner of Figure 4-7, showing that the deployment of STZs is administered by a network entity dedicated to this scope.

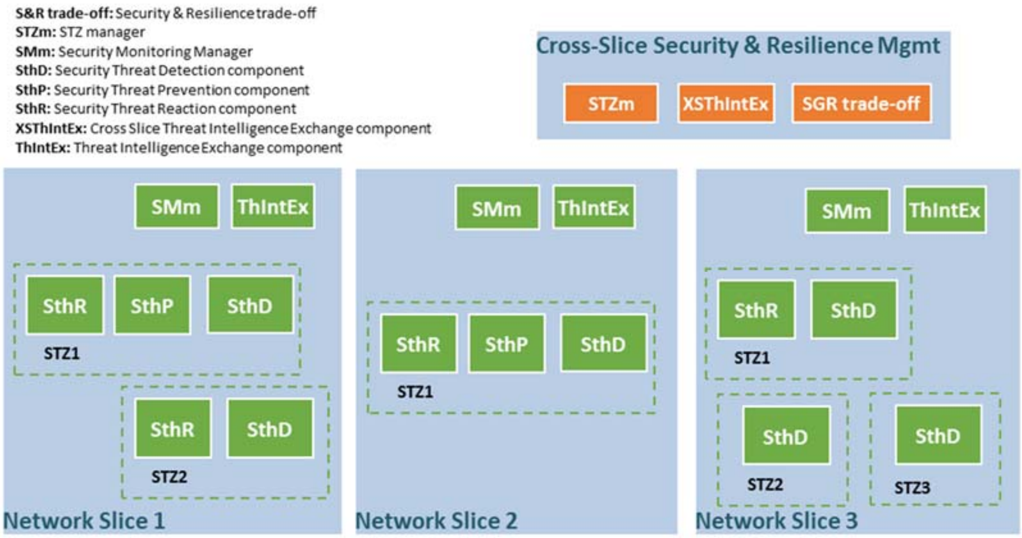

Figure 4-7: Deployment of security trust zones

4.6.1.4 Initial technical evaluation plans

Fault management and RAN reliability in slicing-enabled 5G networks

As indicated in [5GM D6.1] the service E2E reliability can be referred to as the availability of the communication resources, e.g. "5 nines reliability" for an availability of 99.999%. The availability if further defined as the relative amount of time that a given function or service is providing the expected output (i.e. availability is given by the ratio between service uptime and sum of uptime and downtime).

To increase the E2E service reliability, the service downtime needs to be minimised. This approach is in fact reflected in both the access and the telco cloud domain, in the sense that high reliability is necessary from an E2E perspective, otherwise any bottleneck would be prohibitive.

Access reliability evaluation concepts

As regards the access reliability (also referred to as RAN reliability), techniques that promise stronger connectivity levels are proposed in the context of 5G-MoNArch. These are directed mainly in two major fields: (i) macro-diversity via data duplication and (ii) network coding.

Macro-diversity is achieved by exploiting special deployments that allow the UEs to simultaneously connect to multiple access points (e.g., base stations). These techniques allow decreasing the probability of insufficient connection between the UE and the network, yet with an inevitable increase in the cost. Such cost increase stems from the fact that on the one hand dense network deployments are needed for providing sufficient coverage through redundant transmissions, and on the other hand from the additional resources that data duplication entails.

Evaluation plan: In the evaluations of WP6, the effect of applying this approach (i.e. the improved connectivity with cost of resource utilisation efficiency) is going to be considered. The primary plan is to demonstrate that UEs with Reference Signal Received Power (RSRP) lower than given optimal threshold experience higher probability of connectivity in addition to higher throughputs. However, serving these UEs requires that both access point allocate them PRBs, which may lead to decrement of total network throughput. In contrast to UEs with low RSRP, macro-diversity cannot improve the connectivity for UEs with high RSRP.

Network coding: In a similar context, network coding is associated with special network design which involves additional signal processing, thereby increasing the complexity. Cost considerations for both macro diversity and network coding implementations is important for evaluating the benefit from deploying RAN reliability techniques concerning the overall "return on investment" related to such deployments.

Evaluation plan: WP6 is going to integrate the improvement of the network throughput and connectivity as the result of applying the proposed network coding algorithm. However, the possibility of quantising the complexity increase is subject to further discussion and studies.

Telco cloud reliability evaluation concepts

As far as the telco cloud is concerned, the service experiences downtime upon the failure occurs until is resolved. The failure resolution comprises the failure detection, diagnosis, identifying the main cause of the problem and performing the adequate problem isolation and healing operation. To increase the E2E service reliability the service downtime needs to be minimised.

The fault management concepts developed within 5G-MoNArch aim at decreasing the time in which the service or the network function is unavailable, i.e. decreasing the service or network function downtime. One of possibilities of achieving this is applying the fast recovery/healing actions. In virtualised environment this can be achieved by starting up new VMs or containers on which the failed function can be migrated.

Furthermore, as the fast healing actions might require the availability of redundant resources, such that the functionality of failing network function can be overtaken, in overall evaluation of our fault management approach the cost of applying certain redundancy with respect to achieved reliability needs to be considered.

Evaluation plan: Within the evaluations in WP6, the recovery delay of failing VMs/Containers hosting the VNFs are going to be estimated. In the next step, the impact of redundancy to evaluation KPIs are going to be estimated.

4.6.1.5 Techno-economic evaluation plans

As outlined in the previous section there are a subset of the 5G-MoNArch enablers which aim to deliver mobile services at the level of security, resilience and reliability required for industrial services such as those specified for Hamburg Port Authority under EC1. Alongside the technical evaluations already detailed, the techno-economic evaluations for EC1 will assess the trade-off between the new revenue streams from the delivery of industrial services and the additional network costs to implement the level of reliability needed to meet the more challenging requirements of these industrial services. This assessment will be done over the time period 2020 to 2030 to understand the cash flow profile, long and short-term business risks and return on investment (ROI). Progress in understanding the Smart Sea Port ecosystem which will underpin the ability to generate new revenue streams is reported in Section 5.3.1.

4.6.2 EC2: Elastic network slices enabling local peak performance

4.6.2.1 Performance profiles

The target performance profile for EC2 is shown in Table 4-21 and represents the use case of an existing eMBB MSP in the Hamburg looking for mechanisms to deal with temporary demand hotspots more resource efficiently and cost effectively. The temporary demand hotspot considered is the arrival of multiple large cruise ships to the port passenger terminals.

Table 4-21: Serving localised temporary demand hotspot from cruise ship arrival

Performance profile: serving localised temporary demand hotspot from cruise ship arrival	
Physical location	Hamburg city study area (see Section 4.2.1)
Infrastructure assumptions	As per Section 4.2.2.
Traffic profile	eMBB for consumer portable devices (see Table 4-8) eMBB for cruise ship passengers arriving a port terminal (see Table 4-4)
Business model assumptions	Existing MNO acting as the MSP and InP with no intermediate tenant i.e. the end users are direct subscribers for consumer eMBB services with an MSP.

As for EC2, the eMBB traffic forecast will be based on Cisco VNI. In terms of the cruise ship passenger traffic volume, in Hamburg there appear to be three main cruise ship terminals [CG18] [PoH18] as follows:

- Steinwerder (2 berths).
- Altona (1 berth).
- Hafencity (Grasbrook) (1 berth) - Planned to be replaced with a new 2-berth terminal at Überseequartier in 2021.

A large cruise liner such as the Queen Mary 2 can hold more than 4,000 passengers with crew members additional to this. On the busiest days, at the busiest times of the season, there can be up to 3 large cruise ships berthed in Hamburg based on data from HPA. These large cruise ships typically arrive early in the morning and then depart late in the evening. This number of 3 large cruise ships being at the same time in the port area is likely rise in the future, due to growth in the cruise ship business, and fuller utilisation of all the facilities (including the new replacement terminal at Hafencity/Überseequartier). In this case up to 5 berths each with some 4,000 or more passengers and crew are considered. However, whilst this is a likely scenario in general, it is unlikely to arise each and every day (especially out of season).

In terms of the temporal and spatial distribution of the eMBB demand hotspot generated by cruise ships arriving, this will peak in the early morning with the arrival of the cruise ships and disperse over the duration of the morning as many passengers leave the port area to explore the city.

4.6.2.2 Baseline architecture deployment

Based on the service definitions and respective performance profiles described above the required network slices for EC2 are listed below. The required extension of the RAN infrastructure for serving the demand hots spots at the cruise ship terminals is crucial for economic considerations and has still to be specified.

eMBB slices

- *eMBB for consumer portable devices:* Since this service requires support for 4K+ video and tolerates high latency, it should be placed in the MNO central cloud.
- *eMBB for cruise ship passengers arriving a port terminal:* This slice could be only instantiated when an increase in demand occurred. This service requires less bandwidth than the service above and also tolerates higher latency, it could be placed in the MNO's edge cloud.

A simplified deployment view is given in Figure 4-8 where the architecture layer hosting is indicated by the grey boxes and the service hosting is depicted by the green boxes.

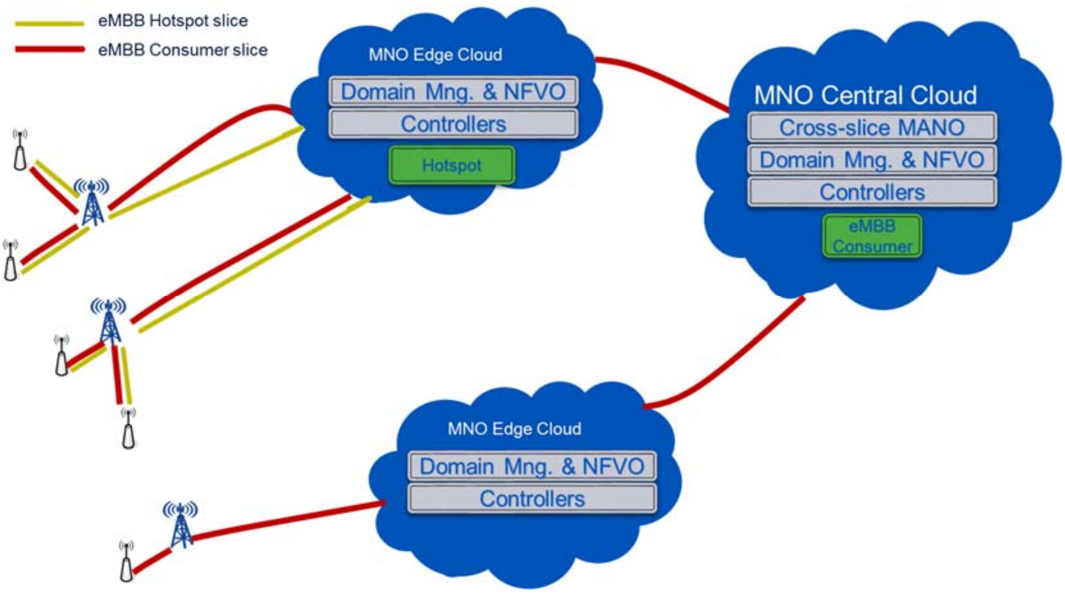

Figure 4-8 Deployment view for the EC2

4.6.2.3 Architectural enablers

The transition from a network of entities to a network of services brought by the softwarisation of network function entails a totally new set of requirements for the mobile network architecture:

- *Intra- slice requirements*: To efficiently support services with very diverse requirements, the architecture shall allow the instantiation of customised network slices, each of them tailored to the specific requirements imposed by the hosted service.
- *Cross-slice requirements:* The architecture shall enable the flexible assignment of resources to slices, when and where they are needed, eventually allowing the control of the resources shared across slices to optimise their utilisation. This entails the definition of a totally new set of management and control functions to deal with the requirements described above. 5G-MoNArch defines a multi-layer architecture that includes: (i) a Management and Orchestration (M&O) layer, (ii) a Network Controller Layer and (iii) a Network layer.

The current overall architecture is depicted in Figure 4-9. The 5G-MoNArch architecture can instantiate multiple slices within the same infrastructure, by creating chains composed by functions that can be either shared or dedicated to a certain slice. The same dichotomy is represented at the Management and Orchestration Layer, with specific modules that tackle the problem of Cross Slice coordination.

4.6.2.4 Cross slice RRM enablers

Another fundamental aspect of cross slice optimisations is the one regarding radio resource management. That is, how to efficiently share spectrum across slices is one of the most important enablers of 5G Networking. The network slice-awareness in 5G RAN will strongly affect the overall RAN design and control plane VNFs: how to deal with different optimisation targets where multiple slices require tailored access functions and functional placements to meet their target KPIs will necessarily entail the design of novel radio resource management (RRM) mechanism.

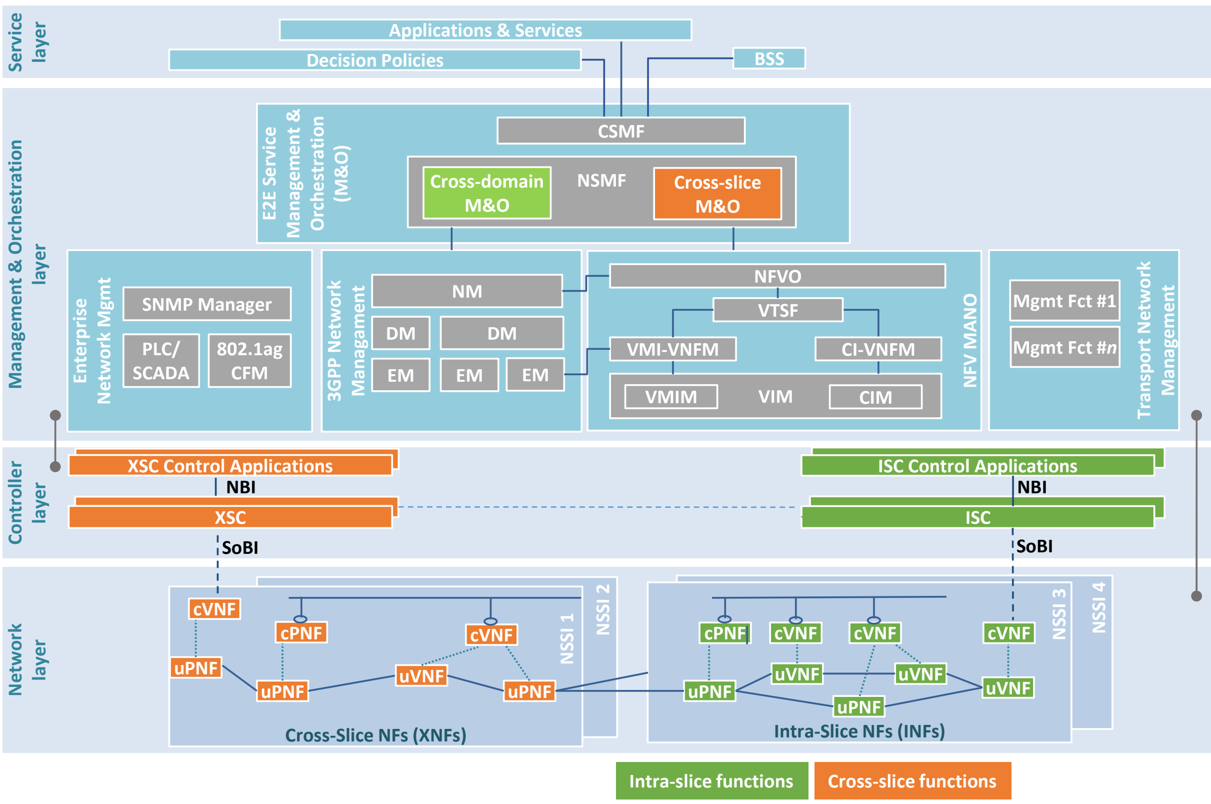

Figure 4-9: 5G-MoNArch overall architecture

As a matter of fact, the operation and placement of RRM will be strongly affected by the slice realisation variants i.e., the slice isolation at RAN level. On the other hand, RAN can provide some limitations on the efficiency of RRM due to the wireless channel, traffic load, and resource availability constraints. In particular, in dense urban heterogeneous scenarios, the signalling and complexity of RRM will be higher due to more signalling exchanges needed for passing RRM information to different entities. Moreover, the distribution of RRM functions in different radio nodes will provide new dependencies between RRM functions, which should be taken care of to optimise performance. In addition, in case of Distributed-RAN (D-RAN), non-ideal backhaul between access nodes (macro and small cells) will put some limitations on the RRM decisions and placement options to meet certain KPIs. These scenarios are addressed throughout this document.

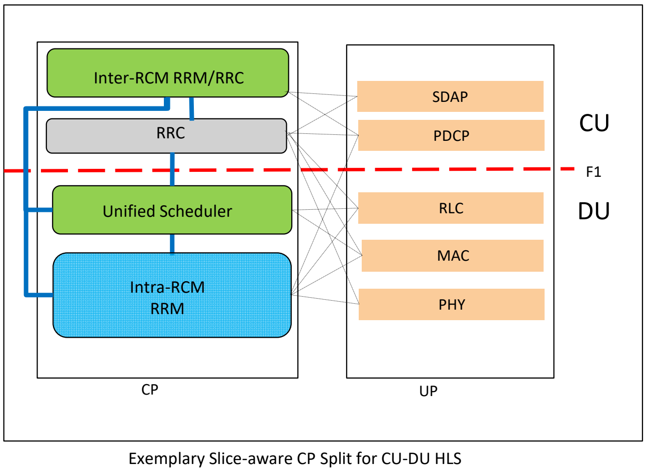

Figure 4-10: Cross slice RRM

A possible architecture is defined in Figure 4-10. The Cross slice RRM can also (as done by the elasticity enabler) exploit data analytics to improve the operation of different aspects. Such data analytics are fed with the data that can be gathered from the network as a whole (i.e., VNFs and PNFs composing a certain network slice and the attached UEs) to analyse the correct resource assignment.

Data gathering in the RAN is achieved through monitoring modules that get information about e.g., the used Physical Resource Blocks (PRBs) by each tenant or the SINR of each user. Other probes can be placed directly on control VNFs such as the AMF, to keep track of registered users, or directly in the M&O layer.

Analogously to the elasticity enablers, this family of enablers allows for a better utilisation of the spectrum that, in turn, allows for an increased cost efficiency. By using smart RRM solution, spectrum can be assigned dynamically to the slices that have to accommodate peak demands on the radio access. This does not only include traditional macro cell coverage, but also to small cells.

4.6.2.5 Resource elasticity enablers

As defined in [5GM-D4.1], resource elasticity is enforced at three different layers: at VNF level, at intra-slice level and at the infrastructure (cross-slice) level. In the following this will be discussed highlighting in general that the concept of elasticity for a NF has not been directly applicable to legacy physical network functions (PNFs). Especially for the case of legacy distributed NFs (e.g., an eNB), the functionality is provided by a physical box that is the result of a thorough joint hardware/software design. Therefore, they have traditionally been designed without any major constraint on the available execution resources as they were expected to be always available by design. In addition, in networks with centralised VNFs, the joint hardware/software design is not possible anymore: VNFs are pieces of software that run on virtual infrastructure on heterogeneous cloud platforms with standard interfaces. Therefore, in this new but already widely adopted scenario, expecting all the needed resources to be always available by design is not reasonable anymore. Furthermore, current VNFs (especially those in the RAN) have been designed under the assumption that required computational resources are always available and they may not be prepared for a shortage of computational resources. Therefore, 5G-

MoNArch designs specific network functions that address the problem of computational resource shortages, exploiting the opportunities given by virtualisation.

The goal of exploiting computational elasticity is to improve the utilisation efficiency of computational resources by adapting the NF behaviour to the available resources without impacting performance significantly.

For example, one potential solution is to design NFs that can gracefully adjust the amount of computational resources consumed while keeping the highest possible level of performance. An exemplary way of working is depicted in Figure 4-11 below. By using an elastic approach, the provided functionality will use less resources to obtain almost the same performance of a standard approach. Elastic VNF design is useful to adjust the amount of resources needed by each slice and in the infrastructure, implementing e.g. a dynamic orchestration algorithm. Examples of elastic VNF design are listed in [5GM-D4.1], such as the Elastic MCS selection and the elastic rank computation.

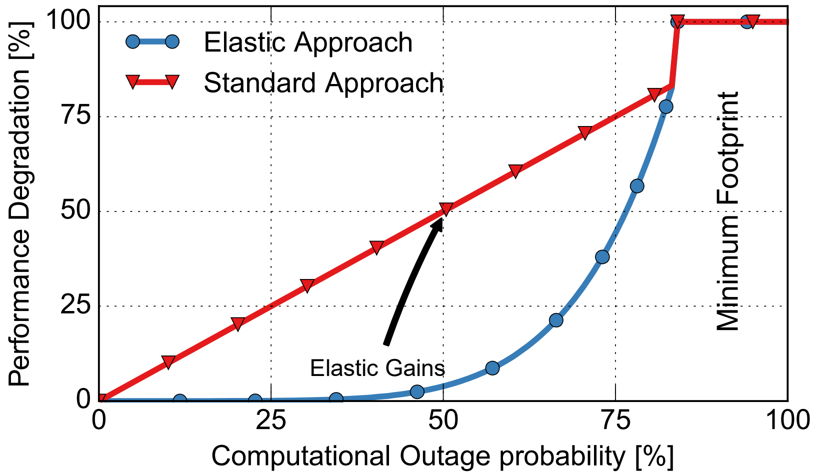

Figure 4-11: VNF resource elasticity

In addition, 5G-MoNArch designs scaling mechanisms, *i.e.*, the modification of the amount of computational resources allocated to such computationally elastic NFs may help in exploiting the elasticity of the system if they are properly designed. There are two significant ways to scale a NF: (i) horizontal scaling, where the system is scaled up or down by adding or removing new identical nodes (or virtual instances) to execute a NF, and (ii) vertical scaling, where the system is scaled out or in by increasing or decreasing the allocated resources to the existing node (or virtual environment). Currently, VM scaling is usually performed via static triggers. By using an elastic approach such as the Elastic NF orchestration using ML [5GM-D4.1], the VNF scaling is performed according to the real needs of the network and, thus, with a better resource utilisation.

Offering cross-slice elastic resource management facilitates the reduction of CAPEX and OPEX by exploiting statistical multiplexing gains. Indeed, due to load fluctuations that characterise each slice, the same set of physical resources can be used to simultaneously serve multiple slices, as Figure 4-12 illustrates.

Cross-slice elasticity is achieved by designing adaptive mechanisms that exploit multiplexing across different slices, aiming at satisfying the slice resource demands while reducing the amount of resources required.

Multiplexing gains can be exploited both at the antenna and in a more centric location such as a cloud datacentre. Hence, the solutions must necessarily dynamically share computational and communications resources among slices whenever needed. However, resource elasticity particularly deals with computational resources. Elasticity at cross-slice level is achieved, by (i) allocating the available resources to each slice, (ii) estimate the overall computational capacity (e.g., NF processing time as a function of input variables such as the allocated number of Physical Radio Blocks in the RAN) (iii) Allocating the available computational resources to different slices, and (iv) observing the network performance and re-allocating the computational resources based on the changes of demands. These lifecycle management tasks can be optimised by applying Big Data and Machine Learning techniques on real data coming from the operational network. As described in [5GM-D41], this operation may be proactively performed by a Cross-slice elastic resource allocation that helps to increase the overall multiplexing gains.

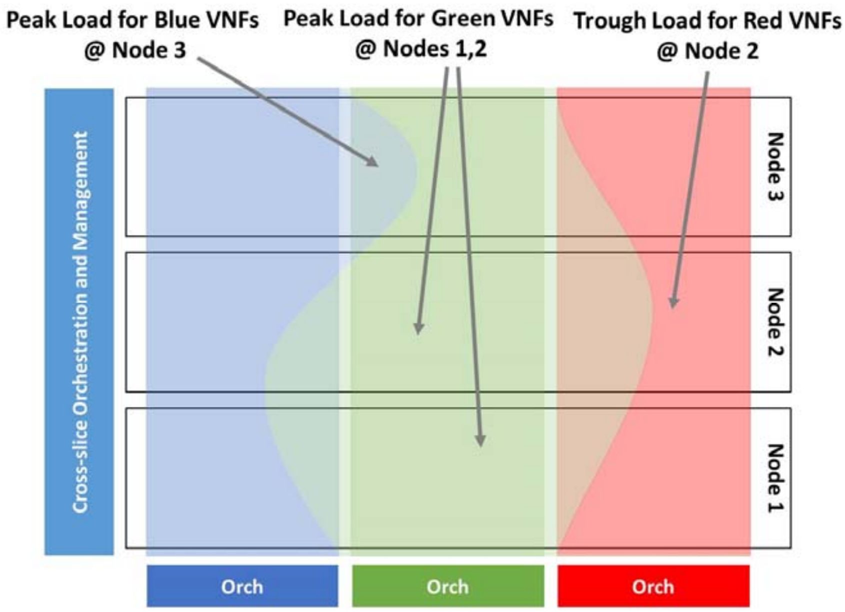

Figure 4-12: Cross slice resource elasticity

Finally, intra-slice elasticity characterises the ability to re-allocate NFs within the heterogeneous cloud resources located both at the central and edge clouds, considering service requirements, the current network state, and implementing preventive measures to avoid bottlenecks. For these reasons special attention needs to be paid to (i) the trade-off between central and edge clouds and the impact of choosing one location for a given function, and (ii) the coexistence of Mobile Edge Computing (MEC) and RAN functions in the edge cloud.

Overall, resource elasticity contributes to reduce the costs associated to the network deployment and operation. By optimally assign resources across slices and reconfiguring the composition of each slice across the assigned resources, providers can both deploy less infrastructure and maximise its utilisation. This approach, that has to rely on a continuous monitoring of the resources used by each slice, is enabled by the elastic design of each VNF that provides graceful degradation in case of unexpected peak loads.

4.6.2.6 Initial technical evaluation plans

Inter-slice radio resource management (WP2)

The network slice-awareness in 5G RAN will strongly affect the RAN design and particularly the CP design, where multiple slices, with different optimisation targets, will require tailored access functions and functional placements to meet their target KPIs. To this end, RRM is one of the key aspects which will be affected. Here to mention that the operation and placement of RRM will be strongly affected by the aforementioned slice realisation variants which correspond to the slice isolation at RAN level. In Slice-aware RAN, to meet diverse KPIs (e.g. rate, latency, reliability etc.), some RRM functionalities will be required to be tailored for different slice requirements.

In slice-aware RAN, the CP can be categorised in the following groups of functionalities based on the RAN Configuration Modes (RCM) framework, as proposed in Deliverable D2.2 [5GM-D22] and sketched next. Four types of RCM as found: (i) Intra-RCM RRM, for slice specific resource management and isolation among slices, utilising the same RAN (ii) Inter-RCM RRM/RRC, which can be defined as the set of RRM policies that allow for sharing/isolation of radio resources among slices or slice types to optimise the resource efficiency and utilisation, by flexibly orthogonalising them in coarse time scales (iii) Topology RRM, another category of Inter-RCM RRM, mainly for D-RAN, where the resource allocation of wireless self-backhauling is essential to allow for joint backhaul/access optimisation, and (iv) the Unified Scheduler. An overarching medium access control (MAC) Scheduler, where different slice types share the same resources and dynamic resource allocation and slice multiplexing is required on top of RCM-specific MAC. They relate among them as depicted in Figure 4-10.

Evaluation plan: Within the evaluations of WP6, the effect of allocation of available radio resources to different slices based on proposed inter-slice radio resource management on the related KPIs e.g., the slice and the total network throughput, average slice delay, and radio resource utilisation is going to be studied.

Computational elastic resource management (WP4)

The goal in 5G-MoNArch is to design NFs that can gracefully adjust their computational resource computation without considerable degradation of performance to avoid the computational outages. The network functions in RAN are optimised designed to be robust against shortages on communication resources. Also, they have to be optimised with respect to their performance of the computational resources. The design of computationally elastic NFs needs to be investigated in detailed and it is also important to study how these approaches impact NF performance.

Evaluation plan: The evaluations of WP6 are going to consider the computational complexity of NFs (i.e., the processing time of NFs) and the changes applied to NFs to reduce the required computational requirements (i.e. limiting the maximum selected MCS).

Orchestration-driven elasticity (WP4)

The aim of these approaches is to satisfy the request for resources by dynamically allocating available resources and avoiding bottlenecks, which may lead to denial of future requests. The key idea in orchestration-driven elasticity is to design a highly-flexible system, which can address the local resource shortages for requests with tight by freeing the allocated resources.

Evaluation plan: The WP6 evaluations target the dynamic allocation of NFs to different computational resource pools with different resource availability. The goal is to evaluate the effect of the orchestration-driven approaches on the related KPIs including the computational time and throughput.

Slice-aware elastic resource management (WP4)

The goal in slice-aware elastic resource management is to serve multiple network slices with different requirements over the same (computational) physical infrastructure and to reduce the CAPEX and OPEX by exploiting statistical multiplexing gains. The algorithms have to consider the requirements of network slices as well as the variation of demands for different slices to achieve the optimal allocation of resources to different resources.

Evaluation plan: The available computational resources are going to be allocated to the slices in the scenario based on their QoS requirement and priority. The performance of the slice-aware resource management is going to be evaluated using the slice-related KPIs (e.g. average slice throughput and processing delay) in addition to global KPIs (e.g., average total network throughput and processing delay).

4.6.2.7 Techno-economic evaluation plans

Alongside the technical evaluations of the network elasticity related enablers of 5G-MoNArch a techno-economic investigation of the potential benefits of network elasticity in the Hamburg verification scenario will be undertaken. Under EC2, the techno-economic evaluations will first examine network costs for providing eMBB traffic across the Hamburg verification scenario including a temporary demand hotspot generated by large cruise ships arriving at the port terminal buildings using the 5G-MoNArch baseline architecture. It is anticipated that these large but temporary peaks in eMBB traffic from the cruise ship passengers arriving will result in over-dimensioning of the network to accommodate them. The second techno-economic evaluation under EC2 will consider serving the same eMBB traffic profile with the temporary demand hotspot from the cruise ship passengers but including the 5G-MoNArch network elasticity related enablers. In this second case the impact of elasticity on network and equipment dimensioning will be implied from the technical evaluations. Ideally network elasticity reduces the need for network over-dimensioning and hence reduces the cost of dealing with temporary demand hotspots whilst maintaining an acceptable level of user experience across all services. By comparing the network evolution and costs over a 2020-to-2030-time period between the baseline network and the network with network elasticity under this EC it is anticipated that potential cost savings due to elasticity will be observed.

Another dimension to the techno-economic evaluations in EC2 will be to understand the different partnerships and deployment models that network elasticity enables and how this changes the way MSPs view the business case for serving localised demand hotspots. An initial analysis of ecosystems related to generating demanding hotspot services is given in Section 5.3.2.

4.6.3 EC3: Integration of resilient and elastic slices into smart city environments

4.6.3.1 Performance profiles

This third EC considers the target performance profiles shown on Table 4-22 and Table 4-23 below with the overall aim of examining the two earlier ECs when a wider scope of services and traffic variations is considered. The increase in services is first achieved by considering a smart city tenant in addition to a Smart Sea Port tenant which will ideally demonstrated any economies of scope from delivering a wider range of services from the same multi-service network via slicing. Secondly the elasticity enablers and temporary demand hotspot will be re-introduced to understand if these elasticity functions benefit any further from a more diverse range of services on the network.

Table 4-22: Serving smart city and Smart Sea Port tenants

Performance profile: serving smart city and Smart Sea Port tenants	
Physical location	Hamburg city study area, see Section 4.2.1
Infrastructure assumptions	As per Section 4.2.2.
Traffic profile	All smart city services including eMBB for consumer portable devices, see Section 4.1.3 All Smart Sea Port services except for “eMBB for cruise ship passengers arriving a port terminal”, see Section 4.1.2
Business model assumptions	HPA as tenant with existing MNO acting as the MSP and InP

Table 4-23: Performance profiles for serving smart city and Smart Sea Port tenants with localised demand hotspots

Performance profile: serving smart city and Smart Sea Port tenants with localised demand hotspots	
Physical location	Hamburg city study area, see Section 4.2.1
Infrastructure assumptions	Still to be specified.
Traffic profile	All smart city services including eMBB for consumer portable devices, see Section 4.1.3 All Smart Sea Port services including “eMBB for cruise ship passengers arriving a port terminal”, see Section 4.1.2
Business model assumptions	HPA and city council as tenants with existing MNO acting as the MSP and InP. eMBB consumers also have direct subscriptions with the MSP.

4.6.3.2 Baseline architecture deployment

This EC combines performance profiles from EC1 and EC2 and adds those for smart city service. First smart city and Smart Sea Port services are combined and then a full-blown service provisioning including the eMBB for the cruise ship passengers is under investigation. The list of required network slices below is related to the full-blown case.

eMBB slices

- *eMBB for consumer portable devices*: Since this service requires support for 4K+ video and tolerates high latency, it should be placed in the MNO central cloud.
- *eMBB for cruise ship passengers arriving a port terminal*: This slice could be only instantiated when an increase in demand occurred. This service requires less bandwidth than the service above and tolerates higher latency, it could be placed in the MNO's edge cloud.
- *Wireless CCTV*: Since this service requires support for 4k+ video and tolerates higher latency, it should be placed in the MNO central cloud.
- *Augmented Reality and virtual reality service for port management and maintenance*: This service requires very low latency (below 10ms), with a 10Mbps minimum required bit rate. A MNO's edge cloud appears to be the only location with the required latency and capability.

URLLC slices

- *Intelligent traffic signal control and connected traffic lights*: Service with minimum connectivity required, not data intensive, high latency allowed, however high E2E reliability required. This service doesn't have a strict placement requirement, so for this proposed deployment, the MNO's edge cloud will be chosen.
- *Automated vehicles and port machinery*: This service requires very low latency (below 10ms), the required bit rate is not high, and the E2E reliability requirements is high. The proposed placement is in the MNO's edge cloud.
- *Semi-automated driving*: E2E reliability is quite high, and data processing and storage requirements seem quite high, leading to the proposal to host this service in the MNO's central cloud.

mMTC slices

- *Environmental data analytics*: Minimum connectivity required, no high E2E reliability, no high requirement for data processing and storage, high latency tolerated, this service could be hosted by the tenant's edge cloud.
- *Cargo tracking*: Same characteristics from the service above, so it could also be hosted in the tenant's edge cloud.
- *Smart grid data collection and control*: This service has similar requirements as cargo tracking and environmental data analytics, however it's more intensive in data processing and storage, so it should reside in the MNO's edge cloud.
- *Assisted driving*: Data processing and storage requirements are quite high, leading to the proposal to host this service in the MNO's central cloud.
- *Waste management and ITS control*: Similar requirements as cargo tracking and environmental data analytics, so this service will also be hosted in the tenant's edge cloud.

Figure 4-13 below uses the same colour coding as the respective figures for the other ECs.

- Architecture layer hosting in the clouds (grey box).
- Service hosting in the clouds (green boxes).
- Cloud infrastructure provider (colour code blue = MNO, colour code grey = tenant).

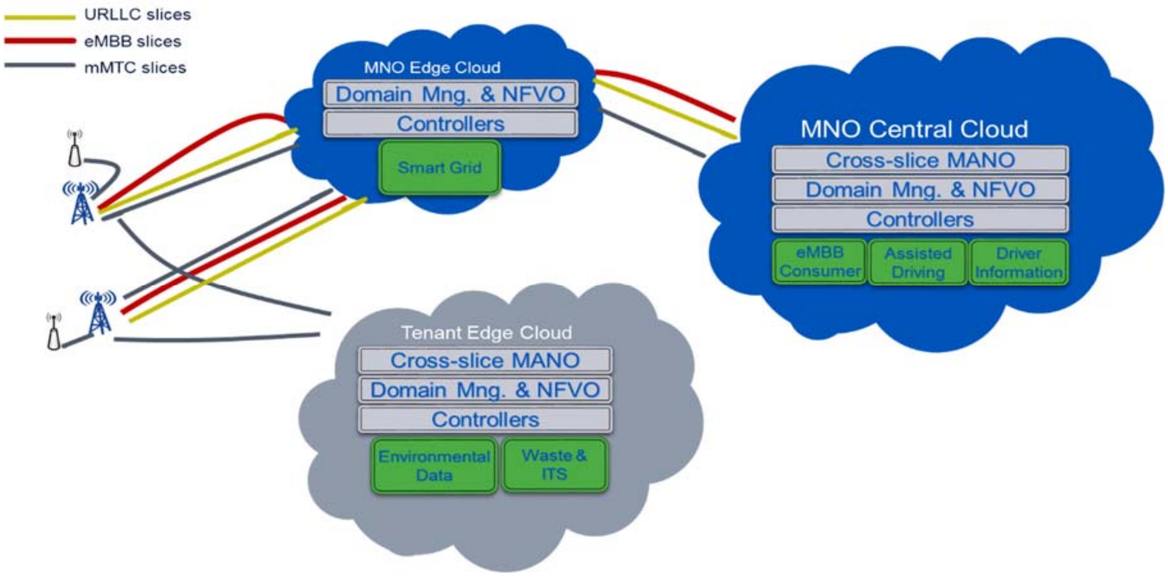

Figure 4-13: Deployment view for EC3

4.6.3.3 Techno-economic evaluation plans

The focus of EC3 is to understand how the business drivers for the 5G-MoNArch elements introduced in EC1 and EC2 change as the scale and scope of the network deployed changes. EC1 will examine the business drivers for extending an existing eMBB only network to provide also Smart Sea Port industrial services via a reliable, multi-service 5G-MoNArch network. Under EC3 an additional tenant of a city council requiring smart city services will be added to the EC1 scenario to understand how the 5G multi-service business drivers change as more services of varying scope are considered in the context of the Hamburg verification scenario. Finally, the temporary demand hotspot from the cruise ship passengers and network elasticity enablers will be re-introduced to observe how the network elasticity benefits change with the scale and range of services considered.

Whilst in EC1 the benefits of 5G-MoNArch will focus on generating new revenue streams, in the case of smart city services in EC3 the benefits may be less commercial. Therefore, socio-economic benefits will also be considered under EC3 with initial ideas for a framework for this provided in Section 5.3.4. Synergies between the value created by parallel services in a smart city environment have also been considered in Section 5.3.3.

4.7 Verification tools

Within the WPs of 5G-MoNArch different set of simulators/emulators are used. Some of the simulators are simplified simulators designed just for to study a specific use-case while the others are general purpose Simulators/Emulators. WP6 verification tools will integrate input from the technical WP’s that are expected to be at enabler level. In the framework of the envisaged ECs joint application of enablers as described in Section 4.6 will be investigated in an up-scaled Hamburg study area.

4.7.1 Verification tools used by the technical WP’s

Besides analytical tools for enabler specific evaluations in most cases link and system level emulators are used.

- *Link-Level simulators:* Link layer simulators are the closest to the wireless access networks regarding accuracy. Network functions starting from PHY to PDCP layer are performed as precisely as a protocol stack. Indeed, the precision comes at the cost of significant computational efforts. Scaling of link level simulator becomes difficult due to the higher complexity and computational efforts. Impact of channel estimation, MIMO gains, channel encoding and decoding can be visualised by link level simulators.

- *System emulators:* System level simulators are designed to simulate at relatively larger scale compared to Link Level simulators. Some of the physical layer network functions are simplified to reduce the complexity and observe the larger scale. Application of system simulator is to verify research related to radio resource management, mobility management, interference management and handovers.

The following paragraphs briefly describe system level emulators used in the 5G-MoNArch project. These emulators are mainly used in the development of cloud-enabled protocol stack (joint work in WP2/WP4) or complexity studies of RAN (WP4).

Open Air Interface (OAI)

The OAI Software Alliance (OSA) is a non-profit consortium fostering a community of industrial as well as academic contributors for open source software and hardware development for the core network (EPC), access network and user equipment (EUTRAN) of 3GPP cellular networks. The Alliance sponsors the initial work of EURECOM to create Open Air Interface towards the development of 5G Cellular Stack on Commercial Off-The-Shelf (COTS) hardware.

The testbed based on OAI can be set up over modern desktop PC with minimum dependency on specialised hardware. Software Defined Radio (SDR) is used for RF frontend processing while rest of the upper layer processing is performed on a PC makes convenient to study, debug and modify. OAI software suit has been mainly divided into 3 submodules, OAI UE, OAI eNodeB and OAI EPC. Each submodule is designed and implemented by keeping interoperability with commercial modules [OAI].

srsLTE

SrsLTE is another open source LTE software suit consisting of the two applications srsUE and srsENB. srsUE is LTE-Release 8 compliant protocol stack implementation from PHY layer to IP layer. srsENB is a protocol stack implementation which consists of PHY, MAC, RLC, PDCP, RRC, NAS, S1AP and GW layers, each one being a separate module. While a highly modular implementation of each layer makes srsLTE more preferable in case of major source code modification, adding support for later released (e.g., 5G NR) due to its high effort requirements is not feasible. srsLTE is available with AGPLv3 license [srsLTE].

4.7.2 Verification tools used by WP6

4.7.2.1 Tools for technical evaluations

Mx-ART (Multi-RAT, Multi-tenant, Multi-Layer, Multi-Network, Multi-Purpose Above Realtime) simulator the network-level simulator from NOMOR, is the primary tool to be used for technical evaluations. Using coarser modelling of the real system, it can run vast scenarios (i.e., whole city) with speed multiple times faster than real-time. Mx-ART has features like network slicing, support of LTE, Wi-Fi, and C-RAN, flexible. The complete list of the network-level simulators of NOMOR can be find on their website [nomor17].

Extension of network level simulator:

The network level simulator of NOMOR requires some extension to host the new enablers for 5G-MoNArch project for verification purposes. In the extension of the simulator in the first year of project can be summarised as follows:

- *Computational resource studies*: The network simulator is extended to simulate the effect changing the allocated computational resources on the processing time of different VNFs. (related to WP4).
- *Telco-Cloud reliability studies*: The support for studying failure in the cloud environment on different network KPIs is added to the simulator. Currently, the simulator can also consider the effects of redundancy on cloud reliability (WP3) and elastic computational resources (WP4).
- *Joint radio and computational resources simulations*: The simulator is extended so the effect of action to save computational resources on the total network throughput can be investigated and vice versa.

- *New coverage visualisation tools*: Means to study the performance of the enablers in WP3 addressing the reliability by increasing the coverage probability has been added to the simulator.

These new features in a proof of concept demo has been presented in European Conference on Communication and Networking (EuCNC'18). The progress of extension of the network level simulator is an on-going task and it will evolve as the enablers in project improve.

4.7.2.2 Tools for economic evaluations

It is envisaged that a range of tools will be used for the economic evaluations at varying levels of detail. The following candidate tools are available from previous projects and notably from 5G NORMA:

- Excel based models of network costs over time to meeting growing demand in an area based on average cell ranges for particular coverage targets and average capacity levels per site type used. These tools can help give an initial indication of network dimensioning for proposed traffic and demand levels. Equipment volumes at a coarse level can also be implied from such models.
- Excel based revenue models for a range of 5G services have been developed as part of 5G NORMA [5GN-D23] and can be used as a start point for 5G-MoNArch.

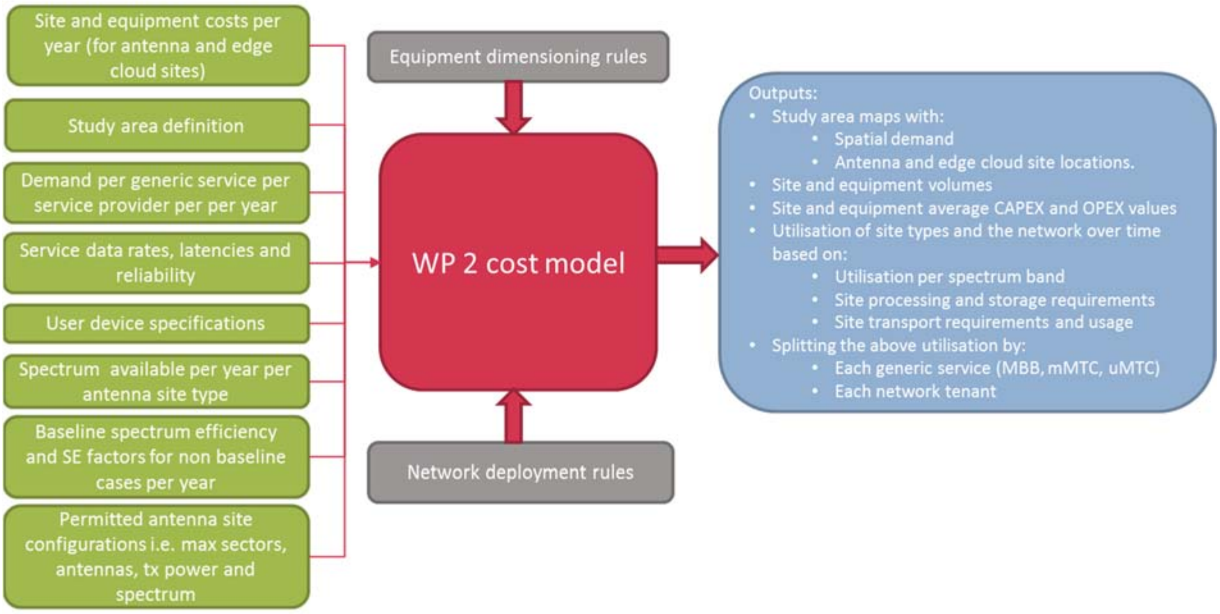

Figure 4-14: Overview of the 5G NORMA WP2 cost model

- A MATLAB based network dimensioning and cost modelling tool that takes into consideration spatial and temporal distributions of traffic. This model has been used for the UK regulator Ofcom [RW 12] and further enhanced within WP2 of 5G NORMA [5GN-D23] to consider virtualised 5G networks. In both projects it has been used for techno-economic modelling with model inputs and outputs summarised in Figure 4-14. In each modelled year the cost model tool forecasts and distributes the demand into the demand sources (spatial-), and into hours of the day (temporal-distribution). The coverage and capacity module of the tool then serves the generated demand based on the current network deployment. Any leftover demand needs to be served by implementing network improvements (new/upgrade antenna sites) and improvement options are ranked by a merit function (of cost over benefit). As this tool has been enhanced as part of 5G NORMA it already considers equipment elements and related costs for the user plane of virtualised networks.

5 Steps towards 5G-MoNArch evaluation

This chapter summarises the status and outcome of the activities being conducted to prepare the technical and techno-economic evaluations. Specifically, the status on the following activities is reported:

- As all verification results will heavily depend on the assumptions adopted for the scenario and service definitions, it is very important to conduct a thorough analysis on the sensitivity on the various parameters. As a first step towards this sensitivity analysis, the possible impact of various factors has been identified, as well the as the interdependencies between key performance indicators that will used for the verification of 5G-MoNArch.
- An insight into planned testbed demonstrations based on [5GM-D51] allows to identify possible input from testbed measurements into the evaluation activities.
- A detailed description is provided for the frameworks to assess the commercial and social benefits obtained in the considered use cases (additional details on this platform can be found in Appendix A).

5.1 KPI interdependencies

An important part of the evaluation process is the sensitivity analysis between the various network configuration parameters, which will allow a better understanding of the interdependencies between network features including cost drivers. In this section, a first qualitative estimation on mutual interdependencies between different selected KPI have been identified, based on expert estimations. Of course, results attained in simulations and analytical evaluations depend heavily on infrastructure and network configuration assumptions. Therefore, it is very important to plan the network setup in a realistic manner. On one hand realistic assumptions will be attained by referring to available networks in the study area. On the other hand, the most important influencing factors have to be investigated by a sensitivity analysis to identify critical influencing factors. Economic evaluations performed in the framework of the three ECs will investigate those interdependencies in detail. As economic evaluation tools allow for modelling of the technical performance only based on empirical rules some of the sensitivities have to be considered also by technical evaluations. For both cases, investigated influencing factors as well as mutual KPI interdependencies have to be narrowed down to reduce the complexity of the analysis.

In the following sections the development of evaluation concepts is prepared by a mapping of considered KPI and most important influencing infrastructure assumptions and network configuration settings.

5.1.1 Network configuration and infrastructure settings to be investigated in by sensitivity analyses

In the framework of the H2020 project 5G NORMA [5GN-D23] extensive sensitivity analyses have been carried out for economic evaluations. With respect to the objectives, there have been different similar methodologies that can be applied for the verification of the 5G-MoNARch enablers.

The first column in Table 5-1 selects the most important KPI proposed for sensitivity analysis. The first row contains factors in terms of infrastructure assumptions and network configuration settings that may influence the listed KPI, which are assessed qualitatively.

5.1.2 Interdependencies between KPIs

Besides the dependencies of KPI from network configuration and infrastructure settings there exist also mutual interdependencies between different KPI itself. For example, an improved coverage area probability due to enablers like data duplication or network coding will at the same time reduce the area traffic capacity. Or improved user experienced data rates due to exploitation of multi-connectivity will also at the same time reduce traffic area capacity as radio resources of multiple cells are used to serve cell edge users and hence are not available to contribute to higher data rates in areas with proper coverage.

In Table 5-2 first estimations of those mutual KPI interdependencies are compiled. The correlation of some KPI combinations depend heavily from the service requirements. This table is not exhaustive and intended to give a first insight into the further planning of verification tasks.

Table 5-1: Impact of factors influencing the different KPI

	(Virtual) antenna site density	**Amount and distri-bution of available spectrum**	**Edge cloud density**	**Traffic profiles**	**Percent-age of resilient cloud resources**	**Multi-service traffic diversity**	**Spatial traffic diversity**
Coverage area probability	Medium	High		High			Medium
Area capacity	High	High				Medium	Medium
User experienced data rate	Medium	High		High		High	High
Telco cloud reliability			High		High	Medium	High
E2E-reliability	Medium	High	High	Medium	High	Medium	High
Cost efficiency gain	Medium	High	High	High	High	High	High
Incremental cost per GB	High	High	High	High	High	High	High

Table 5-2: Correlation between KPI combinations proposed for sensitivity analysis

	Coverage area probability	**Area Capacity**	**User experienced data rate**	**Telco Cloud reliability**	**E2E-reliability**	**Cost efficiency gain**
Coverage area probability						
Area Traffic Capacity	Service dependent					
User experienced data rate	Service dependent	Service dependent				
Telco Cloud reliability						
E2E-reliability	Cloud reliability dependent			Depends on coverage area probability		
Cost efficiency gain	High	High	High			
Incremental cost per GB	High	High	High	High	High	High

5.2 Summary on potential WP5 verification input

5G-MoNArch will be using two testbeds to demonstrate some of the innovations developed by the project. The *Smart Sea Port testbed* will implement and demonstrate a selected set of innovations and concepts from WP3 on the topics of network reliability and resilience while a *Touristic City testbed* will implement and demonstrate a selected set of innovations from WP4 on the topic of network elasticity.

Initial Smart Sea Port testbed demonstration results will be used to verify:

- Technical feasibility of network slicing on commercially available equipment including definition commissioning and management of the slices.
- Reliability of mobile and wireless communication for industrial services provided.
- Isolation schemes for a) slice operation b) resources c) reliability.

The majority of these requirements will be verified by demonstrating their successful operation. Additionally, regarding performance, end-to-end latency, throughput, packet loss rate and resources used by both radio and computing components will be measured and evaluated. The use cases that will be studied in this testbed along with case specific solutions that will be implemented and resilience and reliability related KPIs that will be measured for this case are presented in Figure 5-1.

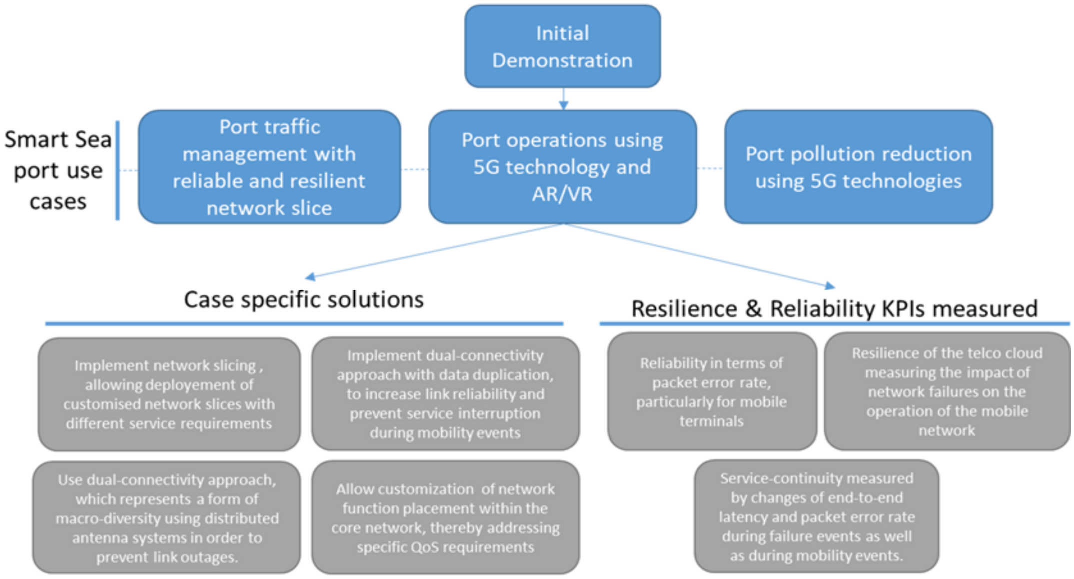

Figure 5-1: Smart Sea Port used cases, specific testbed solutions and KPIs that will be measured

Initial Touristic City testbed demonstration results, will be used to verify:

- The optimal network slicing strategy and transfer of operations between edge and remote server.
- Strategies to accomplish minimum latency along with streaming high-volume data, e.g., a high quality 360-degree video.

During the demonstration of an enhanced touristic experience using VR, bandwidth capacity, transfer times, response delays between clients and server and latency in the communication between clients and server will be measured and evaluated. The use cases that will be studied in this testbed along with case specific solutions that will be implemented and elasticity related KPIs that will be measured for this case are presented in Figure 5-2.

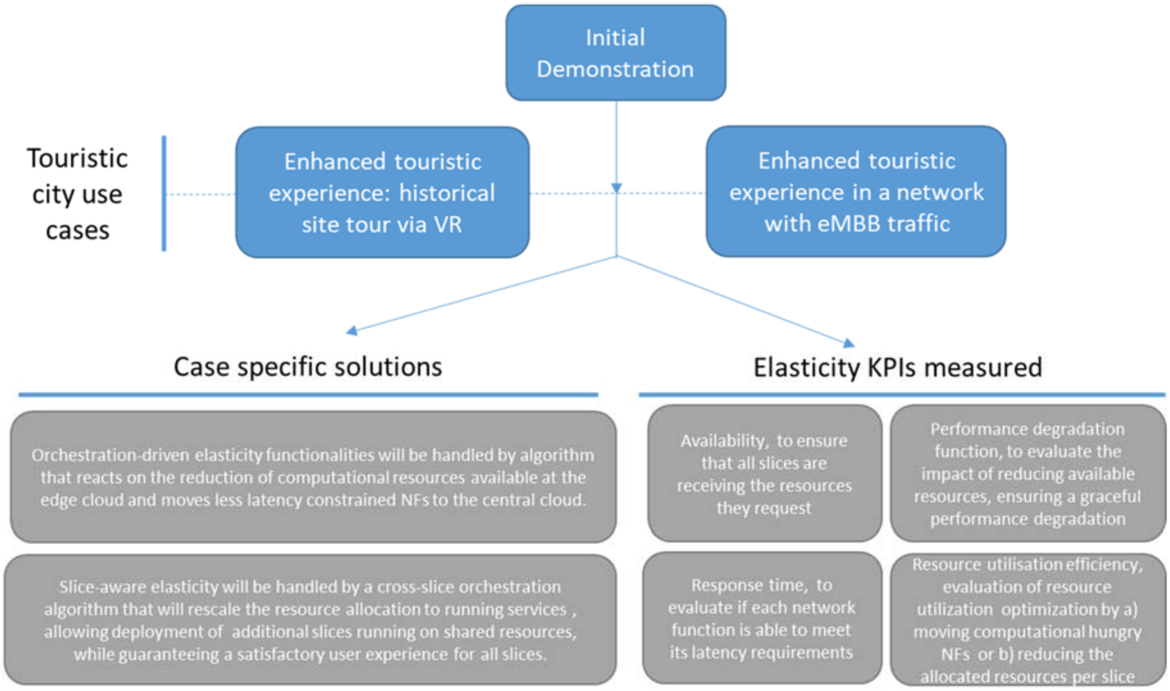

Figure 5-2: Touristic city used cases, specific testbed solutions and KPIs that will be measured

5.3 Techno-economic verification – commercial and social benefits assessment for the 5G-MoNArch ECs

As described earlier, the techno-economic analysis fits into the overall verification framework of 5G-MoNArch by assessing the business case for a baseline 5G system in each of the three ECs and then comparing this with when the 5G-MoNArch innovations and enablers are introduced. In each case, this analysis is done by quantifying and combining:

- Revenues and social benefits – This includes identifying opportunities for 5G-MoNArch to improve the stakeholder experience of existing services or to deliver new services beyond today's networks. This may increase willingness to pay and hence increase existing revenue streams, unlock new revenue streams via new services and/or deliver social benefits.
- Network costs – This includes understanding the existing infrastructure, deployment approaches, migration strategies and the impact of 5G-MoNArch enablers on network equipment in the targeted ECs. Some enablers may have a cost penalty but enable new services and revenues, such as those enabling higher reliability. Other enablers may deliver cost efficiencies, such as those related to resource elasticity.

This section focuses on the first of the above bullet points. It presents work to date on determining revenues and social benefits related to the three ECs and covers:

- EC1 - The localised ecosystem that exists in Hamburg sea port and the potential for mobile services to generate value in this ecosystem.
- EC2 - An exploration of the types of ecosystem that emerges from using immersive technologies to enhance visitor experience to cities and venues and generating demand hotspots.
- EC3 - A review of the value generated by smart city services (based on the framework already used in 5G NORMA [5GM-D23]).
- All ECs - A review of the framework used in 5G NORMA for assessing social value against current state of the art

5.3.1 The existing ecosystem in the Hamburg sea port and the potential for value generation via new mobile services

Large ports involve a diverse set of organisations and operational activities. They require major investments in infrastructure and there is fierce competition between ports to capture hinterland trade. The efficiency of these activities depends heavily on operational data to optimise cargo flow through the port area. Wireless technologies are already used in the Hamburg port area for telemetry and private mobile radio. However, for the most important communications functions fixed links are implemented.

5G-MoNArch technology has the potential to provide secure, resilient, flexible and high-speed communications with extremely high reliability. The provisioning of such an enhanced wireless network allows the rapid deployment of new systems and the ability to trial new services on a localised basis in a cost-effective manner. Network slicing allows optimised operations to meet the specific needs of the port authority and their tenants. In this section the existing ecosystem in the Hamburg port is described, and it is highlighted how the 5G-MoNArch technology and the new services it enables can generate value for this environment.

HPA is the owner of the Hamburg port ground, and is responsible for maritime traffic within the Hamburg port area being considered in the 5G-MoNArch verification scenario underlying all three ECs. However, there are many other organisations that use the port, and 945 such organisations are listed on HPA's website. In general, these are concerned with handling cargo within the port, the transport of goods by sea and land, sales and administration, and companies that support port operations.

The types of organisation operating in the port are provided in Table 5-3. The organisations that potentially benefit most from 5G-MoNArch technology are those concerned directly with the handling of cargo and passengers in the port. These are from the warehousing and logistics, handling, carrier and cargo service categories. However, also other individual service organisations can benefit where they provide services to HPA or support construction projects across the port area.

Table 5-3: Organisation types active within the port of Hamburg (Source: HPA website)

Warehousing and Logistics	**Handling**	**Carrier**	**Cargo Services**
Container (Depot) Container (CFS) General Cargo Bulk Cargo Temperature controlled Dangerous Cargo	Container Bulk Cargo Liquid Cargo Multi-purpose Passenger Container (Inland)	Liner Agent Railway Truck Barge Forwarding Agent	Packaging Stevedoring & Lashing Tally Container Custom Clearance Foodstuff
Marine Services	**Knowledge and Consulting**	**Finance and Trading**	**Other Suppliers**
Ship Suppliers Pest Control Nautical technology Tug & Mooring Shipyards & Repair Ship-owners	Education Further Education Research Consulting IT Service	Logistics Real Estate Finance and Insurance Container Leasing Trading & Renting	Marketing and PR Railway Services Manufacturer Health & Social Care

Another major stakeholder in the port ecosystem is the City of Hamburg. It contributes funding to HPA and benefits from the economic activity of the port. The road and rail network in the port is integrated within the wider city's transport system and the city is responsible for traffic control across the port area.

There is the opportunity for HPA to play a major role in the provisioning of 5G services in the port environment as shown in Figure 5-3. As a tenant, HPA could provide communications services optimised for its tenants using the port area as well as supporting its own port management activities. This at least requires investment in the development of infrastructure that supports network slicing in the port area. However, additional investment is required to develop the according applications to support the vertical's precise business needs. Complex applications require customised user terminals or automation controllers, analysis and control software and a database with Application Programmable Interfaces (API) for global cargo scheduling and asset management systems.

Given the potentially large scale of investment and specialist expertise required, there are other investment structures that could be applied. For example, the end customer organisations can invest directly in application development and they can also choose to develop their own network slice agreements or implement part of the network slices that they use. However, in this case, HPA can act as a catalyst for development in particular if several end customer organisations share a network slice. Further information on port operations and the existing value flows within this ecosystem supporting the findings here are given in the Appendices A.1.2 and A.1.3.

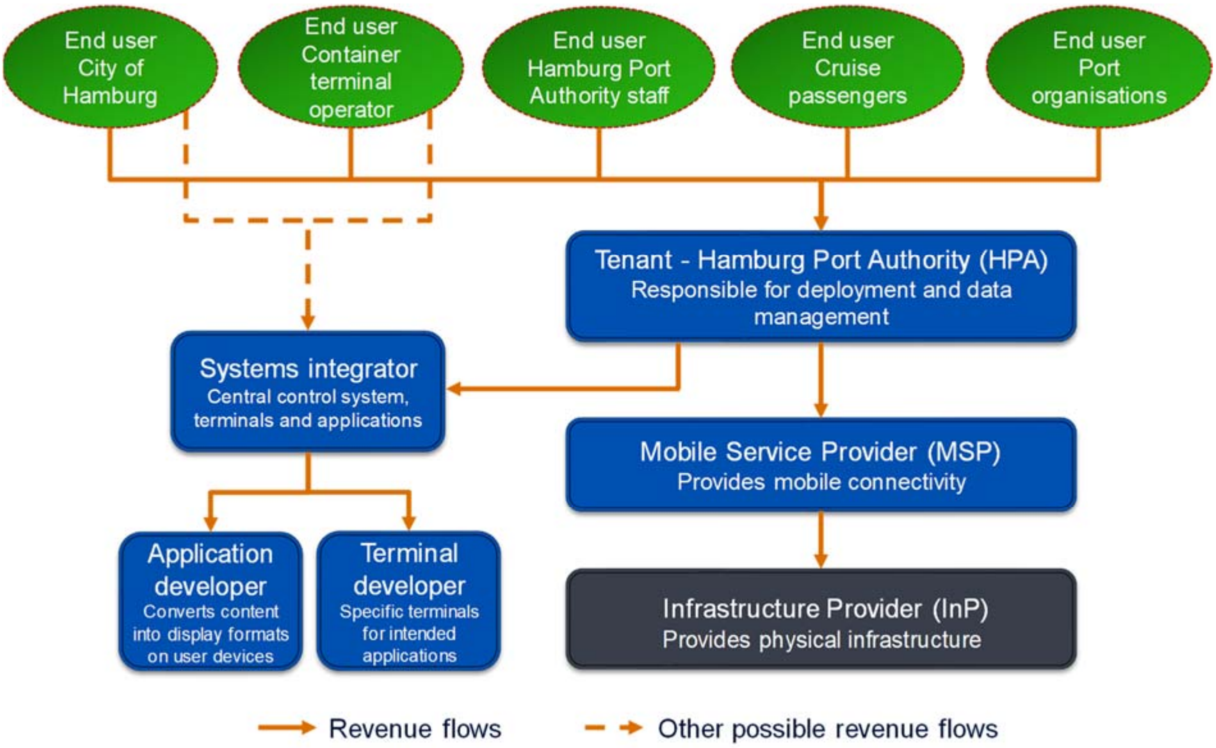

Figure 5-3: Possible players and payment flows in the Smart Sea Port ecosystem

Based on input from HPA, a set of target mobile services for use in a Smart Sea Port environment have been captured (see Section 4.1.2 with further service descriptions in Appendix A.1.1). As outlined earlier, these will be used as the basis for technical and economic verification of 5G-MoNArch under EC1 in particular. Appendix A.1.4 examines the potential benefits from 5G-MoNArch for each of these services with initial thinking on monetising these benefits in A.1.5. The findings from this analysis are summarised on Table 5-4 in terms of the key factors impacting the benefit that can be delivered by each of the envisaged services under 5G-MoNArch and the information that will be targeted in next steps to quantify these.

Table 5-4: Business drivers and information required for assessment of economic benefits

Service	Business drivers	Information required
Enhanced traffic control	Volume of traffic in port area Numbers of control points, monitoring points and secure cameras Efficiency of traffic flow through the port	What are typical vehicle movements within the port in terms of volume and average journey times? What traffic levels are experienced across the city of Hamburg? How many control points, monitoring points and CCTV cameras are there in the port traffic management system? How is traffic control infrastructure connected currently? What impacts do incidents and construction work have on the efficiency of traffic flow?
Automated vehicles and cargo handling	Scale of potential port automation projects Costs of communications elements of a typical automation project Benefits of standardised 5G technology compared to proprietary alternatives	How many containers and what volumes of other cargo are handled by the various terminals at the Port of Hamburg? What improvements in efficiency and capacity can be achieved through automation? What KPIs are appropriate for container handling? What degree of automation is feasible at smaller terminals and non-container terminals?
Environmental monitoring	Scale of deployment to achieve monitoring and identification of sources General benefits of pollution control Costs of monitoring equipment	What types of sensor may potentially be deployed? How many sensors may be needed to effectively monitor the environment? Where would sensors need to be located? What is the potential for identifying sources of pollution?
Augmented Reality (AR) for site maintenance and monitoring	Number and scale of construction projects undertaken each year Degree and causes of potential overruns Number of inspection/maintenance teams performing inspections Cost of AR solution	What extent of construction work is undertaken typically across the port area in each year? What is the value of this construction work and what is the impact of potential overruns? What time savings may be obtained from use of AR technology? What hardware/software is required for a practical AR based inspection system?
Enhanced Mobile Broadband (eMBB) services	Number of passengers and staff Volume of usage Types and volume of assets that can be tracked in the port area	How many passengers use the Hamburg Cruise terminal each year? What is the greatest concentration of passengers that can be experienced at one time? How many staff works in the port of Hamburg? Broken down into HPA employees and others? What assets can be tracked within the port area?

5.3.2 Emerging ecosystems for immersive technologies to enhance visitor experience to cities and venues and generating demand hotspots

The Touristic City testbed in 5G-MoNArch delivers a specific instantiation of a VR (virtual reality) service in a museum alongside changing and challenging eMBB traffic levels as part of a multi-slice scenario to demonstrate the potential for resource elasticity in a cloud-based, virtualised 5G network architecture.

The economic analysis for the verification process needs to take a broader view than just this testbed scenario because due to practical reasons the testbed is limited in terms of:

- The area that it can demonstrate extreme service delivery and network elasticity in. This is limited to a single museum room in the testbed, but for economic verification it is important to understand how network elasticity contributes to cost benefits in a more commercial, real deployment across a wider area, to include more users and better opportunities for spatial diversity of traffic. This is covered by the evaluation scenarios described earlier, and EC2 in particular, where the benefits of network elasticity are assessed in the context of supporting temporal demand hotspots in the Hamburg sea port area from passengers arriving at the cruise terminal.

- The range of services and applications that can be demonstrated. While an immersive VR experience for a museum visitor is central to the testbed demonstration, for economic verification it is looked at how this capability to support extreme low latency AR (augmented reality) and VR services on the 5G-MoNArch network are applicable and beneficial beyond the testbed use case.

In this section the applicability of advanced 5G wireless services is examined, such as VR, AR and mixed reality[1], to the tourism industry and venues to understand the potential ecosystem and benefits that can be generated if the capabilities of the Turin Touristic City testbed were to be applied to a wider touristic city environment. Within this analysis the aim is to understand the potential benefits that can be generated by making the investment in serving demand hotspots generated by extreme but short-term clusters of users and/or extreme service requirements. This supports the analysis in EC2 by showing whether the cost efficiencies delivered by resource elasticity would be enough to unlock the emerging ecosystems and benefits of some example demand hotspots.

5G services are suitable in several different tourism and venue contexts such as:

- VR can be used in tourist sites to allow users enjoying an immersive experience in a safe, controlled environment such as an area dedicated to VR inside a museum. VR experiences have also taken place in outdoor areas with security limits (as evidenced by Bristol University's 2018 5G weekend which took place in the city of Bristol's Millennium Square [Wat18]). Purpose built spaces can also be developed for VR-based commercial entertainment, which are likely to become tourist attractions in a similar way as theme parks and funfairs are today. The availability of a multi-service 5G network reduces the investment costs and risks of ideas (compared to having to deploy a proprietary network) and stimulate innovation.
- AR and mixed reality can be used for enriching tourism outdoors, for example showing ancient sites as they looked in their prime, adding historical characters to city tours or providing information of the historical background of interesting locations around the city. AR is much more suitable for outdoor use than VR since it can be viewed in parallel with the tourist's actual surroundings as opposed to VR, which requires a controlled space for safety reasons. Guided tours are one element of tourism which can benefit from these types of application.
- AR can be used at entertainment venues such as sports stadiums and concert arenas, by providing contextual information (text, images and video) or replays of sporting action etc.
- Other 5G services such as enhanced mobile broadband will support tourism by enabling visitors to access information in conjunction with their visit. The use of massive machine type communications in intelligent transport services improve the visitor experience through smart parking, bicycle share schemes, better public transport and traffic management services.

A review of how VR and AR is currently used by tourist attractions and venues is given in appendix A.2.1.

Figure 5-4 below presents the initial thoughts on the players that benefit from providing tourism services using AR and VR, as an initial example of applications with the potential to generate demand hotspots. The arrows indicate the direction of payments and revenue flows between the players. For completeness it shows the infrastructure provider (InP) at the bottom of the chain, however, the focus is on the interactions from the MSP upwards as this is where the biggest uncertainty and the highest potential for new relationships expected.

[1] Mixed reality is the latest development in this space and encompasses placing virtual content in the physical world such as Microsoft's HoloLens and incorporating real world objects into a virtual experience. The 5G Smart Tourism testbed in the West of England is planning to deploy this through virtual characters appearing in city guides in Bath and Bristol.

End users *could* have relationships with a number of different players as displayed in this diagram, including venue owners; VR/AR platform providers; tourism application providers and MSPs. This leads to a more complex market form, called a two-sided (or multi-sided) market. This is where a customer has a relationship with more than one producer of goods or services (e.g., advertisers pay a television company to place their adverts in front of viewers, and the television company provides programmes to the viewers for free). There are many different models, for example, the customer pays one or both producers or pays nothing at all (though having access to the customer or its personal information may have a value in itself). One implication of this is that payments flow either way between different of service providers, depending on who has the financial relationship with the consumer.

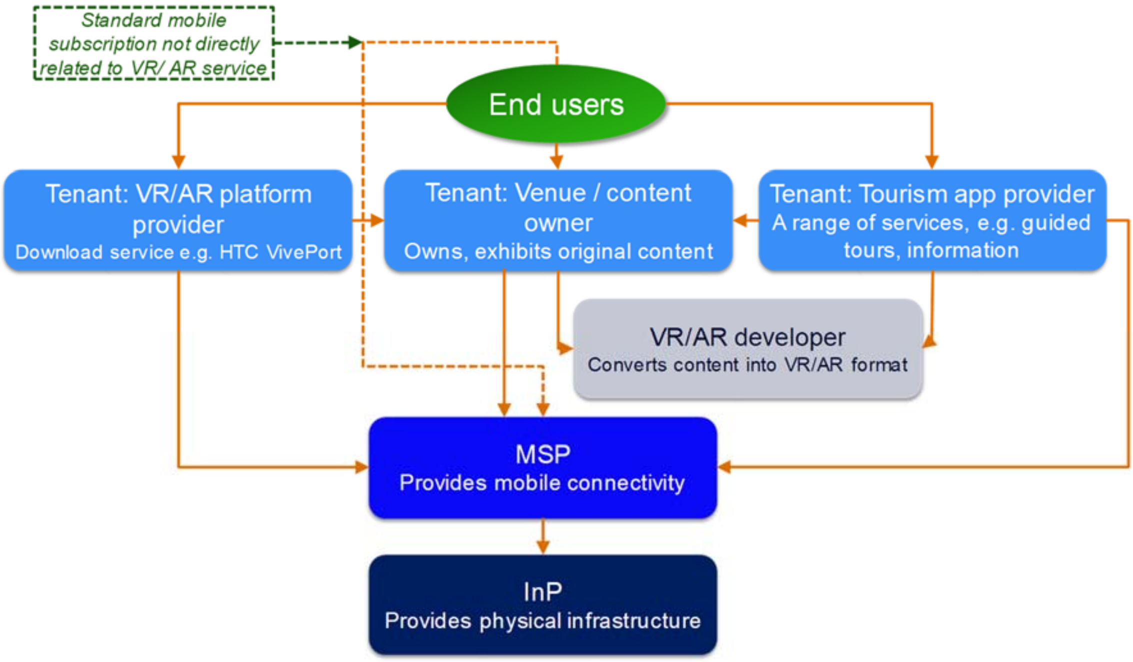

Figure 5-4: Possible players and payment flows in the Touristic City eco-system

The venue / content owner is for example a museum, as in the Turin Touristic City testbed, but it can also be an entertainment venue, a sports stadium, a local tourism authority or a tour company. This player works together with a content developer to transform and enhance the original content into a VR/AR format. The venue / content owner can be customer of an MSP if it provides end users with the equipment to access the VR / AR experience. Alternatively, end-users can access the service on their own devices. Finally, consumers can get the content on the venue site, or use – independently of the venue – a VR/AR platform provider[2] or a third-party app provider to get access to the content from home.

The VR/AR developer typically works with the owner of the original content. Some larger developers may seek to establish joint ventures with content owners particularly if the developer is also creating unique facilities for a VR/AR installation which may represent a significant investment.

Tourism app providers may or may not be present in an actual market. If they are present they can aggregate VR and AR experiences across a number of different venues in the city. They can even provide services on behalf of municipal authorities. Tourism app providers can also create services on their own, for example guided tours enhanced with AR. The app then generates revenue through a charge to end-users or by advertising.

[2] The VR/AR platform provider is separate from the Touristic City in that it enables the VR experience to be enjoyed away from the city. However, it is part of the eco-system because it shares the same content.

Finally, the MSP can have a relationship with venue /content owners, tourism app providers, and of course directly with the end user. MSPs can thereby provide connectivity services to any or all of these players. MSPs can also consider other roles in this market (e.g. providing tourism applications) perhaps as part of a bundle of services for consumers, though this may be outside their core area of capability.

A hypothetical example of the above eco-system is given in the Appendix A.2.2 with potential charging mechanisms examined in A.2.3. Overall the charging mechanisms for such immersive services are still emerging and very scenario specific. For example, in the case of a Touristic City, the ability to monetise these services may be limited but the ability to generate economic value for the city could be high by making it more competitive against other touristic cities. This indicates the need for public private partnerships to maximise the social and wider economic benefits, by investing in infrastructure that would not be deployed if purely a commercial perspective is taken. However, for more commercial venues, the route to monetisation of these services and a positive business case for investing in networks to serve the subsequent demand hotspots is clearly visible.

Given that the benefits of these services and demand hotspots are very scenario specific, the next step in developing this analysis is to devise some scenarios for demand hotspot services and user behaviour and to connect these with the ECs. These will cover a high-level segmentation of the market, e.g., cruise ship terminals, sports stadiums, concert venues, museums and outdoor applications. Scenarios for potential service take-up and usage also need to be devised, as well as a limited number of revenue models, e.g. fee-based access, advertising funded, or expanded visitor numbers.

Even a small share of the revenues of the wider tourism and entertainment events sectors can be quite substantial for MSPs. While UK mobile communications revenues reached £15.3 billion in 2015 [Ofc17] the tourism sector is particularly large with an estimated value for domestic and international tourism in the UK of £102.8 billion in 2015 [Tou17]. Expenditure on sporting and musical events in the UK was at a different order of magnitude but still substantial at £5.1 billion in 2015. [Eve15].

5.3.3 A review of the value generated by smart city services

Smart (or intelligent) cities are a very important part of the landscape for the Internet of Things (IoT) and 5G services. Worldwide, cities are becoming larger and more densely populated. Rapid growth is creating a strain on existing facilities and can generate unwelcome side-effects such as greater pollution and waste production. Added to wider issues such as the need to reduce greenhouse gases emissions, cities face a raft of unprecedented challenges. Technology offers a means to help cities meet these challenges including: more efficient and/or alternative ways to manage local amenities, infrastructure and services; the potential to engineer changes in how inhabitants and visitors use local amenities to improve the quality of life in the city; and empowering citizens by providing open access where possible to smart city information hence giving the citizen a say in their interaction with the intelligent city.

Many cities around the world have already launched smart city initiatives using current technology and 5G promises to open up even more opportunities. This area of the role of 5G in delivering smart city services and related benefits is considered as part of EC3. Here the 5G-MoNArch architecture and its enablers will be assessed in terms delivering an expanded mix of services to a wider range of tenants to understand economies of scale and scope in 5G-MoNArch networks and its enablers. Part of this objective includes understanding the impact on the wider city of improving operations in the port area and synergies in benefits obtained by delivering improved mobile connectivity to different tenants in the same geographic region.

5G NORMA, the predecessor project to 5G-MoNArch, made an initial analysis of smart cities based on these initiatives. Developments continue apace, new applications emerge, and more are likely to emerge in the future, particularly as the capabilities of wireless networks improve. Since it is difficult to predict these uncertain, future smart city services, 5G-MoNArch focuses on the key developments and leading services that are seen in smart cities already today.

An investigation of the supporting eco-system or value chain for smart cities and the relationships between the key service providers within it have been reviewed against the existing 5G NORMA framework and presented in Section A.3. From this review it can be concluded that the smart city analysis carried out in 5G NORMA continues to be a solid basis for assessing the potential economic impact of smart city services. Although this approach was not comprehensive in terms of covering all smart city services, it covered the services which appear to carry the best economic potential. 5G-MoNArch continues to review this conclusion as the smart city concept continues to develop in the real world during the remainder of the project.

Synergies between smart city services will add value to the business case for cities and for service providers. The quantitative impact of these synergies is difficult to predict. However, as the project progresses, synergies between smart city services and some of the services envisaged in the Hamburg Smart Sea Port will be examined. For example, environmental monitoring and intelligent transport systems are services envisaged for both the Smart Sea Port and smart city tenants.

5.3.4 A framework for assessing social value

While the commercial business case for 5G networks and services is key if the deployment of 5G networks is to be driven by market mechanisms, it is also important to understand less tangible social value generation. This is needed particularly in case where the commercial assessment reveals risk and uncertainty, and there can be a case for public private partnerships to ensure that the maximum benefits in a commercial and wider economic sense are not lost. This is particularly relevant in an environment of increasing network infrastructure and sharing consolidation and the new deployment models made possible by more virtualised networks. Social value will be applicable therefore to all three ECs outlined but in particular to EC3 where smart city services and synergies between benefits generated by delivering improved mobile services to a range of tenants in a city environment are considered.

The aim of this section is to produce a framework for assessing social value based on previous research and international best practice. In Appendix A.4 the approach is reviewed that was taken to measuring wider economic and social value in first phase of 5G-PPP projects, and in particular the 5G NORMA project. Furthermore, the literature on regulatory approaches has been reviewed, to measure social value and summarise what can be considered to be best practice and leading academic research in this area. Based on this review the proposal is to follow the same general approach as recommended in the UK and US guidelines on public policy appraisal, to assess socio-economic benefits in this study.

The table below sets out the categories under which socio-economic benefits are identified for each of the 5G services relevant to 5G-MoNArch, and it illustrates how the approach would work by giving an initial assessment of the potential sources of benefit in each case.

Table 5-5: Illustration of potential social benefits

	Social & environmental capital	**Social benefits**	**Environmental benefits**	**External effects**
Intelligent Transport System	City centres are more attractive as have less vehicle traffic and are easier to navigate.	Facilitates cycling bringing public health benefits Road users feel safer due to better accident response capability.	Reduces CO2 emissions due to better traffic management. Public transport is more effective also reducing CO2 emissions. Reduces air pollution.	Shorter journey times for all transport modes. Smart parking increases road capacity for other users.
Smart energy			Reduces CO2 emissions	May boost e-vehicles by helping electricity grids to manage new patterns of energy demand.
Smart water and waste		Water quality is higher due to better monitoring.	Smart bin tech reduces recycling costs leading to more recycling.	

Environmental monitoring		Public feels more secure with better warnings of and response to environmental disasters.	Improves identification and strategic response to pollution etc.	
Touristic city	Makes cultural heritage available to more people (e.g. if access is difficult for some or all society).			More business for restaurants, hotels and bars if more tourism.
Hamburg Port Authority services		Road users feel safer due to better accident response capability. Public feels more secure as hazardous goods can be handled more safely and tracked.	Reduces CO2 emissions due to better traffic management. Better traffic management and environmental monitoring combine to reduce air and waterway pollution.	Shorter journey times for all transport modes due to better routeing of traffic and management of loading / unloading.

6 Steps towards 5G-MoNArch validation

In addition to conducting the verification and evaluation activities described in the previous chapters, the 5G-MoNArch project also intends to conduct activities to validate that the features provided by the architecture satisfy the requirements of the different stakeholders. This chapter reports on the progress of such *validation* activities. Specifically, the validation activities conducted up to date involve verticals, industry fora, vendors and technical community like operators, chipset and device manufactures as well as VNF providers.

6.1 Validation with verticals and industry fora

A self-evident course of action was to first contact groups in the project environment and collect information that is publicly available. This includes:

- Interactions with consortium partners involved in the testbed scenarios to understand the service set (including those beyond the example cases given on the testbeds) and potential business models that are of interest in these environments.
- Interactions with the 5G-MoNArch advisory board and other industry groups to understand requirements for 5G services.
- A review of user requirements from public sources, events and informal discussions.

6.1.1 Feedback on service definitions and ecosystems in the testbed scenarios

Discussions have taken place with Hamburg Port Authority to understand the requirements of an industrial user of 5G services and potential business models for delivering these. The services identified from these discussions have been captured and specified in Section 4.1.2 with these further elaborated upon in terms of the stakeholder groups making use of these services and the drivers for introducing them (i.e. potential for value generation) given in Section 5.3.1.

Similarly, there have been discussions held with the partners involved in the Turin Touristic City testbed to define the services being demonstrated there and further elaborate on scenarios where immersive technologies such as mobile AR or other 5G services can help to generate value and benefit in Touristic City scenarios. The service definitions developed from these discussions are given in Section 4.1.1 with these services and the potential stakeholders involved in delivering them in the context of a Touristic City environment given in Section 5.3.2.

6.1.2 Advisory board and GSMA input

The 5G-MoNArch project includes an advisory board of industry stakeholders to give feedback on the project direction and findings. A teleconference meeting was held with the advisory board during March 2018 with the following feedback related to end user requirements raised:

- Some services such as vehicle services will require interoperability across international boundaries. 5G-MoNArch should therefore consider harmonisation of slice blueprints and slice roaming in use cases such as these.
- Many industrial mobile services are safety or operationally critical and have severe implications if not delivered at the required level of service reliability. It will take time for industry to build trust that mobile networks can deliver such service levels. Building this trust will involve showing real deployments delivering 100% safe solutions. This is particularly true for applications such as automation.
- 5G-MoNArch should monitor and align with on-going standardisation in bodies such as 3GPP and review existing Intellectual Property Rights (IPRs) to ensure open and interoperable network solutions.

Additionally, GSMA have undertaken a study which has involved interviewing different industry groups to collect user requirements for 5G services. Two teleconferences were set up between GSMA and the 5G-MoNArch to help with sharing of user requirements between the two projects. Generally, there was alignment on user requirements but with the following additional points raised by the GSMA work:

- Global slice blueprints to allow for roaming of network slicing across regional and international boundaries.
- A requirement for high levels of periodicity and synchronisation in the delivery of signalling for automation services in particular.

6.1.3 User requirements from 5G public sources and discussions

Examining public sources for user requirements and drivers for mobile services show that for today's consumers of mobile networks price is a key driver and more important than coverage or data rates. This is shown by consumer surveys such as those reported by which in the UK [TR18] showing low priced Mobile Virtual Network Operators (MVNOs) delivering high satisfaction ratings and much higher than those of the main MNOs. Therefore, the most immediate requirement on today's mobile networks appears to be delivering existing services more cost effectively as opposed to delivering new eMBB services such as immersive experiences. This needs to be done against the back drop of also finding business models and partnerships to deliver improvements to mobile coverage and to introduce Internet of Things (IoT) services for applications such as smart cities to unlock the fuller extent of social benefits possible from mobile services.

In the medium term, the transition of MBB services to a utility like service in consumers' minds and the on-going risk to the commercial viability of delivering MBB services alone that this brings makes engagement with industrial users of mobile services more attractive for MNOs. However, discussions with industrial stakeholders indicate that existing wireless solutions are enough to meet their current requirements for wireless. Additionally, while there is interest in extending the range of wireless services used in industrial settings the following key challenges have been highlighted:

- Industrial users need to build trust in wireless solutions before implementing them due to the critical safety and operational nature of them. They therefore typically make use of wireless solutions that are already relatively mature and proven in real deployments.
- Industrial settings and, in particular manufacturing facilities, have long procurement and deployment cycles. Therefore, it takes time to introduce new technologies.

Engaging with and delivering industrial services is hence seen as a medium-term requirement of users.

Longer term mobile services can include extreme services such as those required by immersive technologies like mobile AR, VR and mixed reality. Interest in these services is certainly growing and expanding to sectors much wider than the gaming industry as shown by Figure 6-1.

However, existing wireless technology does not appear to be a limiting factor for developments in this industry currently making this a longer-term requirement for mobile services. Discussions with venue owners who are interested in using immersive technology solutions in the future also indicate that, while there is interest in these services in the long term, there are more short-term issues that are desirable to address first such as mobile capacity issues in and around venues during large events.

6.2 Validation with vendors and technical community

The second part of the validation action was on collecting non-public information from vendors and the technical community, i.e., stakeholders implementing or using the 5G-MoNArch technologies. More specifically, stakeholders can belong to one or more of the following categories [5GM-D21]:

- Mobile Service Provider (MSP): Is responsible to provide mobile internet connectivity and telecommunication services to either end users directly or via an intermediate "tenant".
- Tenant: Usually a business entity, buys and leverages a 5G-MoNArch network slice and services provided by the MSP.
- Infrastructure Provider (InP): Belongs to an entity or company that owns and manages infrastructure of the network under consideration. (e.g. antenna site infrastructure provider, transport network provider, data centre service provider).
- Mobile Network Operator (MNO): Belongs to an entity that operates and owns the mobile network and integrates the role of MSP and INP.

- Virtualisation Infrastructure Service Provider (VISP): Belongs to an entity that designs, builds and operates its virtualisation infrastructure and offer it to MSP.
- HW supplier: Is responsible to provide hardware to the Infrastructure Providers (e.g. server, antenna, cable, etc.).
- Network Function Virtualisation Infrastructure (NFVI) supplier: Is responsible to provide Network Function Virtualisation infrastructure to Virtualisation Infrastructure Service Providers or to Mobile service providers.
- Virtual Network Function (VNF) supplier: Is responsible to provide virtualised software components to Mobile service providers.

Industry	Value share (next 5 years)	Dominant technology	Transformational use case
Video Games	30 - 35%	VR	Heighten the gaming experience by transporting gamers onto the playing field, allowing users to explore new "illusory" environments
Healthcare	10 - 15%	AR/VR	Boost medical training procedures and enhance physical therapy treatment options for doctors to speed up the process of rehabilitation
Engineering	10 - 15%	AR/VR	Equip engineers to test scenarios and designs before products are manufactured, allowing rapid prototyping, enhanced productivity and reduced costs
Live Events	10 - 15%	VR	Enable people to watch and experience live events from the comfort of their homes, solving the problem of limited seating
Video Entertainment	5 - 10%	VR	Present the story in a VR format captivating the audience with its immersive potential
Real Estate	5 - 10%	VR	Allow people to visualise their dream homes and view show flats without being physically present
Retail	5 - 10%	AR/VR	Revolutionise the way people shop by elevating the shopping experience and strengthening the emotional connection to a brand or product
Military	1 - 5%	VR	Create large scale simulation environments to train recruits and optimise operations, while removing the element of danger
Education	1 - 5%	AR/VR	Stimulate the senses to help people understand and learn faster, providing an interactive way to gain knowledge

Figure 6-1: Selected use cases for virtual, augmented and mixed reality. Source: Delta Partners [DP18]

To address these communities, a questionnaire has been set up by the project, with the intention to provide this to the respective members of the community. Since stakeholders come from different interest groups, companies and organisation, they are expected to perceive different objectives and benefits.

The questionnaire that will be used to poll stakeholder's opinion corresponding to the projects' innovation elements. The questionnaire template provided in Annex B includes both general and technical questions. 5G-MoNArch introduces five key innovations in the context of 5G networks while additionally providing, a detailed overview of 5G architectural gaps and the enabling and functional innovations proposed to cover these gaps. The list of the observed gaps, shown in Table 6-1 and the list of the innovation elements that correspond to each enabling innovation, shown in Table 6-2, set the basis for the design of the stakeholder questionnaire.

Table 6-1: List of observed gaps [5GM –D21]

Gap	Description
GAP #1	Inter-dependencies between Network Functions co-located in the same node
GAP #2	Orchestration-driven elasticity not supported
GAP #3	Fixed functional operation of small cells
GAP #4	Need for support for computational offloading
GAP #5	Need for support for telco grade performance (e.g. low latency, high performance, scalability)
GAP #6	E2E cross-slice optimisation not fully supported
GAP #7	Lack of experiment-based E2E resource management for VNFs
GAP #8	Lack of a refined 5G security architecture design
GAP #9	Lack of a self-adaptive and slice-aware model for security
GAP #10	Need for enhanced and inherent support for RAN reliability
GAP #11	Indirect and rudimentary support of telco cloud resilience mainly through management and control mechanisms
GAP #12	Need for (radio) resource sharing strategy for network slices

Table 6-2: List of innovation elements [5GM –D21]

5G-MoNArch innovations	Innovation elements
Cloud enabled protocol stack	Telco cloud – aware protocol design
	Terminal – aware protocol design
Inter-slice control and management	Inter-slice context aware Optimisation
	Slice aware Functional Operation
	Inter-slice resource management
	Terminal analytics driven slice selection/control
	Inter-slice Management & Orchestration framework
Experiment Driven Optimisation	E2E management of computational storage and networking resources consumed by VNFs
Secure and resilient network functions	Multi-connectivity and network coding for improving the RAN reliability
	Enhancements in telco cloud resilience through improved failsafe mechanisms and fault management
	Flexible security monitoring and detection algorithms
	Secure exchange of threat intelligence
	Self – adaptive deployment model
Resource elastic virtual functions	Elastic functions redesign
	Elastic NF scaling mechanism
	MANO elastic orchestration mechanism
	ISRB for handing elastic network slices

The questionnaire is composed of three parts. Each of these parts will be described in this section while an initial draft of the questionnaire can be found in Appendix B.

- Part A of the questionnaire aims to extract demographic information about stakeholders maintaining their anonymity. Each Stakeholder is expected to belong in one or more of the categories described. The primary purpose of this part is the categorisation of stakeholders into different sub-groups. The classification is necessary as different categories are expected to have different needs and expected benefits. Moreover, a clear separation of classes will allow in future analysis to check if any correlation between the needs of stakeholders who belong to different categories exists.
- Part B of the questionnaire consists of a System Usability Scale (SUS) based questionnaire that measures the usability of the results of innovations and beyond that technical questions. Under this consideration, theoretical concepts (e.g., usability) can directly be quantified, together with gaining information on stakeholders' opinions. More specifically, Part B.1 contains seventeen 5-point Likert scale questions. Stakeholders are asked to express their opinion, choosing an answer from strongly agree to strongly disagree, with regard to how useful the innovations elements are to their requirements. Part B.2 consists of ten 5-point Likert scale questions based on the SUS Questionnaire [Bro96]. The SUS has become an industry standard, with references in over thousand articles and publications. Among its advantages are the following:
    - It is a very easy scale to administer to participants.
    - Can be reliably used on small sample sizes.
    - SUS's validity has been extensively tested, meaning it can effectively differentiate between usable and unusable systems.

  The Stakeholder's responses for the B.2 part will be converted to a number as follow: they added together and then multiplied by 2.5, to convert the original scores from the range of 0-40 to 0-100. Though the scores are between 0 and 100, these are not percentages and should be considered only in terms of their percentile ranking. Based on research, a SUS score above a 68 would be considered above average [BKM09], however the best way to interpret results involves "normalising" the scores to produce a percentile ranking. The SUS questionnaire as part of the questionnaire will provide information about stakeholders' opinion regarding the usability of the results of the innovation elements.
- Part C contains seven open-ended questions. Open-ended questions aim to enrich the results obtained from Stakeholders. Based on Stakeholder's answers, the expectation is to derive new information and expressed needs that may be omitted from the usage of close-ended questions. More specific the issues that addressed by open-ended questions are to identify stakeholder's opinion and needs regarding how essential are innovations, such as the Telco cloud – aware protocol. Moreover, the open-ended questions aim to motivate stakeholders to express their needs and demands regarding the cloud-enabled protocol stack, the inter-slice control and management, the experiment-driven optimisation, the secure - resilient network functions and the resource-elastic virtual functions.

7 Summary

This document has focused on (i) the methodology designed for verification and validation of the 5G-MoNArch architectural innovations, and (ii) the first steps that have been taken towards the realisation of such evaluation and validation activities.

The key objective of WP6 is to verify in a quantitative and qualitative manner that the envisaged innovations are technically and economically feasible (***verification***) and at the same time fit to stakeholder needs (***validation***).

The verification conducted by 5G-MoNArch is an interactive process that has to be performed in close collaboration with the technical work packages and the testbed activities. The quantitative verification will include enabler specific verification from the technical work packages, measurement results from the testbeds as well as output from network-level simulations integrating multiple enablers. The latter results will be based on a verification scenario that has been defined in Hamburg and will ensure that all evaluations including techno-economic considerations are based on the same assumptions and scenario.

The verification methodology adopted by the project has been described in Chapter 3. It includes (i) a selection of KPIs, (ii) the definition of verification elements within the proposed framework, (ii) a collection all the information and assumptions to specify the verification scenario.

To conduct the desired verification, the project has identified the following three ECs which cover the key functionalities provided by 5G-MoNArch:

- EC1: Resilient network slices for industrial applications.
- EC2: Elastic network slices enabling local peak performance.
- EC3: Integration of resilient and elastic slices into smart city environments.

The instantiation of the verification elements for the above ECs is ongoing. Chapter 4 reports on the current status of this work. The services definitions for the above use cases have been completely specified. Furthermore, the following three verification scenarios have been identified and are being specified:

- One of the verification scenarios will be an area within the city of Hamburg that comprises the sea port as well as other parts of the city; this verification scenario will be used for the three ECs defined above.
- Another verification scenario will be the Smart Sea Port testbed; the network configurations and assumptions in the testbed will be specified to align the testbed setup with the rest of the verification activities and thus be able to use the testbed measurements within WP6.
- The third verification scenario will be Touristic City testbed in Turin, whose measurements will also be leveraged within WP6.

Building on the above verification scenarios, 5G-MoNArch will evaluate the benefits resulting from the proposed technology. To this end, WP6 has closely collaborated with the technical work packages to select the 5G-MoNArch enablers that will be targeted by the verification activities. The performance provided by these enablers will be compared against performance in baseline deployments comprising 5G networks but excluding enablers.

The verification will be conducted by bringing together the results from the verification tools: (i) the testbeds experiments, (ii) the enabler specific verification performed by the technical WPs, and (iii) the network level simulation results performed by WP6. The methodology proposed, including definition of the evaluation concepts, will allow the integration of all these inputs.

Since it is expected that the results obtained in the verification are highly dependent on the scenario parameters, it is very important to conduct a sensitivity analysis to capture the depending on such parameters. To prepare sensitivity analyses, potential KPI interdependencies have been identified (Section 5.1). A description of relevant testbed activities refers to potential verification input from experiments in the testbeds (Section 5.2).

Along with the verification of the technical KPIs, work has also been performed towards the verification of economic KPIs. To this end, a comprehensive framework for techno-economic verification to assess the impact of the 5G-MoNArch innovations on the business-related KPIs has been provided in Section 5.3. In particular the following topics have been covered:

- The localised ecosystem that exists in the Hamburg sea port and the potential for mobile services to generate value in this ecosystem.
- An exploration of the potential ecosystem for Touristic City services.
- A review of the value generated by smart city services.
- A framework for assessing social value.

Finally, validation is also a crucial activity within the project. This activity will gather feedback from the stakeholders on 5G-MoNArch technology. Validation will focus on the different stakeholder groups' that have already identified. Their feedback will comprise both the technical as well as the techno-economic aspects of the project. The validation activities conducted so far have been summarised in Chapter 6, and include the identification of stakeholder groups and the methodology to gather their feedback.

8 References

[3GPP 22-886] 3GPP, "Study on enhancement of 3GPP support for 5G V2X services", TR 22.886 V15.1.0, Release 15, March 2017.

[3GPP 23-203] 3GPP, "Policy and Charging control architecture", TS 23.203 v15.2.0, Release 15, March 2018.

[5GM-D12] 5G-MoNArch, Deliverable D1.2 "Intermediate Report on Project, Technical and Innovation Management", June 2018

[5GM-D21] 5G-MoNArch, Deliverable D2.1 "Baseline architecture based on 5G-PPP Phase 1 results and gap analysis", October 2017

[5GM-D41] 5G-MoNArch Deliverable D4.1, "Architecture and mechanisms for resource elasticity provisioning", May 2018.

[5GM-D61] 5G-MoNArch Deliverable D6.1, "Documentation of Requirements and KPIs and Definition of Suitable Evaluation Criteria", September 2017.

[5GM-D22] 5G-MoNArch Deliverable D2.2, "Initial overall architecture and concepts for enabling innovations", June 2018

[5GM-D31] 5G-MoNArch Deliverable D3.1, "Initial resilience and security analysis", May 2018

[5GM-D51] 5G-MoNArch Deliverable D5.1, "Testbed setup and 5G-MoNArch technologies demonstrated", August 2018

[5GN-D21] 5G NORMA, "Deliverable D2.1, "Use cases, scenarios and requirements", October 2015

[5GN-D22] 5G NORMA, "Deliverable D2.2, "Evaluation methodology for architecture validation, use case business models and services, initial socio-economic results", August 2016

[5GN-D23] 5G NORMA, "Deliverable D2.3, Evaluation architecture design and socio-economic analysis - final report", December 2017.

[5GN-D33] 5G NORMA, "Deliverable D3.3, 5G NORMA network architecture – Final report", October 2017.

[5GN-D42] 5G NORMA, Deliverable D4.2 "RAN architecture components – Final report", June 2017.

[BCC+15] P. Barwise, M. Cave, P. Culham, T. Lavender, N. Pratt, D. Tambini, "Incorporating Social Value into Spectrum Allocation Decisions", Report for UK DCMS, November 2015, Online available at: https://www.gov.uk/government/publications/incorporating-social-value-into-spectrum-allocation-decisions

[BCC+17] A. Baiocchi, L. Chiaraviglio, F. Cuomo, and V. Salvatore, "Joint Management of Energy Consumption, Maintenance Costs, and User Revenues in Cellular Networks With Sleep Modes", IEEE Transactions on Green Communication Networks,, vol. 1, no. 2, pp. 167–181, June 2017.

[BMK09] A. Bangor, P. Kortum, J. Miller, "Determining Whar Individual SUS Scores Mean: Adding an Adjective Rating Scale", Journal of Usability Studies, 4 (3), pp. 114-123, 2009

[Bro96] J. Brooke, "SUS-A quick and dirty usability scale", Usability evaluation in industry, 189(194),4-7. 1996.

[CG18] Cruise Gate Hamburg, https://www.cruisegate-hamburg.de/en/terminals, visited May 2018.

[Dom18] http://www.turismoroma.it/cosa-fare/progetto-domus-aurea-visite-al-cantiere-di-restauro, visited May 2018

[DP18] Delta Partners, "A new reality awaits: are AR and VR the next big platforms?", January 2018, Online available at: https://www.deltapartnersgroup.com/new-reality-awaits-are-ar-and-vr-next-big-platforms

[Dun18] http://www.storynest.com/pix/_4proj/i_dunhuang2016/p0.php?lang=en, visited May 2018

[Eve15] Events are GREAT Britain, Business Visits & Events Partnership, 2015

[GSMA2016] GSMA, Mobile IoT Industry Alignment Group. (n.d.), "3GPP Low Power Technologies", White paper, Online available at: http://www.gsma.com/connectedliving/wp-content/uploads/2016/10/3GPP-Low-Power-Wide-Area-Technologies-GSMA-White-Paper.pdf

[HHL17] Hamburger Hafen und Logistik, "Annual report 2017"

[HP11] G. Harper and R. Price, "A framework for understanding the social impacts of policy and their effects on wellbeing", DEFRA, April 2011, Online available at: https://www.gov.uk/government/publications/understanding-the-social-impacts-of-policy-and-their-effects-on-wellbeing

[HPA17] HPA, "Road Traffic Report 2016", December 2017

[IEEE2011] IEEE, "IEEE 802.16p Machine-to-Machine (M2M) Evaluation Methodology Document (EMD)", Technical Report IEEE 802.16p-III0014, May 2011

[Mad18] https://ghostbusters.madametussauds.com/, visited May 2018

[Mer10] Olaf Merk, "The competitiveness of global port-cities: Synthesis report", edited by Olaf Merk, OECD 2010.

[MS+14] A.M. Martin-Soberon, A Monfort, R Sapina, N Monterde & D Calduch, "Automation in Port Container Terminals", XI Congresso de Ingenieria del Transporte (CIT) 2014.

[Nomor17] Nomor Reseach GmbH, Online available at: http://www.nomor.de

[OAI] Open air interface Introduction, Online available at: http://www.openairinterface.org/?page_id=864

[Oce18] https://b-com.com/en/news/virtual-dive-oceanopolis, visited May 2018

[Ofc17] Ofcom, "The Communications Market Report 2017", August 2017, Online available at: https://www.ofcom.org.uk/research-and-data/multi-sector-research/cmr/cmr-2017

[Omb03] Office of Management and Budget, US Government, Circular A-4, September 2003, Online available at: https://obamawhitehouse.archives.gov/omb/circulars_a004_a-4/

[PoH18] Port of Hamburg, https://www.hafen-hamburg.de/en/cruise-terminals, visited April 2018.

[RW 12] Real Wireless for Ofcom, „Techniques for increasing the capacity of wireless broadband networks: UK, 2012-2030“, March 2012, Online available at: https://iperf.fr/

[srsLTE] Readme srsLTE, Online available at: https://github.com/srsLTE/srsLTE

[Suk18] Magiczny Krakow, "The Sukiennice Gallery - branch of the National Museum in Krakow", Online available at: http://www.krakow.pl/english/instcbi/43582,inst,13813,1626,instcbi.html

[Tou17] Tourism Alliance, UK Tourism Statistics 2017, Online available at: www.tourismalliance.com/downloads/TA_395_420.pdf

[TR18] The Register, "Bargain-happy Brits snub big four mobile network operators", April 2018, Online available at: https://www.theregister.co.uk/2018/04/24/bargain_happy_brits_snub_big_four_mobile_operators/

[Wat18] Watershed, "Layered Realities Weekend – 5G Showcase", March 2018, Online available at: https://www.watershed.co.uk/5g

A Supporting analysis for value flows and benefits frameworks proposed under the techno-economic modelling

A.1 Hamburg Smart Sea Port – ecosystem, targeted services and potential benefits

This appendix provides supporting information on the potential economic benefits of 5G-MoNArch technology as presented in Chapter 1 for the vertical industry use case of the Hamburg Smart Sea Port as considered in the verification scenario underpinning all ECs but targeted in EC1 in particular. It aims to evaluate the 5G-MoNArch innovations in terms of:

- Setting out opportunities for improvements to relevant stakeholder experience of existing services and the ability to deliver new services beyond today's networks which may increase willingness to pay, unlock new revenue streams and/or deliver social benefits.
- Showing potential to deliver services more cost efficiently than in existing networks.

This analysis has been undertaken in parallel with a practical testbed implementation in the port. The services implemented in the testbed have been chosen to showcase the range of advantages of 5G technology, whereas this economic analysis considers a broader range of services and applications.

A.1.1 Scope of services considered in the Hamburg port area

Current wireless services in the port area

Aside from general use of cellular mobile services by personnel and passengers in the port area, there is limited use of other wireless systems. Some environmental monitoring of water pollution levels is undertaken and sensors are also deployed to measure water levels. Both of these systems use 4G mobile service connections to relay data back to the Hamburg Port Authority (HPA).

Private mobile radio networks are used by HPA and the emergency services on land and on water. Some other organisations in the port area also operate their own wireless networks within their facilities.

Services for the testbed

A testbed has been set up at the Port of Hamburg to show how 5G-MoNArch can securely deliver a range of services in the port area with a huge volume of users (made up of both people and machines). The testbed will demonstrate the key innovations of 5G-MoNArch in a real-world deployment utilising three slices on the 5G platform, which are chosen to demonstrate the three main service classes envisaged for 5G: Massive machine type communication, critical machine type communication and massive broadband. The three slices are:

- Connected traffic lights and intelligent signal control (URLLC slice) – will connect traffic lights allowing traffic light control and implementation of an intelligent transport system. The benefits of this are expected to be increased number of automated vehicles and avoidance of critical waiting times.
- Environmental sensors (mMTC slice) – will allow deployment of low throughput mobile sensors on barges for emission measurements and monitoring of particulates leading to benefits of identifying pollution causes and improved pollution control.
- Augmented reality for port management and maintenance (eMBB slice) – will enable use of Augmented Reality (AR) to assist with port management and maintenance. Equipping maintenance personnel will AR glasses may improve operations support and safety.

The testbed will support the above services using a single test macro cell set up in the port area and will be operated by Deutsche Telekom with the Hamburg Port Authority (HPA) as a tenant. The testbed will allow the capacity requirements for these services to be assessed and how well the 5G-MoNArch technology delivers the high reliability and high security for service delivery. These services are included in the broader assessment of economic benefits of 5G-MoNArch.

Services considered for broader socio-economic analysis

The key groups of 5G-MoNArch innovations that are anticipated to be captured in the ECs are envisaged to map to economic benefits as follows:

- Flexible multi-service architecture – will ideally enable delivery of higher value services than traditional eMBB services and improve revenue whilst utilising economies of scope to deliver these additional services efficiently from a shared network.
- Enhanced security and resilience – will provide access to stakeholder engagements and new revenue streams by improving the quality of experience possible on high security and reliability services from mobile networks. These high security and reliability techniques may come at a higher cost than for baseline services though and so this trade-off between increased revenue and increased cost needs to be assessed.
- Elasticity of resources – will ideally deliver a wide range of services more cost efficiently and in line with a more diverse range of demand and user profiles than in a static network.

In discussion with the Hamburg Port Authority, the following set of services were identified for socio-economic analysis.

- Enhanced traffic control – Secure CCTV cameras (to monitor traffic levels) and traffic lights are placed at key locations in the port area so that traffic flow can be optimised across the City of Hamburg. HPA could locate CCTV cameras, traffic count sensors and traffic lights more flexibly and enhance traffic flow by scheduling road and rail traffic according to the current traffic conditions.
- Automated cargo handling – Two of the largest cargo terminals have already implemented automated cargo handling machinery at the Port of Hamburg. These are based on container carriers following transponder-defined guided routes within automated areas. The Automated Guided Vehicles (AGV) are controlled using an industrial Wireless LAN system. 5G-MoNArch technology provides the necessary high reliability of communications to allow automated machinery to use a standardised platform, enabling greater scale economies and lower costs, thereby facilitating low risk implementation for smaller terminal operators.
- Environmental monitoring –HPA is trialling methods of measuring pollutants at various locations in the port area. 5G-MoNArch technology enables remote sensors to do this at low cost which means that more monitoring locations may be implemented and they may be placed in hard to reach locations. The potential benefits of this are more widespread monitoring and potential identification of precise sources of environmental degradation. Sensors could also be deployed to monitor water levels.
- Augmented Reality (AR) – Many large-scale construction projects are undertaken within the port area each year. AR enabled by 5G-MoNArch technology would allow inspection engineers to observe construction progress with an overlaid image of relevant site plans. This more efficient process allows more frequent inspections and the chance to identify deviations from the plan at an earlier stage with consequent savings in overall cost.
- Enhanced Mobile Broadband (eMBB) – 5G-MoNArch technology will provide a faster and richer experience to mobile broadband users. Cruise passengers could enjoy improved mobile broadband services. In addition, the productivity of HPA and other organisation operating in the port could be improved by access to the 5G mobile broadband service by port employees and asset tracking using logistics sensors.

Economic assessment principles

In undertaking an economic assessment of the benefits of implementing 5G technology in the port of Hamburg, it must be distinguished between those benefits which constitute increases in welfare as opposed to benefits which result in economic advantages for individual stakeholders. Implementing 5G-MoNArch technology in the port of Hamburg may increase welfare by generating both consumer and producer surplus. For example, the availability of a 5G-MoNArch network would enable HPA to undertake improved environmental monitoring in a more cost-effective manner and to undertake monitoring that would not be feasible otherwise. The resulting overall improvements in pollution control may benefit consumers across the city of Hamburg. Individual companies in the port area and the Hamburg Port authority itself should also benefit in terms of higher productivity and lower costs resulting from the implementation of enhanced communications services.

Higher productivity and reduced transport times should increase the competitiveness of terminal operators and allow them to increase the volume of cargo handled (or maintain current volumes of cargo in the face of similar efficiency improvements in other North Range ports[3]). Although these competition benefits do not tend to increase overall welfare (since they are in effect transfers of value from other ports), they do reinforce incentives to implement innovative technologies. In particular, the Hamburg Port Authority may benefit from increases in the scale of usage of the port from increased ground rents and berthing fees.

Terminal operators may also benefit from the availability of a 5G-MoNArch communications network. Although two of the largest container terminals in the Hamburg Port operated by Hamburger Hafen und Logistik AG (HHLA) have been automated for the unloading and storage of containers, other terminals have yet to introduce extensive automation. Smaller terminal operators may lack the scale for investment in an automation process based on fixed infrastructure. The presence of a 5G-MoNArch network with comprehensive coverage could provide a platform for the introduction of cost effective wireless based automation. Wireless operation should allow lower risk implementation of automation and enable efficiency benefits to be obtained by smaller terminal operators. Although the terminal operators would need to invest in the automated machinery, the network slice supporting automation could be either jointly funded by multiple terminal operators, or initially by HPA acting as a catalyst for investment and implementation.

A.1.2 The structure of port operations

The port of Hamburg is concerned with the transfer of goods between land-based transport to and from sea-based transport. Goods may be raw materials and components for processing and manufacturing or end products for distribution. Cargo handling in the port area involves loading/unloading of ships, storage, disaggregation, transport by road/rail, customs and excise verification, border control and passenger services. These operations are undertaken by dedicated terminals in the port area. The port also provides access for passengers who may board cruise ships from Hamburg or may be visitors to the city for a day or two whilst the ship is in port.

In 2016, Hamburg was the 17th largest container port in the world and was the 3rd largest in Europe after Rotterdam and Antwerp. Nearly two thirds of the 136.5 million tons of cargo handled by the port in 2017 was containerised with the remainder being a mix of grab cargo, liquids, bulk agricultural produce and break bulk. Of the 8.8m TEU[4] per year shipped, 64% of these containers were transported to/from the hinterland and the remaining 36% transhipped to other maritime destinations. Of the hinterland traffic, 42% was transported by rail and 56% was transported by road, with the remaining 2% being transported by barge. Hamburg port also contains 3 cruise ship terminals which accommodate around 900,000 passengers per year. A single cruise ship calling at the port may carry up to 5,700 passengers.

The port area is owned by the Hamburg Port Authority (HPA), which is in turn owned by the City of Hamburg. It covers an area of around 100 km^2 and includes all the navigable waterways and the locks, bridges and tunnels associated with them. Within the port area, HPA is responsible for all fixed infrastructure including roads, rail and berthing areas. The road and rail networks are extensive in the port area; there are more than 300 km of rail lines and 200 km of road managed by the authority. The port lies approximately 100 km inland from the coast (see Figure A-1) which presents significant challenges for control of ship movements and environmental management. HPA is also responsible for the smooth functioning of maritime traffic: traffic management, environmental monitoring, tugboats, pilots and dredging.

[3] The North range ports are those located around the Northern and Western coast of Europe. They include the major ports of Rotterdam, Antwerp, Hamburg, Le Havre, Zeebrugge and Bremen & Bremerhaven.

[4] Twenty-foot Equivalent Unit (TEU) is the size of a standard shipping container.

Figure A-1: Map of the port of Hamburg showing typical instantaneous ship locations (>50m length). Source: HPA website

HPA is the landlord for the various organisations that use the port. Foremost of these are the terminal operators which have dedicated facilities for loading and unloading specific types of cargo. There are 23 terminals at the port of Hamburg. Four of these are dedicated to containerised cargo, 3 for cruise ships, 11 for bulk cargo and the remaining 5 are considered multi-purpose. The terminal operators own the cranes and other cargo handling equipment. HPA operates the three cruise terminals through its affiliate company Cruise Gate Hamburg (CGH) which it jointly owns with Flughafen Hamburg GmbH.

Aside from the terminal operators, there are many other organisations in the port area that are concerned with warehousing, trans-shipment and administration. HPA obtains the majority of its revenue from the rental of land and quays, port fees from ships that use the port and volume-based charges for the use of rail and road facilities owned by HPA.

A.1.3 Value flows in the port ecosystem

Ports are in competition with other ports. Part of the basis for this competition is geographic i.e. the position of the port to serve the city of Hamburg (~50 km^2) and its hinterland. However, the port also competes on the basis of its services offered. This includes efficiency (speed) of cargo handling, flexibility and the integrity of goods in transit and storage. The efficiency of handling translates into lower stock requirements for Just-In-Time (JIT) manufacturing, flexibility allows the port to handle goods with specific requirements and good security reduces the incidents of theft, misplacement and damage. Enhanced traffic control in the port area should improve the speed of cargo handling and enhance the service proposition of terminal operators to their customers.

Many large ports around the world have made major investments in recent years to automate the handling of goods within ports. For example, in 2014, twenty container terminals worldwide had been automated including two of the container terminals in the port of Hamburg. Four of these were in Rotterdam and one in Antwerp, which compete directly with the port of Hamburg. Automation is usually undertaken by the largest ports and requires substantial investment; for example, a Shanghai container automation project starting operation in 2018 cost more than €1.8 billion.

This has largely been driven by the increasing use of containers which has enabled the standardisation of shipping units. In container terminals, automation of stacking cranes, guided shuttle carriers and quay cranes may be optimised for containerised goods. Other terminals are more specialised for bulk materials or cruise ships. At these terminals there is less scope for automation. A prerequisite for automation is the instrumentation of the terminal; consisting of the installation of equipment, devices, field transmitters, control and supervision systems, transmission and data gathering systems, and real-time software applications to carry out, control and supervise operations [MS+14].

There is a complex system of revenue flows between the stakeholders that use the port. On the contracting side, freight forwarders establish carriage contracts with ships and haulage companies for transport in and out of the port area. Container traffic is commonly handled by terminal operators and there are dedicated terminals for cruise ships and Roll-on/Roll-off (RoRo) traffic. For other more specialised goods, other intermediaries such as port agents may be used who have expertise in accessing charter services.

HPA is publicly owned and its revenues arise primarily from the charging of rent for the use of the port infrastructure such as land and the quay walls. In addition, HPA charges fees for ships using the port and passenger services. HPA also receives income from rail operations.

The multitude of other organisations that support logistics, construction and maintenance are contracted by the terminal operators, ship-owners and HPA.

There is also a broader economic benefit to the city in that a competitive port facilitates trade between port regions and countries, provide port related employment and they are spatial clusters for innovation, research and development [Mer10].

A.1.4 Service enhancements enabled by 5G-MoNArch

This section focuses on the five service areas that may be enabled or enhanced by the implementation of 5G-MoNArch technology under EC1.

Enhanced traffic control

The benefits of enhanced traffic control include improved efficiency which potentially leads to faster movement of vehicles (lower transit times) and increases in overall port capacity. Enhanced traffic control may also reduce the number of incidents of major congestion or collisions and provide more reliable transit times in the port area. In addition, integrating 5G traffic control features with the more widespread traffic control by the city of Hamburg should improve the transit of port related traffic into the city area and beyond.

Traffic is substantial through the port of Hamburg area. For example, in 2016, around 18.1 million cars and 4.2 million trucks entered the port's main road network and on the main route between the eastern and western areas of the port, around 11,000 cars and 6,000 trucks travelled in each direction each day. There were 780 traffic accidents on the port's roads in 2016 which declined from the previous year, causing 82 injuries including 2 deaths. Roadworks and restrictions around construction sites resulted in 1,700 traffic jam hours over the course of the year [HPA17].

Traffic control in the City of Hamburg and publicly accessible parts of the Hamburg port area is the responsibility of the Transport Department of the Hamburg Police. Traffic control includes a monitoring function using secure CCTV cameras and control of traffic lights.

- Traffic monitoring using secure CCTV cameras – secure CCTV cameras are placed at key locations in the city and the port area so that traffic flow can be optimised across the city. The cameras are connected to the control centre using a fibre network.
- Traffic control of traffic lights – Within the wider city of Hamburg there is interest in connecting the traffic management being done in the port area with intelligent transport systems in city overall as the port has a significant impact on traffic levels in the city. In addition, Hamburg will host the 2021 Intelligent Transport System World Congress and as such is keen to have intelligent transport systems in the city to show case at this. These include intelligent, wireless control of traffic lights based on monitoring of traffic levels as foreseen for the port area.

There is potential for HPA to enhance traffic flow by scheduling road and rail traffic according to the prevailing traffic conditions. However, the 2016 Annual Traffic Report from HPA looked at the impact of offloading container ships on the city's traffic levels and found that because it takes a finite amount of time to load a truck there tends to be a constant flow of traffic from the port into the city rather than large peaks each time a ship arrives. This homogeneity of traffic may reduce the potential benefits of traffic control in the port area. Nevertheless, there are often temporary traffic lights in the port area due to construction works. Monitoring and control of these lights by HPA has potential to be a valuable traffic control function.

Implementing ITS and CCTV based on 5G-MoNArch wireless connections could provide the high security and reliability required for these applications. Moreover, wireless cameras deployed by HPA may have many advantages over fibre networks, being able to provide more extensive coverage at lower cost, faster deployment (responding quickly to changes in user needs) and enabling temporary deployment (to cover short-term construction projects within the port area).

To implement a HPA traffic control system would require secure cameras, traffic sensors and control points equipped with 5G-MoNArch transceivers and a fully staffed control centre for monitoring of CCTV feeds, traffic scheduling software and a means of disseminating information to traffic sources. ITS data analytics and optimisation algorithms would also be needed to make best use of and get efficiency gains from the traffic monitoring data collecting and remote control of the traffic control network.

Automated vehicles and cargo handling

More than half of cargo handled by the Port of Hamburg is containerised at 8.8 million TEU/year, of which approximately 13% are empty containers. HPA expects container volume to grow to over 18 million TEU/year in 2030 (4% AGR). A major focus for terminal operators worldwide is to increase the degree of automation in container handling. The benefits of automating container handling are that efficiency is improved which leads to faster movement of containers (lower transit times) and more reliable transit times.

Two of Hamburg's container terminals (HHLA's Altenwerder and Burchardkai terminals) have already implemented automated cargo handling machinery. The automated guided vehicles rely on transponders sets beneath the road surface which allow straddle carriers to travel along predefined lanes. The loading cranes place containers within a secure area and all container movement to the storage area and transport area are undertaken wholly by automated machinery, with personnel excluded from automated areas for safety reasons. This separation of automation and personnel is being reconsidered by HHLA as part of a research project "Container terminal 4.0 – a paradigm shift in the automation of container terminals via human-machine interaction rather than separation" which is being conducted as part of the German government's Innovative Port Technologies (IHATEC) incentive scheme [HHL17].

An automated system requires considerable investment; for example, HHLA made investments in 2017 amounting to €81.2m in the Container segment. This capital expenditure was dominated by the procurement of handling equipment and storage capacities at the Hamburg container terminals. At present, only the largest container terminal operators worldwide have sufficient scale of operation to justify the investment. 5G technology has potential to provide the necessary high reliability of communications to allow automated machinery to operate at low cost. It may facilitate a low-cost low risk means of implementing automation for smaller terminal operators.

System deployment includes:

- A control centre requiring location tracking software and control staff.
- Automated machinery which includes a loading cranes, straddle carriers and stacking cranes.
- Sensors on containers which would allow location monitoring and monitoring of environmental aspects of container (e.g. temperature).

Environmental monitoring

Ships, machinery and other transport vehicles have potential to emit considerable pollutants into the air and waterways. HPA is trialling methods of measurement of pollutants at various locations in the port area. 5G technology may enable this to be done at low cost which means that more monitoring locations may be implemented and they may be placed in hard to reach locations. The potential benefits of this are more widespread monitoring and potential identification of precise sources of environmental degradation.

The system requires mass deployment of sensors across the port area with parameters monitored to include temperature, humidity, various gaseous emissions including carbon monoxide, carbon dioxide, nitrogen dioxide, sulphur dioxide, hydrogen, ozone, ammoniac, methane, isobutane, propane, and fine dust (PM10). The monitoring would be part of a broader initiative for environmental monitoring across the City of Hamburg.

There are also other types of sensor that may be deployed on barges to monitor tidal flows, water quality and other meteorological data. System deployment would include a control centre for aggregation of sensor data, alerts and a means of information dissemination. Equipment on barges would include location sensing and environmental data sensing.

Augmented Reality (AR) for site maintenance and management

There are many large-scale construction projects undertaken within the port area each year. For example, in 2016 HPA invested €217m in improving the road and rail networks, building new road and rail bridges and refurbishment of the St. Pauli Elbe Tunnel. Like most large construction projects, these are prone to cost overruns due to delays and mistakes made during construction. In general, the earlier mistakes are identified then the lower the costs of rectification. HPA project management personnel regularly inspect the progress of construction projects and during these inspections the current status of construction must be compared with detailed plans. Currently this comparison is done by observing scale drawings on site and comparing these to observed site progress.

HPA is to introduce more digital methods into the planning and construction of infrastructure projects by adopting Building Information Modelling (BIM) which is mandatory for all German road and rail projects by the end of 2020. In parallel, HPA is undertaking research into the use of VR/AR technology in planning projects. Augmented Reality enabled by 5G-MoNArch technology has potential to allow inspection engineers to observe construction progress with an overlaid image of relevant digital site plans. This more efficient process could allow more frequent inspections and the opportunity to identify deviations from the construction plans at an earlier stage with consequent savings in overall cost. The lack of reliance on paper based plans would allow faster more efficient quality inspections and easier correlation. Benefits would be real-time process and earlier capture of deviations (resulting in fewer cost overruns).

The benefit of using 5G-MoNArch for this application is that the system can deliver the high throughput and low latency required for AR. Deployment of an AR system of this nature would require 5G enabled terminals equipped with AR glasses. The network slice supporting the application would need to have an interface to the BIM system which appropriate software to structure the images for viewing based on the inspector’s location. Experience from the 5G NORMA project has shown that extremely good small cell coverage is required to support AR applications.

Enhanced Mobile Broadband (eMBB) services

Deploying a 5G-MoNArch system will provide a platform for the development of enhanced services across the port area. 5G technology will provide a faster and richer experience to mobile broadband users across the port area, making eMBB services available to both passengers and port staff.

eMBB - Cruise passengers

HPA controls the three cruise terminals; two of which are located in the city of Hamburg and one in the port area. The cruise terminals include restaurants and souvenir shops. The Hafen City Terminal complex is a new €1bn development that will include hotels, offices, shops and a new expanded terminal due to be finalised in 2024. Transport to and from the terminals for passengers is generally by taxis or private cars (or on foot at Hafen City). Rail services are not convenient for the passenger terminals. Cruise passengers using the port area are currently able to enjoy mobile broadband services using 4G mobile technology and Wi-Fi implemented in terminal buildings. 5G-MoNArch technology deployed at the terminals would allow cruise passengers to access eMBB services.

The number of ships using the three cruise terminals in 2018 is expected to exceed 218 carrying more than 870,000 passengers[5]. In 2017, the busiest month was in May with 29 ships calling at the terminals with a passenger volume of 120,000. Typically, there is a single cruise ship at a cruise terminal at one time and a single ship calling at Hamburg may have up to 5,200 passengers.

[5] Port of Hamburg Press Conference 2018, HPA website

5G system deployment to provide eMBB services for cruise passengers will require specific coverage of passenger accessible areas and capacity requirements need to be structured around very high instantaneous user densities. The eMBB enabled user devices are likely to be sourced by the passengers themselves.

eMBB - Organisations in the port area

Benefits to eMBB users are that HPA and other companies enjoy greater productivity. There were approximately 130,000 employees in Hamburg dependent on the port functions in 2014. In 2016, 1,759 were employed directly by HPA. Mobile broadband services are used by employees throughout the port area and enhancements to the mobile broadband service could help to increase productivity in port operations.

In 2014, HPA commenced a strategic initiative called smartPORT with the aim of advancing digitisation in the port of Hamburg and increase the efficiency of all modes of transport as well as improve the logistical and traffic related processes in the port. Developments from smartPORT have included the digital Touch Table which provides instantaneous water depths in the port, the Virtual Depot aimed at coordinating empty containers. In parallel, the smartROAD project coordinates information from sensors placed in roads and bridges and enables more efficient investment decisions. HPA sees that with increasing traffic volumes, digitisation of traffic processes is required to maintain the efficiency of its maintenance and project management systems.

The 5G-MoNArch technology can support this vision by facilitating logistics tracking in the supply chain and other operational services for companies in the port area. Generally, the 5G network should be able to provide these services from macro cells, although specific operational requirements may require more focussed coverage (e.g. container yards). However, the 5G technology is not the only enabler required to obtain these benefits. Big data is important to be able to collate, analyse and make best use of data collected for HPA operationally or for third parties in the port area.

A.1.5 Initial charging models and investment

Although the economic benefits of 5G-MoNArch technology may exceed the cost of investment in each of these service areas, it is important that investment takes place for the platform to be developed. Project sponsors such as terminal operators and HPA need to be incentivised to commit the necessary funds. Efficiency improvements in HPA operational activities may justify direct investment in 5G-MoNArch technology. HPA also benefits from the overall scale of shipping operations and should therefore benefit indirectly from all efficiency and productivity improvements made by organisations in the port. However, being able to charge directly for the provision of 5G services would make users' willingness to pay more measurable and a more sustainable business case for individual services.

HPA may expect lower barriers to paying for 5G services where such services can be accommodated within existing charging mechanisms. In 2016, HPA had a turnover of €184.8m which was distributed as shown in Table 8-1.

Table 8-1: Distribution of HPA turnover in 2016 (Source: HPA annual report 2016)

Source of revenue	**Million €**
Rental income from land held	69.1
Rental income from quay walls	17.0
Other rental income	7.8
Subtotal rental income	*93.9*
Port fees and charges	52.3
Income generated by the port railway	20.5
Elbtunnel fees / bridge fees	0.1
Fees and charges	2.5
Income from the supply of maintenance and other services	15.2
Turnover unrelated to the accounting period	0.2
Total turnover	***184.8***

In addition to the revenues shown in Table 8-1 HPA receives grants and subsidies from the City of Hamburg for maintenance and expansion of the general infrastructure within the port area.

The port fees and charges are applied to all ships entering the port area according to the schedule detailed in Table 8-2.

Table 8-2: Schedule of fees and charges

Item	€
Terminal fees	
Basic fee per commenced 24 hours and 100 tons of gross tonnage	3.25
Occupancy fee per commenced 24 hours (per person embarking, disembarking or in transit)	6.60
Minimum charge per ship per commenced 24 hours	1,500.00
Security fees	
Basic fee per commenced 24 hours (per person embarking, disembarking or in transit)	1.00
Minimum fee per call/ship per commenced 24 hours	900.00
Other fees apply to luggage and passenger screening, visitor groups, additional security, water supply and disposal and additional gangways.	

In a 5G network HPA could potentially be procuring network slices from an MNO and acting as an intermediate tenant between the MSP and end users in the port area. The structure of rents, fees and charges provides considerable flexibility for HPA to increase revenues to reflect the services provided using 5G-MoNArch technology. Each of the 5G services considered may use a different mechanism for HPA to recover its investment.

Enhanced traffic control

Since HPA owns all the land in the port area, it has a potential mechanism for applying charges to individual organisations. However, commercial land rents are usually set in the context of long-term lease or tenancy agreements with limited flexibility to vary charges. Investments made by HPA in 5G-MoNArch enabled traffic control infrastructure would need to be considered alongside other general improvements made to the road network and rents varied in the longer term according to the quality of road transport infrastructure. Since traffic control in the port area has benefits for the city of Hamburg it may be appropriate for additional grants from the city of Hamburg to subsidise the development and installation of 5G based traffic control equipment.

Automated vehicles and cargo handling

Automation in terminals would require substantial investment by the terminal operator in automated vehicles and cranes. The 5G wireless communication system would require an appropriate network slice, control software and specific small cells to ensure coverage across docks and yards used for cargo handling. The approach to investing in the development of an appropriate network slice and control software to support 5G communications would depend upon whether terminal operators were willing to commit at an early stage of the project. If there is sufficient interest then initial research and development funding could be provided jointly by terminal operators.

Alternatively, HPA could undertake the initial communication system deployment to act as a catalyst for terminal operators to join the initiative. Recovery of HPA investments could be by means of specific charges to participating terminal operators or are absorbed by HPA as a measure that is likely to increase the overall scale of port operations in future.

Environmental monitoring

The main beneficiaries of environmental monitoring and pollution control are workers in the port area and the inhabitants of the City of Hamburg more generally. Monitoring activity helps HPA to fulfil its statutory duties to manage and maintain the port area. Therefore, the most appropriate source of funding for a 5G-based monitoring service are likely to be specific grants from the city of Hamburg or government. Land rents could also be increased to reflect the direct benefit to employees in the port area.

An alternative means of monetising the provided service relates to the identification of the major sources of pollution in the port area. Particular types of ship or specific vessels may be identified as primary sources of pollution and, where this is the case, higher berthing fees may be charged.

Augmented Reality (AR) for site maintenance and monitoring

The use of AR technology considered here is dedicated to construction projects being wholly within the remit of HPA. Therefore, HPA is the main beneficiary of any cost savings resulting from more efficient control of construction projects. This suggests that HPA should fund the necessary development of 5G network facilities required to support AR services.

Enhanced Mobile Broadband (eMBB) services

HPA already charges cruise operators for services provided to cruise passengers on a per passenger basis. Therefore, where eMBB services are provided to cruise passengers, there is opportunity for HPA to monetise service provision. Specific charges for eMBB may be added to the schedule of charges for the number of passengers requiring access.

For eMBB services provided more generally to organisations in the port area (such as asset tracking and logistics), HPA may enter into service provision agreements with organisations directly and chargeable separately by HPA. Where specific network slices are required to support the operational requirements of other organisations, the costs of developing the slices and specific coverage requirements may be factored into the charges.

A.2 Immersive technology for touristic locations and venues generating demand hotspots – emerging ecosystems and potential charging mechanisms

This section provides supporting information and analysis on the existing use of immersive technology in tourism applications and venues and emerging ecosystems and charging mechanisms related to these services and locations. This analysis supports Section 5.3.2 which summarises initial thinking on the benefits that might be generated if investment is made to serve demand hotspots such as those considered in EC2 and ideally efficiently served via resource elasticity in 5G-MoNArch.

A.2.1 Objectives of existing VR/AR initiatives in tourism venues and museums

5G-MoNArch has analysed what might motivate tourism venues to use VR and AR. This will inform the future analysis of business model drivers and will be a useful input in assessing the potential revenues and wider benefits that these services could generate.

The following potential objectives have been identified:

- Protection of works of art and artefacts of cultural significance – VR can allow the public to view fragile objects without the risk of unintended damage so that items of artistic and cultural interest to which access would otherwise be restricted can be enjoyed by the public (e.g. the Buddhist grottoes of Dunhuang, China [Dun18]).
- Education – some museums have focused on the possibilities of VR and AR as educational tools. VR is particularly exciting because it may open completely new ways of providing educational content and its experiential nature may transform the type of messages that educators are able to bring to the public (Océanopolis, Brest [Oce18]).
- Enhancing the visitor experience – VR can be used to add another dimension to the cultural or entertainment value provided to the visitor. For example, London Tate Modern’s temporary Modigliani exhibition re-creates the artist’s studio in a dedicated room; and VR is used in tours of the Domus Aurea in Rome [Dom18] to show visitors what this ancient structure would have looked like when first constructed.

- Increasing access and inclusion – many museums have targets to increase their use by underrepresented sections of the community, and VR is seen as a means to make museum more attractive e.g. for younger people (e.g. Sukiennice Gallery, Krakow [Suk18]). VR can also be useful in reaching out to potential visitors who might otherwise feel excluded from visiting an exhibition in person for health reasons or because of their geographical location.
- Increasing visitor numbers – increasing overall visitor numbers is seen an objective itself, alongside with objectives to increase access and inclusion for certain groups which also increases visitor numbers.
- Revenue generation – VR creates tourism or entertainment experiences itself, by transforming the source material into a unique experience for which consumers are willing to pay extra (Madame Tussauds, Ghostbusters Experience, New York [Mad18]).

It is worth noting that most of the current VR initiatives are tethered, using a fixed rather than a wireless connection. The Madame Tussauds Ghostbusters experience is one of the few current untethered offerings. The developers made a sizeable investment in making the most of the freedom of the players to roam across the physical site of the attraction.

A.2.2 Hypothetical example services to illustrate the value flows

The following diagram in Figure A-2 shows an example of the possible value flows for a commercial VR experience based around an action an adventure film. The end-user pays either the IMAX cinema (which has an agreement with the film studio) or through HTC VivePort depending on whether the service is experienced at an IMAX studio or downloaded at home.

The Film Studio purchases a network slice from the MSP, but it doesn't make sense for HTC VivePort to purchase a network slice because the end-user can be anywhere in the world. In the home download case the MSP relies on being able to charge a higher mobile package to the end user who is willing to pay more since she has already made an investment in her home VR equipment.

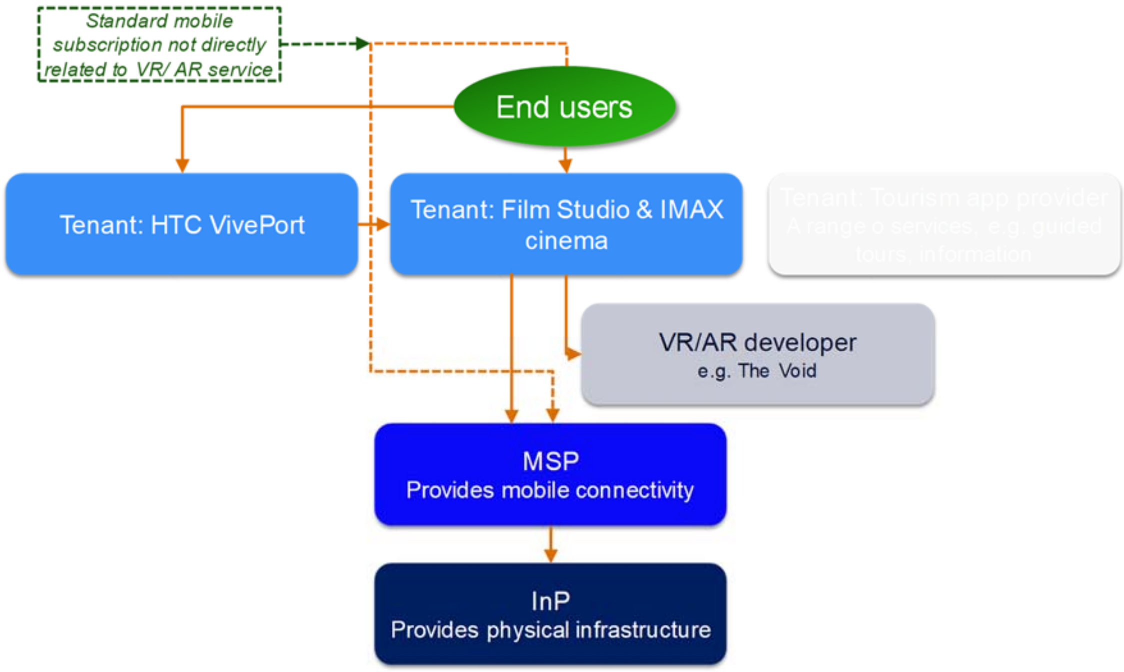

Figure A-2: Action adventure film VR experience (note compared with the players shown in Figure 5-4 the tourism app provider is not relevant in this example and greyed out)

Figure A-3 provides another example scenario with two related services. Outdoors in the historic plaza, the mixed app provided by PlazaTours lets visitors see how the plaza has changed over the ages on their tablets and smartphones, and provides information on the architecture, history and cultural significance of the buildings and statues in the plaza. The app was initially funded by advertising, but tourists are now more generally accepting of paying for such. In addition to the outdoor service in the plaza, several venues offer their own VR services within their premises, based on their exhibitions.

PlazaTours initially purchased two network slices from the MSP to support the outdoor mixed reality service in the plaza and to support the VR services of Museum X and Palazzo V for whom it acted as an intermediary. Now, however the latter two directly purchase the network slice from the MSP as demand is more predictable and the service is easier to manage.

PlazaTours uses content from Museum X and Palazzo V as part of its AR service, however it repays this in kind by cross-promoting visits to Museum X and Palazzo V.

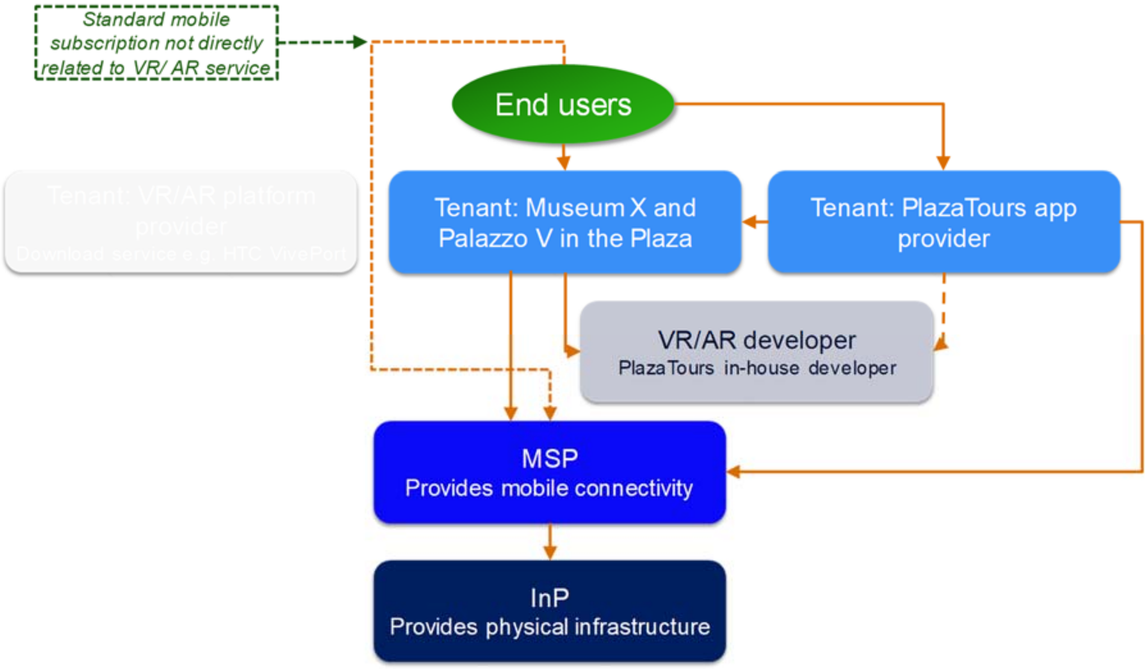

Figure A-3: Historic city plaza mixed reality guided tour and VR experience in surrounding venues (note compared with the players shown in Figure 5-4 the VR/AR platform provider is not relevant in this example and greyed out).

A.2.3 Initial charging models and value flows

In this section the form of the possible commercial relationships between the players in the market is examined.

Value flow between Venue / content owner and end-users:

For venues in particular, one of the main choices will be whether or not to charge for the VR (or AR) experience. This will depend on:

- The venue's objectives for VR.
- The cost of providing the VR service.
- Whether VR is used to provide a substantially different or enhanced experience.

For example, a museum with a strong focus on education and increasing access may decide to offer the VR service free of charge if it feels that a charge would restrict the use of the VR service and run counter to achieving its goals.

Moreover, VR content could help to increase visitor attendance, e.g. by attracting new audiences, hence providing the VR experience free of charge could generate income for the venue while helping with meeting the venue's wider objectives.

However, if the cost of providing VR is significant, e.g. creating dedicated sets and special equipment as well as designing the VR content, there will be more of an incentive to charge to cover these costs.

The extent to which VR creates significant additional value for visitors will also affect the charging decision. This will be particularly important for venues with a purely commercial focus, such as event spaces, stadiums and tourist attractions.

In the case of the consumption of VR content in locations other than the venue, e.g. downloaded for use at home, the extent to which VR and AR provide a good substitute for or enhancement of the real-life experience will affect the level of charges, in addition to the other factors set out above.

Relationships between tourism app providers and end-users, and MSPs

Tourism app providers, e.g. tourism guides with an AR enhancement, will have to decide how to generate income from using VR and AR. Customers may be willing to pay for innovative services or significant enhancements to existing services. The customer could be a municipal tourism agency, if the tourism app is a replacement or enhancement of existing local tourism services. Advertising could be another option depending on the nature of the app.

In terms of the relationship between tourism app providers and MSPs, tourism app providers may be resistant to purchasing a network slice to guarantee a smooth quality of experience for the end-user. Buying a network slice would involve a financial commitment based on the number of predicted users of the tourism app. Revenue share arrangements would share the risk between MSP and tourism app provider, however the cost of sale to the MSP is higher under this type of arrangement. More research is necessary to determine the financial viability of a revenue share arrangement in this case.

A different type of approach for the tourism app providers is to rely on the end-user's standard mobile package being sufficient to provide a good quality of experience. In this case, the MSP needs to be able to generate additional revenues in respect of AR (or mixed reality) probably through end-users signing up to an enhanced mobile subscription that provided the necessary QoE (since there is little evidence of the general population being willing to pay significantly more for a standard mobile services).

Charging mode between venues /content owners and MSPs

The main focus for the relationship between venues and MSPs will be the use of the service on location at the venue site rather than for download in other locations such as at home. The expectation is that it will be challenging for MSPs to gain a contribution from venues for effectively guaranteeing the quality of experience for home download users (as opposed to visitors using the service on site). Home download is unlikely to be the key objective of the venue who will probably place the onus on the end-user to have an appropriate mobile connectivity service, similarly to the tourism app provider. Net neutrality issues also need to be addressed if MSPs were able to sell differentiated levels of service for this market segment.

However, for VR/AR use at the venue site, the MSP is in a strong positioner to earn revenues from venue owners for the use of VR/AR. It's worth noting that VR/AR devices could be quite diverse ranging from VR headsets and sensor equipped clothing to smartphones. The prospects for selling network slices to the venues within a city will depend on the alternatives the venues face for provisioning the service:

- Would a high QoE VR experience depend on the venue buying a network slice or would standard eMBB be sufficient for the venues and the visitors? Low latency is likely to be important for VR therefore assuming that 5G has an advantage over proprietary technologies, this will be favourable to MSPs.
- Would the use of a proprietary system, e.g. LAA, by the venue obviate the need for 5G? This depends on whether the QoE would be sufficient, particularly if the service were provided using unlicensed spectrum which carries more risk of interference. It would also depend on whether the venue would be willing to take on the (possibly substantial) investment risk.
- How much difference would the use of a mobile network (vs. a fixed or proprietary indoor network) make to the QoE?

Museums and stadiums are likely to be multi-million-euro businesses, particularly in larger cities, and will have the resources to engage with MSPs over the details of a network slice. However, small venues may find this more challenging. This may create a role for third parties which deal on behalf of a number of touristic venues. Local authorities and tourism agencies (including commercial companies) may be well placed to do this.

Other interactions

The other interactions between the players in the market appear to be relatively straightforward. Payments from venues and content owners to VR content developers should be normal commercial transactions.

VR platform developers may expect to take a share of revenues if venues / content owners charge for their services. This should be relatively simple to implement with the end-user paying through the platform as happens today on platforms such as HTC VivePort.

Tourism app providers may negotiate for access to third party content – which could take the form of an annual licensing payment or a revenue sharing arrangement.

Finally, city councils may have an interest in supporting the development of 5G services targeted at tourism. There may be a case for public intervention to fully obtain the wider benefits of the increased economic activity (employment, and turnover in related sectors such as restaurants and transport) that 5G tourism services could bring. The case for public intervention, such as a public private partnership, would depend on the strength of the commercial business case for 5G tourism services and the scale of any wider benefits that intervention might bring.

A.3 Value generation and synergies in value generation in future smart city services – a review against the 5G NORMA approach

A.3.1 Re-cap of the scope of the 5G NORMA smart cities analysis

5G NORMA produced an indicative business case analysis for a subset of leading smart city services:

- Intelligent traffic systems.
- Smart energy (metering and grids).
- Smart water and waste management.

In particular, revenues were forecasted and the costs of supplying these services as part of a multi-service network alongside enhanced mobile broadband (eMBB) services were modelled. The conclusion of this analysis was that the business case for such a multi-service network is positive and that, compared to a stand-alone eMBB network, smart city services improved the business case and reduced risk.

A.3.2 Description of smart city analytical framework which seeks to incorporate the revenue analysis of 5G NORMA into a wider strategic (business model) framework

The services considered in this analysis include the three services studied in 5G NORMA plus environmental monitoring and management. Depending on the city environment, the latter involves the use of sensors to monitor environmental data such as air and waterway pollution, and even soil moisture and the risk of landslides.

Each service is assessed against the following factors, which broadly describe the market landscape and provide a qualitative framework for assessing the business models for the smarty city services:

- Potential customer segments.
- Key service providers involved in delivering the service in addition to the MSP;
- Sources of value (private & social6).
- Options for charging for mobile connectivity.
- The position of MSPs in the market segment, their relationship to other service providers and the control of the customer relationship.

[6] Private value is that gained by the seller of a service and its buyer. Social value accrues to the wider community or society. It comes on top of private value and is not taken into account by either the original seller or buyer of the service (unless the government is involved in the transaction).

A.3.3 Assessment of each smart city service against the framework

Intelligent transport systems and traffic management

The diagram in Figure A-4 summarises our analysis of intelligent transport systems. The applications include facilitating the management of traffic flows in the city (particularly, but not limited to motor vehicles), integrating different modes of transport (e.g. bicycles and cars) and parking to reduce congestion and increase safety, and optimising public transport. Cities can also gain strategic benefits from the provision of data on traffic patterns by type of vehicle, accident causation, sources of pollution etc. to effect more fundamental changes in these areas.

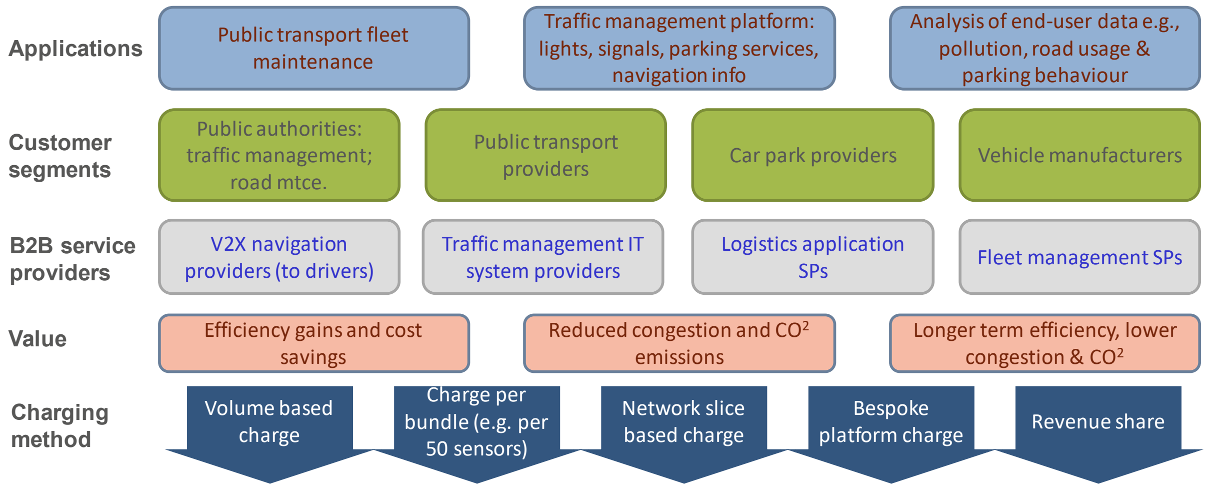

Figure A-4: Intelligent transport systems business model issues

The most important customers are the city and other public authorities, some of which may operate at a national level such as highways agencies. Private sector contractors running public transport services are also potential customers. Citizens and vehicle manufacturers may also be consumers of some ITS services (such as parking applications) or the information produced by them, but are unlikely to be paying customers.

In terms of value, authorities will benefit directly from being able to manage the city's transport infrastructure and services more efficiently. There will also be a range of wider socio-economic benefits from reducing traffic flows to better accident response of the kind which was evaluated in 5G NORMA.

In addition to mobile service providers, there are a range of other service providers that will be involved in delivering these primarily business to business services to the customers illustrated in the diagram.

Figure A-4 also shows the range of charging methods available to the MSP from a simple volume based charge to a revenue sharing agreement with other service providers (e.g. perhaps for parking services). These options are similar for each smart city service, however specific market conditions will determine which charging methods are most appropriate such as: which type of service provider owns the customer; or the need for additional features such as security and reliability.

With regard to the MSP's position in this market, and the issue of who controls the customer, the initial view is that providers such as IT solutions companies may already have a strong relationship with city authorities and other potential customers, particularly where they have developed bespoke systems. This may be important because, from current indications, intelligent transport systems need to be highly tailored to each city's needs. For example:

- London's Surface Intelligent Transport System is replacing legacy CCTV systems, and is focused live traffic monitoring and predictive signalling to reduce road congestion.
- Copenhagen is focusing more on green mobility including bikes, CO2 emissions and increasing road safety.
- Rio de Janeiro focused on reducing congestion and improving public transport for the Olympics and beyond.

- Cascais, Portugal, has an integrated vision for traffic management including smart parking, bicycle rental, public transport and tourism.

On the other hand, network slicing would allow the MSPs to tailor the mobile connectivity services much more easily than with current 4G networks. Hence, the MSPs may be able to use this as a way to build their relationships with those responsible for commissioning and managing ITS, and to challenge the IT solution providers for control of the customer.

Smart energy

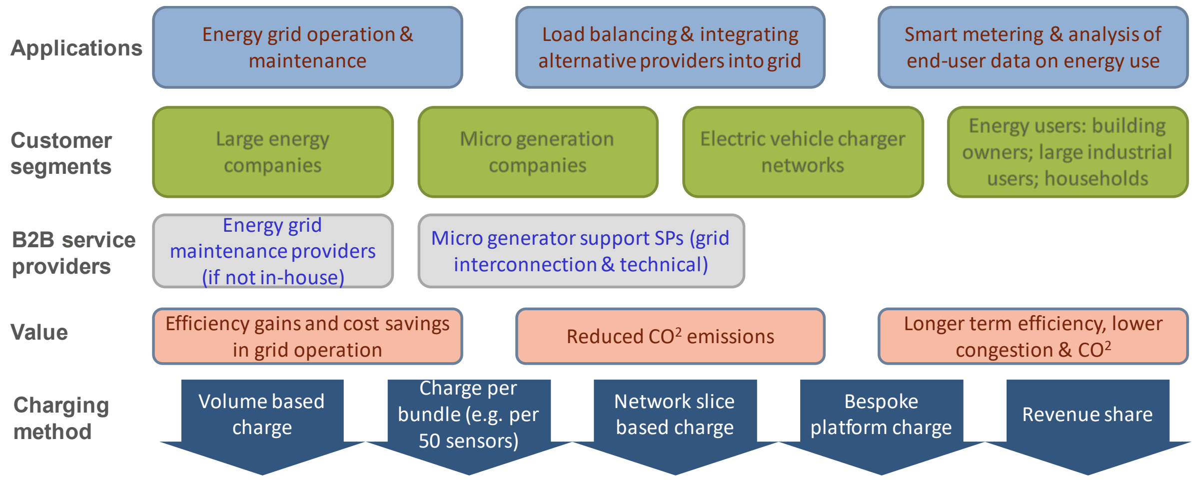

Figure A-5: Smart energy business model issues

As the diagram in Figure A-5 shows, smart energy applications range from more efficient management and a better response to changes in demand through supporting decentralised energy provision to enabling more efficient energy usage by end-users.

The main customers are likely to be the national and regional players in the energy supply industry. In some countries, public authorities are involved in energy supply, in others privately owned providers are the rule. However, micro-generation will bring a new class of customer into the market who are much smaller and more numerous. Energy users may also be customers for smart energy services. For example, large users may have strong incentives to deploy applications which integrate them more tightly into load balancing across the energy grid. It is also feasible that building owners and households may use smart energy applications to control their own usage in the future.

The value created by smart energy will fall into the categories described in 5G NORMA, i.e.: potentially significant reductions in CO^2 emissions and efficiency savings for energy suppliers; and lower costs for energy users (all other things being equal).

The current expectation is that there may be a few other types of service provider in addition to the MSPs, but this will be more limited in comparison to intelligent transport systems.

If the role of other service providers is relatively limited, MSPs will be in a stronger position to control the customer relationship. This may be the case if energy suppliers closely manage the development of smart grid systems (even though they may contract out parts of the deployment to external suppliers). Furthermore, the main customers are likely to be large and few in number. This will play to the MSPs' strengths in terms of having account management structures geared to working with large clients and tailoring services to their needs.

Smart water and sewerage

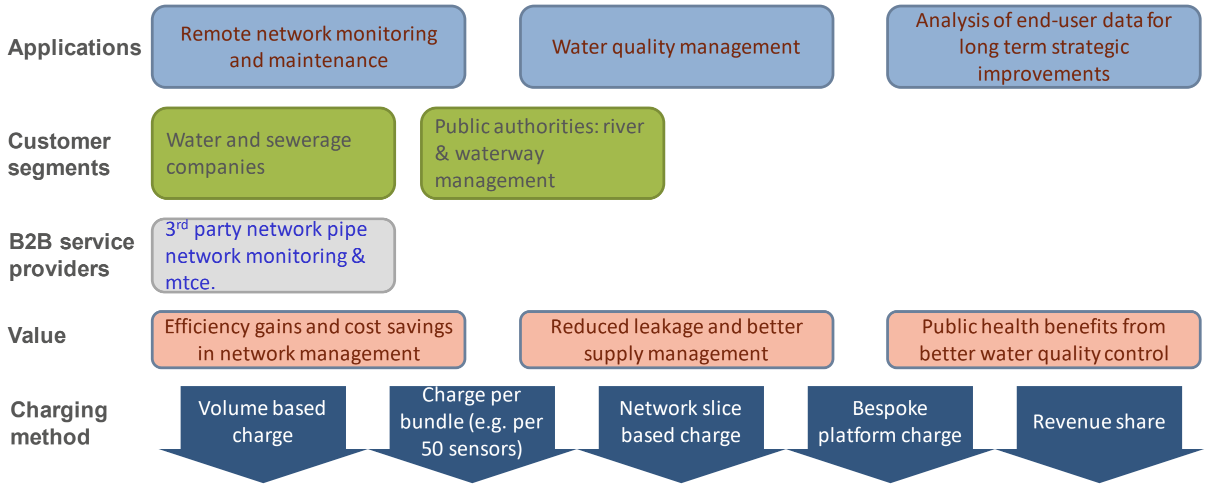

Figure A-6: Smart water and sewerage business model issues

Smart water and sewerage applications range from managing and monitoring the condition of water network infrastructure to measuring water quality as shown in the diagram in Figure A-6. Regional or national water companies and authorities responsible for managing waterways are likely to be the main customers for smart water services.

In addition to generating private value for water companies by enabling more efficient management and maintenance of the network, social value may also be created from improving water quality and reducing the incidence and effects of water supply pollution.

As with smart energy, the fact that customers are likely to be few and large in size will play to the MSPs' strengths in managing large client accounts. MSPs will also face limited competition to control the customer relationship from third party network management/ maintenance and water quality management specialists. This should present MSPs with the opportunity to build a strong position in this market. In contrast to smart energy, however, the potential for technology to promote radical change to either supply or consumption seems more limited. Hence, the role of smart technology may be more limited and this may push the industry towards simpler less differentiated services rather than potentially higher revenue bespoke deals.

Environmental monitoring and management

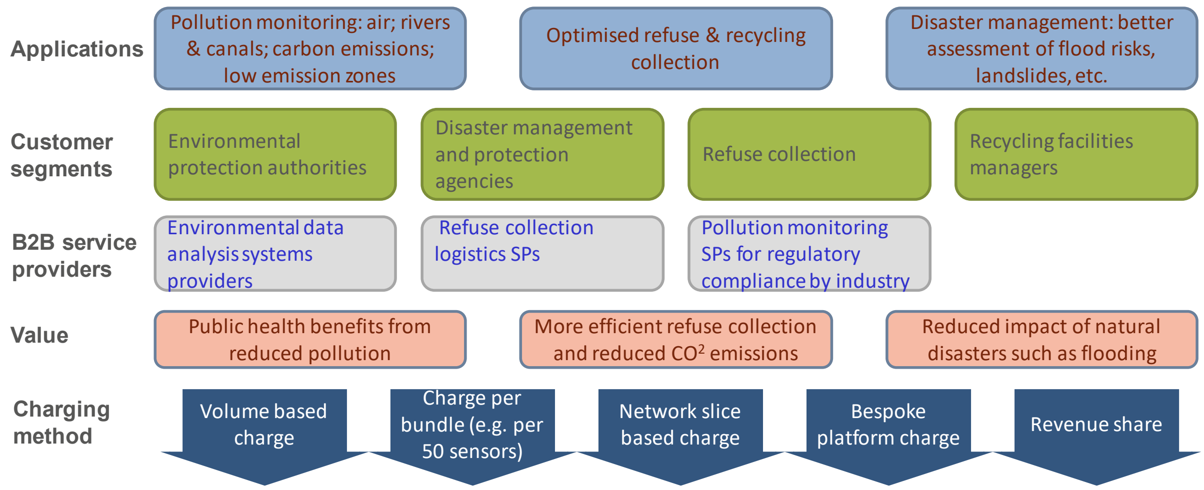

Figure A-7: Environmental monitoring and management business model issues

As shown in the diagram in Figure A-7, environmental monitoring and management services involve the monitoring of pollution in the natural and urban environment, waste collection and the response to natural disasters typically around the use of sensors and the data derived from them.

The customers for these services are most likely to be municipal authorities with an interest in and responsibilities for environmental protection and national bodies with overarching responsibilities. In addition, private companies involved in the operation of waste collection and recycling may be customers for the smart waste applications included in this category.

As for the other smart city services, private value will be generated from more efficient management of environmental monitoring and management services. Public health benefits should also come from the more detailed and accurate environmental monitoring data that new systems can provide.

There are a number of different types of service provider that may operate in this space in addition to MSPs. Interpreting environmental data may require sophisticated analysis which may be carried out by a specialist or may need specific software tools. Public authorities may choose to contract with specialist monitoring companies rather than develop the expertise in-house. Finally, there are already a number of companies that provide end-to-end services in waste management, from monitoring refuse and recycling bins to developing systems for optimal refuse collection based on the smart bin data.

MSPs will face competition from other service providers to control the customer relationship, in particular where there is a need for specialised tools or expertise to assess data. A better strategy for MSPs in this case may be to explore the opportunities for partnerships with these specialists.

A.3.4 Potential synergies between smart city services

The direct potential to generate revenues and social benefits from smart city services has been described above. However, the detailed information on the city, its environment and the use of city facilities that will be produced could unlock substantial synergies between smart city services if the data is made open to other uses. The potential for cross-fertilisation is exciting and it is expected to deepen as smart city usage increases and the information available becomes richer and more extensive. It is important to note that the potential to collect lots of data on the use of city infrastructure and amenities and to make it available to other branches of the public sector and third parties will create challenges in terms of protecting citizens' rights to privacy and guarding against unlawful exploitation.

In the following some examples of potential of synergies are set out, though the assumption is that many additional innovative uses will emerge over time which are not yet considered here.

1. Detailed environmental monitoring data on roadside air pollution could be useful for strategic planning of road traffic management and attaining environmental protection objectives. This type of information would help inform the objectives of intelligent transport systems and provide additional measures of its effectiveness. There could also be shorter term benefits e.g. from integrating air pollution alerts from environmental monitoring data with real-time traffic information and alternative route suggestions for road users (drivers, cyclists and pedestrians) who may be affected by pollution.
2. Although the assumption is that water companies do their own monitoring of water quality, having access to environmental monitoring data on the pollution of water courses could enhance their ability to manage water quality. Equally, if authorised environmental management users can access real-time information on the state of the water and sewerage network (with due regard to confidentiality issues), this could improve their ability to respond to environmental issues and emergencies linked to infrastructure problems.
3. If e-vehicles become a significant part of the automotive market, information on traffic and parking patterns across the city from intelligent transport systems could be used in smart grid development, e.g. to optimise the location of e-vehicle charging points and as input to balancing energy supply and demand.

A.4 Review of frameworks for assessing social value

The aim of this section is to produce a framework for assessing social value based on previous research and international best practice. The section starts with reviewing the approach that was taken to measure wider economic and social value in the first phase of 5G PPP projects, in particular within 5G NORMA. Within 5G-MoNArch, the literature on regulatory approaches to measuring social value has been reviewed, and it is summarised in the following what can be considered to be best practice and the leading academic research in this area. Finally, suggestions are provided on how the 5G NORMA framework could be updated in the light of best practice and current academic developments.

A.4.1 Re-cap of 5G NORMA – social benefits and productivity

The 5G NORMA project took a holistic view of the potential value that 5G services and the 5G NORMA architecture could create. It framed wider economic and social value in the context of a relationship between the private and the public sector. It proposed that it was important to consider both private and public value to realise the full benefits of 5G services and that the relationship between them was dynamic.

Firstly, private sector companies maximise their own profits without taking social benefits (or costs) into account. Therefore, social benefits may not be fully realised if the private sector acts on its own. So, some form of public intervention may be necessary for society to gain the maximum benefit. Secondly, public sector support may have beneficial spin-offs for the private sector. For example, temporary support for innovative networks and services may enable firms to take a longer-term perspective than otherwise, leading to higher private sector profits and further benefits to society.

The analysis concluded that policy makers should ideally assess the scale of the potential wider economic and social benefits and whether they were likely to be achieved by the private sector on its own. If there was a significant risk that they might not, policy makers should consider the options for public intervention – from public private partnerships to tax incentives to subsidies – and the effectiveness of each option.

Three sources of wider economic and social value were identified:

- Indirect private benefits – e.g. in addition to meeting a need for mobile connectivity, the use of 5G can generate additional benefits such as a longer-term boost to productivity.
- Spin-off effects, or externalities, can create additional value for consumers, businesses and particularly society (e.g. environmental impacts).
- Social value can arise from improving the wellbeing of individuals as citizens, for example reducing social and geographic exclusion.

In its quantitative analysis, 5G NORMA focused on assessing the impact of productivity improvements and externality effects, in particular reductions in greenhouse gases (environmental) and reduced congestion. These were judged to be the most relevant to the services considered in 5G NORMA's multi-service EC: 'vehicle to anything' services (V2X); intelligent transport systems and smart energy.

A.4.2 Review of best practice and the state of the art

There is broad agreement on the fundamental principles for assessing social benefits in the context of regulatory impact analysis and public policy appraisal.

The UK government's Treasury Green Book and the US Office of Management and Budget's Circular A-4 [Omb03] are regarded as models of best practice. Both take a similar approach and include the assessment of social benefits (and costs) within the wider framework of cost benefit analysis for public policy decisions.

The key elements of these approaches are to identify the impact that economic activity has beyond the direct value created for the producer/seller and the consumer. These approaches are similar to the 5G NORMA approach described in the previous section. They include impacts on society (i.e. on individuals as citizens and on communities as a whole) and indirect effects on the private sector (i.e. on other producers and consumers not part of the original transaction). They can be summarised as follows:

- Indirect benefits to citizens and consumers that result as spin-off effects from direct economic activity – known as externalities or private external value.
- Environmental impacts that result from economic activity – these are typically not considered in market transactions.

- Impacts on citizens and communities in terms of social connectedness, security, sense of freedom, health, etc.

A report for the UK's DEFRA [HP11] makes a useful distinction between social and environmental capital on the one hand, and socio-economic activities (i.e. flows of social benefits and costs) on the other. Public policy appraisal should consider both, for example:

- Public service broadcasting may build social capital by promoting social cohesiveness and an informed citizenry. This may in turn generate social benefits such as reducing crime and other social ills.
- Society as a whole benefits from the connection of remote areas to telecommunications networks. This is why governments often intervene to ensure network coverage in areas which are unprofitable to connect from a purely commercial perspective. The same could apply to smart city and VR/AR services. E.g. the business case for an accident warning and response system requiring video surveillance and high reliability is unclear from the purely commercial perspective of an MSP's, but the overall benefits are likely to outweigh the costs once the benefits to society are considered.

Hence, as the previous paragraphs show, international best practice suggests a relatively general framework for assessing socio-economic impacts. Part of the reason for this is that socio-economic impacts can be very diverse and quite specific to the activity that public policy seeks to regulate. As a result, trying to pre-judge the detailed social impact is unlikely to be effective as a framework for public policy appraisal.

The regulatory/academic discussion has focused more on how to measure socio-economic effects within a generalised framework. This is an important issue because, in many cases, finding data to evaluate such effects is not straightforward. For example, it is difficult to assess the value of reducing air pollution directly because the public does not directly pay for clean air (and it would be impractical to do so since it is a shared public resource). Equally, if television broadcasts were financed solely by payments from viewers, their willingness to pay for TV access would only consider the value to each person from watching television and not the wider benefits to society from public service broadcasting. Furthermore, concepts such as social connectedness and security are more intangible and even more difficult to measure directly.

The DCMS report [BCC+15] sets out a number of different techniques, such as consumer surveys (revealed and stated preference analysis) and subjective wellbeing analysis to address these measurement challenges. For example, by examining attitudes to how much people would be prepared to pay on uncongested roads (and with reference to road tolls), an assessment of the value of reducing congestion could be made.

The aforementioned topics are not discussed in more detail as the intention is not to carry out primary level market research of this type. Where necessary, existing primary level research results shall be used. Instead, the focus in the coming stages of this project will be on identifying and evaluating the wider socio-economic impacts of 5G services. To do this the intention is to:

- Identify the potential size of the relevant socio-economic effects in volume terms.
- Apply existing market research data (often carried out by public bodies) on the unitary values of socio-economic and environmental factors – e.g. the value of reduced congestion in € / minute of travel time saved.

B Questionnaire for Stakeholders

The objective of this questionnaire is to gain all the necessary information regarded to the stakeholder's opinion about 5G-MoNArch innovations as well as to extract more information from Stakeholders. See Section 6.2 for details.

A. Please indicate to which of the following categories you belong:

I provide mobile internet connectivity and telecommunication services. *[Mobile Service Provider (MSP)]*.	□
I belong to an entity or company that owns and manages infrastructure of the network under consideration. (e.g. antenna site infrastructure provider, transport network provider, data centre service provider). *[Infrastructure Provider (InP)]*.	□
I belong to an entity that operates and owns the mobile network that integrates the role of Mobile Service Provider and Infrastructure Provider. *[Mobile Network Operator (MNO)]*.	□
I belong to an entity that designs, build and operates its virtualisation infrastructure and offer it to Mobile Service Provider. *[Virtualisation Infrastructure Service Provider (VISP)]*	□
I provide Hardware to the Infrastructure Providers (e.g. server, antenna, cable, etc). *[HW supplier]*.	□
I provide Network Function Virtualisation infrastructure to Virtualisation Infrastructure Service Providers or to Mobile service providers. *[Network Function Virtualisation Infrastructure (NFVI) supplier]*.	□
I provide virtualised software components to Mobile service providers. *[Virtual Network Function (VNF) supplier]*.	□

B. For each of the following statements, mark one box that best describes your opinion.

B.1. Technical part questions	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
1. I think that a Telco cloud – aware protocol design would be a helpful innovation.	◻	◻	◻	◻	◻
2. I think that a Terminal – aware protocol design would be a helpful innovation.	◻	◻	◻	◻	◻
3. I found inter-slice context aware optimisation necessary.	◻	◻	◻	◻	◻
4. I think that slice aware functional operation is necessary	◻	◻	◻	◻	◻
5. I found that inter-slice resource management is imperative need	◻	◻	◻	◻	◻
6. I think that terminal analytics driven slice selection/control is significant	◻	◻	◻	◻	◻
7. I think that is required inter-slice management & orchestration framework	◻	◻	◻	◻	◻
8. In my opinion it is demanded E2E management of computational storage and networking resources consumed by VNFs	◻	◻	◻	◻	◻
9. I found multi-connectivity and network coding for improving the RAN reliability necessary.	◻	◻	◻	◻	◻
10. I think that enhancements in telco cloud resilience through improved failsafe mechanisms and fault management are demanded.	◻	◻	◻	◻	◻
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
11. In my opinion flexible security, monitoring and detection algorithms are helpful.	◻	◻	◻	◻	◻
12. I think that secure exchange of threat intelligence is crucial.	◻	◻	◻	◻	◻
13. In my opinion, a self – adaptive deployment model would be helpful.	◻	◻	◻	◻	◻
14. I think that elastic functions redesign is an imperative need.	◻	◻	◻	◻	◻
15. I find elastic NF scaling mechanism necessary.	◻	◻	◻	◻	◻
16. In my opinion, a MANO elastic orchestration mechanism would be helpful.	◻	◻	◻	◻	◻
17. I believe that Inter Slice Resource Broker for handing elastic network slices are a helpful innovation.	◻	◻	◻	◻	◻

B.2. General part questions					
18. I think that I would like to use the conclusions of the results of the innovations frequently.	□	□	□	□	□
19. I found the results of the innovations unnecessarily complex.	□	□	□	□	□
20. I thought the results of the innovations were easy to use.	□	□	□	□	□
21. I think that I would need assistance to be able to use the results of the innovations.	□	□	□	□	□
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
22. I found the various functions in the results of the innovations were well integrated.	□	□	□	□	□
23. I thought there was too much inconsistency in the results of the innovations.	□	□	□	□	□
24. I would imagine that most people would learn to use the results of the innovations very quickly.	□	□	□	□	□
25. I found the results of the innovations very cumbersome/awkward to use.	□	□	□	□	□
26. I felt very confident using the results of the innovations.	□	□	□	□	□
27. I needed to learn a lot of things before I could get going with the results of the innovations.	□	□	□	□	□

C. Please describe briefly your proposals to the following questions.

Feel comfortable to leave any answer without response, if you are not familiar to the subject or you have not any new contribution-proposal.

1. If you agree that a Telco cloud – aware protocol design would be a helpful innovation, please describe briefly the main reason.

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2. The 5G-MoNArch project aims to design a new RAN protocol stack tailored to fully exploit virtualisation and orchestration techniques called "cloud enabled protocol stack". The cloud enabled protocol stack will be based on two innovation elements: the telco cloud-aware protocol design and the terminal aware protocol design. Please, write briefly your opinion about that, are there any needs or demands regard to the cloud enabled protocol stack, which you would like to be considered?

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3. The 5G-MoNArch project is targeting to design and develop network control functions to achieve a flexible and programmable inter-slice management framework that can be used to realise multiplexing gains across slices while guaranteeing slice-specific Service Level Agreements. Please, write briefly your opinion about that, are there any needs or demands regard to inter-slice control and management, which you would like to be considered from the 5G-MoNArch project?

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4. The 5G-MoNArch framework builds on two models, which capture the behaviour of the Network Function and the Infrastructure respectively. Experiment-driven modelling is a key innovation for that. Please, write briefly your opinion about that, are there any needs or demands regard to the experiment-driven optimisation, which you would like to be considered from the 5G-MoNArch project?

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5. The 5G-MoNArch project through the investigation on network resilience will address problems in the network operation that are caused deliberately by the human factor and as well as that they can be related to other network aspects, such e.g. software, infrastructure etc. Please, write briefly your opinion about that, are there any needs or demands regard to the secure and resilient network functions, which you would like to be considered from the 5G-MoNArch project?

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6. 5G-MoNArch project will develop elasticity techniques that take into consideration not only the availability of communication resources, but also computational and storage resources. Please, write briefly your opinion about that, are there any needs or demands regard to the resource-elastic virtual functions, which you would like to be considered from the 5G-MoNArch project?

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7. What particular challenges do you foresee in deploying mobile networks targeting localised scenarios such as touristic venues or sea ports as examined in 5G-MoNArch?

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C Glossary

5G-MoNArch enablers [5GM-IR61]

5G-MoNArch enablers are modules, algorithms or schemes to be developed by WP2 to WP4 that essentially contribute by physical means to improvement in one or more KPIs. For verification of these improvements specific analysis tools are needed (denoted as available tools in WP6 context) that have to be provided by the owners of the enablers. A set of enablers will be used in the framework of ECs to optimise a certain performance profile.

Area traffic capacity (based on 3GPP/ITU-R; aka **traffic volume density** by 5G PPP):

The total traffic throughput served per geographic area (in bps/m^2). This metric can be evaluated by two different traffic models: Full buffer model and non-full buffer model.

- By full buffer model: Total traffic throughput served per geographic area. The computation of this metric is based on full buffer traffic.
- By non-full buffer model: Total traffic throughput served per geographic area. Both the user experienced data rate and the area traffic capacity need to be evaluated at the same time using the same traffic model.

The area traffic capacity is a measure of how much traffic a network can carry per unit area. It depends on site density, bandwidth, and spectrum efficiency. In the case of full buffer traffic and a single layer single band system, it may be expressed as:

- Area traffic capacity (bps/m^2) = site density (site/m^2) × bandwidth (Hz) × spectrum efficiency (bps/Hz/site)

Site here refers to single transmission and reception point (TRxP). It is proposed to perform full buffer evaluation, using the spectrum efficiency results together with assumptions on available bandwidth and site density to derive a quantitative area traffic capacity KPI for information.

Area traffic capacity is typically evaluated through system level simulations. Note that D2D traffic should be evaluated independently from the cellular one. Besides, the link between source and destination may cover multiple hops especially when non-ideal backhaul is taken into consideration.

Assessment model [5GM-IR61]

An assessment model introduced in D6.1 [5GM-D61] prepares a selection of KPIs to be introduced into the different assessment metrics and provides a link between technical and economic evaluations. For the purpose of linking the results of technical and economic evaluations some of the technical verifications will need to be done in up-scaled verification scenarios allowing for comparison between costs vs. benefits. In this case a network level simulation helps to observe KPIs on a larger scale with the aid of suitable look up tables to emulate the impact of lower radio protocol stack layers for example.

Available Tools [5GM-IR6.1]

Available Tools in the sense of WP6 verification methodology are tools that are needed for verification of 5G-MoNARch enabler contributions to KPI improvement. According to D6.1 [5GM-D61] there exist three types of tools for verification:

1. **Analytical evaluation**: The verification process is performed through an analytical evaluation based on theoretical assumptions and values of the considered system.
2. **Simulation**: The verification process is performed through a software simulation of the considered system that is modelled according to the goals of the verification.
3. **Testbed measurements**: The verification process is performed through experimental measurements during trials in the testbeds. The collected data is processed statistically according to the goals of the verification. Data can be objective (collected from systems) or subjective (collected from users).

Coverage (based on 3GPP):

Maximum coupling loss (MaxCL) in UL and DL between UE and TRxP (antenna connector(s)) for a data rate of [x] bps, where the data rate is observed at the egress/ingress point of the radio protocol stack in each direction.

Link budget and/or link level analysis are typically used as evaluation methodology.

CL is defined as the total long-term channel loss over the link between UE antenna ports and the TRxP antenna ports, and includes in practice antenna gains, path loss, shadowing, body loss, etc. The MaxCL is the limit value of CL at which the service can be delivered, and therefore defines the coverage of the service. The MaxCL is independent of the carrier frequency. It is defined in the UL and DL as:

- UL MaxCL = UL Max Tx power - TRxP Sensitivity
- DL MaxCL = DL Max Tx power - UE Sensitivity

Note: 3GPP proposed a target for coverage of 164 dB for an mMTC service assuming 160 bps. For a basic MBB service characterised by a DL/UL data rates of 2(1) Mbps/60(30) kbps for stationary users, 3GPP proposed a target MaxCL of 140(143) dB. For mobile users 3GPP assumes a DL data rate of 384 kbps as acceptable. At a coupling loss of 143 dB relevant DL/UL control channels should also perform adequately.

End-to-end latency (based on 3GPP/5G PPP):

The time that takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination. It is also referred to as one trip time (OTT) latency.

Another latency measure is the round-trip time (RTT) latency which refers to the time from when a data packet is sent from the transmitting end until acknowledgements are received from the receiving entity.

Evaluation cases [5GM-IR61]

Evaluation cases focus on optimisation and network configuration sensitivity analysis for one or more *performance profiles*. *Evaluation cases* pursue the following tasks:

- Check of fulfilment of user related KPIs as defined in the service definitions.
- Optimisation of performance profiles with respect to selected KPIs.
- Sensitivity analysis with respect to network configuration settings including detection of KPI interdependencies.
- Quantitative identification of performance and economic benefit by application of a 5G-MoNArch enabler or a set of enablers.
- Provisioning of input to validation activities making sure that the introduced innovations fit to stakeholder requirements.
- Specification of verification tasks and timeline.

Evaluation criteria (by 5G-MoNArch):

Evaluation criteria are derived from an overall KPI list, Criteria with similar features are grouped into sub-categories that can be jointly arranged and discussed (examples: Performance requirements, Operational Requirements, Functional requirements, Elasticity requirements, Security requirements…)

Evaluation Concepts [5GM-IR61]

Evaluation concepts are needed for joint evaluation of sets of enablers to estimate performance gains in cases where simple addition of single enabler contributions is not possible or KPI improvements depend on the scale of the verification scenario. As a general rule, ideally the results of WP2 to WP5 specific verification will contribute directly to an evaluation case without any post processing by WP6.

Mobility (based on 3GPP/ITU-R):

Maximum speed at which a defined QoS and seamless transfer between TRxPs which may belong to different deployment layers and/or radio access technologies (multi-layer/-RAT) can be achieved (in km/h).

The evaluation methodology should be link level evaluation with deployment scenario specific operating point.

Network slice (based on 3GPP):

A set of network functions and corresponding resources necessary to provide the required telecommunication services and network capabilities.

Performance Profiles [5GM-IR61]

Performance profiles play a central role in 5G-MoNArch evaluations. According to the DoW performance profiles shall describe sets of services offered by a MSP or tenant, hence performance profiles are defined to be a combination of selected services that are to be provided in a specific verification scenario. Performance profiles aggregate all problem space related assumptions needed to execute a specific verification task (verification scenario attributes and sub set of service definitions). A complete set of those assumptions is also denoted as an evaluation scenario and defines the problem space.

Reliability (based on 3GPP/ITU-R/5G PPP/NGMN):

Percentage (%) of the amount of sent network layer packets successfully delivered to a given system node (incl. the UE) within the time constraint required by the targeted service, divided by the total number of sent network layer packets.

Note 1: The reliability is evaluated only when the network is available.

Note 2: Dependent on the targeted service the RTT latency instead of the E2E (OTT) latency may be applied.

The RAN reliability can be evaluated by the success probability of transmitting X bytes within a certain delay of [t] ms, which is the time it takes to deliver a data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface. The target communication range and reliability requirement is dependent of the selected deployment and operation scenario, i.e., by taken into account a certain channel quality (e.g., at the coverage edge).

Link level evaluation with deployment scenario specific operating point and system level simulations are to be performed (e.g., Indoor Hotspot and Urban Macro for eMBB; Highway and Urban grid for connected cars/URLLC).

In the classical resilience theory, the reliability of a system/component over time is directly related to its MTBF. In the simplified case that the MTBF will not change over the system's/component's lifetime, it can be calculated as follows:

$$R(t) = \exp(-t/MTBF).$$

It should be noted, however, that the MTBF of most systems/components (respectively their failure rate = 1/MTBF) will change significantly over time (see e.g. ETSI GS NFV-REL 003 V1.1.1 (2016-04) w.r.t. reliability considerations for systems consisting of NFV-based components).

Resilience (based on ITU-R):

Resilience is the ability of the network to continue operating correctly during and after a natural or man-made disturbance, such as the loss of mains power.

Service definitions [5GM-IR61]

Service definitions set the target performance (KPI) either from the user or from service point of view and comprise of a description (narrative), a set of performance benchmarks and radio capacity as well as radio coverage KPIs

User experienced data rate (based on 3GPP/ITU-R; aka **experienced user throughput** by 5G PPP):

The achievable data rate that is available ubiquitously across the coverage area to a mobile user/device (in bps). It is usually related to the minimum data rate required to achieve a sufficient quality experience (dependent on the selected service type).

The user experienced data rate can be evaluated for non-full buffer traffic and for full buffer traffic, but non-full buffer system level simulations are preferred for the evaluation of this KPI taken care of respective deployment scenarios and using bursty traffic models.

For non-full buffer traffic, the user experienced data rate is the 5%-percentile (5%) of the user throughput. User throughput (during active time) is defined as the size of a data burst divided by the time between the arrival of the first packet of a burst and the reception of the last packet of the burst.

For full buffer traffic, user experienced data rate is calculated as:

User experienced data rate = 5% user spectrum efficiency × bandwidth.

Here it should be noted that the 5% user spectrum efficiency depends on the number of active users sharing the channel (e.g. 10 in the evaluations in ITU-R Report M.2135), and that the 5% user spectrum efficiency for a fixed transmit power may vary with bandwidth. To keep a high 5% user spectrum efficiency and a few users sharing the channel, a dense network is beneficial, i.e. 5% user spectrum efficiency may vary also with site density (site here refers to single TRxP).

5% user spectrum efficiency means the 5% point of the cumulative distribution function (CDF) of the normalised user throughput. The (normalised) user throughput is defined as the average user throughput (the number of correctly received bits by users, i.e., the number of bits contained in the SDU delivered to Layer 3, over a certain period of time, divided by the channel bandwidth and is measured in bps/Hz. The channel bandwidth for this purpose is defined as the effective bandwidth times the frequency reuse factor, where the effective bandwidth is the operating bandwidth normalised appropriately considering the uplink/downlink ratio. In case of multiple discontinuous “carriers” (one carrier refers to a continuous block of spectrum), this KPI should be calculated per carrier. In this case, the user throughput and channel bandwidth on the specific carrier are employed.

The user experienced data rate is calculated separately for DL (transmission from TRxP(s) to UE), UL (transmission from UE to TRxP(s) and (potentially) for D2D (transmission directly between involved UEs).

Verification scenarios [5GM-IR61]

Verification scenarios complement the description of the problem space by adding geographical based information and service related traffic profiles (traffic mix, spatially as well as timely distribution of traffic demand). Especially for economic evaluations assumptions on the infrastructure (site densities, spectrum usage, etc.) are important and in scope of the verification scenario specification. The attributes to be specified by the verification scenarios heavily depend on the input needed by tools that are selected for execution of the different verification tasks.