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for 5G Heterogeneous Radio Access Networks

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Executive Summary

This document describes the techno-economic model, the value and the exploitation potential of COHERENT innovation resulting from research activities carried out by the project. It starts with the market evolution in terms of the increase in the future use of data consumption. The main drivers such as RAN sharing, spectrum sharing, infrastructure sharing which are the enablers for providing benefits to the actors involved in different parts of the COHERENT network are exemplified.

The objective of this deliverable is to present the market context, value chain analysis, stakeholder perspectives, techno-economic simulation and exploitation strategy for leveraging the COHERENT results in the context of its vision of Central Control and Coordination of a wireless system.

The value proposition is of interest to stakeholders throughout the telecom sector: mobile service providers, infrastructure, software vendors and application developers. The gains provided by the COHERENT concept of central coordination and control also synchronize with 5G objectives; C3 is an integral part of the 5G system, allowing the seamless merging of the C3 server into both centralized and disaggregated deployments. The TE analysis provides comparative results on the revenues for the C3 producer and the operator who operates C3 in its network.

Porter's five forces and SWOT modelling are described for presenting the power, threats and competition between the different actors in the value chain.

Lastly, exploitation plans from each partner are provided to show how the results of COHERENT could possibly be used from the partners.

Table of contents

EXECUTIVE SUMMARY 3
TABLE OF CONTENTS 4
LIST OF ABBREVIATIONS 5
LIST OF FIGURES 8
LIST OF TABLES 9
1. INTRODUCTION 10
1.1 GOAL OF THIS DOCUMENT 10
1.2 STRUCTURE OF THE DOCUMENT –RELATION TO THE OTHER WORK PACKAGES 10
2. METHODOLOGIES, TOOLS AND BUSINESS MODELS 11
2.1 MOTIVATION AND DRIVERS FOR COHERENT ARCHITECTURE 11
2.2 CONCEPTUAL OVERVIEW OF THE COHERENT ARCHITECTURE 13
2.3 ANALYSIS OF THE MAIN COHERENT RESULTS AND VALUE ADDED ELEMENTS FROM THE BUSINESS POINT OF VIEW 17
3. BUSINESS ACTORS IN THE COHERENT SYSTEM 24
3.1 RAN VIRTUAL/PHYSICAL INFRASTRUCTURE PROVIDERS 24
3.2 NFV PROVIDER 24
3.3 C3/RTC PROVIDER 25
3.4 CLOUD PROVIDERS 25
4. COHERENT IN PORTER’S FIVE FORCES MODEL 27
4.1 DESCRIPTION OF PORTER’S FIVE FORCES MODEL 27
4.2 ANALYSIS OF COHERENT C3 CONTROLLER AND COORDINATOR WITH PORTER’S MODEL 28
5. TECHNO-ECONOMIC ANALYSIS OF EMPLOYING THE COHERENT ARCHITECTURE 31
5.1 INTRODUCTION 31
5.2 FINANCIAL ANALYSIS 31
5.3 SENSITIVITY EFFECTS 40
5.4 SWOT ANALYSIS FOR C3 PRODUCER AND FOR NETWORK OPERATOR 42
6. EXPLOITATION PLAN 44
6.1 VTT EXPLOITATION PLANS 44
6.2 EURECOM EXPLOITATION PLANS 44
6.3 COMMAGILITY EXPLOITATION PLANS 46
6.4 OTE EXPLOITATION PLANS 46
6.5 FBK EXPLOITATION PLANS 47
6.6 TCS EXPLOITATION PLANS 47
6.7 4GC EXPLOITATION PLANS 48
6.8 UDE EXPLOITATION PLANS 49
6.9 SICS EXPLOITATION PLANS 50
6.10 TP EXPLOITATION PLANS 50
6.11 EICT EXPLOITATION PLANS 51
6.12 AALTO EXPLOITATION PLANS 51
6.13 PUT EXPLOITATION PLANS 52
7 CONCLUSIONS 54
REFERENCES 55

List of abbreviations

2G	2nd Generation Mobile Networks
3GPP	Third Generation Partnership Project
5G	5th Generation Mobile Networks
5G PPP	5G Infrastructure Public Private Partnership
AI	Air Interface
API	Application Programming Interface
ARPU	Average Revenue Per User
BS	Base Station
C3	Central Controller and Coordinator
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CN	Core Network
C-RAN	Cloud Radio Access Network
D2D	Device-to-Device
DAS	Distributed Antenna System
eNB	Evolved Node B
eMBB	enhanced Mobile Broadband
E-UTRAN	Universal Terrestrial Radio Access Network
ETSI	European Telecommunications Standards Institute
EU	European Union
ForCES	Forwarding and Control Element Separation
GWCN	Gateway Core Network
HSS	Home Subscriber Server
IEEE	Institute of Electrical and Electronics Engineers
KPI	Key Performance Indicator
LSA	Licensed Shared Access
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution Advanced
M2M	Machine-to-Machine
MAC	Media Access Control
MANO	MANagement and Orchestration
MBMS	Multimedia Broadcast Multicast Service
MEC	Mobile Edge Computing
MIMO	Multiple-Input Multiple-Output
MIoT	Massive Internet of Things
MME	Mobility Management Entity

MN	Mobile Network
MOCN	Multi-Operator Core Network
MTC	Machine-Type Communication
mmWave	Millimeter Wave
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
Naas	Network as a service
NFV	Network Function Virtualisation
NFVO	Network Functions Virtualisation Orchestrator
NFVI	Network Function Virtualisation Infrastructure
NGMN	Next Generation Mobile Networks Alliance
NPV	Net Present Value
NRA	National Regulation Agency
OPEX	Operational Expenditure
PCC	Primary Component Carrier
P-GW	PDN gateway
PHY	Physical Layer
PLMN	Public Land Mobile Network
PMR	Private (or Professional) Mobile Radio
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RAU	Radio Access Unit
RB	Resource Block
RF	Radio Frequency
RN	Relay Node
RT	Radio Transceiver
RRM	Radio Resource Management
RTC	Real-Time Controller
SA	Service and System Aspects
SC	Small Cell
SDK	Software Development Kit
SDN	Software Defined Network
SME	Small and Medium Enterprises
SWOT	Strengths, Weaknesses, Opportunities and Threats
TCO	Total Cost of Ownership
TE	Techno-Economic

TN	Transport Node
TR	Technical Report
UE	User Equipment
UM	Unacknowledged Mode
UP	User Plane
V2X	Vehicle-to-X Communications
VM	Virtual Machine
VNF	Virtual Network Function
VNFD	VNF Descriptors
VNFM	VNF Manager
VNF	Virtual Network Function
VNO	Virtual Network Operator
WACC	Weighted Average Cost of Capital
WiFi	Wireless Fidelity
WP	Work Package, Working Party

List of figures

Figure 1: Three dimension on the RAN sharing problem 11
Figure 2: Different types of RAN sharing (3GPP TS 23.251) 13
Figure 3: COHERENT architecture with actors 13
Figure 4 COHERENT value chain in Porter style 15
Figure 5: Possible functional splits discussed at 3GPP 21
Figure 6: Anatomy of network slicing image by https://techneconomyblog.com/tag/t-mobile/ 23
Figure 7: Porter’s Five Forces (from [3]) 27
Figure 8: Costs and revenues per year for the C3 Producer 35
Figure 9: Net revenues per year for the C3 Producer 35
Figure 10: Costs and revenues per year for the Operator 38
Figure 11: Net revenues per year for the Operator 38
Figure 12: Cash flow for both C3 producer and Operator 39
Figure 13: Net present value cumulative for both C3 Producer and Operator 39
Figure 14: Effects to the revenues of the C3 producer with changes in the C3 server cost 40
Figure 15: Effects to the revenues of the C3 producer with changes in the C3 server number 41
Figure 16: Effects to the net revenues of the operator when the number of customers’ changes 42
Figure 17: Effects to the net revenues of the operator when the ARPU changes 42

List of Tables

Table 1: Actors in the COHERENT architecture ... 14
Table 2: Base Scenario in Mobile Network: the network operation ... 16
Table 3: General costs and revenues of the C3 Producer ... 32
Table 4: COHERENT techno-economic analysis from C3 Producer's point of view ... 34
Table 5: General costs and revenues of the Operator ... 36
Table 6: COHERENT techno-economic analysis from Operator's point of view ... 37
Table 7: SWOT analysis for the C3 producer ... 42
Table 8: SWOT analysis for the Operator ... 43

1. Introduction

According to Cisco Visual Networking Index “Mobile data traffic will grow at a CAGR of 47 percent from 2016 to 2021”. So mobile network operators are facing massive data growth but their revenue is usually not following this trend directly. This means that the operators need to provide the capacity in more efficient way.

Moreover, mobile operators need to re-evaluate their network architecture due to advanced requirements of various applications. So it is crucial to identify the most flexible and cost-effective infrastructure model for next-generation services. In particular, the new mobile network needs to provide capacity exactly when and where it is required.

Another challenge is that despite the fact that LTE and next generations of mobile networks offer lower price per bit, operators cannot switch off their legacy 2G / 3G networks. Thus operational costs need to be optimised by outsource or shared operations.

There are also high expectations related to new markets toward which the 5G technology is evolving. These are markets associated with machine to machine (M2M) type communication and Ultra-Reliable Communication (URLLC). However, these markets are not yet well understood by operators and the forthcoming battle over the Internet of Things is still ahead of mobile operators. Therefore flexibility of configuration and operation are probably the most profound features expected from future 5G networks in order to provide these new types of services. A new sharable architecture is needed which can be flexible, easily manageable to satisfy the needs of the end users. The network controller and the agents at the RAN level have to be highly adjustable to accommodate changing traffic characteristics such as bandwidth and latency requirements.

1.1 Goal of this document

The goal of the deliverable D7.4 is to define the business benefits of the significant results produced in COHERENT project, such as the C3, the network abstractions and programmability, the business benefits of virtualised base stations and the benefits brought by the RAN and spectrum sharing concepts. In addition, this document performs a techno-economic analysis to motivate and highlight the gains of adapting the COHERENT C3 global controller approach. Lastly, it describes the exploitation plan of each partner.

1.2 Structure of the document –relation to the other work packages

This document is structured as follows: Section 1 provides an introduction to the deliverable. Section 2 describes the methodologies and business models used in the report. The benefits brought by the main drivers of COHERENT are detailed in this section. Section 3 describes the business actors of COHERENT. Section 4 describes the Porter’s Five Forces Model and section 5 provides the techno-economic analysis for the COHERENT C3 global controller. Finally, section 6 details the exploitation plan of every partner for the COHERENT project. Section 7 summarizes the main conclusions of this report.

2. Methodologies, Tools and Business Models

2.1 Motivation and Drivers for COHERENT architecture

The COHERENT architecture enables dynamic and flexible programming of the control plane, which has consequences in the efficiency and handling of the resources of the system. New usages and paradigm, like RAN and spectrum sharing and slicing (see subsections) need improved systems flexibility and dynamic resource management. These can be proven to be powerful drivers for the support of COHERENT concept/architecture.

- Sharing the Infrastructure: The switch fabric and the core network/system (CPU, storage, memory) are virtualized and shared between tenants, for the deployment of physical or virtual network elements (e.g. SGW, MME, HSS in LTE).
- Sharing the RAN: Different sharing schemes and scenarios exist where the focus is concentrated on the way that base station (eNodeB in LTE) resources are shared, like Resource Blocks (RB) in frequency/time/space domain.
- Sharing the Spectrum: This is related to techniques like carrier aggregation with flexible fragmented spectrum usage and dynamic spectrum sharing where spectrum is shared between different operators. Cognitive radio techniques fall under this category.
  In the evolved LTE, one observation that cannot be skipped is that Network Slicing is closely related to the concept of RAN Sharing. In principle, different kinds of active infrastructure sharing vary in terms of the degree of sharing. By means of resources actually three dimensions of the RAN Sharing problem exist:

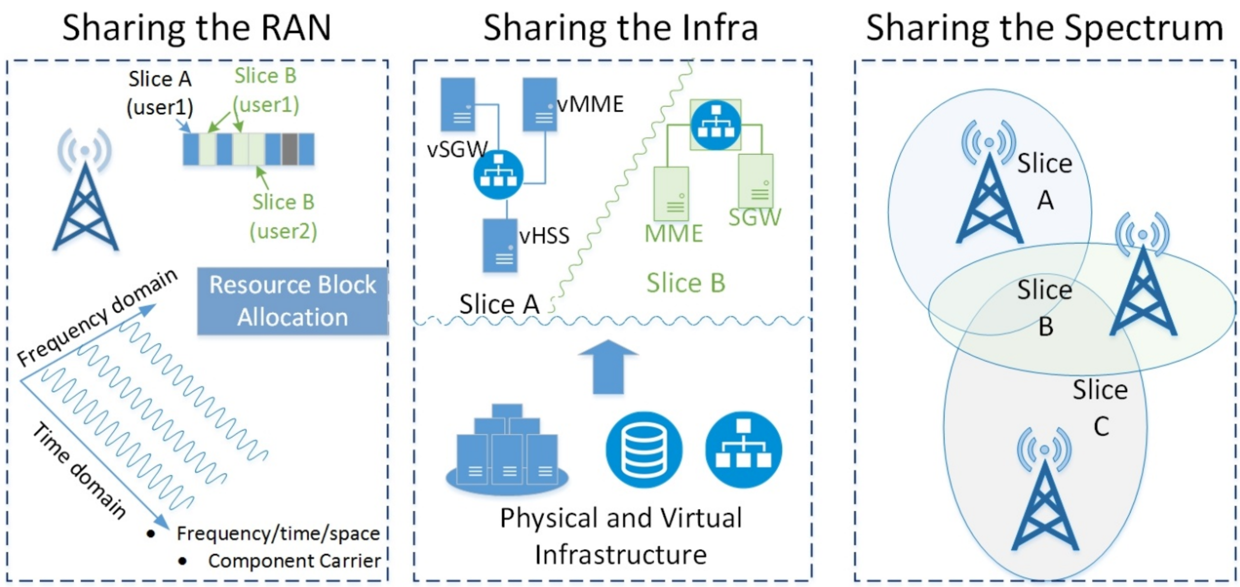

Figure 1: Three dimension on the RAN sharing problem

2.1.1 Slicing

A network slice is a logical network that comprises a set of Network Functions and the corresponding resources required to provide End-to-End support for specific network services, network applications and radio configurations. The network services may be specific to some particular use cases or business applications. A network slice can span all domains of the network: software programs running on cloud nodes, specific configurations of the transport network, a dedicated radio access configuration, as well as settings of wireless access entities. Different network slices may contain different network applications and configuration settings, and it can be shared by multiple (virtual) network operators.

A network operator may provision a network slice to a customer, e.g. a corporate or a government agency, in order to isolate the communications and to provide extended robustness, with differentiated quality of service per slice (URLLC, eMBB or MTC). Then, different scheduling operations may apply per network slice basis, which means a complete separation of slices not only at Core Network (CN) level but also at Radio Access Network (RAN) level, including PHY resources. The operator may also decide to differentiate between different subgroups of the same customer, with respect to their service requirements for voice, video or small data transmission. For example, different teams of public safety officers may need to be connected to different instances (with different characteristics in terms of security and/or robustness, and/or latency) of the network slice reserved for that public safety agency. Then, the slice could scale up until a certain degree, but if more capacity is required the network could instantiate an additional slice (e.g. a spare slice). In the case when an additional slice is created from already used resources, it may be necessary to pre-empt it, which may increase the number of blocked services and decrease the QoS for some other active users, which has to be avoided to a certain extent. Another challenge is to define the size of the slice and to find the trade-off between the number of users and the number of slices, as a function of service type.

All these new use cases require more flexibility on both network and user side, with potential modifications of the RAN, as we know it today. For example, network slices have to be instantiated, configured and properly controlled to insure isolation at all levels from PHY Layer to Application Layer. The COHERENT APIs would allow RAN re-configuration with respect to both operator and user needs, in a very flexible manner. Moreover, differentiation between time-critical (such as run-time phase where scheduling operation may be involved) and time-constrained phases (but not-time-critical, such as slice preparation or slice instantiation phases) would allow deporting non-essential processes in the cloud, while saving computational resources at the RAN side. For example, the time-constrained phases which may refer to slice preparation phase (e.g. creation of a slice), or may refer to slice instantiation phase (e.g. configuration of shared/dedicated resources to be used per slice) may require different instantiation procedures and different control levels, by different (virtualised) entities located in the cloud.

2.1.2 Spectrum/RAN sharing

A side effect from the densification of cells is the increase of the infrastructural CAPEX and OPEX. This leads to the creation of new business models, where multiple Mobile Network Operators (MNOs) share the same passive infrastructure such as masts and backhaul links in order to save costs. On top of that, a second level of active sharing can happen, where MNOs share the network equipment as well as provide wholesale access to Mobile Virtual Network Operators (MVNOs), allowing them to provide voice and data services using part of the available resources. However, this can pose a significant challenge for the management of the RAN, since the requirements of operators in terms of the radio resources and the applied policies of scheduling and mobility management can constantly change based on the needs of their subscribers and the underlying setting. The control and management of such operations can be greatly simplified through the introduction of programmability in the RAN.

Indeed, towards 5G communications and with the emergence of virtualization technologies, the concept of RAN sharing is gaining significant attention. The reason is that NFV and SDN mechanisms now give the ability to physical Radio Access Network (RAN) owners to open their infrastructure to third parties and virtual operators. However because of trade-offs between performance and fairness no solid mathematical framework exists that is able to provide provable sharing guarantees, between different MVNOs when sharing eNodeB resources. In addition there is no available open-source solution that allows for enhanced programmability features in the eNodeB in a way where each tenant can exploit, implement his own scheduling policy and evaluate it under multi-tenant operation.

3GPP has defined and ratified different kinds of architecture with varying degrees of sharing (3GPP TS 23.251, TS 22.951 specification): Multi-Operator RAN (MORAN) only equipment is shared; Multi-Operator Core Network (MOCN) both spectrum and equipment are shared and Gateway Core Network (GWCN) both the RAN and some elements of the core network are shared.

In MORAN architecture, as you see in Figure 2, just the base station is shared but spectrum is not the same. In MOCN architecture spectrum is also shared. In GWCN the gateway part of core network is also shared in RAN sharing scenario.

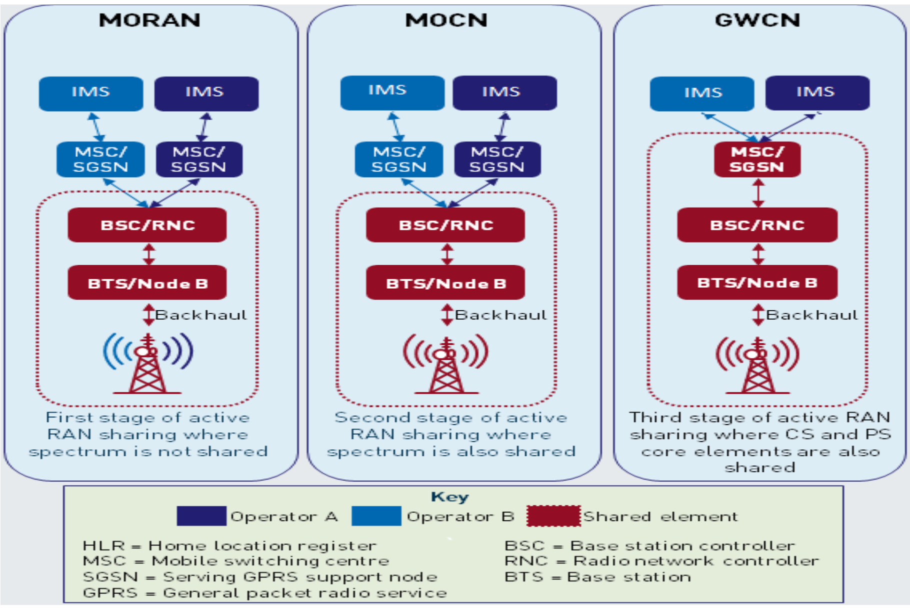

Figure 2: Different types of RAN sharing (3GPP TS 23.251)

2.2 Conceptual overview of the COHERENT architecture

This section describes the actors who are involved and may benefit from the COHERENT architecture. The actors and their involvements in the COHERENT architecture are shown in Figure 3.

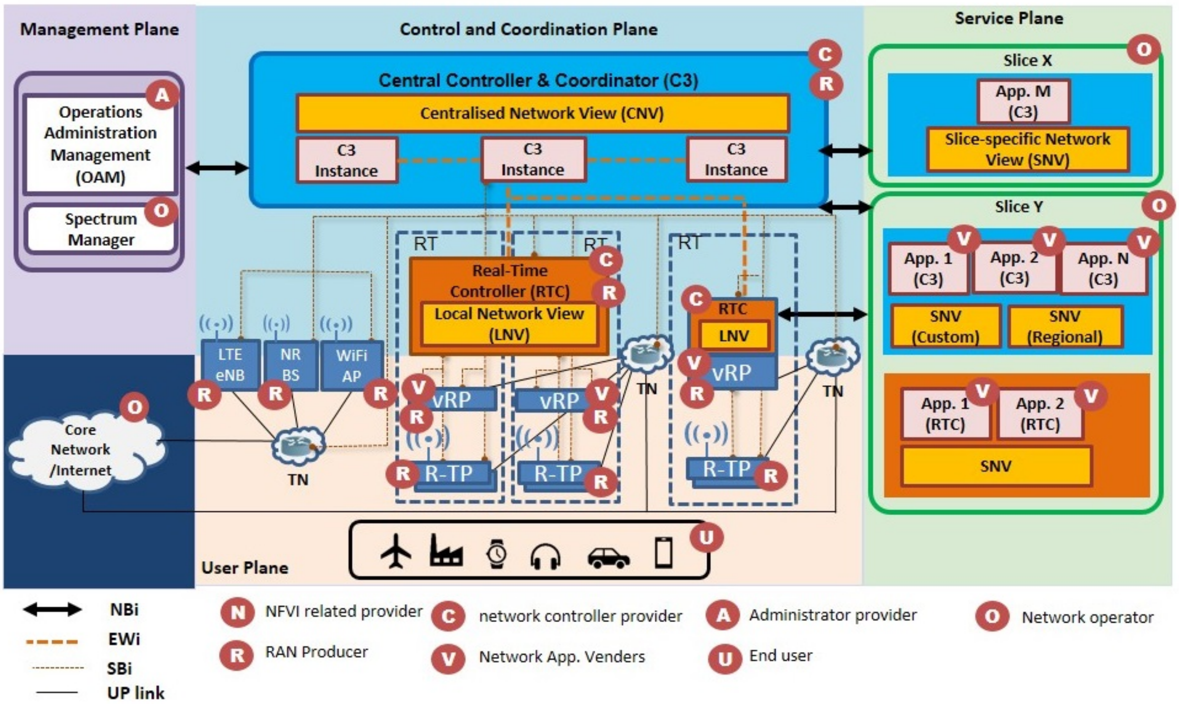

Figure 3: COHERENT architecture with actors

The actors related to COHERENT include end user, administrator provider, application provider, controller provider, network operator, RAN provider, and NFVI operator. Description of these actors is provided below:

Table 1: Actors in the COHERENT architecture

Identified business actors	
NFVI operator (V):	This actor offers access to the data center for the other actors and uses models like network as a service (NaaS), Platform as a service (PaaS) and Infrastructure as a service (IaaS). Examples are the OpenStack cloud platform, Kubernetes, JuJu, TOSCA, etc.
RAN producer (R):	This actor produces the RAN infrastructure which is used by the end users to access the network. Examples are Ericsson, Nokia, Huawei, ZTE, etc.
Network operator (O):	This actor runs the network and provides requested services to end users. Examples are Deutsche Telekom, Korea Telecom, NTT, SK Telecom, Telefónica, Swisscom, Telecom Italia, OTE, Verizon.
Controller provider (C):	This actor produces and provides the C3/RTC elements who controls and coordinate the RAN infrastructure. This is a new actor who is foreseen in the COHERENT environment.
Application VNF provider (V):	This actor connects the appropriate VNFs to provide the virtualized service to the end user.
Administrator provider (D):	This actor is the one who administeres the whole network.
End user	The C3 end user is the Wireless Network Operator or the RAN provider, who may subcontract the services of the .

2.2.1 Value chain

The value chain created from the platforms, architecture and concepts of COHERENT is described in the following subsections.

2.2.1.1.1 Value chain definition

Based on definitions in [1] a value chain is “a high-level model developed by Michael Porter used to describe the process by which businesses receive raw materials, add value to the raw materials through various processes to create a finished product, and then sell that end product to customers. Companies conduct value-chain analysis by looking at every production step required to create a product and identifying ways to increase the efficiency of the chain. The overall goal is to deliver maximum value for the least possible total cost and create a competitive advantage.”

In the case of COHERENT:

- Efficiency of the chain is related to the cost of providing wireless services to end users.
- The raw materials represent the entities of the wireless network supplied by infrastructure and software producers.
- The finished product is the operational wireless network.

For limiting the scope of our analysis to aspects relevant to COHERENT, we will not address here the marketing of services to end users.

2.2.1.1.2 Porter-style value chain for COHERENT

The best way to determine the COHERENT impact on the value chain is to consider the Porter-style analysis of the value chain, based on the top-down view, from Services through Assets to Producers. While Porter uses "manufactures", we use "producers" as a better description of automatic activities for the multiplication of hardware and software developments.

The value chain is split into three levels, as is shown in Figure 4.

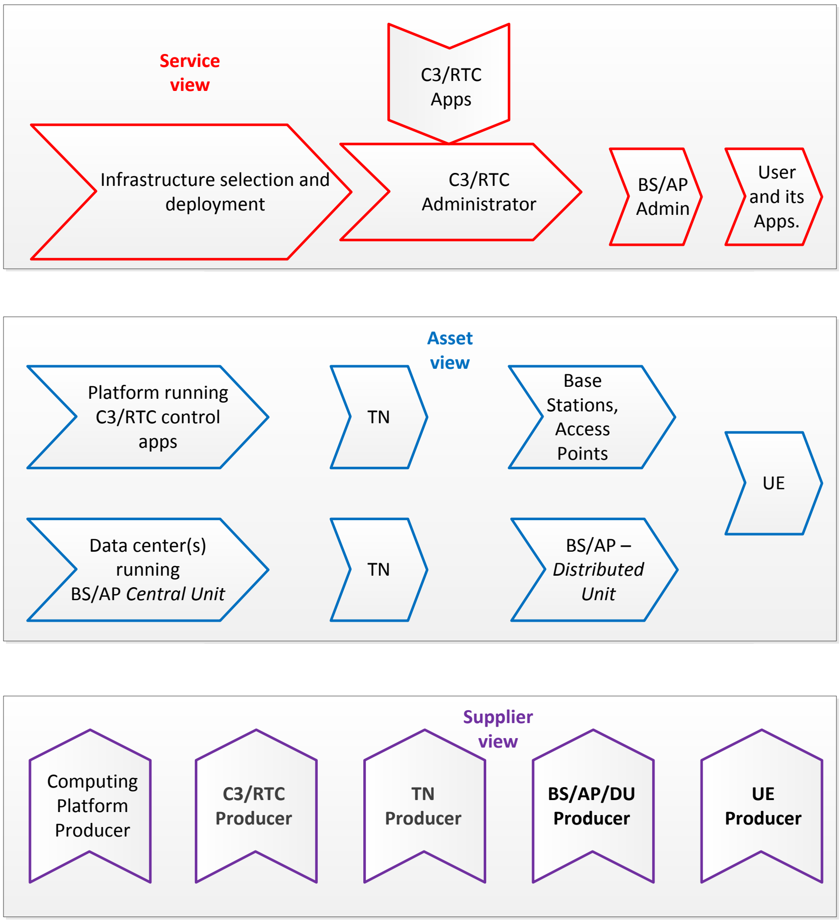

Figure 4 COHERENT value chain in Porter style

1. The service perspective tries to **represent the activities** impacted by COHERENT for offering of wireless communication services to end users. Below the asset level is presented.
2. The asset level is used for providing a **value description of network entities** needed or impacted by COHERENT. The service and asset levels are in strong interaction, as a control service application can impact on the cost of network entities in the asset level.
3. The supplier level indicates the producers involved in COHERENT ecosystem.

2.2.2 Impact of COHERENT in the value chain

This section analyses of the impact of COHERENT architecture. It describes the impact of COHERENT C3, RTC and NG in terms of new business actors, new revenues and how the businesses can change with COHERENT in order to add value to end users.

2.2.2.1.1 The Service View

Working upstream from the user, their apps and data are communicating to the Internet (cloud providers, internet content) via the following activities:

1. The service provided by the BS/AP administrator. This may be the users themselves (such as a residential scenario), or designated employee(s) of a company or public area, or the Mobile Network Operator. This administrator is responsible for ensuring that the BS/AP configuration is done such that the UE can be connected to BS/AP. The configuration may include security or accepted use restrictions, for example group access restrictions.

2. The service provided by C3/RTC administrator, selecting the used control applications and making sure that they are connected only to the compatible APs/BSs.

3. The service provided by the Mobile Network Operator or a designated team for providing network-wide connectivity of the User to Internet, after the selection and deployment of the suitable equipment.

2.2.2.1.2 The Asset View

Again looking back from the User, the assets involved in the above chain are:

1. Devices used – such as smart phones or other terminal types (tablets, connected objects).
2. APs/BSs, connecting to the user terminal through radio or alternatively, in the centralized 5G deployment, the Distributed Units of the BS/AP.
3. The transport Network (TN) connecting the radio entities to:
    - a. Computing platform containing the C3 or RTC;
    - b. In mobile network the TN will also provide the connectivity to the Core;
    - c. In centralized deployment is needed a TN for CU(Central Unit) – DU (Distributed Unit) connection.
4. Computing platform containing the C3 or RTC software and a data-base for memorizing the Network Graphs. Even if shown as a separate entity, in the first stage of 5G deployment is more likely that C3 asset will be deployed in the data center hosting the CU, while the RTC can be also located in the data center or can be hosted by one of DUs.
5. C3/RTC as standalone entity, possibly located in a data center.

2.2.2.1.3 The Supplier View

Complementing the ecosystem are the producers of the assets involved in the chain. This includes both producers of physical assets and software, tools and such like.

2.2.2.1.4 Cost impact

We will consider the cost impact on Operator assets in several scenarios:

Table 2: Base Scenario in Mobile Network: the network operation

	Base line	Type of coordination	Existing situation	C3 functional impact	C3 cost impact
1.	3GPP Rel. 13 Note1	Distributed, no inter-base station hierarchy	Each BS contains software for X2 distributed operation based on smart algorithms	Distributed X2 is replaced by centralized control >Algorithms run in C3/RTC	Lower procurement (infrastructure) cost for BS/AP
2.	3GPP Rel. 13 Note2	Distributed, no inter-base station hierarchy	Each BS contains X2 interface, requiring high transport capacity in UL	Distributed X2 is replaced by centralized control -> Number of needed connections and their	Lower cost Transport Network

				capacity is reduced	
3.	3GPP Rel. 13 Note3	Distributed, no inter-base station hierarchy	High interference, higher power consumption	Reduce power consumption	Lower Operator operational costs
4.	3GPP Rel. 14	Introduces infrastructure sharing concept	No operational concept for infrastructure sharing	Introduces C3 as coordinator of dynamic allocation of resources per operator	Lower Operator infrastructure and operational costs
5.	3GPP Rel. 14	Introduces E2E slicing concept and slicing isolation	No operational concept for slicing isolation	Introduces C3 as coordinator of dynamic allocation of resources per slice	Higher Operator revenues

2.2.2.1.5 Performance impact

The performance impact of COHERENT is evident given the increase in data rates due to better control of resource (time, frequency, power, space) allocation and multi-connectivity. However, it is difficult to quantify this business-wise, as the Operators do not expect an increased ARPU from Mobile Broadband subscribers.

However the Operators expect to increase the revenues when adding new services, such as Cellular V2X. V2X implies low handover time, enabled by C3 selection of the TRP suitable for a given vehicle.

2.3 Analysis of the main COHERENT results and value added elements from the business point of view

This section describes the benefits brought by the different drivers and value added elements of the COHERENT architecture.

2.3.1 Business benefits of slicing

Slicing can be the change required in the industry to enable growth. Network slicing offers both customization and optimization of the network to meet market demand for specific end-to-end requirements. In fact, slices can be customized to meet the needs of each application and can be also optimized by a huge variety of characteristics, including latency or bandwidth requirements. To give a simple example, applications like remote operation of machinery, tele-surgery and smart-metering all require connectivity, but with vastly different characteristics.
The potential benefits of slicing are discussed in the following: cost reduction, product management improvement and greater agility.
Build, develop, and maintain services: Slicing can help Service Providers (SPs) to develop services that are more relevant to their customers, opening up new revenue opportunities. In this way, network slicing will benefit many industries by offering a smart way to segment the network and support particular services. It will enable SPs to better control the QoS delivered to their clients and better penetrate the enterprise segment. The upcoming offered highly differentiated services will be able to attract this enterprise segment and bring more profits to industries.
Agility and flexibility: Slicing could provide for the logical separation of virtual networks for different services, which would be independent of each other. This means that teams within the organization could similarly become more independent in how they work; changes to a particular slice could be made without having to consider the implications across the entirety of the network and all stakeholders or customers involved. Development efforts on new and existing services could be decoupled from each

other and from the underlying infrastructure. They could each progress under their own constraints and timelines, but still benefit from common infrastructure. For example, if the operator wanted to introduce something new to the current core services, there is no need to redesign the whole network every time.
Cost and efficiency: New networks have to support all potential applications and use cases and must be built to serve needs not well met by existing networks. Therefore, the network of the future needs to be designed in a way to address this feature by removing unnecessary functionalities and adding new technologies. Using virtualised slices could enable the cost-effective use of resources by having a common underlying infrastructure, where resources can be partitioned, as well as shared, to be optimised, so that total cost of ownership (TCO) may be reduced. By decoupling the physical and virtual infrastructure, an operator would be able to have a single, shared physical infrastructure and run slices on top for each of their operations, maximizing the use of their resources.
Management: Having separate slices for different types of customers could allow the operator to better manage services, rather than have to operate them all within one network. This could have further benefits when it comes to designing revenue models and the associated systems for particular sets of customers. In the short term, there is an opportunity for operators to apply this concept to better manage transitions from legacy services. Also, supporting hybrid networks (2G/3G/4G/5G) and hybrid virtualised/non-virtualised legacy networks will also present notable transition challenges.

2.3.2 Business benefits of spectrum management

C3 contains dynamic spectrum management. In the dynamic spectrum management, the stakeholders are Incumbent, Licensee, National Regulatory Authority (NRA) and possible external C3 spectrum management service provider.

Incumbents can avoid costs related to spectrum changes. Generally, there is a pressure to increase the number of users in a defined allocated spectrum and to allocate more capacity for mobile broadband use. Dynamic spectrum management makes it possible to add users on the incumbent bands so that the incumbents can still use their radio systems without harmful interference. The device and system investments have a longer payback time due to extended period of use. Possibly, they can enter spectrum leasing business by directly getting revenue from the licensees.

Licensees can build their network on dynamically managed spectrum resources earlier than if they had to wait for clearing the band first. The dynamically managed spectrum can be used for increasing both coverage and capacity in the mobile networks. Dynamic spectrum management improves possibilities for increasing the spectrum efficiency and such decreasing the cost that an operator pays for spectrum rental. Dynamic spectrum management allows new business opportunities for example for micro-operators to run networks on industrial sites.

National Regulatory Authority benefits from dynamic spectrum sharing by improving the efficiency of spectrum use, simplifying spectrum management through higher level of automation, and getting a better awareness of real spectrum use.

An external C3 spectrum management service provider gets revenue by developing, integrating, licensing, maintaining, and providing spectrum management software and services. The services can be provided directly by C3 spectrum management service provider or they can be integrated into management systems of incumbents, licensees, or the national regulatory authority. C3 spectrum management service provider can add value to the customers by carrying out big data analysis in the dynamic spectrum management data.

2.3.3 Business benefits of network abstraction, network programmability, RAN configuration and CU-DU separation

Network services and functions have previously been performed by complicated boxes based on proprietary hardware and software. The operations of them are costly and time-consuming because of the problems of scalability, elasticity, and lock-in. SDN allows network providers to develop and deploy new services in a timely manner and automate the network configuration by introducing network programmability. COHERENT architecture enables network programmability in the form of SDN paradigm by providing open application programming interfaces (APIs), separation of the control and data planes and the layers of abstractions.

How to deploy, configure and manage the devices in mobile networks is completely changed by network programmability. Instead of configuring them in the traditional way, the desired behaviours or parameter settings of network devices are programmed using high-level programming languages, e.g. Python through application programming interfaces (APIs). Consequently, network programmability enables the ability to define/update network policies, and to agilely deploy RAN functions based on the demand. The potential benefits introduced by network programmability which dramatically improve the speed of 5G evolution in mobile networks, will be introduced below.

Current RAN modules in the infrastructure are configured/changed as part of the network operations. They are normally done by manual command line interactions to the RAN functions in the boxes. Nevertheless, programming for configuration and operations means to orchestrate the infrastructure using software through programmatic interfaces. Therefore, network programmability improves network efficiency and operation agility by enabling RAN configurations to be aligned with business requirements. Simple command line interactions may not be able to handle large amount of updates and policy changes which involve many configuration actions to a large number of RAN devices. The risk of human error is therefore very high. Network programmability could also achieve operation automation and reduce the risk of human error. This could help maintain the operating cost when the network is becoming larger and more complex.

- **Simplified development of control applications**

New applications and network mechanisms could be easily developed when the network intelligence is programmable. However, programming network behaviours would require physical changes to the network devices. The development of traditional RAN services/applications were closely coupled with particular radio access technologies (RATs), e.g. WiFi or LTE. The critical challenging is to allow the application developers modifying the network functions without having to know the hardware implementation details in any kind of RATs. COHERENT architecture provides northbound APIs to abstract the radio access functions. The abstraction is COHERENT is RAT agnostic. The complicated abstraction of underlying radio access infrastructure simplifies the development of RAN applications by allowing the developers to program the RAN behaviours from their perspective.

- **Rapid creation of new services**

Business must be able to promptly adapt to the swift changes of the mobile network market. Agility is the key to success. Network programmability offered in the COHERENT architecture is the enabler for providing rapid creation and dynamic change of the development of new services. As mentioned previously, network programmability could simplify the application development. Furthermore, it could provide agile configuration and operation automation. In summary, it is possible to design, configure and deploy new applications and services in shorter time than it was previously.

For enabling these features, common and easily understandable APIs must be available in order to set new service requirement to the network. COHERENT is working in this field and service providers are also interested to 3GPP work on this field. As an example, at 3GPP SA plenary meeting #75 (in March 2017) it has been approved a new Study Item on Common API Framework for 3GPP Northbound APIs, and now the SA6 Working Group (responsible for application layer functional elements and interfaces such as Mission Critical) has started investigating the topic. The new SA6 Study on Common API Framework for 3GPP Northbound APIs will consider their development, specifying common capabilities so that all Northbound APIs function similarly (see draft TR 23.722 for more information). As a result of this action, it is obvious that 3GPP seeks to provide standards for integration with a growing range of “vertical” business sectors - those services can be exposed within the operator network or to third parties in other networks, which may increase the business opportunities also for different (third-party) application service providers, meaning new potential business opportunities.

- **RAN configuration flexibility**

From the point of view of the infrastructure and service-oriented network 5G technology is a revolution that will represent the first step towards higher system flexibility and mobile system re-configurability. In some sense, the flexibility can be a consequence of the programmability, but some level of flexibility already exists in current mobile systems, as it will be explained later on. In this subsection we are trying to evaluate the benefits of network programmability and central databases with respect to technical innovation (such as radio access and network flexibility) and with respect to business innovation (such as both reduced OPEX and potentially reduced CAPEX).

First of all, it is important to mention that LTE (4G) already has some level of inherited flexibility in terms of spectrum bands, flexible bandwidth allocation, and interoperability with other systems and radio technologies, and for this reason LTE has become the global de-facto standard for next generation mobile communication with over 480 LTE network deployments in 157 countries [2], as in January 2016. This trend applies also to 5G, where the “flexibility” is oriented towards the support of multiple services even with diverse requirements. A 5G network could be therefore adapted to support 1) mobile broadband communication (enhanced MBB), 2) ultra-reliable and low latency communications (URLLC), 3) or massive machine type communications (eMTC). In terms of radio access and core network design, or different quality of service Key Performance Indicators (KPIs) such as total supported throughput, latency and bit error rate, it is somewhat obvious that previous potential use cases require different configurations (and which to some extent are actually conflicting with each other).

Different type of users may benefit from this architecture, because it will allow new markets to evolve (e.g. vehicular, train, public safety and mission critical, etc.) but operators would also benefit because in this way they could reconfigure the same radio access for different type of services and different purposes. The same physical entity (AP, eNB, gNB, etc) will be able to react differently in a different context, with direct and most importantly real-time control through APIs. In this context, central data bases are important to capture a sufficiently large and realistic view over the entire network, in order to continuously adapt the entire system to new (service) demands, in a real-time manner, without any service disruptions. From the point of view of a User Equipment (UE) all actions will be transparent, since any potential system and radio access new configuration will not affect end-user equipment.

With the evolution towards 5G, now operators are conducting field trials of new radio technology that operates both above and below 6GHz. For the core network part, operators’ efforts tend to be focused toward testing and deploying NFV and SDN functionality, which is supposed to increase the re-programmability of the network, with reduced OPEX. CAPEX may be higher for the initial deployments, but at the long term, OPEX will alleviate the initial investment costs.

For many operators, the radio network is regarded as an appropriate domain for initial field trials, with an emphasis on lower-layer functionality. These trials tend to be less costly and easier to conduct in isolation from other systems. Therefore, on top of the use cases previously mentioned (eMBB, URLLC, eMTC), which would require different configuration of the radio access and core network, network operators are also searching how to deport functions from the RAN protocol stack closer to the CN. Firstly, this would help for example to reuse several higher layer functionalities for different radio access points, but also to reduce the costs of the radio access point itself which will implement only low-layer functionalities. Secondly, separation between real-time control and less time-critical control (as for example for slicing purposes where MAC requires real-time scheduling while slice allocation for example less time-critical control) could allow new business opportunities for new market players. And last but not least, this would require powerful databases which may again create new business opportunities for 3rd party applications, but also for database providers (which could be different).

Furthermore, in parallel to 5G field trial activities, many operators are testing and deploying core network technologies like NFV and SDN. For these reasons, telecom software investments and business process transformations are required to support the diverse business models and system architectures being proposed for 5G. Underinvestment in these areas could restrain the rate at which meaningful 5G commercialization can be achieved.

3GPP has proposals to bring flexibility to 5G RAN architecture by functional split through the various working groups and COHERENT is in line and beyond this, therefore having good business benefits. The 3GPP flexibility aims to hit the areas of RAN, core and application level, in order to provide new services & new potential functionalities through a new radio, a novel network architecture, new protocols and algorithms, without neglecting new means & methods to control and to configure/re-configure those protocols and algorithms (which could be achieved through APIs for example).

For example RAN3 considers different splitting options as represented in the figure below, with different components in the distributed unit (closer to the radio access part) and different components in the central unit (closer to the core network part).

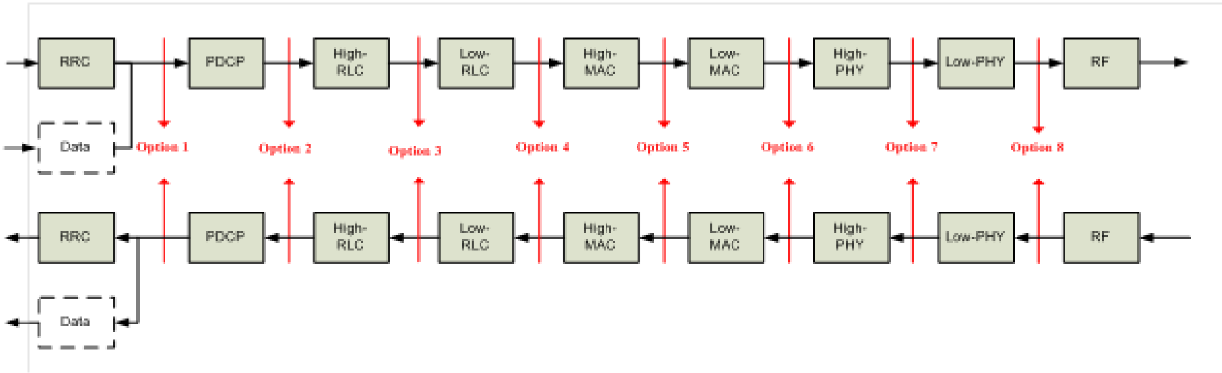

Figure 5: Possible functional splits discussed at 3GPP

During RAN3 meeting #95bis (April 2017), RAN3 has decided to select (higher-split) Option 2 (based on centralised PDCP/RRC and decentralised RLC/MAC/PHY) for normative work in Release-15. It is already clear after the October meeting that part of the DU and UE control and coordination functions will be located in CU (Central Unit).

Other splitting options, like option 6 or 7, are much closer to the PHY layer and, if standardization work will continue and will be finalized, they could have an impact on Cloud RAN hardware and implementation, in particular of remote radio head equipment. Option 6 for example considers a MAC-PHY split, where physical layer and RF are in the distributed unit (DU). Upper layers are in the central unit (CU).
Option 7 for example considers an intra-PHY split – where part of physical layer function and RF are in the distributed unit (DU).

Other options are also described in TR 38.801.

Hereafter we describe some activity which shows 3GPP interest on this topic, which will continue.
Moreover, during RAN plenary meeting #75 (March 2017), at RAN3 2 major Study Items on CU-DU split have been approved one for NR and another one for LTE:

1) New SID on Study on CU-DU lower layer split for New Radio**:** RP-170818. The objective of this Study Item is to continue and complete the study for the CU-DU lower layer split.

2) New SID: Study on Architecture Evolution for E-UTRAN: RP-170843 Starting from NR CU and DU in higher layer split, the goal of this Study Item is to target a unified architecture for E-UTRAN and NR, in light of functional split and enabling easy CU/DU deployment, while identify the impacts on legacy functionality.

On top of all this, SA5 work group - dealing with network management of orchestration, currently reuses concepts from ETSI NFV and other standardization bodies that work on NFV/SDN technical area. We can cite at least the following contributions:

- General technical contributions, with respect to networks including virtualized network functions (for LTE, Rel-14) Technical Specification TS 28.500 "Management concept, architecture and requirements for mobile networks that include virtualized network functions", 27 pages, 100% complete. Four others specifications dealing with configuration, fault, performance and lifecycle management are 60 - 80% complete.

All these applications and implementations resulted from increased network flexibility will obviously require more control, and therefore the databases become of huge importance in order to collect real-time and non-real time information. This would also probably require database providers (meaning new potential business opportunities) which may be seen as third-party providers helping to store and to have a correct interpretation of the stored information, information that operators may use for adapting their network performances.

Operators usually encourage works on radio access and core network flexibility, for reasons related to energy efficiency, maintenance, reconfiguration of equipment, essentially to reduce OPEX (and potentially CAPEX). However, for the vendors is not obvious since it means more costs involved in development, and it could also affect their market benefits since different network entities & equipment from different vendors would now be able to inter-connect much easier with each other, and therefore this might divide the system in different (smaller) components, meaning that a vendor will not sell anymore an entire solution (at higher cost) but potentially a small part of a solution (at much lower cost). On top of this, the level of competition may also increase since new vendors may appear - which may also have impact on decreasing the cost of network entities & equipment from legacy vendors and equipment providers.

2.3.4 Business benefits of virtualized base stations, RAN-sharing to MVNO

After years of controversy in the industry, operators have now started to believe in the huge potential and superiority of RAN-sharing. Tier-one operators in the world, such as Vodafone, Orange, T-Mobile, and Optus, have expressed general interest in the RAN-sharing solution, and are now in the process of performing tests on RAN-sharing, or have required RAN-sharing to be a feature for network admission, especially in Europe.

An important aspect of RAN-sharing is enabling virtualization on base stations. Virtualized base stations bring new benefits for operators:

- **Cost reduction:** Deployment of selected network functions of base stations on general purpose hardware platform reduces operator costs as the complexity of base band units and their maintenance will be simplified. The investments into high-volume general purpose hardware platform are expected to be less than into proprietary solutions.
- **Easier migration to 5G:** Virtualization of the base station will allow faster roll-out of new 5G functionalities.
- **New services:** Flexible architecture of virtualized base stations allows introduction of new services faster and easier.
- **Better integration:** When operator maintains multi-RAT and multi-vendor network, virtualized base stations allows tight integration of base station software for different RATs and from different vendors. Through tight integration, KPI improvement and time-to-market will be significantly improved.
- **Scalability:** Relying on virtualized base stations improves scalability of software and hardware architecture of operator's network.
- **Efficient network dimensioning:** Virtualized base stations will allow dimensioning the network in operation by dynamically allocating HW resources to virtualized base stations.

Virtualised base stations also bring new opportunities for vendors:

- **Lower time-to-market:** Base station vendors can benefit from reduction of costs and development time for designing and testing virtualised network functions previously optimised for the proprietary hardware platform.
- **Easier market entry:** Virtualised base stations offers new business opportunities for new software design companies beyond traditional vendors with proprietary hardware architectures.

2.3.5 RAN-Sharing between different operators - Cooperation and Business Benefits

As Figure 6 demonstrates, we could have different level of cooperation between Operator and VNOs. This architecture simply shows that cooperation can be defined in different layer and task services for different kinds of network entities. The green part is the shared part of operation between two Operators A and B.

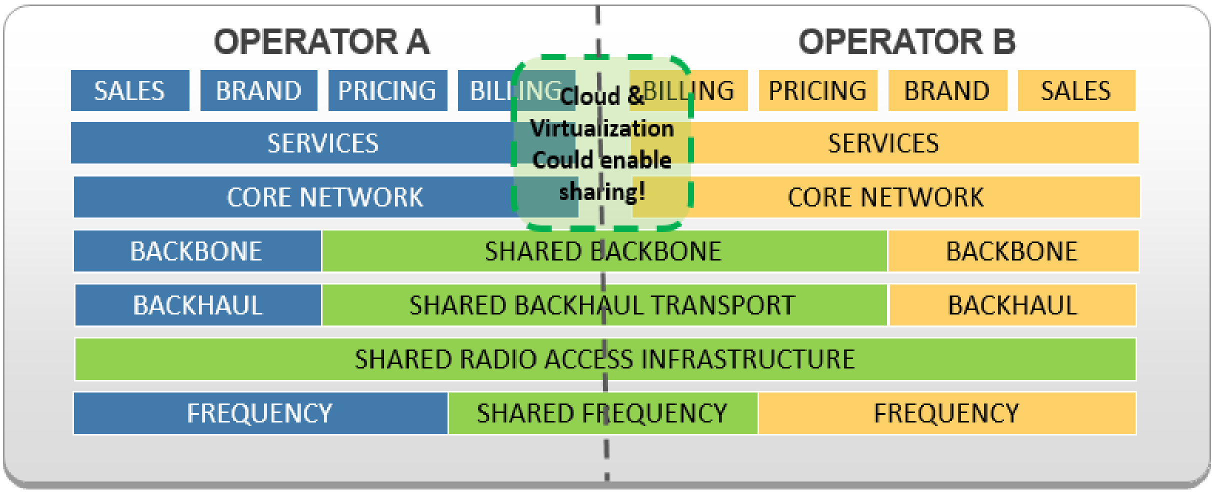

Figure 6: Anatomy of network slicing image by https://techneconomyblog.com/tag/t-mobile/

Another dimension is related to reducing pressure for operators as explained below.
RAN-sharing involves a MOCN solution and a Logic RNC solution, depending on whether the carriers are shared or dedicated. Operators can broadcast independent PLMN IDs on their own carrier, while UEs can receive messages only from their home operators, thus ensuring the accurate network selection. The solution supports flexible networking. The shared RNC can connect to other shared RNCs or non-shared RNCs, so normal handover can be performed between RNCs of the same operator, thereby ensuring seamless connection. Under the shared RNC, either shared NodeBs or non-shared NodeBs can be connected; thus operators can deploy partial network sharing with the smallest granularity. As a result, the overall capacity of the RNC can be made full use of, and networks of the same operator can logically become an independent entity. The solution also supports independent deployment of services in the shared network.

3. Business Actors in the COHERENT System

This section analyses the main business actors associated with COHERENT architecture and describes possible business relationships between the actors based on Porter's five forces model.

3.1 RAN Virtual/physical Infrastructure Providers

RAN Virtual provider will build its revenue stream by operating on abstraction of the physical network maintained by the physical infrastructure provider. RAN Virtual provider will have own customer base, but do not own infrastructure. RAN Virtual provider involved in COHERENT RAN sharing and multi-operator cooperation concepts:

- RAN sharing among heterogeneous mobile networks

- The RAN sharing concept aims to allow the RAN Virtual provider to dynamically use available infrastructure in the network which belongs to physical infrastructure providers. This sharing scheme can reduce the capital expenditure (CAPEX) and/or the operational expenditures (OPEX) of the RAN Virtual providers. Cooperation among multi-operators

Sharing of RAN is supported by COHERENT architecture in the form of "controller" which is a dedicated entity responsible for coordination of specific functions, for example, Licensed Shared Access (LSA) controller developed by FairSpectrum for LSA.

3.2 NFV Provider

In the COHERENT ecosystem Mobile Network Operators (MNO), Enterprises, and Over-The-Top (OTT) third parties need to be provided with a NFV-ready Network Store. The NFV provider is the actor who is going to investigate in the production of various VNFs for the benefit of the end user. These VNFs are going to construct new services for the benefit of the ecosystem. The assembly of the VNFs produce a Network Store that serves as a digital distribution platform of programmable Virtualized Network Functions (VNFs) that enable 5G application use-cases. Currently existing application stores, such as Apple's App Store for iOS applications, Google's Play Store for Android, or Ubuntu's Software Center, deliver applications to user specific software platforms. Our goal is to exploit a digital marketplace, gathering 5G enabling Network Applications and Network Functions, written to run on top of commodity cloud infrastructures. The 5G Network Store will be the same to the cloud as the application store is currently to a software platform.

NFV-based Network Store can serve as a digital distribution platform for 5G application use-cases. The goal of the Network Store is to provide programmable pieces of code that on-the-fly reserve required resources, deploy and run the necessary software components, configure and program network elements according to the SDN and NFV paradigms, and provide the end-user with a 5G slice that perfectly matches the demands. The Network Store is a necessity as the 5G networking opens a multitude of applications. The Next Generation Mobile Network (NGMN) association's white paper [NGMN] alone envisions 28 use-cases combined with multi-Radio Access Technologies (RATs) and various performance expectations, as also suggested in other proposals (e.g., Ericsson's 5G white-paper [ERICSSON]).

Note that according to ETSI MANO, there are four types of repositories (catalogues):

- VNF Catalog: is a repository of all usable VNFDs (VNF Descriptor). Such a VNFD is a deployment template which describes a VNF in terms of its deployment and operational behavior requirements.
- Network Services (NS) Catalog: is a list of the usable Network services.
- NFV Instances: NFV Instances list holds all details about Network Services &VNF.
- NFVI Resources: It is a repository of NFV Infrastructure resources utilized for establishing NFV services.

3.3 C3/RTC provider

In the COHERENT ecosystem, different entities could be responsible for the development and whole lifecycle management of both the C3 and the RTC software components. The core requirement is that the agent-controller of the RTC must be physically collocated with the eNodeB.

In COHERENT a Central Controller and Coordinator (C3) is a logical centralised entity in charge of logical centralised network-wide control and coordination among entities in RAN based on centralised network view. C3 could be implemented with distributed physical control instances sharing network information with each other. Sharing network information among C3 instance creates the logically centralised network view and therefore achieves logical centralised control and coordination.

Furthermore in COHERENT a Real-Time Controller (RTC) is a logical entity in charge of local or region-wide control, targeting at real-time control operations, e.g., MAC scheduling. It has local network view. It could run directly on one RT or on a virtualised platform and receives monitoring information gathered from one RT or multiple RTs. It can delegate control functionality to the RTC agent on the RTs. RTC communicates with an RTC agent/RTC agents on one RT or multiple RTs.
Regarding the RTC functionalities we exploit the FLEXRAN protocol together with the necessary agent-controller infrastructure.

FlexRAN is an SDN software which allows also to delegate agents whenever the link between controller and agents are not good for application or when D2D communication and cooperative coordinative networking bolds as an essential way of interacting in mobile Edge.

Regarding the C3/RTC entities of the architecture, they could be produced by an independent provider, other than the operator, such as a Software company. The benefits for this company could be to provide a main q

3.4 Cloud providers

COHERENT control framework takes the advantage of the cloud platform to implement a scalable, flexible and open control solution for 5G RAN. As the key component C3 and control applications will be realized in operators' own cloud or may be outsourced to third party's cloud platform, cloud providers play the vital business role in the COHERENT systems.

It is a common understanding that mobile operators will embrace cloud-computing technologies to enhance their operation, reduce the cost, and deliver cloud services to end users [4]. Perspicacious operators have spent huge investment to capture the share of global cloud services opportunities. Mobile operators can act as cloud providers by themselves or utilize services from third party cloud providers, through a variety of business models, i.e. Software as a service (SaaS), Platform as a service (PaaS), and Infrastructure as a service (IaaS).

From the technical perspective, since the COHERENT system deals with the RAN aspect in mobile networks, the cloud implementation of COHERENT will most likely rely on RAN vendors. Major RAN vendors, like Ericsson, Nokia, and Huawei, have rolled out their Cloud-RAN products. In Nokia's Air Scale Cloud RAN, the virtualization of RAN functions is one of the key features. Ericsson Virtualized RAN enables Virtual Network Functions (VNF) on a split architecture, with parts of the protocol stacks centralized on commercial off-the-shelf (COTS) hardware. CommScope offers the OneCell solution for virtualized small cells, where the cell virtualization and pooled baseband processing are introduced to manage a group of small cells under a single super cell. The COHERENT control framework can build upon the current C-RAN implementation with the extensions so it can provide coordination not only for C-RAN but also for distributed RAN. RAN vendors could take advantage of the COHERENT concept to extend their product lines.

However, one idea of COHERENT is to utilize the general cloud platform to implement the high-level coordinator unit, named C3, on top of different RATs. The ultimate goal is to provide a unified, programmable control and coordination framework for heterogeneous RAN. General cloud platforms deployed by operators could be utilized to implement COHERENT C3 as one of its applications. It means the C3, the network graph database, and control applications can be implemented in the operator's cloud infrastructure. The time sensitive functions in RTC will need to keep in vendor specific equipment, in order to guarantee the control latency requirements. Enterprise cloud platform producer, just naming a few, VMware, CISCO, IBM and Huawei, can act as solution providers to enable the COHERENT framework.

Mobile operators may utilize third party cloud platforms, for instance, Microsoft Azure, Amazon Web Services, Google App Engine, or IBM SmartCloud to implement services. While the C3 will need to be implemented inside the operator's network for security, reliability and performance, the control applications, which are developed based on the northbound API of C3, may be hosted by those third party cloud platforms. Considering the network slicing support in 5G networks, as verticals or OTT providers may request network slicing for particular services, control applications on top of C3 for particular network slice can be implemented remotely at OTT providers' cloud platform.

4. COHERENT in Porter's five forces model

4.1 Description of Porter's five forces model

As the name implies, Porter's Five forces model, referred also in sections 2.3.1.1 and 2.3.2.1, has been proposed by Michael E. Porter - principal innovator of Harvard University. He is a well-known economist, consultant, lecturer, and author of a number of books. Porter's five forces model should be used before attempting to enter the market as it serves to assess the attractiveness of the sector and is based on five different factors that are relevant to the business environment.
A modern description of the Five Forces can be found in the figure below.

Figure 7: Porter's Five Forces (from [3])

- **Industry rivalry**
  At the beginning of five Forces analysis there is a need to define the competition and assess the current competition in the industry. It is best to identify the main players which can provide the COHERENT Central Controller/Coordinator (C3) and to analyse their market shares.

The main topics to be addressed are:

- Number of competitors
- Quality of their proposals
- Differences between proposals
- Cost of introducing a competitor
- Loyalty of a competitor.

- **Threat of new entrants**
  The next important force is the threat of new entrants, i.e. all the companies that can enter the market. There may be also companies that are just emerging. The easier it is for a new entrant to enter the market, the more often they are competing. Therefore, we investigate potential competition by analysing barriers. So when evaluating this risk, we need to identify and evaluate barriers to entry. The higher they are, the lower the risk of new entrances.

  - When analysing this threat, the following aspects are typically addressed:
    - Time and cost of entry

- Specialist knowledge
- Economies of scale
- Cost advantages
- Technology protection
- Barriers to entry, as detailed above.

- **Threat of substitutes**
  Another threat that needs to be analysed during Porter's 5 Forces analysis is the threat posed by the introduction of substitute products or services. When considering substitutes for a market threat, account should be taken of the degree to which they meet buyer needs and the prices offered. Also we need to evaluate aspects directly related to the introduction of competitive products which could be a potential replacement of C3.

  The main aspects to be addressed are:
  - Substitute performance
  - Cost of changing.

- **Bargaining power of buyers**
  When we analyse the customers' bargaining power we should focus on the arguments which can be provided by the buyer for obtaining a price reduction of the product.

- **Bargaining power of suppliers**
  In order to evaluate bargaining power of suppliers we need to consider the arguments which can be provided by a supplier for supporting their own product against a competing product. The main aspects to be addressed are:
  - Number of suppliers
  - Size of suppliers
  - Uniqueness of product
  - Ability to substitute
  - Cost of changing.

4.2 Analysis of COHERENT C3 Controller and Coordinator with Porter's model

4.2.1 Mapping of business actors

Before starting the actual analysis of the five forces is needed to identify the actual business players in COHERENT context, as detailed below:

- Competition, i.e. the competing C3 providers
- Buyers, i.e. Operators
- Suppliers, i.e. C3 equipment and software producers
- New entrants, i.e. start-ups competing between themselves to become a C3 contractor working for the big Producers.
- Substitutes, i.e. competing solutions instead of C3.

4.2.2 Competition power

At this moment in time there is no doubt that a central RRM block, located in CU, very similar in functionality with C3, is strongly needed. However many big producers prefer to have this block and the protocols over the F1-C interface proprietary.

4.2.3 Competition power between Producers

While the mobile system performance will be influenced directly by the C3 algorithms, it is known that the overall cost and financial conditions are the main criteria for selecting a Producer.

Based on this, we assess that the influence of C3 in selecting a system Producer is MEDIUM.

4.2.4 Competition power between subcontractors

A C3 functional block may be developed in-house by a Producer or can be developed by a Subcontractor, as it is the case for the O&M (Operation and Management) systems. In both variants the main Producer will provide the integrated equipment to the Operator. In the second scenario, for limiting the risks, the big Producer will work with multiple Subcontractors, as is customary in the mobile industry.

From this discussion it results that there will be competition for providing C3 to a Producer.

The Competition Force is analysed below:

- Number of competitors: relatively small;
- Quality of their proposals: it will be assessed by system performance metrics;
- Differences between proposals: there will be inherent differences between C3 algorithms;
- Cost of introducing a competitor: once completed the definition of the F1-C interfaces, of the product requirements and of the test procedures, the Producer cost for changing C3 producers will be limited to tests;
- Loyalty of a competitor: any competitor will be limited by the contract with the big Producer, at least by the NDA (Non-disclosure Agreement).

Based on the above analysis, we conclude that the Competition Force between Subcontractors providing C3 is MEDIUM.

4.2.5 Buyer power: Mobile Network Operators

The MNOs perceive NFV and SDN as main drivers of improving their revenues. When combined, the cost of the base station is significantly reduced, based on two main elements:

- Reduced functionality required for the Distributed Unit (RTP in COHERENT)

- Centralization of the base station functions in Central Unit (vRP in COHERENT).

The MNOs **have driven the entire supplying industry in 3GPP to agree** defining two possible splits of the traditional base station:

A. A high layer split, including the RRM (Radio Resource Management) in the CU and DU; The CU part of the RRM is the equivalent of the C3 in COHERENT; CU coverage area may be limited from a neighbourhood and up to a region in a country

B. A low layer split, which may have the MAC sub-layer in Central Unit and the PHY sub-layer in the Distributed Unit, where the MAC sub-layer is actually the equivalent of the RTC in COHERENT.

From these developments in 3GPP it is obvious that the MNOs are a HIGH influential force and favour COHERENT principles.

An additional proof for the MNO’s HIGH force is the agreement by the Producers to standardize an interoperable protocol (F1) between the CU and DU; initially the interface was mainly related to the User plane, however COHERENT contributions had an impact on general understanding that there is a need for centralized RRM (read C3) functionality. We expect to see this impact partially materialized in F1-C protocol already in Release 15.

And a third proof of the HIGH power of MNOs is the approval of a study item targeting to apply the CU-DU architecture to LTE; when a CU will serve both 5G and LTE subscribers we will make another step towards the implementation of the COHERENT architecture.

The adoption of the new 5G technology and the apparition of new services (mIOT and C-V2X) will increase the competition between the MNOs on different areas:

- Subscription costs
- Service offering
- Timeline for 5G capabilities.

In this context, implementation of the COHERENT principles, mainly the Central Coordination (centralized RRM) either included in the Central Unit or as a separate entity, is essential for network operation and the cost-effectiveness of MNO business.

4.2.6 Producer power: Mobile equipment and SW Producers

The producers (suppliers) of the cellular equipment and software have a power derived from their knowledge, range of products and most important, from their credit conditions of MNO payments. They have the interest to keep their income high.

The producers have the interest to reduce the competition, and for them the 5G RAN network architecture is a treat, as the less intelligent Distributed United could be procured by MNOs at a lower cost.

This interest was translated in 3G by a very high amount of proprietary protocols, making the interoperability of 3G network a costly problem for MNOs. The Producers will try to continue in this way, however it is too early to estimate their success in this direction, given the high force of the Operators.

Regarding C3/RTC producers, we see that the Split 6 in Small Cell Forum is similar with RTC concept; on the other hand, once the F1 interface is defined, we can predict the apparition of C3 producers.

We consider that the Producers represent a HIGH force in the competitive environment of MNOs and they will have a very positive role in the adoption of Central RRM (C3), however their power may be used for driving the prices high, by avoiding the full standardization of the F1-C interface.

4.2.7 New Entrant power

A new entrant will aim to provide a competing solution for C3. As subcontractor, the new entrant will depend of the desire of the big producer to add a one more subcontractor. The new entrant can have a higher power only if the F1-C will be fully standardized, but this eventuality does not seem realistic right now. As result, we consider the new entrant power as LOW.

4.2.8 Substitution power

The substitution power is MEDIUM, given that the big producer can always select between its sub-contractors.

5. Techno-economic analysis of employing the COHERENT architecture

5.1 Introduction

This chapter performs a techno-economic (TE) analysis for the COHERENT architecture in the existing wireless communications network. This TE analysis is executed in a series of steps in order to provide a viable means for a C3 producer and network operator implementing in its network the C3 controller to be able to have business in a profitable way. The business plan is divided in two steps. The first step is the analysis where various parameters and key metrics are determined and utilized, and the second is the process where economic parameters and figures are calculated and analysed.

- **The planning step**

A key step in the process of planning a transition path towards COHERENT network deployment is evaluating the network economics. Specifically, operators should consider choosing the evolution path that yields the most economic value, including revenues and network costs, capital expenditures (CAPEX), and operating expenditures (OPEX) over the economic life of the system. Economic evaluation may have to be based on assumptions about the evolution of demand and service penetration.

To implement a financial model where all of the described aspects are properly taken into account, specially designed tools are normally used. This implies a sequence of steps to go through to associate values to the input parameters and to acquire the network engineering rules. Running the model generates the technical and financial outputs driven by geographical data, service demand and network costs. The implementation of a financial model is normally conceived so that further information on specific aspects may be obtained by increasing the level of detail in the description of the network infrastructure and/or network components.

- **The process step**

During this step, parameters such as the Net Present Value (NPV) are evaluated for different network parameters and costs.
A key metric in the evaluation is the NPV understood as the net present value of the network, and the cumulative cash flow generated to present. On a less formal level, this metric is indicative of the profitability of a business (when NPV is positive), over a span of 7 years.

The economic evaluation comprises the following logical phases:

- Estimation of the number of persons needed to run the business for C3 production;
- Estimation of the cost of each employee;
- Estimation of fixed assets;
- Estimation of production cost;
- Estimation of marketing and sales costs;
- Estimation of company's overhead;
- Estimation of the cost as a percentage in the business of the C3 producer;
- Estimation of the agent software embed in DU;

5.2 Financial analysis

This section presents a detailed financial analysis of employing the COHERENT architecture from two different business actors' point of view:

- C3 Producer's point of view and,
- Operator's point of view.

5.2.1 TE analysis from the C3 Producer's point of view

This subsection describes a techno-economic analysis of employing the COHERENT architecture from the C3 Producer's point of view.

The viability of the C3 Producer (i.e. start-up company) is going to be evaluated over a period of seven years. The C3 Producer is going to invest on this architecture (i.e. constructing the product and selling its services to multiple operators) because it would like to gain some revenues. The results of this analysis will show the economic benefits of employing the COHERENT architecture from the C3 Producer's point of view.

Initially, the costs and revenues of the C3 Producer are categorized into the following general groups, as shown in Table 3.

Table 3: General costs and revenues of the C3 Producer

C3 Producer	
Costs	**Revenues**
Cost of business	*SW C3 + agent*
C3 server	*Spectrum sharing*
SW agent	*Infrastructure sharing*
-----	*RRM*
-----	*Network slicing*
-----	*Maintenance*

More specifically, each group is further explained below, after making the necessary assumptions:

Cost of business—includes the sum of the personnel-related cost, i.e. head count (15-25) and cost per employee (80-84.000 €), the fixed assets (10k€-50k€), the production cost (60k€-150k€) and the marketing cost (50k€-100k€). It is also taken into consideration a company overhead factor (e.g. accounting, depreciation, insurance, license fees, taxes, rent), which is usually 0,3-0,5.

C3 server cost—includes the C3 server's basic cost (30000 €) multiplied by the quantity of C3 servers (one C3 server is required for maximum 1000 micro DUs and macro DUs, which are Distributed Units (DUs) in 5G architecture with low and high power transmission, respectively and particularly the micro DUs are micro base stations that usually support plug and play and automatic deployment, while the macro DUs are the current R-TPs and traditional base stations.). A 3% to 5% of the total served infrastructure cost is also added to the total C3 server cost. This cost is directly deducted from the relevant revenue. It is assumed that in the first years the C3 will not work at full capacity and that the deployments will add a steady number CUs and DUs per year.

Due to the fact that most of the C3 R&D will be ready after 3 years the Operator will press for price reduction and may also introduce also other competing producers, such that the cost of the C3 server will represent a lower percentage of the infrastructure cost (i.e. 3% instead of the initial 5%) towards the end of the considered period.

SW agent cost—this cost is directly deducted from the relevant revenues.

The approach is that there is a basic functionality, such as mobility and load balancing, which can be enhanced by additional features. For each additional feature the producer revenue is defined as percentage of the infrastructure served by one C3 and a penetration factor. The producer will have revenues on both C3 and agents.

Basic SW C3 + agent revenues—the revenues from the C3 are assumed to be the total C3 server cost multiplied by the number of C3 servers. Additionally, the revenues from the SW agent are assumed to be 5% of the total infrastructure cost served by one C3 multiplied by the penetration percentage of SW agents. In this case, the penetration percentage is 100%, since the SW agents are installed at each micro/macro DU.

Spectrum sharing revenues—include the added value multiplied by the basic SW C3 + agent revenues. Added value is the price that the product or service is sold at. In this case, added value is assumed to increase from the initial 20% up to50% for spectrum sharing. Also, the penetration percentage waves from 10% to 70% over the years for spectrum sharing.

Infrastructure sharing revenues—include the added value multiplied by the basic SW C3 + agent revenues. In this case, added value is assumed to be 30% for infrastructure sharing. Also, the penetration percentage waves from 10% to 70% over the years for infrastructure sharing.

RRM revenues—include the added value multiplied by the basic SW C3 + agent revenues. In this case, added value is assumed to be 30% for RRM. Also, the penetration percentage is from 20% to 40% over the years.

Network slicing revenues—include the added value multiplied by the basic SW C3 + agent revenues. In this case, added value is assumed to be 30% for network slicing. Also, the penetration percentage is up to 50% over the years.

Maintenance revenues—it is usual practice to assume that maintenance is the 10% over the sum of revenues (i.e. SW C3 + agent revenues plus infrastructure sharing revenues plus spectrum sharing revenues plus RRM revenues plus network slicing revenues).

Furthermore, there is one more input parameter that is needed, namely the ***Weighted Average Cost of Capital (WACC)*** of the company for this investment. The WACC is the average rate of return that the company expects to compensate all its different investors. The weights are the fraction of each financing source in the company's target capital structure. The WACC can serve as a useful reality check for investors. In this analysis, the WACC for the company is 10%.

Finally, as briefly introduced already at the beginning of this section, the main financial parameter that reflects the success of an investment is the ***Net Present Value (NPV)***. The NPV of an investment is the present (discounted) value of future cash inflows minus the present value of the investment and any associated future cash outflows. NPV is important because without using the net present value of benefits and cost the comparisons drawn between solutions in the out years are not accurate. By considering the time value of money, it allows consideration of cost of capital, interest rates, and investment opportunity costs. This metric recognizes that money has different real value over time and makes the values of money constant by discounting costs and benefits over a specific period of time—an asset's life cycle or any selected period of analysis. Given the (period, cash flow) pairs (t, Rt) where N is the total number of periods, the NPV is given by:

$$\boldsymbol{NPV(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}}$$

t – the time of the cash flow. Cash flow equals to the revenues minus the costs.

i – the rate of return WACC that could be earned on an investment in the financial markets with similar risk; the opportunity cost of capital.

$\boldsymbol{R_t}$ – the cash flow at time t.

Thus, taking into account all the aforementioned parameters, the Table 4 demonstrates in detail the procedure followed in order to estimate the NPV and the Figure 8 and Figure 9 display the expenses and revenues per year and net revenues for the producer, respectively.

COHERENT TE Analysis ---- C3 Producer							
Year	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Cost of Business							
Head count	15	20	20	25	25	20	15
Cost/employee	80.000 €	80.000 €	80.000 €	82.000 €	82.000 €	82.000 €	84.000 €
Personnel-related costs	1.200.000 €	1.600.000 €	1.600.000 €	2.050.000 €	2.050.000 €	1.640.000 €	1.260.000 €
Fixed assets	50.000 €	40.000 €	15.000 €	20.000 €	10.000 €	10.000 €	10.000 €
Production costs (includes trials)	80.000 €	150.000 €	150.000 €	150.000 €	120.000 €	80.000 €	60.000 €
Marketing and sales costs	50.000 €	80.000 €	100.000 €	100.000 €	100.000 €	80.000 €	70.000 €
Company Overhead	0,3	0,4	0,5	0,5	0,5	0,5	0,5
Total cost of business	**1.794.000 €**	**2.618.000 €**	**2.797.500 €**	**3.480.000 €**	**3.420.000 €**	**2.715.000 €**	**2.100.000 €**
Infrastructure Cost							
Micro DU/BS cost	700 €	700 €	700 €	700 €	700 €	700 €	700 €
Macro DU cost	8.000 €	8.000 €	8.000 €	8.000 €	8.000 €	8.000 €	8.000 €
Served Micro DU/BS number	300	400	600	1000	1000	1000	1000
Served Macro DU number	30	40	60	100	100	100	100
Total infrastructure cost	**450.000 €**	**600.000 €**	**900.000 €**	**1.500.000 €**	**1.500.000 €**	**1.500.000 €**	**1.500.000 €**
Revenue Calculation							
C3 server cost percentage	5%	5%	4%	4%	3%	3%	3%
C3 server basic	30.000 €	30.000 €	25.000 €	25.000 €	20.000 €	20.000 €	20.000 €
C3 Server number	8	20	50	100	90	70	50
per C3 server revenue	52.500 €	60.000 €	66.000 €	90.000 €	75.000 €	75.000 €	75.000 €
Basic SW (Load balancing, HO) C3 revenues	**420.000 €**	**1.200.000 €**	**3.300.000 €**	**9.000.000 €**	**6.750.000 €**	**5.250.000 €**	**3.750.000 €**
Agent - Basic SW percentage of unit cost	5%	5%	5%	5%	5%	5%	5%
Total sales basic SW agent	**180.000 €**	**600.000 €**	**2.025.000 €**	**6.750.000 €**	**6.075.000 €**	**4.725.000 €**	**3.375.000 €**
Total sales basic SW C3+agent	**600.000 €**	**1.800.000 €**	**5.325.000 €**	**15.750.000 €**	**12.825.000 €**	**9.975.000 €**	**7.125.000 €**
Spectrum sharing added value	20%	50%	50%	50%	50%	50%	50%
Spectrum sharing penetration	10%	15%	30%	50%	60%	70%	70%
Total sales spectrum sharing C3+agents	**12.000 €**	**135.000 €**	**798.750 €**	**3.937.500 €**	**3.847.500 €**	**3.491.250 €**	**2.493.750 €**
Infrastructure sharing added value	30%	30%	30%	30%	30%	30%	30%
Infrastructure sharing penetration	10%	15%	30%	50%	60%	70%	70%
Total sales infrastructure sharing C3+agent	**18.000 €**	**81.000 €**	**479.250 €**	**2.362.500 €**	**2.308.500 €**	**2.094.750 €**	**1.496.250 €**
RRM added value	30%	30%	30%	30%	30%	30%	30%
RRM penetration	20%	30%	40%	40%	40%	40%	40%
Total sales RRM C3+agent	**36.000 €**	**162.000 €**	**639.000 €**	**1.890.000 €**	**1.539.000 €**	**1.197.000 €**	**855.000 €**
Network slicing added value	30%	30%	30%	30%	30%	30%	30%
Network slicing penetration	30%	40%	50%	50%	50%	50%	50%
Total sales network slicing	**54.000 €**	**216.000 €**	**798.750 €**	**2.362.500 €**	**1.923.750 €**	**1.496.250 €**	**1.068.750 €**
Pre-total revenues	**720.000 €**	**2.394.000 €**	**8.040.750 €**	**26.302.500 €**	**22.443.750 €**	**18.254.250 €**	**13.038.750 €**
Maintenance Percentage	0%	10%	10%	9%	9%	8%	8%
Maintenance	0 €	239.400 €	804.075 €	2.367.225 €	2.019.938 €	1.460.340 €	1.043.100 €
Total revenues	**720.000 €**	**2.633.400 €**	**8.844.825 €**	**28.669.725 €**	**24.463.688 €**	**19.714.590 €**	**14.081.850 €**
Net revenues	**-1.524.000 €**	**-584.600 €**	**5.147.325 €**	**23.689.725 €**	**19.543.688 €**	**15.499.590 €**	**10.481.850 €**
Revenues Present Value	-1.524.000 €	-531.455 €	4.253.988 €	17.798.441 €	13.348.602 €	9.624.026 €	5.916.731 €
Revenues Present Value Cumulative	-1.524.000 €	-2.055.455 €	2.198.533 €	19.996.974 €	33.345.576 €	42.969.602 €	48.886.333 €
NPV	**48.886.333 €**						

Table 4: COHERENT techno-economic analysis from C3 Producer's point of view

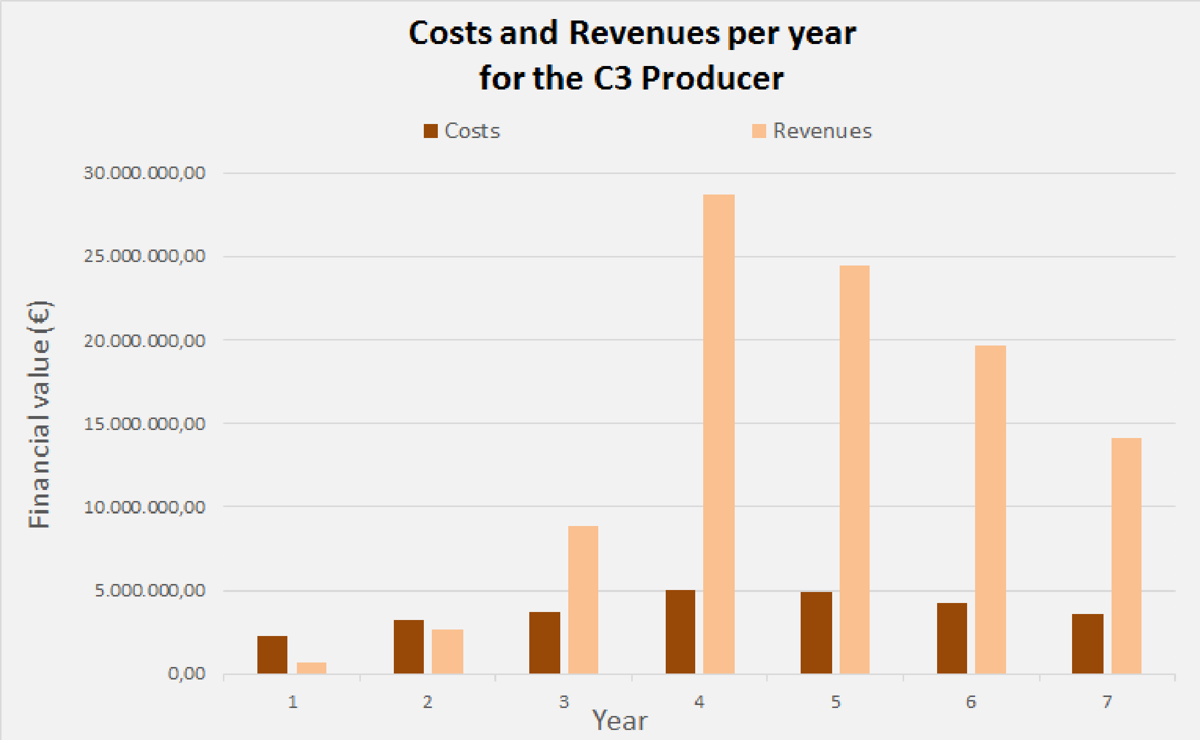

Figure 8: **Costs and revenues per year for the C3 Producer**

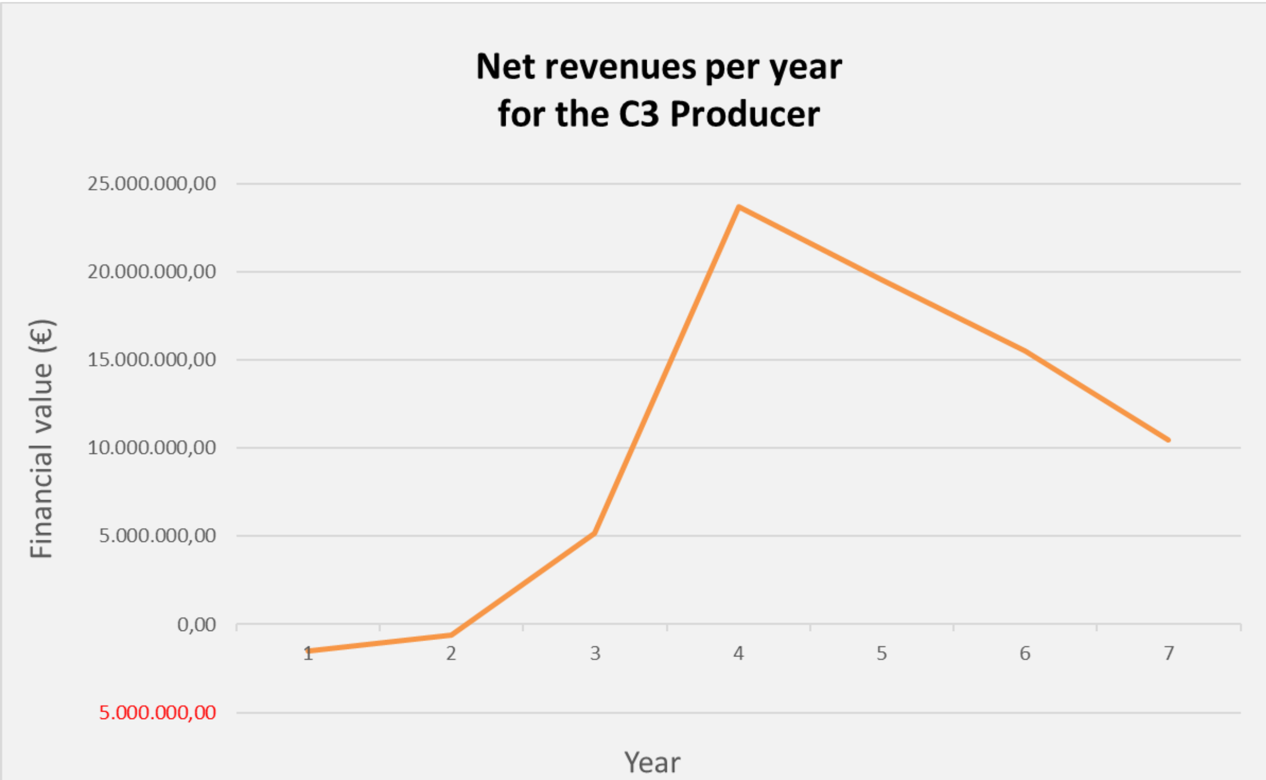

Figure 9: **Net revenues per year for the C3 Producer**

From both Figure 8 and Figure 9, where the revenues, costs and net revenues for the C3 Producer are seen, it is observed that only after the Year 3 the revenues-to-cost ratio is more than 15. It is also shown that the Years 5, 6, 7 have the highest and almost stable performance, since these years the C3 production and relevant sales reach their peak. Therefore, from the C3 Producer's point of view, it seems that it is beneficial to employ the COHERENT architecture since the techno-economic analysis's results reflect the success of this investment.

5.2.2 TE analysis from the Operator's point of view

This subsection describes a techno-economic analysis of employing the COHERENT architecture from the Operator's point of view.

The viability of the Operator (e.g. OTE) is going to be evaluated through a 7-year analysis. The Operator is going to invest on this architecture (i.e. buying the product and services from the C3 Producer) because it would like to improve the performance of its network and at the same time gain some revenues. The results of this analysis will show the economic benefits of employing the COHERENT architecture from the Operator's point of view.

Initially, the costs and revenues of the Operator are categorized into the following general groups, as shown in Table 5.

Table 5: General costs and revenues of the Operator

Operator	
Costs	**Revenues**
Infrastructure Cost	*C3 + agent related ARPU*
Cost of business	-----

More specifically, each group is further explained below, after making the necessary assumptions:

Infrastructure cost—infrastructure includes the micro DUs and macro DUs. Specifically, DU is a hardware box with RLC, MAC and PHY layers, radios and antennas. The micro DU and macro DU cost is 600 € and 4500 €, respectively. The macro DU/micro DU ratio is considered to be 1/10.

Cost of business—it is actually the price that the Operator will pay to the C3 Producer in order to employ the COHERENT architecture in his existing network. A C3 producer can sell to multiple Operators. The relevant techno-economic analysis from the C3 Operator's point of view is shown at the **Table** 6. It is worth mentioning that there is one year difference between the research and the start of deployment, i.e. the C3 Producer starts its research in 2018 and the relevant infrastructure is deployed to the Operator side in 2019.

C3 + agent related ARPU—First of all, it is assumed that the Operator deploys the new technology for providing coverage to customers; the increase in infrastructure coverage is reflected in the yearly increase of the customer number. In addition, each year the customer base increases 10% The indicative average revenue per user (ARPU) is 25 €, which is reduced by 3% every year, according to data provided by OTE. The income generated by ARPU is partially used (starting with 20% and increasing in time to 30%) for paying the infrastructure, C3 and agents costs. The SW cost is covered by the proportional part of the ARPU,

The Operator will decrease the percentage of payments for the maintenance, arguing that is less and less R&D due to the stabilization of the technology.

Furthermore, like the C3 Producer's case, there is one more input parameter that is needed, the ***Weighted Average Cost of Capital (WACC)*** of the company for this investment. In this analysis, the WACC for the Operator company is 5%. ***Net Present Value (NPV)***, which is the main financial parameter that reflects the success of an investment, is calculated in this case, too.

Thus, taking into account all the aforementioned parameters, Table 6 demonstrates in detail the procedure followed in order to estimate the NPV and the Figures 5-3, 5-4, 5-5 show the relevant results:

Table 6: COHERENT techno-economic analysis from Operator's point of view

COHERENT TE Analysis ---- Operator							
Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Infrastructure Cost							
Micro DU/BS cost	700 €	700 €	700 €	700 €	700 €	700 €	700 €
Macro DU cost	8.000 €	8.000 €	8.000 €	8.000 €	8.000 €	8.000 €	8.000 €
Served Micro DU/BS number	250	500	1000	2000	4000	4000	4000
Served Macro DU number	25	50	100	200	400	400	400
Total DU number	275	550	1100	2200	4400	4400	4400
DUs per C3 server	200	300	500	700	1000	1000	1000
Total C3 servers	2	2	3	4	5	5	5
Total infrastructure cost	**375.000 €**	**750.000 €**	**1.500.000 €**	**3.000.000 €**	**6.000.000 €**	**6.000.000 €**	**6.000.000 €**
Cost of Business							
C3 server cost percentage	5%	5%	4%	4%	3%	3%	3%
C3 server basic	30.000 €	30.000 €	25.000 €	25.000 €	20.000 €	20.000 €	20.000 €
Total buys basic SW C3	97.500 €	135.000 €	255.000 €	580.000 €	1.000.000 €	1.000.000 €	1.000.000 €
Agent-Basic SW percentage of DU cost	5%	5%	5%	5%	5%	5%	5%
Total buys basic SW agent	18.750 €	37.500 €	67.500 €	135.000 €	270.000 €	270.000 €	270.000 €
Total buys basic SW C3+agents	116.250 €	172.500 €	322.500 €	715.000 €	1.270.000 €	1.270.000 €	1.270.000 €
Total buys spectrum sharing C3+agents	2.325 €	12.938 €	48.375 €	178.750 €	381.000 €	444.500 €	444.500 €
Total buys infrastructure sharing C3+agents	3.488 €	7.763 €	29.025 €	107.250 €	228.600 €	266.700 €	266.700 €
Total buys RRM C3+agents	6.975 €	15.525 €	38.700 €	85.800 €	152.400 €	152.400 €	152.400 €
Total buys network slicing	10.463 €	20.700 €	48.375 €	107.250 €	190.500 €	190.500 €	190.500 €
Pre-total cost of business	139.500 €	229.425 €	486.975 €	1.194.050 €	2.222.500 €	2.324.100 €	2.324.100 €
Maintenance Percentage	0%	10%	10%	9%	9%	8%	8%
Maintenance	0 €	36.893 €	71.640 €	151.292 €	307.490 €	363.728 €	371.856 €
Total cost of business	**139.500 €**	**266.318 €**	**558.615 €**	**1.345.342 €**	**2.529.990 €**	**2.687.828 €**	**2.695.956 €**
Revenue Calculation							
Year End Customer Base	7500	23250	72075	223433	692641	1454546	3054546
Net Additions	7500	15750	48825	151358	469208	761905	1600000
Average Customers	3750	15375	47663	147754	458037	1073593	2254546
Indicative ARPU	25,00 €	24,25 €	23,52 €	22,82 €	22,13 €	21,47 €	20,82 €
Percentage allocated to infra+SW	20%	24%	28%	30%	30%	30%	30%
Percentage allocated for software payment	5,4%	6,3%	7,6%	9,3%	8,9%	9,3%	9,3%
Total revenues	**61.006 €**	**281.378 €**	**1.022.203 €**	**3.757.552 €**	**10.824.301 €**	**25.670.314 €**	**52.399.533 €**
NPV							
Net Revenues	-78.494 €	15.060 €	463.588 €	2.412.210 €	8.294.312 €	22.982.486 €	49.703.577 €
Net Present Value	-78.494 €	14.343 €	420.488 €	2.083.758 €	7.369.389 €	20.815.945 €	44.135.354 €
Net Present Value Cumulative	-78.494 €	-64.151 €	356.337 €	2.440.094 €	9.809.483 €	30.625.428 €	74.760.782 €
NPV	**74.760.782 €**						

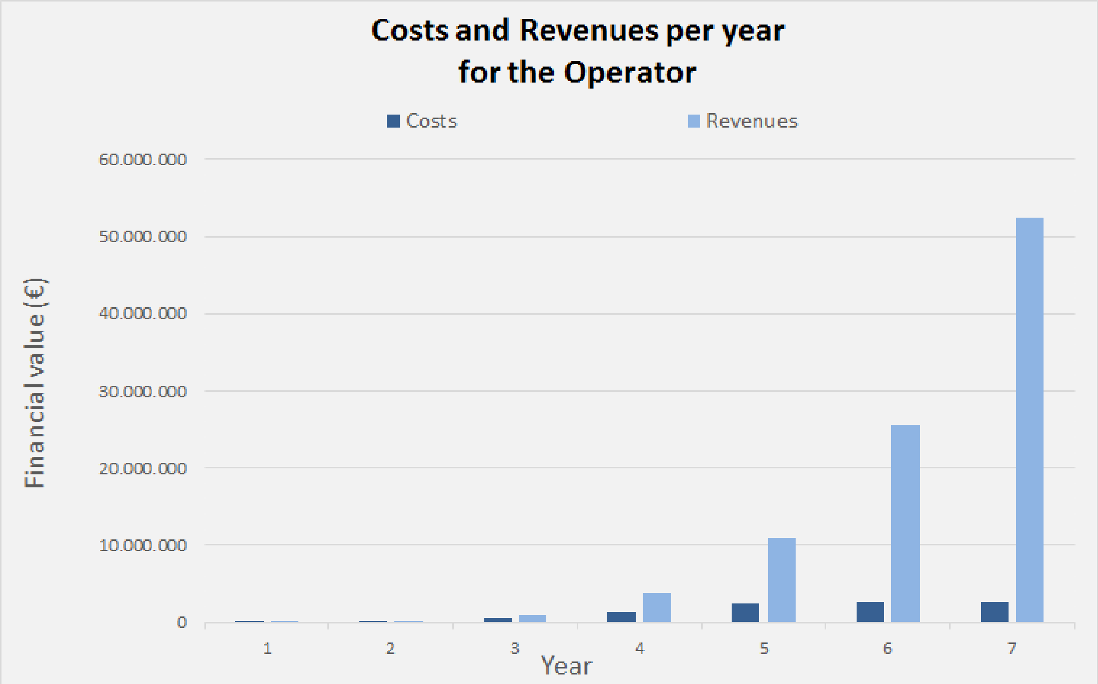

Figure 10: Costs and revenues per year for the Operator

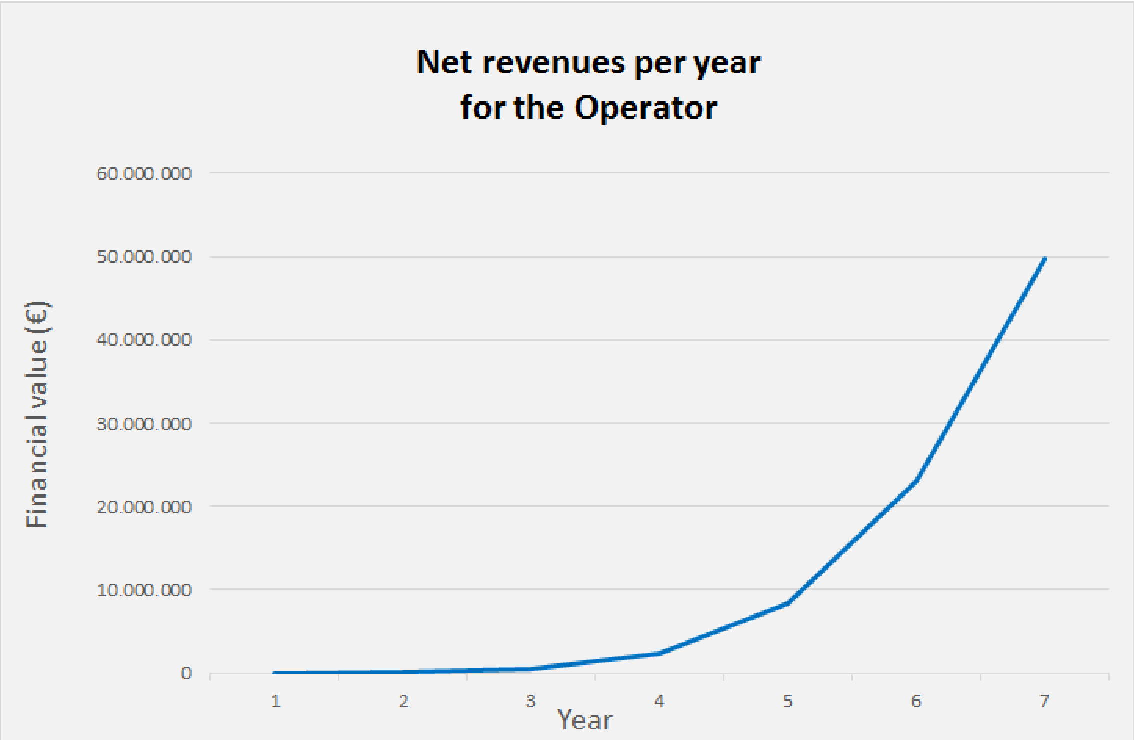

Figure 11: Net revenues per year for the Operator

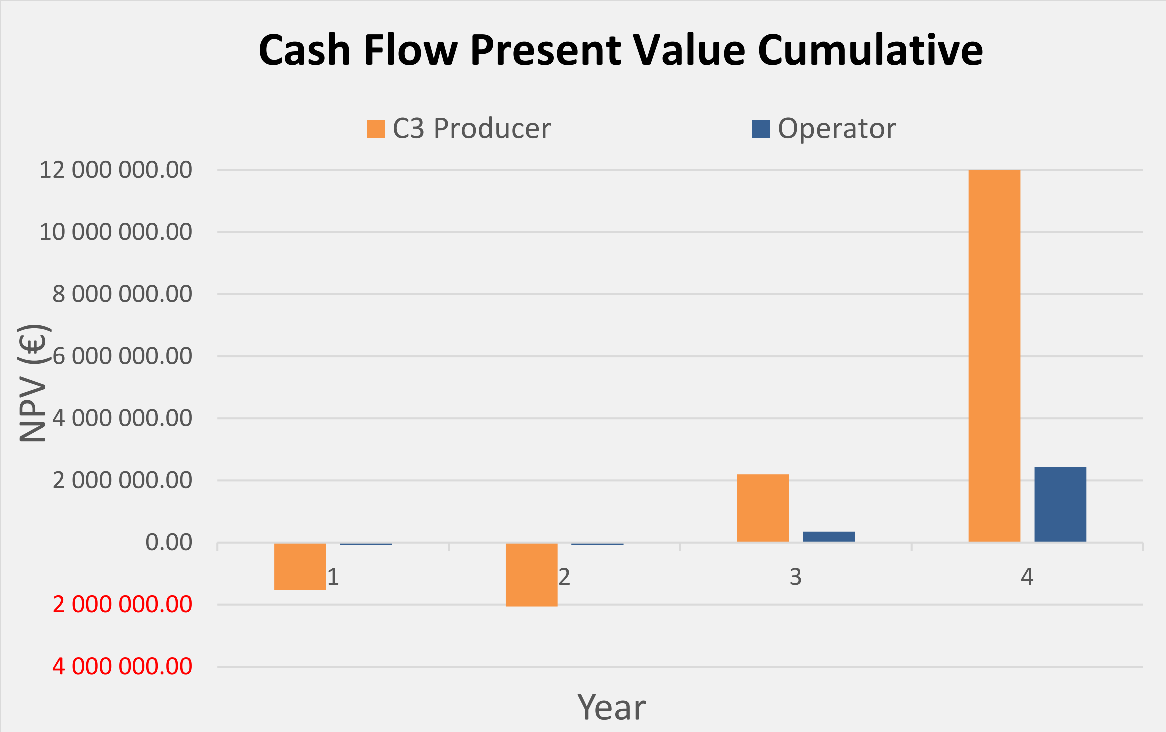

Figure 12: Cash flow for both C3 producer and Operator

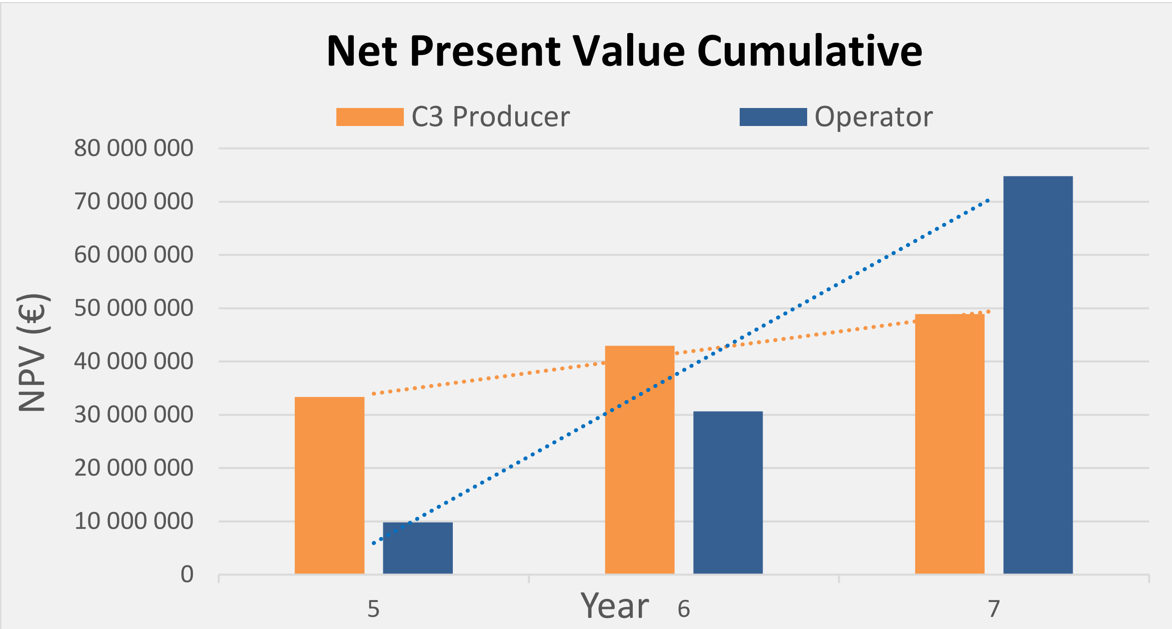

Figure 13: Net present value cumulative for both C3 Producer and Operator

From both Figure 10 and Figure 11, where the revenues, costs and net revenues for the Operator are shown, it is observed that the revenues exceed the costs from the starting year and during the whole period analysis. The Operator starts with limited amount of money from the customer ARPU and invests strongly in the technology; in time the investments are reduced and the customer base increase significantly, such that the Operator gets significant earnings and has limited costs. Nevertheless, the net revenues show only a small increase during the first years, while a large increase is observed after 5 years period. Finally, in Figure 13, it is observed that the gradient of the Operator's NPV is higher for the operator and after the fourth year the revenues for the producer slows down since the market starts to reach a saturated level of this technology and the competition is stronger.

Therefore, from the Operator's point of view, it results that is beneficial to employ the COHERENT architecture since the techno-economic analysis's results reflect the success of this investment.

To summarize, through this 7-year detailed financial analysis, it was proved that the adoption of COHERENT architecture could be profitable in economic terms and a viable solution for the wireless ecosystem, for both C3 Producers and Operators but with different attributes. It is also important to note that the assumptions made were modest, neither pessimistic nor optimistic. Thus, the results of techno-economic analysis' results reflect the success of the COHERENT investment from both C3 Producers' and Operators' point of view and can drive to great development for future wireless networks.

5.3 Sensitivity effects

The sensitivity aspects are used for presenting the affect that small changes in initial variable parameters, such as, C3 server basic cost, or the C3 server number for the Producer, while for the Operator if there are any small changes in the parameters of C3 related ARPU percentage or the number of customers. The C3 Producer will need to consider these affects in order to have a viable product in the long run.

Sensitivity graphs for the C3 Producer
For the C3 Producer, it can be seen from **Figure 14**, that a change by 50% in the C3 server cost, this may have about 25% increase or decrease depending if there 50% increase or decrease in the server cost respectively and this happens for the fourth year of production of the C3.

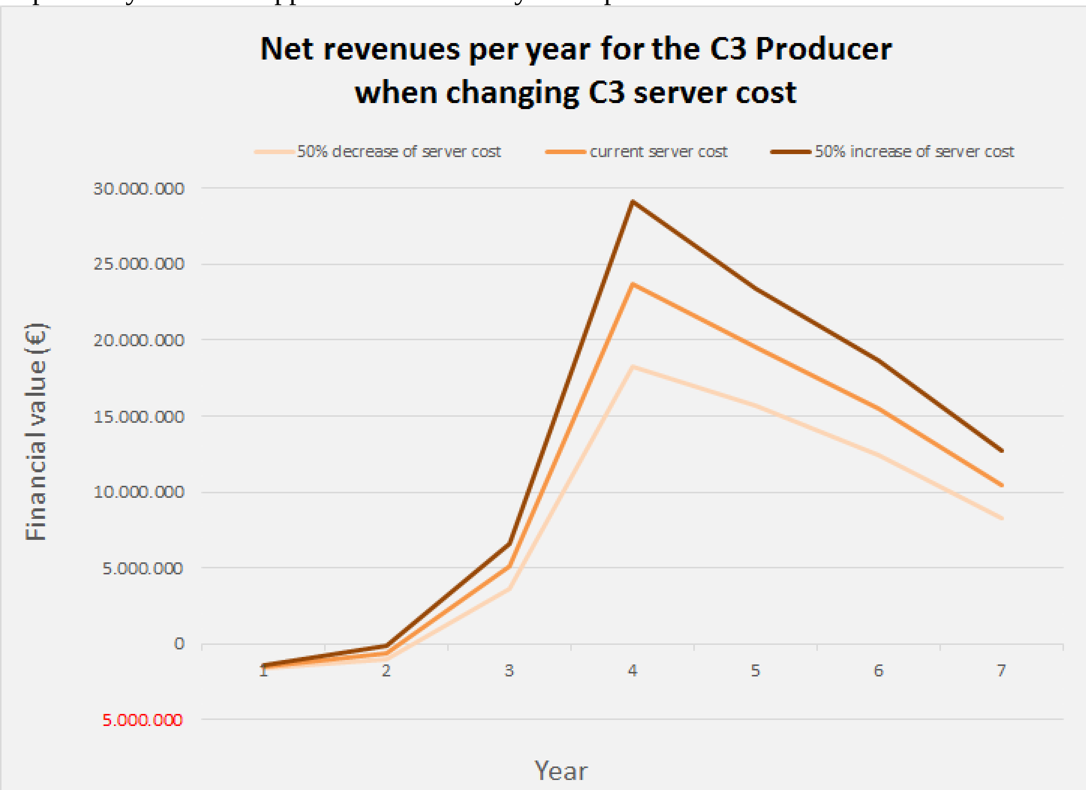

Figure 14: Effects to the revenues of the C3 Producer with changes in the C3 server cost

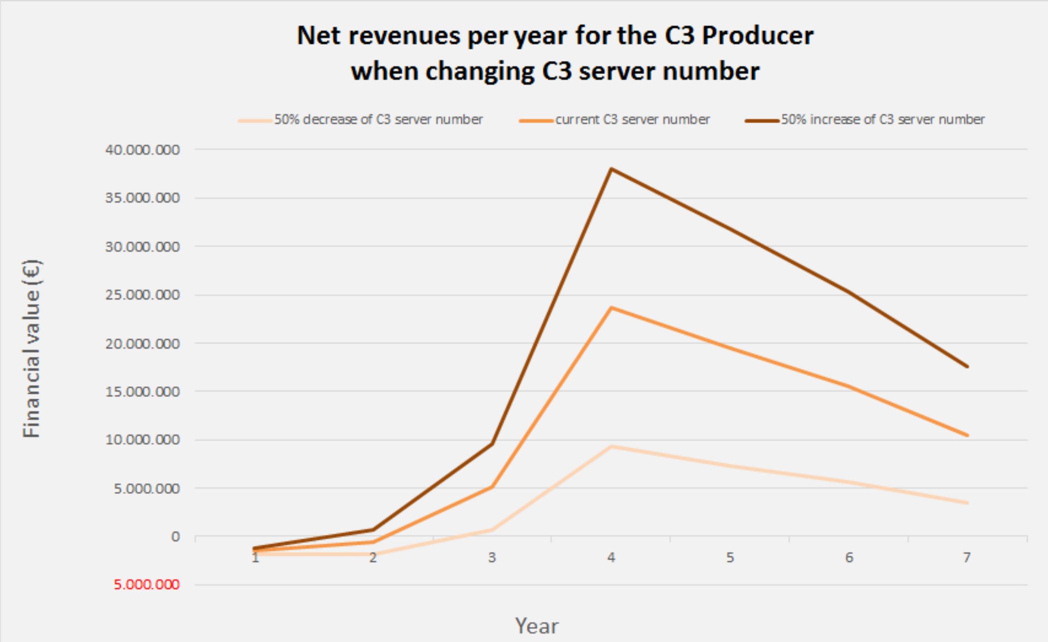

Figure 15: Effects to the revenues of the C3 Producer with changes in the C3 server number

From **Figure 15**, it is seen that a 50% increase in the production of C3 servers leads to 38% increase, while a 50% decrease in the production leads to a 61% decrease in the revenues. In the same way it is observed for the Operator when changes are considered with respect to the number of customers or to the changes of ARPU per user. It is seen in **Figure 16**, that when the number of customers changes, this has affects in the revenues of the Operator in the long run. From **Figure 17**, it is seen that the ARPU has higher effects on the net revenues of the Operator than the changes of the number of customers.

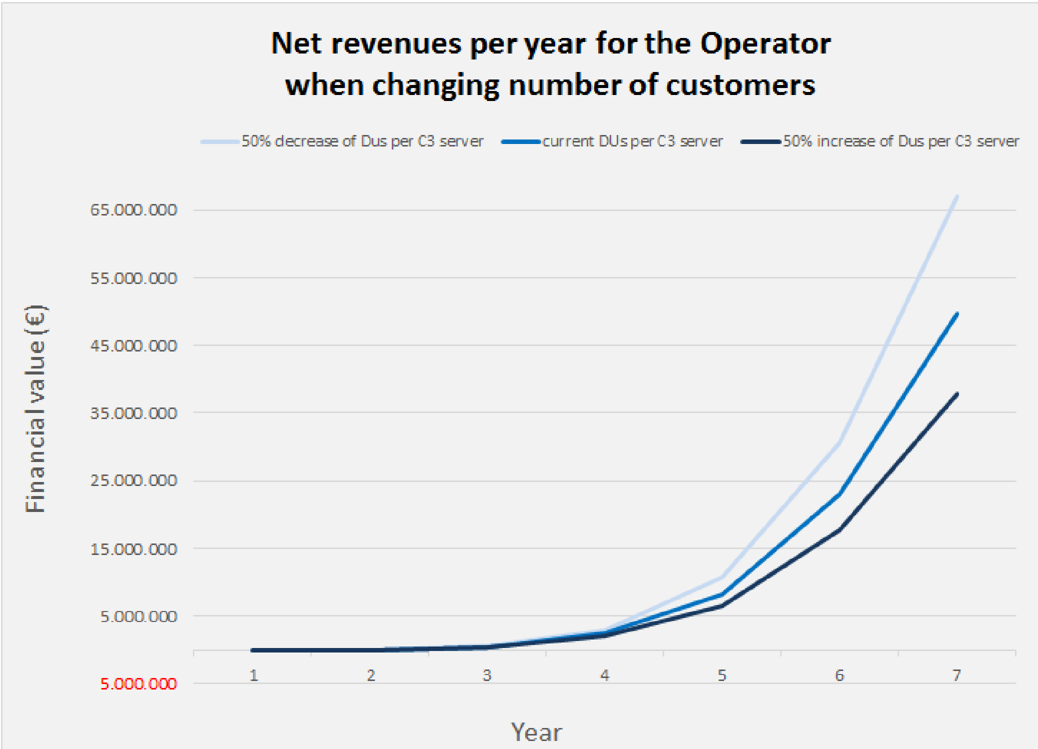

Figure 16: Effects to the net revenues of the Operator when the number of customers' changes

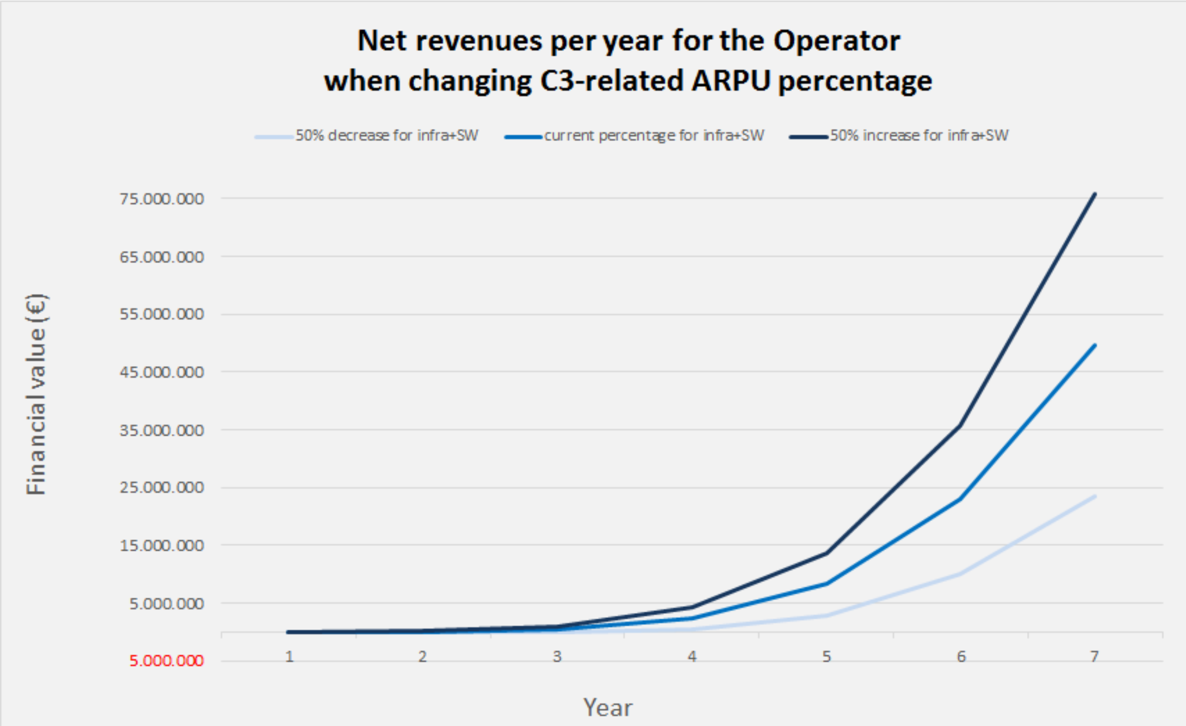

Figure 17: Effects to the net revenues of the Operator when the ARPU changes

5.4 SWOT analysis for C3 producer and for network operator

This section considers the high level technical characteristics presented in the above sections and discusses how these characteristics can be translated into business strengths, weaknesses, as well as to identify the external environment and the main opportunities and threats derived from it. This is guided by Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. The analysis has been performed in accordance to the two main actors of COHERENT, which are the C3 producer and the network operator.

5.4.1 SWOT analysis for the C3 producer

As it is mentioned in COHERENT, the C3 producer is expected to make a platform that provides a lot of opportunities in increasing the financial base. In the near future, when 5G will come into the arena of network operators, there will be the need for the operators to have a platform such as C3 that controls and orchestrates the infrastructure, slicing aspects and resources. The SWOT analysis is shown underneath in Table 7.

Table 7: SWOT analysis for the C3 producer

Strengths	Weaknesses
• Automatic network reconfiguration • Decreased OPEX • Cost effective for big networks • Decreased network planning costs • New revenue opportunities	• High initial cost
Opportunities	**Threats**

• 5G network deployments • New actor in the market	• Competition from different C3 producers

5.4.2 SWOT analysis for the Operator

Regarding the Operator, the COHERENT C3 solution will bring benefits to the operator in terms of providing less CAPEX and less OPEX since most of the EPC based core equipment will be replaced by C3. Threats to the operator may be the high initial cost or the time period it will take to replace all the access infrastructures. The SWOT analysis in this case is shown in Table 8.

Table 8: SWOT analysis for the Operator

Strengths	Weaknesses
• Flexible network • Decreased OPEX & CAPEX • Cost effective for big networks	• Time to replace all access network • High initial cost
Opportunities	**Threats**
• 5G network deployments • Flexible upgrade in the network	

6. Exploitation Plan

This chapter presents the exploitation plans of each partner in the project.

6.1 VTT Exploitation Plans

6.1.1 Internal exploitation

VTT has the mission to transfer technology to business. The COHERENT project increases VTT's know-how on 5G RAN architecture and implementation in general and provides specific knowledge on RAN virtualization and slicing, licensed shared access (LSA) based spectrum sharing, RAN control algorithms, and concept prototyping. The COHERENT results are exploited in different directions inside VTT to meet its mission. Firstly, the COHERENT key findings on spectrum sharing and RAN slicing are exploited in VTT's 5GTNF testbed through national 5G projects, including TAKE5 and WIVE. Small cell network based on COHERENT control framework is integrated as part of the 5G testbed in VTT. VTT's 5G testbed will be further developed in current and follow-up testbed projects and the aim to open the testbed to other companies for service evaluation and innovation. Secondly, VTT is exploring new business opportunities on autonomous systems, where 5G is the key enabler for the connectivity. The potential of COHERENT concept, architecture and implementation will be evaluated to support these systems. Lastly, VTT has published the COHERENT results in leading magazines and conferences, including IEEE Communications Magazine, IEEE Wireless Communications Magazine, etc. The key findings of COHERENT will be further explored and published in prestigious journals and conferences.

6.1.2 Project results exploitation in products and services

By cooperating with COHERENT partners, VTT has established the COHERENT demo system based on OpenAirInterface and FlexRAN. VTT has further extended the system by developing the visualization tool and control applications. The demo system developed in COHERENT will be integrated into the 5GTNF testbed in Espoo. The purpose of the testbed is to provide as a national 5G test ecosystem for local companies, particularly for verticals, to test 5G new services. Through the 5GTNF initiative, the COHERENT concept and key results will be further exploited by other companies.

VTT has involved in the spectrum sharing study in COHERENT. As a national research institute, VTT has been playing the very active role to promote new spectrum sharing schemes to ITU and ETSI. The knowledge and results obtained from the project will be utilized by VTT to promote the spectrum sharing in 5G to international regulatory bodies and to offer the consulting service to other companies.

Other exploitation synergies

VTT takes opportunities to utilize and further extend the COHERENT results in current and future national 5G and EU projects, with the focuses on two aspects: i) network virtualization technologies in RAN to enable network slicing for verticals; ii) the flexible spectrum sharing for 5G services. From these projects, the COHERENT results, including RAN sharing, spectrum management and others, will be integrated into the 5G trials through the cooperating with telecom vendors, and vertical companies in automotive, energy and building sectors.

6.2 EURECOM Exploitation Plans

6.2.1 Internal exploitation

The COHERENT project has been one of the main drivers to extend the EURECOM experimental research activities towards software-defined 5G systems. On one hand, EURECOM works on the network abstraction approaches in both utility-based multi-connectivity and autonomous self-backhauling for WP2/WP3 in order to utilize the devised RTC/C3 network architecture. Such results justify the capability of the COHERENT architecture in terms of enable abstractions, QoS guarantee, and RAN control-plane protocol, which is to our knowledge is the first concrete specification on RAN control plane protocol and south-bound interface. Also, the investigation results of these two technical components are published in the world-wide journals (IEEE Access, WCL) and conference proceedings (WCNC, VTC, WiMob, GlobeCom) to show the benefits (i.e., network and user performance) and feasibility (i.e., inter-operability of RTC/C3) leveraging the COHERENT architecture. On the other hand, EURECOM extends the OpenAirInterface (OAI) platform with the COHERENT SDK as well as the necessary APIs based on the FlexRAN platform in WP2/WP6. As presented in the Deliverable D2.4, multiple network applications and tutorials are provided to demonstrate the benefit of COHERENT SDK in fast prototyping of network control applications. Such materials also fit in the multi-RAT scenario aimed for COHERENT and help the developers to create their own models, analyses and formulations without investigating the underlying RAT-specific statistics information. These developed control applications can also be utilized by other applications as a baseline to build a more sophisticated multi-service and multi-tenant environment. Moreover, in WP5 context, EURECOM is working on the RAN slicing topic to evolve the RAN for a multi-service execution environment. Such exploitation leverages the OAI and FlexRAN platform to provide the required customization and sharing for each service at different levels.

6.2.2 Project results exploitation in products and services

Based on the internal exploitation, EURECOM is now delivering the software-based 4G/5G service delivery platform for telecommunication industry to increase the network flexibility, incorporate the network intelligence through sophisticated control applications, and experiment the emerging use-cases for various services. In this sense, the Mosaic-5G.io is formed to develop, promote and share an agile network service delivery platforms. Moreover, our aim is also to bridge the gap between communications, computing and data analysis in the 5G era. More specifically, three major platforms are provided under the umbrella of the Mosaic-5G ecosystem:

- **FlexRAN platform:** It relies on the RAN runtime to abstract in a customized way the network functions, resources and states of the underlying disaggregated RAN nodes for each service. Moreover, the RTC can provide the slice-specific information and SDK to enable the real-time control application development.
- **LL-MEC platform:** It implements the interface standardized by ETSI MEC and provides the data-plane programmability. Practically, the included edge packet service that performs ETSI traffic rule control is able to provide static or dynamic OpenFlow rulee, gather statistics, and control/monitor the related radio information.
- **JOX platform:** It provides the multi-service orchestration platform with several JoX plug-in frameworks (e.g., RAN, CN, MEC) and JoX core to manage each slice for the underlying network and infrastructure. Such JoX platform has interfaces to the Juju VNFM and relies on the network function and application stores to compose the network services across a reusable modules (i.e., OAI charms, network service templates, SDK, control applications).

More information can be found in the mosaic-5g.io website and the associated gitlab repository: https://gitlab.eurecom.fr/mosaic5g/mosaic5g.

6.2.3 Other exploitation synergies

Based on the research outcome from the COHERENT and the corresponding development over the OpenAirInterface platform, EURECOM also aims to exploit toward other Horizon 2020 projects as well as the events (workshop, tutorial) hosted by the OAI software alliance.

EURECOM exploits the results of COHERENT to enrich its education offer with the novel concepts of software-define mobile networking principles and methodology that will be identified and developed during the COHERENT project. Some of the theoretical and experimentation topics related to networking algorithms (handover parameters and logic), radio resource management in support of abstraction, multi-connectivity, self-backhauling in COHERENT will become part of master courses, as well as argument for master and PhD theses. In addition, EURECOM will organize several (online) training sessions related to programmability in RAN, and in particular on the impact of centralized control logics and algorithms on the underlying network and consequently on the quality of experience as perceived by the final user.

The impact of COHERENT will be on the development of the OAI and Mosaci5G platforms towards a fully software-defined mobile networks realizing service-oriented 5G vision, which provides more flexible and open mobile network. Moreover, it will allow their platforms to be used by partner laboratories and create synergies for future co-development activities.

6.3 Commagility Exploitation Plans

6.3.1 Internal exploitation

CommAgility designed software concepts for coordinated RRM including a load-balancing function extended eNodeB software with a new module inside the commercial eNodeB acting as COHERENT agent interfacing with other internal eNodeB's modules and the COHERENT coordinator.
The designed SW runs on the commercial product LTE eNodeB card based on TI's TCI6630K2L SoC and allows performing extensive testing of handover operation. The COHERENT setup can be used in future internally for testing special RRM functions (e.g. frequent handover operations). The experience obtained during the project will be used in the company for optimal control and data plane separation among the core network and radio network (eNodeBs).
Furthermore, the COHERENT agent at eNodeB is a prototype that can be used by CommAgility for integration with other coordinators (e.g. for coordinated SON/RRM functions in cooperation with partners).

6.3.2 Project results exploitation in products and services

Within CommAgility, COHERENT IPR results will help to learn and better understand customers' requirements and needs related to future eNodeB software releases, to develop novel and advanced solutions for COHERENT business cases, to broaden and expand know-how of 5G, and to generate further relevant IPR. The achieved results will strengthen the CommAgility IP portfolio with key contributions in the area of RRM coordination and will be elaborated regarding its relevance for product development.

6.3.3 Other exploitation synergies

The results will be used in on-going and future projects in H2020 program and beyond.

6.4 OTE Exploitation Plans

OTE is the dominant telecommunications operator in Greece, and along with its subsidiaries one of the largest telecom groups in south-eastern Europe. Moreover, OTE offers broadband services, fixed and mobile telephony, high-speed data communications and leased lines services. In addition, the OTE Group in Greece is involved in a range of activities including satellite communications, and in particular satellite broadcast television.

6.4.1 Internal exploitation

The COHERENT project focuses on providing a flexible control plane that could be the forerunner of low cost networks which will use generic purpose equipment anywhere in the architecture levels. Consequently, this network architecture proposal could be a useful asset in order to deal with the challenges of growing complexity and high cost of operation which advanced applications and services causes. OTE provides a variety of services and it is of high interest pursuing a high outcome from the operations' and cost reduction.

6.4.2 Project results exploitation in products and services

The target of COHERENT project is to provide a generic global RAN controller to control and manage the underlying RAN infrastructure which seems to be the key for achieving goals such as the reduction of the operational cost. The use of such network model scenario appears to be of a high interest and OTE is considering to exploit the benefits it offers. Also the techniques of flexible RAN and spectrum sharing are very promising for cost reductions and network improvement that are under consideration. OTE could consider a pilot program to examine the advantages of the C3 controller for current networks.

6.4.3 Other exploitation synergies

OTE will exploit the project's outcomes by acquiring experience and deep knowledge on dynamic network environments such as software-defined or virtual networks. Afterwards, this experience could be used to set up an initial plan by exploiting the insights and the results of COHERENT as described above. In these respects, OTE has experimented with virtualization functions and control/orchestration platforms like Open Stack which can be very valuable to be presented to OTE management in order to

be possibly implemented in OTE network that currently uses traditional methods for service transmission.
Also the techno-economic analysis of C3 has initially showed that the investment in such controllers and their implementation in an operator's network can bring financial benefits without losing in performance.

6.5 FBK Exploitation Plans

6.5.1 Internal exploitation

FBK CREATE-NET is a research center that pursues research driven innovation among its key objectives for Horizon H2020 projects. The COHERENT project has been one of the main drivers for several CREATE-NET internally developed tools and prototypes for 5G networks. The COHERENT project results have been exploited internally to not only extend the knowledge base on heterogeneous network control but also on developing abstractions that can programmatically manage the radio resources for multiple network services/tenants. More concretely, the COHERENT project has resulted in adding new innovative features for multi-tenancy, heterogeneous radio access control and spectrum management applications in the 5G-EmPOWER platform. Fine-grained resource slicing features have been added to the 5G-EmPOWER platform for supporting multi-tenancy in RAN. At organizational level at FBK CREATE-NET, the COHERENT project results have strengthened the understanding of 5G core concepts such as network programmability, Software-defined Networking, Radio Resource Management, RAN sharing and Network resource abstraction. Furthermore, the dissemination activities undertaken during the project in the form of conference and journal publications have served as reference to several other research projects and development activities at the FBK organizational level.

6.5.2 Project results exploitation in products and services

FBK CREATE-NET is already working on different spin-offs that were orignated from past FP7 research projects and are currently encouraged and supported by the local public bodies. The innovations made during the COHERENT project are candidate for further business exploitation within new spin-offs targeting network programmability and elastic methods to RAN multi-tenancy. Moreover, FBK CREATE-NET, as an official member of the EIT Digital initiative, will identify exploitation opportunities along with other key stakeholders to ensure faster go-to-market opportunities from the COHERENT network abstraction and programmable control concepts and technologies. It is anticipated that the results from the COHERENT project will contribute to the overall strategy in the 5G landscape. FBK CREATE-NET is deeply involved along with its partners in its participation to several other 5G-PPP projects such as 5G-ESSENCE. CREATE-NET plans to exploit the COHERENT results on network abstraction and programmability for: (i) enhance its know-how in the field of heterogeneous RANs and programmable network infrastructures, (ii) connect with similar initiatives at the european and eventually global level, and (iii) strengthen its position in the development of future infrastructures for research and innovation.

6.6 TCS Exploitation Plans

6.6.1 Internal exploitation

COHERENT is part of TCS research strategy on 5G systems and beyond, with other H2020 projects and national research programs. COHERENT results are exploited inside TCS to enrich TCS knowledge background on broad topics like next-generation network function virtualization and software defined networking. COHERENT brings knowledge about the virtualization of the RAN (WP2/WP6) and the application of the SDN concept to the RAN architecture, in particular for network slicing (WP2/WP6). Also knowledge on specific technical topics about relaying in the context of the LTE-A Pro (3GPP Rel 13-14), about reconfigurability of relay stacks and strategies (thanks to network function virtualization) and about high speed platforms were accumulated during the project, thanks to the effort provided in WP3. Results on auto-reconfigurable relaying strategies over LTE networks have been patented (2 patents, please see COHERENT D7.3 for more details).
The code partially developed by TCS in WP2 and the testbed built in the context of WP6 (by using EURE OAI platform) is part of TCS research strategy and it provides a solution for quick

demonstrations of innovative ideas around network slicing and virtualization of (part of) the RAN control plane.
Internal exploitation of the project results has started already by producing an internal TCS publication on May 2016 about COHERENT partial results which is addressed towards the community of internal experts and developers (> 300 persons). Then we disseminate knowledge acquired on Device-to-device (D2D) communications in LTE-A Pro to product line managers at the end of 2017. Additional internal exploitation actions are the internal dissemination of final COHERENT results (presentation), internal demonstrations with the testbed built during the project towards technical directors, interested product managers and TCS 4G/5G research community. COHERENT results may also be exploited as an input to write proposals for future research projects.

6.6.2 Project results exploitation in products and services

In TCS strategy COHERENT is a research project, which produces results at relatively low technology readiness level. Even if COHERENT results cannot be immediately used in products and services as they are, they contribute to clarifying the roadmap of technological components of future products.
In particular the two patents submitted during the project are important to assess TCS knowledge and mastership on direct communication and relaying, which represent essential features for Professional Mobile Radio (PMR) and Public Safety applications. For this reason, TCS considers these two innovations relevant to the evolution of three THALES products:

- NEXIUM Wireless - LTE solution adapted to both civil and security forces mission-critical applications. NEXIUM Wireless offers high speed data services based on LTE 3GPP standard, including broadband video applications, while still providing existing PMR services.
- TeSquad - professional smartphone delivering broadband mission-critical applications in a ruggedized form-factor and enabling secured communications. TeSquad integrates a Push-To-Talk (PTT) solution enriching NEXIUM Wireless by offering professional services (group communication, conference, emergency calls) to protection forces.
- Eiji - a suite of secure mobile telecommunications services for professional use, designed to provide secure, resilient communications for public and private security missions. It is designed to provide essential operators, major corporations and civil security forces with secure, resilient communications for public and private security missions, through a Mobile Virtual Network Operator (MVNO) solution.

Eiji is also a good target product for innovations on RAN network slicing investigated in WP6.
Finally, the work about high speed platform can help in steering decisions about the roadmap of product exploiting LTE modems in high speed trains or in planes.

6.6.3 Other exploitation synergies

As far as research knowledge management is concerned, exploitation synergies are possible by joining the results of COHERENT to the ones of other previous or ongoing H2020 projects.

6.7 4GC Exploitation Plans

6.7.1 Internal exploitation

Mariana Goldhamer (secondary name: 4GCelleX) is self-employed, being engaged in a variety of activities, including participation in collaborative research projects, patent development in areas related to mobile communication, standardization in 3GPP and ETSI BRAN, consultancy on standardization and on European regulations.
In COHERENT Mariana has been involved in RTD activities in WP2, WP3, WP4 and was the lead of WP7 and the standardization task 7.2.
During standardization activity, mainly in RAN3, Mariana has acquired an important asset: knowledge related to 3GPP 5G architecture and high layer protocols.

6.7.2 Project results exploitation in products and services

As consultant and independent researcher there are several tracks which can be followed, as detailed below:

A. Exploitation Scenario #1: Consulting with regards to 5G standards

In this scenario Mariana will provide consultancy in relation to 5G standards or will participate in further 5G standardization for interested companies. The customers could be: universities, research centres, small enterprises. The value gained is income and up-dating the expertise in line with technology developments.

B. Exploitation Scenario #2: Patent Monetization

As result of RTD activity, she submitted four independent patent applications in USA. The full list of patents is provided in D7.3. It will still be necessary lots of investments in work and funding in patent prosecution process.

The monetization of the patents, if awarded, could be done by selling the patents or by licensing.

C. Exploitation scenario # 3

In this scenario Mariana will continue the research in collaborative projects at national and international level, as RTD partner and standardization professional.

The partners could be: universities, research centres, small and large enterprises.

6.7.3 Other exploitation synergies

5G network slicing (studied in COHERENT) opens opportunities for new services, some of them requesting the adaptation of the system architecture beyond the standardization done in 3GPP. This opens opportunities for further standardization and/or collaborative projects.

6.8 UDE Exploitation Plans

6.8.1 Internal exploitation

UDE will exploit achievements and extended experience gained from COHERENT project in its research and education activities. UDE is committed to research in future wireless communication systems, localization and material characterization with new technologies like Massive MIMO and millimeter wave with extreme bandwidth. The COHERENT project enhanced UDE’s physical layer oriented research scope with the view on innovative control and coordination procedures with higher layers. Key findings of COHERENT concerning coverage extension, rapid frequency reuse and interference mitigation based on distributed antenna systems (DAS) and full duplex (FD) transmission will be further investigated and advanced in conjunction with a highly flexible Massive MIMO System with up to 128 antennas. This Massive MIMO System is part of a new ultra-high precision radiolocation measurement system PreSyse, which will be built up within the next two years at UDE. It will be used by the three doctoral candidates involved in the COHERENT project to advance and finish their studies in the related research areas. Furthermore, UDE established a truly engineer-oriented nationwide remote teaching program (http://www.online-master-eit.de/) for Master studies in the area of electronic and information technologies. Knowledge and results from COHERENT project will be transferred into this program as live material for the subjects of software defined radio and networks.

6.8.2 Project results exploitation

As university, UDE focusses mainly on research and education. Project results, like algorithms and software code developed within COHERENT, will be reused in further research activities in the area of distributed antenna systems (DAS) and Massive MIMO, contributing to doctoral studies and attendant bachelor and master theses. Thereby further advanced results will be published in international workshops, conferences and journals with excellent reputation.

6.8.3 Other exploitation synergies

At UDE and partnered by other universities and institutes, a Collaborative Research Center CRC/TRR 196 has been established in 2017. This public funded CRC with the title Mobile Material Characterization and Localization by Electromagnetic Sensing paves the way towards localization and generation of material maps based on THz frequencies. Means like Massive MIMO for coverage improvement or distributed antennas utilized for localization are of significant importance in conjunction with small antennas and low transmit/receive power in the THz region. Potential exploitation of research synergies is given and will be considered by transferring relevant COHERENT approaches into THz frequency bands, for localization as well as for communication.

6.9 SICS Exploitation Plans

6.9.1 Internal exploitation

During the project, SICS has disseminated results and knowledge through regular technical seminars and by appearing with posters showcasing COHERENT concepts at the annual SICS Open House exhibition 2017. Another appearance is planned for the SICS Open House in 2018 where we will show the final results of the project.

Moreover, a new research group, Network Intelligence, headed by Dr. Rebecca Steinert was created in the fall of 2015 at SICS, with focus on applied machine learning for distributed and intelligent programmable systems (https://www.sics.se/groups/network-intelligence). In this context, COHERENT has enabled the full-time employment of Dr. Shaoteng Liu and the support of one PhD student at SICS, MSc Akhila Rao, since 2016. Finally, initiatives towards new proposals constitute a central part of the activities at SICS - since the start the group has successfully established a number of new international and national research collaborations.

6.9.2 Project results exploitation

As part of the COHERENT project, SICS has been able to develop and establish a new line of research oriented on fundamental methods for robust distributed controller planes for virtual and software-defined infrastructures. Additionally, research on data-driven methods for radio access networks has also been established. Both lines of research will continue beyond COHERENT. The concepts and ideas are now taken further into new proposals and in ongoing projects, such as the SSF (Swedish Foundation for Strategic Research) Time-Critical Clouds which is a flagship project at SICS carried out in collaboration with KTH, associated industries and research institutes. Continued collaboration with both EURECOM and CNET in this context and beyond COHERENT is planned. Open source code has been released for continued development and integration in relevant platforms (e.g. ONOS, EmPOWER, FlexRAN, etc).

6.9.3 Other exploitation synergies

SICS is leveraging upon the results in COHERENT developing intelligent controller mechanisms for software-defined infrastructures suitable for the next generation networks in the national project SSF Time-Critical Clouds (2016-2021) in collaboration with KTH. Further efforts on continuing the established line of research in terms of future H2020 calls (e.g. 5G and the Next Generation Internet initiatives), EIT-Digital and EUREKA initiatives are continuous activities.

6.9.4 Open source code releases

SICS has released one open source contributions to the COHERENT SDK – a predictor for attainable throughput for WiFi and LTE, respectively, both licensed under Apache 2.0:

AQuaMet: Technology agnostic link quality metrics for radio access. The code is available at: https://github.com/nigsics/aquamet.

6.10 TP Exploitation Plans

6.10.1 Internal exploitation in products and services

TP expects to strengthen its competence in mobile network solutions based on standard architectures and their evolution towards 5G networks. Therefore, TP has exploited the project result internally to leverage the project concepts, e.g. programmability and network abstraction, in TP's product design, especially in the open source erGW project. The project architecture has the potential to further improve network automation through programmability, which inspired TP to pursue network solutions toward cloud native NFV.

6.10.2 Project results exploitation in products and services

The goal of the COHERENT project is to provide a programmable radio access networks (RAN) by using a flexible and logically centralized control plane to manage the whole network. TP is exploiting this design concept to enhance TP's public WiFi Transport Service [5]. In this product, TP has delivered network control and management service for all distributed wireless access points on 1000 buses. The new design based on network programmability is expected to improve the management efficiency and network performance. Furthermore, COHERENT results, especially SDN, NFV and cloudification, help TP to build our future innovative products for TP's network as a service (NaaS) business.

6.10.3 Other exploitation synergies

TP is also involved in the research projects funded by ZIM (Zentrales Innovationsprogramm Mittelstand). ZIM is a German funding programme for small and medium sized enterprises (SME) with business operations in Germany that want to develop new or significantly improve existing products, processes or technical services. The COHERENT results are already utilized, especially the outcomes of the erGW open source project, in the context of on-going ZIM projects as well as future research projects.

6.11 EICT Exploitation Plans

6.11.1 Internal exploitation

EICT is a private-public partnership aiming at the promotion of ICT innovations. As a result of participation in the project, EICT has increased its know-how in the area of wireless networks and 5 G RAN architecture. Expertise gained from the results of COHERENT will be used for consultancy and especially for advances in innovation management.

6.11.2 Project results exploitation in products and services

EICT has no commercial exploitation plans related to the results. Research done related to 5G RAN architecture have been disseminated in conference papers and in COHERENT deliverables. In addition, EICT intends to promote the project results to its large networks in mobility sector to endorse the 5G developments in the field of automated driving.

6.11.3 Other exploitation synergies

Through project participation, EICT has expand its collaboration networks in the field of 5G. In addition, the knowledge related to project dissemination and communication activities will directly flow into further elaboration of project management expertise.

6.12 AALTO Exploitation Plans

6.12.1 Internal exploitation

Aalto University is an academic partner of COHERENT. One master thesis (Biza Sewda, 2017), one PhD thesis (Sergio Lembo, 2017) and one PhD thesis in part (Furqan Ahmed, 2016) have been written and accepted based on work done in COHERENT. One more PhD thesis will be defended in 2018 (Junquan Deng), based on COHERENT work. Aalto has published two journal papers and six conference papers based on COHERENT work, and two more journal papers are in the review process. The work in WP4 acts as the inspiration to at least two more journal papers that are under preparation. Aalto University offers education on the highest academic level. The COHERENT approach will be used to enrich the course "ELEC-C7320 Ohjelmistoradio" (Software defined Radio), which is offered for bachelor students of information technology. COHERENT results are vital in the ongoing reformulation of the master degree curriculum in Information and Communications Technology, where the relative weight of teaching lower vs. upper layers is perennially revalued.

6.12.2 Project results exploitation in products and services

The department of Communication and Networking at Aalto offers service to the Finnish ICT industry in the form of direct subcontracting projects. The know-how generated in COHERENT has directly impacted these projects, as well as collaboration projects within the EIT Helsinki node. This impact will be growing. Machine learning for network management, realizing COHERENT principles, will be a mainstay in industry collaboration in the coming years.

6.12.3 Other exploitation synergies

Collaborative ties that have emerged within COHERENT will be a valuable asset for Aalto in the future. The results will be used in future project applications.

6.13 PUT Exploitation Plans

6.13.1 Internal exploitation

PUT is one of the academic partners in the COHERENT project consortium. During the lifetime of this project PUT team was mainly involved in three technical work-packages (mainly WP3, WP4 and WP6) and was responsible for spectrum and PHY layer related aspects. In essence, all PUT representatives who participated in this project have been involved for longer time in research related to optimization of the spectrum resources utilization and to the PHY layer signal processing. In that respect COHERENT project was a part of the broader research strategy at PUT, however, COHERENT played an important role in that context. Mainly, it was a key driver for defining fresh investigation concepts related to spectrum management techniques in fully virtualized wireless telecommunications networks. The new findings made for last 2.5 years shaped the new understanding at PUT on the role of spectrum resources for the future wireless network, where various functions will be fully virtualized. The new COHERENT architecture identified the logical location of the Spectrum Management Application in the overall telecommunication ecosystem.

The knowledge gained during the project lifetime has been presented many times at the local seminars of the Chair of Wireless Communications at PUT, which are open for audience interested in the recent advances in the field of wireless communications. Moreover, numerous conference publications (on both national and international events), journals and book-chapters, where the COHERENT results have been presented, have shaped the new perception of PUT skills when referring to the spectrum management issues.

Next, COHERENT project has a significant impact on the scientific development of PUT staff. Beside scientific publications, which were high for PUT in this project, the research achievements will be in the nearest future a part of a Master Thesis, and of the habilitation application. Moreover, some persons had a chance to participate in longer scientific visits, and this aspect is of crucial importance from the perspective of improving the academic-staff qualifications. Clearly, further publications in prestigious journals are planned, where the main COHERENT achievement will be examined.

6.13.2 Project results exploitation in products and services

During the project lifetime PUT was actively involved in conducing real field-experiments with real wireless network in order to evaluate the correctness of the proposed theoretical solutions. In the context of PUT, a set of intensive experiments have been carried out in order to assess if the vertical spectrum sharing in 3.6GHz band can be truly beneficial for the end-users and for operators in practice. Two trials conducted in the last project year are of particular importance, as they provided new insight towards spectrum utilization in future wireless systems. The real-time demonstrator has been established at PUT premises, where the COHERENT achievements related to sophisticated spectrum management if partially-virtualized network can be observed. These demonstrators have been already and will be used in the future for attracting industry partners in this research path, and in consequence to transfer the knowledge and technology to business.

Beside trials, PUT has implemented the Spectrum Management Application for OAI platform, and as such this demonstrator is also highly attractive for stakeholders interested in application of advanced spectrum management schemes for 5G.

Based on these findings PUT has gained great experience in “spectrum virtualization”, and this experience has resulted in new industry projects related to advanced, database oriented spectrum management. Further new opportunities are of course subject to continuous considerations.

6.13.3 Other exploitation synergies

It is also worth mentioning that since the project beginning PUT has established fresh research collaborations with foreign and local partners. These result in new projects proposals and new investigation opportunities. In particular, new intensive connections have been established between PUT and FS, INEA and EURECOM, and new projects are considered. It is also considered to organize the short- or long-term scientific visits this year in order to further exploit the achievements made during the COHERENT project.

Also the connection with other partners are very vivid, and these connections will be further exploited while preparing a book, where the key COHERENT results be presented.

Finally, let us mention that PUT became also a member of some working groups or alliances, such as 5G-PPP SPECTRUM working group or the OpenAirInterface Alliance. These memberships allow for further continuation of the work on spectrum management application (e.g., in OAI environment).

7 Conclusions

This report presents the main market stakeholders involved in the COHERENT architecture, which is presented too as well as the motivation that led to this specific architecture. The main target of the report is to investigate the business models and actors in the COHERENT concepts, the business relationships between them and perform a techno-economic analysis form both the producer and operator point of views. To do so, it is important to identify the main parts of the ecosystem. Thus, the C3, the RTC and the NFV-based Network Store, are considered to be important network elements that bring together producers, Enterprises and operators.

After identifying the actual business players in COHERENT context, the Porter's five forces model is applied to the COHERENT project case. The Porter model is used to estimate the financial results in the specific use cases where COHERENT will be applied. Finally, the importance of the model factors that are relevant to the business environment (Industry rivalry, Threat of new entrants, Threat of substitutes, Bargaining power of customers, Bargaining power of suppliers) are estimated.

Moreover, this report include a 7-years detailed financial analysis for both C3 Producers and Operators point of view in order to identify the financial benefits by the adoption of the COHERENT architecture. The results of this numerical analysis is based both on real values according to the experience of each partner and by well-balanced and acceptable assumptions in order to clearly highlight the potential business benefits from the COHERENT approach. It is found that the adoption of the COHERENT architecture will bring financial benefits to the producer of C3 but also to the operator who implements the C3 architecture. This implementation will bring also some additional benefits in terms of architecture flexibility and in self autonomic management.

The document presents also a short SWOT analysis for both the C3 producer and the operator who buys and uses this product.

Finally, this document describes the exploitation roadmap and plans of each partner by leveraging the COHERENT results in their ongoing and future activities.

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