Grant Agreement N°: 957317
Topic: ICT-42-2020
Type of action: IA

AFFORDABLE 5G

High-tech and affordable 5G network roll-out to every corner

D5.3: Value proposition, stakeholder analysis and initial business models

Revision: v.1.0

Work package	WP 5
Task	Task 5.2
Due date	31/08/2021
Submission date	31/08/2021
Deliverable lead	inCITES Consulting
Version	1.0

Abstract

The objective of this deliverable is to investigate the business aspects of Affordable5G solutions. A market analysis is performed for each part of the proposed solution as well as for 5G private networks in general. This allows to understand market dynamics and identify the competitive products. A roadmapping is then carried out to identify the factors that will influence the market adoption and evolution of Affordable5G. According to expert's opinion, business aspects are most important while critical communications are considered the most important sub-factor in the global priorities list. The actors of 5G private networks ecosystem are also presented. New operators for private networks are discussed in detail. A reference model illustrating all players, their relationships and revenue streams is provided. Business models for each of the proposed solutions are drafted and discussed.

Keywords: 5G Non-Public Networks, O-RAN, Business Model, Market Analysis, Roadmapping, Reference Network

Document Revision History

Version	Date	Description of change	List of contributor(s)
V0.0	9/7/21	ToC and first contributions	inCITES (input from all partners)
V0.1	8/8/21	First draft consolidated	inCITES (input from all partners)
V0.2	14/8/21	Comments by NKUA	NKUA
V0.3	25/8/21	Comments by 8bells	8bells
V0.4	27/8/21	Revised version for Quality Control	inCITES
V1.0	30/08/21	Check for submission	ATOS

Disclaimer

Project co-funded by the European Commission in the H2020 Programme		
Nature of the deliverable:	R	
Dissemination Level		
PU	Public, fully open, e.g. web	√

CI	Classified, information as referred to in Commission Decision 2001/844/EC	
CO	Confidential to Affordable5G project and Commission Services	
PP	Restricted to other programme participants (including the Commission Services)	

** R: Document, report (excluding the periodic and final reports)*

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

OTHER: Software, technical diagram, etc

EXECUTIVE SUMMARY

The objective of this deliverable is to investigate the business aspects of Affordable5G solutions. Towards this direction, three different types of activities are performed: market analysis, roadmapping and business modelling.

The first step in this endeavour is to assess the current status of the market of the different components of Affordable5G through a market analysis. Several data are provided. Among others market size and market growth and the factors contributing to the potential growth of the market. A benchmarking about spectrum allocation strategies is also given which is very important for the future of private networks. Information about market players and competitive products is also included. The fact that all the studies from market research firms forecast a significant growth of all the relevant markets is very promising for Affordable5G components.

Regarding roadmapping activity, factors affecting market adoption and evolution of Affordable5G solutions are identified and assessed by experts within the project using the Analytic Hierarchy Process (AHP). A survey is conducted to evaluate the relative importance of these factors and classify them. The survey is correctly completed by 16 experts from several European countries belonging to a variety of different sectors including industry, SMES, research institutes and academia and having a professional background in telecommunication technologies. The derived results show that Business is rated as the most important criterion followed in turn by Acceptance, Flexibility and Technology; whilst Performance has the lowest weight. Based on global priorities, the most weighted sub-criterion is that of reliable communications, followed by New market opportunities, Edge computing, Open platforms/Open RAN, Interoperability, Cost reduction and Network operation automation.

After defining and prioritizing the aforementioned factors, a business modelling is performed where new players of the value chain are identified and incorporated accordingly. The relations between actors along with the revenue streams are described. Initial exploitation strategies and the business model canvas are provided per solution.

This deliverable can be used by both Affordable5G partners and other stakeholders involved in the deployment of private and enterprise networks since it provides useful guidelines towards their exploitation. It can also serve as a baseline for the technoeconomic analysis, performed in the same work package that will build on and further elaborate the described business cases.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

4G	Fourth Generation
5G	Fifth Generation
5GC	5G Core
5GNR	5G New Radio
5G-RAN	5G Radio Access Network
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
ANN	Artificial Neural Networks
ANR	Automated Neighbor Relation
API	Application Programming Interfaces
AS	Application Server
AWS	Amazon Web Services
B2B	Business-to-Business
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expeditures
CBRS	Citizen broadband radio Services
CI	Continuous Integration
CD	Continuous Delivery
CN	Core Network
CNCF	Cloud Native Computing Foundation
COTS	Commercial off-the-shelf
CR	Consistency Ratio
CS	Circuit Switch
DCAE	Data Collection Analytics and Events
DU	Distributed Unit
E2E	End to End
eMBB	enhanced Mobile Broadband
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
EU	European Union
FAQs	Frequently Asked Questions
FRMCS	Future Railway Mobile Communication System
FWA	Fixed Wireless Access
GPP	General Purpose Processors
GPU	Graphic Processing Unit

HW	Hardware
ICT	Information and Communications Technology
IDG	International Data Group
IoT	Internet of Things
IP	Internet Protocol
IPR	Intellectual Property Right
IT	Information Technology
LMR	Land Mobile Radio
LTE	Long Term Evolution
MCS	Mission Critical Service
MDAF	Management Data Analytics Function
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MNO	Mobile Network Operator
MTX	Mission Critical Communication
MVNO	Mobile Virtual Network Operator
Naas	Network-as-a-Service
NGMN	Next Generation Mobile Networks Alliance
NG-RAN	5G ‘Next Generation’ RAN
NF	Network Function
NFV	Network Function Virtualization
NH	Neutral Host
NM	Network Monitoring
NPN	Non Public Network
NR	New Radio
NSA	Non-Standalone
NT	Network Telemetry
NWDAF	Network Data Analytics Function
O-DU	Open RAN Distributed Unit
ONAP	Open Network Automation Platform
OPEX	Operatign Expeditures
O-RU	Open RAN Radio Unit
O-RAN	Open RAN
OSM	Open-Source Mano
OTIC	Open Testing and Integration Centres

OTT	Over the Top
PHY	Physical Layer
PMR	Private Mobile Radio
PPDR	Public Protection and Disaster Relief
RT-RIC	Real-Time RAN Intelligent Controller
QoS	Quality of Service
RAN	Radio Access Network
RIC	Radio Intelligent Controller
RU	Remote Unit
SA	Standalone
SDN	Software Defined Networking
SLA	Service Level Agreement
SME	Small of Medium Enterprise
SW	Software
TCO	Total Cost of Ownership
TIFG	Testing and Integration Focus Group
TRL	Technology Readiness Level
TSN	Time Sensitive Networking
UDM	Unified Data Management
UPF	User Plane Function of 5GC
UE	User Equipment
vEPC	Virtualized Evolved Packet Core
vEPC	virtualized Evolved Packet Core
VNF	Virtual Network Function
WISP	Wireless Internet Service Providers

1 INTRODUCTION

Multiple industry analysts predict that the global private fifth generation (5G) network market size is expected to grow significantly over the next decade[1]. A 5G private network, or Non-Public Network (NPN) in 3GPP terminology, is a physical or virtual network that is intended to be used by an enterprise or organization.

NPNs have actually been around for a while, but really took off with the introduction of 4G. Main reasons were the capacity improvement of the radio interface, network simplification by removal of the Circuit Switch (CS) core, introduction of all IP architecture, and creation of smaller and more efficient equipment that simplified rollouts.

The introduction of 5G brings an even more significant capability improvement targeting NPNs. The long list includes improvements in throughput, latency, coverage, availability, energy efficiency, traffic capacity and user device density. Concurrently, key technical enablers such as cloud-based core, flexible small cells, disaggregated radio access network (RAN), self-organizing networks, have the potential to lower both capex and opex requirements. Realizing that private and enterprise networks are a catalyst for industry transformation, many countries have set aside spectrum to be used for local 4G or 5G deployment. In Germany for example, the telecoms regulator reserved 100MHz of spectrum in the 3700MHz-3800MHz band for exclusive use from private companies[2]. Within the first few months, 33 companies bought 5G private licenses including Bosch, BMW, BASF, Lufthansa, Siemens, and Volkswagen. Another method of facilitating private networks, followed by France and Greece, is through obligations imposed to spectrum assignees requiring from them to accept reasonable requests from other entities and allow them to access their network or utilise their assigned frequencies[3].

Commercial mobile network service providers focus on public consumer needs. Enterprises require NPNs tailored to specific service-level performance. NPN deployments therefore require greater control over QoS (coverage, throughput, latency, uplink/downlink ratio, KPI values), availability, reliability and security.

Applications of NPNs in industrial context range from cost reduction to process reinvention. Introduction of 5G could enable cable replacement, remote-controlled machines, new device categories such as AR/VR, productivity improvements, new operating models and increased asset mobility. NPNs are applicable to a wide range of verticals including Manufacturing, Mining, Energy/Utilities, Infrastructure & Transportation, Retail, Travel/Tourism, Education, Communications & Media, Agriculture, Health, Government and Public Sector.

Affordable5G investigates a cost-efficient 5G solution targeting NPN deployments. Main drivers behind the cost optimization include the Network Function Virtualization (NFV) paradigm, open-source solutions, open interfaces, and network programmability & automation. Affordable5G will also help reduce cost by using novel sharing techniques based on network slicing and neutral hosting.

NFV allows decoupling the network functions from dedicated and proprietary hardware, enabling their execution in Commercial Off-The-Shelf (COTS) equipment. Open solutions include adherence to O-RAN architecture, opening up the access network interfaces and allowing mixing products from different vendors. Open software platforms are adopted

[1] https://www.marketwatch.com/press-release/private-5g-network-market-2021-2027-few-ways-create-better-out-of-it-2021-08-20

[2] https://rb.gy/5r7h81

[3] https://www.arcep.fr/uploads/tx_gsavis/19-1386.pdf

throughout network functionalities at RAN, Edge, core, management and orchestration. Intelligent management of the network, the infrastructure resources and the services is facilitated by AI/ML and the provision of data analytics.

The concepts of Network Sharing and Neutral Hosting, currently mostly applicable to Public Networks, are investigated within the context of NPNs, as with the introduction of Network Function Virtualisation (NFV) and Software Defined Networking (SDN) flexibility in 5G, they have the potential to bring cost efficiencies by providing tailored and differentiated services to multiple users. Network topology choices for positioning edge computing servers from the cell site to the central data centre are also considered, balancing the latency vs cost trade-offs.

The purpose of this deliverable is to explore the means of Affordable5g successful exploitation and to support the consortium in this effort by providing a detailed market analysis relevant to Affordable5G offered components. For this purpose, an investigation of current market dynamics is performed along with the assessment of key players and trends that are identified as crucial in the effort to conduct an accurate placement of the diverse Affordable5G components to the appropriate markets in business terms. The goal is to thoroughly understand which are the drivers that Affordable5G components' providers should focus on, to create a positive force that will aid their offered products to flourish.

The main outtake is that the components are in sync and positively affected by concepts such as open RAN, cloud-native, acceleration, critical communications, and more, that project to increase not only in popularity but also in importance and societal and economic beneficial impact.

As such the Affordable5G components are well positioned in their ability to compete for the projected future demand in a variety of markets that are analysed in detail resulting from a per-components basis study. This rigorous process of examination allows the deep understanding of the components' potential by gathering information on their competitive advantages, the competition, their value proposition, its weaknesses, potential revenue streams, and more. By combining the outcomes of the analyses conducted throughout this deliverable, a knowledge base of considerable size is being built that enables the selection of the most appropriate business models that will propel Affordable5G to sustainability and success.

Drafting business models for services that are under development is a challenging process that needs to consider developmental risks and possible fuzziness that relates to the expected final product. It is entirely possible that as development goes on, feature changes take place.

Assessment and prioritization of several crucial technological and socioeconomic issues that are expected to influence the market adoption of the Affordable5G solutions is also performed. This evaluation is carried out through a number of surveys conducted using elements of the Analytical Hierarchy Process (AHP) framework, and more specifically pairwise comparisons. The obtained results will be a valuable tool for policy and decision makers, in order to accelerate the successful deployment of similar solutions.

The deliverable is structured as follows: Following an initial introduction about 5G private networks, a market analysis illustrating the current status of the relevant markets is given in Chapter 2. A Roadmapping overview of the various technologies and challenges is then presented in Chapter 3. The methodology underpinning the on-line expert survey is also described while the derived results are presented and analysed. Chapter 4 presents the factors that will affect the success of Affordable5G. Business modelling is then presented in Chapter 5 defining the relations between the involved players and describing revenue streams. Finally, some concluding remarks are drawn and provided in Chapter 6.

2 MARKET ANALYSIS

2.1 Introduction – The Private Networks Market

Private networks have been employed in the past with regularity as a way to introduce security and flexibility to the working environment. Such is also the case for wireless private networks that couple the aforementioned benefits along with mobility that has become a key connectivity feature. The emergence of 5G ushers a brand-new era of private networks since it provides added benefits through its enhanced technical characteristics. High connection speed, greater capacity, and increased adaptability to end-user needs render private 5G networks a highly attractive option for businesses that aim to increase their efficiency through the adoption of state-of-the-art technologies.

Several vertical industries and associated use cases have been identified as potential frontrunners in their ability to leverage the benefits of private 5G networks, part of whom are depicted in Figure 1.

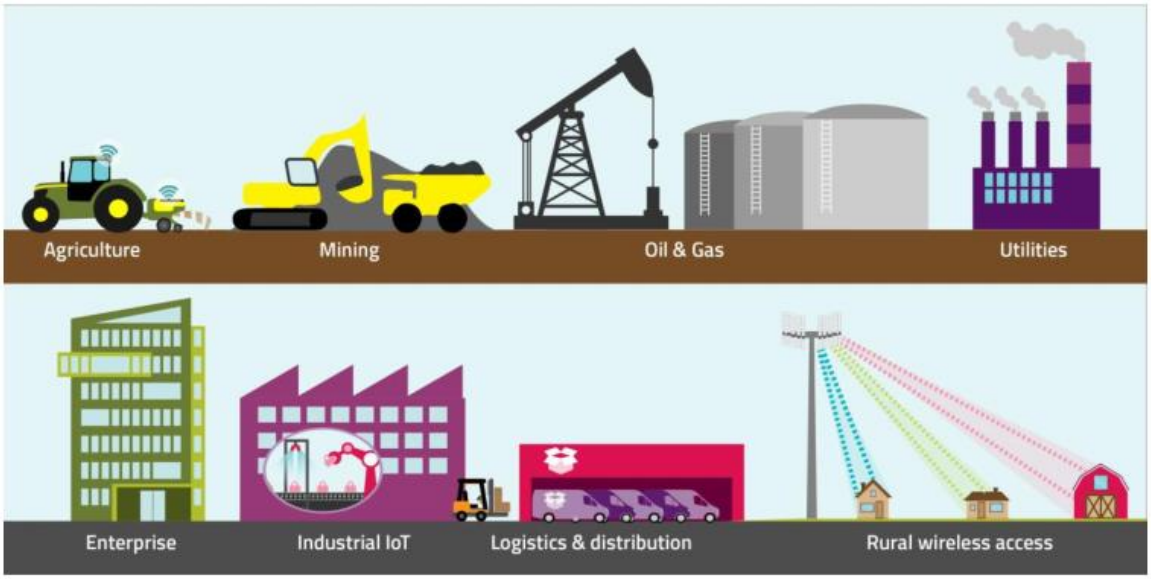


Figure 1: Private 5G network use cases (source: Ofcom)

As public 5G networks are being deployed across the globe, the importance of private 5G networks is moving from the stage of expectation to that of its realisation. The number of projects from vendors and telcos reveals an accelerating uptake. For example, Nokia, which is one of the biggest players in the market, had deployed more than 60 networks during 2020, reaching about 180 deployments in total by the end of the year. Another player, Edzcom, had deployed at least 27 networks in the Nordics by the end of 2020, although many are based on Nokia equipment.

Various Regulatory Authorities have expressed their belief on the potential of private 5G networks, allocating spectrum accordingly to facilitate their development. The German NRA has made available spectrum for local usage as universities, consulting agencies, aerospace corporations, automotive manufacturers, research centres, and more, have taken advantage of the opportunity validating at the same time the bright future of private 5G networks [1]. In fact, it had awarded more than 130 licenses to enterprises by mid-2021. Similarly, in the USA FCC established the CBRS creating an authorisation framework for shared spectrum use [2]. As various network providers expectedly acquired licences in the CBRS auction (the auctioned portion of the CBRS attracted 228 buyers), other non-traditional stakeholders such as utility providers, manufacturers, universities, etc, winningly participated in the auction, expected to

utilise their lots and exploit the great capabilities of 5G networks. Several other countries have also identified the usefulness of local/private 5G deployments either by allocating slots or recognizing publicly the potential benefits and the prospect of creating a 5G driven ecosystem. UK, Denmark, the Netherlands (more than 150 licenses have been awarded), the Czech Republic, Finland have reserved spectrum for local or private deployments, for example, while France, Greece, Italy, Croatia include in their auctions provisions that facilitate potential negotiations for the deployment of private networks between spectrum holders and interested parties.

Apart from the identified prospects when examining the way competent authorities approach 5G spectrum and private deployments, there also exist signals from the industry that underline the potential of private networks, as agreements between network providers and industrial stakeholders are being announced with increasing frequency. One such case is the “Minerva” 5G private network deployed in the port of Antwerp which is expected to provide improved speed, reliability, and security for the cooperating parties that deploy the network [3]. The port of Antwerp deployment is referenced among six others by NEC in an article discussing the increasing momentum of private 5G deployments. The conclusion drawn is that “in recent months, there is significant demand for private 5G networks from a variety of industries, and momentum continues to mount” [4].

Meanwhile, GSMA reports in its survey on 5G private networks [5]:

- Almost 25% of surveyed enterprises requires location-specific coverage in 2020.
- Of those that require a private network, 88% on average have either invested in or would be likely to invest in their own private network.
- 68% of operators claim to currently sell private wireless networks specifically deployed for enterprise customers while the rest plan to do so by 2025.
- The vast majority of surveyed operators have between 10 and 100 private network enterprise customers.

Figure 2 shows the industries that are identified by the operators as major demand drivers for private networks.

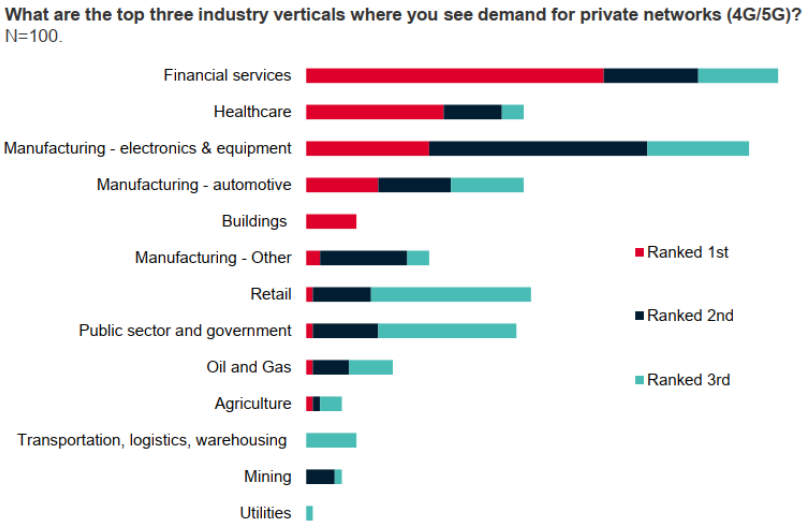


Figure 2: Industry vertical demand for private networks [5]

The GSA notes that the demand for private mobile networks is driven by the greatly increased requirements for data, security, digitisation, and mobility. Organisations are now keen to move fully into the digital era, striving to achieve great efficiency while exploiting the vast amount of

data that are produced along the way through data analytics and Artificial Intelligence (AI) based automations [6].

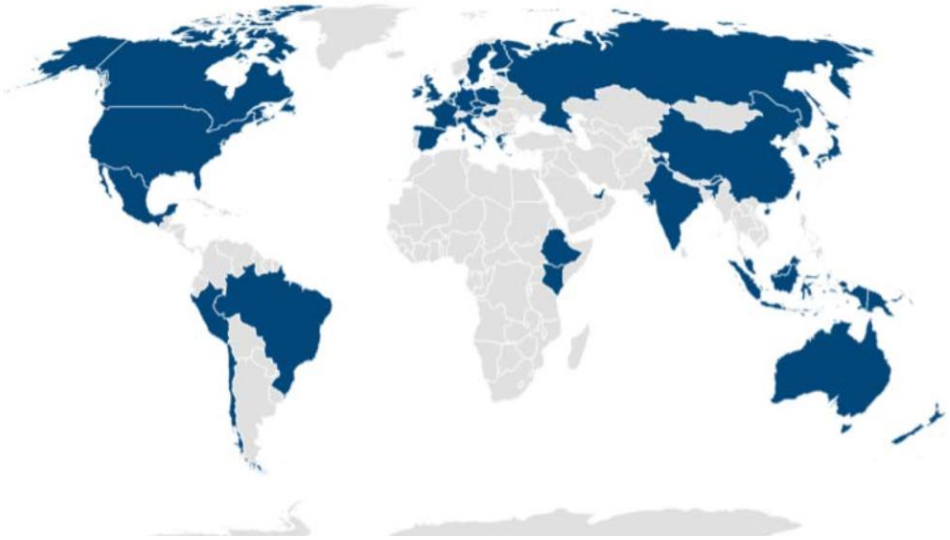


Figure 3: Countries with identified private network deployments [6]

While estimating around 500 companies worldwide with investments in private networks, GSA also states that this number is likely to be a substantial underestimate of the overall global market due to difficulties in accurately tracking the overall market status, as details are often not made public. Figure 4 shows the status of deployment for 311 identified networks, depicting a considerably mature picture for the examined networks.

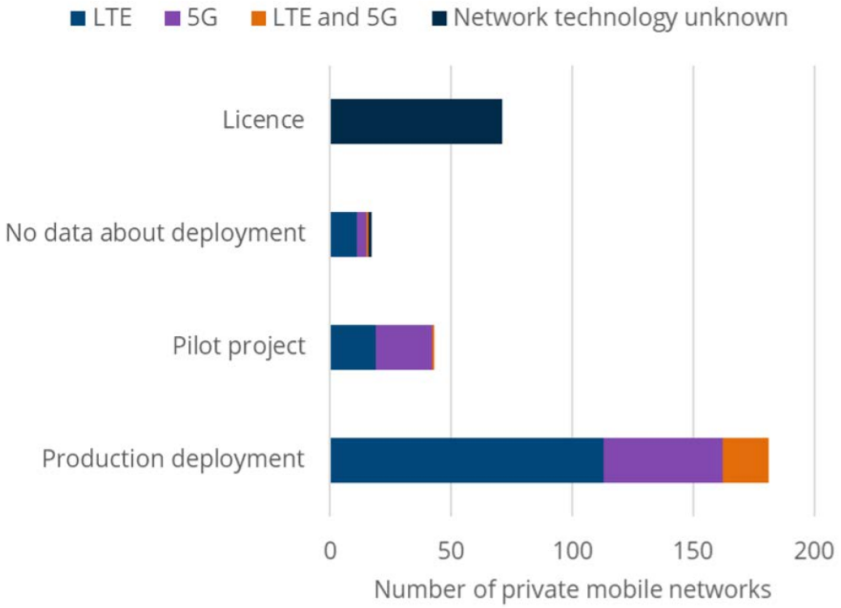


Figure 4: Private network deployments by status [6]

According to Grand View Research, the global private 5G network market was valued at $1,224.3 million in 2020 and is expected to grow with a CAGR of 39.7% from 2021 to 2028 [7]. The evolution of Industry 4.0 and the growth of Internet of Things (IoT) are expected to be a key driver for the growth of the market as industries deploy sensors and combine them with software-based solutions to achieve greater levels of operational efficiency. Moreover, the focus on security will also promote the private network market to ensure data integrity.

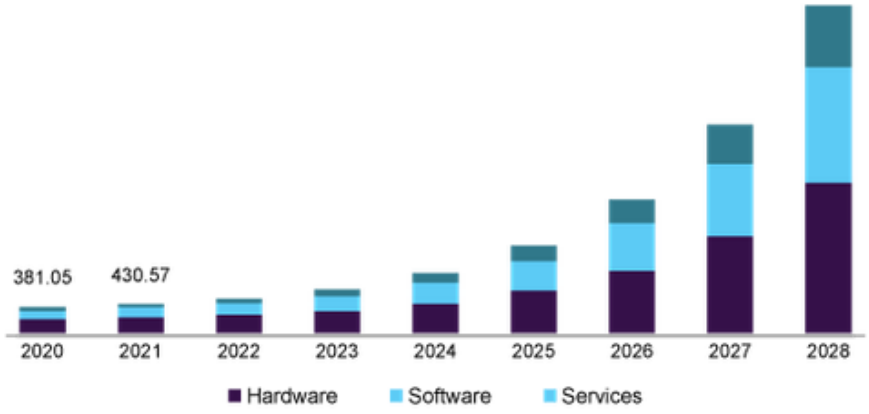


Figure 5: North America private 5G network market size by component [7]

Polaris Market Research estimates the global private 5G network market to be valued at $924.4 million in 2020 and is expected to register a 40.9% CAGR from 2020 to 2028 in what is touted to be tremendous growth due to the introduction of 5G while also attributing part of its potential to the impact of COVID-19 [8].

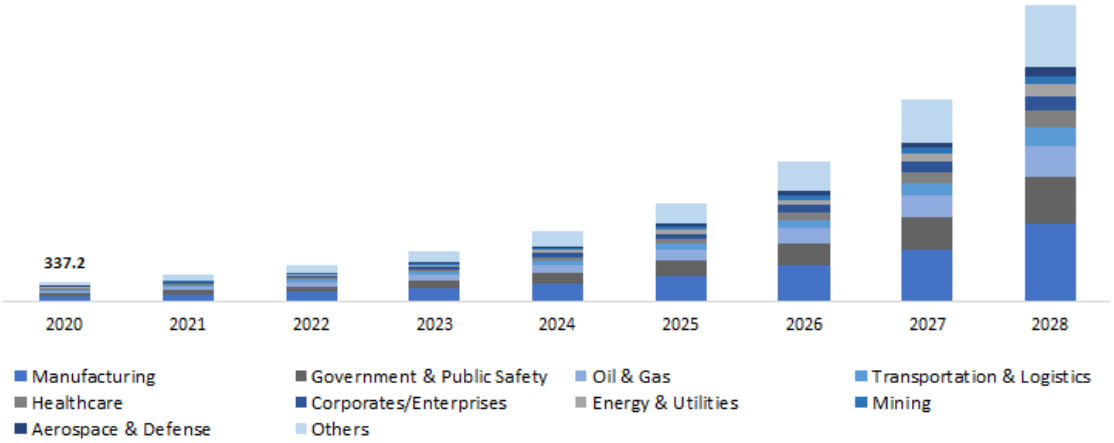


Figure 6: U.S. private 5G network market size by vertical (USD million) [8]

Harbor Research also foresees a similar grow on the market, adding the different technologies to the equation.

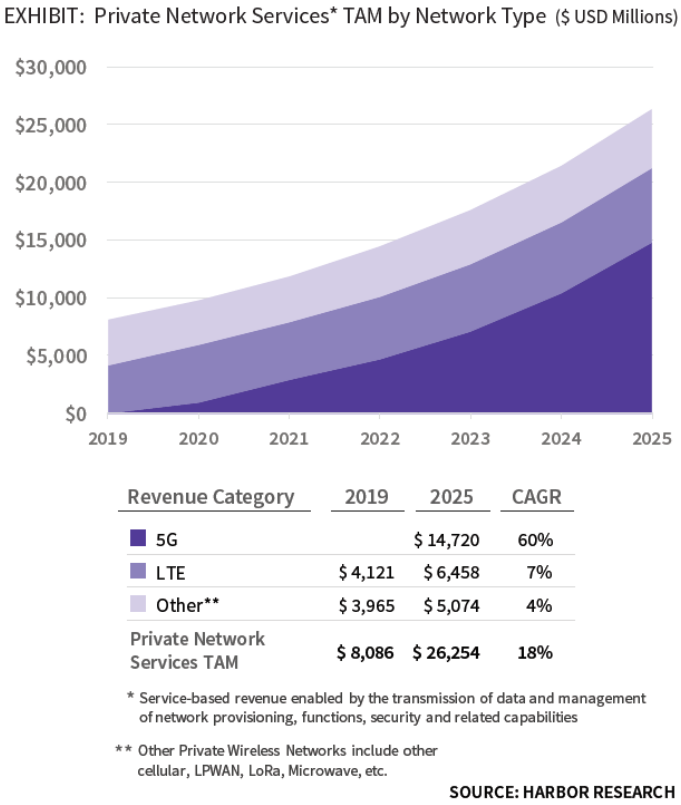


Figure 7: U.S. private 5G network market size by vertical (USD million) [8]

Features of private networks that directly benefit digital enterprises include, per Harbor Research, QoS and low latency, seamless mobility, higher performance, superior performance compared to Wi-Fi, and more. As 5G technology is maturing, these benefits will be solidified and build upon, providing even greater opportunity for growth [9].

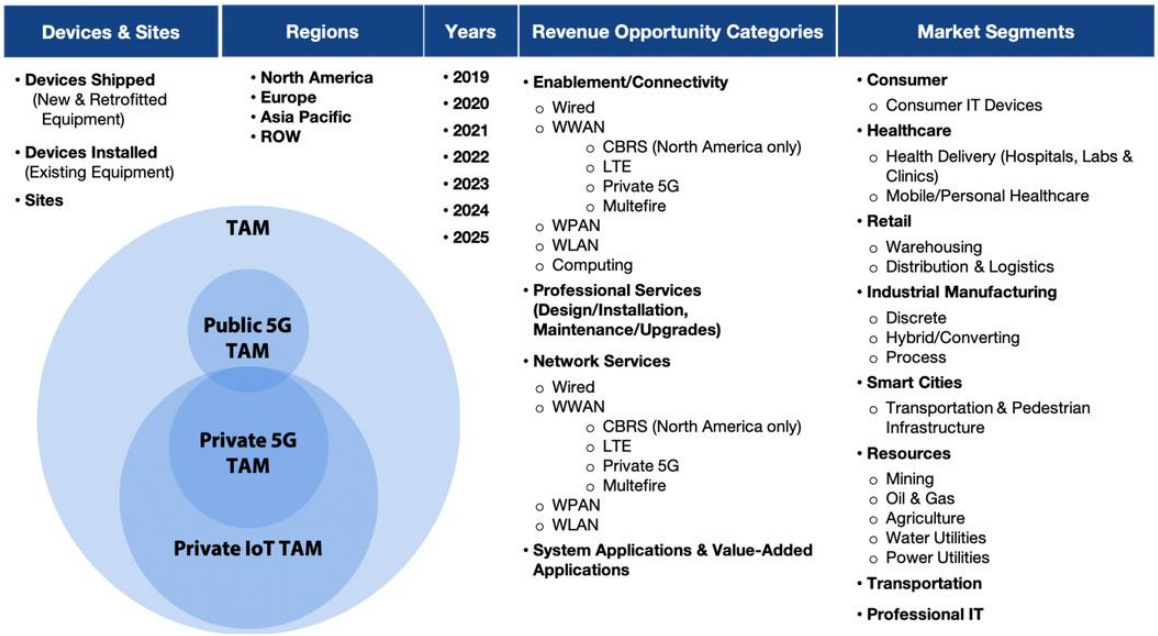


Figure 8: Private networks market model elements [9]

As the potential of private networks is gradually explored and heavily discussed by experts, well known organisations and industry leaders are validating expectations by actively deploying their private networks to facilitate a wide array of use cases. Some notable examples are depicted in the following Figure 9.

Sector	Network	Enterprise	Supplier	Site	Primary use cases
Manufacturing	5G	Ford UK	Vodafone	Factory	Real-time monitoring and control of industrial equipment (for example, welding machines)
Manufacturing	LTE	Osram	Deutsche Telekom	Factory	AGVs
Transport	5G	Ningbo Zhoushan Port Authority	Huawei	Port	Remote monitoring, control and video surveillance of gantry cranes
Transport	LTE	Groupe ADP (HubOne)	Ericsson	Airports	Push-to-talk communications and asset tracking
Mining	5G	Sandvik	Nokia	Mine	Support for AGVs
Retail	LTE	Ocado	Cambridge Consultants	Warehouse	Remote control of semi-autonomous warehouse vehicles
Oil and gas	LTE	Phillips66	Accenture/AT&T	Oil refinery	Safety applications and capacity monitoring

Figure 9: Examples of private 5G deployments, by vertical [10]

Several providers are offering commercial products for private LTE/5G networks looking to capitalise on the growth potential by providing streamlined solution with enhanced security, reliability, flexibility, etc. In Table 1, an indicative list of private network solutions is presented showing that various stakeholders are already investing in establishing a foothold within the market.

Table 1: Indicative list of private networks products

Provider	URL
Ericsson	https://www.ericsson.com/en/press-releases/2021/6/ericsson-private-5g-set-to-transform-secure-on-site-connectivity
Verizon	https://www.verizon.com/business/products/networks/connectivity/on-site-5g/
D-Link	https://www.dlink.com/en/mwc2021/virtual-booth/5g-private
Nokia	https://www.nokia.com/networks/solutions/industrial-grade-private-wireless-solutions/
Celona	https://www.celona.io/
Athonet	https://www.athonet.com/
Intel	https://www.intel.com/content/www/us/en/wireless-network/5g-overview.html
Vodafone	https://www.vodafone.com/business/iot/end-to-end-solutions/mobile-private-networks
Samsung	https://www.samsung.com/global/business/networks/solutions/private-networks/

Provider	URL
AT&T	https://www.business.att.com/products/att-private-cellular-networks.html
Enea	https://www.enea.com/products-services/5g-data-management/enea-5g-microcore

The private network market is already showing signs of great potential as industries start to comprehend the impact that 5G can have on their operations. As we enter into the Industry 4.0 era, the benefits of wide digitalisation are going to draw even greater attention to the private network market, providing credibility to the very positive projections for the future of the market.

2.2 The RAN Market

2.2.1 Small Cells Market

LTE and LTE-Advanced offer attractive data rates of over 100Mbit/s as well as low latency and high spectral efficiency. However, it is widely accepted that to achieve significantly increased speeds in real world deployments and, therefore, "meet" the forecasted growth in demand, densification of networks using a large number of small cell sites will be required. Small cells are a growing part of network planning across the world and likely to become part of future rollouts for most operators.

There is no single prediction that envisions a market reduction for Small Cells market. Some examples are:

- "According to Markets and Markets[4], the small cell 5G network market size is expected to grow from USD 626 million in 2020 to USD 2,413 million by 2025, at a Compound Annual Growth Rate (CAGR) of 31.0% during the forecast period. The major growth drivers for the market include the increase in the mobile data traffic, the emergence of Citizen broadband radio Services (CBRS) band, and the minimization of CAPEX and OPEX."
- "As per Mordor intelligence report[5] the small cell networks market was valued at USD 3.34 billion in 2020; it is expected to reach USD 10.96 billion by 2026 and witness a CAGR of 26.82% over the forecast period from 2021 - 2026. The rapidly growing number of IoT devices and the capability of a small cell network to offer direct connectivity among those devices is increasing the demand for the small cell networks market."
- "GrandViewResearch[6] forecasted that the global small cell 5G network market size was valued at USD 310.8 million in 2019 and is expected to grow at a compound annual growth rate (CAGR) of 77.6% from 2020 to 2027. In terms of volume, the market was worth 215 thousand units in 2019. The ever-rising demand for fast mobile data

[4] https://www.marketsandmarkets.com/Market-Reports/small-cell-market-216204568.html?gclid=CjwKCAjwuvmHBhAxEiwAWAYj-AiZNXuGEpv5ohoebXLOwiNehAWNzpysF5YbOFHi_xCJiu4Z3u0UnhoCMLIQAvD_BwE

[5] https://www.mordorintelligence.com/industry-reports/small-cell-network-market

[6] https://www.grandviewresearch.com/industry-analysis/small-cell-5g-network-market

connectivity among consumers has surged the deployment of the next-generation Radio Access Network (RAN)."

- "Global Small Cell 5G Network Market is valued approximately USD 521 million in 2019 and is anticipated to grow with a healthy growth rate of more than 31.2% over the forecast period 2020-2027, as per a report by MarketInsightsReports[7]"
- "According to Market Study Report[8], the global small cell market was appraised at USD 2105.19 million in the year 2018 and is likely to account for USD 18690.89 million by the year 2028, recording a CAGR of 24.38% during the study duration."

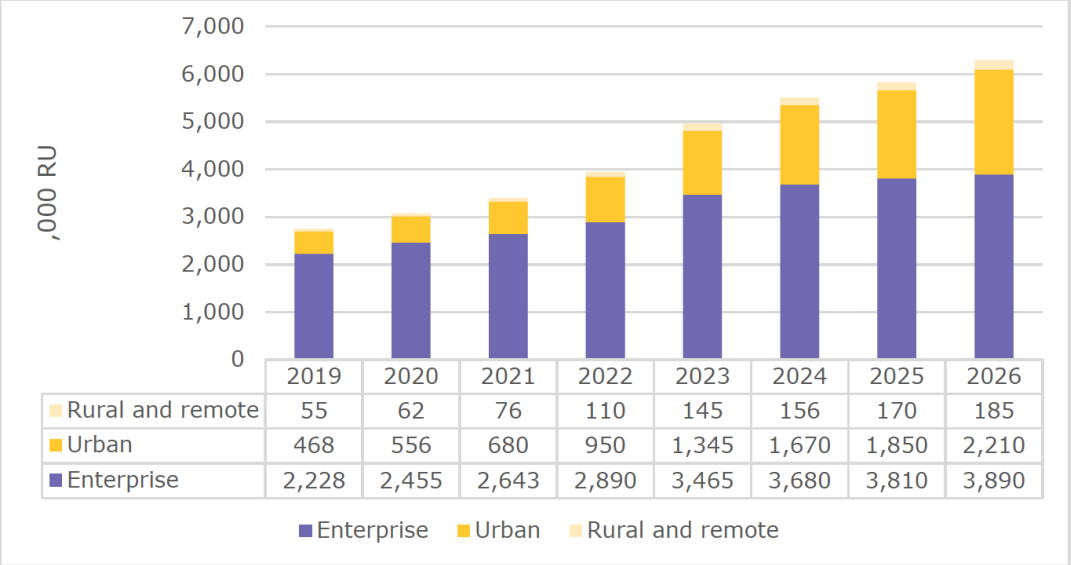
According to the latest Small cells market status report[9] issued by Small Cell Forum, "*an important factor in making small cell networks optimal for a diverse range of industries and environments is the emergence of flexible architectures. Many small cells will continue to be integrated, all-in-one access points, but there will also be architectures that split network functions in various ways between the radio unit and the cloud. One of the hottest topics of 2021 is how far these vRAN architectures, with their standardized splits and fronthaul interfaces, will drive an open multivendor ecosystem. Common underlying platforms are important to accelerate roll-out by future-proofing the network and ensuring interoperability between different components and equipment.*"

The impact of the Covid-19 pandemic, and the intensifying 5G-related tensions between the USA and China, have both had an effect on the progress of mobile build-outs, including small cells, causing some delays. Slower deployments than expected can be seen in the period 2020-2022. However, as shown in Figure 10, strong recovery is anticipated from 2022 and onwards mainly due to 5G upgrades in all environments. The new deployments and upgrades are forecasted to reach ~6.29 million radios. The enterprise sector is expected to be the largest one (3.89 million units) followed by urban sector (2.21 million deployments) by the end of the forecast period.

[7] https://www.marketwatch.com/press-release/global-small-cell-5g-network-market-size-in-depth-analysis-report-and-forecast-to-2027-2021-06-24

[8] https://www.globenewswire.com/news-release/2021/04/20/2213023/0/en/Worldwide-small-cell-market-size-to-exhibit-24-38-CAGR-during-2019-2028.html

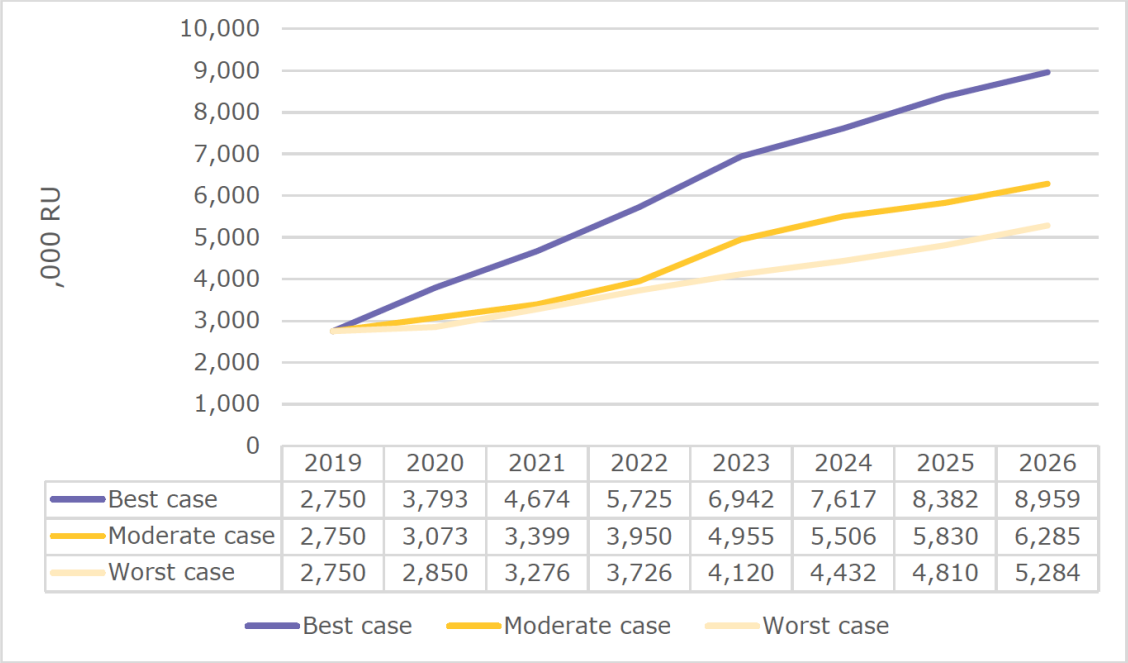
[9] https://www.scf.io/en/documents/050_-_Small_cells_market_forecast_July_2021.php



	2019	2020	2021	2022	2023	2024	2025	2026
Rural and remote	55	62	76	110	145	156	170	185
Urban	468	556	680	950	1,345	1,670	1,850	2,210
Enterprise	2,228	2,455	2,643	2,890	3,465	3,680	3,810	3,890

Figure 10: New deployments and upgrades by environment 2019-26 (Source: SCF)

Figure 11 also illustrates both the best (total of 8.96 million in 2026 at a CAGR of 18%) and the worst-case scenarios (total of 5.28 million in 2026 at a CAGR of 10%). Depending on the strength of drivers and barriers, there is potential upside of 2.7 million units or a downside of 1 million (compared to the base case) by 2026.

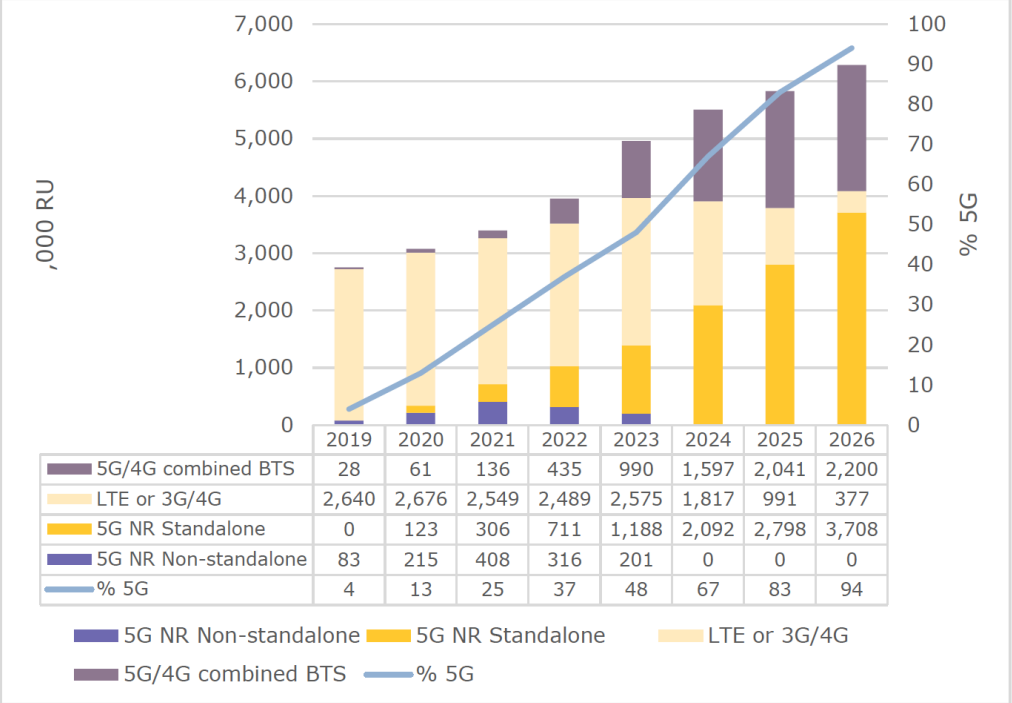


	2019	2020	2021	2022	2023	2024	2025	2026
Best case	2,750	3,793	4,674	5,725	6,942	7,617	8,382	8,959
Moderate case	2,750	3,073	3,399	3,950	4,955	5,506	5,830	6,285
Worst case	2,750	2,850	3,276	3,726	4,120	4,432	4,810	5,284

Figure 11: New deployments and upgrades of small cells by environment 2019-2026 – best case, worst case and core scenarios (Source: SCF)

These factors are distinct in the indoor/enterprise and the outdoor/urban environments and include the degree to which network operators could be automated to improve cost, scalability and simplicity, the total cost of ownership (TCO), the availability of technologies that can support specific and demanding enterprise use cases, clarity of the ROI case, simplicity of deployment and revenue and risk sharing structures.

As shown in Figure 12, LTE densification will continue and coexist with 5G deployments which will be limited in selected location at the beginning of 5G era. It is expected that 5G densification will be mainly triggered by the transition from 5G NR Non-standalone (NSA) architectures to 5G Standalone, which requires a 5G core. Another important thing is that the standalone 5G new radio will overtake the non-standalone version in 2021 while 5G or multimode deployments and upgrades will only overtake non-5G (mainly 4G, with some 3G/4G) in 2024 (late 2023). Finally, by 2026, more than 90% of new deployments will be 5G or 4G/5G.



	2019	2020	2021	2022	2023	2024	2025	2026
5G/4G combined BTS	28	61	136	435	990	1,597	2,041	2,200
LTE or 3G/4G	2,640	2,676	2,549	2,489	2,575	1,817	991	377
5G NR Standalone	0	123	306	711	1,188	2,092	2,798	3,708
5G NR Non-standalone	83	215	408	316	201	0	0	0
% 5G	4	13	25	37	48	67	83	94

Figure 12: New deployments and upgrades of small cells, by radio technology 2019-26 (Source: SCF)

Another factor that is expected to significantly affect network densification if the availability of larger quantities of affordable spectrum (the midband 5G spectrum in 3.4-4.2 GHz, and the millimeter wave (mmWave) bands such as 26/28 GHz and 39/41 GHz). It should be highlighted that higher frequencies are more appropriate for the small cell due to their high capacity and short range. As shown in Figure 13, sub-6 GHz will be the dominant frequency band till 2023. From 2026 and onward, it is anticipated that most of the new or upgraded small cells will be deployed above 10GHz. However, it should be stressed that mmWave spectrum is usually allocated/reserved for shared usage or for short-term and/or localised licenses. The latter will greatly affect the enterprise adoption of 5G and the diversification of service providers allowing non-MNOs to deploy such networks.

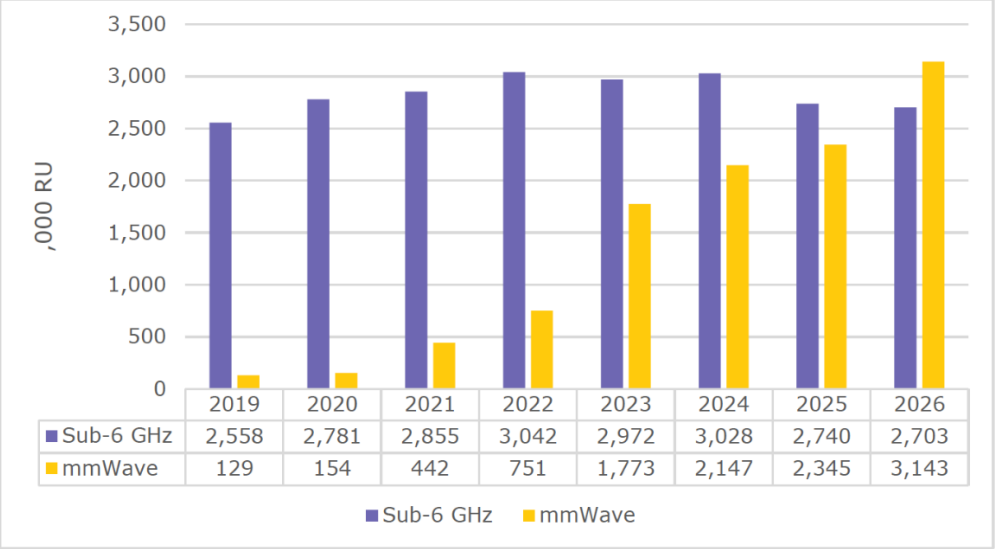


Figure 13: New deployments and upgrades of small cells by spectrum 2019-26 (primary band – many cells will be multiband) (Source: SCF)

Figure 14 shows the declining role of the public MNO network in enterprise indoor environments. It can also be deduced that enterprises are reluctant to deploy and operate their own networks mainly due to their limited skills.

Amongst other new deployment and ownership models, private networks option deployed and managed by SP as well as Neutral Host seem to be the most promising providing advantages like reduced cost, risk and management effort factors that expected to accelerate network deployments. Such models will be supported by technological advancements like spectrum sharing as well as by the need for mobile networks which are specifically optimized for a particular vertical industry or use case. The Neutral Host model (NH) also allows multiple providers to deploy services on a single physical infrastructure.

As shown in Figure 14, by the mid-2020s, the fastest growing model will be public-facing neutral host, as large locations such as stadiums and transport hubs require high quality and ultra-dense 5G; and the largest category will be the fully outsourced private network, accounting for 34% of radio units deployed in 2026. Other approaches are also illustrated in Figure 14.

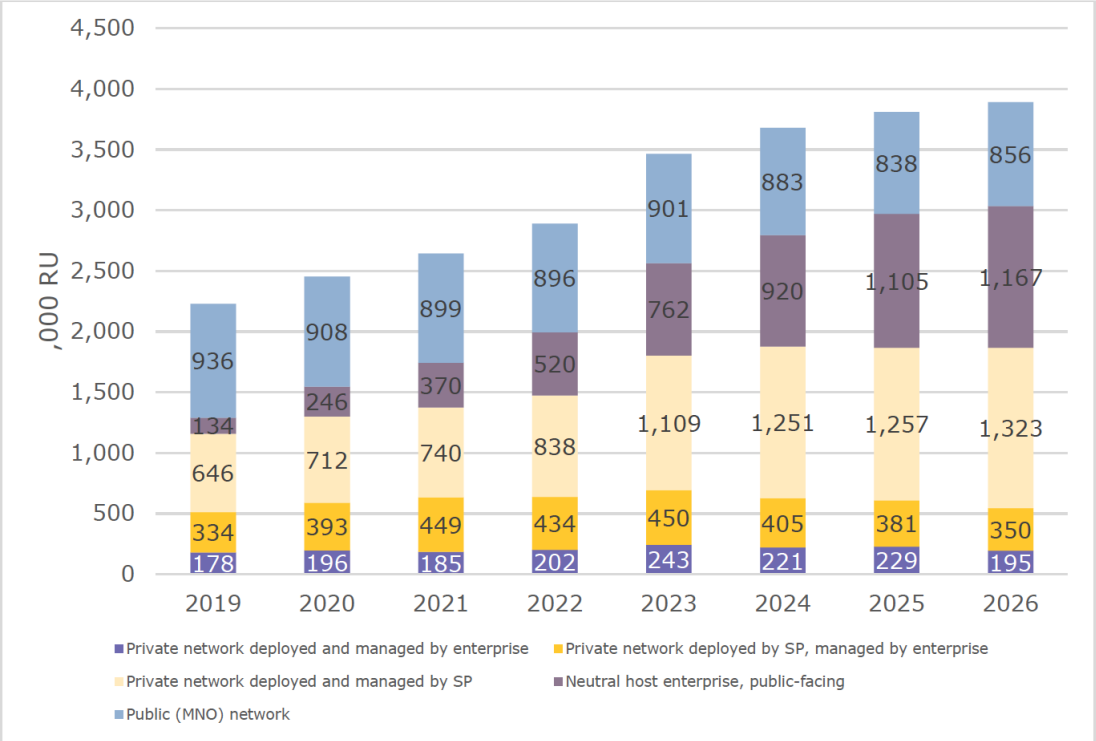


Figure 14: New deployments and upgrades of indoor and enterprise small cells by network type (Source: SCF)

As shown in Figure 15, pure-play private network operators will be the dominant deployer by 2026, overtaking the vertical market specialist integrators that have dominated the traditional proprietary private networks space.

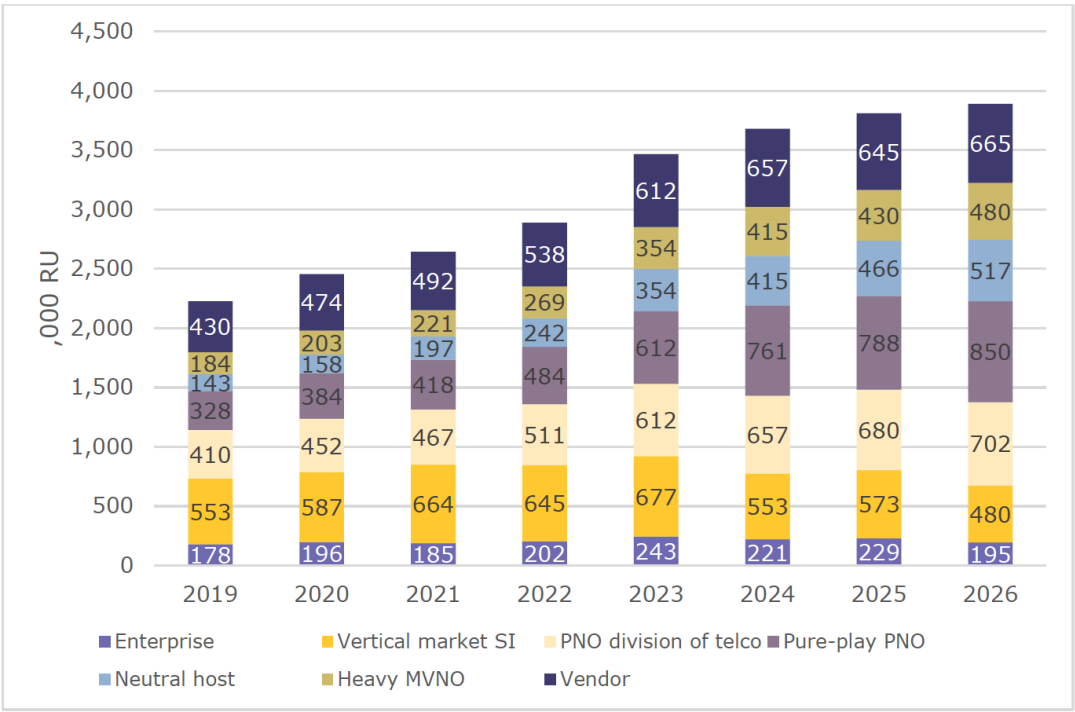


Figure 15: New deployments and upgrades of indoor and enterprise private network small cells by service provider type (Source: SCF)

At the time of writing, the following vendors are known to have small cell products:

Table 2: Small Cells Vendors

Vendor Name	Vendor Web Site	HQ Region
Accelleran	http://www.accelleran.com/	Europe
Airspan	http://www.airspan.com/	USA
Airvana Commscope	http://www.commscope.com/	USA
Alpha Networks	http://www.alphanetworks.com/en	Taiwan
Arcadyan	http://www.arcadyan.com/	Taiwan
BaiCells	http://www.baicells.com/en/index.jsp	China
Casa Systems	http://www.casa-systems.com/	USA
Cisco / SpiderCloud	http://www.cisco.com/c/en/us/products/wireless/universal-small-cell-8000-series/index.html	USA
Contela	http://www.contela.com/	Korea
Ericsson	https://www.ericsson.com/ourportfolio/products/small-cells?nav=productcatagory006|fgb_101_0516	Europe
Huawei	http://carrier.huawei.com/en/products/wireless-network/small-cell	China
IP Access	http://www.ipaccess.com/	Europe
Juni	http://www.juniglobal.com/	Australia
Luminate	http://www.luminatewireless.com/	USA
NEC / SpiderCloud	http://spidercloud.com/	Europe / USA
Nokia / ALU	https://networks.nokia.com/products/small-cells	Europe
Qucell + Radisys	http://www.qucell.com/	USA
Ranberry	https://ranberry.net/en/	Russia
Samji Electronics	http://www.samji.com/eng/business/sub_01_04_01.asp	Korea
Samsung	http://www.samsung.com/global/business/networks/small-cells/small-cells/outdoor-small-cells	Korea
Sercomm	http://www.sercomm.com	Taiwan
Sistelbanda	http://sistelbanda.es/	Europe
SpiderCloud	http://spidercloud.com/	USA
Sunnada Network	http://www.sunnada.com/en/?p=210	China
ZTE	http://www.zte.com.cn/global/products/wireless/Base-Station-Series/Small-Cell	China
ZyXEL	http://www.zyxel.com/solutions/Small-Cell-Solution-20130208-286809.shtml	Taiwan

2.2.2 Open RAN market

The emergence of open RAN architectures constitutes one major trend that is expected to increase flexibility and help avoiding vendor lock-in effect enabling thus a broader ecosystem. These establish open interfaces at each layer of the network, from the chipset, to the xHaul between different network elements in a vRAN, to the APIs for processes such as network automation. Undoubtedly, open RAN will be the buzzword of the next years leading to a significant market growth. There is no market study predicting a decline of open RAN market size. All the studies forecast a significant growth in the next years.

- As per a report by ResearchNester[10], the global O-RAN market is estimated to attain a revenue of USD 419.51 Million in 2021 and USD 21,371.47 Million in 2028 by growing at a CAGR of 83.1% over the forecast period, i.e., 2020-2028. Increasing utilization of online applications, such as virtual meetings, cloud-based services, streaming of 3D & ultra-HD (8K) resolution video content, and others, along with the growing demand for high-speed data is anticipated to raise the adoption of 5G technology in the coming years, and in turn drive the market growth during the forecast period.
- Open RAN investments are growing faster than expected, with network operators in the Asia-Pacific region responsible for a current ramp in open, disaggregated radio access network deployments, according to research house Dell'Oro[11], which has increased its Open RAN market value outlook to more than $500 million for 2021. According to Dell'Oro, the level of investment in macro and small cell radios, plus baseband hardware and software, compatible with O-RAN Alliance or TIP OpenRAN specifications during the first three months of this year was five times greater than a year earlier.
- The global open RAN market will be worth US$3.2 billion in 2024m close to 10% of the total 4G and 5G market, according to estimates by market research firm Omdia[12]. Of this Open RAN market size, it is estimated that 10-15% would be for CU/RIC network functions, with the bulk for radios (RU), other baseband (DU) functions and transport networks.

[10] https://www.researchnester.com/reports/open-radio-access-network-market/2781
[11] https://www.delloro.com/open-ran-revenues-up-5x-in-1q21/
[12] https://www.lightreading.com/open-ran/open-ran-will-be-$32b-market-in-2024-says-omdia/d/d-id/765889

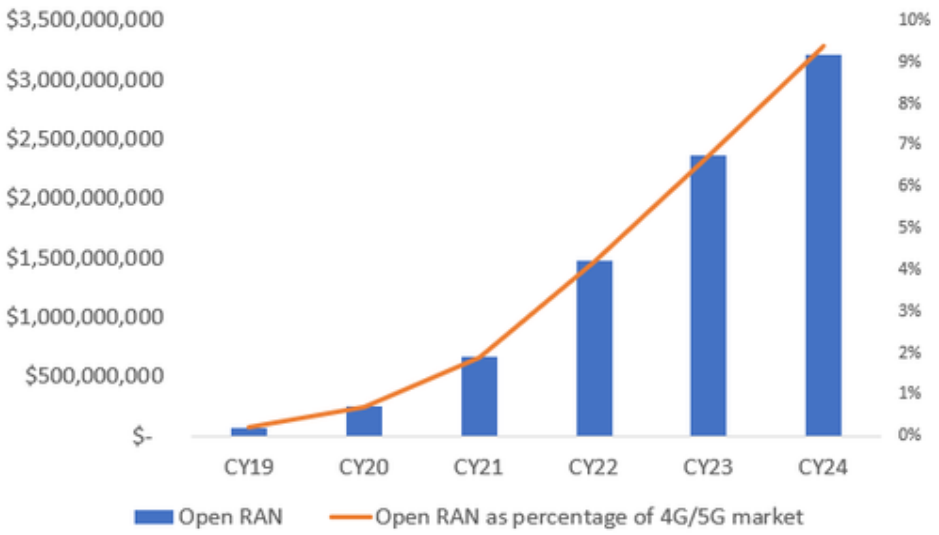


Figure 16: Open 4G/5G RAN market

It is a 33% increase from Omdia's previous estimation of US$2.4 billion. Last year, the open RAN was worth only US$70 million. Carriers were leading the way for open and virtual RAN development, Omdia said, while the ban against Huawei by the US government is also impacting growth. Long time carriers that need to worry about syncing open RAN with their old networks will inevitably be slow to adopt open RAN. Carriers are hoping to reduce cost by adopting open RAN. Rakuten Mobile claimed it has reduced CAPEX by 40% and operating cost by 30% by building an open RAN[13].

- According to a recently published report by Dell'Oro Group[14], the worldwide sales of Open RAN revenues are forecasted to grow at double-digit rates over the next six years with cumulative Open RAN investments – including hardware, software, and firmware excluding services – projected to approach $10 B over the 2020-2025 forecast period. The report also highlighted that:
  - Open RAN is expected to account for more than 10 percent of the overall RAN market by 2025, reflecting healthy traction in multiple regions.
  - Short-term projections have been adjusted upward while the near-term outlook has been revised slightly downward, reflecting the state of the market for both greenfield and brownfield networks.
  - Cumulative Virtualized RAN revenues—here defined as the proportion of RAN baseband/compute capex that will utilize general-purpose processors for CU and/or DU—are projected to surpass $5 B over the forecast period.
- Analysys Mason forecast open RAN's impact on global GDP would grow to reach $91 billion annually by 2030, cumulatively contributing $285 billion between 2021 and 2030. It added this estimate was conservative, noting the cumulative impact could reach as much as $725 billion, depending on adoption rates.

[13] https://telecoms.com/506005/rakuten-still-sailing-smoothly-on-its-disruptive-mission/

[14] https://www.prnewswire.com/news-releases/open-ran-market-expected-to-approach-10-b-according-to-delloro-group-301222861.html

- According to ABI research firm[15], it is expected that the revenue of the Open Ran market will grow at a CAGR of 126.7%, representing approximately 17.6% of the total outdoor revenue reaching US$ 23.6 billion by 2026.

According to the SCF market study, these open architectures are likely to be adopted first in greenfield deployments. Thus, small cells deployments seem to be ideal for this purpose. As shown in Figure 17, in 2024, more than half of new small cell deployments or upgrades will be based on open xHaul interfaces, and this figure will rise to 77% in 2026.

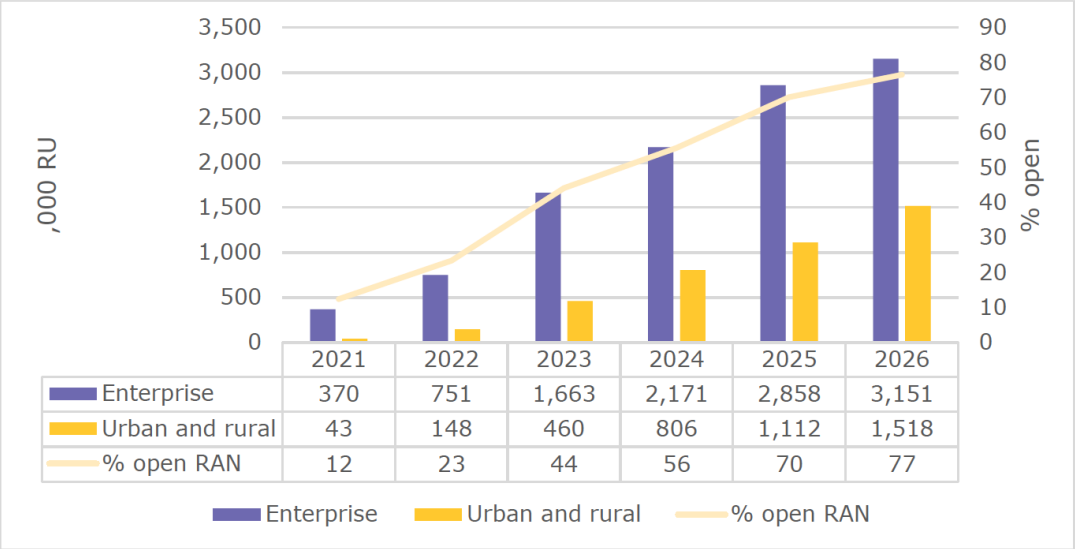


Figure 17: Small cells supporting open RAN architectures by environment, and percentage of total deployments that support these architectures (Source: SCF)

2.2.2.1 dRAX™ vRAN solution enhanced with O-RAN

As 5G network deployments accelerate across the globe and the OpenRAN system of standards gathers momentum, service providers from mobile operators and edge computing infrastructure providers, to system integrators are turning to 4G/5G RAN cloud-native software (like Acceleran's dRAX™ product line). 5G networks provide an enhanced broadband experience with speeds of up to 1 Gbps and latency of 10ms, as well as a platform for cloud and AI-based services.

dRAX™ delivers proven containerized software components to enable real-world deployment of multi-vendor, intelligent, and disaggregated OpenRAN, in alignment with the open standards such as the O-RAN Alliance. These Cloud-Native components deliver reliable, cost-effective, and scalable solutions for both 4G and 5G networks, including artificial intelligence-based automation.

From the forecasted Open RAN market size, it is estimated that 10-15% would be for CU/RIC network functions, with the bulk for radios (RU), other baseband (DU) functions and transport

15 https://www.abiresearch.com/press/5g-network-densification-and-mmimo-will-drive-cellular-infrastructure-spending-us191-billion-2026/

networks. This provides an annual TAM (Total Addressable Market) up to €405M in 2024 (€825M in 2027) for Accelleran dRAX™.

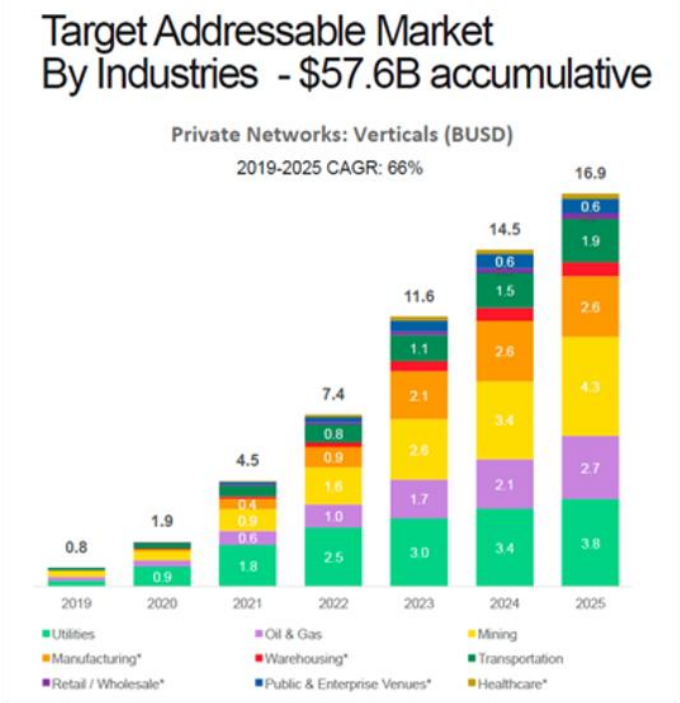


Figure 18: Private 4G/5G Networks by Vertical

As shown in Figure 18, the 'Industry 4.0' vertical is about 40% of the Private 5G market. The specific annual TAM for Accelleran dRAX™ for this vertical is thus €162 million in 2024.

The opportunity for RAN sharing and for 'neutral hosting' operation[16,17], by new infrastructure owners like towercos (like Cellnex in Europe, Crown Castel and BAI Communications[18] in US and many other regions like China) and new specialist operators is growing massively. SCF's latest market status report[19] predicts strong growth for indoor and outdoor neutral hosting – forecasting 37-40% compound annual growth to 2026. By that time, more than 70% of enterprises' indoor small cells will be deployed by neutral hosts and other new entrants.

[BEREC BoR (18) 116][20] predicts that active RAN sharing (incl. spectrum = MOCN) will provide cost savings: [33%-45%] CAPEX and [30%-33%] OPEX.

While neutral hosting is predicted to address multiple applications, including rural macro coverage and indoor (typically addressed today with DAS Distributed Antenna Systems), the focus is small cells for outdoors (like smart cities and ultra-dense events like sports stadiums) and indoor (airports, railways stations, shopping malls, enterprise and industrial shared networks) 4G/5G networks.

[16] https://www.adlittle.com/en/insights/report/network-sharing-5g-era

[17] https://rethinkresearch.biz/articles/neutral-host-infrastructure-is-as-essential-to-open-networks-as-new-ran-platforms/

[18] https://www.telecomtv.com/content/5g/neutral-host-market-goes-into-high-gear-as-bai-snaps-up-mobilitie-41842

[19] https://www.smallcellforum.org/press-releases/small-cell-forum-launches-neutral-host-group-to-capture-technology-requirements-for-alternative-deployment-models-serving-enterprise-and-communities/

[20] BEREC Report on infrastructure sharing, BEREC (Body of European Regulators for Electronic Communications), BoR (18) 116 2018, https://berec.europa.eu/eng/document_register/subject_matter/berec/download/0/8164-berec-report-on-infrastructure-sharing_0.pdf

It is thus evident that the 'neutral host' market vertical is about 40% of the Open RAN TAM, so the specific annual TAM for Accelleran dRAX™ is thus €162M in 2024 and €330M in 2027.

2.2.2.2 Open RAN Radio Unit (O-RU)

The global 5G market is anticipated to exhibit high growth in the near future. Some of the major driving factors contributing to the expected market growth include an increasing need for an energy efficient communications network infrastructure. Moreover, rising demands for network slicing on the functional aspects of the infrastructure to enhance network efficiency are expected to significantly drive the 5G markets. However, the huge initial investment costs for installations and implementations may adversely impact the growth of the market in the coming years. Despite the market growth restraining factors, the splurge in the number of devices on the network as a result of advent of IoT together with the accompanying influx of huge amounts of data post the advent of Big Data are projected to generate huge demand opportunities for 5G technology implementations. A number of research firms show great potential revenue for technologies like open RAN radio units (O-RU) (such as RunEL's Sparq2020-O-RU).

The market for Open RAN-enabled radio units is set to be worth more than $47 billion by 2026, according to the analyst team at ABI Research[21], which believes network operator investments in Open RAN gear will exceed those spent on traditional cellular network equipment in 2027-2028.

According to the research firm, capex spent on Open RAN radio units (RUs) for public outdoor networks (including macro and small cell deployments) will hit $40.7 billion in 2026, while the expected spend on indoor enterprise units in that same year is $6.7 billion.

RunEL anticipates huge market demand for its developed solution. Market expectations of more than 8 million gNB BS for outdoor macro in the next 6 years at an average cost of €15K yields a potential of €110 billion alone. In addition, expected outdoor small cell and 5G non-residential indoor access nodes, targeted at €1,400 and €700 each respectively, point a potential of €13 million units in a 6-year period leading to a potential of additional €15B.

RunEL's innovation is coping with and taking advantage of the technological challenges mentioned above and is focused in the 5G RAN gNB PHY (Physical Layer) Distributed solution which is the heart of the mobile network (as can be seen in the figure below).

[21] https://www.telecomtv.com/content/open-ran/open-ran-radio-unit-market-to-be-worth-47-billion-by-2026-report-39866/

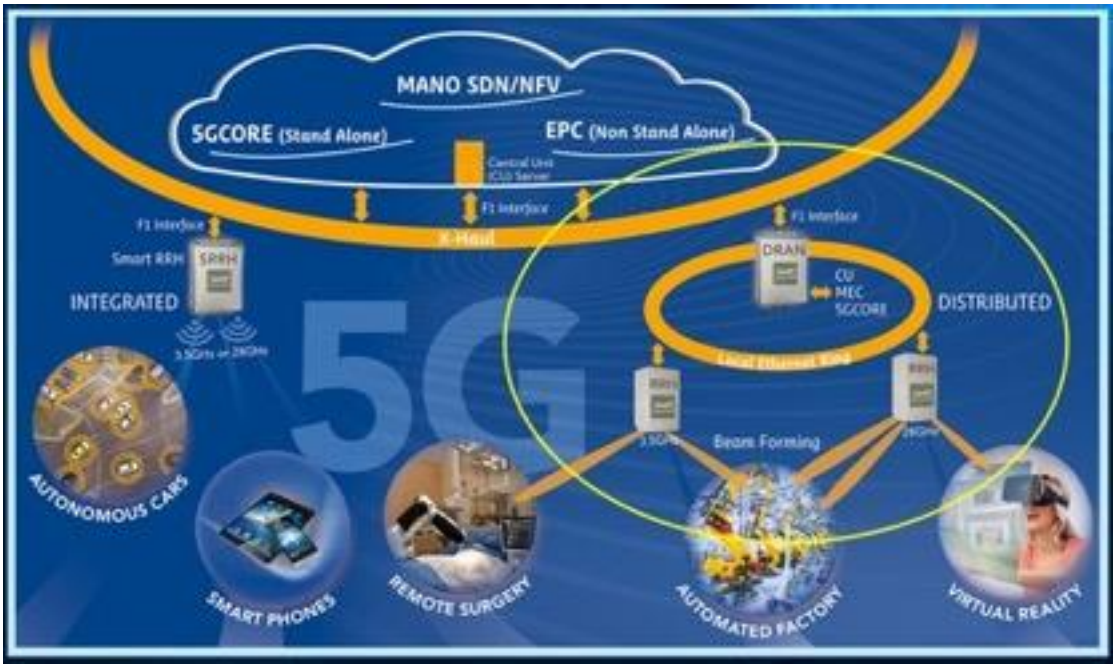


Figure 19: Sparq2020-O-RU platform architecture

2.2.2.3 Open RAN Intelligent Controller (RIC)

RIC functionality delivers intelligence into the Open RAN network with near-RT RIC functionality providing real-time optimization for mobility and handover management, and non-RT RIC providing not only visibility into the network, but also AI-based feeds and recommendations to near-RT RIC, working together to deliver optimal network performance for optimal subscriber experience.

Recently, ATT and Nokia tested the RAN E2 interface and xApp management and control, collected live network data using the Measurement Campaign xApp, neighbor relation management using the Automated Neighbor Relation (ANR) xApp, and tested RAN control via the Admission Control xApp - all over the live commercial network.

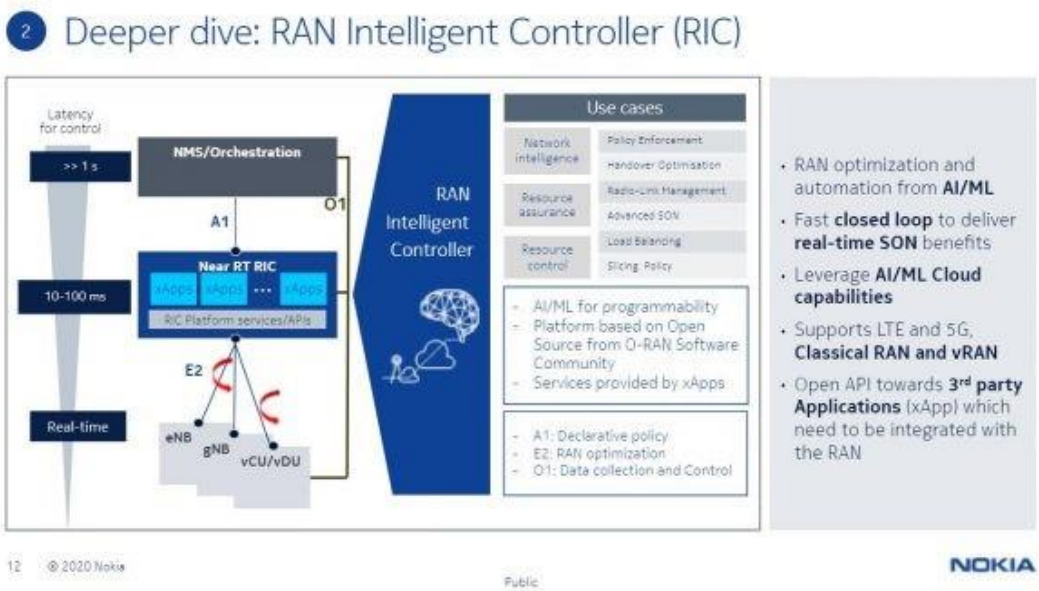


Figure 20: RAN Intelligent Controller (source: Nokia)

AT&T and Nokia ran a series of xApps at the edge of AT&T's live 5G mmWave network on an Akraino-based Open Cloud Platform. The xApps used in the trial were designed to improve spectrum efficiency, as well as offer geographical and use case-based customization and rapid feature onboarding in the RAN.

AT&T and Nokia are planning to officially release the RIC into open source, so that other companies and developers can help develop the RIC code.

Parallel Wireless is another vendor that has developed RIC, near-RT and non-RT. What makes their approach different is that the controller works not only for 5G, but also for legacy Gs: 2G, 3G, and 4G. Their xApps or microservices are virtualized functions of BSC for 2G, RNC for 3G, x2 gateway for 4G among others.

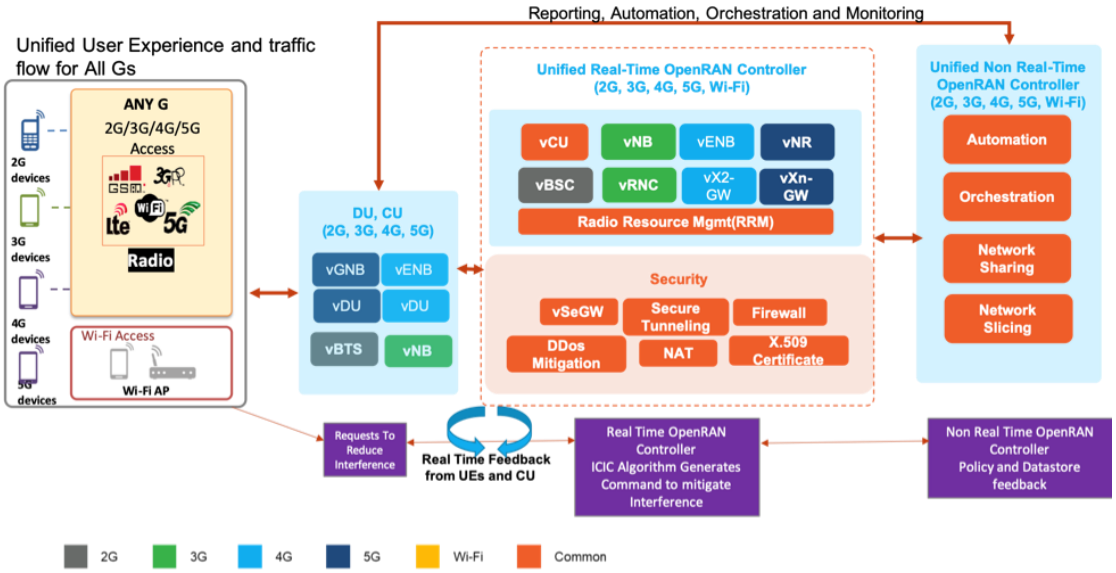


Figure 21: Near-RT and non-RT RIC (Source: Parallel Wireless)

In September 2020, Samsung and KDDI demonstrated network slicing involving a RIC to manage radio resources to guarantee required service levels. The companies managed network slicing on a network using Samsung's virtualized core, RAN, and orchestration.

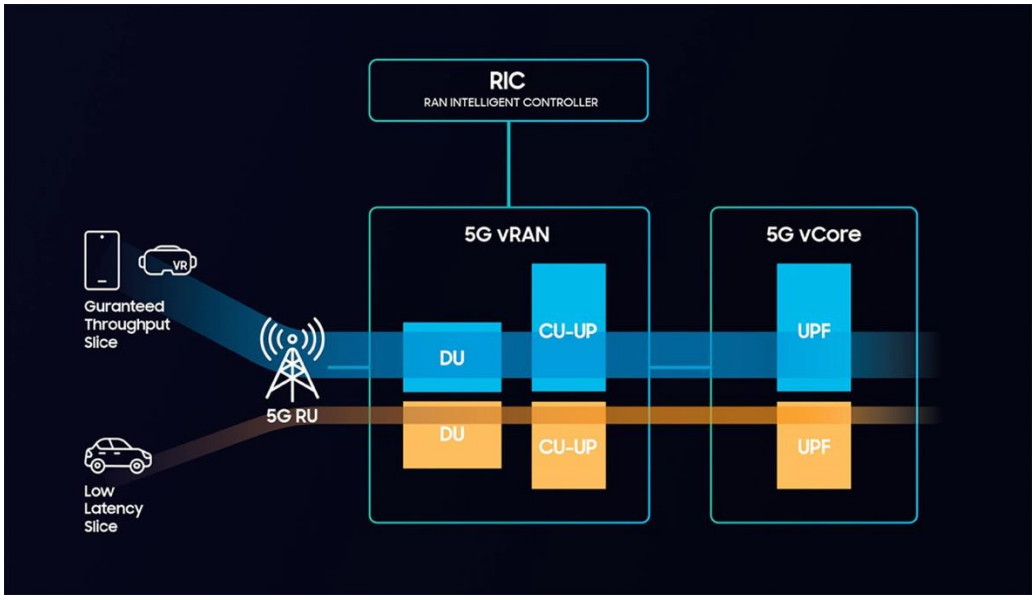


Figure 22: RIC by Samsung

2.2.3 Time Sensitive Networking

According to a study published by Research and Markets[22], the actual market size of TSN is estimated in about USD 134 million in 2021 but is expected to be USD 1,188 million by 2026. This represents a market growth defined by a CAGR of 54.7%, as it is depicted in Figure 23.

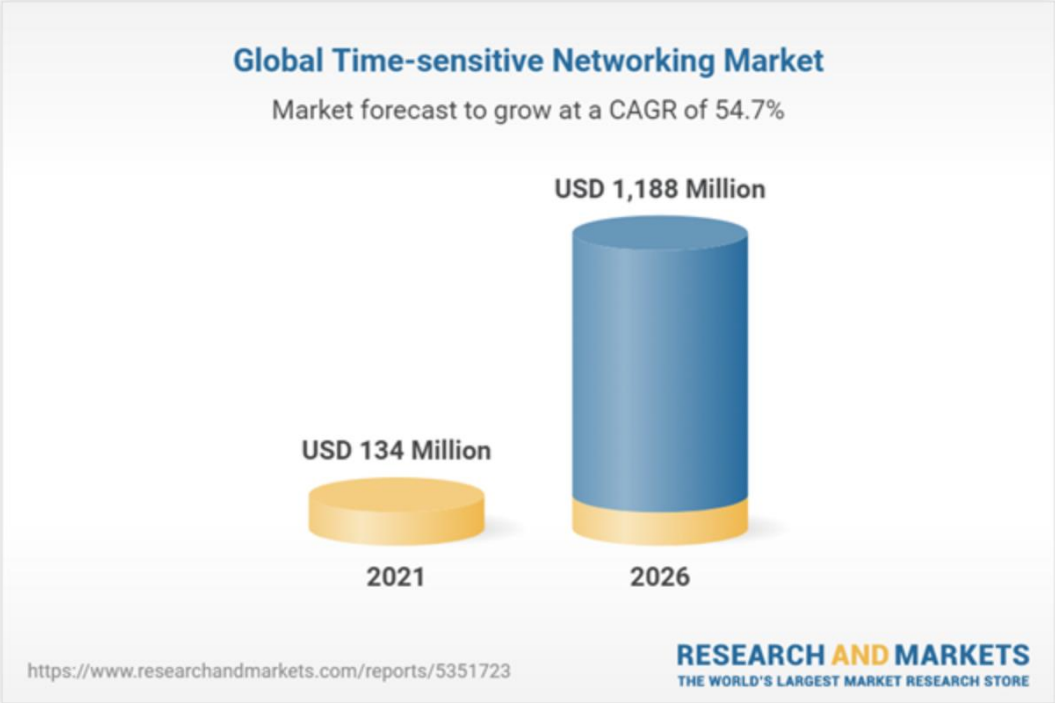


Figure 23: TSN market size estimation

Growing adoption of industrial automation in manufacturing industries, rising demand for deterministic Ethernet for real-time applications, and challenging multiple controller applications are among the factors driving the growth of the TSN market.

In addition, Industry 4.0 is focused, among other things, on turning most industrial networks into wireless ones, but maintaining the reliability of such connections. This is why TSN growth will be mainly driven by TSN over 5G networks.

An important study to understand this change is found in [11], which estimates the market size of 5G for 2035 and differentiates the impact of this technology in main industries.

As per a study conducted by IHS Markit, it is expected that 5G will represent a total of USD 13.2 trillion of market size in 2035 The impact of TSN on different industries is shown in Figure 24.

[22] https://www.researchandmarkets.com/reports/5351723/global-time-sensitive-networking-market-with?utm_source=BW&utm_medium=PressRelease&utm_code=bfhvkp&utm_campaign=1557741+-+Global+Time-sensitive+Networking+Market+(2021+to+2026)+-+Integration+of+5G+with+TSN+for+Mobile+Network+Sharing+Presents+Opportunities&utm_exec=jamu273prd

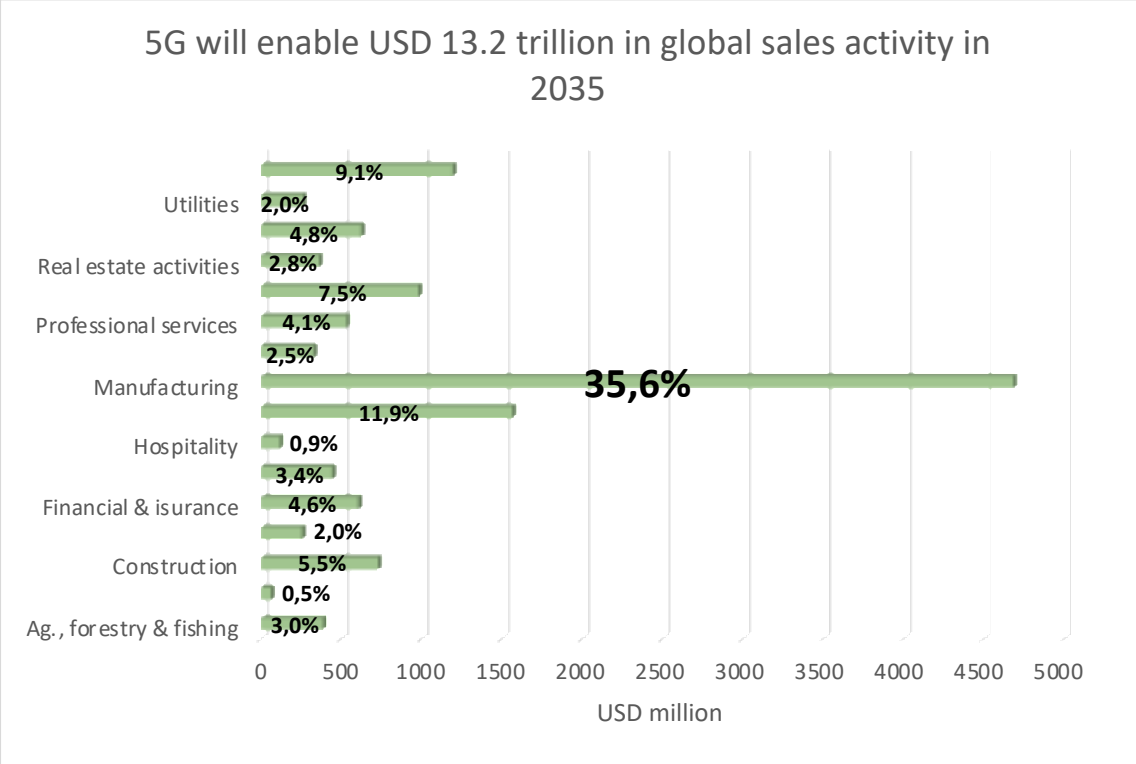


Figure 24: 2035 5G market size by industries

From the total of USD 13.2 trillion 5G market size, this study states that manufacturing will garner almost USD 4.7 trillion, which represents 36 percent of the full segment. This is thus, by far, the largest industry to take advantage of 5G deployment.

5G technology applicable to manufacturing industry is directly related to TSN over 5G. Thus, it is reasonable to estimate that TSN over 5G market size in 2035 will be directly USD 4.7 trillion, even though TSN could be also feasible for other industries.

Major players in the TSN market are Belden Inc. (US), Cisco Systems, Inc. (US), Intel Corporation (US), National Instruments Corporation (US), Marvell Technology Group Ltd. (Bermuda), NXP Semiconductors N.V. (Netherlands), Microchip Technology Incorporated (US), Analog Devices, Inc. (US), Broadcom Inc. (US), and Advanced Micro Devices, Inc. (US).

Affordable5G product, developed by UMA, is a TSN over 5G test bed, composed of the necessary facilities to test all TSN requirements before customers launch their products into the market to check whether they are totally operative. Therefore, Affordable5G solution will be directly affected and benefited from this market growth, as the USD 4,7 trillion market size in 2035 indicates a big number of potential customers for the platform.

It is true that the current market size of TSN is USD 134 million yet, but this because TSN over 5G is an emergent technology and all the growth is still to come in the near future, as we have seen in these studies.

This is, in fact, a good sign, as it means that a lot of TSN over 5G solutions are not in the market yet. So, it will be necessary to test them before they are commercialized, giving a critical role to Affordable5G solution. In addition, the lack of similar test beds in the market yet can be considered a competitive advantage of Affordable5G solution.

2.3 Cloud Native Platforms

Cloud native applications can be considered those that run “on cloud infrastructure and are built around design patterns that allow it to scale globally, support thousands of concurrent users and survive hardware and system failures and malicious attacks” [12]. According to a survey of Canonical [13], the top benefits of cloud native technologies for businesses to innovate and achieve their goals are:

- Cutting-edge technology
- Developer productivity
- Elasticity and agility
- Global reach
- Open-source software
- Portability
- Resource optimisation
- Simpler operations

These are concepts that were developed and significantly grew up in the last 10 years, constituting now a days the de-facto standard to develop and deploy high-impact applications i.e., Netflix, Skype, Power BI, etc.

One of the reference organisations in the field of Cloud Native application is the Cloud Native Computing Foundation (CNCF), which is part of the Linux Foundation and gathers some of the largest Open-Source projects in the Cloud Native space like Kubernetes, Prometheus, Fluentd and Helm. CNCF has been conducted a survey among their members for the last 5 years and according to the 1,324 responses gathered in 2020 (71% of which from Europe and North America) the use of containers in production has increased to 92% in 2020, from 84% since 2019 survey, and up to 300% from the first CNCF survey in 2016 [14]. This outlook is confirmed by the analysis of International Data Group (IDG), a research company, which through their studies and interviews confirmed that the overall public cloud services market grew 24.1% in 2020, consistent with the past four years and expects spending on cloud services to continue growing at the same or a higher rate. In particular in Europe, the expected average growth in the next 5 years is around 21.8% whereby, in the same period, it is expected to be only around 18% in the US. As a side note, it is worth noting that in 2020 the top 5 public cloud service providers (Amazon Web Services, Microsoft, Salesforce.com, Google, and Oracle) captured 38% of the worldwide spending for Cloud Native Applications, with a growth of 32% year over year [15]. This calls for a European solution to Cloud (and Edge) applications, to move away from non-EU cloud and edge platforms, to foster EU technological sovereignty as highlighted by the new European Alliance for Industrial Data, Edge and Cloud[23].

In May 2021, the Next Generation Mobile Networks Alliance (NGMN), an organization promoted by world-leading mobile network operators with the goals of assuring that the next generation network infrastructure, service platforms and devices will meet the requirements of operators, released the “Cloud Native Enabling Future Telco Platforms” [16]. In this study, it is highlighted how the “future of mobile networks is being reshaped by the rise of Cloud architectures that extends levels of efficiency and scale from the datacentre to the mobile

[23] https://digital-strategy.ec.europa.eu/en/policies/cloud-alliance

network and Edge. With Software-Defined Networking (SDN) and Network Function Virtualization (NFV), General Purpose Processors (GPP)-powered cloud servers have the flexibility to change workloads based on demand. This allows Telcos to exploit the flexible infrastructure, with different kinds of network functions or applications [16]. However, this comes with a cost and requires the network operators to revisit their technical, organizational and operational set-up. These aspects must be taken into account to provide a smooth transition, in particular considering global standards, including open interfaces and components. Moreover, due to the fact that Cloud Native applications rely on reference implementations (i.e., Kubernetes) that are not commonly adopted by Network Operators, the portability of Telco cloud functions into Cloud Native ones could be complex and time-consuming.

The role of Affordable5G is in this context essential to fill the gap that exists between the Open-Source projects like OpenStack, Kubernetes, OSM, ONAP and the Telco designed application like ETSI NFV. ETSI (European Telecommunications Standards Institute) NFV has defined an architectural framework for NFV which is, however, not addressing the application configuration of the network functions that run on top of the VNFs or the management and orchestration of resources based on VM and those instead relying on VNFs containers.

In Affordable5G the partners' efforts are towards an integration between ETSI NFV and OSM MANO with Kubernetes and NearbyOne. While NearbyOne is providing a tool for orchestrating, configuring and monitoring VNF, with Kubernetes the approach is twofold: an extension of MANO to explicitly allow the placement of pods on specific nodes of a Kubernates cluster and an infrastructure as a code approach for the Kubernetes Network Function. This should also facilitate the Network operations and service teams to adopt a DevOps mindset and start relying on Continuous Integration and Continuous Delivery/Deployment processes and thus foster the uptake of Native Cloud applications among Telco operators.

In doing this, Telco operators can profit from the opportunity offered by the edge and cloud revenue growth which is estimated in the order of 700 billion USD until 2030 in the "Cloud Native Enabling Future Telco Platforms" [16] based on Gartner data[24], shown in Figure 25.

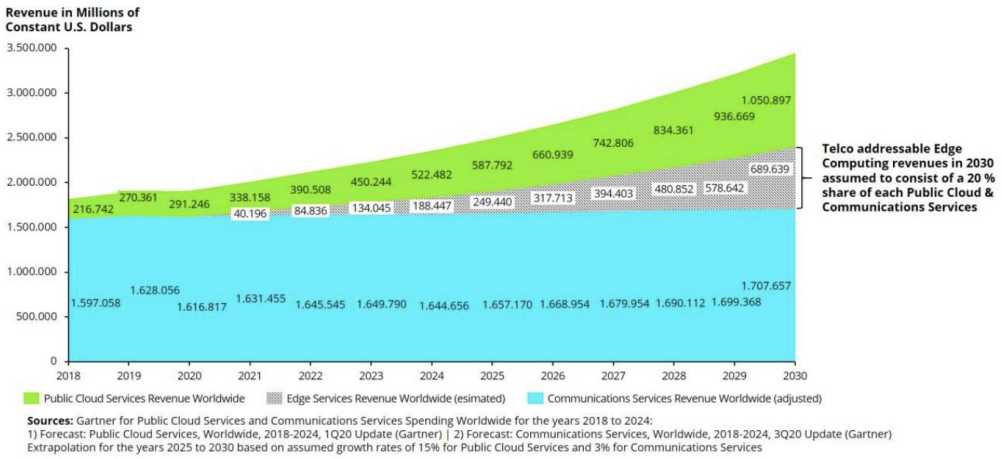


Figure 25: Edge and cloud revenue growth

[24] Gartner for Public cloud Services and Communications Services Spending Worldwide for the years 2018 to 2024: 1) Forecast: Public cloud Services, Worldwide, 2018-2024, 1Q20 Update (Gartner) | 2) Forecast: Communications Services, Worldwide, 2018-2024, 3Q20 Update (Gartner)

2.4 Hardware acceleration

According to a 2019 Global Market Insights, Inc. report by focusing on the graphic processing unit (GPU) market, it is predicted that its revenues will be over USD 80 billion by 2024 when the worldwide GPU industry shipments are anticipated to reach 121,000 thousand units. The market growth is attributed to a surge in the adoption of the IoT in industrial and automotive sectors. As the IoT devices gather huge amounts of data that need to be tracked and analyzed, the demand for high-end edge-computing increases. This further propels the need for general purpose GPUs (GPGPUs) that provide the requisite support for analyzing complex datasets in a quick manner. Other factors fueling the general-purpose graphic processing unit (GPU) market growth include various government-led investments in the semiconductor industry and a rise in the uptake of the AI technology to drive innovations in sectors such as healthcare, automotive, and manufacturing. A closer focus on the growth of the 32-bit MCU market targeted by the RISC V GPU for GPGPU processing to be developed within the project (Figure 26), it reveals that it is expected to reach $20Bn by 2027 with a high growth rate of 9% CAGR. The target application segments involve but are not limited to Smart-/Fitness-/Health-/Multi-sports Watches, multifunctional wearables, POS/POI Terminals, Building Control/Automation, Healthcare, and Home Appliances. Based on the above discussion and market analysis reports, both the current and future technological trends are in favour that RISC-V hardware accelerators will be used in other technological segments like in 5G edge processing functionalities.

Figure 26: MCU Market Growth Driven by 32-bit and specific applications

An additional factor for the development of the GPGPU market is the artificial intelligence technology in areas such as health, the automotive industry, etc. Focusing more on the growth of the 32-bit MCU market, which GPGPU is aiming for based on the RISC V architecture to be developed in the project (Figure 26), it is expected to reach $ 5 billion by 2021 with a growth rate of 9% (CAGR).

Based on the above, both current and future technology trends are in line with the Affordable5G goal of exploring a GPGPU based, RISC-V architecture in the context of edge level management of 5G applications.

A study from Tractica (Figure 27) shows that the market for more efficient data processing products and solutions for Artificial Intelligence applications will increase to $ 66 billion in 2025.

In fact, it is emphasized that 75% of the market will refer to devices used at the "edge" of the network.

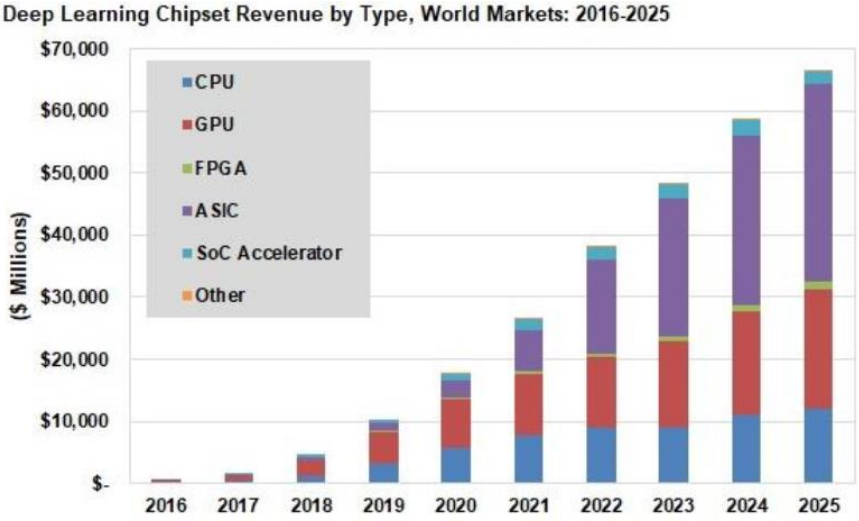


Figure 27: Market Growth for semiconductor products that rely on AI technologies (Source: Tractica)

This forecast also shows the dynamic value of the Affordable5G project, as it is going to exploit a particular vertical of the 5G marker: the need for ultra-low power accelerators.

2.5 Core & Services

2.5.1 Virtualised 5G core

With the advent of 5G, there is an increasing demand for advanced application and services like mission critical services as well as IoT services. However, in order 5G networks to meet the requirements (like low latency) of these services and applications, 5G SA networks are needed (mainly based on cloud-native architectures). As mentioned before, the transition from 5G NR Non-standalone (NSA) architectures to 5G Standalone, requires a 5G core. Thus, it is expected that the fast deployment of 5G SA networks will also increase the demand for advanced 5G core solutions. In the last years, all market research firms have forecasted that the 5G core market will constantly grow for the next years.

- According to the MarketsAndMarkets analysis[25], "the global 5G core market size is projected to grow from USD 630 million in 2020 to USD 9,497 million by 2025, at a Compound Annual Growth Rate (CAGR) of 72.0% during the forecast period. The 5G core market is gaining traction due to its cloud-native and service-based architecture that will improve the modularity of products with greater emphasis on low latency, URLLC, eMBB, and mMTC offerings. The rapid rise in the volume of data being carried by cellular networks has been driven largely by consumer demand for video, and the shift of business toward the use of cloud services. There are significant growth opportunities for 5G core vendors. The commercialization of 5G services in enterprises

[25] https://www.marketsandmarkets.com/Market-Reports/5g-core-market-136573849.html?gclid=CjwKCAjwo4mIBhBsEiwAKgzXOOMwghMoDOwFpNITik7Zn8JIxrvnrgw6fg0v3hG5U_LZiBtj0C3lFBoCWdAQAvD_BwE

such as private 5G and the availability of unlicensed and shared spectrum in the globe are expected to shape the future of the 5G core market." In Figure 28, the opportunities in the 5G core market are illustrated.

Figure 28: Opportunities in the 5G core market (Source: MarketsAndMarkets)

- As per a report by ReportsnReports[26], "the global 5G core market size is projected to grow from USD 630 million in 2020 to USD 9,497 million by 2025, at a Compound Annual Growth Rate (CAGR) of 72.0% during the forecast period. The 5G core market is gaining traction due to the evolution of cellular network technology, which has offered higher data speeds and lower latency. The 5G core market is gaining traction due to its cloud-native and service-based architecture that will improve the modularity of products with greater emphasis on low latency, URLLC, eMBB, and mMTC offerings."
- According to a recent report published by Facts and Factors, "the global 5G Core market was valued at approximately USD 349.4 Million in 2019 and is expected to generate revenue of around USD 13163.1 Million by end of 2026, growing at a CAGR of around 69.3% between 2020 and 2026. The availability of unlicensed and shared spectrum around the world, as well as the commercialization of 5G networks in businesses such as private 5G, are expected to form the future of the 5G core market. Furthermore, the extensive adoption of the Internet of Things paired with on-going advances in M2M communication networks is transforming a variety of industries by linking all forms of appliances, devices, systems, and services. IoT is one of the many use cases supported by 5G core-enabled 5G, allowing communication between large numbers of sensors and connected devices."

Some main participants of the 5G Core market are Oracle, Athonet, Samsung, Affirmed Networks, NEC, Cisco Casa Systems, Mavenir, IPLOOK, Cumucore, ZTE, Nokia, Ericsson, Huawei, Metaswitch, HPE, and Druid Software amongst others. Descriptions of indicative market products are provided in the following sub-sections.

[26] https://www.prnewswire.com/news-releases/global-5g-core-market-size-growth-key-players-analysis-network-function-insights-end-user-regional-data-and-forecasts-to-2025--reportsnreports-301320841.html

2.5.1.1 Ericsson's dual-mode 5G Core

5G capable networks are now a reality around the globe, however, these new 5G networks will co-exist side by side with 4G ones for many years, while at the same time efficiencies need to be improved in order to capture new opportunities.

Ericsson's dual-mode 5G Core is built on cloud-native, microservices-based technology and combines Evolved Packet Core (EPC) and 5G Core (5GC) network functions into a common multi-access and cloud-native platform that supports 5G and as well as previous generations for optimized footprint and TCO efficiency. It is an evolution of our powerful virtualized portfolio, designed for cloud deployment, consisting of our Cloud Packet Core, Cloud Unified Data Management (UDM) and Policy and Signaling Controller products.

The solution includes built-in software probes enabling a full end-to-end monitoring and troubleshooting tool for improved customer experience and an integrated firewall to increase 5G network security[27]. It also includes network exposure capabilities including an embedded Application Programming Interfaces (APIs) management module to enable service providers to explore new business opportunities with increased network programmability.

The dual-mode 5G Core enable CSPs to:

- Introduce 5G quickly and effectively while protecting existing services
- Have a controlled and smooth migration to 5G aligned to business needs
- Address new segments with flexibility and agility
- Reduce cost and increase performance with cloud native design
- Quickly introduce new functionality and do maintenance updates

2.5.1.2 Mavenir's Converged Packet Core

Mavenir's end-to-end, fully containerized packet core portfolio offers a flexible, cost-effective journey to 5G with multi-generational support for all G's to modernize existing mobile networks while evolving to 5G. In addition to multi-generation support for all G's, the Mavenir Converged Packet Core also supports non-3GPP access and can be tailored to fit any customer infrastructure and business needs.

Mavenir's Converged Packet Core solution uses cloud-native architecture where applications and services are purpose-built for the cloud model to offer easy scaling, hardware decoupling, agility, portability, and resilience across public, private, and hybrid clouds. A Fully containerized, granular microservice architecture provides carrier-grade resiliency that meets web-scale requirements such as high availability, security, and performance.

Mavenir's Converged Packet Core Solution offers 5GC NF applications that are de-coupled and built independently of the platform so that open APIs can integrate with any 3rd party observability framework and provide flexibility and extensibility for service agility. With the ability to run in any underlying CaaS, PaaS, and IaaS layer, Mavenir has de-coupled the 5GC NF application services from the common platform services to provide a truly disaggregated and independently scalable packet core architecture.

[27] https://www.ericsson.com/en/blog/2019/2/transforming-4g-into-5g-ericssons-dual-mode-5g-cloud-core

Mavenir is committed to changing network economics and driving positive business outcomes. Mavenir's packet core network architecture simplifies network transformation and focuses on core principles that have consistently resulted in customer success.

Some of the features of Mavenir's core network are:

- **100% cloud-native, 100% containerized, 100% multi-generational support:** CSPs gain the ability to support existing subscribers while deploying new commercial-grade 5G use cases, standalone or not. A light hardware footprint reduces costs while fine-grained microservices lend control and simplicity to the environment. A cloud-native environment helps create and sustain a culture where building, testing, releasing, and deploying happens swiftly and consistently.
- **Service-based architecture:** Application services are decoupled from the network and platform infrastructure. 3GPP standards-based APIs provide flexibility and extensibility for service agility. Now, CSPs can rapidly launch new services with service deployment agility and AI/ML for network scaling that also results in reduced OPEX.
- **Network slicing:** Traffic isolation, security, and differentiated performance gives operators the ability to customize the network to suit any specific requirements of their customers with minimal resources and an optimized footprint.
- **Continuous Integration and Continuous Development (CI/CD):** DevOps-based software release and upgrade cycles reduce time to market, cost, and lengthy integration processes. An automated path for continuous delivery lets developers rapidly deploy to production environments.
- **Access agnostic core for access independence:** A common core serves all types of access (3GPP, non-3GPP, and wireline convergence) allowing seamless interworking between them and enabling operational efficiencies.
- **Multi-Access Edge Computing (MEC):** Operators can fulfill the requirement of low-latency and high throughput for specific use-cases enabled by 5G. Natively de-coupled control and user plane functions allow CSPs to bring the user plane closer to the edge and deploy it alongside the MEC application.
- **High-Performance User Plane Function (UPF).** Mavenir's cloud-native, highly optimized packet processing design for UPF uses software acceleration technologies such as DPDK, VPP, and hardware offloading using SmartNICs. These technologies deliver a low hardware footprint and reduce cost per bit.

Mavenir is an award-winning 5G core network technology provider. Being a master innovator of the 5G core network technology, Mavenir's cloud-native Converged Packet Core solution goes beyond the 3GPP standards to provide operators with innovative and cost-effective solutions for all Gs.

Mavenir enables new revenue-generating use cases while staying focused on mobile network economics. Mavenir's solution offers flexibility to operators and enterprises with a multi-cloud environment, that optimizes resources based on the organization's business objectives.

2.5.1.3 Athonet's cloud-native core

With Athonet's cloud-native mobile core on Amazon Web Services (AWS), operators and enterprises can deploy 5G-type use cases rapidly today, while earning new revenues and validating business models with real commercial customers. It allows mobile operators who move fast to seize the advantage and pre-empt competition from their peers and new entrants on open spectrum. Moreover, the cloud allows a smooth transition to 5G without the high capex, high-risk investment profiles of cycles. Mobile operators who grasp this opportunity now

will leapfrog competition well ahead of 5G achieving critical mass - and with higher returns at lower risk.

Athonet is differentiated by the maturity, reliability and versatility of its Professional-Grade solution which combines the highest range of carrier type features and reliability with an IT-friendly footprint and user interface which makes it consumable by enterprises and non-telco end-users. Athonet's solution is highly automated and built for its vision to deploy a million private networks by the end of the decade.

Whilst Athonet's initial deployments were custom-designed, fully on-premises deployments for mission critical use-cases, we recognized the potential for shared and unlicensed spectrum to propel the industry to an altogether different scale of private network deployments, potentially reaching a million networks deployed by the end of the decade.

With this is mind, Athonet developed the world's first fully automated hybrid-cloud core network, the Athonet BubbleCloud, that could be very simply deployed from the public cloud by mobile operators or their system integrator partners. The solution allows a multi-tenanted, multi-sliced solution that combines the low-latency and data security of fully onsite solutions with the scalability, simplicity and affordability of the public cloud.

The Athonet BubbleCloud won a record 4 GSMA Global Mobile Awards at Mobile World Congress 2019, unprecedented for a single product in the event's more than 20-year history. Today it is deployed in a wide range of use cases varying from robotics, COVID field hospitals, schools and the Angel Stadium in Los Angeles, USA.

2.5.2 3GPP-compliant mission critical systems

Mission critical communications are applied in various sectors, from Public Safety and Emergency first-responders (including police forces, fire brigades, health services, etc.) to operators and industrial fields such as Oil & Gas, Mining, Transport, etc. Given their criticality, in order to guarantee mission-critical communication and to offer increasingly advanced functionalities, companies in the sector have invested time and effort in the technological evolution of the proposed solutions.

Traditionally, this immediate reaction, service assurance and encrypted communications' systems have been deployed on the basis of Private Mobile Radio (PMR) / Land Mobile Radio (LMR) technologies. Depending on the geographical scope, different technologies such as P25 or TETRA offer network infrastructures with integrated service management.

This market has traditionally been a niche or captive market, dominated by large companies. The major problems of these technologies are the lack of interoperability between different networks and between different customer devices, and the high cost due to the lack of competition and lack of possible innovation of other parties. However, spectrum scarcity, technological obsolescence and its intrinsic limitations compared to the capabilities of commercial mobile technologies have led to the development of new open, internationally harmonised standards based on 4G/5G technologies. Examples of benefits for end-users would be the possibility of obtaining a higher transfer rate to enrich mission-critical communications with additional services (data, video, positioning and navigation) and the availability of user devices based on mass-market chipsets (greater choice and lower cost).

In the same way, broadband communication turns the tide with respect to narrow band in Mission Critical Communication. Specific radio legacy communication knowledge loses value as IP Networks & Voice over IP are on the increase. Currently the quality of audio in narrow band meets high standards but the demand on higher data transfer rates, will spurn this trend to introduce mission critical communication. In contrast to dedicated narrow band

communication, the usage of commercial broadband networks and bandwidth rise in turn, new challenges on billing, availability, priority, symmetric up/download rates and robustness.

In brief, the transformation of mission critical services in the 5G architecture aims to revolutionise the way people work and collaborate, notably sharing data and video with a dedicated QoS to maximise call set-up times and prioritization of services in the event of congestion and operation in isolated mode while keeping robustness and security.

This chosen path will lead mission critical system into innovative, interoperable and future seeking ways to communicate within first responders and business ecosystems.

Based on the Global Mission Critical Communications Market Report 2021 published by Research and Markets[28], "AI-powered IoT Critical Communication Market in Public Safety will Surpass $20 Billion by 2028. The mission critical communications market is rapidly evolving as developing technologies (5G, AI, IoT, Big Data etc.) provide solutions necessary to meet emerging demands for improved voice, data, and machine-oriented communications. Industry verticals that manage critical infrastructure (such as utilities, ports, and transportation) and services also require enhanced communications to safeguard assets and optimize operations. In conjunction with land mobile radio (LMR) modernization, and industry digitization for the public safety sector transition from LMR to 4G and beyond, LTE Advanced and 5G networks establish and support mission critical voice and data communications as well as facilitate opportunities for new mission critical applications. While mission critical communications technology is often referred to synonymously with the public safety sector, the need for ultra-reliability, low-latency, and/or high bandwidth capabilities are also necessary for enterprise, industrial, and government sectors. Like public safety, solutions in the commercial arena are typically realized via dedicated networks for specific industries including the public safety sector, transportation (air, rail, road, and water), utilities, mining, manufacturing, and the oil & gas industry. The market for mission critical communications is rapidly moving beyond voice to encompass data, and machine-oriented communications. For example, the public safety community increasingly relies upon IP-based solutions for first responders (ambulance, police, fire) and dispatch communications as well as overall coordination in the event of a disaster. Private IoT networks will also connect mission critical commercial operations, such as connecting infrastructure with monitoring and control, supported by AI and advanced data analytics. This will involve intelligent and connected systems that rely upon newly allocated 5G spectrum sharing management solutions for communications. Each of these technologies are evaluated in the report."

In the same report, the following findings are also highlighted:

- The global mission critical communication market will reach $32.6 billion by 2028, growing with 9.8% CAGR through 2028
- Military, public transportation, and smart grids are the largest industry verticals in the non-public safety critical communication market segment
- The global AI-powered IoT critical communication market in public safety will approach $20.6 billion by 2028, growing 17.8% CAGR during 2021 to 2028
- Asia Pacific is the largest region with a 43.8% of the total mission critical communications market and the greatest opportunity for certain technologies

[28] https://www.prnewswire.com/news-releases/global-mission-critical-communications-market-report-2021-ai-powered-iot-critical-communication-market-in-public-safety-will-surpass-20-billion-by-2028-301242381.html

- IoT in critical infrastructure is the largest segment with 52% of the total market with growth driven by the need for inter-system communications and AI integration
- Other than cybersecurity for support of critical infrastructure, there is nothing more important to government and sovereign nation safety and security than critical communications.

As per a report published by Market Research Future[29], "The global mission critical communication (MTX) market is expected to reach USD 26.66 billion by 2025 with a CAGR of 10.5% during the period 2019-2025.

Key players of mission critical communication market are Motorola Solutions, Harris Corporation, Hytera, Nokia Corporation, AT&T, ZTE Corporation, Ericsson, Huawei Technologies, Nemergent, Iridium, Cisco, Kapsch, Leonardo, StreamWIDE, TASSTA, Cobham Wireless, Ascom. In the following subsections some indicative products are presented.

2.5.2.1 Ericsson Mission Critical Communications

Using leading 3GPP LTE and 5G technology and critical broadband capabilities, Ericsson delivers mission critical mobile communication solutions to mobile service providers and other partners. This enables them to offer future-proof, highly secure, reliable and resilient cellular connectivity to government and public safety agencies such as first responders, as well as utilities and rail transport industries.

Ericsson Mission Critical Networks are deployed nationwide and across regions to enable critical agencies to modernize their respective networks with future-proof investments. In this way, interoperability is achieved among agencies and beyond borders, and sensors, robots and drones can be used to save lives and enhance operational effectiveness.

Energy utilities benefit significantly from the speed, flexibility and reliability of our Mission Critical Networks, all of which enable them to cope with fundamental changes – both in terms of the generation and distribution of power, and new patterns of consumption.

Railway companies profit from the interoperability enabled with legacy networks and across multiple communication infrastructures. They achieve enhanced connectivity with a high level of reliability and availability with 5G, preparing them well for the Future Railway Mobile Communication System (FRMCS).

These solutions represent the latest mission-critical mobile networks and are designed to complement or evolve existing national or regional Land Mobile Radio (LMR) networks, providing comprehensive voice, data and video services.

This technology evolution is enabling a wider range of business models, delivering more cost-effective solutions – from dedicated LTE/5G networks to commercial mobile networks with specialist embedded mission-critical capabilities.

Ericsson's cutting-edge Mission Critical Networks and related applications are designed to complement or replace existing national or regional Land Mobile Radio (LMR) networks, providing comprehensive voice, data and video services.

[29] https://www.marketresearchfuture.com/reports/mission-critical-communication-market-8654

Ericsson's Mission-Critical Networks offering leverages the entire Ericsson portfolio, spanning areas such as radio, core networking infrastructure, network management, operational and business support systems, expert analytics, security and services. It includes enhanced features and capabilities to ensure mission-critical grade performance in the areas outlined in Figure 29:

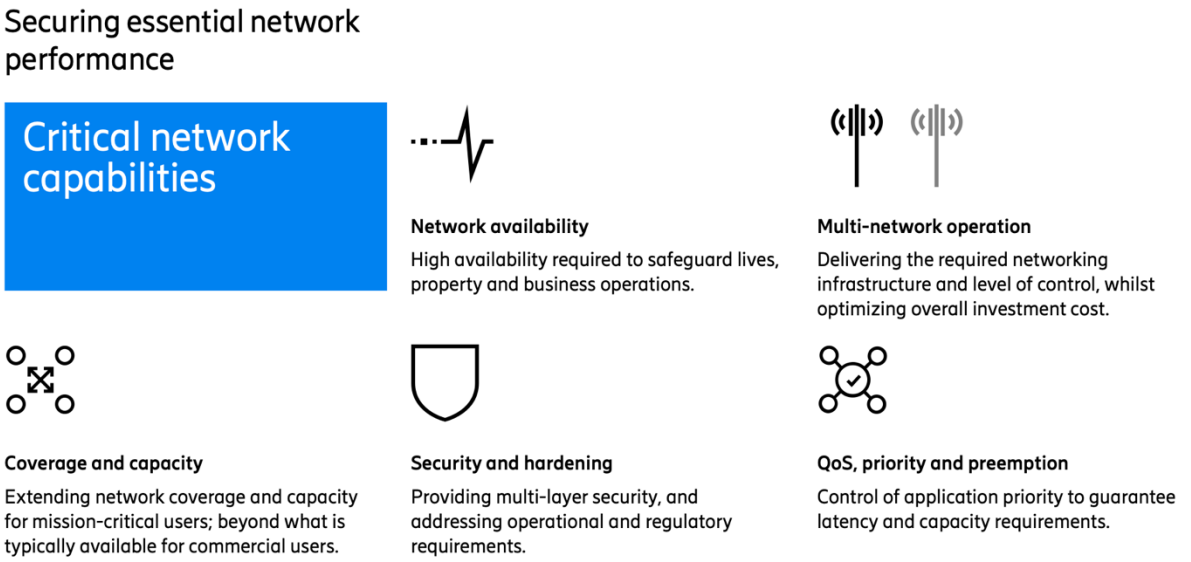


Figure 29: Performance of Ericsson's Mission Critical Systems (Source: Ericsson)

2.5.2.2 Nemergent's Mission Critical Solution

The Nemergent Mission Critical Services solution provides the application-level components required to deploy the 3GPP MCX Solution. The main product line is related to the MCX servers. The solution also includes other SW elements that complement a full operational system. All the products are software elements, which can be deployed either as standalone hardware elements or as virtual instances on partner HW / NFV infrastructures.

The main product in the Nemergent portfolio is the MCX Server, which consist of an Application Server (AS) and the Management Servers (IdMS, CMS, GMS and KMS). The AS implements both controlling and participating roles, and the required interfaces to the underlying LTE network, Rx and MB2.

Nemergent OAM is designed as a web-based frontend, supporting wide MCX configuration flexibility. Nemergent Android GUI provides operational customization over the Android SDK.

Open interfaces to foster the interconnection with external systems. MCX Client / Dispatch SDK for quick creation of MCX capable user equipments. Inter-working Enabler for the interconnection between MCX and legacy systems.

Service monitoring & management modules to integrate with external NMS / OSS / BSS. Media and data recording interfaces.

The versatile Nemergent MCX software can be deployed over 4G/5G infrastructures and integrated into third-party systems to create a scalable, adaptable, and multi-vendor end-to-end system.

2.5.2.3 STREAMWIDE's Team on Mission

Team on mission is the next generation solution to address the challenges of the demanding public safety environment – voice, data, video, interoperability and location services all bundled in one solution in real time.

Team on mission enables a smooth transition from PMR to MCPTT over 4G/5G LTE with the reliability and assurance that communications will be there when and where needed.

It has interoperability with TETRA, Tetrapol, P25. It is compliant with the next generation 3GPP and compatible with ruggedized smartphones, tablets (Android), while it is certified ATEX handsets.

Team on mission has always taken data security seriously – from high-quality military-grade encryption through to high-quality double-authentication standards.

Some of the characteristics of the team on mission solution are the following:

- Fully secured PTT application/PTT server connection via TLS: SIPS, HTTPS, cryptographic suite: TLS 1.2, cipher up to AES-256 and hash up to SHA-512
- Secure voice communication using SRTP
- Optionally, specific encryption modules can be integrated
- Dispatcher can wipe-out data remotely in case of mobile loss or employee resignation
- Block or remove user access to service
- Focus on securing sensitive information includes the storing of application logs remotely using syslog and the encryption of all stored passwords
- All communication made with external systems such as map servers or narrow band PTT gateways are encrypted
- Communication between the HQ and the engineers on the oil rig is possible through an LTE autonomous mobile network for remote places. The control center receives and monitors pictures sent by the drones.
- Dispatcher can track and monitor all emergency units in real-time. He can write a specific address to see from the map which is the closest to the emergency area.

2.6 Management & Orchestration

2.6.1 Network Orchestration

Telecommunications industry is currently experiencing an unprecedented paradigm shift, moving towards virtualized and disaggregated solutions. According to recent reports, the global **Network Function Virtualization (NFV) market is expected to grow from $12.9 billion in 2019 to $36.3 billion by 2024**, at a Compound Annual Growth Rate (CAGR) of **22.9%** during the forecast period[30]. In such scenarios, the ability to optimize network

[30] https://www.marketsandmarkets.com/Market-Reports/network-function-virtualization-market-93929190.html?gclid=CjwKCAjw3riIBhAwEiwAzD3TiY7qkulkV_cdMkaqDqyWAYPKIvjOYPSzAssjioFMV3GYmTW9sX-IdhoC3VoQAvD_BwE

management and service delivery is of paramount importance to communications services providers. This is especially the case as 5G networks will add a level of unprecedented complexity of hybrid LTE/5G environments for carriers as well as enterprise and industrial private networks. Network automation and orchestration are dependent upon a multi-faceted approach including smart antennas, network slicing, and optimization of cloud resources, especially at the edge of networks.

To that end, **both open source and commercial products** have been built to provide the next generation networks with orchestration capabilities. **Open-Source MANO (OSM)**[31] is one of the most important and widely adopted open source projects, aligned with ETSI NFV specifications. In the same context, **Open Network Automation Platform (ONAP)**[32] is a comprehensive platform for orchestration, management, and automation of network and edge computing services for network operators, cloud providers, and enterprises. **SONATA platform**[33] is the outcome of 2 EC-funded projects, i.e., SONATA and 5G-Tango[34], being a vendor-agnostic MANO platform that fully embraces the flexible programmability of 5G networks and the virtualization of the communication services. The widely adopted **Cloudify solution**[35] for multiple cloud platforms orchestration is aligning with ETSI specification and it offers an open-source version as well as commercial options. With respect to the **commercial world, Netcracker's suite**[36] includes orchestration capabilities, an SDN Controller, and a range of virtual network functions (VNFs), such as virtualized customer premises equipment (vCPE), virtualized evolved packet core (vEPC), and other value-added VNFs and management offerings. Nokia has designed **Cloudband**[37] that facilitates the hosting, orchestration, automation, and management of VNFs, CNFs and services. Huawei Network Control Engine[38] is the "brain" of **Huawei's Intent-Driven Network** (IDN), integrating the network management, control, and analysis functions. **HPE NFV Director**[39] claims full compliance with ETSI NFV specification and provides VNF and CNF orchestration and management, design and edition of descriptors, and automated actions based on policies. **Amdocs NEO**[40] is a comprehensive solution providing design, orchestration and inventory management capabilities of cloud-native services.

However, these initiatives have focused on the orchestration of network resources and data centers, without explicitly taking into account the **challenges** of the network edge: i) limitation of resources, as storage, communication and computational resources are more scarce (and thus valuable) as we move towards the edge of the network; ii) the consideration of network edge makes the network truly heterogeneous, stressing the need for orchestrating different functions (both physical and virtual) and different devices (e.g., sensors, cameras, etc.); and iii) as more technological domains are incorporating in the network, the possibility of having multiple administrative domains and underlying infrastructures (e.g., VMs or containers) increases significantly, requiring high level orchestrators that orchestrate the individual domain

[31] https://osm.etsi.org/
[32] https://www.onap.org/
[33] https://www.sonata-nfv.eu/
[34] https://www.5gtango.eu/
[35] https://cloudify.co/
[36] https://www.netcracker.com/
[37] https://www.nokia.com/networks/solutions/cloudband/
[38] https://e.huawei.com/en/products/network-management-and-analysis-software
[39] https://assets.ext.hpe.com/is/content/hpedam/documents/a00016000-6999/a00016377/a00016377enw.pdf
[40] https://www.amdocs.com/amdocsone/open-cloud-networks-ngoss/automate-service-network-operations

orchestrators. In addition, the recently formed O-RAN Alliance[41] aims at re-shaping the RAN industry towards more intelligent, open, virtualized and fully interoperable mobile networks. These challenges have also boosted the edge computing market, with recent forecasting reports stating that the overall mobile edge computing market is expected to reach $2.8 billion by 2027, at a CAGR of 30.1% during the forecast period of 2020 to 2027.

Nearby Computing S.L (NBC) has already released the first version of their flagship product NearbyOne Edge Orchestrator to the market. NearbyOne is able to provide **complete end-to-end orchestration solutions** in real 5G infrastructures, composed of heterogeneous components, i.e., from virtual network functions to MEC resources and hardware devices, spanning across multiple domains with various underlying technologies (i.e., Openstack and K8s).

NBC, having innovation as major priority, targets at upgrading the existing features of NearbyOne and adding novel functionalities in the upcoming release version. In particular, the **advanced AI-enabled algorithms** developed in the context of Affordable5G will be incorporated to enable the network automation, minimizing the human intervention towards zero-touch network provisioning. In addition, we foresee and **alignment with the O-RAN specifications** by designing O-RAN-compliant relevant interfaces (e.g., O2), allowing the easy integration towards open and fully interoperable mobile networks. These advancements are expected to strengthen further the position of NBC in the market and create opportunities for new collaborations and partnerships.

2.6.2 Network Telemetry

Network Telemetry is real-time data collection in which devices push data to a centralized location. Telemetry metrics are generated from enterprise resources, such as switches, routers, wireless infrastructure and IoT systems, and used by business and technology applications to monitor trends and help IT respond to threats or react to changing network conditions.

Network telemetry market will have a key role in the proper design and deployment of Non-Public Networks (NPNs). The market is expected to undergo a dynamic transition as advancements in network architecture and emerging networking technologies are driving the demand for efficient telemetry solutions. There is no market research study forecasting that the network telemetry market will not grow in the following years. Indicative market research finding are as follows:

- Network Telemetry Market is Expected to Expand at a 39.4% CAGR to Reach USD 826.1 Million by 2025 as per a report by Market Research Future (MRFR)[42].
- According to MarketsAndMarkets, “The global network telemetry market size is expected to grow from USD 140 million in 2019 to USD 704 million by 2024, at a Compound Annual Growth Rate (CAGR) of 38.1% during the forecast period (Figure 30)[43]. An increase in network attacks and security breaches and the growing need to quickly resolve downtime issues are major factors expected to drive the growth of the network telemetry market. However, additional factors also drive technological

[41] https://www.o-ran.org

[42] https://www.globenewswire.com/en/news-release/2021/07/14/2263074/0/en/Network-Telemetry-Market-is-Expected-to-Expand-at-a-39-4-CAGR-to-Reach-USD-826-1-Million-by-2025-Report-by-Market-Research-Future-MRFR.html

[43] https://www.marketsandmarkets.com/Market-Reports/network-telemetry-market-110999318.html

evolutions in network telemetry, such the growing data traffic, growing uptake of digital transformation trends and adoption of SDN technologies. Need to handle massive network performance data and emerging technologies, such as IoT, AI, and SDN are expected to offer vast market opportunities for network telemetry vendors in the next 5 years. The emergence of the hybrid cloud approach and 5G deployment are expected to create massive opportunities for the network telemetry vendors."

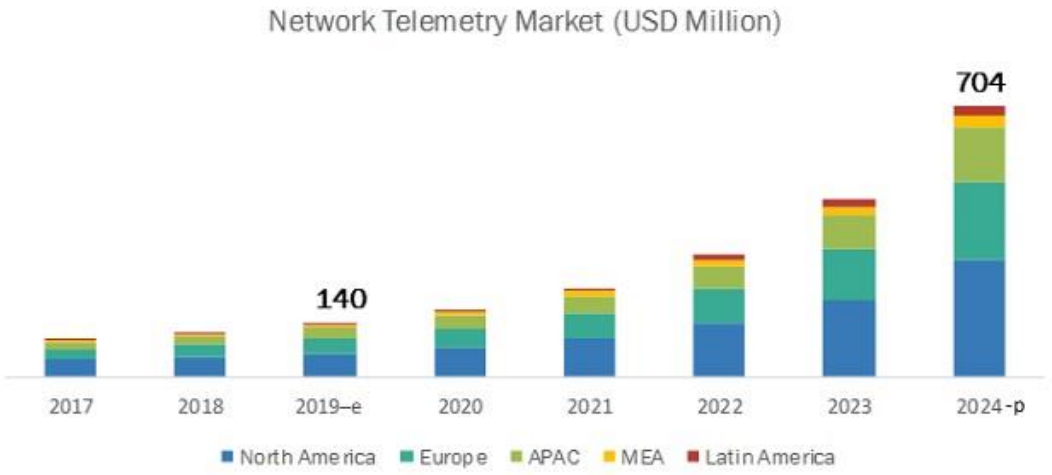


Figure 30: Network Telemetry Market (USD Million)[43]

- Based on a report published by MarketResearch[44], "Amid the COVID-19 crisis, the global market for Network Telemetry estimated at US$188.9 Million in the year 2020, is projected to reach a revised size of US$1.4 Billion by 2027, growing at a CAGR of 33.6% over the period 2020-2027. Solutions, one of the segments analyzed in the report, is projected to record 31.8% CAGR and reach US$751.4 Million by the end of the analysis period. After an early analysis of the business implications of the pandemic and its induced economic crisis, growth in the Services segment is readjusted to a revised 35.8% CAGR for the next 7-year period. The U.S. Market is Estimated at $50.7 Million, While China is Forecast to Grow at 41.5% CAGR."
- According to Global Market Insights[45] "The Network Telemetry Market size exceeded USD 350 million in 2019 and is anticipated to grow at over 30% CAGR between 2020 and 2026. The market is expected to undergo a dynamic transition as advancements in network architecture and emerging networking technologies are driving the demand for efficient telemetry solutions.

[44] https://www.marketresearch.com/Global-Industry-Analysts-v1039/Network-Telemetry-14481517/
[45] https://www.gminsights.com/industry-analysis/network-telemetry-market

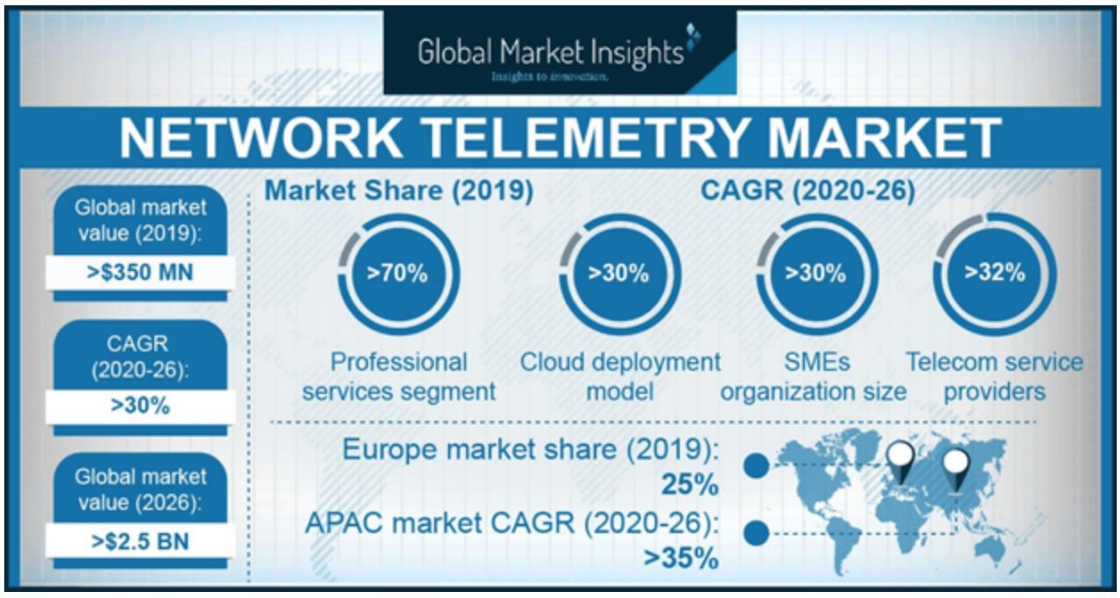


Figure 31: Network telemetry market (Source: Global Market Insights

Rising industry competition has pressured enterprises in reducing network downtimes for ensuring a competitive edge in a dynamic market. This has led to a rapid surge in the market demand for network telemetry tools. In addition, the growing stress on networking infrastructure due to work from home policies amidst the COVID-19 outbreak has also boosted the market growth. For instance, in March 2020, Cloudflare reported an additional stress of over 25% on global fixed and wireless networks after the imposition of global quarantine policies. In China, the on-premise segment held a significant market share of around 65% in 2019 due to shifting preference of Chinese telecom providers toward on-premise hosting of network telemetry tools. The large enterprises segment accounted for over 70% share of the Brazil network telemetry market in 2019 on account of increasing importance of network performance monitoring and real-time fault resolution amongst large enterprises. Europe network telemetry market held a significant revenue share of around 25% in 2019 due to increasing uptake of telemetry solutions for cloud network analysis and security management. The growing penetration of telemetry tools in the UK and Germany to support data center virtualization has further accentuated the market growth. In addition, European cloud computing SMEs are rapidly adopting telemetry tools for efficient network management and reduction of cybersecurity policy violation, influencing the market size expansion". Market dynamics per region are shown in the following figures.

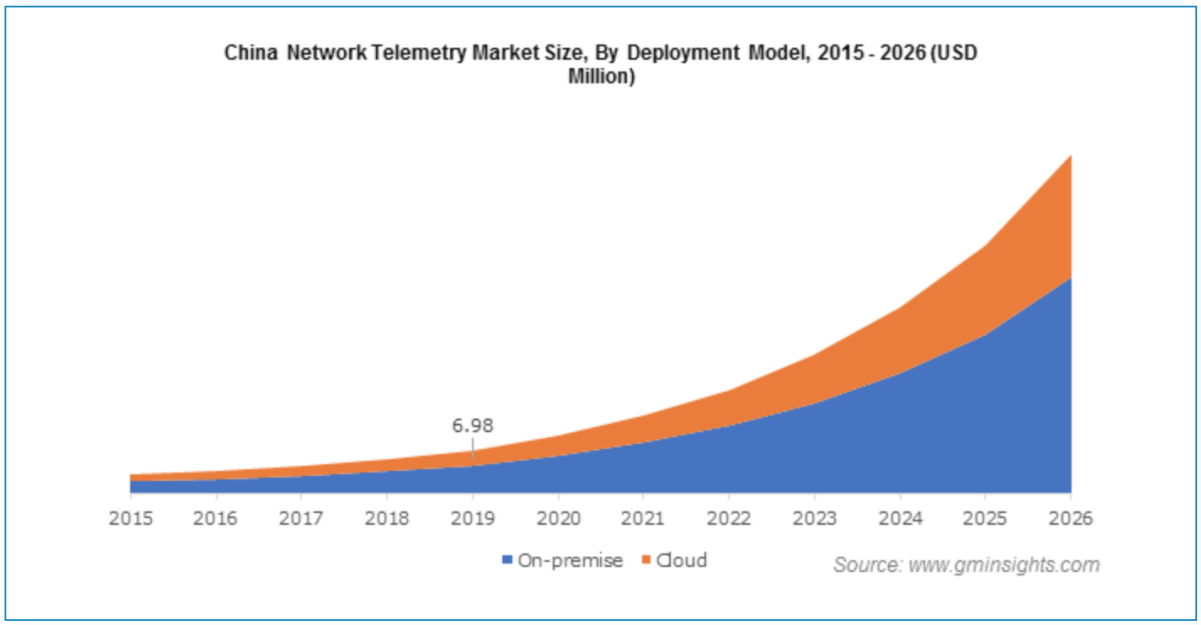


Figure 32: China Network Telemetry market

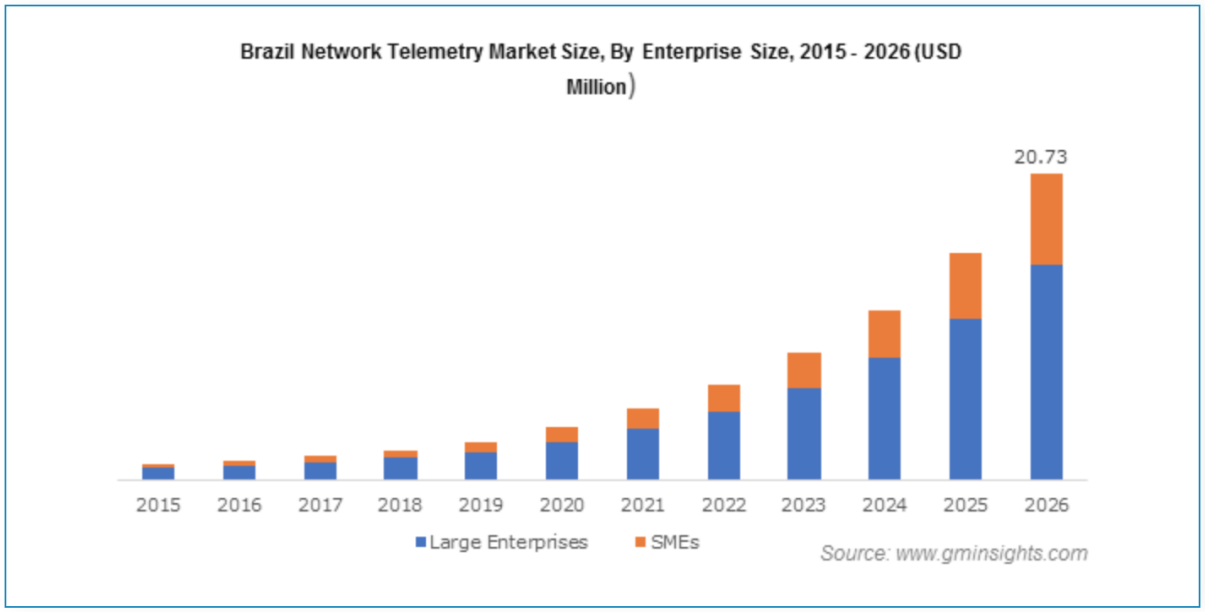


Figure 33: Brazil Network Telemetry market

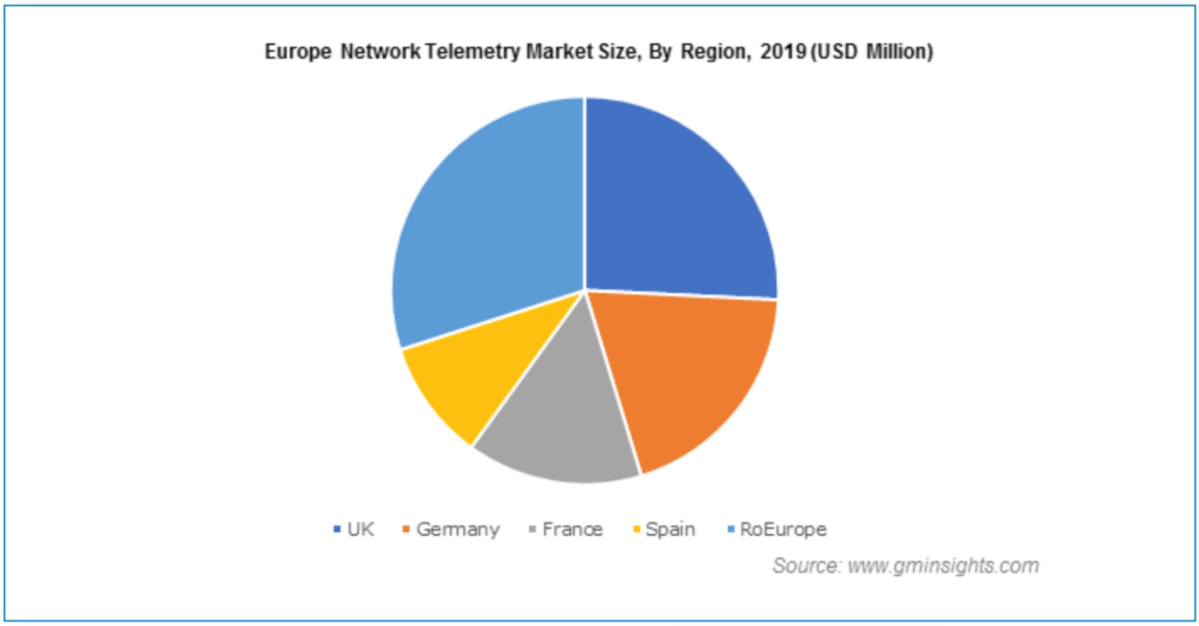


Figure 34: Europe Network Telemetry market

Dominant key players on Network Telemetry Market are: Arista Networks (US), Cisco Systems Inc. (US), Juniper Networks (US), Mellanox Technologies (US), VOLANSYS (US), Pluribus Networks (US), Solarflare Communications (US), Marvell Semiconductor Inc. (US), Google (US), Anuta Networks (US), Waystream AB (Sweden), Apcela (US), Netronome (US), Barefoot Networks (US).

In the framework of Affordable5G, a network monitoring (NM) and telemetry (NT) structure, able to gather related data from all defined architectural layers (Infrastructure Layer, Network Function Layer, and Management, Orchestration and Automation Layer) will be developed and deployed by NKUA. In this context, two significant components are the NWDAF and the C-MDAF, where the first one is a well-specified component of the 5G Core Network according to 3GPP standards and ETSI technical documents. In parallel, this telemetry approach will be also integrated with state-of-the-art ML/AI frameworks (e.g., TensorFlow, etc.) in order to be evaluated against various use case requirements. Therefore, the ultimate goal is to provide a reliable tool for holistic network monitoring and self-improvement based on appropriate pre-and-post processing of data. The finer granularity and higher frequency of data available through telemetry enables better performance monitoring and therefore, better troubleshooting. It helps a more service-efficient bandwidth utilization, link utilization, risk assessment and control, remote monitoring and scalability. Therefore, owners of private and enterprise networks are expected to be the main beneficiaries of this telemetry approach combined with advanced AI/ML algorithms, since network maintenance and consequently production costs are expected to be reduced via an effective predictive maintenance. This “dual” operation (i.e., data gathering and advanced AI/ML algorithms) is particularly important in current and future generation broadband networks, especially for the NPNs, since they are business oriented and inextricably connected with complex tasks and holistic product monitoring. With the increased importance of wireless connectivity for business-critical applications in large and complex industrial spaces, 5G NPNs offer stringent end-to-end synchronization for time-deterministic packet delivery, precise positioning, and seamless mobility for the most diverse set of use-cases with a single global wireless standard, which makes 5G the foundation for industry 4.0.

Many private companies have also built their own network telemetry and monitoring infrastructure. For example, RADCOM has provided a 3GPP compliant approach of NWDAF[46]. In this context, AI and ML algorithms are continually utilized to assist zero-touch slice management by forecasting resource utilization trends and proactively improving/configuring the network resources.

Sandvine has engineered an enriched 3GPP standards-compliant and cloud native NWDAF[47] which incorporates proven machine learning and the industry's most advanced traffic classification technology. Arista has provided[48] a state-streaming architecture that is based on an open industry-standard framework for a variety of integration options. In the same context, Juniper Networks (US) aims at providing networking products, services, and solutions for technologies such as IoT, big data, 5G, Artificial Intelligence (AI), and multi-cloud to bring down their complexity level by providing simpler solutions to its customers[49]. Junos Telemetry Interface supports an extensible and open data model.

From the above analysis, it becomes apparent that key technological solutions in network monitoring and telemetry include two conceptual approaches: support of advanced AI/ML algorithms, as well as open-source frameworks.

In Affordable5G approach, an open source NWDAF has been considered, able to gather requested data and info from various NFs. This will encourage and allow multivendor deployments and facilitate customization to suit individual service needs by the utilization of 3GPP compliant implementation. In this context, the currently defined Nrf/Nnwdaf interfaces will be appropriately utilized to facilitate data collection from the 5GS. To the best of our knowledge, no such open-source solution currently exists. Additionally, a cross-layer approach has been considered, since related information will be gathered from all architectural layers. In this context, our solution will also support data collection from OpenStack environments (performance data from Virtual Machines) and Kubernetes environments (performance data from Containers), while also monitoring tools will be in place to provide data from the network infrastructure (such as Prometheus). It also worth mentioning that our unlike other market approaches, our developed framework will be O-RAN compliant, since the O-RAN specifications towards realizing this interconnection in a manner that would be interoperable with any O-RAN compliant implementations in the future will be taken into consideration.

2.6.3 Network Slicing

5G mobile network promises a game changing disruption for wireless networking. Data speeds, ultra-low latency, greater reliability and increased overall network capacity, among other improvements, uniquely position 5G to support the data and connectivity requirements of many thousands of connected systems. Aside from increased performance, **the architectural shift to virtualized network functions enables critical services delivery capabilities such as network slicing**, which will allow for configured services aligned with customer specific applications and use cases.

In the last years, there is an increasing demand for network slicing solutions which was also illustrated in the various studies conducted by market research firms.

[46] https://radcom.com/network-data-analytics-function-nwdaf/

[47] https://www.sandvine.com/service-providers/nwdaf

[48] https://www.arista.com/en/products/eos/telemetry-analytics

[49] https://www.juniper.net/documentation/us/en/software/junos/interfaces-telemetry/topics/concept/junos-telemetry-interface-oveview.html

- According to MarketsAndMarkets[50], "The global network slicing market size is projected to grow from USD 161 million in 2020 to USD 1,284 million by 2025, at a Compound Annual Growth Rate (CAGR) of 51.5% during the forecast period. The network slicing market is gaining traction due to the evolution of cellular network technology which has offered higher data speeds and lower latency. The rapid rise in the volume of data being carried by cellular networks has been driven largely by consumer demand for video, and the shift of business toward the use of cloud services. There are significant growth opportunities for Network Slicing vendors. The commercialization of 5G services and availability of unlicensed and shared spectrum in the globe are expected to shape the future of the Network Slicing market. The increasing business demand for enhancing network efficiency, high speed and virtualisation of network security is expected to make network slicing a dominant model. North America and Europe are leading the market in terms of market share. The market growth in APAC can be attributed to the digital transformation and automation across businesses in the region."
- As per a report by Global Market Insights[51], "network slicing market size exceeded USD 200 million in 2019 and is estimated to grow at a CAGR of over 15% from 2020 to 2026. Rising demand for next generation 5G network due to its better bandwidth and speed capabilities will drive the market growth. Different industry verticals are expected to increase their productivity owing to commercialization of 5G network. Network slicing is supporting these businesses with massive IoT and low latency services for their digital transformation.

Figure 35: Network slicing market (Source: Global Market Insights)

In UK, solutions segment dominated more than 80% of the market share in 2019 led by rising demand for better speed and bandwidth connectivity by telecom operators to serve

[50] https://www.marketsandmarkets.com/Market-Reports/network-slicing-market-120515704.html?gclid=CjwKCAjw0qOIBhBhEiwAyvVcf761inQnzTZSCoR-xruH7HMtLXR0NsP0QiyJXhBTrnUu8IkdpAlW3hoC4eQQAvD_BwE

[51] https://www.gminsights.com/industry-analysis/network-slicing-market

different customer needs. The healthcare application segment in China accounted for around 20% of industry share in 2019 impelled by the growing adoption of remote healthcare services. The increase in number of wireless medical devices for improving healthcare services is supporting market expansion. Asia Pacific network slicing market will showcase growth of over 20% till 2026 on account of rising adoption of mobile devices in developing countries such as India and China."

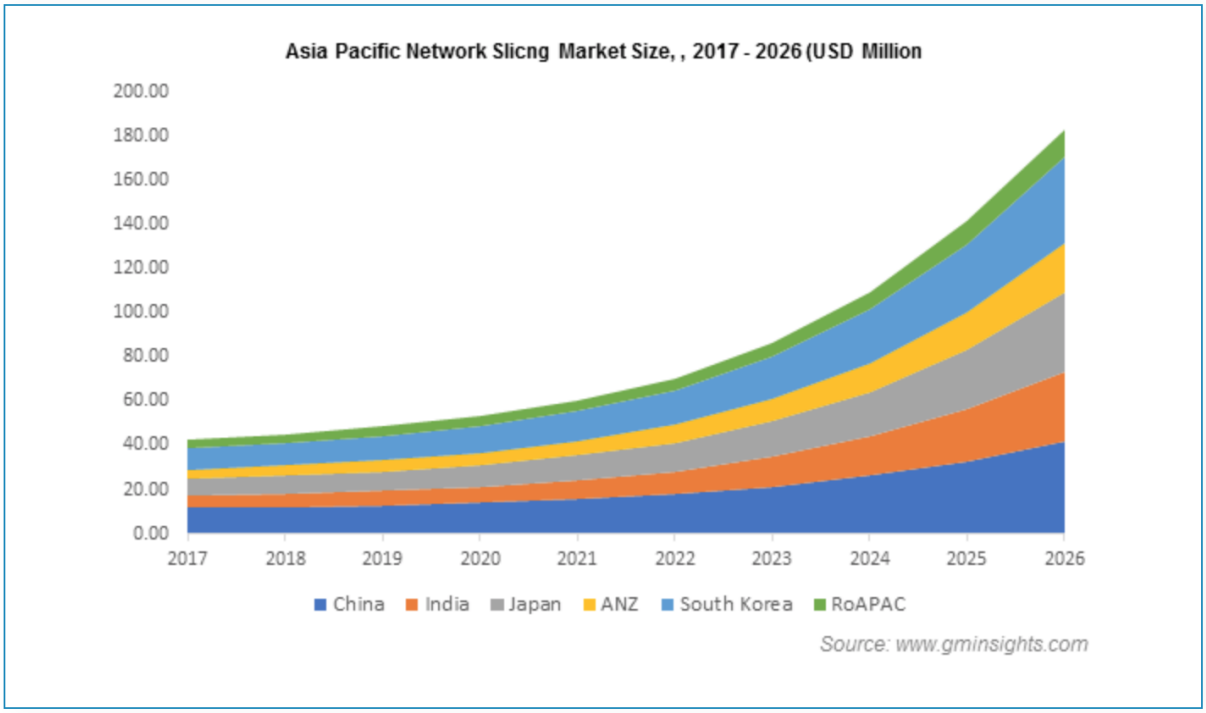


Figure 36: Asia Pacific Network Slicing market

- According to Mordor Intelligence[52], "The Network Slicing Market was valued at USD 143.63 billion in 2020 and is expected to reach USD 446.33 billion by 2026, at a CAGR of 20.8% over the forecast period 2021 - 2026. According to GSMA, network slicing, in combination with other enablers and capabilities, will aid operators to address a revenue opportunity worth USD 300 billion by 2025. The market is fragmented with players collaborating with each other to provide required availability, a specified latency, data rate and security. Network slice management solutions can also help carriers implement network slice lifecycle management in the preparation of 5G. Key market trends are:
  - APAC is expected to grow at the fastest rate owing to the development of network infrastructure and 5G being the biggest telecom trend.
  - ZTE, a provider of telecommunications, enterprise and consumer technology solutions for the mobile internet, and China Mobile announced its 5G Oriented future network architecture design concept and network slice prototype system in December 2018.

[52] https://www.mordorintelligence.com/industry-reports/network-slicing-market

- The biggest example of network readiness is expected to be seen in 2020 Tokyo Olympics where 360-degree, 8K video streams will be showcased across high-resolution devices.
- In China, Ericsson is already working with AstraZeneca on 5G-enabled medical devices that support predictive maintenance.
- 5G's network slicing capabilities will allow telcos to offer critical service providers their own private 5G networks for secure and real-time connectivity to the cloud, helping to meet their ever-evolving infrastructure needs and improve operational efficiency.

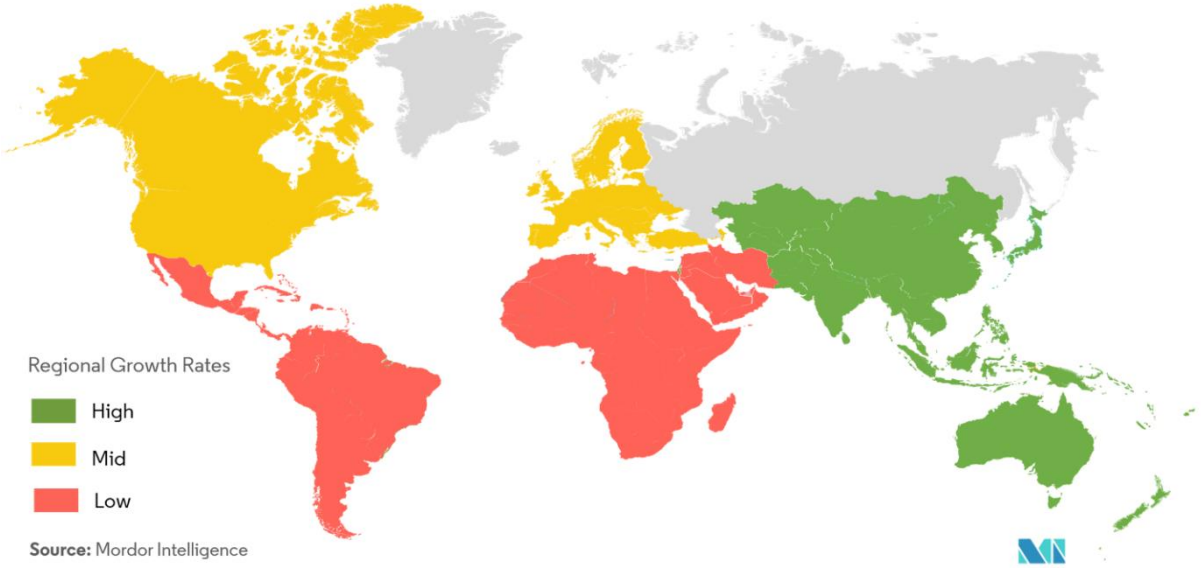


Figure 37: Network slicing market growth rate by region (Source: Mordor Intelligence)

- Based on a report published by ResearchDive[53], "The global network slicing market's revenue forecast shall be $1,456.6 million by 2027, increasing from $270.1 million in 2019 at a healthy rate of 24.20%. The North America network slicing market is estimated to grow at a CAGR of 23.40% by registering a revenue of $410.3 million by 2027. Strategic collaborations among the market players, along with the launching of advanced network slicing services, are expected to accelerate the North America network slicing market growth. The network slicing market industry is witnessing massive growth mainly because of increase in the adoption of network slicing in overcoming the challenges caused by mobile data traffic. The increasing mobile data traffic, internet subscribers and government support will drive the network slicing market. The network slicing industry is growing at a very fast pace due to the implementation of 5G network slicing capabilities in the businesses, which offers service providers a platform for creating their own private 5G networks for real-time connectivity and security to the cloud for increasing efficiency of their operations. Solution sub-segment is dominating the market and it will generate 188.3 million in 2019 mainly attributed to its operational efficiency. The services sub-segment shall have a speedy market growth and it is anticipated to generate a revenue of $513.7

[53] https://www.researchdive.com/5670/network-slicing-market

million by 2027, growing from $81.7 million in 2019. The growth of this sub-segment for the global network slicing market is mainly attributed to its support to the network resources for maintaining the QoS and its role in 5G networks. Solution sub-segment shall have a dominating market share in the global market and is expected to register a revenue of $942.7 million, during the analysis timeframe. Owing to its applications in every sector, societies and industries. Also, technological advancements along with growing customer demand for QoS, data security, energy efficiency and massive connectivity are some of the key factors are surging the demand for network slicing. These initiatives may create massive opportunities for the sub-segment, throughout the forecast period. The global professional services sub segment for network slicing market will have the fastest market growth; this is mainly because it offers operators for configuring different virtual networks."

These trends reveal that Network Slicer will be a key element on the management of the private networks, being part of the software and ideally service chunk of the market growth. Dominant key players on Network Slicing Market are: Affirmed Networks, Amdocs, Argela Technologies, Cisco Systems, Inc., Cloudstreet, HCL Technologies Limited, Huawei Technologies Co., Ltd., Mavenir, Nokia Corporation, Parallel Wireless, Inc., RedZinc Services Ltd., Telefonaktiebolaget LM Ericsson, and ZTE Corporation.

Existing Telecom providers such as Ericsson, Nokia or Huawei who are developing their capacities to adapt to the new 5G requirements providing close solutions based on their own expertise in the field. This solutions trend to be on turnkey basis, where there is no option for interoperability or, even vendor diversity. Affordable5G competitive advantage in front of them is the vendor agnostic design, and the capacity to offer the management solution across not only 5G but also WiFi and LTE networks. A multi-vendor and multi-radio access technology that can offer more customized solutions is also adopted by Affordable5G.

New incumbents who embody the 5G disruption that enables the new ecosystem where enterprises can manage their own networks. In this category we can see Companies like Celona, FreedomFi or Expeto in the US. Affordable5G competitive advantage is the bundle between technologies and the multi-access approach. Neither Celona nor FreedomFi offer slicing and none of the three offer the option to manage WiFi.

2.6.4 Artificial Intelligence (AI) and Machine Learning (ML)

Artificial Intelligence (AI) and Machine Learning (ML) techniques are gaining traction in technological ecosystems and many companies are exploring the benefits that AI/ML bring to their respective business. All research firms are predicting that AI/ML market will expand in a fast pace.

- According to Facts and Factors market research report[54], "the Global Artificial Intelligence Market size & share revenue is expected to grow from USD 29.86 Billion in 2020 to reach USD 299.64 Billion by 2026, at 35.6% annual CAGR growth during forecast period of 2021-2026. The rising growth of the global artificial intelligence market can be contributed to the extended support offered by the latter to the healthcare sector during a time of rising COVID-19 cases. Additional factors include a surge of data being handled by electronic health records due to the rising medical demand. AI algorithms can sort and quantify a huge quantity of data in an efficient and

[54] https://www.globenewswire.com/en/news-release/2021/06/28/2253975/0/en/Global-Artificial-Intelligence-Market-Size-2021-Rise-at-35-6-CAGR-Will-Grow-to-USD-299-64-Billion-by-2026-Facts-Factors.html

rapid form. This is said to increase the footprint of the artificial intelligence market during the forecast. Moreover, the rising adoption of AI for a range of advanced features such as augmenting messages, rapid sorting, and enquiring solutions, automated email and phone support, and management of support agents will further open new revenue opportunities for the market during the forecast."

- According to the predictions of Grand View Research[55], the global AI/ML market size was valued at USD 62.35 billion in 2020 expecting to expand at a compound annual growth rate (CAGR) of 40.2% from 2021 to 2028, experiencing a huge market size increase as depicted in the following Figure.

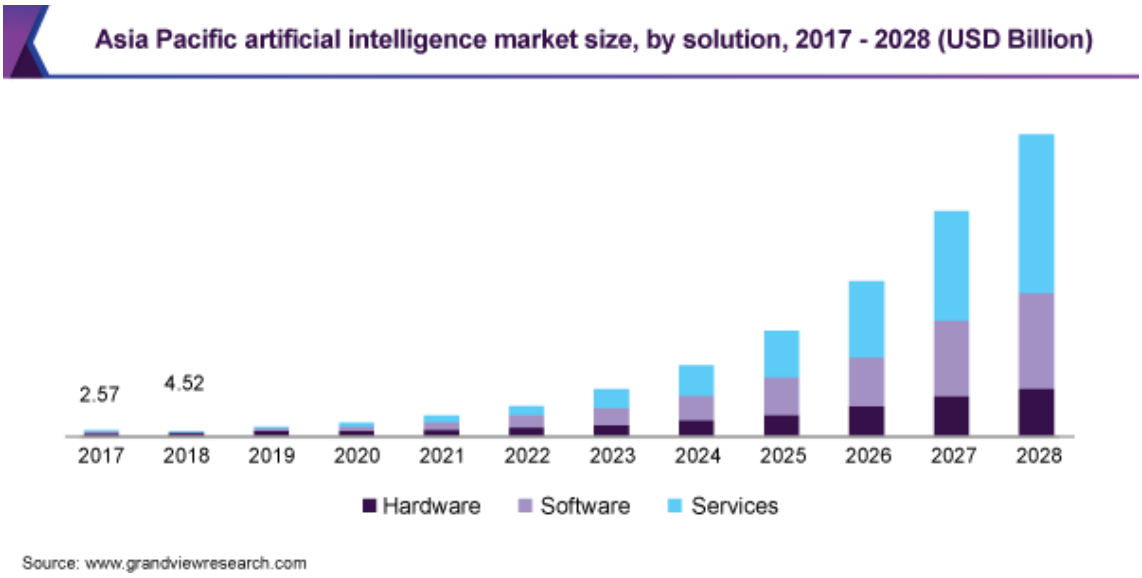


Figure 38: Asia pacific artificial intelligence market size (Source: GrandViewResearch)

The essential facet accelerating the rate of innovation in the field of AI is accessibility to historical datasets. Since data storage and recovery has become more economical, healthcare institutions and government agencies are building unstructured data accessible to the research domain. From historic rain trends to clinical imaging, researchers are getting access to rich datasets. The next-generation computing architectures, with access to rich datasets, are encouraging information scientists and researchers to innovate faster. Furthermore, progress in profound learning and Artificial Neural Networks (ANN) has also fuelled the adoption of AI in several industries, such as aerospace, healthcare, manufacturing, and automotive."

- MarketsandMarkets[56] forecasts the global AI market size to grow USD 58.3 billion in 2021 to USD 309.6 billion by 2026, at a Compound Annual Growth Rate (CAGR) of 39.7% during the forecast period. Various factors such as growth of data-based AI and advancement in deep learning and need to achieve robotic autonomy to stay competitive in a global market are expected to drive the adoption of the AI solutions and services.

[55] https://www.grandviewresearch.com/industry-analysis/artificial-intelligence-ai-market
[56] https://www.marketsandmarkets.com/Market-Reports/artificial-intelligence-market-74851580.html

Figure 39: Opportunities in the AI market

The cloud segment is expected to account for higher CAGR during the forecast period. The cloud deployment mode provides multiple benefits, such as reduced operational costs, hassle-free deployment, and high scalability. Cloud deployment for NLP and ML tools in AI is expected to grow with the increasing awareness related to the benefits of cloud-based solutions contributing to its growth in the market.

The AI market is segmented into five geographic regions: North America, Europe, APAC, MEA, and Latin America. Among these regions, North America is projected to hold the largest market share during the forecast period. The market in APAC is anticipated to grow at the highest CAGR during the forecast period. This growth can be attributed to the adoption of AI services in end-user industries, such as manufacturing, healthcare, and automotive in countries such as Japan, China, Australia, and South Korea.

- Another recent study from IDC[57] indicates even a better growth in worldwide revenues for AI market including software, hardware, and services, are forecast to grow 16.4% year over year in 2021 to $327.5 billion. By 2024, the market is expected to break the $500 billion mark with a five-year compound annual growth rate (CAGR) of 17.5% and total revenues reaching an impressive $554.3 billion. Among the three technology categories, software represented 88% of the total AI market revenues in 2020. However, it is the slowest growing category with a five-year CAGR of 17.3%. Within the AI software category, AI Applications took the largest share of revenue at 50% in 2020. In terms of growth, the AI Software Platforms market is forecast to be the strongest with a five-year CAGR of 32.7%. The slowest will be AI System Infrastructure Software with a five-year CAGR of 13.7% while accounting for roughly 36% of AI software revenues. Within the AI Applications market, AI ERM is expected to grow slightly stronger than AI CRM over the next five years. The global pandemic has pushed AI to the top of the corporate agenda, empowering business resilience and relevance. AI is becoming ubiquitous across all the functional areas of a business. Advancements

[57] https://www.idc.com/getdoc.jsp?containerId=prUS47482321

in Machine Learning, Conversational AI, and Computer Vision AI are at the forefront of AI software innovations, architecting converged business and IT process optimizations, predictions and recommendations, and enabling transformative customer and employee experiences. In Figure 40, the top 3 Companies in the AI Software Primary Market and the 3 AI Software Platforms Functional Markets are illustrated.

AI Software Market	**AI Type**	**#1**	**#2**	**#3**
AI Software Platforms	AI Centric	IBM	Microsoft	SAS Institute
AI Applications	AI Centric	IBM	OpenText	Slack
	AI non-Centric	Microsoft	Intuit	Google
AI System Infrastructure Software	AI Centric	IBM	Microsoft	Dynatrace
	AI non-Centric	Microsoft	VMware	McAfee
AI Application Development & Deployment	AI Centric	Microsoft	Google	Palantir
	AI non-Centric	Microsoft	ESRI	Teradata

Figure 40: Top 3 Companies in the AI Software Primary Market and the 3 AI Software Platforms Functional Markets (Source: IDC)

The AI hardware market is the smallest category with approximately 5% share of overall AI revenues in 2020. The share is forecast to increase slightly in 2021 at the expense of AI Software. The AI Server market grew faster than the AI Storage market in 2020, but these results are expected to the reverse in 2021 when AI Storage is forecast to grow 31.8% year over year compared to 26.4% for the AI Server market. By 2024, AI Hardware is forecast to be a $30.5 billion market with AI Servers representing an 82% revenue share."

Future networks are expected to offer unprecedented response times and bandwidth that will enable a huge set of ground breaking services around the cellular networks' ecosystem, but at the same time the management and operation complexity of cellular networks will heavily increase. The flexibility of the new service-based mobile architectures and the introduction of the new big set of analytics functions (e.g., NWDAF, MDAF) in the 5G ecosystem, brings new business opportunities for AI/ML techniques, enabling higher degrees of autonomous operation, evolving into intelligent networks, aiming to reduce the capital expenditures, optimize the performance and quality of service, enabling new revenue streams.

The development and deployment of AI/ML algorithms requires a set of tools in order to facilitate the orchestration, operation, execution and integration of machine learning workflows with the different components of the 5G architecture.

Major players in the AI software market and related platforms are Advanced Micro Devices, AiCure, Arm Limited, Atomwise, Inc., Ayasdi AI LLC, Baidu, Inc., Clarifai, Inc, Cyrcadia Health, Enlitic, Inc., Google LLC, H2O.ai., HyperVerge, Inc., International Business Machines Corporation, IBM Watson Health,Intel Corporation,Iris.ai AS., Lifegraph, Microsoft, NVIDIA Corporation, Sensely, Inc., Zebra Medical Vision, Inc... Moreover, there are plenty of companies in the AI Services market enabled by open-source AI/ML frameworks such as TensorFlow, H2O.ai or Acumos to run trained models. For that reason, Affordable5G solution developed by ATOS aims to integrate one of the most widely used AI/ML frameworks, TensorFlow, with all the different components conforming the Affordable5G architecture, enabling an ecosystem to develop, train, evaluate, test and export AI/ML algorithms and later execute and serve those algorithms to the access, core and MANO components.

Affordable5G aims to integrate such AI/ML platform with widely adopted open-source management and orchestration frameworks such as Open Source MANO (OSM). In the latest releases of OSM network elasticity mechanisms are triggered reactively based on a set of thresholds. Nonetheless, this reactive approach may not be an ideal solution for certain situations since the monitored network service could suffer performance issues before the failure is detected. In such situations, predictive mechanisms based on AI/ML techniques could heavily improve the elasticity mechanisms, therefore demanding a tighter integration of OSM with AI/ML frameworks. Other open-source initiatives like ONAP are also adopting this strategy by integrating AI/ML algorithms in their architecture. ONAP community is working in realizing this by integrating its Data Collection Analytics and Events (DCAE) system with competing AI/ML platform Acumos. This integration allows ONAP to deploy and incorporate ML algorithms in the service control loop [17].

3 ACTORS IN AFFORDABLE5G AND PRIVATE NETWORKS

3.1 Affordable5G/Private Networks Ecosystem

The 5G era has begun and 5G networks are being deployed in full speed. Vendors started to deploy network equipment while operators are seeking for profitable cases. Although operators have initially focused on outdoor enhanced mobile broadband, it seems that B2B services (mostly indoor) can be the solution for mobile network operators and other interested parties. Enterprises are interested in building their own private networks to address specific requirements of their business. Industries and companies are willing to adopt private networks in order to receive the maximum benefits in terms of optimization of operations, increased productivity, cost reduction etc.

In this new era, 5G private networks involve a number of actors/players cross collaborated in the value chain. These players include not only traditional telecom roles (service operator, network operator), but also players from other industries – content, IT, verticals, facilities owners etc. New business roles emerge, and their relationships are growing complex as the time to enter the market is relevant for all of them.

Many players (like private networks operators) are entering the market following different approaches, either collaborating or competing with traditional mobile network operators. Taking into account the increased adoption of private networks, all these players are trying to understand their position in the value chain (assessing all opportunities) in order to provide greater value and maximize their profit potential.

Taking into account Affordable5G architecture and Use Cases, private network service provider is assumed to be the main player in the ecosystem since it will mainly adopt the proposed solutions and tools. The description of the main actors/players along with some example entities is presented in Table 3.

Table 3: Actors/Players of the ecosystem

Player	Description – Product/service details	Example entities
Private Network Service Provider	PN Service Provider is responsible for configuring the network, provisioning the service, and maintaining the private network infrastructure.	Vodafone, Ericsson, Cellnex
Infrastructure/Connectivity Provider	Infrastructure/Connectivity Provider provides the necessary infrastructure (fiber, transport, wireless backhaul) from the sites where the equipment is installed to the external network (typically to the MNO networks) and among them. Cloud infrastructure can also be included in this category	Cellnex, Amazon
Mobile Network Operator (MNO)	MNO provides wireless access to end users in wide areas.	Orange, Deutsche Telekom, AT&T, Telefonica
Spectrum owner	Possess and rent spectrum licenses to interested parties (MNOs, verticals or PN Service	Orange, Deutsche Telekom, AT&T, Telefonica, Bosch,

Player	Description – Product/service details	Example entities
	Provider). Although MNOs currently possess spectrum licenses, this is slowly changing.	BMW, BASF, Lufthansa, Siemens, and Volkswagen.
End-user	Businesses and/or Industries including verticals (Automotive companies, eHealth companies, Manufacturing companies, Energy companies, Media & Entertainment companies) that "consume" services or products	BMW, SES, RAI, BETEVE, BBC, Hutchison Whampoa Europe, UnitedHealth Group
HW manufacturer and equipment vendor	An entity manufacturing and providing IT and network equipment such as servers, switches, routers, EPCs, Small Cells etc.	Huawei, Cisco, Ericsson, HP, Dell, Accelleran, ADVA, RunEL, Athonet, Think Silicon
SW / Functions Developers	They supply virtual network appliances, gateways, proxies, firewalls, transcoders, etc., eliminating the need for the customer to acquire install and maintain specialized hardware. They are also developing several types of software programs	NEC, Nearby Computing, ATOS, Ubiwhere
Facility Manager	An entity that provides space (malls, stadiums, streetlights, etc.) to operators, verticals and/or PN service provider for equipment installation	Public (e.g. Municipality), or private (venue owner, transportation players, etc.)
Integrators	An entity that specializes in bringing together components into a whole, ensuring that those components function together.	HCL, Cognizant, KPMG, Deloitte, Tata Consultancy Services

3.2 Affordable5G Reference Model

The next step is to define the relationships between the players in Affordable5G environment. The related model involves many different players and a complex value network. The related reference model involves many different players and a complex value network. In Figure 41, this reference model is described with all the participating players, relationship interfaces and revenue streams.

Definitions:

- The direction of the arrows in the model represents the direction of service flow.
- Revenue flow is considered to be in the opposite direction. In some cases, revenue sharing exists between two players, which is bidirectional.

- The ellipse represents a player. A player may take up one or more roles. The rectangular boxes within the ellipse represent the roles.

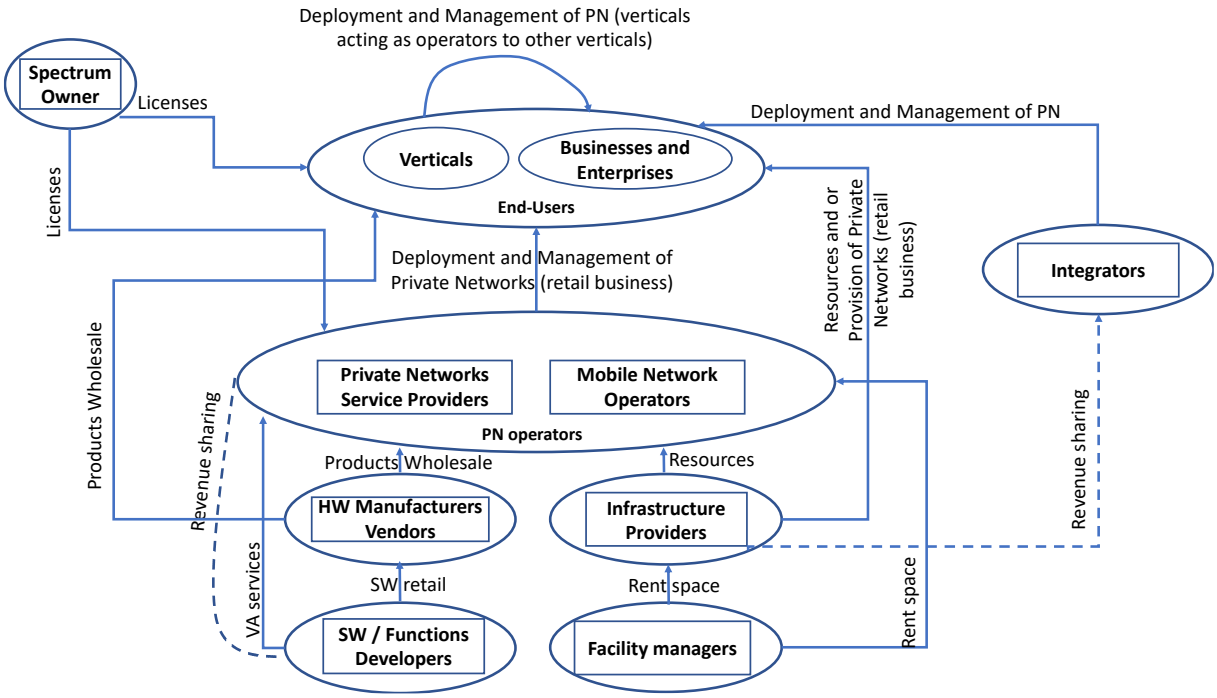


Figure 41: Reference Model

Due to the limited resources and sometimes expertise, many mobile operators cannot meet the increased demand for private networks from enterprises on large scale. On the other hand, several enterprises are not willing to collaborate with mobile operators mainly due to increased cost and operators' abilities in vertical markets. This situation propels the emergence of new types of operators like the Private Network Service Providers filling the created gap.

Private Network Service Providers are responsible for configuring the network, provisioning the service, and maintaining the private network infrastructure. Some of them may also have access to spectrum and buy network equipment and technologies directly from network equipment vendors.

However, the deployment of a private/enterprise network is a collective process, requiring a number of collaborating partners, covering a wide range of tasks including equipment provision and installation, infrastructure building, IT systems provision and integration, spectrum provision etc. Depending on the main partners, there are three approaches of private networks deployment:

- Mobile Network Operators: Businesses can collaborate with MNOs to build their private networks (e.g., BMW partnering with Deutsche Telekom and Lufthansa partnering with Vodafone). In order to meet the specific needs of vertical industries, operators' enterprise or integration units are gaining ground in the deployment of dedicated private networks.
- Private Network Service Providers/New Operators: Businesses can collaborate with specialized in private networks or neutral host (e.g., Cellnex/Edzcom, Citymesh etc) deployments. Since existing companies are focused on B2B, it is not expected that these will become full-market MNOs servicing consumers as well. The following players can act as a PN service provider:

- Telecoms stakeholders and Infrastructure/connectivity providers: They do not have nationwide networks but they can offer connectivity solutions. These include Fixed and cable providers, MVNOs, Tower and infrastructure companies, fixed wireless access (FWA) and wireless internet service providers (WISPs).
- Enterprise connectivity and solution providers: Companies providing connectivity solutions to enterprises. Such companies would like to exploit the opportunity of 5G networks to enhance their enterprise portfolio and develop their vertical expertise. These are Neutral host players, Specialist IoT connectivity providers , IT and networking services firms, Hyperscalers and cloud service providers.
- Vertical specific players: Industries or verticals operating their own private networks in their facilities and would like to capitalise their expertise by acting as operator or a system integrator to other stakeholders and customers within their respective verticals. These can be: Energy and utility providers, City municipalities and local authorities, Railway operators, Airlines and airports, port operators, shipping companies and other stakeholders within the transport and logistics sector, Universities and educational establishments.

- Businesses deploying and operating their own networks (Hub One – Paris airport). This requires that the involved staff (IT and Telecom) will build up the necessary “cellular” skills.

4 FACTORS AFFECTING THE SUCCESS OF AFFORDABLE5G

In this section, the factors that will affect the success of Affordable5G will be presented. Factors affecting the market adoption of Affordable5G are initially investigated. Factors for multi-vendor interoperability are also discussed.

4.1 Factors affecting the market adoption of Affordable5G

This section aims to assess the various challenges that are related to the successful adoption of Affordable5G solutions. In order to identify the barriers and drivers of the uptake of Affordable5G an expert survey was conducted to rate the different criteria that are expected to be relevant to its success. To assess the relative importance of these criteria, the Analytic Hierarchy Process (AHP) method was selected as the most appropriate. A set of criteria and their corresponding sub-criteria were selected and an online survey was implemented. Experts from the Affordable5G project were invited to express their opinions regarding the factors that will most influence the future of Affordable5G solution. The responses collected and processed in order to derive the final results.

4.1.1 Decision making using the AHP framework

AHP was proposed and developed by Thomas Saaty [18] in the early 1970s mainly for military purposes. The AHP is actually a multi-criteria decision-making approach. In the past, AHP was extensively used covering several application areas such as education [19], engineering [20], industry [21], manufacturing [22] and resource allocation [23]. Recently, AHP was widely used for selecting and ranking alternatives in the field of Information and Communication Technologies (ICT) [24]–[27].

Analytic Hierarchy Process is a structured technique for dealing with complex decisions. It describes a rational and comprehensive framework for decomposing an unstructured complex problem into a multi-level hierarchy of interrelated criteria, sub-criteria and decision alternatives. By incorporating judgments on qualitative and quantitative criteria, AHP manages to quantify decision makers' preferences. The priorities of criteria, sub-criteria and alternatives are finally reached by combining these judgments.

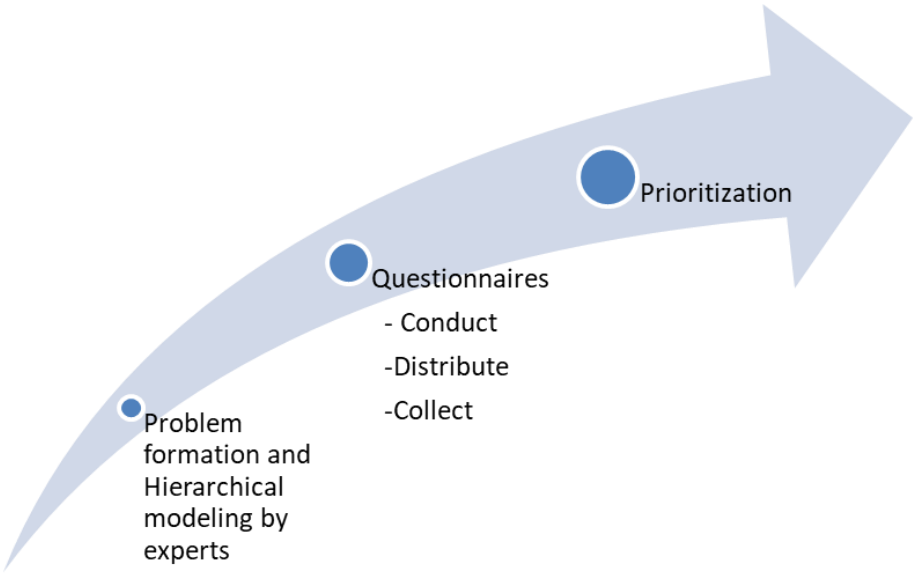


Figure 42: Analytic Hierarchy Process steps

Figure 42 illustrates the required steps of AHP. In the first step, the problem that is investigated is formed while criteria and sub-criteria contributing to objective's satisfaction are determined through interviews and/or group discussions with experts. The multi-level hierarchy is then constructed (Figure 43) consisting of three levels. In the first level, the objective under investigation is shown. In this work, the factors affecting the adoption and evolution of Affordable5G and its proposed solution in general is examined. In the next level, the criteria, C_{rk} with k=1,2,…,N and N the total number of criteria, participating in the decision-making process are determined. Criteria should be general enough, incorporating several features resulting in a rough description of the objective. In the lower level, criteria are further analysed into their sub-criteria SC_{rjk}, where j=1,2,…,M_k and M_k is the number of sub-criteria under criterion k. Sub-criteria represent a specific feature characterizing a criterion. Identification of criteria and sub-criteria is accomplished based on the focus of their preferential independence.

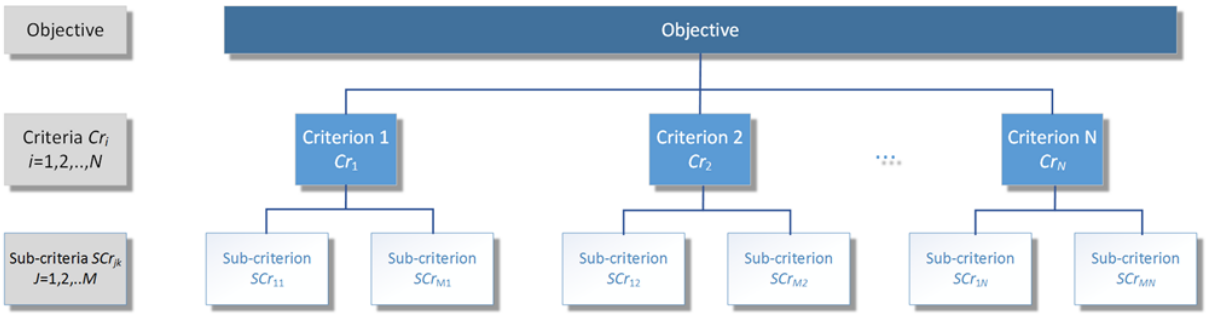


Figure 43: Multi-level hierarchy of interrelated criteria and sub-criteria

Once the hierarchical structure is constructed and criteria and sub-criteria are determined, appropriate questionnaires are conducted and distributed to experts (step 2). This procedure is based on pairwise judgments of experts from the second to the lowest level of the hierarchy. In each level, the criteria (sub-criteria) are compared pair wise according to their degree of influence and based on the specified criteria in the higher level. The described comparisons are performed using the standardized nine levels scale shown in Table 4.

Table 4: The Saaty Rating Scale

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	The two criteria contribute equally
3	Moderate importance	Experience and judgment favour one of the criteria
5	Strong importance	A criterion is strongly favoured
7	Very strong importance	A criterion is very strong dominant
9	Extreme importance	A criterion is favoured by at least an order of magnitude
2, 4, 6, 8	Intermediate values	Used to compromise between two of the above numbers

The set of pairwise comparisons on the N criteria results in an N x N evaluation matrix A=[A_{ij}] in which the elements A_{ij} (>0) represent the relative importance of criterion Cr_i compared to Cr_j. It should be noted that A_{ii}=1 for every i while matrix A is symmetrical across the main diagonal that is A_{ji}=1/A_{ij}. The same steps are followed regarding sub-criteria of each criterion k and the results are summarized in a similar to A matrix called A_k.

The last step (step 3) towards the evaluation of the objectives is the estimation of criteria and sub-criteria weights, w_k and s_{jk} respectively. This requires the calculation of the principal eigenvector $\mathbf{v}=[v_k]$ (or $\boldsymbol{u_k}=[u_{ik}]$) that is the eigenvector corresponding to the maximum eigenvalue λ_{max} (principal eigenvalue) of matrix **A** (or $\boldsymbol{A_k}$). The weights of criterion *k* and of its sub-criterion *j* are given by:

$$w_k = \frac{v_k}{\sum_{i=1}^{N} v_i} \quad (1)$$

$$s_{jk} = \frac{u_{jk}}{\sum_{i=1}^{M_k} u_{ik}} \quad (2)$$

where *N* and M_k is the number of criteria and sub-criteria of criterion *k* respectively.

4.1.1.1 Consistency of pairwise comparison matrices

In order to maintain a certain quality level of a decision, the consistency of the data should also be investigated during the analysis. It should be noted that the rank of matrix *A* (or A_k) equals to 1 and $\lambda_{max}=N$ (or M_k) if the pairwise comparisons are completely consistent. In this case, weights can be estimated by normalizing any of the columns or rows of *A* (A_k). A consistency index (*CI*) was introduced by Saaty in 1977:

$$CI = \frac{\lambda_{max}-N}{N-1} \quad (3)$$

where λ_{max} is the largest (maximum) eigenvalue and *N* is the number of criteria. The final consistency ratio (*CR*), showing how consistent the judgments have been relative to large samples of purely random judgments, is given by:

$$CR = \frac{CI}{RI} \quad (4)$$

where *RI* is the random index calculated as the average *CI* across a large number of randomly filled matrices using the scale described earlier in this section. The random indices for several values of *N* were calculated by Saaty (2003) and are given in Table 5. The consistency ratio should be less than 0.1. A CR larger than the tolerable level of 0.1 demonstrates the need to exclude the pairwise comparison matrix of this respondent for further analysis so as not affecting the overall accuracy of the results.

Table 5: RI values for different values of n

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

4.1.2 Determining the set of criteria and factors to be used in the surveys

In order to identify the factors that influence the adoption of Affordable5G solutions, a survey was designed in WP5 in line with the AHP methodology.

For this purpose, the following set of criteria covering a wide range of factors were initially defined:

- Performance
- Business
- Acceptance
- Flexibility

- Technology

Each of these criteria was further broken down into sub-criteria that are usually indicative attributes that can be quantified and are closely related to the criteria. A brief description of criteria and their sub-criteria is shown in Table 6.

Table 6: Description of criteria and sub-criteria

Criteria / Sub-criteria	**Description**
C_1: Performance	**Measures of service quality**
SC_{11}: Low latency	Round-trip delay time
SC_{12}: High data rate	Throughput
SC_{13}: Efficient energy consumption	Energy efficiency per gigabyte
SC_{14}: Reliable communications	Proper operation under stated conditions for a specified time
SC_{15}: Resiliency	Ensure continuity of service against any damage
C_2: Business	**Market related issues**
SC_{21}: Cost reduction	Cost includes hardware, software, installation and maintenance
SC_{22}: CAPEX transforming to OPEX	Network-as-a-Service, limiting upfront investment
SC_{23}: New business models	New players entering the market, traditional roles will be changed. Advanced applications/services will emerge changing the revenue streams
SC_{24}: New market opportunities	New value propositions. Private and enterprise networks can be a means for market growth
C_3: Acceptance	**Incorporates many user-related concerns**
SC_{31}: Advanced applications	Applications with requirements that cannot be provided by legacy systems
SC_{32}: Ease of deployment	Simplification of how networks are designed, deployed, operated and managed
SC_{33}: Security and privacy	Confidentiality of data, user identity, trustworthiness of information flows, etc.
SC_{34}: Regulatory issues	Spectrum access, roaming between private and public networks, promote competition
SC_{35}: Health issues and impact on environment	Impact of radiation on health, visual impact on surroundings, etc.
C_4: Flexibility	**It refers to the overall usability of the system**
SC_{41}: Resource/spectrum sharing	Intra-system spectrum use, geographical reuse, use of higher frequency bands, co-existence with new and legacy systems, unlicensed spectrum

SC_{42}: Interoperability	Compatibility with User Equipment, interworking with legacy enterprise networks
SC_{43}: SLAs tailored to needs	Customize service level according to requirements
SC_{44}: Needs-based configuration	According to use case (i.e. uplink/downlink ratio, bandwidth vs latency)
SC_{45}: Network operation automation	Minimize need for human intervention
C_5: Technology	**Techniques and methods that will be used in Affordable 5G networks**
SC_{51}: Small cells / Open RAN	Allowing network densification while increasing the interoperability, adhering to standards
SC_{52}: SDN and NFV	Decouple software from hardware resources, use of general-purpose devices
SC_{53}: Cloud native	Applications packaged in containers and managed on elastic infrastructure
SC_{54}: Edge computing	Executing network functions closer to the edge. Contribute to low latency

The full list of the criteria and the corresponding sub-criteria is illustrated at the hierarchy of Figure 44.

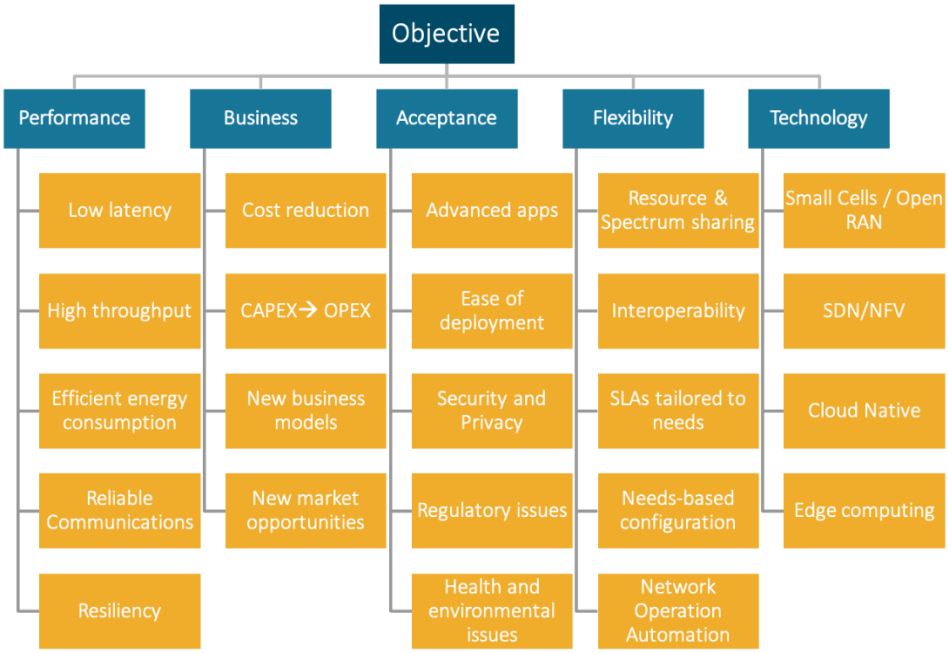


Figure 44: Affordable5G hierarchy

4.1.3 Survey Description

The survey was implemented in the form of an online set of questions created using LimeSurvey (https://www.limesurvey.org/), an open-source tool for web surveys, and hosted at: https://www.incites.eu/pollsurvey/index.php/192514?lang=en.

An introductory page provides information on the project and the AHP methodology as portrayed indicatively in the following figures.

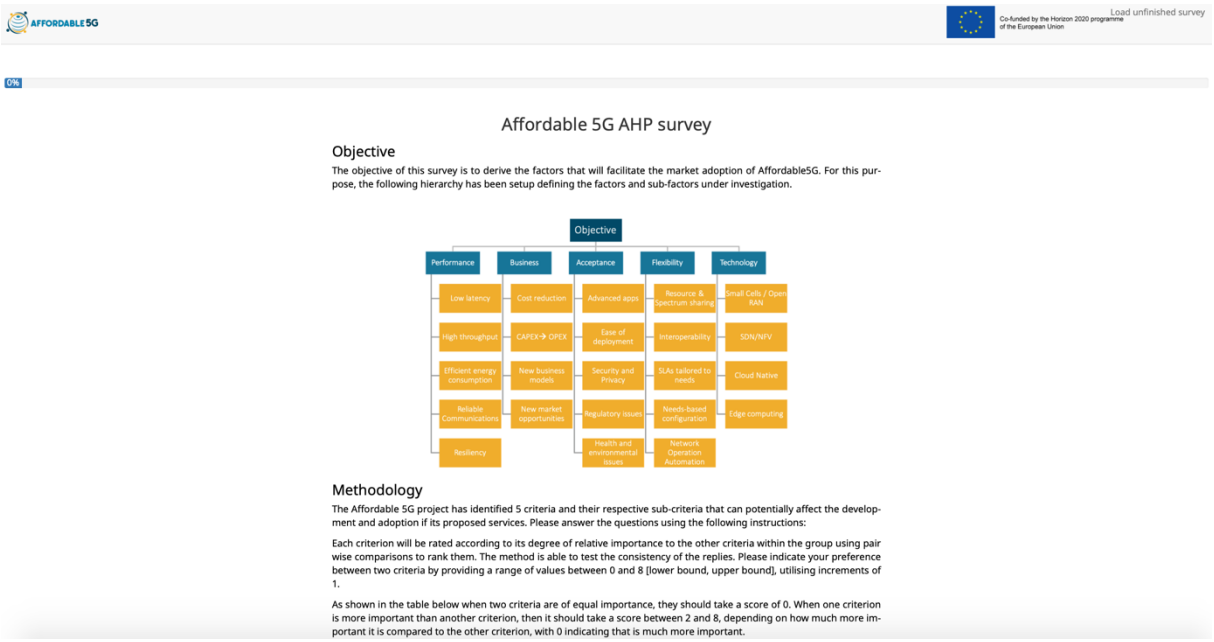


Figure 45: Affordable5G survey introductory page

The following Figure depicts an example of the AHP question implementation in the survey. Due to technical limitations of the survey tool used[58], the [1,9] range described in the methodology has been adapted into a [0,8] range while left hand side selection utilises the [-8,0] range. These adaptations come without loss in methodological effectiveness as the numerical representation of the responders' assessments remains unaffected. The necessary calculations were performed using Matlab, leading to an estimation of the weights signifying the importance of criteria and sub-criteria. The responses were strictly anonymous. A brief info-sheet was presented to inform responders about the purpose of the survey.

[58] Lime Survey doesn't have inbuilt modules for implementing the AHP

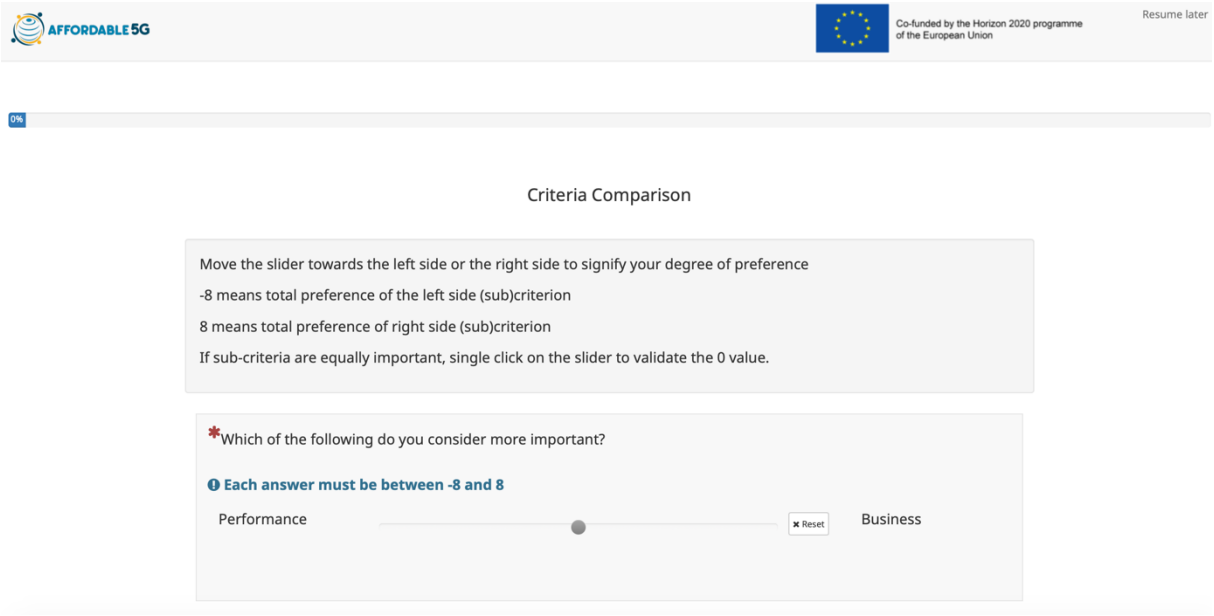


Figure 46: Example of AHP questions

The survey had a total of 57 questions some of which were not AHP based. Table 7 presents an analysis of the number of questions in terms of criteria and sub-criteria.

Table 7: Analysis of the number of questions

Type	***Description***	**Number**	**Number of questions**
Criteria	Criteria that affect Affordable5G	5	10
Sub-criteria	Related to Performance criterion	5	10
Sub-criteria	Related to Business criterion	4	6
Sub-criteria	Related to Acceptance criterion	5	10
Sub-criteria	Related to Flexibility criterion	5	10
Sub-criteria	Related to Technology criterion	4	6
Demographic	Type of organization, Sector, Number of employees, Position and Gender	5	5

At the end of the survey five questions were posed about the type of organisation, the sector, the number of employees, the position and the gender of the participants. The following figures illustrate the statistics of the participants.

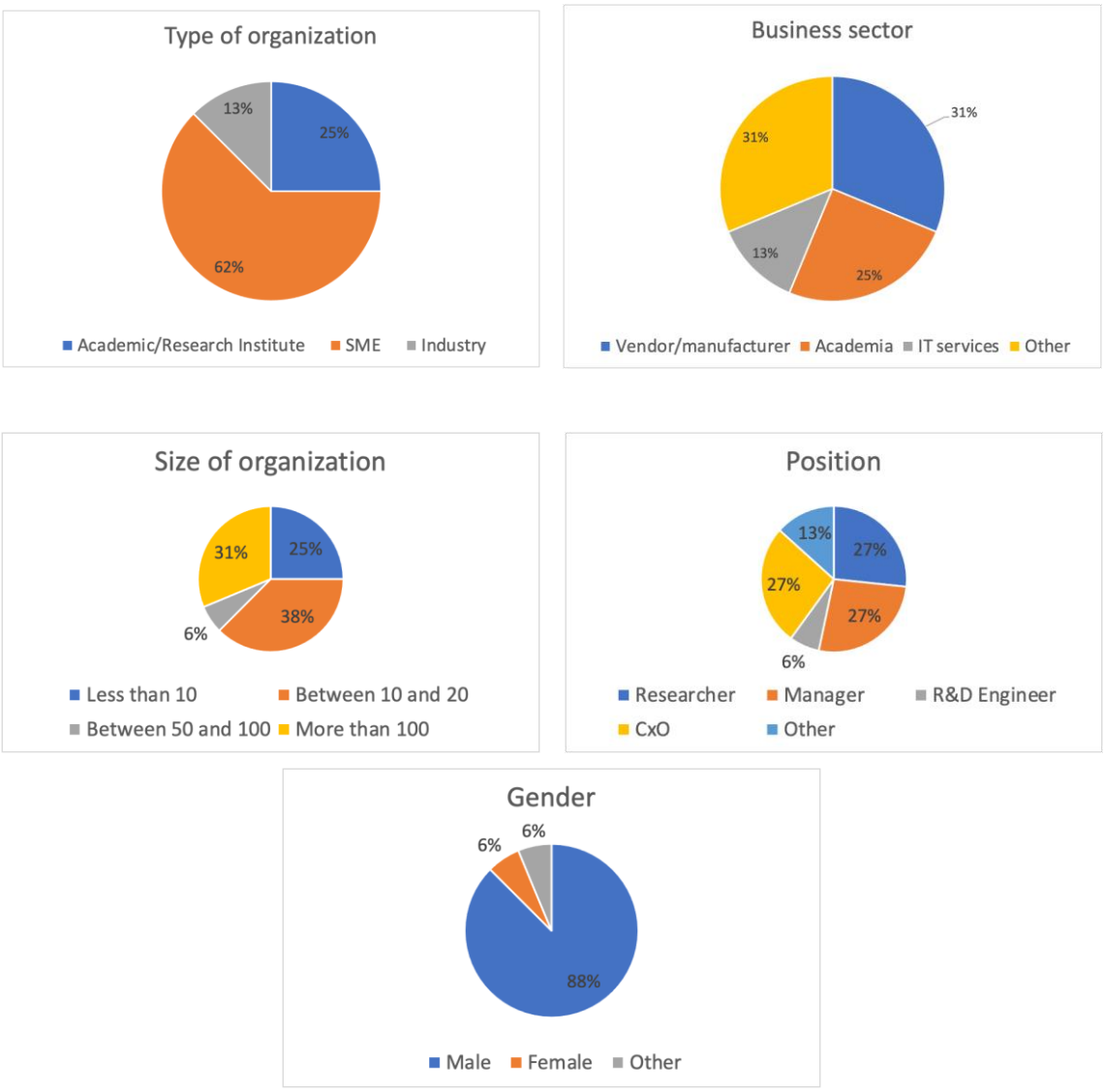


Figure 47: Statistics of the participants

4.1.4 Results and Discussion

In this section, we present and discuss the results of the survey concerning the evaluation of the importance of the criteria and sub-criteria that are expected to affect the market adoption of Affordable5G solutions. From the twenty experts who initially participated in the survey, four questionnaires were discarded as inconsistent, since their associated Consistency Ratio (*CR*) was >0.1. The questionnaires were conducted and completed during a period of 1 month. This can be assumed a sufficient size for the purpose of an AHP analysis since as shown in [28], [29], the changes in the probability of rank reversal when an additional expert is added in the group are below 1% at $M = 15$ (where M is the number of experts). Using the methodology described above, one can easily estimate the weights prioritizing the criteria and sub-criteria (Table 8).

Table 8: Weights prioritizing the criteria and sub-criteria

Criteria / Sub-criteria	Weight
C_1: Performance	**0,16**
SC_{11}: Low latency	0,19
SC_{12}: High data rate	0,16
SC_{13}: Efficient energy consumption	0,12
SC_{14}: Reliable communications	0,35
SC_{15}: Resiliency	0,18
C_2: Business	**0,22**
SC_{21}: Cost reduction	0,26
SC_{22}: CAPEX transforming to OPEX	0,17
SC_{23}: New business models	0,24
SC_{24}: New market opportunities	0,34
C_3: Acceptance	**0,21**
SC_{31}: Advanced applications	0,18
SC_{32}: Ease of deployment	0,24
SC_{33}: Security and privacy	0,25
SC_{34}: Regulatory issues	0,12
SC_{35}: Health issues and impact on environment	0,21
C_4: Flexibility	**0,20**
SC_{41}: Resource/spectrum sharing	0,15
SC_{42}: Interoperability	0,27
SC_{43}: SLAs tailored to needs	0,15
SC_{44}: Needs-based configuration	0,18
SC_{45}: Network operation automation	0,2
C_5: Technology	**0,20**
SC_{51}: Small cells / Open RAN	0,32
SC_{52}: SDN and NFV	0,19
SC_{53}: Cloud native	0,16
SC_{54}: Edge computing	0,33

4.1.4.1 Weighting of Criteria

The results concerning the weights of the criteria that are expected to affect Affordable5G penetration are shown in the following figure. It is interesting to note, that according to the

opinion of the experts, Performance receives the lowest weight while the rest criteria are of the same importance. This is also a confirmation of the fact that the first massive deployments of 5G will be based on enhanced broadband and all the involved stakeholders are focusing on the deployment of private and enterprise networks as a means to compensate the huge investments needed. Thus, factors that will facilitate the deployment of such networks and lead to new business models and market opportunities will play a significant role.

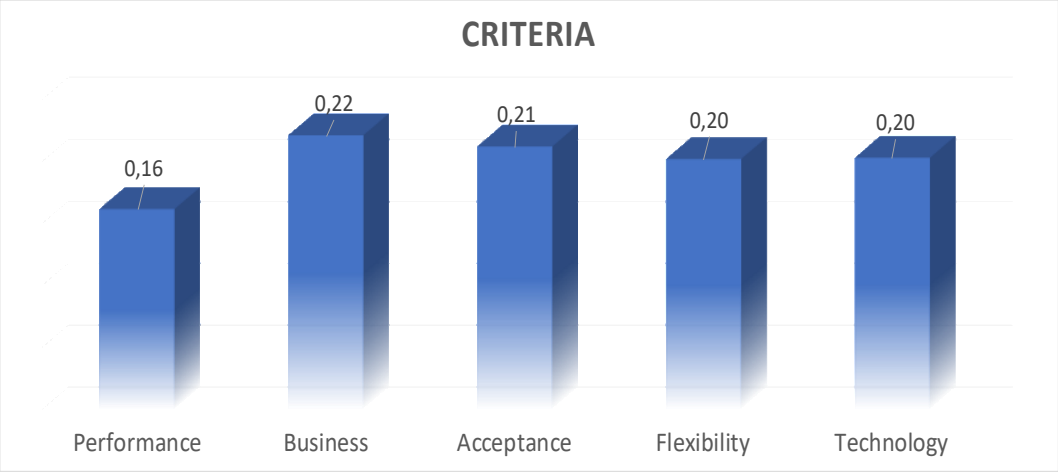


Figure 48: Relative weights of criteria

4.1.4.2 Weighting of Sub-criteria under each criterion

It is also interesting to examine the weights of the sub-criteria under each criterion. Regarding Performance (Figure 49), the experts seem more concerned about reliable communications in view of the many new industrial applications and services where reliability requirements are very tight and crucial. For example, factories are expecting reliable communications in order to proceed to “cable replacement”.

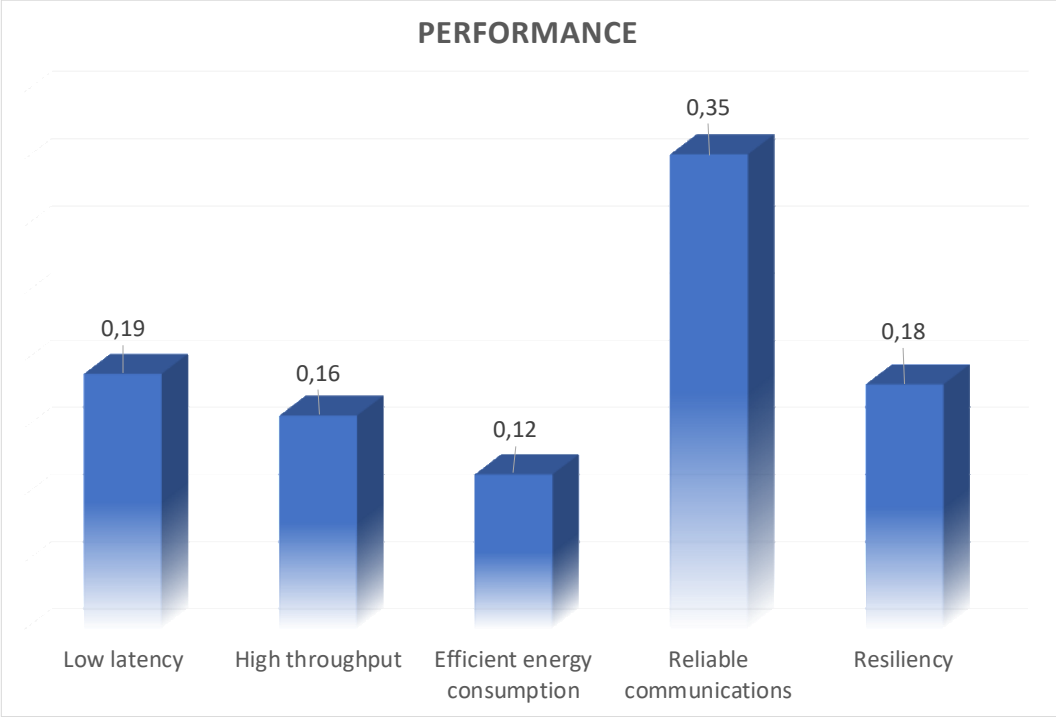


Figure 49: Relative weights of Performance Sub-criteria

Low latency and resiliency are the second most important issues, accumulating a weight of 0.19 and 0.18 respectively. These factors are also closely related to enterprise and private networks especially in industrial environment. It is expected that such factors will ensure the smooth and safe operation of such enterprises. High data rate can be found in the third place since it is also a key issue for 5G access networks. Taking into account the expected increase of traffic, one should look for schemes to further enhance network capacity.

It is interesting enough that low energy consumption can be found in the last position. This is something unexpected since in an enterprise/industrial environment, power consumption will be of high importance.

Figure 50 shows that new market opportunities is ranked first indicating its increased importance and revealing market expectations. Affordable5G will significantly contribute to the expansion of existing, as well as the creation of new, market opportunities, leading to increased profitability by adopting several technologies like NFV, edge computing, open RAN, etc. Affordable5G will facilitate the deployment of 5G networks by increasing the flexibility and interoperability between vendors' equipment. This will unlock a wide range of opportunities for private networks and enterprises.

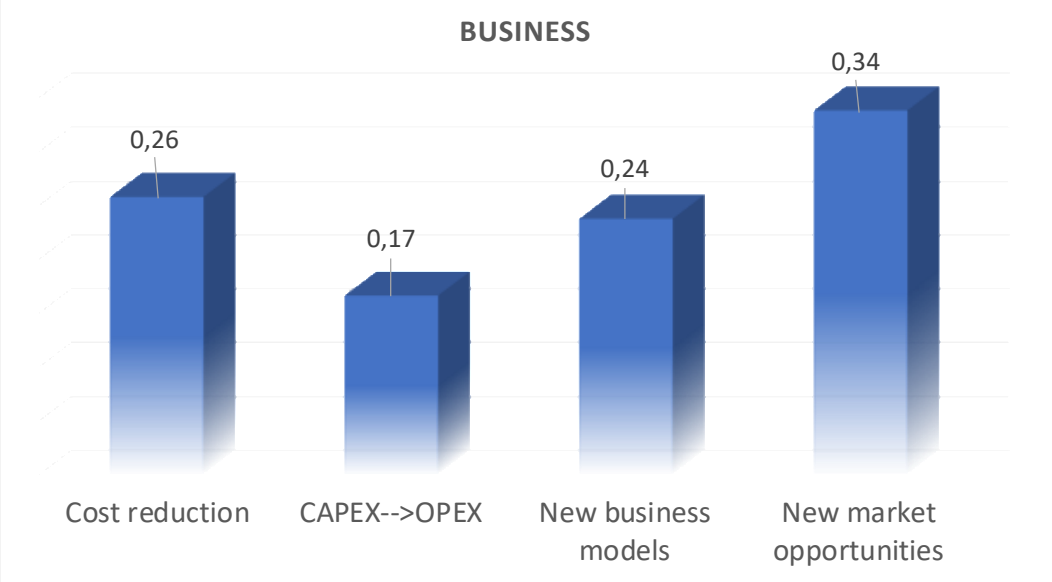


Figure 50: Relative weights of Business Sub-criteria

According to the experts' opinions, cost reduction and new business models are in the second place (weights: 0.26 and 0.24). This is not surprising as the cost of deployment is very important. Moreover, the whole telecom ecosystem itself has evolved considerably in recent years, illustrating that business relationships are no longer bilateral. A factor that significantly boosts this trend is that of virtualization, enabling new models such as the neutral host (NH) model to emerge as well as some vertical industries and Over the Top (OTT) players to operate in a Network-as-a-Service (NaaS) mode and offering services on top of NH or MNOs' infrastructure. The NH model will play a significant role in business environments and venues where the deployment of parallel networks is prohibited mainly due to the lack of space. Last but not least, is the criterion of CAPEX transforming to OPEX. This is one of the main characteristics stemming from the introduction of cloud-based networks that could be offered to users with consumption-based fees, reducing the need for up front investments.

Regarding the sub-criteria of the Acceptance criterion, security and privacy issues are the most important (weight: 0.25). This is to be expected for mainly two reasons: The softwarization of networks alongside the use of NFV/SDN technologies make end-to-end security more challenging. The 5G environment is characterized by multi-tenancy, heterogeneity and

resource sharing, also leading to security and privacy concerns. Especially in industrial environments, security and privacy are of paramount importance in order to ensure both the smooth operation of machines and the safety of employees.

Experts seem to have also highly prioritized ease of deployment (weight: 0.24). Ease of deployment is a factor that will influence Affordable5G adoption and speed up its evolution. The ease of deployment heavily depends on the ability of systems to reuse or upgrade existing network infrastructures. In addition, features, like plug and play, self-configuration, optimization and healing will play an important role in the deployment and management of 5G networks.

Health and environmental issues can be found in the third position (0.21). These are always an important aspect to consider along with the measures that should be taken in order to address growing possible public concern. This is further enhanced in indoor industrial and enterprise environments. However, it should be highlighted that certain standards addressing the health concerns have been established, such as the IEEE C95.1-2005 which provides recommendations to protect against the possible harmful effects of humans being exposed to electromagnetic fields (3 kHz to 300 GHz).

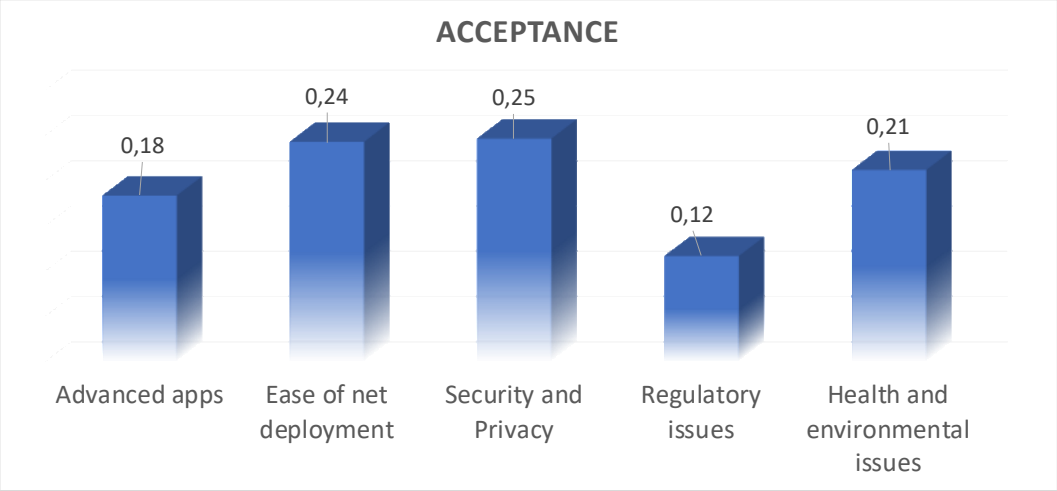


Figure 51: Relative weights of Acceptance Sub-criteria

In the next position with weigh 0.18, one can found the Advanced applications. Innovations in the space of service- and network-level function development in combination with advanced application development are expected, fully capitalizing the increased performance in terms of low latency and high data rates, as well as the flexibility that will be afforded by Affordable5G. This is further enhanced by the use of NFV, edge computing and other technologies.

Surprisingly enough, regulatory issues are deemed of secondary importance compared to the other sub-criteria. The low priority of regulatory issues is somehow unexpected and cannot be easily explained. In the new era of 5G where heterogeneous networks will be combined, while resource sharing and open access will enable service provision on top of third-party infrastructure, regulation is expected to play a central role. However, previous experience has shown that regulatory decisions are not always desirable from the market players' side and usually lead to market disruption. Thus, regulatory issues should be of increased importance regarding the deployment of private and enterprise networks as well as of 5G networks in general.

Regarding the sub-criteria of the Flexibility criterion, interoperability and network operation automation are the most important as shown in Figure 52. Interoperability is obviously important as the main reason for the introduction of NPNs is to facilitate and enhance the interconnection of enterprise systems extracting additional value out of them. Network

operation automation is crucial since enterprises do not have the specialized know-how and resources necessary for the day-to-day operation of cellular networks.

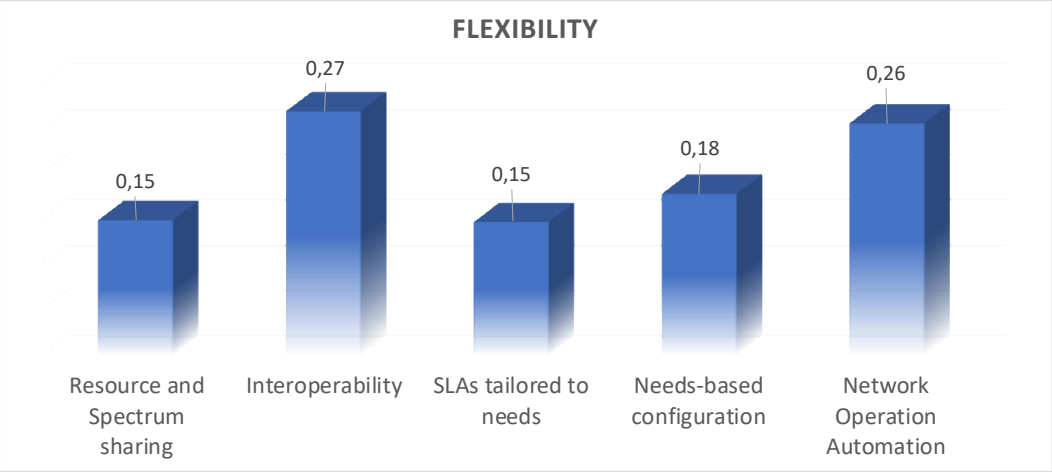


Figure 52: Relative weights of Flexibility Sub-criteria

Needs-based configuration, in the third place, is also important as the ability to customize the NPN according to specific use case requirements is one of the NPN main drivers. For example, while public networks are usually configured to support 3 to 1 downlink to uplink ratio, an enterprise network might need a higher uplink allocation to support collecting data from sensors throughout the campus.

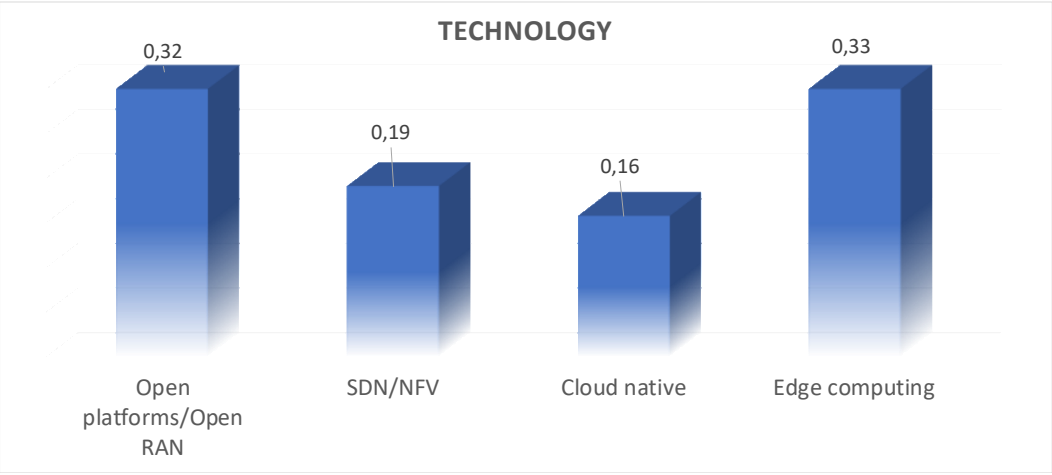


Figure 53: Relative weights of Technology Sub-criteria

As shown in Figure 53, Edge computing and Open platforms/Open RAN sub-criteria are the first choices among the experts regarding the Technology criterion. They are also shown to be of almost equivalent importance with weights 0.33 and 0.32 respectively. This ranking is fully consistent with vision of Affordable5G according to which 5G will be driven by software and network functions that will run especially at the edge of the network for meeting performance targets while open interface will increase the flexibility and interoperability of network elements. In addition, these will enable a number of private network-based applications including smart city, connected factories, etc.

SDN and NFV is the next sub-criterion since these technologies are anticipated to drastically affect the development of next-generation mobile technology standards expected to rollout under the “5G” banner. This is usually stemming from the need for more rapid scalability in order to address the growing demand, as well as for a more efficient network resource

provisioning. This is also confirmed by the trend of the telecoms industry that is moving quickly to virtualized and software-controlled solutions.

4.1.4.3 Global priorities of sub-criteria and Policy Implications

In order to capture a global view of the sub-criteria ranking, the global priorities need to be calculated. The global priorities are obtained by multiplying the local priorities (sub-criteria weights) by their parent's priority (weight). The global priorities for all the sub-criteria add up once again to 1. Table 9 presents the global weights for all the sub-criteria considered.

Table 9: Global Priorities of sub-criteria

Sub-criteria	Global Priority
SC_{11}: Low latency	0,038
SC_{12}: High data rate	0,032
SC_{13}: Efficient energy consumption	0,023
SC_{14}: Reliable communications	**0,071**
SC_{15}: Resiliency	0,036
SC_{21}: Cost reduction	**0,052**
SC_{22}: CAPEX transforming to OPEX	0,033
SC_{23}: New business models	0,048
SC_{24}: New market opportunities	**0,068**
SC_{31}: Advanced applications	0,037
SC_{32}: Ease of deployment	0,049
SC_{33}: Security and privacy	0,049
SC_{34}: Regulatory issues	0,023
SC_{35}: Health issues and impact on environment	0,042
SC_{41}: Resource/spectrum sharing	0,030
SC_{42}: Interoperability	**0,054**
SC_{43}: SLAs tailored to needs	0,029
SC_{44}: Needs-based configuration	0,036
SC_{45}: Network operation automation	**0,051**
SC_{51}: Small cells / Open RAN	**0,064**
SC_{52}: SDN and NFV	0,038
SC_{53}: Cloud native	0,032
SC_{54}: Edge computing	**0,066**

Global priorities depict that the most important factors that will affect Affordable5G market adoption are in descending order of importance: Reliable communications, New market opportunities, Edge computing, Open platforms/Open RAN, Interoperability, Cost reduction and Network operation automation. It is interesting to note that the most important factors are

mainly included in the four categories / criteria namely: Performance, Business, Flexibility and Technology. This is totally aligned with the aims of Affordable5G to easily deploy private and enterprise networks with low cost. In such environments, interoperability and flexibility is of paramount importance because it allows the interconnection of systems adding value to them and unlocking new market opportunities.

4.2 Factors for multi-vendor interoperability

Interoperability is key towards 5G commercialization and meeting the emerging 5G use cases. In theory, a RAN built by any vendor is interoperable with any device, any core, any transmission network due to its conformance with 3GPP standards. The vision of the Open RAN, adopted by the Affordable5G consortium, is that multi-vendor interoperability is extended within the RAN, building a modular base station software stack that operates on common-off-the-shelf (COTS) hardware, with open interfaces. Open RAN is about standardizing open interfaces that allow a service provider to build best of-breed and cost-effective networks using radio and baseband functions from different vendors.

However, while vendors and standards bodies are working hard to publish open interfaces, multi-vendor interoperability is not always guaranteed. Even with products built to comply with published guidelines, a substantial question remains: do the implementations successfully work with each other to provide the desired services?

In order to address interoperability and serviceability of multi-vendor RANs it is critical that the ecosystem develops and maintains truly open specifications and robust interoperability programs to generate confidence in open RAN networks.

Operators of multi-vendor networks need confidence that the products they are deploying interoperate, especially so in the market segment of private networks where most players lack the large technical departments that can engage in detailed testing.

The O-RAN Testing and Integration Focus Group (TIFG) defines O-RAN ALLIANCE's overall approach to testing and integration, including Test & integration specifications, and processes for performing integration and solution verification.

Additionally, O-RAN plugfests[59] support the ecosystem players in testing and integration of their solutions, while various Open Testing and Integration Centres (OTIC) provide a collaborative, open, and impartial working environment[60].

The factors that have an impact on multi-vendor interoperability are the following:

Focus on end-to-end solution validation: Even though O-RAN standards are in fact open, products must be tested for standards compliance and differences in interpretations of specifications must be corrected. In the past, interoperability of different vendors' RAN systems only needed to focus on successful handover of an active call from one RAN to another. In a multi-vendor O-RAN environment, it is critical to identify and eliminate the risks of incompatibilities between many different interfaces across the disaggregated radio and control products from different vendors.

[59] A plugfest is an event based on a certain technical standard where the designers of electronic equipment or software test the interoperability of their products or designs with those of other manufacturers.

[60] https://www.o-ran.org/testing-integration

Address Lifecycle Management: Once a solution has been deployed, lifecycle management becomes necessary to constantly update, upgrade, fine tune, and improve the functionality of the network.

Assure end-to-end service performance & SLAs: Performance and SLAs need to be met not only for individual components but also at the total system level.

In order to ensure multi-vendor interoperability, the Affordable5G architecture is solely based on open standards.

At the Network Function Layer, the Affordable5G RAN adopts a double split option (RU-DU-CU), employing the 3GPP option 2 high-layer split and the O-RAN Alliance option 7.2 low-layer split. An O-RAN Near-RT Radio Intelligent Controller (RIC), is connected to the underlying nodes through the E2 O-RAN alliance interface. The CU connects to mobile core (5GC) via the N2 and N3 3GPP backhaul interfaces.

Two different end-to-end 5G network implementations will be employed at the two Affordable5G sites (Malaga and Castelloli). These sites will be used for the interoperability testing across the different components of the system both at system and service level. More details on the integration and testing methodology can be found in the deliverables of WP4 (Integration, roll-out and pilot validation).

5 BUSINESS MODELLING

The “business model” concept unifies important decision variables from different areas of economics, operations and strategy. There are many definitions for business models, some are only limited on the economics examining how profit can be produced [30]. The value created for the customer and the value production architecture is the target for the second category of definitions [31]. Strategic decisions such as selection of customers, offerings differentiation, utility creation and outsourcing are the focus of a third group [32]. A different approach is to specify business model’s primary elements and their interrelations [33].

The definition adopted in this document is as follows: A business model stands for the architecture for the product, service and information flows, including a description of the various business players and their roles, the potential benefits within a value network and the sources of revenue [34].

Actually, a business model is a conceptual interpretation of firm’s strategic decisions, such as market positioning and goals, into a conceptual scheme explaining how business works. It serves as a plan to realize business structure. It also portrays a conceptual tool that describes a set of objects, concepts and their relationship to provide value towards the customer taking into account the financial consequences of this relation. It provides a tool to managers in order to understand how business really operates and how delivers value to customers.

The “value proposition” particularly refers to the reasons a customer pays for the product or service offered. In addition, it includes the intended customer or target market. Another important component within the value proposition concerns with value added, that differentiates the offer from that of the competitors.

Then, it is necessary to describe the “value creation”, the firm’s sources of competitive advantage such as resources and capabilities, for example, how the firm creates, produces, sells and delivers its offering to customers. In this context the “value chain” or the “value network” are represented as structural elements.

A model to coordinate the generation of revenues to provide a profit margin over its cost is necessary to guarantee the survival of a firm. In this framework, revenue streams are stated as sources to monetize the product and services a company offers, thus, to indicate the “value capture”.

5.1 Business Model Canvas methodology

The Business Model Canvas is a tool and methodology created to be used as a guide for entrepreneurs, helping them to identify and define consistently business opportunities. The process consists of 9 building blocks, grouped in 2 tasks/steps: looking externally and looking internally.

External Aspects: The aim of this task is to identify external topics outside of the company control, but with impact in the Business Model proposal, such the market or the environment. This process allows to identify the environment where the proposal is built. This task includes the following blocks:

- Customer Segments: An organization serves one or several Customer Segments.
- Value Propositions: It seeks to solve customer problems and satisfy customer needs with value propositions.
- Channels: Value propositions are delivered to customers through communication, distribution, and sales Channels.

- Customer Relationships: Customer relationships are established and maintained with each Customer Segment
- Revenue Streams: Revenue streams result from value propositions successfully offered to customers. For instance, this block includes the definition of the price mechanism.

Internal analysis: This task requires to identify what is needed internally in the new company or product in order to implement the value proposition. This task includes the following blocks:

- Key Resources: Key resources (human, physical, etc.) are the assets required to offer and deliver the value proposition.
- Key Activities: Which actions are needed to be performed.
- Key Partnerships: The partnerships needed, since often some activities are outsourced and this involves engagement of resources outside the enterprise.
- Cost Structure: The structure of the costs associated with the development of the value proposition.

5.2 Affordable5G Business Model Portfolio

In this section, Affordable5G are briefly described. An initial discussion on their Intellectual Property Rights and exploitation strategy is also provided. The Business model canvas of each solution is also presented and discussed in an attempt to identify their potential business opportunities.

5.2.1 5G dRAX

5.2.1.1 Description

The 5G dRAX, developed by Accelleran, is a set of 5G Standalone dRAX™ cloud-native OpenRAN software components. Delivering reliable, cost-effective, and exceptionally scalable solutions for both 4G and 5G networks, dRAX™ implements the key control and resource management functions of the RAN, including Service Orchestration, RIC, CU-CP, and CU-UP. Comprising proven, cloud-native and microservice-based software components, dRAX™ enables real-world deployment of multi-vendor, disaggregated Open RAN, aligned with open standards such as the O-RAN Alliance.

Fully integrated with popular orchestration platforms such as Kubernetes, dRAX™ supports cost-effective deployments by leveraging standard IT DevOps and CI/CD practices. Along with this ease of implementation, the dRAX™ RIC offers a production-ready Open RAN development platform, enabling real-time RAN data to be leveraged to create AI-based xApps and enhanced RAN intelligence and automation.

dRAX™'s exceptional scalability supports everything from small-scale office deployments to large-scale solutions with multi-node clustering, load balancing, geo-redundancy, and edge services, benefitting mobile network operators, neutral host operators and system integrators alike. Developers can either integrate dRAX™ software components into their own solutions or leverage Accelleran's capability to deliver turnkey Open RAN networks.

At the current stage of the project, the Technology Readiness Level (TRL) of 5G dRAX is 3 for while the targeted TRL at the end of the project is expected to be 8.

5.2.1.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that the proposed 5G dRAX innovative solution is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. **IPR Assets**. The development of 5G dRAX is based on 4G dRAX. Background IP, related to the development of 5G dRAX, brought in the project by the partners, belongs only to these partners. There is no joint ownership of any IP while boundaries between subsystems are clear. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. Other partners have not contributed to the development of 5G dRAX. Therefore, the IP created during the project lifetime and beyond, related to 5G dRAX, belong to Accelleran, who is the sole owner of the solution.

Although there are no IPRs limiting the commercial exploitation of 5G dRAX, it should be noted that in order to run 5G dRAX, 3rd party 5GC, DU & RU for full 5G system are mandatory.

The form of exploitation that has been decided for 5G dRAX is that of licensing agreements and direct industrial use through commercial licenses. The goal of exploitation is the generation of revenues that will contribute to the sustainability of the solution.

Competition: Competitive products in the market are the Open vRAN[61] provided by Mavenir and the Radio Access Software[62] offered by Altiostar. dRAX™ is unique in the marketplace, unleashing the full potential of OpenRAN by including 3GPPP Rel-15 specifications for 5G standalone and addressing several key requirements for organisations deploying private networks in different verticals. Developers have the choice of building dRAX™ into their solutions, or they can benefit from a pre-integrated dRAX™ version with a range of DU, RU and Core solutions from known players within the Open RAN ecosystem.

5.2.1.3 5G dRAX Business Model

The 5G dRAX business model proposes a set of cloud-native OpenRAN software components implementing the key control and resource management functions of the RAN allowing thus the fast deployment of private networks in different verticals.

In Figure 54, the 5G dRAX business model canvas is depicted.

[61] https://www.mavenir.com/portfolio/mavair/radio-access/vran/

[62] https://www.altiostar.com/products/software-platform/radio-access-software/

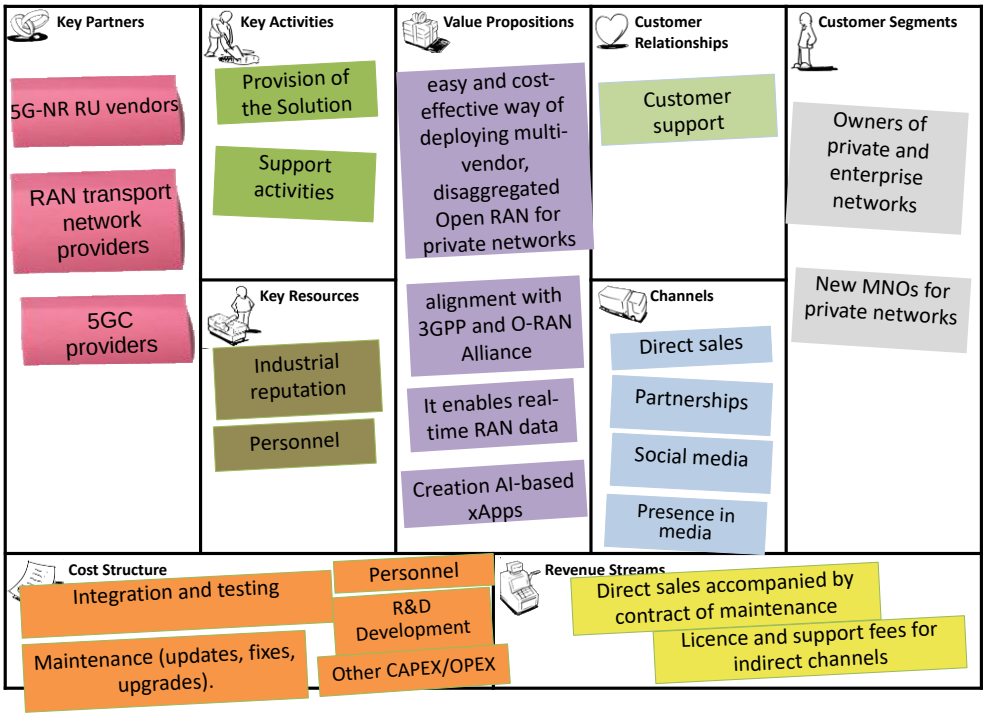


Figure 54: 5G dRAX business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: 5G dRAX refers to anyone who is interested in deploying private networks. So, potential customers are: 1) the owners of private and enterprise networks and 2) new MNOs for private networks.

Value Proposition: It provides an easy and cost-effective way of deploying multi-vendor, disaggregated Open RAN for private networks, aligned with 3GPP and O-RAN Alliance, through a virtualized cloud native implementation. The dRAX™ enables real-time RAN data to be leveraged to create AI-based xApps and enhanced RAN intelligence and automation providing thus AI/ML intelligent extensibility via xApps.

Channels: The following paths to reach the final clients were identified:

- In-house salesforces: Promote the 5G dRAX through direct sales to systems integrators & new private 5G opertors
- Indirect through 5G solution providers and networking equipment hardware vendors
- Social media using specific campaigns and platforms
- Presence in the media (sectorial journals and magazines) through the preparation of specific press releases

Customer Relationships: Customer support to 5G RAN network function suppliers and RAN integrators as well as to professional services and maintenance providers.

Revenue Streams:

- The main revenues will come from product sales. However, this will also be accompanied by contracts for maintenance. These are mainly related to upgrades of the product.
- Licence and support fees for indirect channels: The first part will be most probably in the form of revenue sharing between Accelleran and third parties/partnerts who will finally sell the product. In addition, revenues are expected from the support services that will provided to them.

Moreover, it should be highlighted that funding from future EU projects (Horizon Europe) as well as from National programs will also be used in order to ensure business sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- Experienced and Qualified Human resources to maintain and improve the product
- Industrial reputation for providing trusted innovative solutions

Key activities: The main activity is to make complex 5G technologies work through expertise, product superiority and flexibility of solution to fit business problems. This also includes the provision of 5G dRAX. Support activities to clients and partners are also within the activities of the entity.

Key partnerships:

- 5G-NR RU vendors
- RAN transport network providers
- 5GC providers

Cost structure:

- Operational Expenses: Expenses related to the operation of the business. It is expected that operational expenses will grow together with the production line.
- Personnel Costs: Hiring in principle follows the need for supporting customers and evolving the product representing a re-investment to innovation. In order to fully commercialize the solution, the following types of human resources should be considered: developers/project managers/systems architects, business developers/sales force, marketing/communication, administrative, support and maintenance, quality assurance.
- High integration and testing resource costs.
- Marketing and Promotion: Costs associated with participation in industrial fairs, advertisement, digital marketing and media presence.

- Maintenance costs: Expenses related to the necessary activities in order to maintain products.
- R&D / Development: Expenses needed to keep the service on top of technological advances.

Strengths: 3GPP & O-RAN alliance alignment, virtualized cloud-native, AI/ML intelligent extensibility via xApps

Weaknesses: ongoing 3GPP release roadmap implies constant product evolution, lack of hardware accelelerated DU vendor ecosystem, and lack of mmWave & mMIMO RU vendor ecosystem

Opportunities: Increased demand for private 5G networks for different verticals

Threats: Existing big 4G/5G (Ericsson, Nokia, Huawei) vendors can stifle competition

5.2.2 Sparq-2020- ORU

5.2.2.1 Description

The Sparq-2020-O-RU is an open RAN radio unit. It is scalable peaking up to 64Gbps aggregate data rate per 100MHz channel BW for a coverage area with 64 beams created by several O-RU transceivers connected to the open RAN distributed unit (O-DU).

At the current stage of the project, the Technology Readiness Level (TRL) of Sparq-2020-O-RU is 6 while the targeted TRL at the end of the project is expected to be 9.

5.2.2.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that the proposed innovative solution is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. **IPR Assets**. Background IP, related to the development of Sparq-2020-O-RU, brought in the project by the partners, belongs only to these partners. RunEL Background IPR for Low PHY was used. There is no joint ownership of any IP while boundaries between subsystems are clear. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. Other partners have not contributed to the development of Sparq-2020-O-RU. The IP created during the project lifetime and beyond, related to Sparq-2020-O-RU, belongs to RunEL, who is the sole owner of the product.

The form of exploitation that has been decided for Sparq-2020-O-RU is through license agreements between the copyright's owner and the users/customers. In this agreement terms about the installation, use, fees, liabilities and other issues will be described. The goal of exploitation is the generation of revenues that will contribute to the sustainability of the service.

Competition: A competitive product is RAN 550 offered by Benetel. Other competitive companies are COMBA , Baycells. The competitive advantage of Sparq-2020-O-RU compared to the competitive products is the supported low latency (< 1 milliseconds).

5.2.2.3 Sparq-2020-O-RU Business Model

The Sparq-2020-O-RU business model proposes cutting-edge, scalable 3GPP compliant Release 15 Radio Unit with O-RAN interface with the DU working at 3.5GHz. The main advantage of Sparq-2020-O-RU is the supported low latency.

In Figure 55, the Sparq-2020-O-RU business model canvas is depicted.

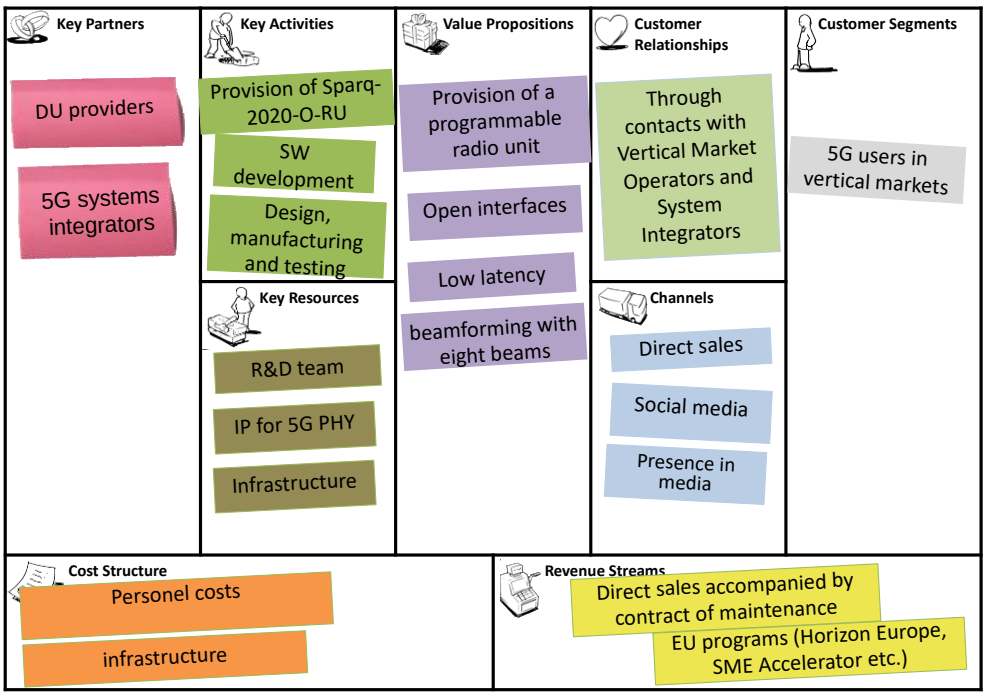


Figure 55: Sparq-2020-O-RU business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: Potential customers of Sparq-2020-O-RU are 5G users in vertical markets.

Value Proposition: It provides a programmable radio unit with open interfaces, low latency and beamforming with eight beams.

Channels: The following paths to reach the final clients were identified:

- In-house salesforces: Promote Sparq-2020-O-RU through direct sales to vertical market operators and integrators
- Social media using specific campaigns and platforms
- Presence in the media (sectorial journals and magazines) through the preparation of specific press releases

Customer Relationships: Customer relationships will be established and maintained mainly through contacts with Vertical Market Operators and System Integrators such as Bosch/Germany for Industry 4.0 vertical markets, and Leditech/Israel for Smart Cities 5G implementation

Revenue Streams:

The main revenues will come from product sales. However, this will also be accompanied by contracts for maintenance. These are mainly related to upgrades of the product.

Moreover, it should be highlighted that funding from EU programs (Horizon Europe, SME Accelerator etc.) will also be used in order to ensure service sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- RunEL R&D team which is a center of Excellence for OFDMA (PHY)
- RunEL IP for 5G PHY
- Necessary infrastructure

Key activities: The main activity is the provision of Sparq-2020-O-RU. Other activities also include the development of code aiming to improve the product or add new functionalities to it, design, manufacturing, testing as well as Marketing and Sales of 5G O-RUs.

Key partnerships:

- DU providers due to the need for open interfaces with DUs
- 5G System integrators who will facilitate the provision of Sparq-2020-O-RU

Cost structure:

- Personnel Costs: Technical personnel are committed to the development, maintenance and update of the proposed solution.
- Infrastructure: All the necessary hardware for the development and testing of the solution as well as cloud infrastructure (CPU and GPU time) can be considered in this category.

Strengths: Low latency, scalability

Weaknesses: The O-RU was designed for outdoor applications, need to be engineered to meet the requirements for indoor like plastic cage (mainly price reduction)

Opportunities: Demand for private networks; Regulators support by allocating 5G unlicensed spectrum for Verticals

Threats: The Main External risk is coming from the success/failure of the O-RAN Association, If the Disaggregation Idea will fail than the market potential of Sparq-2020-O-RU will decrease.

5.2.3 O-RAN non real-time RIC

5.2.3.1 Description

The O-RAN non real-time RIC, developed by i2CAT, is responsible for performing non real-time actions on the O-RAN elements based on data analytics and AI/ML algorithms. It is specified for control loops of more than one second.

At the current stage of the project, the Technology Readiness Level (TRL) of O-RAN non real-time RIC was 2 while the targeted TRL at the end of the project is expected to be 4.

5.2.3.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that the proposed innovative concept of O-RAN non real-time RIC is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. **IPR Assets**. Background IP, related to the development of O-RAN non real-time RIC, brought in the project by the partners, belongs only to these partners. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. Other partners who contributed to the development of O-RAN non real-time RIC are Accelleran, NKUA and ATOS. However, the IP created during the project lifetime and beyond, related to O-RAN non real-time RIC, belong to i2CAT, who is the sole owner of the product.

Although there are no IPRs limiting the commercial exploitation of O-RAN non real-time RIC, it should be noted that in order to implement the solution, O-RAN near-RT RIC is mandatory.

The form of exploitation that has been decided for O-RAN non real-time RIC is through scientific publications and technology transfer. However, it should be noted that technology transfer of O-RAN non real-time RIC either for commercial or for research purposes will be performed through an open-source license.

Competition: Competitive products are: Mavenir's Artificial Intelligence (AI) and Analytics Solutions[63], RIMEDO LABS's non-RT RIC[64] and ERICSSON's non-RT RIC[65]. The competitive advantages of the proposed solution compared to the competitive ones are: Non real-time control loop for radio resource management, optimization and RAN policy provisioning.

[63] https://www.mavenir.com/resources/mavenirs-artificial-intelligence-ai-and-analytics-solutions/
[64] https://www.rimedolabs.com/blog/o-ran-near-real-time-ric/
[65] https://www.ericsson.com/en/blog/2020/10/innovation-potential-of-non-real-time-ran-intelligent-controller

5.2.3.3 O-RAN non real-time RIC Business Model

The O-RAN non real-time business model proposes an innovative concept addressing the need for a non real-time control loop capable of supporting non-real-time radio resource management, higher layer procedure optimization, policy optimization in RAN, and providing guidance, parameters, policies and AI/ML models to support the operation of near-RealTime RIC functions in the RAN to achieve higher-level non-real-time objectives.

In Figure 56, the O-RAN non real-time RIC business model canvas is depicted.

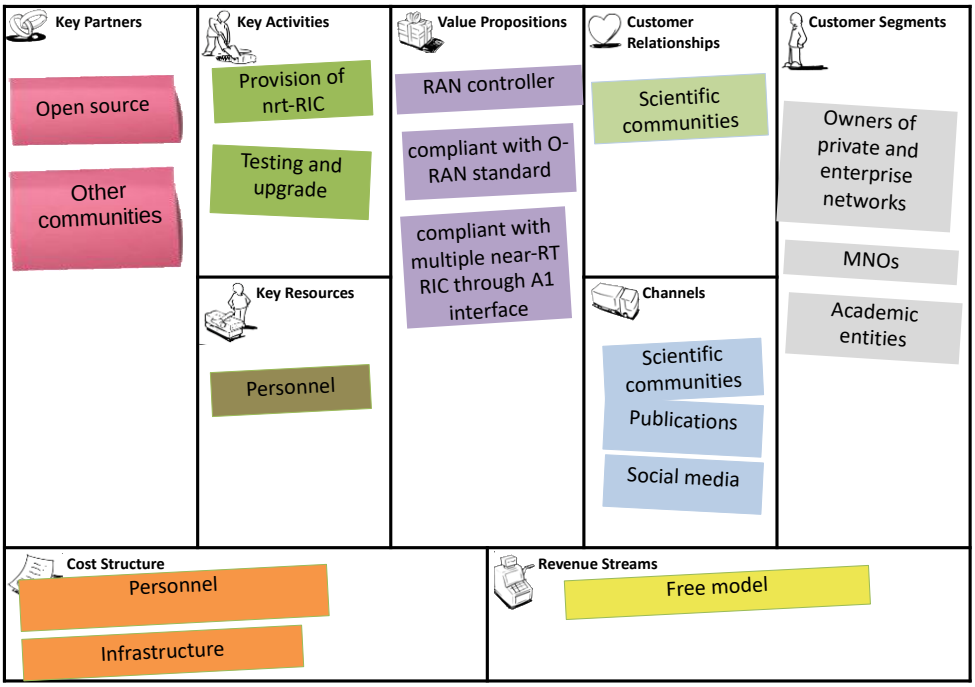


Figure 56: O-RAN non real-time RIC business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: Owners of private and enterprise networks, MNOs and academic entities interested in network RAN controllers.

Value Proposition: It provides a RAN controller which is compliant with O-RAN standard and compliant with multiple near-RT RIC through A1 interface.

Channels: The following paths to reach the final clients were identified:

- Through scientific communities
- Through scientific publications in journals and conferences
- Social media using specific campaigns and platforms

Customer Relationships: Through scientific communities where interested parties can exchange ideas and solve problems.

Revenue Streams: The O-RAN non real-time RIC will be provided free of charge. So, no revenue streams are foreseen. However, funding from future National and EU projects (Horizon Europe) will be used in order to ensure service sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources: Human resources can be considered the most important resource in this case. These include the experienced and qualified personnel to maintain and upgrade the product.

Key activities: The main activity is the provision of O-RAN non real-time RIC. Other activities are related to the testing and upgrade of the product. This also includes the deployment of the non-RT RIC in an O-RAN testbed and validation of key features as well as the validation of the component with near-RT RICs supplied by different vendors.

Key partnerships:

Open source and other communities

Cost structure:

- Personnel Costs: Technical personnel are committed to the development, maintenance and update of the proposed solution. Partnerships with developers and other third parties can also be included in this category.
- Infrastructure: All the necessary hardware for the development of the solution.

5.2.4 Time Sensitive Networking (TSN)

5.2.4.1 Description

The TSN, developed by UMA, allows interconnection of multiple devices in an industrial environment with time critical applications, providing easy deployment of new connections and avoiding a wired network.

At the current stage of the project, the Technology Readiness Level (TRL) of TSN solution is 4 while the targeted TRL at the end of the project is expected to be 7.

5.2.4.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their

components. The survey showed that the proposed TSN innovative concept is not covered by any patent. *So overall, no IPR barrier to entry is foreseen.* **IPR Assets**. Background IP, related to the development of TSN, brought in the project by the partners, belongs only to these partners. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. ATHONET has also contributed to the development of TSN solution. The IP created during the project lifetime and beyond, related to TSN, mainly belong to UMA, who is the owner of the product.

Although there are no IPRs limiting the commercial exploitation of TSN, it should be noted that in order to implement the product, TSN endpoint, TT and bridges from different vendors in order to evaluate the complete solution and ATH 5G Core developed in Affordable5G are mandatory.

The form of exploitation that has been decided for TSN solution is 1) direct industrial use through an open-source license and 2) through publications.

Competition: Competitors are: Belden Inc. (US), Cisco Systems, Inc. (US), Intel Corporation (US), National Instruments Corporation (US), Marvell Technology Group Ltd. (Bermuda), NXP Semiconductors N.V. (Netherlands), Microchip Technology Incorporated (US), Analog Devices, Inc. (US), Broadcom Inc. (US), and Advanced Micro Devices, Inc. (US). The competitive advantage of Affordable5G TSN is the ability to integration the complete TSN over 5G solution.

5.2.4.3 TSN Business Model

The TSN business model proposes an innovative concept over 5G test bed composed of the necessary facilities to test all TSN requirements before customers launch their products into the market.

In Figure 57, the TSN business model canvas is depicted.

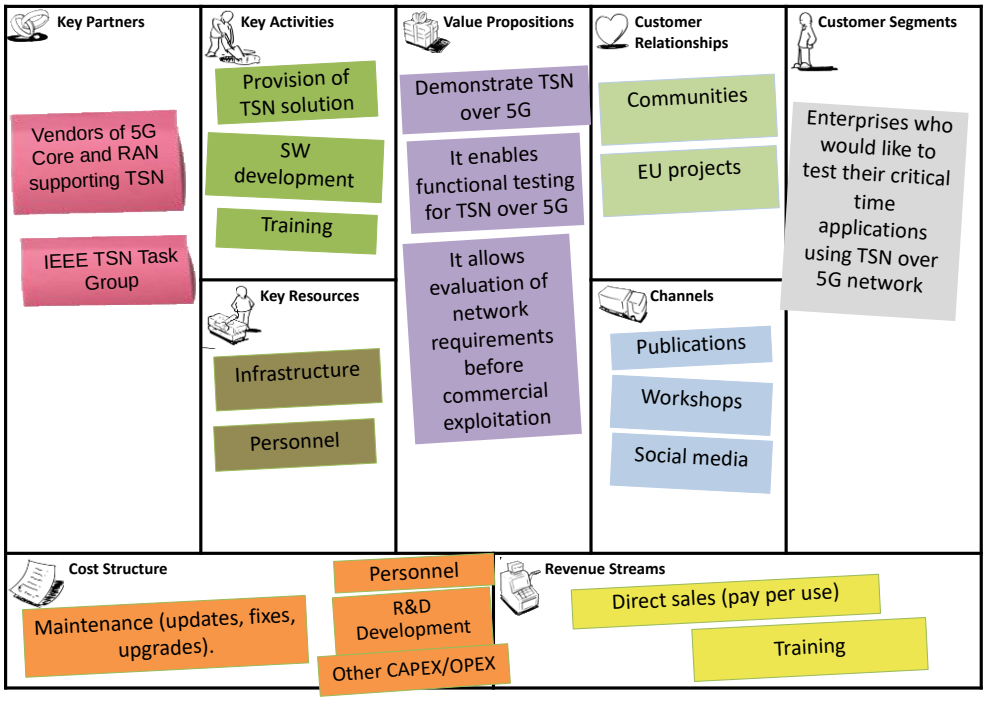


Figure 57: TSN business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: Potential customers of the product are enterprises who would like to test their critical time applications using TSN over 5G network.

Value Proposition: The TSN provides the ability for early steps test bed to demonstrate TSN over 5G. It also enables functional testing for TSN over 5G and allows evaluation of network requirements before commercial exploitation.

Channels: The following paths to reach the final clients were identified:

- Through publications in journals and conferences
- Through the participation in workshops
- Social media using specific campaigns and platforms

Customer Relationships: Affordable5G project and related future projects acting as communities. In general, communities where interested parties can exchange ideas and solve problems will be the main means for customer relationships.

Revenue Streams:

- Provision of the product – Pay per usage: In this case, a dynamic charging can be assumed. The customer pays a particular fee for its usage. This fee can be associated, for example, with the number of applications tested.
- Training: Training on how to use the product.

Moreover, funding from future EU projects will also be used in order to ensure service sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- Qualified personnel to maintain and upgrade the platform.
- Necessary infrastructure, Affordable5G system

Key activities: The main activity is the provision of TSN solution. Activities also include the development of code aiming to upgrade. Training activities to clients on how to use the solution.

Key partnerships:

- Vendors of 5G Core and RAN supporting TSN
- IEEE TSN Task Group to upgrade TSN functionalities.

Cost structure:

- Personnel Costs: Mainly developers
- Maintenance costs: Expenses related to the necessary activities in order to maintain the involved components.
- R&D / Development: Expenses needed to keep the service on top of technological advances.

Strengths: Integration of the complete TSN over 5G solution

Weaknesses: Replacement of commercial equipment for proprietary solutions; Not standardizes according to 3GPP releases; Low test bed portability

Opportunities: TSN over 5G should be included in next 3GPPP release; TSN over 5G solution should be adopted by most manufacturing facilities (increased demand)

Threats: If radio authorities don't release specific frequency bands for NPN, the deployment of commercial TSN over 5G will be impossible.

5.2.5 KNF Placement for OSM (KNF)

5.2.5.1 Description

KNF solution, developed by Martel, is an engine to place cloud native functions for ETSI OSM. At the current stage of the project, the Technology Readiness Level (TRL) of KNF was 3 while the targeted TRL at the end of the project is expected to be 5.

5.2.5.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that the proposed KNF innovative concept is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. **IPR Assets**. Background IP, related to the development of KNF, brought in the project by the partners, belongs only to these partners. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. Other partners have not contributed to the development of KNF solution. The IP created during the project lifetime and beyond, related to KNF, belongs to Martel who is the sole owner of the product.

Although there are no IPRs limiting the commercial exploitation of KNF, it should be noted that in order to implement the solution, ETSI OSM and Kubernetes are mandatory.

The form of exploitation that has been decided for KNF is direct industrial use through open source licenses.

Competition: Although placement is quite a common function offered in other frameworks, to the best of owner's knowledge there is no competitors in the context of OSM for the KNF part.

5.2.5.3 KNF Business Model

The KNF business model proposes an innovative concept for the placement of cloud native functions in a distributed cluster, taking into account location requirement, and other constraints.

In Figure 58, the KNF business model canvas is depicted.

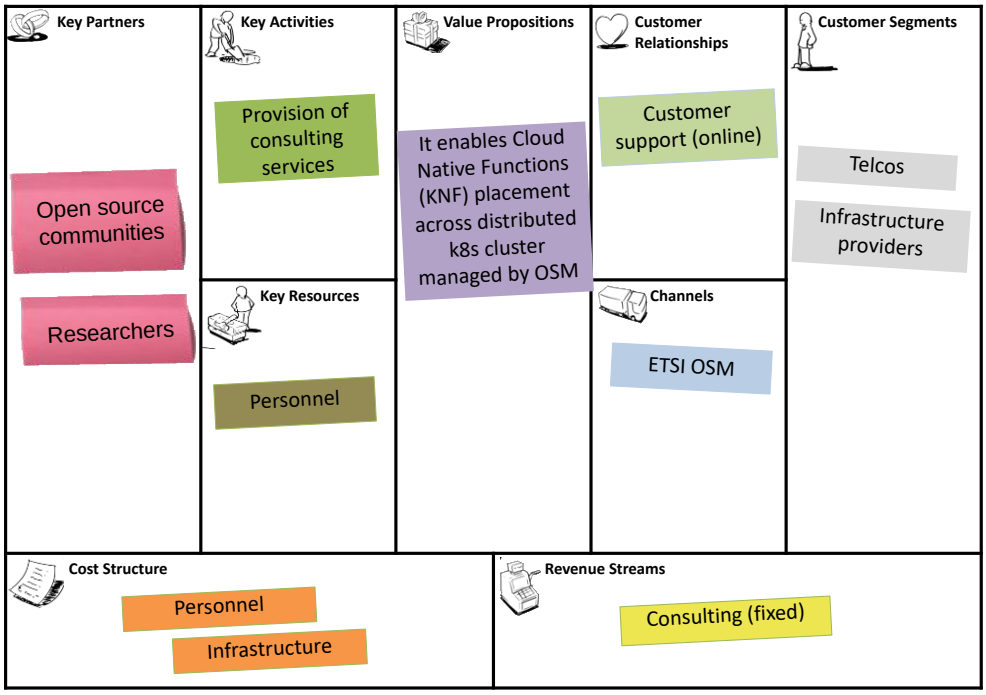


Figure 58: KNF business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: Potential customers of KNF solution are Telcos and other infrastructure providers leveraging OSM

Value Proposition: The solution enables Cloud Native Functions (KNF) placement across distributed k8s cluster managed by OSM.

Channels: The following paths to reach the final clients were identified:

- Through ETSI NFV OSM

Customer Relationships: Not defined at the moment.

Revenue Streams: The main source of revenues will be consulting services on how to maximize the value users can get out of KNF solution.

Moreover, funding from future EU projects will also be used in order to ensure service sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources: Experienced and Qualified Human resources to develop, maintain and improve the solution.

Key activities: The main activity is the provision of consulting services.

Key partnerships:

- Open-source communities providing advices and codes
- Researchers working on the field

Cost structure:

- Personnel Costs: Technical personnel are committed to the development, maintenance and upgrade of the proposed solution.
- Infrastructure: Fixed costs for development and testing infrastructure

Strengths: A new feature

Weaknesses: Not standardized

Opportunities: Increased interest by ETSI OSM

Threats: Slow take up of cloud native and devops approaches by telco

5.2.6 Urban Platform (UP)

5.2.6.1 Description

The Urban Platform, developed by Ubiwhere offers municipalities and their operational teams a holistic view of their cities, presenting effective insights based on the cross-domain data processed in a unified way.

At the current of the project, the Technology Readiness Level (TRL) of UP is 8 while the targeted TRL at the end of the project is expected to be 9.

5.2.6.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that UP innovative concept is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. Background IP, related to the development of UP, brought in the project by the partners, belongs only to these partners. There is no joint ownership of any IP while boundaries between subsystems are clear. The partners have already signed the Consortium Agreement that clearly defines the background rights.

Foreground and Postground IPR. Other partners have not contributed to the development UP. The IP created during the project lifetime and beyond, related to UP, belongs to Ubiwhere, who is the sole owner of the service.

Form of exploitation: The form of exploitation that has been decided for UP is through license agreements between the copyright's owner and the users/customers. In this agreement, terms about the installation, use, fees, liabilities and other issues will be described. The main goal of exploitation is the generation of revenues that will contribute to the sustainability of the service.

Competition: The main competitive products are Indra's Onesait and IBM's Intelligent Operations Center. Competitive advantages of UP are: the openness of the data as well as the open-source business model to be adopted.

5.2.6.3 UP Business Model

The UP business model proposes an innovative concept that will open data to break existing data silos in cities, enable data exploration in a cross-domain manner (i.e. understanding the impact of different verticals in others) and make data available to third parties in a standardized way.

In Figure 59, the UP business model canvas is depicted.

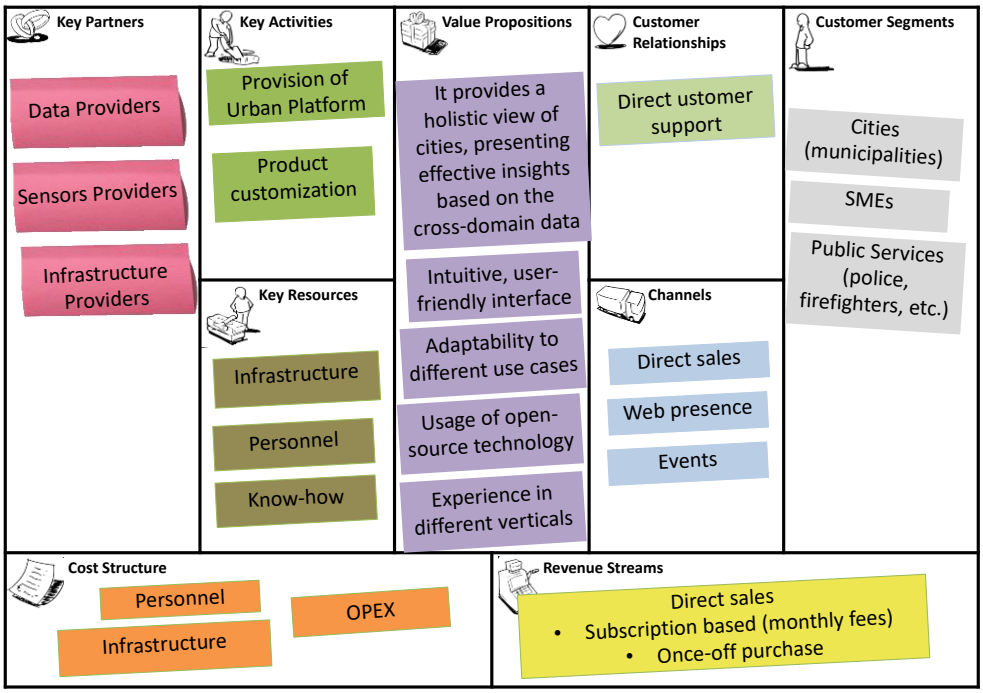


Figure 59: UP business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: Potential customers of UP are Cities (municipalities), SMEs, Public Services (police, firefighters, etc.) who would like to receive effective insights based on the cross-domain data processed in a unified way.

Value Proposition: UP provides:

- Intuitive, user-friendly interface
- Adaptability to different use cases
- Usage of open-source technology
- Experience in different verticals (mobility, environment, communications, etc.).

Channels:

- Direct sales, exploiting the in-house business development team with sales reps.
- Web presence and mainly through social media
- Participation in events like trade fairs

Customer Relationships: Direct customer care with direct, continuous customer communication (maintenance, customization, integrations, etc.)

Revenue Streams:

- The main revenues will come from product sales which can be
    - Subscription-based (monthly fees) or
    - Once off purchase

Moreover, it should be highlighted that funding from future EU projects (Horizon Europe) will also be used in order to ensure business sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- Experienced and Qualified Human resources to develop, maintain and upgrade the product
- Know-how/Experience
- Necessary infrastructure for the development and upgrade of the product.

Key activities: The main activity is the provision of the Urban Platform. Other activities also include customization of the product based on customer's use cases and data sources.

Key partnerships:

- Data providers
- Sensors providers
- Infrastructure providers (hardware or cloud).

Cost structure:

- Operating costs: Costs (rental, utilities etc) required for the operation of the business.
- Personnel costs: Technical personnel are committed to the development, maintenance and upgrade/customization of the proposed solution.
- Infrastructure costs: Mainly hosting infrastructure

Strengths: Simple to use and deploy, cloud-based in AWS, one solution for all verticals

Weaknesses: Number of off-the-shelf integration options

Opportunities:

- Cities becoming more aware of the benefits of having a centralized management system for different domains
- Cities becoming aware of the importance of managing data and making it available

Threats: Cities are complex organisms. Moreover, public funding and projects tend to be slow and cumbersome

5.2.7 NEOX

5.2.7.1 Description

NEOX[66], developed by Think Silicon S.A., NEOX™ is an Ultra Low Power Accelerator for AI/ML and graphics Workloads. It is a parallel multicore and multithreaded GPU architecture based on the RISC-V RV64C ISA instruction set with adaptive NoC. The number of cores varies from 4 to 64 organized in 1-16 cluster elements, each configured for cache sizes and thread counts. Depending on cluster / core configuration, NEOX™ compute power is ranging from 12.8 to 409.6 GFLOPS at 800MHz with support for FP16, FP32 and optionally FP64 and SIMD instructions.

The various configuration possibilities of the NEOX™ IP with custom user instructions, make it flexible to configure key applications, such as computer graphics, machine learning, vision/video processing and general-purpose compute. It serves a wide range between power, performance and functional integration with different levels of SoC platforms sporting Microcontroller, Crossover Processors and Application Processors. NEOX™ addresses

[66] https://www.think-silicon.com/neox-graphics

multiple verticals in AI, IoT/Edge and performance media processing in consumer and industrial markets.

At the current of the project, the Technology Readiness Level (TRL) of NEOX is 4 while the targeted TRL at the end of the project is expected to be 6.

5.2.7.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that NEOX innovative concept is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. It should be notes that two patents are being prepared by Think Silicon S.A. **IPR Assets**. Background IP, related to the development of NEOX, brought in the project by the partners, belongs only to these partners. There is no joint ownership of any IP while boundaries between subsystems are clear. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. Other partners have not contributed to the development of NEOX. The IP created during the project lifetime and beyond, related to NEOX, belongs to Think Silicon S.A., who is the sole owner of the service.

Form of exploitation: The form of exploitation that has been decided for NEOX is threefold: 1) technology transfer; 2) direct industrial use through commercial agreements; 3) license agreements between the copyright's owner and the users/customers. In this agreement, terms about the installation, use, fees, liabilities and other issues will be described. The main goal of exploitation is the generation of revenues that will contribute to the sustainability of the service.

Competition: The main competitive product is NPU IP[67] offered by Vivante®. Synopsis is another competitive company. Competitive advantages of NEOX are: the innovative design of vector and SIMD RISC-V instructions; ultra low power consumption.

5.2.7.3 NEOX Business Model

The NEOX business model proposes an innovative concept for ultra low power consumption acceleration of AI/ML workloads for the edge. In Figure 60, the NEOX business model canvas is depicted.

[67] https://www.verisilicon.com/en/IPPortfolio/VivanteNPUIP

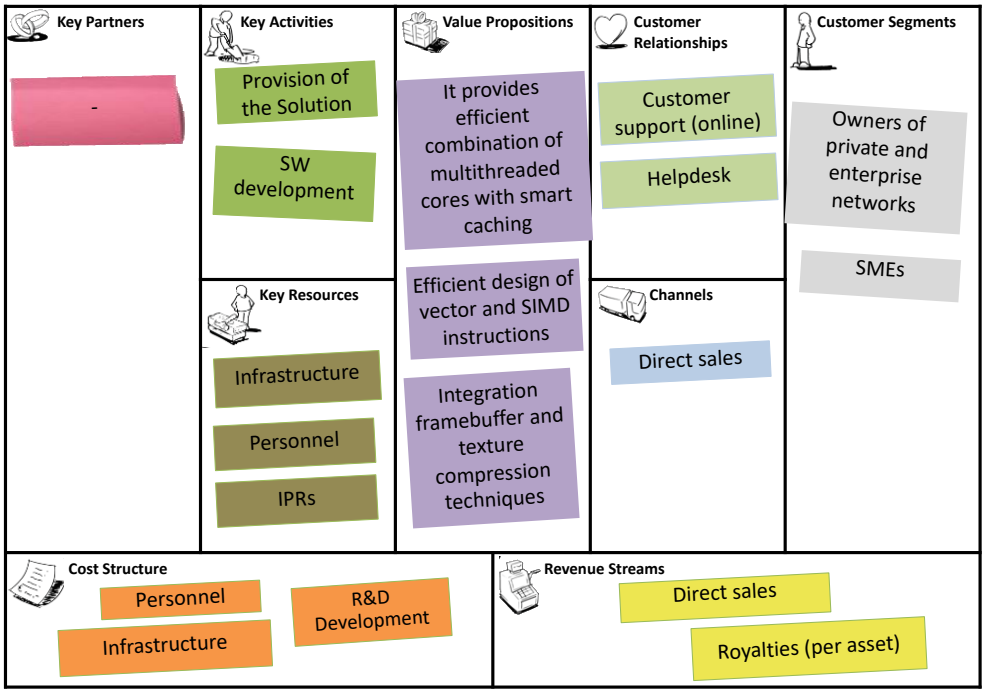


Figure 60: NEOX business model canvas

c. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: Potential customers of NEOX service are:

- Owners of private and enterprise networks,
- SMEs

Value Proposition: The service provides efficient combination of multithreaded cores with smart caching. It also demonstrates an efficient design of vector and SIMD instructions. It integrates framebuffer and texture compression techniques.

Channels: Through direct sales, exploiting the in-house business development team with sales reps and FAEs.

Customer Relationships: Customer-centric (B2B) using customer care with online support and helpdesk.

Revenue Streams:

- The main revenues will come from product sales.
- Royalties: For the ongoing use of their assets, including copyrighted works governed by a licensing agreement.

Moreover, it should be highlighted that funding from future EU projects (Horizon Europe) as well as from National programs will also be used in order to ensure business sustainability.

d. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- Experienced and Qualified Human resources to develop, maintain and upgrade the product
- IPRs
- Necessary infrastructure for the development and upgrade of the product.

Key activities: The main activity is the provision of the NEOX accelerator. Other activities also include the development and improvement of the product.

Key partnerships: Not defined.

Cost structure:

- Operating costs: Costs (rental, utilities etc) required for the operation of the business.
- Personnel costs: Technical personnel are committed to the development, maintenance and upgrade of the proposed solution.
- Infrastructure costs: All the necessary infrastructure for the development of the solution.
- Marketing and sales costs: Cost for the promotion of the proposed solution.

5.2.8 Bubblecloud

5.2.8.1 Description

The Bubblecloud[68], developed by Athonet, is a cloud-based 5G Core Network enabling 5G private network coverage for several verticals. Athonet's BubbleCloud LTE makes the most sophisticated wireless technology available to every user. BubbleCloud, the award-winning Athonet mobile core is now available on AWS to serve CBRS and OnGo, open spectrum initiatives and licensed spectrum with seamless integration to AWS IoT.

At the current stage of the project, the Technology Readiness Level (TRL) of Bubblecloud is 5 while the targeted TRL at the end of the project is expected to be 8.

[68] https://athonet.cloud

5.2.8.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that the innovative concept of Bublecloud is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. **IPR Assets**. Background IP, related to the development of BubbleCloud, brought in the project by the partners, belongs only to these partners. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. Other partners have not contributed to the development of BubbleCloud. Therefore, the IP created during the project lifetime and beyond, related to BubbleCloud, belongs to Athonet, who is the owners of the product.

The form of exploitation that has been decided for BubbleCloud is the industrial use commercial licenses. The goal of exploitation is the generation of revenues that will contribute to the sustainability of the service.

Competition: The main competitors of BubbleCloud are Tier-1 vendors for private networks. A competitive to BubbleCloud product is Cloud Packet Core[69] by Nokia. The main advantage of BubbleCloud over its competitor is its ability to be deployed directly from AWS marketplace.

5.2.8.3 BubbleCloud Business Model

The BubbleCloud business model proposes an innovative and easy way to deploy 5G private networks directly from the public cloud of Amazon. Industries and academics with a 5G radio can connect to it via a VPN and create a 5G end-to-end ecosystem. This implementation meets the demands of the evolving 5G standalone ecosystem for a simple way to test interoperability for radios and devices against a highly featured core network product. Local user planes can be added to create the next generation of the 5G BubbleCloud.

In Figure 61, the BubbleCore business model canvas is depicted.

[69] https://www.nokia.com/networks/solutions/cloud-packet-core/

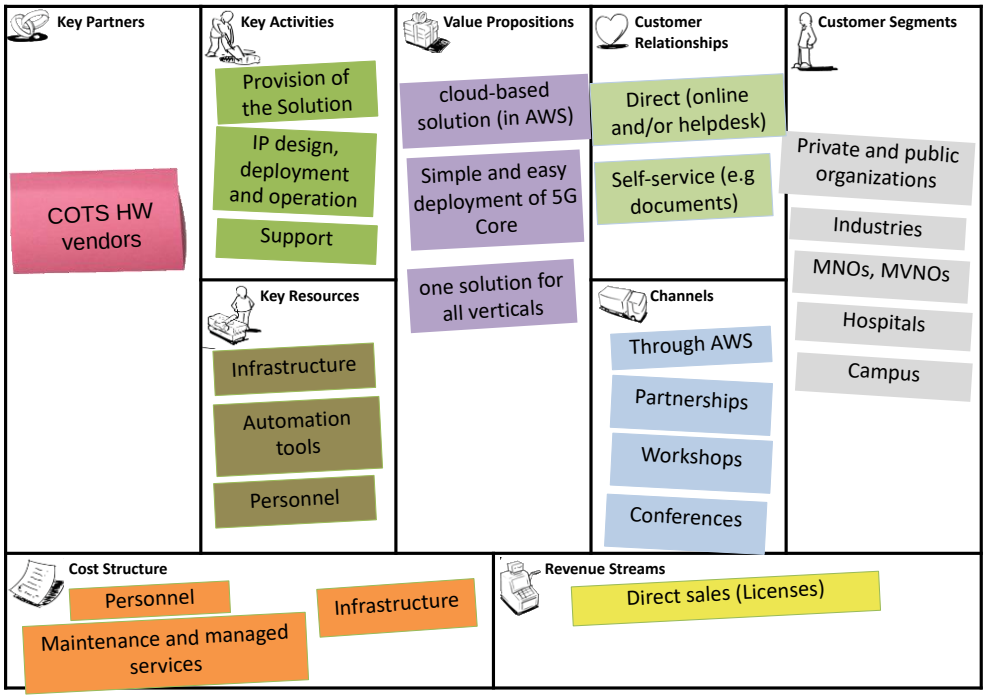


Figure 61: BubbleCore business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: Potential customers of BubbleCore are private and public organizations, industries, MNOs, MVNOs, hospitals, campus, all related to private networks.

Value Proposition: The BubbleCore provides a cloud-based solution (in AWS) leading to a simple to use and deploy the core part of private networks. BubbleCore offers one solution for all verticals leading to increased cost efficiency and improved scalability.

Channels: The following paths to reach the final clients were identified:

- Through AWS
- Presentations in workshops and conferences
- Partnerships and collaborations with integrators and MNOs.

Customer Relationships: These refer to B2B customer relationships that can be achieved through:

- Direct options: Through customer care that can be offered via a helpdesk or online support.
- Self-Service Options: Through readily available support and education documents (help desks, FAQ pages, and online reference materials)

Revenue Streams: Provision of Bubble Core solution. The revenue streams foreseen will be through user licenses. However, funding from future National and EU projects will be used in order to ensure service sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- Necessary infrastructure
- Automation tools
- Personnel for providing help desk and support
- Experienced personnel for the development, support and upgrade of the product

Key activities: The main activities are the provision of BubbleCore. IP design, deployment, operational support, maintenance, managed services are also included amongst the key activities.

Key partnerships: COTS HW servers' vendors (e.g. Dell) who will provide the necessary infrastructure

Cost structure:

- Personnel Costs: Technical personnel are committed to the development, maintenance and upgrade of the proposed solution.
- Infrastructure Cost: Cost of the necessary hardware for the development of the solution as well as cloud infrastructure can be considered in this category.
- Cost for maintenance and managed services

Strengths: Simple to use and deploy, cloud-based in AWS, one solution for all verticals

Weaknesses: Not meant for national wide scale (Tier-1 operators) coverages

Opportunities: AWS cloud; availability of unlicensed and shared spectrum for private networks across countries; commercialization of 5G networks in businesses and private 5G; diffusion of IoT and machine-to-machine applications

Threats: Slow adoption of unlocked spectrum

5.2.9 3GPP-compliant mission critical systems over neutral host and hybrid deployments (MCS NH/HD)

5.2.9.1 Description

MCS (NH/HD)[70], developed by Nemergent will deliver a 3GPP-compliant MCS VNF(s) and Android application for such communications alongside with NEM MCS Application Server, NEM MCS Management Servers (Identity MS, Group MS, Configuration MS, Key MS), MSC Dispatcher, NEM MCPTT/MCS Enabler, MCS OAM system and a core IMS.

At the current stage of the project, the Technology Readiness Level (TRL) of MCS NH/HD was 5 while the targeted TRL at the end of the project is expected to be 6+.

5.2.9.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that the proposed innovative concept of MCS NH/HD is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. **IPR Assets**. Background IP include QoS N5 interface framework. Background IP related to the development of MCS NH/HD, brought in the project by the partners, belongs only to these partners. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. No other partner contributed to the development of MCS NH/HD product. The IP created during the project lifetime and beyond, related to MCS NH/HD, belongs to Nemergent, who is the sole owner of the service.

Although there are no IPRs limiting the commercial exploitation of MCS NH/HD, it should be noted that in order to implement the solution, 5G Core, MANO, and UEs are mandatory.

Form of exploitation: The form of exploitation that has been decided for MCS NH/HD is threefold: 1) technology transfer; 2) direct industrial through commercial agreements; 3) license agreements between the copyright's owner and the users/customers. In this agreement, terms about the installation, use, fees, liabilities and other issues will be described. The main goal of exploitation is the generation of revenues that will contribute to the sustainability of the service.

Competition: Competitive products are:

- MCPTT Application Servers: Airbus, Cisco, Ericsson, Harris Corporation, Kapsch, Leonardo, Motorola, Nokia, StreamWIDE, TASSTA.
- MCPTT Clients: Airbus, Armour Communications, Etelm, Funkwerk, Harris Corp., Kapsch, MCOP, Leonardo, Nokia, Softil, Sonim, Valid8, Prescom, Spirent, TASSTA.

[70] https://www.nemergent-solutions.com

The competitive advantage of the proposed solution against other solutions in the market is that it is compliant with the standards making it pluggable with other standard-compliant vendors.

5.2.9.3 MCS NH/HD Business Model

In Figure 62, the MCS NH/HD business model canvas is depicted.

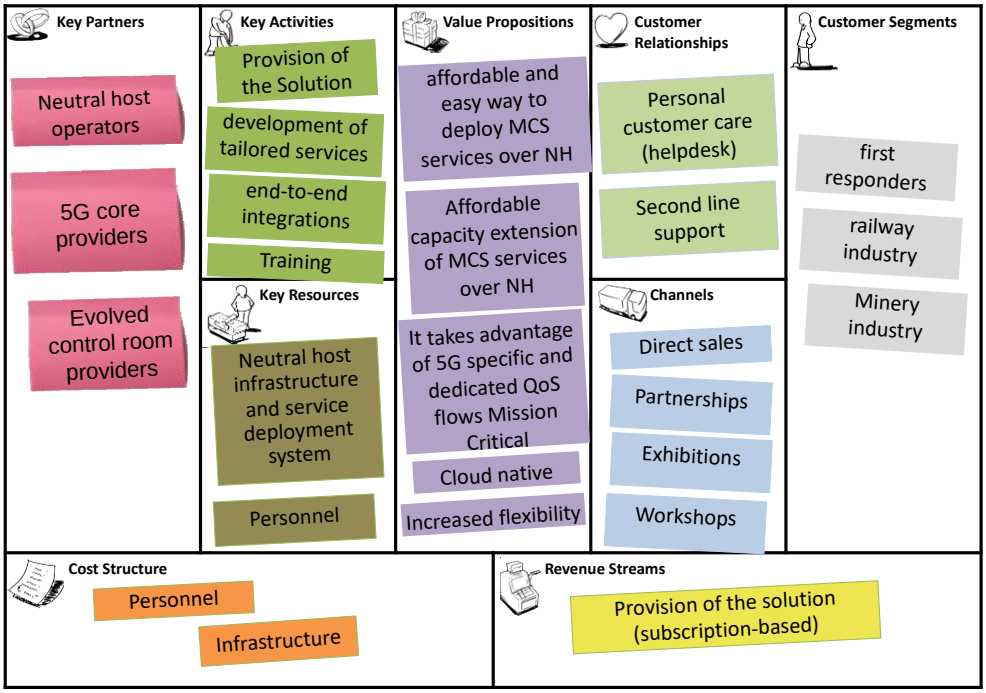


Figure 62: MCS NH/HD business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: M(V)NO, first responders, railway industry, minery industry, etc. looking for an easy way to deploy mission critical systems are the potential customers of the product.

Value Proposition:

- The MCS NH/HD provides an affordable and easy way to deploy MCS services over neutral host infrastructures
- Affordable capacity extension of MCS services over neutral host infrastructures
- It takes advantage of 5G specific and dedicated QoS flows for Mission Critical

Channels: The following paths to reach the final clients were identified:

- Through direct sales

- Participation in exhibitions
- Presentations in workshops and conferences
- Through partnerships with integrators and other parties.

Customer Relationships: Personal customer care will be offered via a helpdesk. Second line support should also be offered.

Revenue Streams: The main revenue stream will come from the provision of CMS NH/HD. A subscription-based approach will be adopted.

However, project-based revenue stream is also applicable to support activities in the framework of a specific project and to ensure solution sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- Neutral host infrastructure and service deployment system
- Experienced and Qualified Human resources to maintain and improve the service
- Personnel for helpdesk

Key activities: The main activities are the provision of CSP NH/HD the development of tailored services as well as end-to-end integrations and training.

Key partnerships: Neutral host operators, Core 5G providers, Evolved control room providers.

Cost structure:

- Personnel Costs: Technical personnel are committed to the development, maintenance and update of the proposed solution as well as the development of tailored services
- Infrastructure Cost: Cost of the necessary hardware for the development and deployment of the service.

Strengths: Guaranteed communications, increased flexibility, cloud-native

Weaknesses: Problems in UE mobility and service continuity in the hybrid mode; Problems with the compatibility of UEs regarding the specific neutral host operating frequencies (5G); Need for service-oriented resources allocation.

Opportunities: Increased demand for private networks and neutral hosting.

Threats: Lack of standardization; low spectrum free usage availability and low spreading of NH.

5.2.10 Network Monitoring and Telemetry (NMT)

5.2.10.1 Description

NMT solution, developed by NKUA, provides a cross layer infrastructure with all related APIs for the monitoring of various Key Performance Indicators of the network in order to be optimized via advanced AI/ML algorithms.

At the current stage of the project, the Technology Readiness Level (TRL) of NMT solution is 2 while the targeted TRL at the end of the project is expected to be 4.

5.2.10.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that the proposed innovative concept is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. **IPR Assets**. Background IP, related to the development of NMT, brought in the project by the partners, belongs only to these partners. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. ATOS also contributed to the development of NMT solution through the development of AI/ML algorithms. The IP created during the project lifetime and beyond, related to NMT, belongs to NKUA, who is the sole owner of the solution.

Although there are no IPRs limiting the commercial exploitation of CAESAR service it should be noted that in order to implement the solution, O-RAN and 5G-Core VNFs are mandatory.

The form of exploitation that has been decided for NMT is through scientific publications. However, it should be noted that initially, NMT will also be provided for research purposes through an open-source license.

Competition: The main competitor of NMT are NWDAF by RADCOM[71], NWDAF by SANDVINE[72] and EOS by ARISTA[73].

The competitive advantages of NMT compared to other market solutions are the following: 1) it is open source NWDAF, able to gather requested info from NFs. This will encourage and allow multivendor deployments and facilitate customization to suit individual service needs by the utilization of 3GPP compliant implementation and 2) it is a cross-layer approach, since related information will be gathered from all architectural layers

[71] https://radcom.com/network-data-analytics-function-nwdaf/

[72] https://www.sandvine.com/service-providers/nwdaf

[73] https://www.arista.com/en/products/eos/telemetry-analytics

5.2.10.3 NMT Business Model

The NMT business model proposes a holistic network monitoring that leads to dynamic reconfiguration of certain parameters based on the outputs of advanced AI/ML algorithms. Based on 3GPP standardized interfaces, this component efficiently addresses interoperability issues related to the disaggregated concept of 5GS. In Figure 63, the NMT business model canvas is depicted.

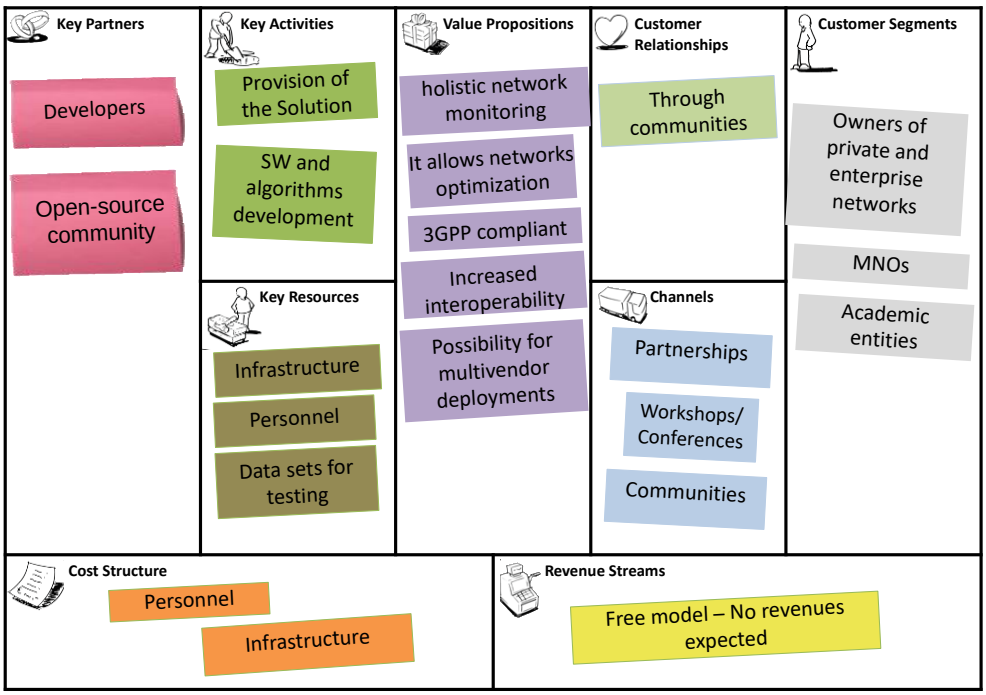


Figure 63: NMT business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: The potential customers of NMT solution are:

- Owners of private and enterprise networks
- MNOs
- Other academic entities interested in network monitoring and telemetry

Value Proposition: NMT provides the holistic network monitoring allowing its optimization. Innovations of the service are the following:

- 3GPP Compliant solution
- Increased interoperability
- Possibility for multivendor deployments
- Extension of already defined interfaces (e.g. Nrf/Nnwdaf) according to Affordable5G

Channels: The following paths to reach the final clients were identified:

- Through scientific and other communities
- Presentations in workshops and conferences
- Partnerships and collaborations with international and national projects

Customer Relationships: Customer care will be offered via communities where interested parties can exchange ideas and solve problems.

Revenue Streams: Initially, the NMT solution will be provided free of charge. So, no revenue streams are foreseen. However, funding from future National and EU projects will be used in order to ensure service sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- Personnel: Experienced personnel for the development, maintenance and upgrade of the solution
- Infrastructure: Necessary equipment for the development, testing and upgrade of the solution (mainly servers).
- Representative data set models in order to evaluate the proposed solution in realistic situations.

Key activities: The main activity is provision of a data telemetry and monitoring platform interacting with an AI/ML based optimization framework. Software and algorithms development can be assumed in this category.

Key partnerships: Developers and open source community supporting the development of the network monitoring and telemetry platform.

Cost structure:

- Personnel Costs: Technical personnel are committed to the development, maintenance and update of the proposed service. Partnerships with developers and other third parties can also be included in this category.
- Infrastructure Cost: Cost of the necessary hardware (mainly servers) for the development and deployment of the platform as well as cloud infrastructure can be considered in this category.

Strengths: Open source, increased interoperability, 3GPP compliant, extension of interfaces, multivendor.

Weaknesses: Not tested/evaluated in large scale networks, not yet a unified data labelling approach for the diverse data collected from the architectural layers and not all related interfaces (e.g., O1, A1) have been fully implemented yet.

Opportunities: Increased demand - The use of network monitoring and telemetry in various sections related to corporate environments, such as prevention of network attacks and security, as well as quality management and customer analysis

Threats: Availability of a representative set of data as close as possible to a real-world set.

5.2.11 NearbyOne Edge Orchestrator v2.0 (NOEO2)

5.2.11.1 Description

NOEO2, developed by Nearby Computing, offers a comprehensive Orchestration and automation for Edge Computing: Infrastructure, NFV and application management, including QoS, SLA enforcement, policies etc. NOEO2 is compliant with ETSI MEC and other industry standards.

The current Technology Readiness Level (TRL) of NOEO2 is 6 while the targeted TRL at the end of the project is expected to be 7.

5.2.11.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that although there is one patent related to the concept of the proposed solution (PCT/EP2018/068367 FOG COMPUTING SYSTEMS AND METHODS (filed)), no IPR barrier to entry is foreseen. **IPR Assets**. Background IP include NearbyOne Edge Orchestrator v1.0. Background IP, related to the development of NOEO2, brought in the project by the partners, belongs only to these partners. There is no joint ownership of any IP while boundaries between subsystems are clear. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. Other partners from Affordable5G project have not contributed to the development of NOEO2. The IP created during the project lifetime and beyond, related to NOEO2, belongs to Nearby Computing SL., who is the sole owner of the solution.

Form of exploitation: It has been decided that NOEO2 will follow two different routes of exploitation. The first one is through patenting of its innovative concepts. The second one is direct industrial use through commercial licenses. The goal of exploitation is the generation of revenues that will contribute to the sustainability of the solution.

Competition: The main competitive products are: HPE Edge Orchestrator[74], Nokia Cloudband[75], Ericsson OMC[76], Netcracker[77], Cloudify[78], and Mobile EdgeX[79]

The competitive advantages of NOEO2 compared to other solution in the market are:

- Introduction of QoS/SLA for applications at the Edge
- Services orchestration merging network and application features and triggers
- Single Pane of Glass for infrastructure provisioning, Radio/NFVI/NFVO, MEC and non-MEC edge application orchestration

5.2.11.3 NOEO2 Business Model

NOEO2 business model proposes a comprehensive device nZTP + VNF/App orchestration on hybrid environments from the Cloud to the Edge, from a single pane of glass.

In Figure 64, the NOEO2 business model canvas is depicted.

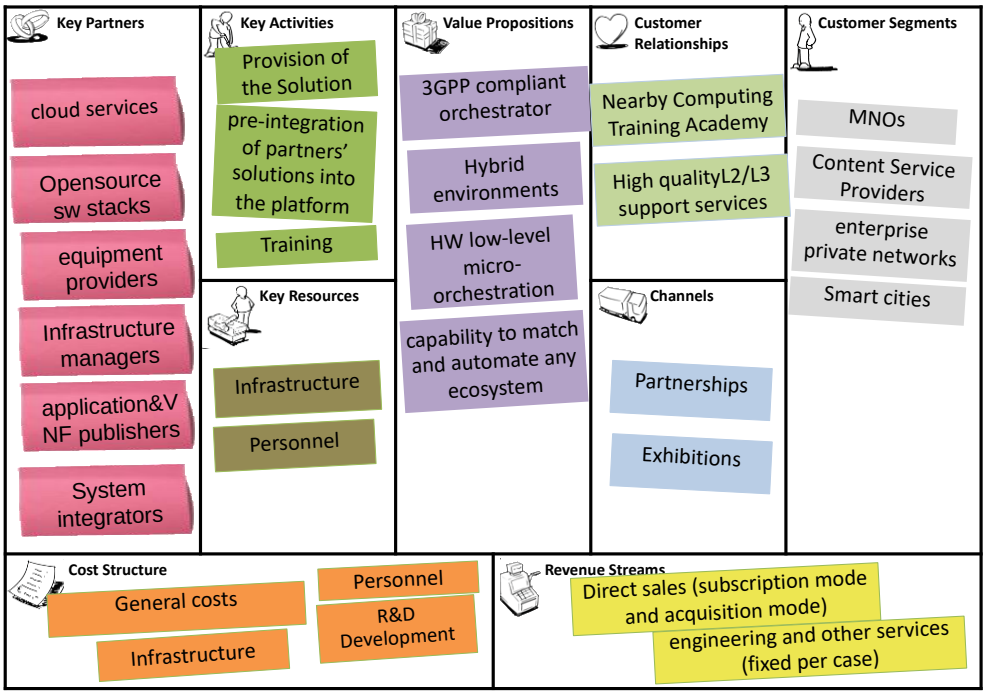


Figure 64: NOEO2 business model canvas

[74] https://www.hpe.com/psnow/doc/a50001643enw
[75] https://www.nokia.com/networks/solutions/cloudband/
[76] https://www.ericsson.com/en/portfolio/digital-services/cloud-infrastructure/operations-manager-cloud-infrastructure
[77] https://www.netcracker.com/
[78] https://cloudify.co/
[79] https://mobiledgex.com/

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: The main customers of this solution are mobile network operators, content service providers, enterprise private networks and smart cities who are interested to incorporate an innovative orchestration solution into their networks.

Value Proposition: It provides a 3GPP compliant orchestrator for edge computing. Innovations of the solution are:

- Hybrid environments,
- HW low-level micro-orchestration,
- Capability to match and automate any ecosystem with very little specific tailored developments - leading to much better TCOs and TTM

Channels: The following paths to reach the final clients were identified:

- Through partnerships with system integrators, equipment vendors, network core vendors and application publishers
- Participation in exhibitions

Customer Relationships: The main means of customers' relationships are:

- Nearby Computing Training Academy
- High qualityL2/L3 support services

Revenue Streams: The main revenue stream will come from the provision of NOEO2. A mix of subscription mode and acquisition mode will be adopted. Other sources of revenues are from engineering and other services. However, public-funded grants (EU, Spanish gvt) for innovation developments will be used in order to ensure service sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- Mainly Experienced and Qualified Human resources to maintain and improve the solution
- Necessary infrastructure to test and upgrade the solution

Key activities: The main activities are:

- provision of the platform

- pre-integration of partners' solutions into the platform
- software development
- training

Key partnerships:

- Suppliers: cloud services - Opensource sw stacks//
- Partners: equipment providers, infrastructure managers, application&VNF publishers, system integrators

Cost structure:

- Personnel Costs: Technical personnel are committed to the development, maintenance and upgrade of the proposed solution.
- Infrastructure Costs: Cost of the necessary infrastructure for the development and testing of the solution.
- General Costs: supplies, professional services, administrative services, travels
- Investments including R&D

Strengths: Hybrid environments, 3GPP compliant, automate any ecosystem

Weaknesses: Lack of AI/ML features, low automatization, low energy efficiency, low scalability

Opportunities: Edge is a trend, but has many internal challenges and complexity, and a wide diversity of potential architectures. Companies will require flexible tools handling all the intertwined component layers of the Edge

Threats: Lack of edge computing easy-to-manage environments

5.2.12 Slice Manager (SM)

5.2.12.1 Description

The SM, developed by i2CAT, provides an easy way to manage private and neutral 5G infrastructures composed of Compute, Transport and RAN segments in a holistic manner. The Slice Manager will be responsible for the pilots performed at the Castelloli circuit taking care of the reservation of resources towards the non-RT RIC.

The Technology Readiness Level (TRL) of Slice Manager at the current stage of the project is 6 while the targeted TRL at the end of the project is expected to be 6.

5.2.12.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that the proposed concept of SM is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. **IPR Assets**. Background IP, related to

the development of SM, brought in the project by the partners, belongs only to these partners. There is no joint ownership of any IP while boundaries between subsystems are clear. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. Other partners have not contributed to the development of the SM. Thus, the IP created during the project lifetime and beyond, related to SM, belongs to i2CAT, who is the sole owner of the service.

Although there are no IPRs limiting the commercial exploitation of SM, it should be noted that in order to implement the solution, non real-time RIC is mandatory.

The form of exploitation that has been decided for SM is twofold: 1) direct industrial use through license agreements; In this agreement, terms about the installation, use, fees, liabilities and other issues will be described; 2) Technology transfer (most probably to Neutroon Technologies). The main goal of exploitation is the generation of revenues that will contribute to the sustainability of the service.

Competition: The main competitors of SM are: Open-source Katana solution[80], Slice Manager by Infosys[81], features from main vendors of Telco equipment like Mavenir, Ericsson, Altiostar. The advantages of SM over its competitors are vendor agnostic software, hard slicing on infrastructure resources, management of 5G services and other access options like WiFi and multi-tenancy.

5.2.12.3 SM Business Model

The SM business model proposes an innovative framework to manage 5G infrastructures and private networks.

In Figure 65, the SM business model canvas is depicted.

[80] https://github.com/medianetlab/katana-slice_manager

[81] https://www.infosys.com/services/engineering-services/service-offerings/slice-manager.html

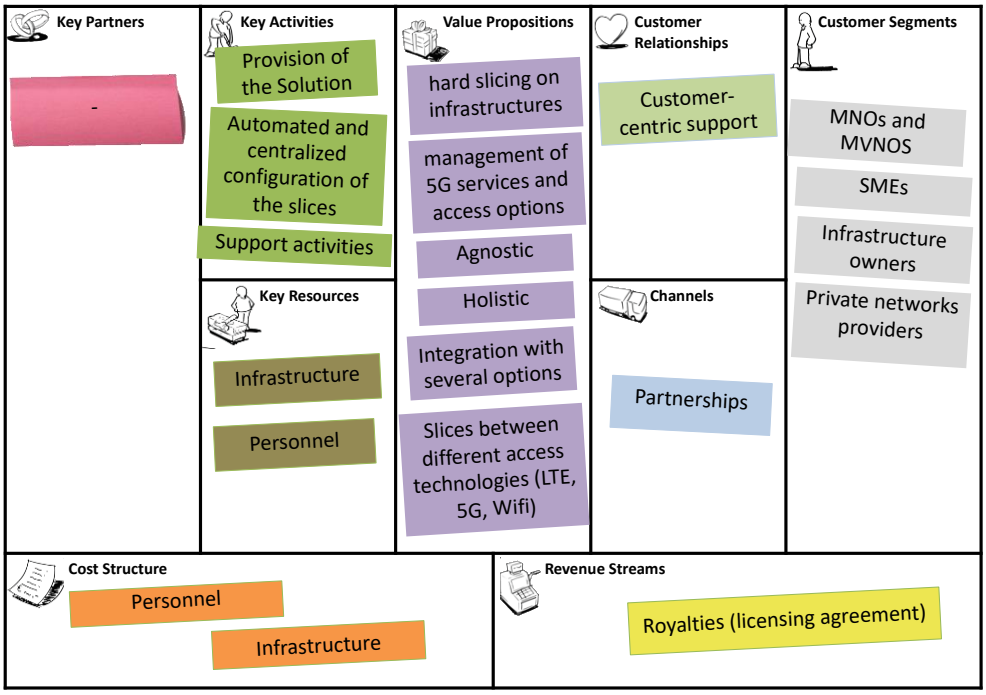


Figure 65: Slice Manager business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: Potential customers of the proposed Slice Manager are MNOs, MVNOs, SMEs, infrastructure owners, Private network providers that need a more efficient and interoperable slice manager for their networks.

Value Proposition: The SM solution provides and agnostic and holistic way for hard slicing on infrastructures and management of 5G services and access options. Innovations of the solution are:

- Software agnostic. Not bounded to a single vendor equipment.
- Integration with several options
- Slices between different access technologies (LTE, 5G, WiFi)

Channels: The following paths to reach the final clients were identified:

- An option currently considered to be relevant for the acceleration of the market take up and penetration is to establish one or more strategic partnerships with complementary players or integrators with a global footprint in the market.

Customer Relationships: Customer-centric (e.g., Neutroon Technologies) using customer care with support staff, online support and helpdesk.

Revenue Streams: Through Royalties - For the ongoing use of their assets, including copyrighted works governed by a licensing agreement (e.g. Neutroon Technologies).

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- Infrastructure to develop and test the solution and its upgrades
- Experienced and Qualified Human resources to maintain and upgrade the service
- Personnel to support partners/customers

Key activities:

- The Provision of the platform
- Automated and centralized configuration of the slices.
- Development of code aiming to update and/or improve the solution
- Customer support

Key partnerships: Not defined

Cost structure:

- Personnel Costs:
  - Technical personnel are committed to the development, maintenance and update of the proposed solution.
  - Customer and Partners' Support
- Infrastructure: Necessary equipment to develop, test and upgrade the solution

Strengths: SW agnostic, slices between different technologies, holistic, hard slicing, multiple option integration

Weaknesses: Integration with a wider amount of RAN providers. Integration with other Orchestrators.

Opportunities: Increased demand for slicing especially in private and enterprise networks

Threats: The spectrum regulation may leave private networks in MNO hands reducing the possibility of new solutions to success on the market and giving traditional providers a head start due its long relation with MNOs.

5.2.13 AI/ML Framework (AMF)

5.2.13.1 Description

The AMF, developed by ATOS, based on TensorFlow enables the development and serving of AI/ML algorithms to all the components of the 5G system, allowing to automate and optimize all kind of operations performed in the 5G network. The AI/ML framework of Affordable5G will be integrated will different open source solutions such as OSM

The Technology Readiness Level (TRL) of AMF at the current stage of the project is 2 while the targeted TRL at the end of the project is expected to be 5.

5.2.13.2 Intellectual Property Rights (IPRs) and Exploitation

Freedom to Operate. To ensure the possibility of commercial exploitation, the project partners have performed a survey for patents potentially blocking the commercial exploitation of their components. The survey showed that the proposed concept of AMF is not covered by any patent. *So overall, no IPR barrier to entry is foreseen*. **IPR Assets**. Background IP, mainly open-source code, related to the development of the AMF, brought in the project by the partners, belongs only to these partners. There is no joint ownership of any IP while boundaries between subsystems are clear. The partners have already signed the Consortium Agreement that clearly defines the background rights. **Foreground and Postground IPR**. NKUA has also contributed to the development of AMF. However, the IP created during the project lifetime and beyond, related to AMF, belongs to ATOS, who is the sole owner of the service.

Although there are no IPRs limiting the commercial exploitation of AMF, it should be noted that in order to implement the solution, Network Monitoring and Telemetry, MANO and non real-time RIC are mandatory.

The form of exploitation that has been decided for AMF is fourfold: 1) standards; 2) direct industrial use through open-source licenses; 3) Technology transfer and 4) Through publications in journals and conferences. The main goal of exploitation is the generation of revenues that will contribute to the sustainability of the service.

Competition: The main competitor of AMF is Acumos AI[82]. The advantages of AMF over its competitors the increased interoperability with other open source components such as OSM.

5.2.13.3 AMF Business Model

The AMF business model proposes a way to orchestrate and serve AI/ML to all the 5G system components, enabling automation and optimization of all kinds of operations.

[82] https://www.acumos.org/

In Figure 66, the AMF business model canvas is depicted.

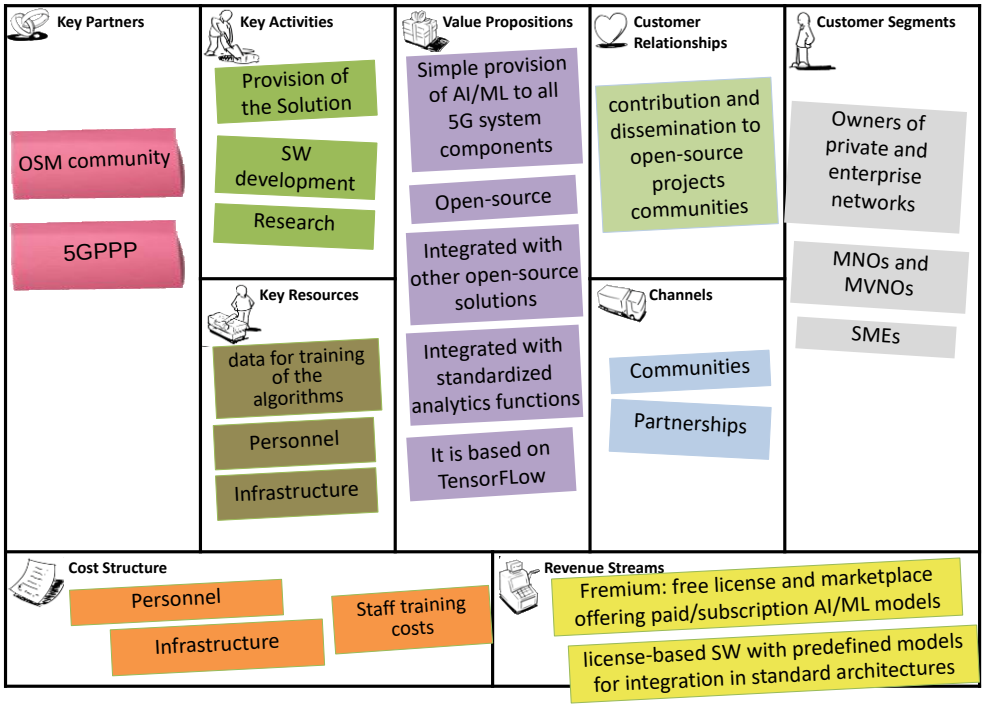


Figure 66: AMF business model canvas

a. External Aspects

The following external aspects have been identified in the completion of this business model canvas.

Customer Segments: Potential customers of AMF are MNOs, MVNOs, owners of private and enterprise networks, SME that need an efficient AI/ML framework to be integrated in their networks.

Value Proposition: The service makes it simple to provide AI/ML to all 5G system components. Innovations of the solution are:

- It is based on an Open source solution
- It is integrated with other Open Source solutions (e.g., OSM)
- It is integrated with standardized analytics functions (NWDAF, MDAF, etc)
- It is based on the most widely used AI/ML ecosystem (TensorFLow)
- Models based on TensorFlow can be executed in web, mobile, edge and embedded devices
- It enables intelligent orchestration and automation of the 5G system components

Channels: The following paths to reach the final clients were identified:

- Through communities

- An option currently considered to be relevant for the acceleration of the market take up and penetration is to establish one or more strategic partnerships with Network Management & Orchestration solution vendors.

Customer Relationships: The approach that will be followed in order to engage customers is through the contribution and dissemination to open-source projects communities like OSM.

Revenue Streams: Most probably a freemium business model with free license and marketplace offering paid/subscription AI/ML models, or license-based software with predefined models for integration in standard architectures

Moreover, funding from future EU projects will also be used in order to ensure service sustainability.

b. Internal Analysis

Key aspects of the internal analysis can be summarised as follows.

Key Resources:

- Infrastructure to develop and upgrade the solution
- Experienced and Qualified Human resources to maintain and improve the solution
- Availability of data for training of the algorithms

Key activities:

- Provision an AI/ML platform integrated with other Open Source frameworks (OSM) and with all the 5G system components
- Software development
- Research on integration of AI/ML algorithms in Smart Networks & Services control loop.

Key partnerships:

- OSM community
- 5GPPP

Cost structure:

- Personnel Costs: Technical personnel are committed to the development, maintenance and update of the proposed solution.
- Infrastructure: necessary equipment for the development, testing and upgrade of the solution
- Staff training costs

- Strengths: Based on an Open-source solution, Integrated with other OpenSource solutions (e.g. OSM), Integrated with standardized analytics functions (NWDAF, MDAF, etc), Based on the most widely used AI/ML ecosystem (TensorFLow), Enables intelligent orchestration and automation of the 5G system components
- Weaknesses: Not officially supported by OSM, Limited to TensorFlow based models, Not supported in windows, Only supports NVIDIA GPU acceleration.
- Opportunities: AI/ML are key enablers for future Smart Networks & Services[83], AI/ML integration is drawing attention from opensource orchestration solutions like OSM[84].
- Threats: Adoption and official integration of a different AI/ML framework from OSM or other open-source solutions, As there is no standardization in the use of AI/ML within Smart Networks & Services, it may be difficult to achieve a wide adoption of the solution due to interoperability issues.

[83] https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_he-partnership_smart-networks-services.pdf
[84] https://osm.etsi.org/wikipub/index.php/OSM_PoC_11_Deployment_of_AI-Agents_in_OSM

6 CONCLUSIONS

Although first commercial deployments of 5G private networks have just started, there are several issues that should be understood and addressed. The embryonic stage of such networks along with the multi-disciplinary nature of the impacting factors complicates the situation leading to the requirement of a clear roadmap containing technical, economic, regulatory and other issues and indicating where the critical decisions need to be made. In addition, a successful rollout strategy requires clearly defined business cases.

In this deliverable, we analysed the current situation in the markets of Affordable5G components and identified their characteristics and trends. Furthermore, we have provided an initial roadmapping exercise of the various technological, techno-economic, standardisation, and regulatory issues that need to be addressed as part of a successful deployment strategy. Finally, business models are provided as a means to approach profitable cases.

Market analysis confirmed the dynamic growth of all the markets under investigation in terms of revenues/size, market growth and number of players/competitors. The results of market analysis indicate that now is the right time to start the deployment of new and innovative solutions related to private networks.

In order to identify and assess the factors affecting the market adoption and evolution of Affordable5G solutions, the Analytic Hierarchy Process methodology was used as a means to accommodate the increased complexity and the inherent uncertainty of the process. The hierarchy of the problem under investigation was initially conducted and both criteria and sub-criteria were chosen amongst multiple alternatives with occasionally conflicting needs through discussions with experts. A questionnaire has been then conducted and distributed. The collected responses have been processed and analysed and the following conclusions were drawn.

Business is rated as the most important criterion followed in turn by Acceptance, Flexibility and Technology; whilst Performance has the lowest weight. Based on the global priorities, the most weighted sub-criterion is that of reliable communications, followed by New market opportunities, Edge computing, Open platforms/Open RAN, Interoperability, Cost reduction and Network operation automation. The high importance of both reliable communications and new market opportunities is not surprising. The former can be attributed to the critical environment of private networks. The new market opportunities are very important, since Affordable5G aims at facilitating the deployment of 5G networks by increasing the flexibility and interoperability between multiple vendors' equipment unlocking a wide range of opportunities for private networks and enterprises.

A business modelling was also performed. Involved actors are defined and new players are identified. Their relations along with the revenue streams have been described.

The scope of the deliverable is to provide a first insight on the business aspects of Affordable5G. These can also be used as guidance to Affordable5G partners and other stakeholders interested in participating in the rollout of private networks. Apart from investment strategies special efforts should be made to increase the awareness of the benefits accruing from 5G private networks. Finally, although regulatory issues are not among the top preferences of experts, these aspects (e.g. allocation of local frequencies) should be taken into serious account since they can significantly affect 5G private networks' success.

REFERENCES

[1] "Bundesnetzagentur - Regionale Netze", Bundesnetzagentur.de, 2021. [Online]. Available: https://www.bundesnetzagentur.de/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OeffentlicheNetze/LokaleNetze/lokalenetze-node.html. [Accessed: 15- Jul- 2021].

[2] “FCC – Federal Communications Commision”, 2021. [Online]. Available: https://www.fcc.gov/35-ghz-band-overview. [Accessed: 15- Jul- 2021].

[3] P. Antwerp, "Further digitalisation of port and urban emergency services thanks to 5G ‘Minerva’ network", Prez.ly, 2021. [Online]. Available: http://prez.ly/GZ1b. [Accessed: 15- Jul- 2021].

[4] "The Growing Case for Private 5G Networks", NEC, 2021. [Online]. Available: https://www.nec.com/en/global/insights/article/2021030002/index.html. [Accessed: 15- Jul- 2021].

[5] "Securing private networks in the 5G era", Data.gsmaintelligence.com, 2021. [Online]. Available: https://data.gsmaintelligence.com/research/research/research-2021/securing-private-networks-in-the-5g-era. [Accessed: 15- Jul- 2021].

[6] "Private Mobile Networks - May 2021 - GSA", GSA, 2021. [Online]. Available: https://gsacom.com/paper/private-mobile-networks-executive-summary-may-2021/. [Accessed: 15- Jul- 2021].

[7] "Private 5G Network Market Size | Industry Report, 2021-2028", Grandviewresearch.com, 2021. [Online]. Available: https://www.grandviewresearch.com/industry-analysis/private-5g-network-market. [Accessed: 15- Jul- 2021].

[8] "Private 5G Network Market Size & Share | Industry Report, 2020-2028", Polarismarketresearch.com, 2021. [Online]. Available: https://www.polarismarketresearch.com/industry-analysis/private-5g-network-market. [Accessed: 15- Jul- 2021].

[9] "Private 5g LTE Market Opportunity Forecast | Harbor Research", Harbor Research, 2021. [Online]. Available: https://harborresearch.com/private-lte-and-5g-networks/. [Accessed: 15- Jul- 2021].

[10] "What are private LTE/5G networks and why are they important?", Analysys Mason, 2021. [Online]. Available: https://www.analysysmason.com/research/content/comments/private-lte-5g-networks-rdme0-rma18-rma17/. [Accessed: 15- Jul- 2021].

[11] Campbell, K., Cruz, L., Flanagan, B., Morelli, B., O’Neil, B., Téral, S., & Watson, J. (2019). The 5G economy: How 5G will contribute to the global economy. IHS Markit. https://www.qualcomm.com/media/documents/files/ihs-5g-economic-impact-study-2019.pdf

[12] D. Gannon, R. Barga and N. Sundaresan, "Cloud-Native Applications," in IEEE Cloud Computing, vol. 4, no. 5, pp. 16-21, September/October 2017, doi: 10.1109/MCC.2017.4250939.

[13] Kubernetes and cloud native operations report 2021 by CANONICAL https://pages.ubuntu.com/rs/066-EOV-

[14] Cloud Native Computing Foundation (CNCF) SURVEY 2020, https://www.cncf.io/wp-content/uploads/2020/12/CNCF_Survey_Report_2020.pdf

[15] International Data Corporation (IDC) Worldwide Semiannual Public Cloud Services Tracker, 13/05/2021 https://www.idc.com/getdoc.jsp?containerId=prUS47685521

[16] NGMN Alliance (Next Generation Mobile Networks Alliance), “Cloud Native Enabling Future Telco Platforms”, Version 5.2, 17-May-2021

[17] H. Lee, J. Cha, D. Kwon, M. Jeong and I. Park, "Hosting AI/ML Workflows on O-RAN RIC Platform," 2020 IEEE Globecom Workshops (GC Wkshps, 2020, pp. 1-6, doi: 10.1109/GCWkshps50303.2020.9367572.

[18] T. L. Saaty, “A scaling method for priorities in hierarchical structures,” J. Math. Psychol., 1977, doi: 10.1016/0022-2496(77)90033-5.

[19] A. M. A. Bahurmoz, “The Analytic Hierarchy Process at Dar Al-Hekma, Saudi Arabia,” Interfaces (Providence)., 2003, doi: 10.1287/inte.33.4.70.16374.

[20] A. Kengpol and C. O’Brien, “Development of a decision support tool for the selection of advanced technology to achieve rapid product development,” Int. J. Prod. Econ., 2001, doi: 10.1016/S0925-5273(00)00016-5.

[21] G. Noci and G. Toletti, “Selecting quality-based programmes in small firms: A comparison between the fuzzy linguistic approach and the analytic hierarchy process,” Int. J. Prod. Econ., 2000, doi: 10.1016/S0925-5273(99)00131-0.

[22] M. M. Albayrakoglu, “Justification of new manufacturing technology: A strategic approach using the analytical hierarchy process,” Prod. Invent. Manag. J., 1996.

[23] R. W. Saaty, “The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation (Decision Making Series),” Math. Model., 1980.

[24] G. Dede, T. Kamalakis, and D. Varoutas, “Evaluation of optical wireless technologies in home networking: An analytical hierarchy process approach,” J. Opt. Commun. Netw., 2011, doi: 10.1364/JOCN.3.000850.

[25] G. Dede, T. Kamalakis, and D. Varoutas, “Towards a roadmap for future home networking systems: An analytical hierarchy process approach,” IEEE Syst. J., 2011, doi: 10.1109/JSYST.2011.2158683.

[26] S. Nikou, J. Mezei, and H. Bouwman, “Analytic Hierarchy Process (AHP) approach for selecting mobile service category: (Consumers’ preferences),” 2011, doi: 10.1109/ICMB.2011.29.

[27] Q. Song and A. Jamalipour, “Network selection in an integrated wireless lan and UMTS environment using mathematical modeling and computing techniques,” IEEE Wirel. Commun., 2005, doi: 10.1109/MWC.2005.1452853.

[28] N. Gerdsri and D. F. Kocaoglu, "Applying the Analytic Hierarchy Process (AHP) to build a strategic framework for technology roadmapping," Mathematical and Computer Modelling, vol. 46, pp. 1071-1080, 2007.

[29] G. Dede, et al., "Convergence properties and practical estimation of the probability of rank reversal in pairwise comparisons for multi-criteria decision making problems," European Journal of Operational Research, vol. 241, pp. 458-468, 2015.

[30] D. W. Stewart, Q. Zhao, “Internet Marketing, Business Models, and Public Policy,” Journal of Public Policy & Marketing: Fall 2000, Vol. 19, No. 2, pp. 287-296, 2000.

[31] J. C. Linder, S. Cantrell, "Five business-model myths that hold companies back", Strategy & Leadership, Vol. 29 Iss. 6, pp.13 – 18, 2001

[32] A. J. Slywotzky, Value Migration: How to Think Several Moves Ahead of the Competition, Boston (MA): Harvard Business Review Press, 1996.

[33] P. Weill and M. R. Vitale, Place to Space – Migrating to eBusiness Models, Boston, MA: Harvard Business School Press, 2001

[34] P. Timmers, Business Models for Electronic Markets, Electronic Markets, Vol. 8, No. 2, pp. 3-8, 1998