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UNICORE

UNICORE: A Common Code Base and Toolkit for Deployment of Applications to Secure and Reliable Virtual Execution Environments

Horizon 2020 - Research and Innovation Framework Programme

D1.7 Innovation Strategy Report

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Abstract

The goal of the EU-funded UNICORE project is to develop a common code-base and toolchain that will enable software developers to rapidly create secure, portable, scalable, high-performance solutions starting from existing applications. The key to this is to compile an application into very light-weight virtual machines – known as unikernels – where there is no traditional operating system, only the specific bits of operating system functionality that the application needs. The resulting unikernels can then be deployed and run on standard high-volume servers or cloud computing infrastructure.

This deliverable provides a report of the innovation activities executed within the UNICORE project and specifically included market analysis, description of unique value propositions and business opportunities, in order to formulate some business model canvas for the exploitation of the innovative results produced by the Consortium.

Target Audience

The target audience for this document is **public**.

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Technical Manager	Felipe Huici, NEC
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List of Authors

Editors	Gino Carrozzo (NXW), Alì Nejabati (NXW)
Participants	IBM, NEC, EPFL, UPB, CSUC, ULIEGE, ACCELLERAN, VU, NXW, OA/EKINOPS, CNW, ORO
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Contents

List of Figures

List of Tables

1 Executive Summary

Innovation management is a structured process which encopasses various phases:

- Monitoring of the partners innovation activities
- Execution of market analyses to define the landscape of the activity areas covered by the project in order to identify business opportunities
- Development of business models to support exploitation strategies and plans
- Planning and execution of activities aimed at generating awareness on the innovative results to ease the market uptake.

This deliverable provides a full report of the innovation management activities undertaken within the UNICORE project, and specifically describes how the Consortium has covered the aforementioned phases.
Specific UNICORE Unique Value propositions and innovative results for joint exploitation are identified and presented, together with Business Model Canvas related to the UNICORE use cases.
The deliverable documents the innovation strategy adopted for the open source software produced in UNICORE and how the Consortium intends to position itself towards the long-term sustainability of the action.

2 Introduction

Innovation can be either a *closed process*, by which a single company can successfully innovate all by itself, and an *open process* which requires collaboration and co-operation amongst autonomous entities to create the innovative technology solution. H2020 Innovation Actions like UNICORE [1] are valuable examples of contexts in which the open innovation can be pursued to generate value.

However, having all the partners individually precise stakes and expectations in the implementation of the research covered by the project, many individual innovation management actions are undertaken also individually to specifically

A typical innovation management strategy includes the following processes:

- Understanding and continuous monitoring of the landscape, in terms of market analysis, stakeholders, technologies, needs and opportunities
- Identification of key innovative assets produced by the project, which can generate impact at economic or societal level in relation to the identified landscape(s);
- Management and definition of measures to ensure that the Intellectual Property Rights (IPR) associate to the innovation assets are properly protected
- Management and definition of measures to ensure that market needs are best met and that the market is aware of UNICORE solutions (e.g. through dissemination and communication target actions)
- Planning of joint and individual exploitation actions which can maximise the impact of UNICORE research.

This deliverable reports on the execution of the aforementioned steps in UNICORE. More specifically:

- Section 3 presents a market analysis which was used to motivate and set the context for the technical activities related to the UNICORE use cases;
- Section 4 summarises the Unique Value Proposition (UPV) generated by UNICORE as applicable to the identified market contexts;
- Given that the major root result of the project is an open source software toolkit, Section 5 describes the decision elements to be considered when defining an open-source innovation strategy, and specifically the UNICORE positioning in this landscape, also in light of a seek for sustainability of the software baseline in the long-term;
- Section 6 presents the Business Model Canvas (BMC) developed by the UNICORE use case teams to identify the main strengths revenue streams coming from the use cases;

- Section 7 sketches the UNICORE exploitation strategy both for joint results and at individual partner level with an assessment and registry of UNICORE innovation assets which are monitored by the Innovation Management and the project management board to maximise their impact;
- Section 8 contains the documents conclusions.

3 Market analysis

This section reports some base market analyses run by the UNICORE use case teams to identify the foundations for the planned innovation strategy.

3.1 Serverless Computing

Cloud computing has evolved over the last 10 years, in part, thanks to the IaaS and PaaS platforms that have made it possible to take advantage of the economies of scale of the large data centers. The advantages that these cloud computing modalities have provided are:

- *Infinite* on-demand computational resources.
- Pay-per-use model, eliminating a large initial investment.
- Cost reduction.
- Increase the factor utilization thanks to virtualization.
- Simplify hardware operations and maintenance.

With all these advantages, more complexity has also come as layers of abstraction have been added to manage virtual resources that have led developers to become a kind of system administrator. The big disadvantage of this model was that for certain environments, the work taken to create the environment in which to run an application was more than the time to develop the application itself.

Serverless computing emerged with this need to gain agility in trivial developments and to dispense with the operating system and scaling plans tasks. Serverless computing allows running specific tasks such as image conversion or video transcoding simply by executing a code (function) in a high-level language without concern about provisioning or managing the resources where the code will be executed.

Currently, the major global cloud providers like AWS, Google and Azure have opted for the serverless computing model by offering their own FaaS services, and it is estimated that in the next 5 years the serverless computing market will grow by $ 7.6 billion to $ 21.1 billion at a rate of 22.7% per year (see Figure 3.1).

The main reasons why cloud users are adopting serverless computing so quickly are, the flexibility to scale, the speed of development and deployment, the decrease in planning and administration tasks and the reduction of the compute resources costs.

Despite all these advantages, serverless computing has certain aspects to improve and here is where unikernels technology can contribute. The main aspect is the startup time. In a normal serverless function, with a firecracker or kubernetes backend the task is scheduled and the platform provisions the resources needed to run the function, then, it will download and prepare the environment with all the software and libraries needed. This second step can take more than expected so using unikernels it is possible to reduce the preparation time by leveraging the fact that unikernels are preprocessed environments so, it will have all the components

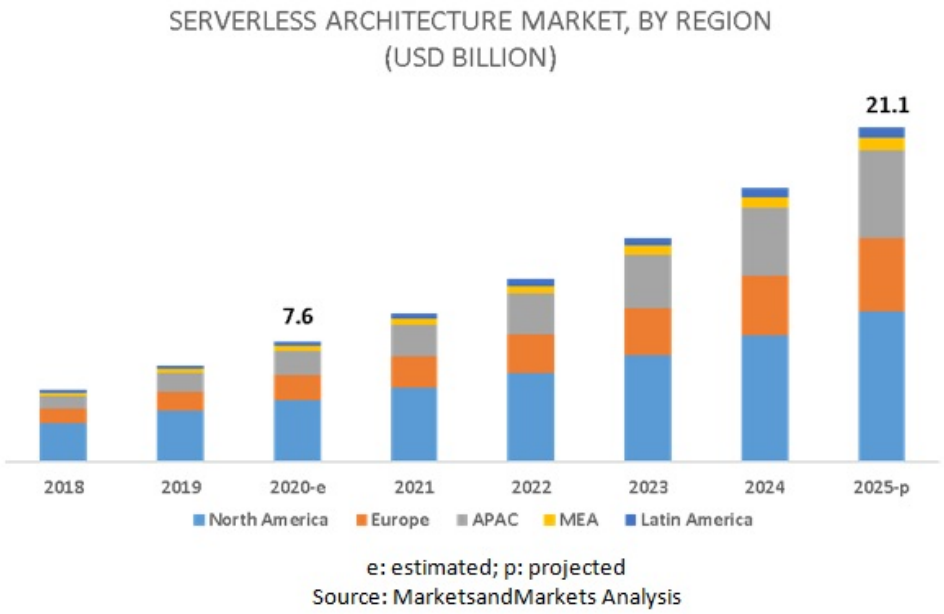


Figure 3.1: Serverless Architecture market by region (src: MarketsandMarkets Analysis)

needed to run the function in the image. In addition, this unikernel image will have only the necessary components to run the specific function so there wont be any other unnecessary components in it, so it will be possible to increase the factor utilization of the hardware by adding more functions simultaneously in the same server.

3.2 Network Function Virtualization

3.2.1 Virtualised RAN

The Open RAN market size has widely differing projections. A realistic analysis by Omida (Light Reading, see Figure 3.2) sizes it to about $3.2 billion in annual revenues by 2024, giving it close to 10% of the total 4G and 5G market. The other 90% will primarily be addressed by the big traditional RAN vendors like Ericsson, Nokia, Huawei, etc.

The impact of Open RAN on the industry was debated at EU Internet Forum. Of this Open RAN market size, it is estimated that 10-15% of that would be for CU/RIC network functions, with the bulk for radios (RU), other baseband (DU) functions and transport networks. This provides an annual Total Addressable Market (TAM) of up to $480 million in 2024 for Accelleran dRAX^{TM}.

Unikernels will be a key element of the industrialisation & commercialisation of low-power embedded Open 5G RAN, targeting the resource & budget constrained deeper edge and embedded environment markets.

Examples of this include mobile UAV/drone gNB (GSMA), (Infocom), and other non-terrestrial 5G base stations, together with future IAB (Integrated Access & Backhaul) devices. Additionally, the following market segments will become addressable: Cruise ships, oil & gas platforms, offshore wind-farms, remote industrial sites, farming, TV/media, fast disaster recovery and rural communities. This is in addition to governmental BVLOS (Beyond Visual Line-of-Sight) operation. See 5G Drones (https://5gdrones.eu/) for more

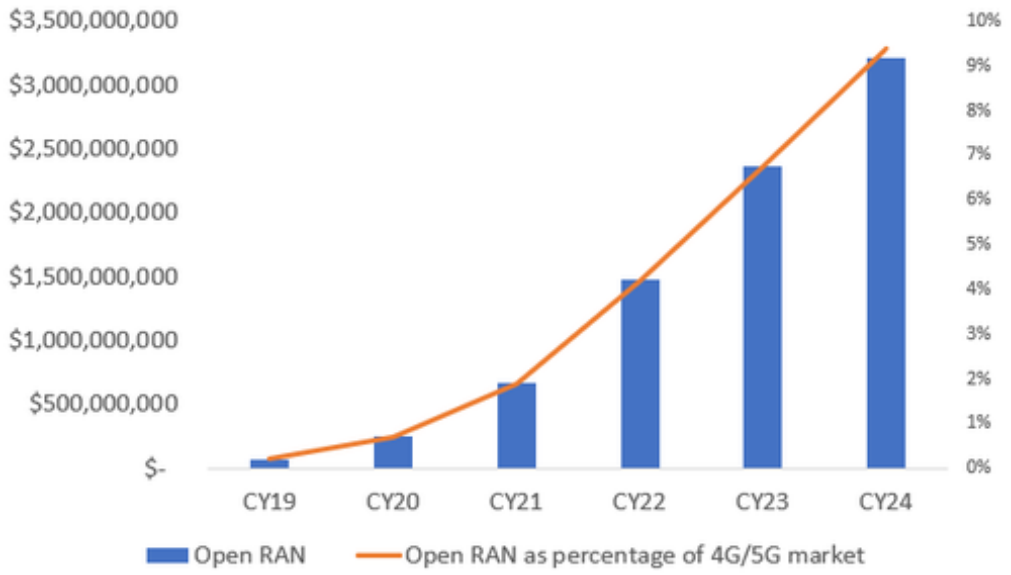


Figure 3.2: Open RAN Market Sizing (src: LightReading)

background.

In more traditional fixed private 5G Open RAN (like Industrial/Enterprise private networks or shared RAN neutral host platforms), it will be harder for Unikernels to replace the increasingly dominant cloud-native containers and Kubernetes architectures. It is anticipated that Unikernel deployments will be slower, with the SAM (Serviceable Available Market) of Unikernels being 5% of TAM in 2024 rising to 30% in 2030. This equates to an annual SAM of at least $24 million in 2024 for Accelleran dRAX^{TM}to a SAM potential of $600 million in 2030.

Due to regional restrictions (e.g. Chinese markets will primary be accessible only to Chinese solutions) and competition, it is anticipated that Accelleran could achieve a 20% SOM (Serviceable Obtainable Market, or market share), so Accelleran Unikernel dRAX^{TM}SOM could be $5 million in 2024 rising to $40 million by 2030 for product sales. Additional recurrent annual licensing, professional services revenues of support, maintenance and non-recurrent engineering could provide an extra 20%.

3.2.2 SD-WAN

Digital transformation and accelerated Cloud adoption are driving the enterprise IT landscape. Indeed, enterprises adopted the Cloud-based applications for business and communication leveraging the Network Function Virtualization (NFV) that brings different usage of the Cloud by offering services such as Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (PaaS). Increasingly, companies are finding the legacy private network services such as Multi-Protocol Label Switching (MPLS) not adapted to fast changes. On the other hand, Software-Defined Wide Area Network (SDWAN) made the connectivity more flexible and well-suited to reach the Internet and adapt to changes.

Comparing the security and reliability of Internet services with the needs of the business, companies are turning to Internet services for new network models as they find the internet access to be as good an alternative

as private networks.

Of course, Dedicated Internet access remains popular and trusted by companies, however a majority of these companies are also working with the broadband and mobile internet services to cope with failovers or the expensiveness of other options.

Dedicated Internet Access (DIA) has been a popular network solution. What is changing is the growing use of broadband internet as a primary connectivity option. According to Omdia, over the next two to three years, 58% of companies expect to connect the majority of their sites with just the internet, while only 13% of multinational enterprises expect to keep private/hybrid WAN serving their sites, as shown in Figure 3.3.

Figure 3.3: Comparing the usage of internet, private/hybrid WAN between todays and the expectations in the next 2-3 years. [src: Omdia, n=106]

To go further in this analysis, Internet Service Providers (ISPs) along with the SD-WAN and its service management capabilities have changed the perception of the internet services considered as best-effort, lacking the reliability, security, and performance features of private networks. Indeed, Omdia had conducted a study of over 100 multinational companies that rated on a scale of 1(extremely dissatisfied) to 10 (extremely satisfied) the experience with their internet services. Omdia had observed that 61 companies have rated the experience 8 to 10 which is extremely happy, while only 2 companies were disappointed (rated less than 5), for the rest they were satisfied (rates between 5 and 7).

According to this reshaping of the network connectivity, SD-WAN mixed with internet and private network seems to be the solution to make the transition to the next-generation networks. Indeed, SD-WAN and hybrid networks are becoming popular, where 56% of large companies have experience with SD-WAN, and about 50% of enterprises are mixing SD-WAN with MPLS according to Omdias Enterprise Network Services Insights 2020 survey. Today about one-quarter of large enterprises have completed initial SD-WAN projects. On the other hand, 43% of companies have their SD-WAN projects in progress. Current multinational enterprise adopters not only plan to continue their existing projects; most expect SD-WAN will serve a majority of their locations in the next two to three years (see Figure 3.4). These companies see the long-term value of SD-WAN from improved performance, reliability, control, and better security.

Strategic Planning Assumptions

- By 2023, to deliver flexible, cost-effective scalable bandwidth, 30% of enterprise locations will have only internet WAN connectivity, compared with approximately 15% in 2020.

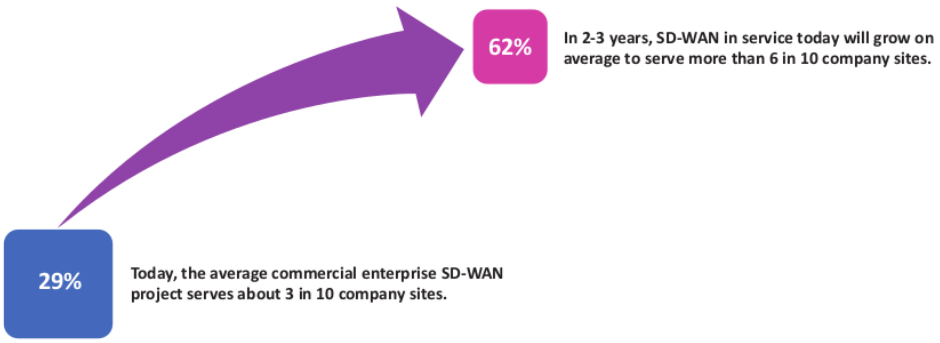


Figure 3.4: Expansion of the SD-WAN in the next 2-3 years [src: Omdia, n=46]

- By 2024, more than 60% of SD-WAN customers will have implemented a secure access service edge (SASE) architecture, compared with about 35% in 2020.
- By 2024, to enhance agility and support for cloud applications, 60% of enterprises will have implemented SD-WAN, compared with about 30% in 2020.
- By 2024, 20% of SD-WAN centralized configuration and troubleshooting will be touchless via an artificial intelligence (AI) assistant, compared with none in 2020.

On the Ekinops side, migrating selected functionalities of the in-house SD-WAN solution from containers to unikernels is seen as a strategic move to stay ahead of the competition. This is especially the case of the key server that is responsible for the distribution and renewal of encryption keys. Today, this functionality is implemented as a container which does not ensure isolation. So moving from container to unikernel will ensure isolation and enhance the performance of the SD-WAN solution, by increasing the number of overlays that can be ensured, reducing the memory footprint and the CPU overheads.

The Total Available Market (TAM) for the Ekinops SD-WAN solution is estimated to increase during the five coming years to reach approximately a value of 1600 million US dollars in 2024 for Small and Medium Enterprises, while for the large companies, this value will be doubled. The Compound Annual Growth Rate (CGAR) should be around 9%. For the Serviceable Available Market (SAM), the CGAR is estimated to be around 62%, increasing from 100 Million USD to 588 Million.

3.2.3 Virtual Broadband Network Gateways

Broadband Network Gateways Functions for Orange. In order to better understand the main drivers behind the Virtual Network Gateways adoption, we must first say a few words about the types of access networks and services that Orange Romania provides using the current (hardware monolithic) BNGs.

As can be seen from the architecture in Figure 3.5, BNGs are used within ORO mainly for GPON (FFTH, FTTB).

The types of B2B or B2C services provided by BNGs for Orange are: RADIUS CoA, IPoE, DHCP/DHCPv6 for Internet and VoIP, CG-NAT for DS-Lite Internet (IPv4 over IPv6), Wi-Fi Gateway (for Mobile Offload),

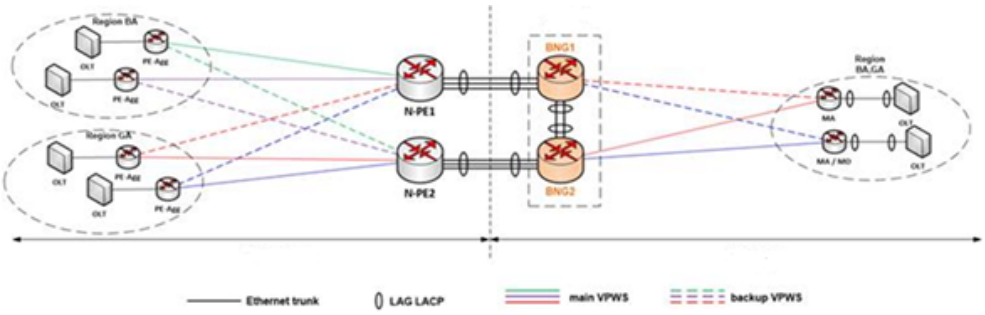


Figure 3.5: BNG - GPON High Level Service Architecture for Orange

TV (DVB-C), L2 and L3 VPN services, Direct Internet Access, CPE management.

The mention of GPON networks is important as we will be subsequently referring to Market Data for GPON networks.

BNG Market Data. The global Broadband Network Gateway (BNG) market size is projected to reach US$ 2530.14 million by 2027, from US$ 902.05 million in 2020, at a CAGR of 18.76% during 2021-2027.

The main drivers of the increase in BNG related services are:

- The COVID-19 outbreak
- Digital Transformation
- The demand for Wireless Broadband Network Systems
- Increasing Fixed Infrastructure Investments

In 2020, due the pandemic learning from home increased, thus net web traffic grew about 30% to 40%, fixed broadband traffic grew by about 30% - 60% and Wi-Fi Calling by about 70% - 80%. Also, VPN usage was up by about 49% worldwide as employees are working from home. Online gaming rose also by about 115% due to individuals remaining in residence as a result of lockdown, resulting in a rise of the home entertainment market.

Considering that the global pandemic is still not over, the social distancing standards and the increase in demand for online education / learning systems, byod, as well as a various sort of voice / video collaboration apps or devices that their employees / communities can connect throughout geographies, gadgets, systems we can only expect the need for fixed broadband services to rise even more throughout 2021 and the following years.

Another factor that will lead to further investments in BNG infrastructure is / will be the transformation due to 5G adoption, which will imply the separation of the user and control plane functions, operation for multi-access broadband gathering, leading to the advancement of fixed-mobile convergence.

All of the increased demand for fixed broadband services will lead to telecom operators supplementing their investments in these services, as can be seen by the scale of investments (180 Billion USD) made by China in

developing its mainland telecommunication framework. Orange Romania has also been investing in upgrading backhaul connections to 100 Gbps and some other Orange subsidiaries have plans to migrate to virtualized BNGs.

GPON Market Data. As discussed earlier, in the case of Orange, the BNG market is highly correlated to the GPON market, as the GPON market will lead to an increase in demand for BNG services.

According to Allied Market Research the global GPON equipment market was valued at $10,084 million in 2016, and is projected to reach $55,551 million by 2023, registering a CAGR of 27.8% from 2017 to 2023.

The global GPON (gigabit passive optical network) equipment market is driven by technological advancements and increase in demand for better quality fiber in the network architecture of service providers. In addition, emergence of FTTH projects, specifically in China and the U.S., has fueled the GPON equipment market growth. Moreover, low cost of ownership, high ROI, advanced security, optimized bandwidth connectivity, and simplified network operations supplement the GPON equipment market growth.

Market conditions are driven by both of the broadband competition and customer needs. Moreover, broadband competition will inuence broadband pricing, network coverage, and bandwidth that will in turn affect the attractiveness of broadband services and hence impact the penetration level achievable by a country relative to other markets.

Virtualization Market Data. The global service virtualization market size was valued at USD 410.8 million in 2016. It is expected to exhibit a CAGR of 17.6% over the forecast period, for a total of 1694.9 million in 2025. Up until 2020, the CAGR has been accurate.

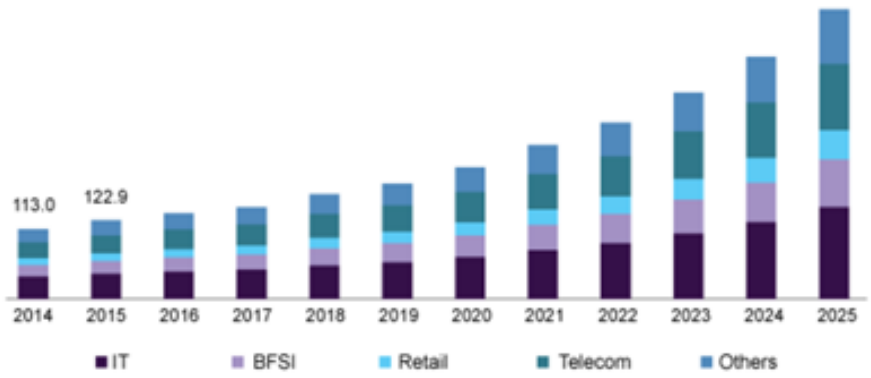


Figure 3.6: US Service Virtualization market size, by vertical (src: Grandviewresearch)

The above metrics, although for the US, emphasize the rising trend of adoption for virtualized services and there is no doubt that it will increase worldwide significantly for the Telco sector in the coming years.

Benefits of Virtualized BNG. With the roll-out of 5G and its core or E2E architecture shaping on concepts like Network Slicing (like ETSI MANO or ONAP E2E Network Slicing) it has become evident for all Telecom Operators that the Network of the Future will be Software Based.

As a result, not only will services provided by a BNG (such as DHCP, VPN, VPWS, VoIP) be decomposed, but they will be moving from the Core to the Edge of the Telecom Provider Network.

These benefits of a Virtualized, Unikenel based BNG and over a Hardware based Monolithic BNG (confirmed by our own experiments during the Unicore project) a can be summed up as:

- **Increased Scalability.** Resources of existing BNGs can be reduced or increased or new BNG instances can be launched as per user base requirements due to the flexibility of a Virtual Infrastructure.
- **Shorter Deployment Time.** BNG services are templates that can be applied to Virtual Machines or Unikernels, offering dynamic template-based configuration of subscriber sessions.
- **Lower Costs.** A Virtualized Infrastructure is more flexible than a Hardware one and will consume less resources when the demand for BNG services is low and more resources when the demand for BNG services is high.
- **Independent Microservices on a VNF model.** Services will be provisioned on the network only when requested by clients on a $1:1$ (client : server) model, meaning that, for example, for a VPN session a client would have 1 micro-service providing him just that DHCP service and for another client requesting a DHCP and VoIP session, that client would have a separate BNG micro-service.
- **Services moving from Telecom Core to Edge.** Services such can be provided with better QoS values (e.g. lower latency) if closer to the client premises.

3.3 Home Automation / IoT

Offloading IoT platform controllers to the cloud is not a new area, yet valid privacy concerns raised by clouds run in different jurisdictions hamper offloading, forcing IoT systems to install hardware in the home to control IoT devices, and reducing economic efficiency. Federated, smaller clouds are a key direction of EU development that aims to enable such offloading to nearby clouds thus retaining the privacy of European users and ensuring compliance to EU general data protection regulation.

In UNICORE, Nextworks is migrating a selected set of application services to unikernels from their Symphony digital living platform, a product developed by Nextworks that is currently deployed in VMs and containers. Possible unikernel-based services can include home and building automation, data storage and analytics, media services and voice/video communications. Additionally, Correct Networks will use PacketCloud serverless computing functions to develop a proof-of-concept IoT controller.

According to a research report on the Internet of Things market published by The Business Research Company [2], the IoT market share by industry reveals that this technology is being adopted primarily by manufacturing and transportation services companies, which will drive the IoT market in the forecast period. Microsoft and Rolls-Royce have established a co-operation focused on future Rolls-Royce intelligent engines, in which Microsoft Suite will be integrated into service solutions to increase the company's digital capabilities.

Global IoT expenditure was expected to climb 8.2% year over year to USD 742 billion in 2020, according to International Data Corporation (IDC), down from 14.9 percent growth anticipated in November 2019. In 2021, however, IDC predicts that worldwide IoT investment will return to double-digit growth rates; it never happened due to the unexpected COVID-19 global pandemic [3]. However, The global internet of things market was valued at USD 244.47 billion in 2020, and it is predicted to reach USD 286.9 billion in 2021, with a compound annual growth rate (CAGR) of 17.4% [4]. The increase is primarily due to companies resuming operations and adjusting to the new normal as they recover from the COVID-19 impact, which had previously resulted in restrictive containment measures such as social distancing, remote working, and the closure of commercial activities, all of which posed operational challenges. The IoT market size is expected to reach USD 767.3 billion in 2025 at a CAGR of 28% (see [5] and Figure 3.7). This comprises IoT-related hardware, software, and services. As a result, IoT adoption is likely to increase demand for IoT.

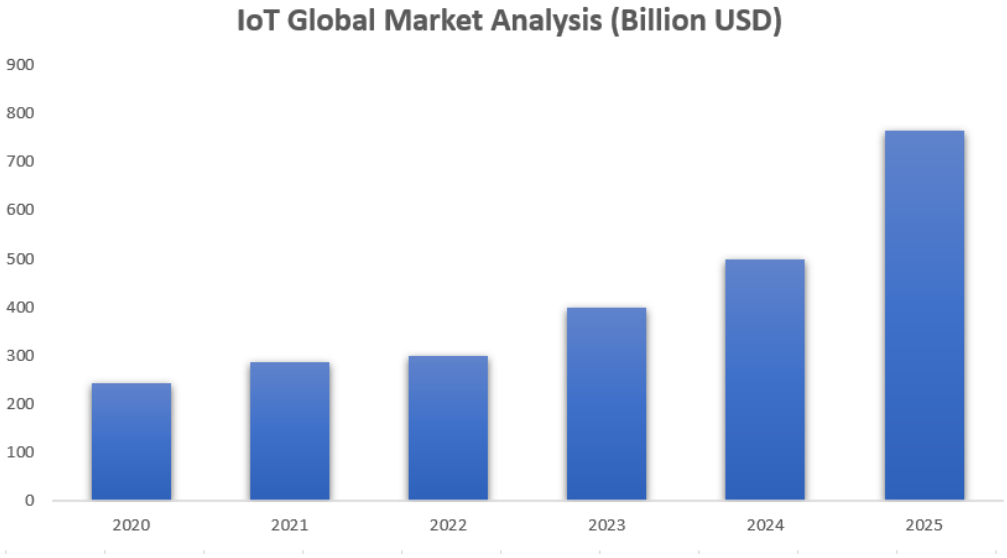


Figure 3.7: IoT Global Market Analysis (src: MarketsandMarkets)

According to MarketsandMarkets (see [6] and Figure 3.8), from 2020 to 2025, the global home automation market is expected to increase at a CAGR of 9.1%, from USD 40.8 billion to USD 63.2 billion. Home automation market development is predicted to be fueled by increased awareness of efficient energy consumption, rising power prices, and technical improvements. Furthermore, rising security and safety concerns spurred the use of home automation systems, supporting market growth. As presented in [7], some top impacting factors of Home Automation market are:

- Global increase in electricity prices
- Government regulations for energy efficiency
- Increase in awareness among consumers
- Technological innovations

- Payback period extend

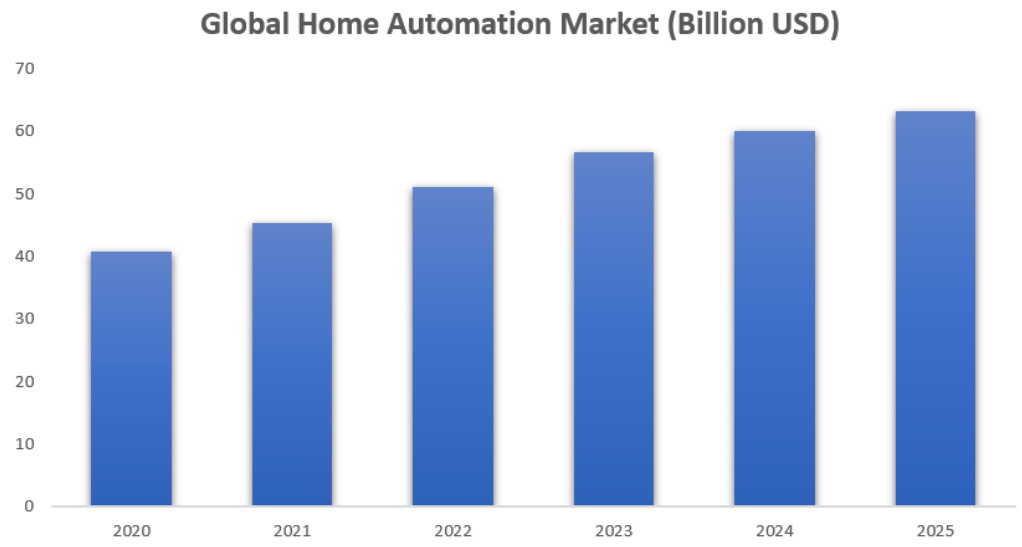


Figure 3.8: Global Home Automation Market (src: MarketsandMarkets)

Growth in the deployment of IoT / Home Automation Devices, increasing acceptance of wireless technologies, the demand for energy-efficient solutions, and government efforts are all major reasons driving IoT / Home Automation growth. With this regard and as presented in [8], IoT / Home Automation key market drivers are:

- The decrease in the hardware cost such as CPU, memory, storage, sensors and actuators.
- Devices such as sensors have proliferated, without which IoT opportunities cannot be realized.
- The lower cost of bandwidth and storage expands the amount of money available for large-scale computing systems.
- Big Data and Cloud Computing provide elastic repositories for storing and processing massive amounts of data.
- The convergence of information technology and operational technology and consequently rise of Fourth Industrial Revolution (Industry 4.0).
- Rise of Fifth Generation (5G) mobile network which is the foundation for realizing the full potential of IoT by providing Ultra-Reliable Low Latency Communications (URLLC), enhanced Mobile Broadband (eMBB) and massive Machine-Type Communications (mMTC).

By considering these key market drivers for IoT / Home Automation, the demand for platform-as-a-service products that use OS-Level and Kernel-Level virtualization to deliver lightweight and standalone software and services can increase massively. Therefore, UNICORE has the potential to make the IoT / Home Automation solutions produced by Nextworks more ready to work in various virtualization environments and specifically at edge/extreme edge, where hardware resources are generally constrained.

3.4 Smart Contracts

Smart contract-enabled blockchains have been around for several years, but the development of smart contracts has been limited to blockchain-specific, restrictive programming languages. These restricted programming languages have been devised to ensure deterministic execution, i.e. that the smart contract outputs are always strictly identical given the same inputs, across platforms and time. However, this requires developers to learn a new programming language and the smart contracts performance is prohibitively slow for certain workloads.

As part of the UNICORE project, the DEDIS lab at EPFL is working towards enabling the efficient execution of smart contracts through unikernels written with general purpose programming languages. Such a solution would significantly accelerate the development and deployment of smart contracts, as well as broaden their use cases, especially in private (or permissioned) blockchains deployed in industrial settings, where blockchain participants are expected to manage a virtualized infrastructure.

Blockchain has been a *hot* topic in the news over the past few years, but industry has also shown a serious interest in this technology: IBM has invested $200 million in the blockchain-powered Internet-of-Thing (IoT), the blockchain-specific investment model of initial coin offerings (ICOs) has skyrocketed to $5 billion, and venture-capital funding for blockchain start-ups has consistently grown and were up to $1 billion in 2017.

According to a research report published by Grand View Research, the global blockchain technology market size was valued at $3.67 billion in 2020. It is expected to expand at a compound annual growth rate (CAGR) of 82.4% from 2021 to 2028 (see [9] and 3.9). Different reports provide us with comparable numbers, such as The Business Research Company [3] indicating a global market size of $2.24 billion in 2020, and a CAGR of 97% over the 2020-2025 period.

Specifically in the European market, according to a new update by the International Data Corporation (IDC, see [10]), spending in 2021 is forecasted to be $2 billion. In addition, spending in Europe is expected to nearly triple from 2020 to 2024.

The payments segment dominated the market in 2020 and accounted for more than 44.0% share of the global revenue. Blockchain technology improves payment systems efficiency, minimizes operating costs, and offers transparency. These benefits provided by blockchain technology are increasing its use in payment solutions, thus, driving the segment growth. At the same time, blockchain reduces the need for middlemen in payment processing, which is also a major factor driving the segment growth.

The smart contracts segment is anticipated to register the highest CAGR over the forecast period. The terms and conditions of smart contracts deployed over a blockchain network cannot be altered. Blockchain technology hence makes it difficult for third parties to tamper or hack the data in contracts. Thus, companies across different industry verticals are adopting blockchain-based smart contracts to reduce the costs of execution, verification, fraud prevention, and arbitration.

In the chart below, Deloitte [11] provides a breakdown of use cases in the smart contract market.

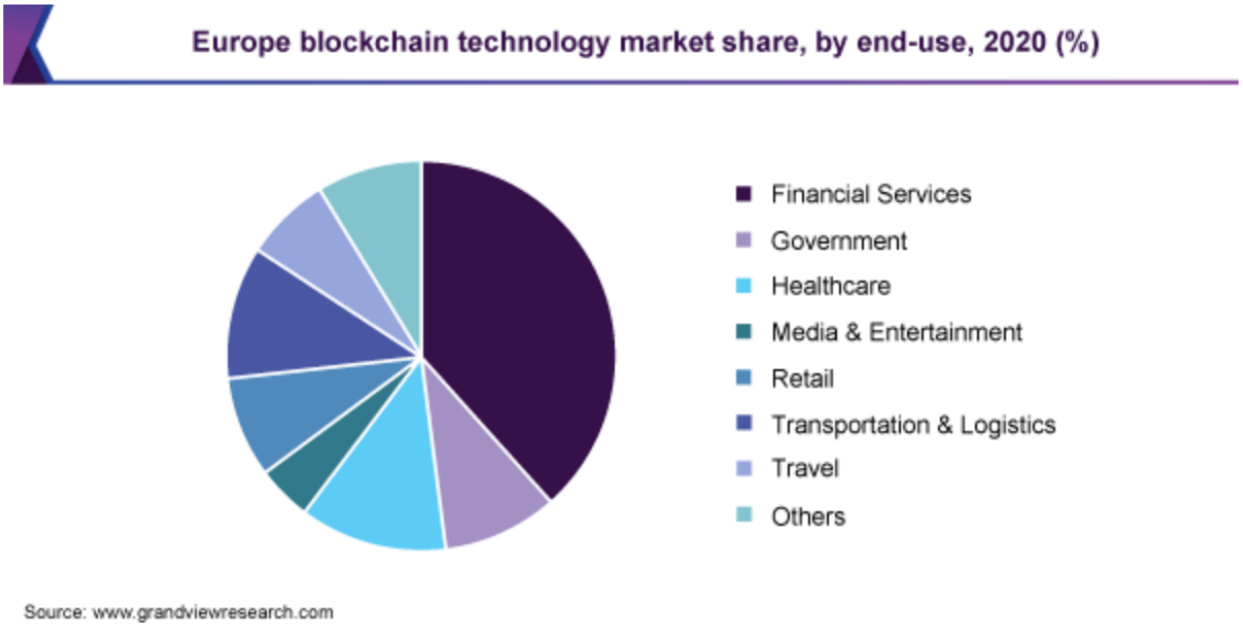


Figure 3.9: EU blockchain technology market share 2020 (src: Grandview Research)

While excitement for smart contracts is growing in the realm of both permission-less and permissioned blockchains, the latter is likely to see faster adoption in industry, given that complexities around trust, privacy, and scalability are more easily resolved within a consortium of known parties.

Federated blockchains (also known as consortium blockchain) are thus expected to be a major trend shaping the blockchain market in the 2020 to 2030 period [3].

Federated blockchains are private, permissioned blockchains, which give permission for multiple entities to have access to the network by voting or token system. Decentralization is maintained by the prior selection of the authority nodes by the organizations in the network which can exchange the data or information continuously. This effort is best incarnated by the HyperLedger Consortium, which unites the likes of IBM, Microsoft, the Linux foundation, JPMorgan, VISA, Walmart, Huawei, EDF, FedEx, and many others to develop a common open-source foundation for permissioned blockchain projects.

While public blockchains are unlikely to adopt a unikernel-based solution due to the need for a virtualization infrastructure, federated blockchains stand to fully benefit from the efficiencies offered by the usage of unikernels as a smart contract execution environment. Therefore, UNICORE has the potential to increase the adoption of smart contracts and blockchain-based solutions, by improving their efficiency, lowering the entry barrier for developers, and thus contributing to the growth of the segment by opening up new business opportunities.

Use case		What the smart contract can do
Financial services	Trade clearing and settlement	Manages approval workflows between counterparties, calculates trade settlement amounts, and transfers funds automatically
	Coupon payments	Automatically calculates and pays periodic coupon payments and returns principal upon bond expiration
	Insurance claim processing	Performs error checking, routing, and approval workflows, and calculates payout based on the type of claim and underlying policy
	Micro-insurance	Calculates and transfers micropayments based on usage data from an Internet of Things-enabled device (example: pay-as-you-go automotive insurance)
Life sciences and health care	Electronic medical records	Provides transfer and/or access to medical health records upon multi-signature approvals between patients and providers
	Population health data access	Grants health researchers access to certain personal health information; micropayments are automatically transferred to the patient for participation
	Personal health tracking	Tracks patients' health-related actions through IoT devices and automatically generates rewards based on specific milestones
Technology, media, and telecom	Royalty distribution	Calculates and distributes royalty payments to artists and other associated parties according to the contract
Energy and resources	Autonomous electric vehicle charging stations	Processes a deposit, enables the charging station, and returns remaining funds when complete
Public sector	Record-keeping	Updates private company share registries and capitalization table records, and distributes shareholder communications
Cross-industry	Supply chain and trade finance documentation	Transfers payments upon multi-signature approval for letters of credit and issues port payments upon custody change for bills of lading
	Product provenance and history	Facilitates chain-of custody process for products in the supply chain where the party in custody is able to log evidence about the product
	Peer-to-peer transacting	Matches parties and transfers payments automatically for various peer-to-peer applications: lending, insurance, energy credits, etc.
	Voting	Validates voter criteria, logs vote to the blockchain, and initiates specific actions as a result of the majority vote

Figure 3.10: Range of use case applications of smart contracts (src: Deloitte)

4 Unique Value Propositions in UNICORE

Unique Value Proposition (UVP) is an explanation of what makes UNICORE different and it is a succinct affirmation about the advantages UNICORE offers to its users/adopters.

The Unique Value Propositions (UVP) generated by the UNICORE project are summarised in the following subsections.

4.1 The UNICORE problem space

First lets try to understand what problem UNICORE is trying to solve.

Quickly developing, upgrading and deploying applications is the core function of the IT industry, above all in Cloud and virtualized environments. In this context, Virtual Machines are a key common building block. However, for the sake of enhanced agility and flexibility, the industry has started embracing containers as a replacement to VMs for a wide variety of applications, to reduce dev-ops costs and speeding-up software deployment. Despite their efficiency, containers offer poor isolation as shown by their many vulnerabilities.

The UNICORE solutions are positioned in the area of toolkits for flexibly and easily building lightweight VMs. With UNICORE, lightweight VMs are built as easy as compiling an app for an existing OS.

4.2 UVP#1 - Unikernels

Unikernels are the smallest lightweight VMs one can create, they are VMs where there is no traditional operating system running underneath the application; instead, the application is compiled against bits of OS functionality that it needs, resulting in a very small app+OS bundle. Many unikernels have been developed already such as ClickOS, MiniCache, Mirage, Minipython, Solo5, OSv, Erlang on Xen, HalVM; they all offer great performance and low memory footprint for their chosen task. Key advantages of unikernels are:

- Fast Boot and Migration Time
- Low memory footprint
- Strong Security
- High Density in hosting guests
- Performance tuned on the implementation of a single function

All these advantages make the unikernels particularly suited to a number of use cases like serverless, NFV scenarios at edge/extreme-edge, IoT, etc. In comparison with other unikernel open-source projects such as Rumprun, OSv and MirageOS, UNICORE based applications offer smaller image sizes (see Figure), less boot time for images (see Figure), less memory needed to run applications (see Figure) and higher performance (see Figure).

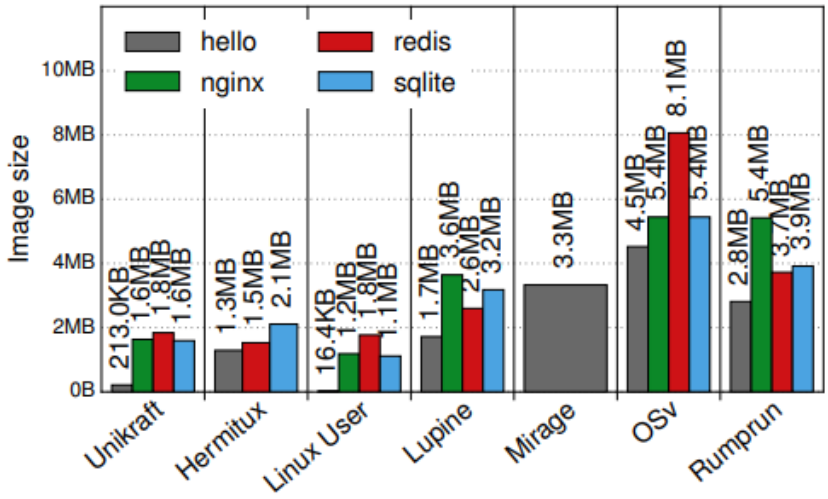


Figure 4.1: Image sizes for UNIKRAFT and other OSes

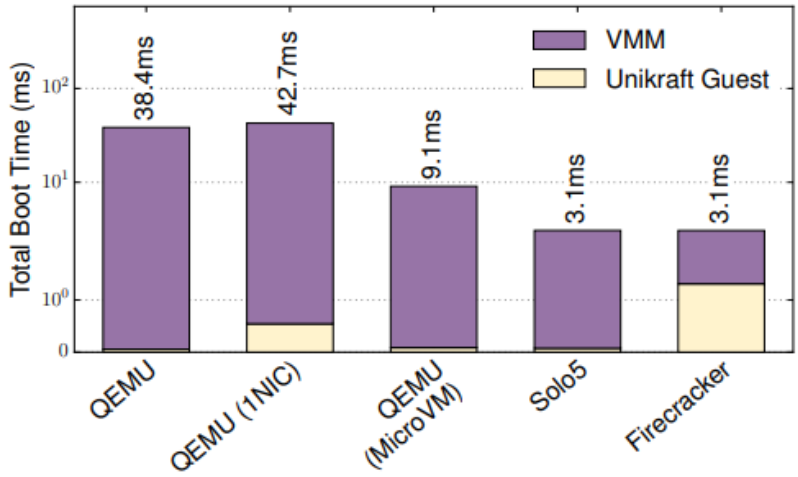


Figure 4.2: Boot time for UNIKRAFT images with different virtual machine monitors

4.3 UVP#2 - UNIKRAFT Open Source unikernel build tool

UNIKRAFT supports multiple platforms (e.g., Xen, KVM, Solo5, Firecracker) and CPU architectures (e.g., ARM, x86). It consists of three basic components:

- **Library Pools**: are UNIKRAFT modules, each of which provides a basic piece of functionality.
- **Configuration Menu**: Inspired by Linuxs Kconfig system, this menu allows users to pick and choose which libraries to include in the build process, as well as to configure options for each of them, where available. Like Kconfig, the menu keeps track of dependencies and automatically selects them where applicable.
- **Build Tool**: Based on make, it takes care of compiling and linking all the relevant libraries, and of producing images for the different platforms selected via the configuration menu.

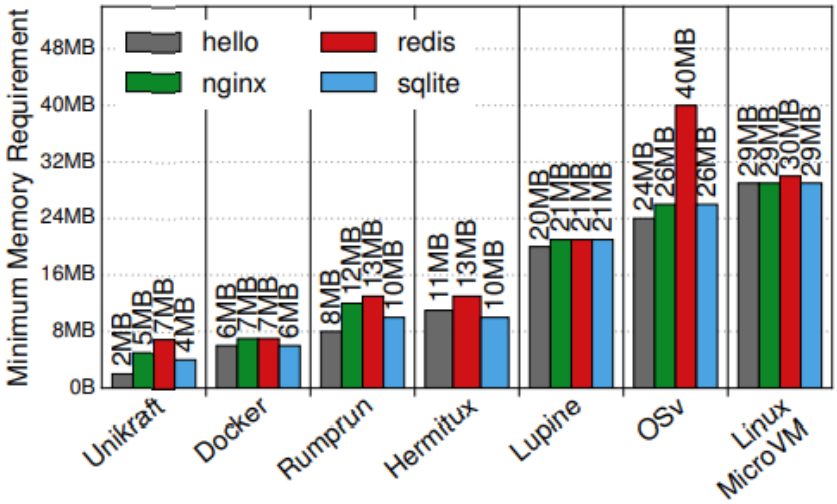


Figure 4.3: Minimum memory needed to run different applications using different OSes, including UNIKRAFT

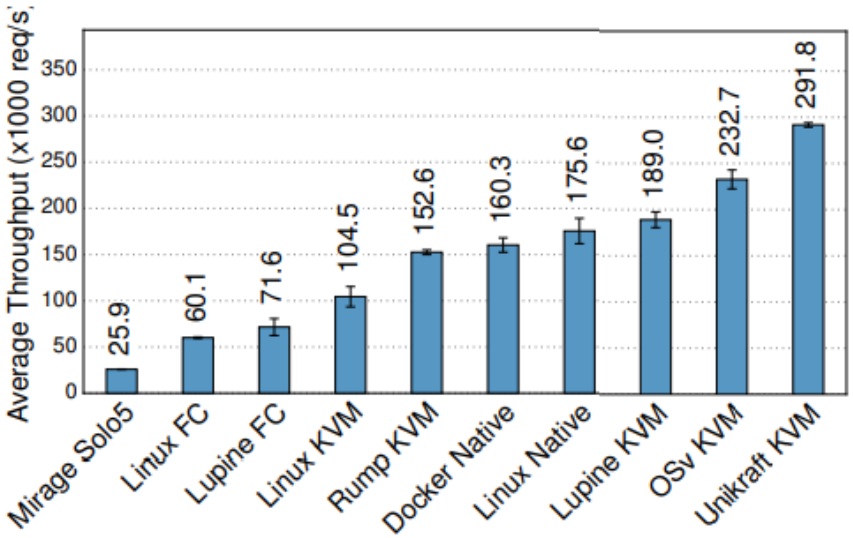


Figure 4.4: NGINX (and Mirage HTTPreply) performance with wrk (1 minute, 14 threads, 30 conns, static 612B page)

UNIKRAFT is a modular system based on micro-libraries, some of which are internal, meaning that they provide low-level functionality such as operating system primitives or CPU architecture specific code and are part of the main UNIKRAFT repository; and external libraries, which tend to provide higher-level functionality (e.g., openSSL, protobuf, etc.) and have their own repository fully independent of the main UNIKRAFT one.

4.4 UVP#3 - Open library of krafted unikernel applications

UNIKRAFT leverages from Library Pools which are modules that provide a basic piece of functionality. Libraries can be arbitrarily small (e.g., a small library providing a proof-of-concept scheduler) or as large as standard libraries like libc. This component handles all the micro-libs that will be used by applications. The pool consists of a set of micro-libs and can be divided into three sub-pools:

(i) Main lib pool will contain all the libraries related to drivers, network stack, memory allocator, etc.

(ii) Platform lib pool will contain all the libraries for a particular target platform such as Xen, KVM and bare metal.

(iii) Architecture lib pool will provide libraries dedicated to a particular computer architecture.

Based in libraries, we developed a number of different application runtimes in UNIKRAFT to support build and run wide range of applications, including:

- C
- Golang
- C++
- Python 3
- Ruby
- WAMR
- Redis
- NGINX
- Micropython
- SQLite
- Click!
- Lua

4.5 UVP#4 - Security and isolation primitives

To efficiently detect all memory and temporal errors, a secure memory allocator (Wilde) has been developed which is capable of detecting any attempt to use a pointer to an object that has already been freed. In particular, the allocator ensures upon allocation time that objects are mapped to their own virtual address page(s), even if they are sharing the same physical page. Furthermore, the tool uses virtualization technology to allow page table manipulation directly, without requiring expensive mode switches.

To reduce the hardware and software attack surface, a multilevel security-enhancing approach has been considered, which offers a portfolio of defense techniques deployed at different stages of the system life cycle. This is summarised by the following four steps:

(i) deploy validation techniques that can prove the absence of vulnerabilities in software.

(ii) deploy fuzzing techniques and operate high-coverage security testing of the target unikernel application.

(iii) deploy hardening techniques for the target unikernel application.

(iv) additional hardening techniques that protect the target unikernel application against hardware vulnerabilities.

4.6 UVP#5 - UNICORE Toolstack

The UNICORE toolstack is used for automating the building, verification, configuration and deployment of unikernel images. The toolstack relies on the inherent modularity of UNICORE components (core APIs, external libraries) to select required software components and build a final specialized unikernel instance. Furthermore, Additional features are provided to UNICORE APIs and toolchain to ensure performance, portability, scalability and security.

Compilation Toolchain. The UNICORE toolchain will provide a set of tools to automatically build images of operating systems targeting applications. In a general way, the toolchain will build unikernels by extracting OS primitives and selecting micro-libs and third party libraries.

Multi-Target Support. In UNICORE we introduced a platform abstraction API that allows UNIKRAFT to seamlessly build images targeting different platform types: virtual machines (VMs) (Xen, KVM/QEMU, Solo5 and Amazon Firecracker), containers (OCI and Docker) and bare metal (x86 64, ARM64). In this fashion, once a particular application has been ported to the system; it should be simple to deploy it to a variety of platforms and architectures.

Validation and Verification Support. symbolic execution is a way to automatically validate large parts of the unikernel libs and applications run on top of them. In order to achieve this, based on symbolic execution engines (KLEE) and other verification tools incorporating symbolic execution (CBMC), we integrated multiple verification/validation techniques: formal verification, runtime security checks, implementation in safe programming languages.

Performance Optimization Tools. The performance optimization tools are planned to use machine learning techniques to optimize a unikernels build configuration options using data collected by the performance analysis. As preliminary steps, support for PGO (Profile Guided Optimization) was added and preliminary performance measurements validating the benefits of specialized UNICORE unikernels were done.

Orchestration Tools Integration. To make the adoption process of unikernels go more smoothly and run unikernels in multiple platforms like KVM, XEN and Containers; we are working on integration into OpenNebula as a virtual machine orchestrator and Kubernetes as container orchestrator.

5 Open Source Software Innovation Strategy

An early and straightforward definition of innovation simply states that

Innovation is the generation, acceptance and implementation of new ideas, processes, products or services.

The tendency is to see three distinct approaches to innovation in businesses today: incremental innovation, breakthrough innovation and radical innovation [12]. These can be mapped against two factors business model newness and technology newness, as shown in Figure 5.1.

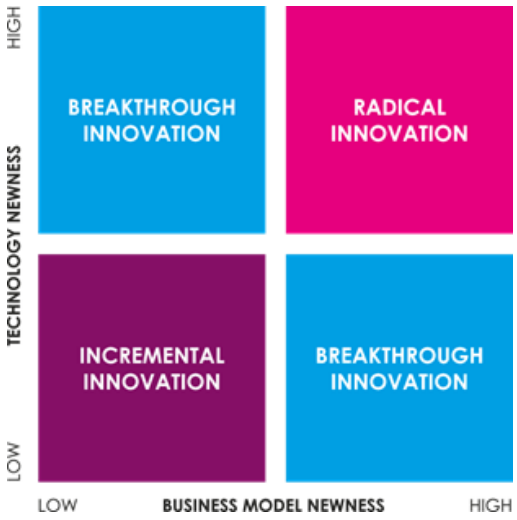


Figure 5.1: Innovation approaches in business (src:Muckersie-2016)

The UNICORE Projects stands with *Breakthrough Innovation* approach since the technology newness and innovation is unique but on the other hand the business model is based on Lean Business Model Canvas (BMC) Approach (see [13]) which is a more practical procedure that serves as a tactical strategy or blueprint for a UNICORE product from the bottom up.

5.1 Licensing models for open-source projects

UNIKRAFT and UNICORE toolstack are FLOSS (Free/Libre and Open Source Software) projects which means they are developed openly and in collaboration within the established community. UNIKRAFT is organized into libraries where each might be individually licensed. In general, each source file should declare who is the copyright owner and under which terms and conditions the code is licensed.

The main license of the UNIKRAFT project is **BSD 3-clause license** [14], which allows unlimited redistribution for any purpose as long as its copyright notices and the license's disclaimers of warranty are maintained. This license applies in particular to source code files that do not declare a license and where there is no license information file (e.g., LICENSE, COPYING) placed in the same or corresponding root folder (see [15]).

5.2 Business models for open-source projects

Before considering how it could be possible to monetize open-source projects, there are two prerequisites need to be discussed which serve as mission goal for the open source innovation strategy:

Widespread adoption. The first requirement of a successful open source project is its widespread adoption, i.e. the open-source project should have a significant user base and community to make impact.
Since an open-source company can only capture a small portion of the value it generates, widespread acceptance is needed. To be specific, an open-source company distributes the majority, if not all, of its produced software for free, and the majority of its users never pay for it.
In reality, most open-source monetization rates (the percentage of users who become paying customers) are low, often in the single digits (if not lower). However, if the population is large enough, the conversion rate will be sufficient. This dynamic is one of the driving forces behind the open-source model's economies of scale. One of the reasons why there are always category "winners" in open-source is the need for wide acceptance.
Primary trustworthiness. The community's primary trustworthiness is the second requirement. This is significant because it allows the open-source business to develop an effective sales and marketing process, which is critical given the low monetization rates.
In UNICORE/UNIKRAFT, the Consortium is working towards reaching a high level of widespread adaptation and trustworthiness through dissemination activities (Social Channels, Conferences, Scientific Papers and Workshops), Xen Incubation Project channel and well structured projects GitHub. If an open-source project gains widespread adoption and primary trustworthiness, it can start building a pipeline of companies that need help and layering in a variety of business models to create a long-term business.
In this respect, several milestones regard of these prerequisites have been achieved by the Consortium, the latest one being the best paper award at EuroSys 2021 (see [16]).
In order to understand deeper on the time-span of commercialisation of the UNICORE project, and to subsequently have a positive impact on both social and economic aspects in Europe, the Project Consortium analysed a variety of business model assumptions. Five common business models for open-source projects are:

- Support Model
- Hosting Model
- Restrictive Licensing Model
- Open-Core Model
- Hybrid Licensing Model
-

5.2.1 Support Model

The support model, also known as the "RedHat" model, works by offering implementation and integration services, production-oriented "insurance policies," accredited binaries, training, bug fixes, and other services

to companies that are implementing the project in production.

This model is limited in the long run for many reasons:

(i) support frequently necessitates a lot of manual labor, which decreases business margins;

(ii) scaling is difficult because support work is rarely easily repeatable; and

(iii) it generates perverse incentives on the part of the open-source organization, where making the product easier to use cannibalizes support revenue.

In reality, when a project requires complex implementations of sprawling environments, this model excels, despite the fact that it always goes against the best user experience.

This model is also notoriously unreliable, with fewer than 1% of all users turning into paying customers. It should come as no surprise that this inefficiency exists. Open-source software is free in and of itself. An organization must depend on the project for mission critical systems in order to feel the need to pay for funding.

Any open-source company still starts with the support model. Despite these obstacles, and the fact that RedHat remains the only open-source company to develop a multibillion-dollar revenue business in the last 25 years, it's clear that open-source businesses need more than just funding.

5.2.2 Hosting Model

Hosting involves providing a completely managed version of the project, so that when users want to check it out or deploy it in production, they can spin up a remote server with the program in a few clicks and not have to worry about keeping it running (i.e., not worry about backups, downtime, upgrades, etc.). The hosting-only model has the potential to be effective.

Databricks and Acquia, for example, have had great success with it. However, hosting is often combined with a few of the following other templates.

5.2.3 Restrictive licensing

The restrictive licensing model gives consumers of open-source software a legal excuse to pay. It accomplishes this by offering an open-source license with slightly onerous terms, incentivizing anyone using the program in development to reach a contractual agreement with the provider. This model is exemplified by the GPL and AGPL licenses, as well as the newly developed Commons Clause (adopted by some Redis modules). AGPL and Commons Clause (as well as MongoDB's new SSPL) are licenses that are specifically intended to protect against public cloud providers.

However, there are some drawbacks to this approach; the GPL-based license provisions do not extend to unmodified use, and only apply if one makes changes and does not wish to open-source them; the Common Clause's wording is ambiguous, and it remains to be seen how this will be resolved in the courts. Even, the most significant disadvantage of this strategy is that these licenses stifle adoption by deterring future consumers. Several major corporations, in particular, have laws prohibiting the use of restrictive licenses.

Many people dismiss this strategy because of the inherent friction, preferring to focus on other business models.

5.2.4 Open-Core

Open-core has rapidly become the most common revenue stream for open-source companies. The concept behind open-core is that the bulk of the code is open-source, with a limited percentage of proprietary code (aimed at production or business users). The proprietary component could be packaged as standalone modules or utilities that interact with the open-source base, or it could be distributed as a fork of the open-source base.

The proprietary features are usually those that are needed for production deployments and/or at scale. Features like monitoring, administration, backup/restore, and clustering, for example, are frequently proprietary for open-source databases. One advantage is that the open-source company can license the core under a very permissive license (such as Apache 2) while still charging for proprietary features. It also helps open-source companies to protect against free-riders (such as public cloud providers) by retaining some features in the proprietary code base.

The difficulty with this model is balancing open-source and proprietary value, if an open-source company gives away too much, it loses the ability to make money; on the other hand, if it gives away too little, the open-source project simply becomes ”lame-ware” (and the project will likely fail to get broad adoption).

Another issue is that it can be difficult to distinguish between open-source and proprietary features in code. Even if separating them is easy, keeping two separate code bases can be difficult from an engineering standpoint: For example, handling independently versioned releases that might need to interoperate and/or back-and-forth porting of code to avoid code divergence over time. Engineers often choose to work in the open-source repo over the ”company” repo.

Regardless of these factors, this model is very successful.

5.2.5 Hybrid Licensing

The hybrid licensing model is the most recent addition.

Hybrid licensing, popularized by CockroachDB in January 2017 and later adopted by Elastic in February 2018, takes the open-core approach but strengthens it in a few main ways. Hybrid licensing combines open-source and proprietary software in a single repository, then makes the entire repository’s code accessible. That is, the entire repository is ”free code” (or ”source accessible,” as the case may be), although not all of it is licensed under an OSI-approved open-source license. Users can choose between using a binary that only contains open-source components (licensed under an open-source license) or a binary that contains both open-source and proprietary components (available under the proprietary license).

Frequently, the proprietary licensed binary can provide paid functionality that is disabled by default but can be activated by buying a license key.

5.3 UNICORE positioning

The approach planned to be followed by UNICORE is Hybrid Licensing model, i.e. a combination of Open-Core model and Support Model.

In fact, the UNICORE toolstack (UNIKRAFT) and its application runtimes are open-source under BSD 3-clause license; certain developments and side-products in Home Automation / IoT and Smart Contracts are using open source core components with proprietary codes.

Furthemore, the UNICORE developers plan to provide assistance to developers/researchers/institutes/enterprises to adopt and integrate UNIKRAFT and other project components into their technology stack. The mechanism by which this support is implemented can evolve from the current model based on research grants to more structured models of support teams and services in the future. Such an approach can allow to sustain the maintenance of UNIKRAFT software in the long term and grant for its evolution.

chapterBusiness Model Development

5.4 Business Model Canvas

The BMC is a process where all business statements are hypotheses unless they are confirmed. We used a variation of the Business Model Canvas called the Lean Business Model Canvas Approach, which is a technique that is more practical and more of a ground-up tactical strategy or blueprint for the UNICORE as an open-source project.

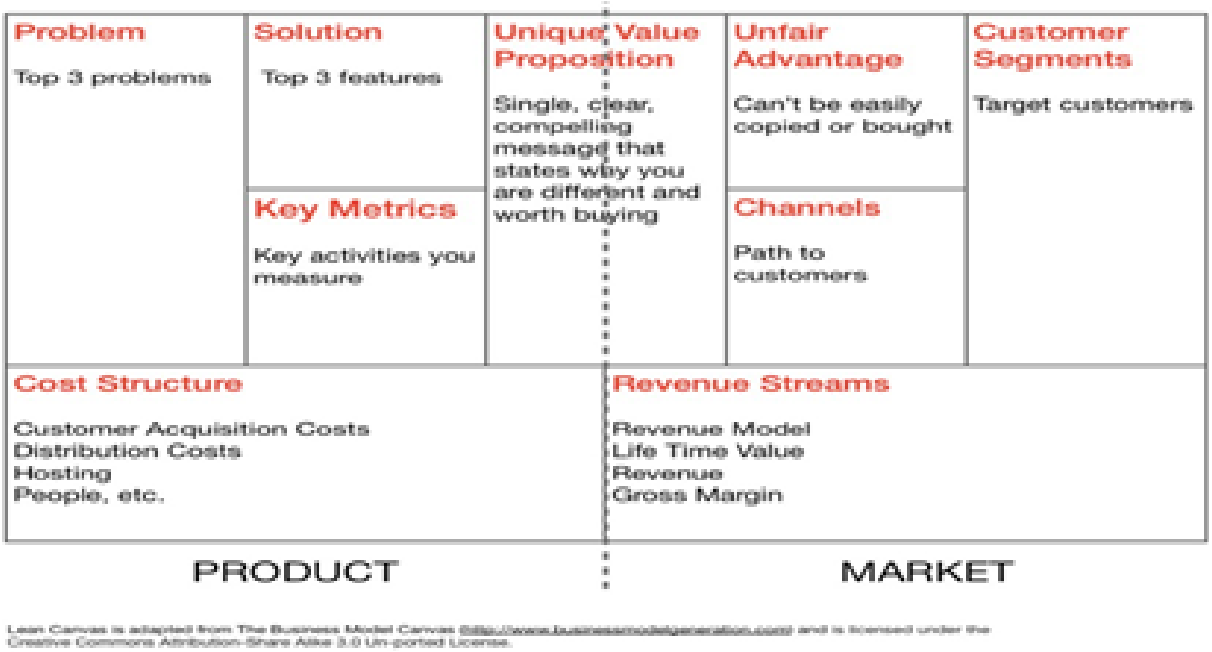


Figure 5.2: Business Model Canva template

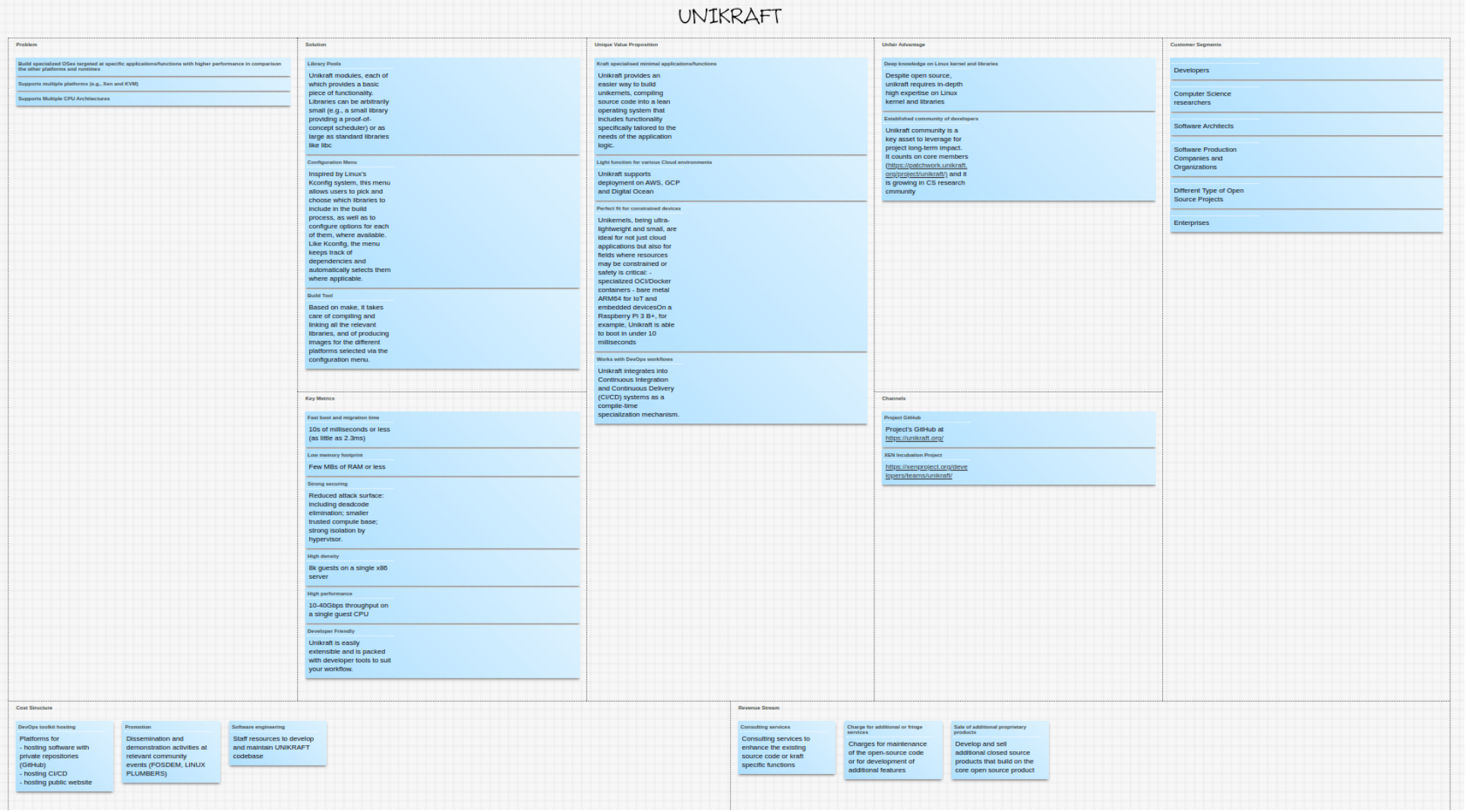
A brief description of each block:

- **Problems.** Brief description of top three problems which project is addressing

- **Customer Segments.** The target audiences for whom the project intends to provide value in the form of products or services
- **Unique Value Proposition.** How the project's unique offer will be valued by customer segments and how it will be distinguished from the competition.
- **Solution.** What is the minimum feature set that demonstrates the Unique Value Proposition up above?
- **Key Metrics.** What operations are critical to business success?
- **Channels.** What channels will you use to convey your value proposition?
- **Cost Structure.** All of the costs related to the business.
- **Revenue Streams.** Identify the revenue model and how the value propositions bring in revenues from each audience.
- **Unfair Advantage.** How do you intend to maintain strong ties with your target markets?

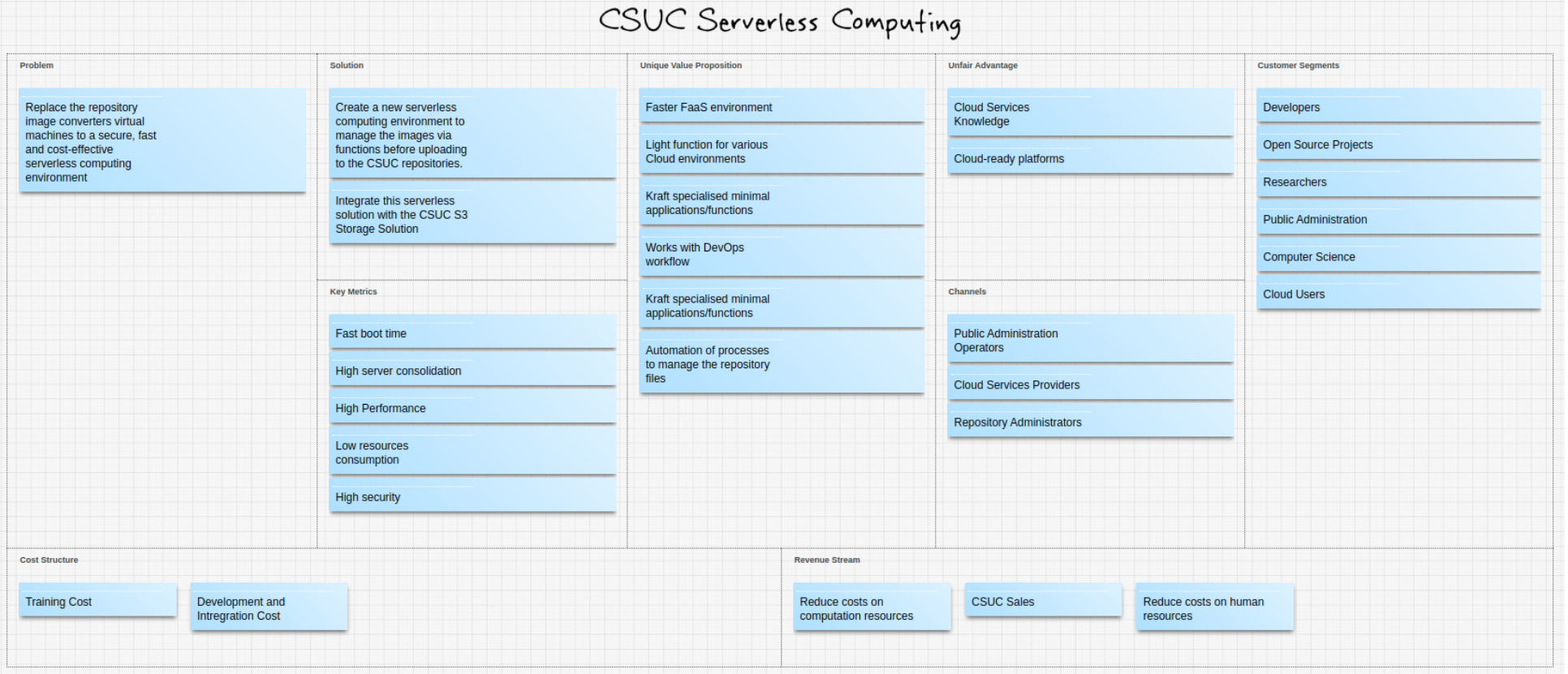
The detailed Business Model Canvas results for the different use cases driven by industrial partners in UNICORE are reported in the following subsections.
These canvas represent live documents which will be used by the project partners during the timeline of the project to further progress the innovation strategy planning and the related exploitation actions.

5.5 UNIKRAFT BMC



Link to the Canvas: https://canvanizer.com/canvas/rD64dZwXTvdkN

5.6 UNIKRAFT-powered Serverless Computing BMC



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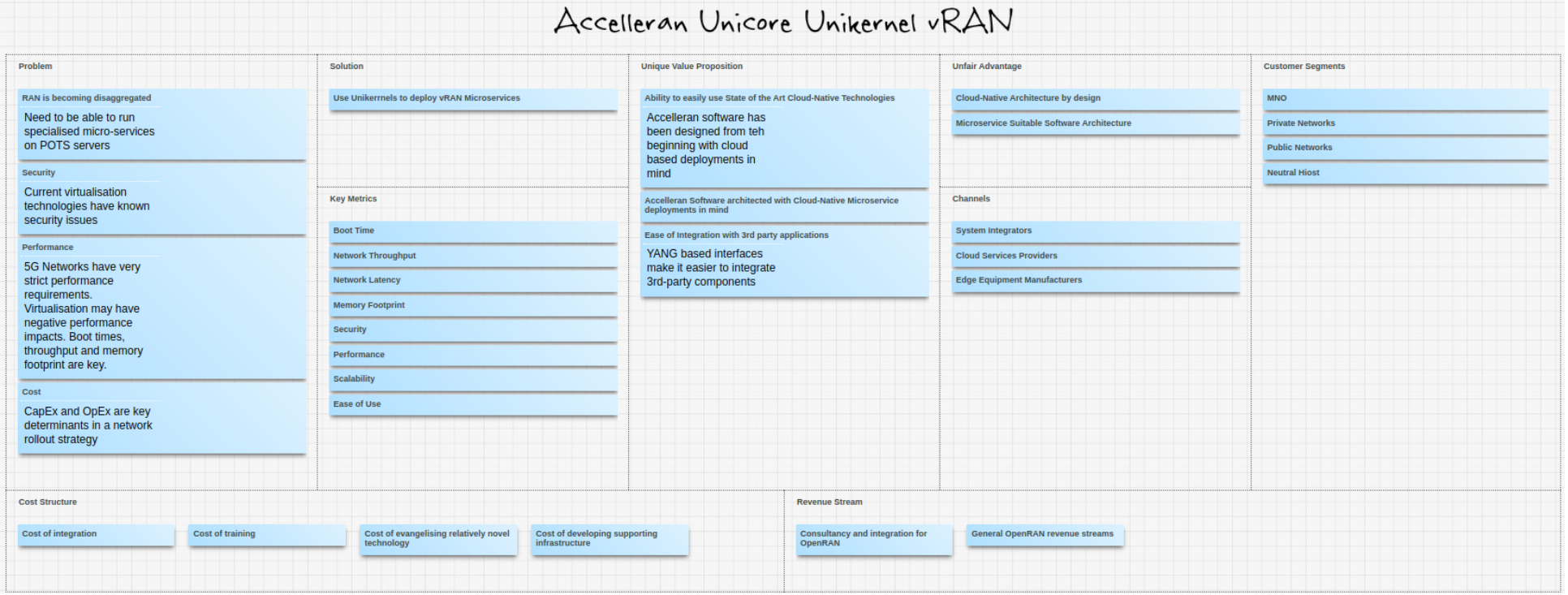
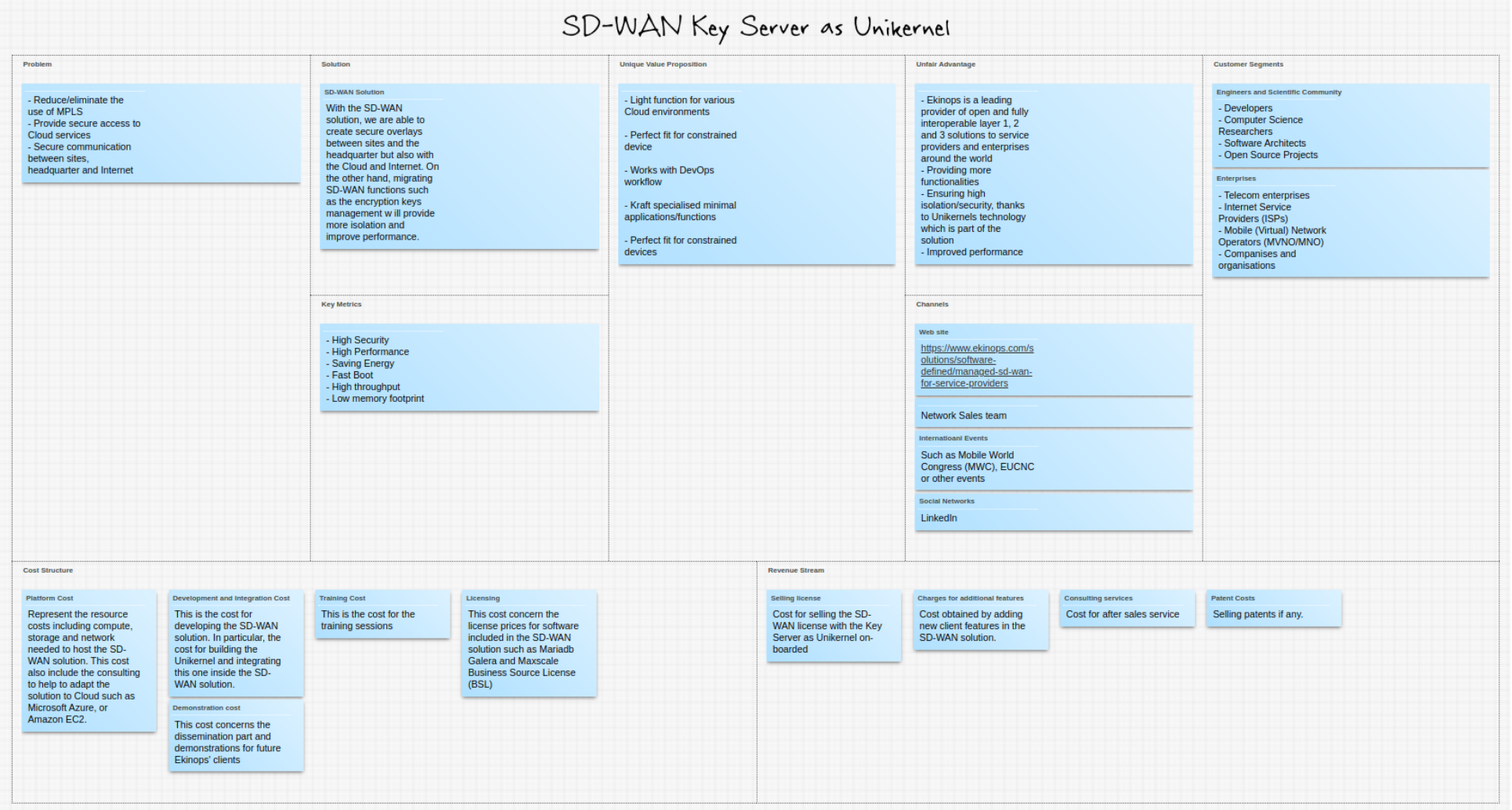
5.7 UNIKRAFT-powered Virtualised RAN BMC



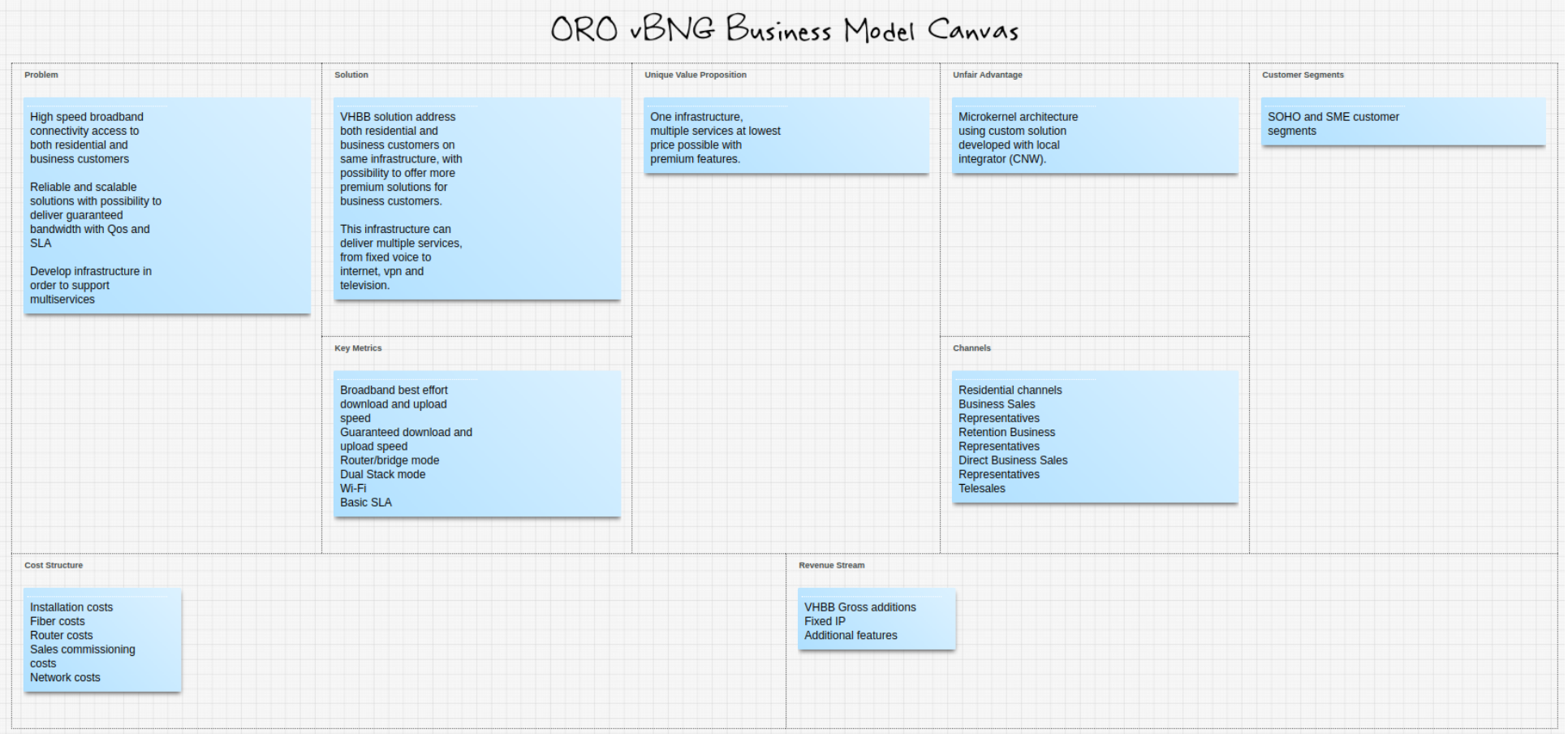
Link to the Canvas: https://canvanizer.com/canvas/rMra33CJgcZgL

5.8 UNIKRAFT-powered SD-WAN BMC



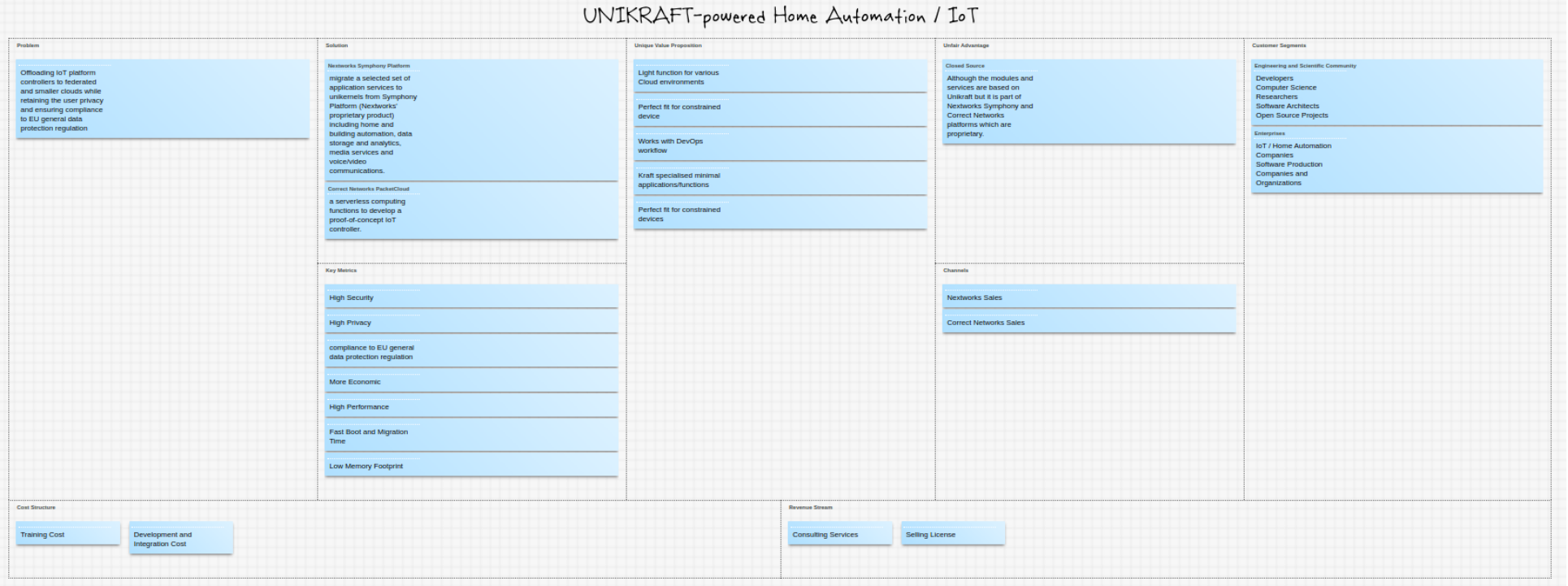
Link to the Canvas: https://canvanizer.com/canvas/rTAfU9rFkUpFp

5.9 UNIKRAFT-powered Virtual Broadband Network Gateways BMC



Link to the Canvas: https://canvanizer.com/canvas/rxdPahsRf2SP2

5.10 UNIKRAFT-powered Home Automation / IoT BMC



Link to the Canvas: https://canvanizer.com/canvas/rC9PqVJrLbvEf

6 Exploitation of Innovation Assets

Based on the Business Model Canvas analysis presented in the previous section and on the main individual exploitation streams summarised in Table 6.1, three main directions emerge for the UNICORE innovation and exploitation strategy:

- **Commercial.** There is clear interest of the partners to have commercial exploitation of the results of the project. Obviously, industrial and academic partners differ in the directions and target communities towards which to direct their exploitation actions, mostly due to the different markets and stakeholders they can contact. Some academic partners consider the creation of startups, whilst other industrial partners intend to pursue a product portfolio strategy for UNICORE/UNIKRAFT results. In both cases IPR protection mechanisms via patents are implemented when needed.

- **Research.** All the partners have strong R&D orientation and intend to continue the work on the topic to address unexplored areas of virtualization and unikernelization.

- **Academic.** Universities within the Consortium are exploiting the know-how acquired through UNICORE to design university or master-level courses that teach the principles of networking and advanced computer science in line with the investigation topics of UNICORE.

Each partner is implementing its own exploitation roadmap based on the individual results presented in Table 6.1, supported by the project for activities like dissemination and communication through the project channels.

6.1 Inventory of joint innovation assets

In this section, the inventory is presented of the joint exploitable results and as such innovation assets of the UNICORE project.
For each of these results the following is reported:

- *Exploitation type*, i.e if Commercial or Research;

- *Lead partner*

- *Other contributing partners*

- *Type of exploitable result/output*, i.e. if Software or Technical Specification or Product;

- *Target segment for application*

- *Time to market*, i.e. when the result might potentially be part of a product on the market

- *Exploitation potential*, i.e. an assessment of the potential of the result to be uptaken by the market. Possible values are: 1 - VERY LOW, 2 - LOW, 3 - MEDIUM, 4 - HIGH, 5 - VERY HIGH;

Table 6.1: Main individual exploitation streams of the UNICORE partners

Partner	Main Exploitation Stream		Partner	Main Exploitation Stream
IBM ISRAEL	• Secret memory areas in Linux v5.11 • Interest by Amazon, Google, Intel, Oracle		ACCELLERAN	• Unikernel-based microservices in dRAX
NEC LABS EU	• Business incubation activity around Unikraft to widen portfolio of cloud solutions		VU	• Patented ZebRAM security sol. • Framework with Philips to patent other results
EPFL	• Unikernel-based execution engine for smart contracts		NEXTWORKS	• Unikernel-based prototypes of Symphony functionalities
UPB	• MSc projects with spinout in Correct Networks		EKINOPS	• Unikernel-based SDWAN
CSUC	• Integrate unikernels in the kubernetes and OpenNebula platforms		CORRECT NETWORKS	• Unikernel-based lightweight virtualization platform (PacketCloud) • PoCs at Orange RO
ULIEGE	• High performance virtual routers (FastClick) • NFV platforms (MiddleClick) • Parallel high-volume IDS • Cloud-based firewalls		ORANGE RO	• Unikernel-based lightweight BNG

- *Current status*
- *IPR protection*, i.e. if actions to protect IPR are (to be) undertaken

The presented inventory is continuously managed within the project to maximise by the end of the Action the opportunities for its capitalization.

6.1.1 Innovation Asset #1. API and library implementation

Result Name	**UNIKRAFT API and Library Implementation**
Exploitation type	Research
Lead partner	NEC
Other contributing partners	UPB
Type of exploitable result/output	Software
Target segment for application	All use cases and segments in scope of UNICORE
Time to market	<1 Yr
Exploitation potential	3 - MEDIUM
Current status	APIs have been designed, implemented, and upstreamed Multiple libraries included in UNIKRAFT
IPR protection	No

6.1.2 Innovation Asset #2. Security and isolation primitives

Result Name	**Security and isolation primitives**
Exploitation type	Research
Lead partner	VUA
Other contributing partners	UPB, NEC
Type of exploitable result/output	Software, Technical Specification
Target segment for application	All use cases and segments in scope of UNICORE
Time to market	1-2 Yrs
Exploitation potential	4 - HIGH
Current status	Many primitives are implemented already (e.g., stack protection, page protection), several are still under development (HW capabilities)
IPR protection	No

6.1.3 Innovation Asset #3. Deterministic execution support

Result Name	Deterministic execution support
Exploitation type	Research
Lead partner	UPB
Other contributing partners	EPFL
Type of exploitable result/output	Software, Technical Specification
Target segment for application	All use cases and segments in scope of UNICORE
Time to market	2-3 Yrs
Exploitation potential	4 - HIGH
Current status	Control of randomness (APIs, memory layout), support for multiple compilers (gcc, clang) and compiler options for determinism, support for multiple languages (D language support added)
IPR protection	No

6.1.4 Innovation Asset #4. Compile Toolchain

Result Name	Compile Toolchain
Exploitation type	Research
Lead partner	ULG
Other contributing partners	NEC
Type of exploitable result/output	Software
Target segment for application	All use cases and segments in scope of UNICORE
Time to market	<1 Yr
Exploitation potential	4 - HIGH
Current status	Most of the tools are implemented and are in the process of being integrated into the UNIKRAFT kraft tool.
IPR protection	No

6.1.5 Innovation Asset #5. Multi-Target Support

Result Name	Multi-Target Support
Exploitation type	Research
Lead partner	NEC
Other contributing partners	UPB
Type of exploitable result/output	Software, Technical Specification, Products
Target segment for application	IoT and NFV use cases and segments within UNICORE
Time to market	1-2 Yrs
Exploitation potential	3 - MEDIUM
Current status	Most of the tools are implemented and are in the process of being integrated into the UNIKRAFT kraft tool
IPR protection	No

6.1.6 Innovation Asset #6. Symbolic Verification Support

Result Name	Symbolic Verification Support
Exploitation type	Research
Lead partner	CNW
Other contributing partners	UPB, NEC
Type of exploitable result/output	Software
Target segment for application	All use cases and segments in scope of UNICORE
Time to market	2-3 Yrs
Exploitation potential	3 - MEDIUM
Current status	Currently in the process of developing UNIKRAFT components (schedulers and memory allocators) with the Daphne language.
IPR protection	No

6.1.7 Innovation Asset #7. Performance Optimization Tools

Result Name	Performance Optimization Tools
Exploitation type	Research
Lead partner	NEC
Other contributing partners	ULG
Type of exploitable result/output	Software
Target segment for application	Serverless and NFV use cases
Time to market	2-3 Yrs
Exploitation potential	4 - HIGH
Current status	The focus is currently on designing a tool for efficient memory deduplication for unikernels.
IPR protection	No

6.1.8 Innovation Asset #8. Orchestration Tools Integration

Result Name	Orchestration Tools Integration
Exploitation type	Research, Commercial
Lead partner	CSUC
Other contributing partners	NEC
Type of exploitable result/output	Software, Technical Specification
Target segment for application	Serverless use case and related market applications
Time to market	1-2 Yrs
Exploitation potential	4 - HIGH
Current status	First prototype able to launch a UNIKRAFT instance via Kubernetes is now ready.
IPR protection	No

6.1.9 Innovation Asset #9. Modular Blockchain

Result Name	**Dedis Ledger Architecture for Modular Blockchain (DELA)**
Exploitation type	Research, Commercial
Lead partner	EPFL
Other contributing partners	-
Type of exploitable result/output	Software
Target segment for application	Smart Contract use case and related market segment
Time to market	1-2 Yrs
Exploitation potential	4 - HIGH
Current status	DELA (https://dedis.github.io/dela/#/) is a set of modular abstractions to perform Distributed Ledger (DL) operations. DELA provides an implementation of a minimalist DL, demonstrates a full working DL implementation based on Collective Signing and offers a platform that supports research in Distributed Ledger Technologies (DLT). The initial development has been completed, but further implementation work and testing is necessary to ensure the solutions robustness.
IPR protection	No

7 Conclusions

This document has presented the UNICORE innovation management activities and related results.

The deliverable marks the completion of the related Innovation Management activity within the workpackage 1 of the Project.

Follow up actions based on the contents presented in this deliverable will be completed by the Consortium as part of the exploitation and dissemination activities covered within the workpackage 6, which lasts until the end of the project.

8 Abbreviations and Definitions

8.1 Abbreviations

AI	Articifial Intelligence
BMC	Business Model Canvas
CGAR	Compound Annual Growth Rate
CU	Central Radio Unit
DELA	Dedis Ledger Architecture for Modular Blockchain
DIA	Dedicated Internet Access
DoA	Description of Action
DL	Distributed Ledger
DLY	Distributed Ledger Technology
EC	European Commission
FOSS	Free Open Source Software
IaaS	Infrastructure as a Service
IPR	Intellectual Property Rights
ISP	Internet Service Provider
MANO	Management and Orchestration
MANO	Management and Orchestration
MEC	Multi-access Edge Computing
MPLS	Multiprotocol Label Switching
NFV	Networks Function Virtualization
PaaS	Platform as a Service
SaaS	Software as a Service
SAM	Serviceable Available Market
SASE	Secure Access Service Edge
SDO	Standard Developing Organization
SDWAN	Software-defined Wide Area Network
SOM	Serviceable Obtainable Market
TAM	Total Addressable Market
UVP	Unique Value Proposition
vBNG	Virtual Border Network Gateway
vCPE	Virtual Customer Premise Equipment
vRAN	Virtual Radio Access Network
VM	Virtual Machine
VNF	Virtual Network Function
WP	Work Package

8.2 Definitions

No definition is introduced by this document

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