Business Models for 5G Experimentation as a Service: 5G Testbeds and Beyond

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2022 25th Conference on Innovation in Clouds, Internet and Networks and Workshops (ICIN) | 978-1-7281-8688-7/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICIN53892.2022.9758131

***Abstract*—The availability of Experimentation as a Service (EaaS) has been crucial in 5G research/market implementation, so far substantially subsidized by EU funding. In this paper, we introduce and evaluate novel business models for 5G EaaS, drawing on insights from the pre-commercial 5G-VINNI experimentation platform. Relying on the concept of value network, we develop a value network for 5G services with relevant business roles and relationships. On the basis of this, we present the different actor roles involved in the provisioning of 5G EaaS, and we investigate alternative business models the actors can combine their offerings. Our analysis has shown that when a 5G vertical market (e.g., e-health, automotive, etc.) is immature, an aggressive business model is more attractive for Experimental Infrastructure Operators, while in the opposite case a conservative strategy is preferable. Finally, our results provide useful insights for the potential business models of a future commercial 5G/6G EaaS market.**

I. Introduction

A driving force in the 5G evolution is to cater to real challenges in verticals such as manufacturing, health, automotive, etc. Thus, it is imperative to enable vertical stakeholders to experiment with 5G for their use cases. In this regard, the European Commission has supported projects which develop experimentation platforms for 5G services through the 5G-PPP program: 5G-VINNI [1], 5G EVE [2] and 5Genesis [3]. The objectives of 5G experimentation platforms are to enable vertical stakeholders 5G experimentation and to accelerate 5G adoption. These platforms are already used by yet other projects eager to experiment with 5G services within specific sectors (e.g., [4], [5]). Mobile Network Operators (MNOs), service providers, vendors, etc., can also benefit from these platforms for obtaining knowledge for the shape of 5G ecosystem and for exploring novel business models.

These projects are committed to maintain their platforms at least one year beyond their lifetime to support verticals' experimentation in other EU-funded projects. 5G-VINNI aimed to offer Experimentation as a Service (EaaS) even beyond that time span and explored commercialization of its offerings. Hence, the design of long-term sustainable business models for operation the of such platforms is necessary. Moreover, the next-generation (5G/6G) networks are designed with no predefined services. They can be conceived as innovation "platforms" hosting constant development and commercial provisioning of innovative services. Therefore, experimentation not only boosts the adoption of 5G by verticals sectors, but also accomplish the full evolutionary potential of the technology. It could be argued that MNOs need to carry the cost of an experimentation platform to enable innovation and in turn fuel demand. Thus, from an MNO's point of view, the identification of economically sustainable business models for commercial EaaS is highly important.

In this paper, we introduce novel business models for the main actors in the 5G experimentation platforms, who will also emerge in a potential 5G EaaS market. We rely on methods such as value networks and Business Model Canvas (BMC). First, we introduce a value network that identifies the main actor roles that appear in the 5G experimentation platforms / EaaS market and the business relationships among them: the Experimentation Infrastructure Operator (EIO), Solution Provider (SP) and Experimentation Support Provider (ESP). Then, we study two value network instances that are identified as the most likely to emerge, namely the conservative and aggressive instances of the value network. In each of these instances, the EIO and SP adopt a different set of actor roles. In the *conservative* instance, the EIO does not have direct customer relationship with the experimenter and is a sub-provider to the SP. In the *aggressive* instance, the EIO is the actor that delivers EaaS to the customers.

We suggest business models for both value network instances and carry out a sustainability analysis under two scenarios of 5G vertical market, namely the *concentrated* (few high market-power players) and *competitive* (multiple "small" players). The results reveal that the aggressive business model is preferable in the competitive markets, while the conservative business model is more attractive in the concentrated markets. These results are insightful for MNOs considering commercialization of 5G experimentation since they provide useful guidelines on the roles to be adopted by the main actors and serve as a foundation for MNOs' business strategy. To our knowledge, this is the first study that defines and assesses business models for 5G EaaS.

Related work. The authors of [6] and [7] study how the business models of telco industry should be transformed to serve the needs of 5G market. The results of this study reveal a shift from the traditional hierarchical and value chain-based business models towards platform-based ecosystems. In [8], the authors perform a technoeconomic analysis of different infrastructure deployment strategies for 5G roll-out against multiple demand scenarios, considering UK as the case study. Accordingly, the authors of [9] performed a technoeconomic analysis for 5G deployment, but they also introduced a pricing model which determines the price of a service based on both its value and volume. Their results have shown that the price elasticity on volume can generate significant benefit. In [10] and [11], the authors introduce a cost model

for 5G networks and perform a technoeconomic analysis to. highlight the benefits of network virtualization in terms of cost reduction against traditional network architectures.

II. Background and Basic Modeling

A. Key Business modeling terms and concepts

Actor. Consumes or contributes to the EaaS provisioning.

Actor role. An actor may hold several actor roles, and an actor role can be adopted by several actors. Each actor role focuses on certain activities, i.e., contributes a different type of service or infrastructure for enabling EaaS.

Business relationship. It captures the provider-consumer relationships (service/money flow) between two actor roles.

Value network. A value network is any set of actor roles and interactions in which organizations engage in exchanges to achieve economic or social good [12]. In our case, the value network captures the business relationships among all actor roles in the 5G EaaS platforms/market.

Value network instance. An instance of the value network reflects the adoption of the different roles that appear in the value network by certain actors. Multiple instances of a value network may exist, even when considering the same actors.

Business Model Canvas [13]. A strategic management template that illustrates an actor's key partners, customer segments, value proposition, cost and revenue, key resources, key activities, customer relationships and channels.

B. 5G value network

Based on the general 5G value network presented in [14], we introduce the actor roles that may appear in 5G experimentation platforms/EaaS market and their business relationship (see Figure 1 for a graphical representation).

Vertical Service Provider (VSP) is a vertical enterprise or organization that does business on a specific vertical sector.

Communication Service Provider (CSP) offers communications services to VSPs over own, leased, or brokered network slices.

Digital Service Provider (DSP) offers to VSPs online applications/services that are specific to vertical industries, such as automotive, media, e-health, etc.

Service Aggregator (SA) bundles multiple services and applications coming for CSPs and DSPs, serving as a one-stop-shop for VSPs.

Customer Support Provider offers technical, business and legal consultancy services to VSPs or DSPs, as a facilitator for the faster adoption of 5G.

Operation Support Provider offers highly focused ancillary operational services such as testing and monitoring of the service performance.

Network Operator maintains and operates a 5G network infrastructure, offers Network Slice as a Service (NSaaS) to DSPs, CSPs and SAs, to enable their applications or services.

Virtualization Infrastructure Service Provider (VISP) offers virtualized cloud infrastructure services to Network Operators, as well as to CSPs, DSPs and SAs.

SW/HW supplier includes Virtual Network Function (VNF), Virtual Application Function (VAF) Cloud-native Network Function (CNF), Management and Orchestration System, Hardware suppliers, etc.

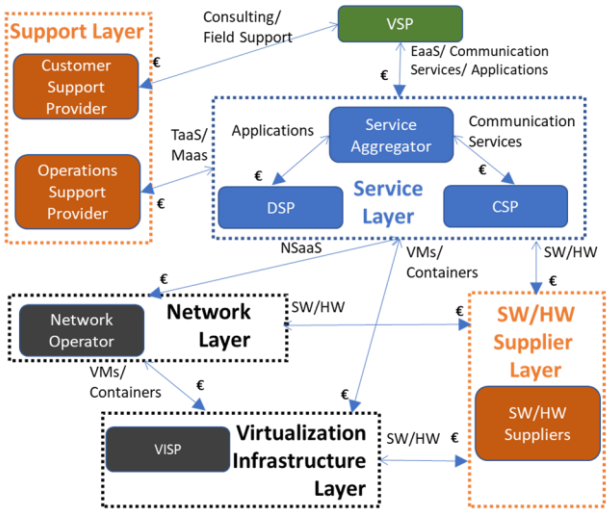

Figure 1: Actor roles and business relationships in 5G EaaS landscape.

C. EaaS enabler services

The provisioning of 5G EaaS requires the bundling of multiple complementary services offered by different actors that adopt specific actor roles. Here follows the *main* enabling *services* for EaaS.

Network Slice as a Service (NSaaS). This is the core service, and it is classified into three standard network slice types, namely the enhanced Mobile Broadband (eMBB), ultra-Reliable Low Latency Communication (uRLLC) and massive Machine Type Communications (mMTC). Network slice types customized to the needs of vertical use cases combine features of multiple standard types.

Testing as a Service (TaaS). This service allows for the automated performance, functional and quality assurance testing of new software/hardware (SW/HW) components or applications, under close-to-realistic 5G network conditions.

Monitoring as a Service (MaaS). This service allows real-time performance monitoring and data-collection of the 5G infrastructure, platform frameworks and services/applications, when different experiments/tests are performed.

Field Support/Consulting. This service supports the EaaS customers that lack the knowledge to design, develop and setup high-quality and targeted experiments, as well as for the analysis and exploitation of the extracted results.

D. EaaS main actors

Below, we introduce the *main actors* that appear in the 5G experimentation platforms, as well as in a commercial 5G EaaS market. These actors may adopt one or multiple actor roles from the ones that appear in Figure 1.

Solution Provider (SP). A SP usually adopts one or multiple roles in the Service layer of the value network, although it may also adopt the Customer Support Provider role in certain cases. The number of roles adopted by a SP may vary and greatly affects its impact on EaaS provisioning. For instance, a SP that adopts all roles in the Service layer acts as the integrator that combines its own applications with services provisioned by other actors in order to offer a complete EaaS solution to the VSPs. On the other hand, a SP may only adopt the role of DSP and complement the EaaS offerings of another actor with an application component, without having a direct interaction with the VSPs.

Experimentation Infrastructure Operator (EIO). An EIO focuses on operating the 5G experimentation infrastructure and offers NSaaS, by adopting mostly the Network Operator and VISP roles. However, in some cases, it may be preferable to adopt additional roles at the Service layer and become the actor that offers EaaS directly to VSPs.

Experimentation Support Provider (ESP). An ESP focuses on complementing the EaaS offering with TaaS and MaaS capabilities, by providing the necessary framework and supporting the relevant tasks during the experimentation of the customers. This actor mainly adopts roles in the Support and Supplier layers of the value network.

III. Business Models for EaaS

Considering the value network presented in Figure 1, one actor may adopt multiple alternative roles. In this paper, we focus on the two instances of the value network most likely to be adopted by commercial 5G EaaS platforms, namely the *conservative* and *aggressive* instances.

When the EIO is *conservative*, it only adopts the Network Operator and VISP roles, offering NSaaS to the SP. All Service layer roles are handled by the SP, which is the only actor interacting with the VSP that consumes the EaaS. The ESP provides the TaaS/MaaS framework for the testbed and supports the framework during the operation. The conservative scenario was adopted by 5G-VINNI. The left part of Figure 2 illustrates the interactions between the main actors for a conservative EIO value network instance.

In the *aggressive* value network instance, presented on the right part of Figure 2, the EIO adopts roles at the Service layer and becomes the contact point for the VSP. This means that beyond operating the experimentation infrastructure, it also acts as an integrator and combines services from multiple sources to offer a complete EaaS solution to VSPs. The SP now adopts only the DSP role and just complements the EaaS offerings without having a direct contact with the customers.

The SP's and EIO's business model canvases are presented in Table 1 and Table 2 for the conservative and aggressive instances, respectively. The ESP business model canvas is almost the same in both instances (see Table 3). The only difference is that in the conservative case the customer is the SP, while in the aggressive case the EIO.

Table 1: BMCs of the SP for the conservative and aggressive instances.

SP	Conservative	Aggressive
Value Proposition	- VSPs can experiment with novel applications/ solutions for certain use cases, in close-to-commercial 5G conditions. - Consulting to VSPs willing to experiment and lack the expertise.	Adds value to the EaaS platform by complementing the EIO's service with vertical applications in the relevant sector, with which the VSPs can experiment.
Key Partners	- EIOs who offer NSaaS for enabling the provisioning of vertical solutions. - ESPs providing the TaaS / MaaS framework.	SW suppliers *(external to the value network)*
Customer Segments	VSPs that do business in the 5G vertical sectors the SP is active.	EIOs that integrated the SP applications in their EaaS offerings.
Cost Structure	OPEX: Personnel, TaaS framework licenses, Experimentation support	OPEX: Personnel, other insourced SW licenses

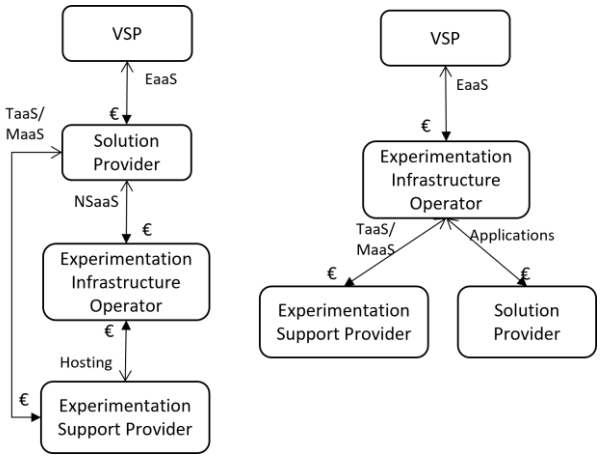

Figure 2: Interactions of main actors in the conservative case (left) and aggressive case (right).

	charge, NSaaS charge, Edge cloud infrastructure rent, other SW licenses.	
Revenue Streams	Revenue comes from VSPs. Lump-sum for multiple experiments or repetitive / variable revenue stream per experiment.	Repetitive / variable revenue stream: charge the EIO each time the offered applications participate in a service/experiment.
Key Activities	- Development of novel applications/solutions. - Consulting, field support and service integration.	Development of novel applications/solutions.
Key Resources	Applications, Personnel	Applications, Personnel
Customer Relationships and Channels	Mostly personalized since setup of different solutions require field support, consulting, and integration effort. Online and offline channels are utilized.	Mostly automated and online. EIOs should provide APIs where the SP will be able to upload its applications in a portal.

Table 2: BMCs of the EIO for the conservative and aggressive instances.

EIO	Conservative	Aggressive
Value Proposition	- NSaaS offerings to SPs with guaranteed QoS and value-added functionalities, in a close-to-commercial 5G infrastructure, at a lower cost than in-house solutions. - Hosting third party (i.e., ESPs) VNFs/VAFs.	- EaaS offerings to VSPs, who can experiment, at low cost, with novel 5G-enabled applications, to validate whether the requirements of their use cases are satisfied. - Consulting to VSPs that are willing to experiment and lack the expertise. - Hosting third party (i.e., ESPs) VNFs/VAFs.
Key Partners	SW/HW Suppliers that supply with the necessary 5G SW/HW components.	- SW/HW Suppliers that supply with the necessary 5G SW/HW components. - SPs that contributed their applications/solutions to the EaaS platform. - ESPs who provide the TaaS/MaaS framework and support VSPs.
Customer Segments	- SPs that adopt roles at the Service layer, i.e., DSPs, CSPs and SAs. An SP may offer solutions to multiple vertical sectors. - ESPs needing to run their VNFs/VAFs on EIO's infrastructure.	- VSPs from different vertical sectors - ESPs who need to run their VNFs/VAFs on EIO compute infrastructure
Cost Structure	- CAPEX: 5G equipment; Cloud	- CAPEX: 5G equipment; Cloud Infrastructure; 5G

	Infrastructure; SW licenses; Power infrastructure. - OPEX: Senior Personnel salaries; Electricity bills.	SW licenses; Power infrastructure, Verticals-related software (optional) - OPEX: Personnel, Electricity bills, Annual licenses for 5G SW, App licenses, Testing framework licenses, Experimentation support charge.
Revenue Streams	Repetitive variable revenue stream by means of cost-based pricing on: (i) SPs per NSaaS request; (ii) ESPs per hour of hosting their VNFs/VAFs.	Repetitive variable revenue stream by means of cost-based pricing on: - VSPs per experiment. - ESPs per hour of hosting their VNFs/VAFs.
Key Activities	Best practices and policies for network deployment, management, and orchestration.	- Best practices for network deployment, management, and orchestration - Novel communication services - Consulting, field support and service integration.
Key Resources	Network and Cloud Infrastructure, Personnel	Network and Cloud Infrastructure, Personnel, Communication Services
Customer Relationships and Channels	- Personalized customer relationships via online channels. - Automated customer relationships through online channels such as an NSaaS portal.	- Personalized relationships when the setup of the different solutions required field support, consulting, and integration effort. - Standard solutions can be offered automated.

Table 3: BMC of the ESP for both conservative and aggressive instances.

ESP	Both for conservative and aggressive
Value Proposition	A complete experimentation support solution to SP which includes: (i) a TaaS/MaaS framework and experimenters support during the experiments' setup, scheduling and execution; (ii) performance monitoring during experimentation and measurements collection.
Key Partners	- EIO that hosts the TaaS/Maas framework - SW/SW suppliers (external to the value network)
Customer Segments	SPs from any 5G vertical sector.
Cost Structure	OPEX: Personnel, HW, other SW licenses, Data centre rental costs for hosting VNFs/VAFs.
Revenue Streams	Revenue comes from Solution Providers in two dimensions: *(i)* annual license fee for using TaaS/MaaS framework (repetitive fixed); *(ii)* volume-based pricing, i.e., per experiment, per test, per customer support issue, etc., (repetitive variable)
Key Activities	Development of a highly automated TaaS/MaaS framework; Introduction of novel testing and monitoring methods; High-quality experimenter support during all stages of experimentation.
Key Resources	TaaS/MaaS framework., Personnel
Customer Relationships and Channels	Personalized customer relationships via direct e-mails or face-to-face meetings.

IV. Comparative Analysis

We assess the viability of the two value networks instances and the attractiveness of the proposed constituent business models for each actor with a discounted cash flow analysis for two different market scenarios. All numerical values in our analysis are based on averages extracted by figures provided in dedicated workshops with 5G-VINNI experts, publicly available data and author assumptions.

A. Cost and Revenue Model

Two essential elements in a business model are the actor's cost structure and revenues. Two actors may follow the same business model design, but can exhibit different cost items, due to architectural decisions (e.g., related to 5G New Radio functional split), varying unit costs (e.g., prices may be country-specific), or number of units serving an area (e.g., number of base stations). Similarly, even if actors offer the same service portfolio and pricing scheme, their revenues may differ e.g., due to different market share levels.

For our techno-economic evaluation of the proposed business models, we define a hypothetical experimentation platform by selecting relevant cost items from a detailed cost model that includes both Capital Expenditures (CAPEX) and Operational expenditures (OPEX) (see Table 4). CAPEX, refer to long-term expenses for acquiring assets such as equipment and perpetual licenses for software or spectrum. OPEX refer to ongoing, recurring and yearly costs.

Table 4: Key CAPEX and OPEX items comprising the 5G cost repository

Cost category	CAPEX items	OPEX items
5G RAN & Transport Costs	5G RAN equipment for alternative options, different transport technologies, spectrum acquisition	a) Maintenance cost of 5G RAN and transport equipment b) Passive network infrastructure rental c) Backhauling costs
Cloud Physical Infrastructure Costs	Physical resources and virtualization software for supporting the core network and vertical applications	Recurring costs for renting cloud resources that host VNFs/CNFs and software for complementary services (e.g., monitoring, testing), other vertical applications
Software licenses costs	Perpetual licenses or in-house development cost for 5G Core VNFs, vertical-related SW, etc	a) annual, fixed SW licenses (regardless of throughput, etc) b) pay-per-use license (e.g., vary with session numbers)
Costs for 5G-based connectivity	-	Costs for NSaaS offerings (e.g., for uRLLC, eMBB, mMTC, custom)
Costs for buildings/ land	Acquisition of new buildings and land	Rental cost: buildings, land
Salaries cost	-	Cost for personnel
Electricity cost	Invest in renewable technologies	Cost for electricity supply, distribution, etc.

The 5G experimentation site is supposed to include 2 macro cells and each hosts an integrated Radio Unit (RU) in a 3-sector configuration. We assume that each (Distributed Unit) DU serves 2 RU on average and thus a single DU is required. Furthermore, a single Central Unit (CU) is needed that runs on a single Metro Data Centre, while the 5G core runs on a single Central Data Centre. The nodes above are connected using existing fiber links and no small cells or MEC nodes exist. The EIO buys a perpetual license for 5G Core software and invests in its own Cloud Physical Infrastructure. The dimensioning of the latter depends on the foreseen 5G EaaS demand levels (see below), while we assume that no extra 5G RAN infrastructure will be needed in the market scenarios studied.

A wide range of revenue streams has been used to model the revenues in a 5G experimentation platform (see Table 5). Note that costs and revenues are bidirectionally connected. A new revenue stream may dictate additional investments or

may need to be cost-based (e.g., if infrastructure was subsidized with public money or due to regulation). Cost-based prices do not exclude the profitability of these services since prices can be adjusted by an appropriate markup.

Table 5: Main 5G EaaS incomes comprising the revenue streams repository

Revenue Stream	Formula
Revenues: 5G NSasS offerings	Hourly charge per eMBB or uRLLC or mMTC session * Average hours per session * Average number of sessions per year per customer * Number of Solution Providers
Revenues: EaaS using 5G slices	Hourly charge per eMBB or uRLLC or mMTC testing session * Average hours per session * Average number of sessions per year per customer * Number of VSPs * Number of regions where EIO is active
Revenues: hosting third-party VNFs for TaaS / MaaS	Hourly charge * hours per TaaS or MaaS VxF per ESP * VMs per VxF *number of ESPs
Revenues: Testing-as-a-Service offerings	Hourly charge per eMBB or uRLLC or mMTC testing session * Average hours per session * Average number of sessions per year per customer * Number of VSPs (in case of conservative business model) or Number of EIOs (in case of aggressive business model)
Revenues: 5G-enabled vertical services	Average number of 5G-enabled vertical services per year (e.g., eHealth) * Charge for 5G-enabled vertical service per year

B. Market conditions affecting EIO costs and revenues

We assume that 8 vertical domains are present and consider 2 cases regarding the existing market conditions in these SP/vertical markets. We assume that an EIO can assess the competitiveness level of a certain market by having access to market reports that state the Herfindahl–Hirschman Index [15] (HHI) the specific market. A high HHI value indicates that a market is *concentrated* (e.g., an oligopoly), while a low HHI indicates that a market is *competitive* (i.e., many "small" SPs are active).

In a *competitive* market, VSPs may be reluctant to test the potential value of 5G in their business processes. In this case, if EIO chooses the *conservative* business model, then it will face *low* demand levels for 5G EaaS. On the other hand, if the *aggressive* business model is chosen, then EIO will need to employ senior personnel that will influence VSPs to experiment with innovative 5G-enabled service offerings and which will result in *high* demand levels for EaaS. Due to their small size, SPs are assumed to be unable to discourage the EIO from entering the SP market and thus they agree to offer access to their vertical-specific software, following the SW-as-a-Service paradigm.

The second scenario assumes that SP markets are *concentrated* i.e., a few dominant providers exist. In this case, VSPs have established long-lasting business relationships with a SP, leading to *high* demand levels for 5G EaaS. If the EIO adopts the *conservative* business model, then it will be asked to serve *high* demand of NSaaS requests. If, on the other hand, the EIO opts for the *aggressive* business model, then increased OPEX are foreseen for the senior personnel that will be interacting with VSPs (as in the *competitive* case), as well as increased CAPEX for developing own vertical-specific software (since SPs will also have high negotiation power and refuse to offer the software through an EIO).

We assume that in each of the 8 vertical domains 2 and 4 VSPs are active in the *low* and *high* demand case, respectively. Each VSP offers 5G-enabled services to its retail customers, which are continuously updated and tested before their roll-out and receives 15,000€ in total every year. Furthermore, VSPs are symmetric in terms of load injected to the 5G experimentation platform. Regarding the SP market, there are 2 competing providers per vertical domain of equal size. If the EIO adopts the *conservative* business model, then they add a 200% markup on the hourly price that the EIO charges for eMBB, uRLLC and mMTC slices. On the other hand, if the EIO follows the *aggressive* business model, then it pays an annual license of 9,500€ to each VSP for the vertical-related software. Finally, the (single) ESP receives 4,000€ for the TaaS and MaaS offerings, while pays 0.36 €/hour to the EIO for hosting its VNF/CNFs to its data center.

Table 6 presents the average number of network slices per type that will be active at any time (i.e., uniform load distribution), for supporting the experimenters demand, assuming that experiments are conducted during a single employee shift (e.g., 8 hours per day). Table 7 provides the user and control plane load per session.

Table 6: Average number of concurrent 5G sessions per slice type (rounded)

	eMBB	uRLLC	mMTC
"Low demand" scenario	4	6	20
"High demand" scenario	10	10	40

Table 7: Avg. of User and Control Plane load per 5G session per slice type

	eMBB	uRLLC	mMTC
User plane	167 Mbps	0.01 Mbps	80 Mbps
Control plane	15 events/sec		

By employing a top-down cost model, based on the Fully Distributed Costs (FDC) approach [16], we computed the cost-based hourly prices for each of the eMBB, uRLLC and mMTC slices (Figure 3). The EIO's OPEX were allocated to the different revenue streams based on their (assumed) consumption in terms of compute and network resources. Note that the CAPEX directly related to the network slice provisioning were excluded as the infrastructure of platforms for 5G experimentation was subsidized by the EU, while the rest ones (i.e., the cost of 300,000€ for the necessary software per vertical domain in case of aggressive business model or alternatively the annual license of 9,500€ to each VSP for the vertical-related software) will have to be recovered by the price markup to the cost-based prices per slice type. We observe that when demand is *low* (i.e., for the "Conservative EIO and Competitive SP market" scenario) the unit prices of the slice types that are sensitive to throughput are almost double compared to the rest scenarios were demand is *high*.

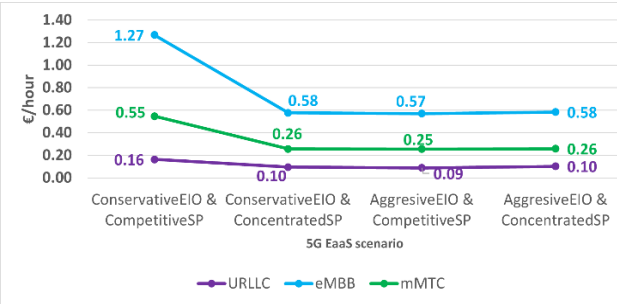

Figure 3: The cost-based hourly prices for eMBB, uRLLC and mMTC network slices

The cost-based prices above are supposed to be effective during the first year (e.g., to promote take up of EaaS offerings), while in the subsequent 4 years of the evaluation period the prices will include a suitable markup to be profitable. We assume that the markup is 80% and 200% in the "Conservative EIO and Competitive SP market" and the "Conservative EIO and Concentrated SP market" scenarios respectively, and 900% in the *aggressive* EIO strategy.

C. Evaluation Results

In this section, we will analyze the attractiveness of the two EIO business models, as well as the profitability of the rest actors in the value network, for two scenarios regarding the competitiveness of the SP market(s) in a 5-year period, by means of their Internal Rate of Return (IRR). IRR is the annual rate of growth that an investment is expected to generate for a particular business actor over the evaluation period (5-years). In more technical terms, the IRR is the *interest rate* at which the *Net Present Value (NPV)* of all the future annual cash flows for that business actor equals zero. If N is the number of years that the 5G testbeds will be operating, C_n is the cumulative cashflow during year n and NPV is the cumulative cashflow at year N, then the IRR is calculated by formula $NPV = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n}$.

Figure 4 presents the IRR for the 4 main actors in a competitive SP market depending on the business model adopted by the EIO. When the EIO adopts the conservative business model (see Figure 4), all actors have a positive outlook, with IRR exceeding 11%. Nevertheless, if the EIO adopts an aggressive business model (see Figure 4) its IRR performance measure increases to 19.2%. The reason is that, in this case, the EIO succeeds in attracting double VSPs compared to the competitive SP market scenario, where the associated revenues are higher compared to the increased OPEX. The effect of EaaS offerings on VSPs' profitability (i.e., IRR) appears as well, assuming that new innovative 5G-enabled services are made available to their end-users.

Figure 5 shows the main actors' IRR for a concentrated SP market when the conservative (left) and the aggressive (right) business models are adopted by the EIO. The EIO realizes that only the conservative business model is profitable, since in the aggressive one, it must develop the necessary, yet costly, software that the VSPs will be using. Thus, under the assumptions adopted in this scenario, the EIO will not pursue the aggressive business model.

V. Conclusions

We proposed business models for the main actors that are involved in 5G EaaS under two alternative instances of the value network, namely the conservative (EIOs do not compete with SPs) and the aggressive (EIOs enters the SP market) value networks. For each of these instances, we assessed the attractiveness and profitability of the business models defined for the actors involved under different market conditions. We conclude that when many "small" SPs are active in a vertical market, then the EIO should choose the aggressive business model. On the other hand, if the vertical market is dominated by a few large SP that have high-market power to force any newcomer (i.e., the EIO) to develop its own vertical-related SW, then the EIO should adopt the conservative business model, unless the latter need to recover only part of the SW development cost.

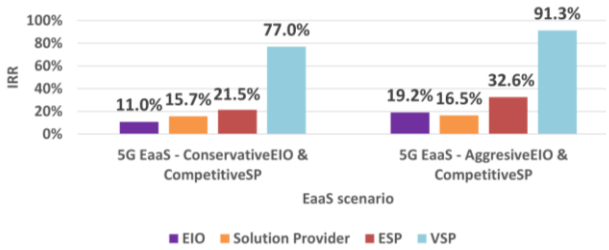

Figure 4: IRR of the main actors for a competitive SP market when EIO adopts the conservative (left) and the aggressive (right) business model.

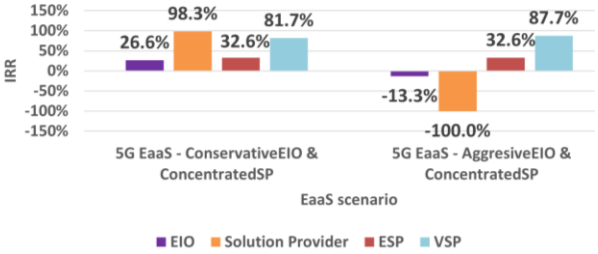

Figure 5: IRR of the main actors for a concentrated SP market when EIO adopts the conservative (left) and the aggressive (right) business model.

Acknowledgment

This work is part of the EU H2020 5G PPP Phase 3 5G-VINNI project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815279. Also, G. Darzanos, C. Kalogiros and G. D. Stamoulis acknowledge the "Theory, Economics, and Services" Laboratory of AUEB.

References

[1] 5G VINNI project. Online: https://www.5g-vinni.eu/

[2] 5G EVE project. Online: https://www.5g-eve.eu/

[3] 5Genesis project. Online: https://5genesis.eu/

[4] 5G Solutions project. Online: https://5gsolutionsproject.eu/

[5] 5G Tours project. Online: https://5gtours.eu/

[6] Yrjölä, S., et al. (2018). Novel context and platform driven business models via 5G networks. *In Proc. of IEEE 29th PIMRC.*

[7] Yrjola, S. (2020). Technology antecedents of the platform-based ecosystemic business models beyond 5G. *In Proc. of IEEE WCNC.*

[8] Oughton, E. J., & Frias, Z. (2018). The cost, coverage and rollout implications of 5G infrastructure in Britain. *Telecommunications Policy*, *42*(8), 636-652.

[9] Smail, G., & Weijia, J. (2017). Techno-economic analysis and prediction for the deployment of 5G mobile network. *In Proc. 20th IEEE ICIN.*

[10] Bouras, C., Ntarzanos, P., & Papazois, A. (2016). Cost modeling for SDN/NFV based mobile 5G networks. *In Proc. of 8th IEEE ICUMT.*

[11] Chiha Ep Harbi, A., et al. (2020). Network slicing cost allocation model. *Journal of Network and Systems Management*, *28*(3), 627-659.

[12] Allee, V. (2008). Value network analysis and value conversion of tangible and intangible assets. *Journal of intellectual capital*.

[13] Osterwalder, A., & Pigneur, Y. (2010). Business model generation: a handbook for visionaries, game changers, and challengers (Vol. 1). *John Wiley & Sons*.

[14] 5G-VINNI report D5.1. (2019). Ecosystem analysis and specification of B&E KPIs". Online: https://doi.org/10.5281/zenodo.3345665

[15] Rhoades, S. A. (1993). The herfindahl-hirschman index. *Fed. Res. Bull.*, *79*, 188.

[16] Braeutigam, R. R. (1980). An analysis of fully distributed cost pricing in regulated industries. *The Bell Journal of Economics*, 182-196.