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Value Creation and Capture From Technology Innovation in the 6G Era

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ABSTRACT In the sixth generation of mobile communication networks (6G) era, in which the convergence of wireless and Internet technologies will drive the digital economy and automation across industries, the focus of innovation will shift from individual technology or products towards innovation within platforms and ecosystems. This paper provides a comprehensive categorised survey of the 6G business literature and the current state of mobile communication intellectual property value creation across the system architecture layers. The key emerging and enabling technologies of the 6G networks are positioned as applicable to areas of value creation and capture, and an outline of the proposed transformation of technology innovation by considering the 6G system architecture layers is provided. Unlike the existing 6G literature focusing on visions, use cases, KPI requirements, and KVI drivers, this study will extend the discussion to the value-creation-and-capture problem of technology innovators. The role of complementary assets, technology policy, standardisation, and intellectual property in 6G is analysed by profiting from innovation lenses. To gain the full potential and capture value from technology innovation in 6G, it is essential that regulators protect the intellectual property contributions to incentive R&D investments by the developers of open, collaborative enabling technologies. The paper further assesses the business model evolution from the 4G engineering platform to modular 5G and 6G, stemming from ecosystems and open value configurations. The results of the technology value analysis show the emerging 6G business to be an oblique hybrid of vertical and horizontal business models and characterise the future 6G networks as a general-purpose technology.

INDEX TERMS Business model, complementarity, ecosystem, general-purpose technology, innovation, platform, regulation, standardisation, 6G.

I. INTRODUCTION

A. MOTIVATION

The sixth generation of mobile communication networks (6G), increasingly underpinning mission-critical functions across communities and businesses after 2030, will not only transform how and what kind of services are offered, but it will also be shaped by the growing societal requirements of resilience, sustainability, inclusion, and empowerment [1], [2]. To make sense of the future digital economy enabled by the convergence of wireless and Internet technologies, we need to envision 6G from technology, business, and societal perspectives in a multidisciplinary way [3]. 6G can

be envisioned as an emerging general-purpose platform [4], impacting both downstream and upstream sectors around telecommunications [5] and having a transformational effect on society at large [6], as proposed in [7]. However, if 6G is to be a real general-purpose technology, it is essential to shift the focus from separate protocol-layered technology innovations of focal firms, as in 5G, to dynamic multi-level innovation in platforms [8] and ecosystems [9], with novel business models that enable the creation and capture of value with 6G services and profiting from 6G innovations.

B. RELATED WORK

In the extant research, mobile network operators (MNOs) have been seen as the focal point of the 5G business ecosystem. The techno-economics perspective, e.g. [10],

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considers 5G connectivity service provisioning and networks an enabling technology: it is an engineering platform with a broad area of application [11], [12]. The business models discussed in the 5G literature have mainly focused on connectivity service provisioning and its differentiation [13], [14]. However, the ongoing convergence of mobile communication networks with digital platforms of various web-scale cloud service providers [15] has triggered studies of mobile businesses at the ecosystem level through the lenses of ecosystemic business models [16]. For example, service continuity as the main driver for collaborative 5G business models was introduced in [17] and extended with stakeholder roles such as system integrator, neutral host, and resource broker in [18]–[20]. Business models utilising cloud technologies were discussed in [16], and related web-service models stemming from exposed MNO network functionalities were analysed in [21]. The localisation trend in 5G services was explored in [22], resulting in the new local 5G micro-operator concept proposed in [23], and related trends in spectrum management and regulation were studied in [24], leading to the identification of centralised, fragmented, and hybrid configurations of converged connectivity and data platforms in 5G in [9].

However, there is very little work on the emerging research topic of 6G business. The first 6G white paper [25] proposed a 6G research vision of an intelligent system of systems that converged connectivity services with complementary services such as imaging, sensing, and location, opening numerous new application areas and business opportunities. The white paper [25] characterised future 6G business ecosystems with novel resource configurations and changing stakeholder roles. Recent white papers and publications on 6G have focused on exploring future communications use cases, enabling technologies, and key performance indicators (KPIs) [26]–[29]. 6G system architecture visions [30] have recently been complemented by 6G business scenarios [3] that examine sustainability in a way that comprises the economic, societal, and environmental perspectives [7], paving the way to identifying key value indicator (KVI) drivers for 6G [31].

It is of fundamental importance to address value-creation and value-capture logics driving innovation in this complex new technology domain to develop commercially viable and technically superior 6G networks. With this aim, this study aims to develop a framework for understanding and analysing 6G, a framework that extends and deepens profiting from the innovation (PFI) framework [4] to emerging general-purpose technologies, taking a more detailed view of the industry's 6G business models, or at the ecosystem level. Thus, the paper will examine the emerging breakthrough technologies, standardisation, intellectual property, and business models of 6G through the lenses of how to profit from innovation, seeking to extend the 6G business discussion from use cases, KVI drivers, and KPI requirements to the value-creation-and-capture problem of technology innovators.

C. MAIN CONTRIBUTIONS

To achieve its goals, this research applies a multi-method approach combining the principles of *futures research* [32], [33] to address the past, present, and future developments of 4–6G as intertwined and brought to the present for analysis; *systems architecture thinking* [34], which addresses 6G as a socio-technical system incorporating various elements and aspects of humans and machines; and *action design research* (ADR) [35], which addresses collaborative action and design to generate new knowledge. The research incorporates both qualitative and quantitative data. The qualitative data for this study are based on a set of virtual future-oriented Business of 6G white paper expert group workshops organised by the 6G Flagship [3] and white papers from adjacent 6G technology workshops [26], and the quantitative data come from the European Telecommunications Standards Institute's (ETSI) patent database [36]. The research process comprised two phases and four processes to draw conclusions. In the first phase, the relevant previous research was reviewed to gain an understanding of the developments in the field. In the second phase, the four research process steps were carried out: problem formulation, which resulted in the research objectives; building and intervention in the form of workshops and the analysis of the patent database; reflection and learning in the form of drawing conclusions; and the formalisation of learning in evaluating the research outcomes and reporting the results.

The main contributions of the paper are as follows:

- i. First, we provide a comprehensive categorised survey of the exclusive business literature on 5G evolution and 6G and discuss their research directions (Table 1).
- ii. We highlight and position the key emerging and enabling technologies of the 6G networks as applicable to areas of value creation and capture (Fig. 1), proposing an outline for the transformation of technology innovations in the 6G system architecture layers.
- iii. Unlike the existing 6G business literature focusing on visions, use cases, KPI requirements, and KVI drivers, this study extends the discussion to the value-creation-and-capture problem of technology innovators. We propose complementary assets necessary for 6G innovation.
- iv. The role of technology policy, standardisation, and intellectual property in 6G is analysed by profiting from innovation lenses. The current state of mobile communication intellectual property value creation was analysed across the system architecture layers via comprehensive survey of IPR databases.
- v. We assess business model evolution from the 4G engineering platform to modular 5G and 6G, which stem from ecosystems and open value configurations.
- vi. Finally, the results of the technology value analysis show the emerging 6G business as an oblique hybrid of vertical and horizontal business models, characterising the future 6G as a general-purpose technology (Table 2).

After the introduction, the paper summarises the main contributions of existing 6G business model studies. The third chapter discusses the key 6G technologies and examines the related value-creation and value-capture mechanisms. Next, the role of technology policy, standardisation, and intellectual property is explored in profiting in the 6G innovations context. In Chapter V, 6G is discussed as an emerging general-purpose technology, and business model elements for value creation and capture are analysed. Finally, the key findings are summarised, and future research suggested.

II. 6G BUSINESS MODELS

This chapter discusses contemporary business model frameworks in general, summarising the major contributions of existing 5G/6G business model studies, as well as their shortcomings. At the end of this chapter, the challenges and drawbacks of existing studies are summarised, including an explanation of how the challenges and drawbacks are going to be addressed in this research.

The business model describes how an organisation creates, delivers, and captures value [37] and designs value-creation, value-capture, and delivery mechanisms [38]. The classical value discussion related to business models stems from Porter's supply-focused value chain concept [39] and considers the business model as a way to capture value from customers [40]. In this classical view, the sole value creator is the focal firm with its activities and resources [41]. The contemporary view emphasises demand-focused business model configurations, the customer interaction mechanisms of which enable value co-creation and utilisation of existing resources and processes [42]. In the digital economy, business models can be categorised in four archetypes [43]: the supplier model as part of the value chain of another company; the multi-channel model across several digital and physical touchpoints to serve customers; the modular service model based on interfaces that enable complementary offerings; and the customer-centric ecosystemic platform model that facilitates interaction with and between customers. The structure of an ecosystem can be seen to arise from network governance, keystone agents and complementors, open interfaces and a pool of innovative capabilities and resources, and a modular core and periphery design [44]. Within an ecosystem of firms, the value capture of a firm depends on its dynamic capabilities, the scarcity of resources within the ecosystem, the nature of complementarities, and the adopted business model [4]. In an ecosystem, value is co-created, co-captured, and shared to maximise the overall value shared and acquired not only by the focal firm, but by the ecosystem's stakeholders [45].

Table 1 summarises the main contributions of existing 5G/6G business model studies.

The extant business and stakeholder analysis research in the 4G/5G context has considered technology as the enabler for business models and a driver of competitive edge and competition with new and improved services, retaining the MNO as the focus of the value chain or

ecosystem. In techno-economics, e.g. [10], 4G and 5G are seen from the connectivity service provisioning perspective [13], [14] and networks as engineering platforms with a broad area of application [11], [12], while the primary business models applied by leading operators have remained surprisingly unchanged [69]. The ongoing convergence of digital platforms [15] has extended business model studies from value chains to business platforms and ecosystems [16], introducing novel stakeholder roles such as system integrator, neutral host, resource broker, and local operators [18]–[20], [23]. As the spectrum and competition regulation have played a pivotal role in allowing, delimiting, or protecting/safeguarding certain business models applied by the operators, technology-oriented business studies have been complemented with research on regulation and policy as an antecedent for new business opportunities [13], [58], [60], [63], [24], [74]. Novel service-based 5G architecture and open innovation-based business models have been studied, e.g., in [51], [52], [69].

The research topic of 6G business emerged with a series of visionary 6G papers that discussed research visions, use cases, emerging architecture, enabling technologies, and key performance indicators (KPIs) [25]–[28], [30]. In 2020, the technology-driven KPI discussion was extended to cover key value indicators (KVI) [31], [29], especially emphasising the role of economic, societal, and environmental sustainability drivers [7] and UN SDGs [2]. The 6G visions were extended to cover political, economic, social, technological, legal, and environmental perspectives in [3]. The platform discussion has been extended from engineering platform thinking (i.e. that platforms comprise components and interfaces) to business platform thinking (which focuses on connecting supply and demand) [65]. Recently, the platform concept has been reconceptualised and extended for the business model and ecosystem research as an ecosystemic platform architecture that comprise components, interfaces, data, and algorithms [27], [73] across service layers [62].

In summary, the early 6G business research has focused on the business model fundamentals addressing opportunities, value creation, and technological advantages. To date, the majority of the 5G and 6G business models presented above call for future development and deployment.

III. 6G AS AN EMERGING GENERAL-PURPOSE TECHNOLOGY

In general, technologies can be defined as discrete, enabling, and general-purpose. Discrete technologies are embedded in the patented solutions of individual firms. Enabling technologies like 5G are innovations that can be applied to driving radical change in the capabilities of its users and are characterised by the rapid development of subsequent derivative technologies, often in diverse fields [75]. This paper sees 6G as an emerging general-purpose technology (GPT), defined in [76] as ubiquitous and with potential for continuous technical improvement, thereby enabling innovation complementarities across industry sectors, not only upstream

TABLE 1. Discussions related to 5G and 6G business models.

Ref	Author, Year	Type of Publication	Focus Topic or Theme	Approach	Key Contribution	Limitations
[46]	Camponovo and Pigneur, 2003	Business	Strategy, actors	Conceptual	Expanded analysis from infrastructure and activities to consider the value proposition, customer relationship, and business partnerships and collaboration.	Voice over 3G-centric as data in emerging phase
[47]	Kuoa and Yub, 2006	Business	Mobile value chain roles	Conceptual	Envisioned service-centric business models to replace technology-centric models.	3G technology
[48]	De Reuver and Haaker, 2009	Business	Business model design	Case study	Context-aware mobile service business model designs from service, technology, organisational, and financial domain perspectives.	3G+ context-aware technologies
[18]	Ballon, 2009	Business	Platform typology, stakeholders	Theoretical	Characterisation of various core components and roles in mobile communications includes platform types as enablers, system integrators, neutral, or brokers.	Impact of policy and regulation
[12]	Basole and Karla, 2011	Business	Platform	Literature review	Studied the evolution of the mobile engineering platform for both mobile ecosystem participants and the future of the app economy. An economic discussion of platform openness was found promising.	Exploratory
[21]	Gonçalves and Ballon, 2011	Business	Service platform	Case study	Operator's capabilities of adopting web-based software-as-a-service and platform-as-a-service models.	Data from early 4G proof of concepts
[49]	Zhang and Liang, 2011	Business	Ecosystem, roles	Case study	Envisioned aggregator- and service-centric models in addition to telco- and device-centric models	China specific, 3G technology
[17]	Noll and Chowdhury, 2011	Engineering	Techno-economic	Conceptual	The paper proposed collaborative heterogeneous 5G radio systems stemming from the user's own home network. Environment requires service continuity, trust-based relationships between networks.	Conceptual
[13]	Ahokangas et al., 2013	Business	Strategy	Exploratory	Scenarios and simple rules strategies developed for operators' future cognitive spectrum-sharing networks. The study highlighted the disruptive role of spectrum sharing in future cognitive cellular networks.	Exploratory
[50]	Feasey, 2015	Policy	Stakeholder roles	Conceptual, commentary	Studied the impact of the Internet services on the mobile industry, introducing a novel approach to competition, interoperability, and innovation.	Commentary letter
[16]	Zhang et al., 2015	Engineering	Techno-economic	System architecture	Introduced a cloud-based engineering platform for the deployment, management, and optimisation of the small cell 5G network.	OAM context
[51]	Ghezzi et al., 2015	Strategic management	Strategy	Multiple case study	Recommendation for MNOs to move from connectivity service protection to a proactive role in the implementation of an innovation ecosystem.	Italy context
[52]	Weber and Scuka, 2016	Business, policy	Innovation	Comment article	Suggestion for MNOs to transform from market protection and risk avoidance to innovative business models.	European MNO-focused
[22]	Ahokangas et al., 2016	Business	Business model	Conceptual	Discussed the ecosystemic, competitive, and scalability elements of local micro-operator business models in 5G.	Theoretical elements discussed
[10]	Palattella et al., 2016	Engineering	Techno-economic	Conceptual	5G technology found to be an essential enabler of a full IoT rollout. Fundamental issues around IoT data privacy and trust.	Technological and standardisation aspects
[11]	Pujol et al., 2016	Engineering	Techno-economic	Stakeholder analysis	Identified the new players entering the RAN ecosystem with 5G evolutions. Introduced a novel concept of the private virtual network operator and related value chain.	RAN-centric
[19]	Rasheed et al., 2016	Engineering	Techno-economic	Stakeholder analysis	The study addressed cooperative business models for smart phone energy efficiency in 5G Networks. Network sharing and neutral hosting highlighted as important cooperation scenarios.	Energy context
[53]	Rao and Prasad, 2016	Business	Innovation	Conceptual	The study expanded the mobile broadband business model with a focus on other-than-consumer customers, the outsourced managed services where the network infrastructure providers offer the network as a service (NaaS), and the virtual network operators. The paper found the evolution of 5G BMs contributed to digital business models in the form of various connectivity providers and partnership business models.	5G, IoT focus

TABLE 1. (Continued.) Discussions related to 5G and 6G business models.

	et al. 2018		analysis, business model		operated 5G networks.	
[60]	Cave, 2018	Policy	Regulation	Commentary	A discussion of potential regulatory changes with 5G, such as extensive regulation of fewer RANs and the need to analyse network operators' services for a variety of content and application providers with substantial market power. Novel sharing, multitenancy, and wholesale business models.	Commentary
[61]	Kukliński et al. (2018)	Business	Business models, stakeholder analysis	Conceptual	The study discussed business models of network slicing, proposing the technical role-based business models of infrastructure broker, network slice broker, and service broker.	5G slicing context
[14]	Ahokangas et al., 2019	Business	Business models	Conceptual	Vertical, horizontal, and oblique business models for local 5G micro-operators were developed and analysed. Anticipated a shift from MNOs' traditional control points, spectrum, and infrastructure to location-specific control points.	Micro-operator context
[62]	Camps-Aragó et al., 2019	Business	Business model	Conceptual	The paper examined mobile network operators' 5G business models: a classification of a micro-operator business models, the cloud-based XaaS/Naas models, a use case enabler for business-to-business customers, the ecosystem orchestrator, and the pervasive platforms business model.	Conceptual
[63]	Teece, 2019	Policy	Competition, Innovation	Conceptual	Analysed the role of an open innovation model in the mobile industry evolution and challenges related to a vertical integration scenario in 5G. It found future generations to be enabling technologies, benefiting from engagement with downstream complementors with a variety of further applications.	US context
[20]	Valtanen, Backman, and Yrjölä, 2019	Business	Value configuration	Theoretical	Found similarities in distributed ledger-enabled value creation between 5G and smart grid use cases in facilitating various value-creating resource configuration processes such as 5G network slice brokering.	Theoretical
[15]	Alvarez et al., 2019	Engineering	System architecture	Experimental	5G network convergence of mobile communication networks with digital platforms of various web-scale cloud service providers. Proposed a novel NFV- and SDN-based service virtualisation platform.	Media context
[25]	Latva-aho and Leppänen (eds), 2019	Engineering, policy	Vision	Conceptual	architecture facilitates future media services on 5G. The first 6G vision paper on future communication needs, enabling technologies, and emerging use cases and applications – and the related research question. Introduced societal and business drivers for 6G.	Conceptual vision
[28]	Letaief et al., 2019	Engineering	Vision	Conceptual	Found AI to be the critical enabler in designing and optimising 6G architectures, protocols, and operations	Conceptual tech. vision
[65]	Hmoud et al., 2020	Business	Business model	Theoretical	Discussed MNO business models targeted at two-sided markets and presented a big data-driven advertising application, and mobile sensing.	Conceptual
[66]	Sacoto-Cabrera et al., 2020	Business	Business model	Theoretical	Analysed MNO and MVNO monopolistic and strategic business models by game-theoretic modelling, concluding that both business models were economically sustainable.	Game theory
[30]	Viswanathan and Mogensen, 2020	Engineering	Vision	Conceptual	Discussed 6G use case themes, their requirements, key enabling technologies and architecture concepts. Proposed a platform approach to the network to meet the requirements of the expansion into many varied use cases and industries.	Conceptual tech. vision
[27]	Saad, Bennis, and Chen, 2020	Engineering	Vision	Conceptual	Envisioned 6G applications, proposed service classes, requirements and performance indicators. Proposed to move from radio-centric “3GPP” system design towards an end-to-end co-design under AI orchestration.	Conceptual tech. vision
[31]	Ziegler and Yrjölä, 2020	Engineering	Techno-economic	Conceptual	Extended 6G key performance indicator analysis to key value indicators and examined their implications for 6G business transformation in growth, sustainability, and efficiency domains.	Conceptual visions
[67]	Bariah et al., 2020	Engineering	Vision	Literature study	Based on literature survey for key enabling technologies, the paper discussed requirements,	Conceptual visions

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[30]	Viswanathan and Mogensen, 2020	Engineering	Vision	Conceptual	Discussed 6G use case themes, their requirements, key enabling technologies and architecture concepts. Proposed a platform approach to the network to meet the requirements of the expansion into many varied use cases and industries.	Conceptual tech. vision
[27]	Saad, Bennis, and Chen, 2020	Engineering	Vision	Conceptual	Envisioned 6G applications, proposed service classes, requirements and performance indicators. Proposed to move from radio-centric “3GPP” system design towards an end-to-end co-design under AI orchestration.	Conceptual tech. vision
[31]	Ziegler and Yrjölä, 2020	Engineering	Techno-economic	Conceptual	Extended 6G key performance indicator analysis to key value indicators and examined their implications for 6G business transformation in growth, sustainability, and efficiency domains.	Conceptual visions
[67]	Bariah et al., 2020	Engineering	Vision	Literature study	Based on literature survey for key enabling technologies, the paper discussed requirements,	Conceptual visions

TABLE 1. (Continued.) Discussions related to 5G and 6G business models.

					challenges, and open research problems stemming from 6G application visions. The study found the emerging societal trends as a key driver, calling for intelligent services based on extended reality and haptics communications.	
[24]	Matinmikko-Blue, Yrjölä, and Ahokangas, 2020	Policy	Regulation	Conceptual	Analysed of the challenges in the 6G spectrum management era. Found spectrum sharing to play an increasing role in accommodating new 6G systems with incumbents.	Conceptual
[64]	Yrjölä, 2020	Business	Ecosystems	Conceptual	Discussed the antecedents of multisided transactional platforms. Analysed the blockchain technology enablers in the integration of ecosystem-focused business model configuration and open value configuration in 6G.	Conceptual
[68]	Ahokangas et al., 2020	Business	Ecosystems	Action research	Examined antecedents of the transformation to a 6G ecosystem. 6G technology convergence might lead to the divergence of traditional vertical and horizontal value flows and value structures.	Indicative
[3]	Yrjölä et al., 2020	Business	Scenarios	Action research	Presented exploratory scenarios for future 6G business, focusing on user experience, business and sustainability, and analysing related strategic options.	Future research
[7]	Yrjölä et al., 2020	Business	Scenarios	Action research	Analysed the role of sustainability as a challenge to and driver of the 6G Business from economic, societal, and environmental perspectives	Future research
[69]	Lehr, Queder and Haucap, 2021	Policy business	Case study	Conceptual	Analysed the transition to the small cell architectures, intelligent core network, and shared spectrum required for 5G. Explored competitive dynamics for how MNOs would address the core market, as well as new opportunities enabled by 5G. Found potential for new business models and competition to disrupt the wireless industry in coming years.	5G MNO
[9]	Ahokangas et al., 2021	Business	Case study	Conceptual	Analysed the convergence of local 5G connectivity and data platform configurations in the industrial multi-stakeholder ecosystems context.	Single case study
[29]	Hoffmann et al., 2021	Engineering	System architecture	Conceptual	Examined 6G trends in and visions of technologies, services, use cases, business, and key societal values. Proposed key value and performance indicators highlighting sustainability drivers.	Conceptual
[70]	Yrjölä et al., 2021	Management	Exploratory	Theoretical	Exploratory analysis of the impact of 6G and AIs for Organisational Agility. Key themes recognised were trust and legitimization, profiting from innovation, APIfication, the rise of the developer, and sustainability.	Descriptive
[71]	Ziegler and Yrjölä, 2021	Business	Techno-economics	Conceptual	Presented the framework of an economic value assessment consisting of ecosystem environment, inputs of resource and investment, process, and performance improvement from 6G technology and architecture, and key indicators of 6G value and output.	Conceptual
[72]	Bhat and Alqahtani, 2021	Engineering	Literature review	Conceptual	Provided a comprehensive list of the literature on 6G and analyse their key contributions. The study found that a 3D connected AI-driven 6G network would bridge the contemporary technology gap to efficiently achieve the SDGs. The paper envisioned AI, intelligent surfaces, cell-free architecture, digital twins, and quantum computing to become key 6G technology candidates.	Tech/System focus
[73]	Yrjölä, Ahokangas, and Matinmikko-Blue, 2021	Business	Platform	Conceptual	The study introduced the extended ecosystemic platform architecture consisting of components, interfaces, data and algorithms, investigating how this business framework could enable the transformation of 5G.	Conceptual
[74]	Moerel and Timmers, 2021	Policy	Case study	Theoretical	Discussed the competition for global leadership leading to ever-increasing geopolitical tensions. The technology battle was found to be mainly related to leadership in the field of 5G, semiconductors and AI.	General

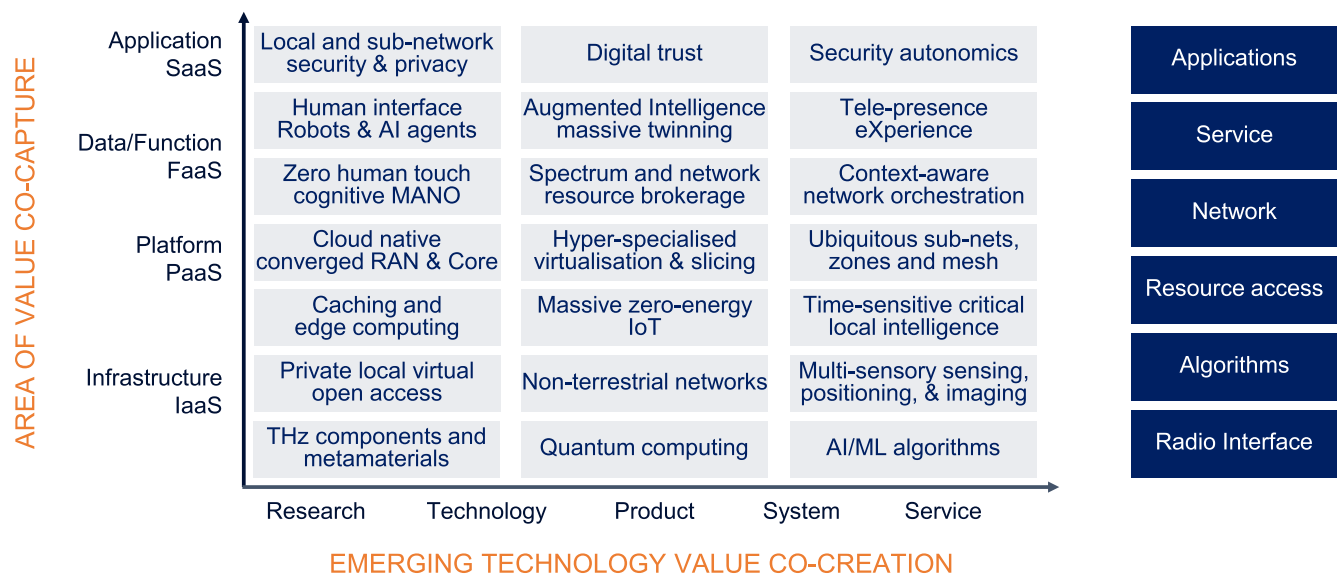


FIGURE 1. Proposed areas of value creation and capture in 6G technologies.

and downstream of value streams within a single sector as is the case with the enabling technologies. As a GPT, 6G faces a new situation in which value creation and capture, i.e. profiting from innovation (PFI), through new technology innovations with novel business models will occur across the ecosystems of stakeholders instead of at the single protocol layer of a single company, as outlined in [73].

The original PFI framework applied to the telecommunications sector by [4] focused on appropriability (the ability to capture profits), complementarity, standardisation, and intellectual property issues utilising the enabling technology perspective and covering the sector's value-creation and value-capture activities. The PFI framework sees profits flowing to those that control bottleneck assets in the sector, arising from unique combinations of technologies and leading to sector-wide gains.

To extend the PFI analysis, a sector's value-creation activities can be depicted across five phases, from research to technology, product, system, and service [77], indicating that value co-creation activities are initiated before any business models have been created [78]. The value capture may be attempted through infrastructure or applications provided by the sector's players and categorised based on the enabled, service logic-driven business models that can also be found in other sectors like the software, web-scale, e-commerce business, cloud, Internet-of-Things (IoT), and platform business sectors. Regarding the digital services to be offered in future 6G, both the everything-as-a-service (XaaS) [79] and the network-as-a-service (NaaS) [54] approaches enable different digital service providers to offer a variety of cloud-based services across the cloud stack layers. Within XaaS, the explored digital-as-a-service business model typologies cover infrastructure-as-a-service (IaaS),

platform-as-a-service, function-(data)-as-a-service (FaaS) and application-as-a-service (AaaS) [79], [80], as Fig. 1 illustrates.

Building on the previous work in 6G visioning [3], [29], [67], [72], [81], this paper summarises and positions key emerging and enabling technologies for further business model analysis, based on their system architecture level and the technology lifecycle, as depicted in Fig. 1 and explored in more detail in later sections of this paper.

A. AN INNOVATOR'S ABILITY TO CAPTURE PROFITS GENERATED BY EMERGING 6G TECHNOLOGIES

Appropriability refers to an innovator's capacity to retain the added value (profit) from its emerging technology innovations and is particularly challenging in the case of GPTs [4], because the widespread economic effects of GPTs typically take a decade to materialise. Innovations [82] and disruptive emerging technologies are associated with lower legitimacy and higher uncertainty [83], [84] and may cause regulatory, incumbent, and social resistance [85]. Thus, new technologies need to be legitimated among their developers, users, and regulators, because legitimation is a precondition for successful value creation and capture [86]. Legitimacy is created or achieved through engagement with the market participants and is thus a resource available to actors in the business ecosystem for their opportunistic purposes.

As a disruptive and emerging innovation, 6G networks may share several legitimacy challenges that stem from following the underlying rules and regulations related, e.g. to data, competition, or environmental regulation. Furthermore, as innovators develop new 6G capabilities, they face associated financial, technological, and reputational legitimacy challenges and need to identify how to reconfigure legitimacy

within their ecosystem. In 6G, “the ability to dynamically revise or reinvent the company and its strategy” becomes essential to identifying and seizing opportunities and innovation [87].

The evolution to a cloud-native infrastructure abstraction on core and radio access empowers technology vendors and service providers to deploy and operate flexible and portable processes and services in dynamic multivendor cloud environments in 6G. In the future, service-oriented 6G architecture with open application programming interfaces (APIs) will enable microservices to provide a dedicated business function that allows independent upgrades and scaling of distinct software modules with zero service impact. Open APIs in 6G will foster faster service development, access, and integration for internal and external ecosystems and in conjunction with value co-creation schemes between the service providers. Open communities will complement traditional telecommunication R&D in accelerating access to new technology with shared innovation, research, and development across industry domains. Open-source lowers vendor lock-in and opens new opportunities for co-creation between vendors and service providers. Instead of creating a feature request to vendors, stakeholders and customers could contribute directly to open-source software. The developer community will also provide excellent feature screening by approving proposals that are seen as valuable while rejecting requests that are not seen as important. Open architecture and the open-source regime will further expand the ownership and control of enabling technologies from private firms and research institutes to open-source consortia, leading to reduced appropriability, as Fig. 2 illustrates.

Emerging and enabling technologies play an intermediate role in the value chain. They are typically licensed to downstream firms and are challenging to profit from compared to profiting from end customers facing the final product. Traditionally, in weak appropriability contexts, the strategy to capture value has been to acquire the required complementary assets for in-house commercialisation and pursue technology and product/service leadership. In 6G, full vertical integration in the value chain and/or horizontal diversification to any segment is unlikely. As technologies comprise numerous innovations owned by several stakeholders, profiting from innovation calls for engagement with partners, driving the technology forward to derivative applications and novel devices. It also calls for diversifying into new licensing domains such as the Internet-of-Things, automotive, utilities, and consumer electronics. Collaboration between business, IT, and telecommunication with a more diverse “rise-of-the-developer” trend will be the key to driving the next wave of business innovation. Fig. 2 illustrates how technology innovation models transform across 6G system architecture layers stemming from the 3rd Generation Partnership Project (3GPP) system architecture [88]. The role of the standard essential patents (SEPs), standardised elements, in-house development, and technology innovation is forecast to extend to the radio interface level. In contrast, the role of

proprietary services, open-source contributions, and business model innovation is expected to be greatest towards the application layer.

Business and regulatory constraints may limit value capture from downstream sectors. In addition to telecommunications regulations, challenges arise from information technology regulation and industry segment-specific regulations. For example, the network neutrality principle may constrain value capture in providing the long-tailed distribution of differentiated future services [58]. Critical issues in 6G will be regulation related to multi-sided platforms and the governance of the privacy and security of users, especially affecting the data protection and artificial intelligence (AI) rights [59].

6G as a GPT may have large positive static and dynamic innovation spillovers and externalities that alter the valuation of existing technologies like 5G and enable opportunities for third-party and novel stakeholders [89]. These effects will make profiting from innovation systemic, complex, and challenging, because the common economic contribution from downstream applications and services across industries will grow. 6G R&D needs to be matched with significant investment, business model innovation, and favourable policies related particularly to patents and licensing to enable profiting from innovations and allow sufficient R&D. This will challenge early innovators’ capabilities of profiting and may further lead to underinvestment in R&D. On the other hand, the deployment of 6G as a GPT will be faster if there is a large community of downstream application developers leveraging cumulative open-sourced effort with a feasible market. Moreover, externalities between 6G and applications and across application verticals may encourage investment in 6G.

B. COMPLEMENTARY ASSETS NEEDED FOR 6G INNOVATION

Complementary assets such as tangible goods, intellectual property, and/or service, perceivable by customers, competitors, and partners alike, are essential building blocks for successfully commercialising 6G innovations. The total economic value-added stemming from the combined embedded complementary assets in a 6G system exceeds the value that would be generated by applying these assets as separate. The traditional way to capture value from mobile technology innovation has been patents and licensing, particularly via standard essential patent (SEP) portfolio cross-licensing, as Fig. 2 illustrates. A SEP protects every implementation of a standard and therefore limits any user of the standard. The value capture potential of complementary assets in 6G may be compromised, because SEPs will increasingly be used to make technology, platform, and ecosystem function. The mobile communication business in 6G will be transformed beyond connectivity to cloud-based delivery, software-led value creation, and network-as-a-service business models across telecommunication, Internet, enterprise, and industrial domains. 6G networks will be designed, deployed, managed,

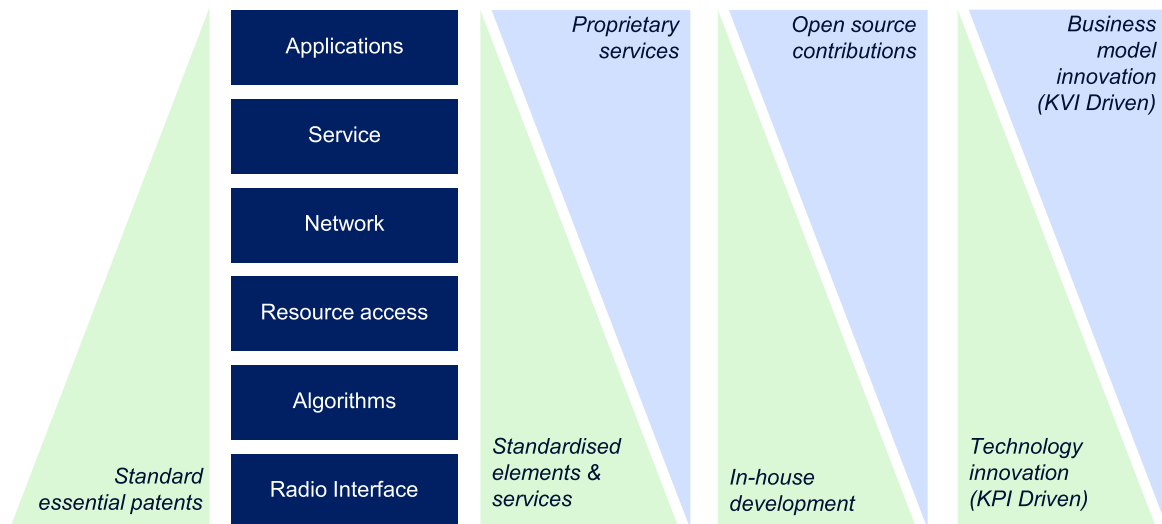


FIGURE 2. The proposed transformation of technology innovation across 6G system architecture layers stems from the 3rd Generation Partnership Project (3GPP) system architecture.

and put on the market not only by the traditional mobile network operators but new stakeholders like local operators, cloud operators, and resource brokers. The pervasive influence of service-driven logic in 6G means meeting each user's diverse needs and preferences or specialised 6G sub-network, whether a human, physical machine, or digital twin. Five types of potential complementarities were found for 6G, based on workshop results and the literature:

- 1) *Production complementarity* founded on prices and quantities is directly related to innovation. From the PFI perspective, the innovations embedded in the 6G platform can be seen to have a positive impact on the demand for complementary applications and services. While earlier generations focused on reaching scale economies, 6G will be generalised towards economies of scope. In [15] a software-defined networking (SDN) and network function virtualisation (NFV), compliant architectures were found to enable new opportunities to facilitate the development, deployment, and operation of services on top of the 5G networks, leveraging the function-as-a-service (FaaS) computing paradigm and AI/ML.
- 2) Converging 6G will provide several opportunities with demand-side *consumer complementarity*, meaning that it is beneficial to consume goods as connected rather than in isolation. Consumer and production complementarities are required to efficiently regulate, standardise, and balance the supply and demand of services. Expanding market access and matching and bridging of customers and their demands across businesses create advantages and can help monetise 6G. 6G, in leveraging its enhanced data and analytics services, can utilise the existing customer base for testing and open new opportunities for diversification [90]. In [29], an extensive list of future customer services and use cases

is envisioned as antecedents for demand-side complementarities. Furthermore, such complementarities can include non-priced government policies such as a novel spectrum regulation paradigm that reduces entry barriers and helps utilise spectrum-sharing technologies in different domains [24].

- 3) In *input oligopoly complementarity*, innovative bottleneck technology assets of separate companies with monopoly power are used to produce something. In the mobile industry, key characteristics of oligopoly have been visible with high barriers to entry due to government spectrum licences, competition regulation and economies of scale, intellectual property, access to expensive and complex technology, and strategic actions by incumbent operators and technology vendors. In [60], the extensive regulation of network operators and number of RANs and application providers with substantial market power were discussed in the context of 5G evolution. The owners of SEPs were seen to pursue self-interested licence pricing that led to cumulative high royalties [91]. In the invention-rich 6G context, this value-capture mechanism may be limited by prolonging the fair, reasonable, and non-discriminatory (FRAND) SEP licensing regime, which will restrict the patent holder's bargaining power [63].
- 4) *Asset price complementarities* stem from foreknowledge of the future development of asset prices. Various innovators in the 6G ecosystem, particularly agile start-ups, could speculate on futures markets and complementary assets with the potential to increase value. For example, spectrum-sharing regulation-triggered spectrum administration and management innovations [24], [69] can change valuation, and the initial invention may create foresight concerning future asset prices.

5) *Technological and innovation complementarities* play a fundamental role in 6G, because the value cannot be captured without other complementary existing or created embedded technologies or innovations. With 5G evolution, open RAN [11] and virtualised service-based core network architecture [54] had already introduced new opportunities for complements across architecture layers and technologies. The complements related to enabling technologies can be associated vertically, horizontally, or laterally, as in the cases of semiconductor components, advanced materials, AI/ML, and quantum computing [72]. Innovation advances will increase productivity and opportunities for innovation in downstream sectors like data application and service technologies. However, in the presence of complementary bottleneck assets, PFI may be compromised. In several 6G visions [3], [27], [29], [70], AI/ML process steps from data access to data engineering and model creation and human-machine interface (HMI) technologies have been found to be transformational potential bottleneck assets.

Managing complementarity in 6G is expected to cause difficult coordination, control, and market development challenges. For an upstream 6G innovator, value capture may be uncertain if there is no guarantee that the downstream adopters and potential complementors will invest in creating good value for the ecosystem. Increasing modularity from 5G towards 6G mobile communication platform-enabled systemic or architectural innovation will enable a rapid pace of autonomous innovation and reduce the role of complementary asset modules as a core value-capture (appropriability) mechanism. Consequently, facing high competition and lower margins, technology vendors may increasingly specialise in selected protocol layers and related modules. There is a risk that emerging technology providers will not capture sound returns for their technological contributors to standards development, despite the royalties from their SEPs. Underinvestment in the emerging technology innovations may have severe consequences for the ecosystem and society leveraging 6G as a GPT with a public common good component.

IV. ROLE OF TECHNOLOGY POLICY, STANDARDISATION, AND INTELLECTUAL PROPERTY IN 6G

A. STANDARDISATION AND INTELLECTUAL PROPERTY

Proprietary technologies that have subsequently been transferred into a series of standards, from the first generation onwards, have been to mobile communications' success. Each new technology generation has required a decade of billions of euros investment in research and development to formalize innovations timely into standards and further to hardware and software products and services. Wireless technology standardization has helped generate foundational platforms on which emerging technology vendors have developed their products and services. For a half-century, all major technology providers have relied on licensing the value capture mechanism leveraging ETSI. ETSI has orchestrated

the development and governance of standards, ruling the technology contributors to make licenses available on a FRAND basis for a wide variety of implementors globally. This nonexclusive licensing model has enabled a combination of technology co-development and widespread global adoption. In addition to essential patent royalties which have created a continuous incentive for standard contributions, technology vendors have leveraged complementarities via adjacent intellectual property.

The collaborative standards development process has enabled massive downstream innovation and a mobile technology and application ecosystem. With the ETSI standards-compliant ecosystem, today's mobile industry comprises dedicated technology/chipset firms, infrastructure equipment providers, mobile network operators, device manufacturers, operating system software providers, application developers, and content providers. Many specialised technology firms and vertically integrated companies in the smartphone industry, such as Samsung or Apple, increasingly engage with two or more roles. Contrary to the single company-owned web-scale "winner-takes-all" platforms, common standards in mobile communications have helped define platforms with many stacked software layers. In the dynamic multi-layered and co-opetitive 6G environment, firms may increasingly cooperate vertically in open architectures while competing horizontally to capture value across services.

Based on the ETSI IPR online database [36], the current state of mobile communication intellectual property value creation was analysed across the system architecture layers. Most 5G patents were declared between 2017 and 2019, and approximately 25% of them had already been declared for 4G, indicating evolution. The declared 5G patent families were categorised in three 3GPP Technical Specification Groups (TSG), Radio Access Networks (RAN), Services & Systems Aspects (SA), and Core Network & Terminals (CT):

- 1) RAN, comprising the radio performance, physical layer, radio resource management specification, specification of the access network interfaces, the definition of the operations, and management requirements and conformance testing for user equipment and base stations were found to encompass up to 84% of the SEPs. Layers 1 and 2 alone add up to 70% of SEPs, as illustrated in Fig. 2.
- 2) SA, covering the overall architecture that includes assigning functions to particular sub-systems, identifying key information flows and service capabilities, architecture, and feature requirements, encompasses approximately 11% of SEPs. Interestingly, SA covers security, management, orchestration, charging, and mission-critical applications areas.
- 3) CT comprises the core network, terminal capabilities, and logical and physical terminal interfaces and encompasses approximately 5% of SEPs. Differentiation and user experience have traditionally been implemented via technology system integration and overall network

design, management, and orchestration. Additionally, the device relevance of all the SEPs was found to be 80–90%, in line with the distribution of licensing royalties.

With a massive diffusion to new application areas and expanding the circle of stakeholders and licensees, the introduction of 6G will lead to an increasingly complex licensing landscape that necessitates novel, more precise rules for FRAND licensing. As with the current 5G, the exact interpretation of FRAND and the associated reasonable licensing fees are not precisely defined by the standardisation organisations.

In 6G, the traditional engineering platform concept, consisting of layered open systems interconnection (OSI) model architecture with components and interfaces, will be transformed into cross-layered functionalities and extended to include data and algorithms [73]. This transformation and extension will lead to the convergence of multiple connected ecosystems, introducing new roles and actors, especially related to system integration, management, and orchestration. To efficiently meet the long-tailed distribution of future needs and requirements of various applications and services, the 6G platform may only continue to specify a few core capabilities at the lower system layers and the open interfaces from the platform to the specialised layers of connectivity, and further to applications and services as Fig. 2 illustrates. Based on this foundation, different stakeholders can specify their higher layer use case scenario-specific specifications to achieve a complete connectivity solution. While the lower-layer processing-intensive radio functions implemented in custom silicon chipsets may continue to be specified by global standardisation for scalability and replicability among connectivity services, the modular architecture with open interface specification will enable the rest of the software functions to be deployed on any commercial computing hardware. From the PFI perspective, this suggests that value should be captured increasingly across multiple protocol layers and levels of the industry, and that the role of the *de facto* standard will need to be revised. Standards for systemic and complex enabling technologies such as AI/machine learning (ML), as Fig. 1 summarises, will continue to require co-opetitive development to gain interoperability across ecosystems and industries. Modularisation and open interfaces facilitate competition and entry, enabling stakeholders to specialise within the ecosystem and develop complements to the platform. Consequently, start-ups can increasingly access complementary assets through various forms of alliance with larger firms.

The protection and enforcement of intellectual property while fostering wide diffusion are among the key challenges of moving toward 6G. In particular, there is an ongoing discussion about who should acquire and pay for a licence for SEPs: the OEMs, end-product manufacturers, or connectivity and application module suppliers. It is key to find compromises that avoid the courts' protracted resolution of licensing disputes, ensure adequate compensation for the developers of these new technologies, and promote their widespread

use through appropriate fees to avoid hampering innovations in 6G application areas. For example, recent antitrust concerns in the US and EU may lead to a compromised ETSI FRAND model and a vertically integrated and more proprietary model, in which the reduced IP protection may be priced into products and services [63]. More severely, this may reduce the currently significant positive externalities that mobile technologies offer and place 6G's role as a general-purpose technology at risk.

B. TECHNOLOGY POLICY

Geopolitical developments are increasingly influencing future telecommunications from economic, societal, and environmental perspectives. At the national level, concerns over sovereignty regarding digital technologies have already become an issue [74]. Four areas of public policy concerns can be seen to guide governments' actions toward the development of 6G.

First, the increasing geopolitical tensions and the competitive security environment urge governments to advance themselves by adopting and using 6G technologies for national security purposes and protecting critical infrastructure to cope with cybersecurity, military and defence, and supply chain security.

Second, due to the increasing dependence of government bodies and critical digital infrastructure providers on a limited number of dominant market players, governments have key interests in reinforcing their nations' economic competitiveness through leading and leveraging 6G development and deployment. Issues such as spectrum policy, standards development processes and organisations, and antitrust and trade practices are present in the realm of technology and innovation leadership. Broadband availability and affordability contribute to bridging the national digital divide. Furthermore, industrial policies that direct investment in critical industries, and technologies that secure supply chain availability and competitiveness and protect intellectual property, remain the main activities at the country level.

Third, the growing reliance on connectivity, cloud infrastructure, and data collection by individuals, companies, and governments has already contributed to increased recognition of the need for trusted communications and increasing autarchy requirements. Such trust undergirds the ability of 6G technology to contribute to economic competitiveness and ameliorates national security concerns through heightened attention to security, privacy, and identity authentication or anonymisation.

Fourth, there is a trend towards the strengthened public-private partners model, in which governments will play a more substantial role in funding the technologies to meet the United Nations Sustainable Development Goals (UN SDGs) [1] and help combat climate change as one goal.

The disparity of policies and legislation between the three major geopolitical groups, the US, China, and Europe, influences technology development and innovation. The global competition in 6G contexts may lead

to technological divergence, compartmentalised innovation ecosystems, techno-nationalism, and market protection, which may negatively affect the scalability, replicability, and internationalisation of 6G services [7]. The market-driven US approach, the rights framework perspective of the EU, and the government-controlled policy of China [92] govern not only the conventional spectrum policies and technology regulation but also the governance of competition and innovation, especially privacy- and security-related decisions. The international network effect risk of data and service colonialism observable in many consumer services may be diffused to services offered across industrial verticals. The polarised regulation and standardisation of 6G technologies may severely affect the 6G business by constraining the scalability, replicability, and economic sustainability of the technology innovations.

Governments are reconsidering the range of complementary assets accessible to them to ensure the competitiveness of domestic firms in profiting from their 6G GPT innovations locally and for supporting national productivity. Policy action can include supporting long-term research, start-up incubation and technology transfer, the capital market for technology companies, and stimulating public capital markets. Furthermore, innovations may require access to new technological public or semi-public complementary assets such as the authorisation of the radio spectrum, access regulation of the obligations for interoperability, and the use of public infrastructure. Spectrum authorisations, including administrative allocation, market-based mechanisms, and the unlicensed commons approach, play a key role in defining the wireless markets and ultimately defining who can operate various wireless systems. Spectrum authorisations are fundamental in allowing new market entry for innovative wireless solutions and a powerful tool for incentivising and forcing different spectrum users to act towards sustainability goals if desired by the national regulators [93]. Rapid access to the spectrum for innovative wireless services is increasingly promoted by local licensing and spectrum sharing. While spectrum authorisations are a national matter, the approaches developed and trialled in one country can help the sector develop by sharing best practices, trialling, and deploying innovative wireless solutions to global sustainability challenges, and enabling scalable, replicable, and economically sustainable solutions business.

V. PROPOSED NEW 6G BUSINESS MODEL AS A PLATFORM FOR VALUE CREATION AND CAPTURE

This chapter presents the evolutionary view of the mobile communication network business models from 4G to 6G based on the 4C framework [94] and analyses alternative 6G value-creation and value-capture logics. The key findings are summarised by adopting the value configuration–business model configuration analysis framework presented in [45]. Fig. 3 summarises the main operation of this study's data collection and research process as a flow chart.

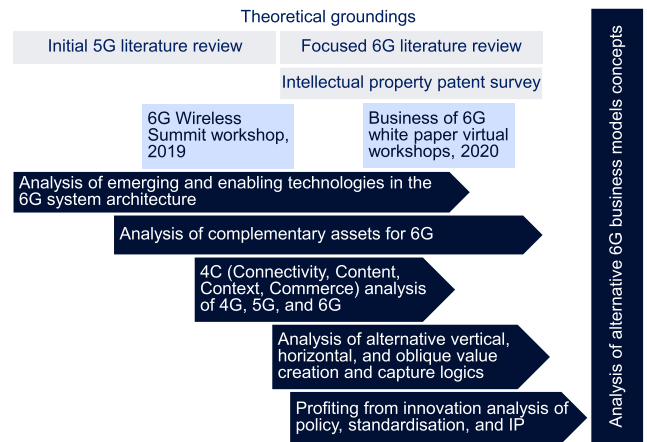


FIGURE 3. The main operation of the research on future 6G business models.

A. FROM ENGINEERING PLATFORM TO MODULARITY AND ECOSYSTEM

Fig. 4 illustrates the evolutionary view of the mobile communication network system from the 4G engineering innovation connectivity platform via 5G service modularity towards 6G as an open ecosystem. In the adopted 4C framework [94], the *connection* layer includes physical and virtualised communication network infrastructures for the ecosystemic value proposition of exchanging information. The *content* layer aims to collect, select, compile, distribute, and present data in the ecosystem in a value-adding, convenient, and user-friendly way. At the *context* layer, the aim is to provide a structure, increase transparency, and reduce complexity by providing a platform for stakeholders' communication and transaction. Finally, the *commerce* layer focuses on negotiation, initiation, payment, and service and product deliveries in the ecosystem, enabling low transaction costs and providing a cost-effective marketplace for matching and bridging supply and demand.

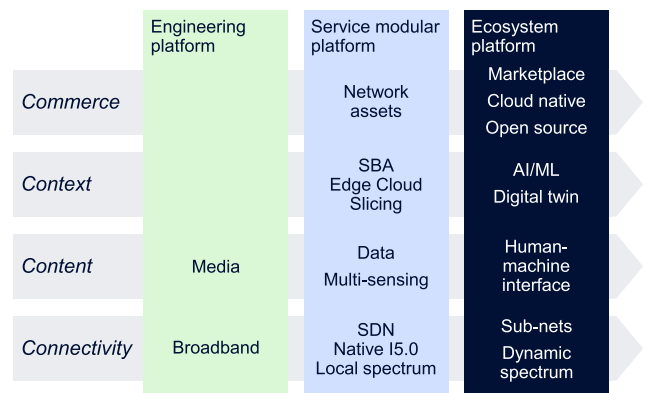


FIGURE 4. From 4G engineering platform towards modularity (5G) and an ecosystem platform (6G).

Despite massive investment in the current 4G/5G networks, the mobile network operators' capacity to differentiate have

been limited, because users have seen differentiation more at the device and content level. Furthermore, the bottleneck assets in the ecosystem have shifted to the mobile operating systems. The digital platform business model enables software developers to add value through applications and complementary assets to the ecosystem by attracting users and building network effects.

5G can be seen as a modular service system stemming from interfaces that enable complementary offerings. The ecosystemic 6G platform model facilitates the value co-creation, co-capturing, and sharing to maximise the overall value generated and acquired not only by a focal firm but also by the ecosystem's stakeholders. The 6G ecosystem can be seen both as a transaction and innovation platform, enabling digital business ecosystems by facilitating exchanges of otherwise fragmented groups of consumers and/or firms (transaction platform) and by providing a technology and distribution system for other companies to base their innovations (innovation platform) [95]. Increasing modularity in the mobile communication platform by systemic or architectural innovations will enable fast-paced autonomous innovation but reduce complementary asset modules' role as a core appropriability mechanism.

With 6G, the systemic "industry architecture" innovation will be vital in enabling business model changes and value capture. Transformational bottleneck assets such as AI/ML and human-machine interface (HMI) technologies leveraged across distributed heterogeneous 6G cloud architecture were found relevant in GPT technologies. A common denominator for the 6G system is the need for the dynamic cross-layered resourcing and reconfigurability of functions and services in operation. The new paradigm of extreme scalability and flexibility in 6G will be managed and orchestrated by autonomous AI- and ML-based functions across all layers and parts of the network abstraction. AI/ML has the potential to replace some of the model-based physical layer (PHY) radio algorithms to achieve better performance and enable flexibility with less complexity [27], [28]. The 5G infrastructure public private partnership (5G PPP) has summarised the views of the European Commission and European ICT industry in [96] highlighting the AI/ML applications that can be applied in the 5G deployments across several network domains. In the context of 5G PPP projects, AI/ML solutions that are designed, implemented, and tested consist of network planning, network diagnostics and insights, and network optimisation and control. The primary focus in the current 4G and early 5G deployments has been on reducing capital expenditure, optimising network performance, and building new revenue streams through the customer experience.

In the dynamic network optimisation and control use case, the mechanisms that use the AI/ML techniques have different time scales, depending on their operational domain, i.e. air interface, core network evolving from evolved packet core (EPC) to 5G core (5GC), and transport systems. The *non-real time* use cases (>0.5 s) closer to the management

plane such as RAN slicing in multi-tenant networks [97], radio resource provisioning in multi-technology RAN [98], and reinforcement Learning (RL) empowered user association [99] can be readily applied in 5G networks, where programmability is enabled by software-defined networking (SDN) and network function virtualisation (NFV). *Near real-time* (10 ms – 0.5 s) functions such as traffic steering [98] and demand-driven power allocation [100] can be deployed as an application in the Open-RAN RAN intelligent controller (RIC). For *real-time* (<10 ms) AI/ML applications, the natural placement of the PHY or the medium access control (MAC) the gNB base station. Real-time application for the 5G networks consisting of e.g. joint MAC scheduling across gNBs [101], prescriptive analytics, channel modelling, and estimation [102] is still under research and development due to the complexity related e.g. to atmospheric effects and massive MIMO beam directionality and pattern optimisation. In December 2021, 3GPP has reached a consensus on the scope of 5G NR Release 18 [103], and the Technical Specification Group of the Radio Access Network (TSG RAN) set the longer-term evolution direction of 5G-Advanced, including several AI/ML-based features such as network energy saving, load balancing, mobility optimisation, and AI/ML for the air interface, focusing on channel state information feedback enhancement, beam management, and positioning accuracy enhancements [104].

The 6G system will employ AI/ML in a fundamental way for air interface design and the optimisation of radios, cognitive dynamic spectrum use, and context awareness. In addition to radio applications, hyper-specialised agile slicing calls for new fully automatised AI-based innovations in service management and orchestration for slice creation and control. AI/ML will become essential for end-to-end network automation, allowing dynamic orchestration and adaptation of network resources according to changing service requests, reducing the deployment time of new services and mitigation of failures, and significantly reducing operating expenditure. Digital trust, enabled by quantum computing and distributed ledger technologies like blockchain and smart contracts, will provide businesses securely and predictably with a digital society with world-class cybersecurity, public safety, and fintech solutions [20], [64].

Downstream digital application platforms converge multimodal engagement with media, and the physicality of lived experiences is seamlessly accessible through a human-machine interface (HMI) extended to all five senses, including the senses of touch and taste. Individual and collaborative users can seamlessly switch between any form of immersive mobile extended reality, encompassing virtual reality, augmented reality, and mixed reality, comprising both virtual and augmented objects. The application of future immersive digital realities, "digital twins", can be found across industries, facilitating novel ways of learning, understanding, and memorising subjects in many sciences such as chemistry, physics, biology, medicine, and astronomy.

B. TOWARDS A NEW OBLIQUE 6G BUSINESS MODEL

The business model has developed into the contemporary concept for exploring novel business-related ideas and conceptualisations and has been used as a means for researching alternative future businesses [105] as part of future corporate activities [106]. The three fundamental strategic business processes, 1) *opportunity* exploration and exploitation, 2) *value* co-creation and co-capture, and 3) exploration and exploitation of competitive *advantages*, should address three key requirements for the business model to be successful: it should be scalable, replicable to new business contexts, and sustainable [105], [107]–[109].

The traditional approach to a mobile communication ecosystem is based on a layered protocol-based technical infrastructure, a platform in which other ecosystem players integrate complementary elements and interfaces. From the business perspective, an ecosystem could be defined to consist of synergistic business models that enable simultaneous value creation and capture. Fig. 5 illustrates mobile industry business models concerning value creation across the technology lifecycle phases (research, technology, product, system, and service) and the value-capture dimension built on technology layers with a service-dominant logic where “as-a-service” (aaS) business models dominate. The labelling as vertical, horizontal, and oblique business model stems from the categorisation presented in [110]. The future 6G business models were evaluated and compared, based on the opportunity, value, and advantage dimensions and the bases for scalability, adaptability, and sustainability. Table 2 provides an overview of the key business model-related discussions presented.

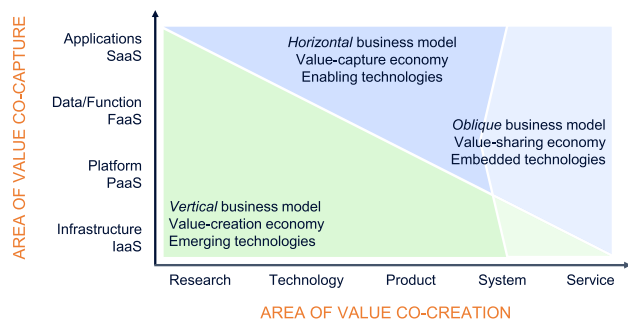


FIGURE 5. Alternative value-creation and value-capture logics in 6G.

Within digitalised industries such as mobile communications, business models typically follow the nature of integration – vertical or horizontal [111]. In the *vertical* business model, traditionally employed by infrastructure and technology providers, a firm controls its suppliers, distributors, or retail locations as part of its supply chain. In business terms, this can be considered the supply side approach. To be competitive, a firm needs to create value for its customers, thereby living in a value-creation economy and being grounded inside its selected verticals. In the modular 4G engineering platform, technical components and products

are usually commercialised through vertical business models in which a competitive advantage arises from focusing on value creation within narrow segments around connectivity and content [14]. As the telecommunication API initiatives have been largely defined from the inside-out perspective, they have not reached the developers’ ecosystem, and infrastructure vendors’ focus has been on offering and controlling a complete technology and service solution [12]. A vertical integration strategy typically involves the acquisition of business operations within the same vertical, clearly seen in the industry transition from 4G to 5G. Despite systemic technology and architectural gains, vertical models are slow to respond to market dynamics [112].

5G is being introduced in an age of digital transformation and network virtualisation and is transforming the horizontal and vertical structure of the mobile sector [60]. In the *horizontal* business model, employed by service-oriented and consumer business firms, economies of scale and scope are important in serving a wide clientele across different segments while maximising value capture. The horizontal model enables fast growth and innovation in the industry, because it allows multiple providers to focus on their respective fields through a common framework [112]. Again, in business terms, this can be considered representing the demand-side approach. Capturing customer value while defending a position against competition has typically been grounded in enabling technology innovations, extreme cost consciousness, and risk awareness. Horizontal business models allow a rapid scale-up of applications and businesses, because in digital multisided platforms, previously distinct products can be converted into apps and brought together on a single platform. On the other hand, the business models are highly dependent on the supporting infrastructure and complementors to run smoothly [112]. 5G service-based open architecture with softwarisation and cloudification technology has enabled a horizontalisation effect on the demand-side platform [62] that enables innovative as-a-service business models to serve a wider value constellation [65]. The network-as-a-service (NaaS) [54] approach enables different digital service providers to offer a variety of cloud-based services across the cloud stack layers building on application-as-a-service (AaaS), function-(data)-as-a-service (FaaS), platform-as-a-service, and infrastructure-as-a-service (IaaS) models [79], [80].

Previous 4G/5G business architectures have considered only one layer of the ecosystem configuration, either through vertical or horizontal business models. In 6G, full vertical integration in the value chain and/or horizontal diversification to any segment is unlikely. As 2030 approaches, digital service chains are becoming more distributed and advanced, requiring abstracted 6G network capabilities built on resources provided as-a-service. Operational processes, infrastructure-as-a-code (IaC), are already mainstream in modern DevOps, and SW developers are the drivers of a new kind of innovation and service delivery [113]. In business terms, such an approach integrates the supply and demand

TABLE 2. The key characteristics of the vertical, horizontal, and oblique business models in 6G.

	Vertical	Horizontal	Oblique
Opportunity exploration and exploitation	<p><i>Key opportunity:</i> Connectivity service provisioning and its differentiation in the existing customer base based on similarities across use cases served.</p> <p><i>Ways of serving the opportunity:</i> Physical and virtualised communication network infrastructures for value proposition on exchanging information. Total cost of ownership competitiveness. Service-level agreement driven connectivity combined with specialised content services.</p>	<p><i>Key opportunity:</i> To employ a service-oriented network to serve a wide clientele across different segments to achieve economies of scale and scope while maximising value capture. To expand connectivity service provisioning to enterprises and physical industries.</p> <p><i>Ways of serving the opportunity:</i> To collect, select, compile, distribute, and present data in the ecosystem in a value-adding, convenient, and user-friendly way. To combine the data content and AI/ML capabilities for creating the user experience of existing products, while enabling other services.</p>	<p><i>Key opportunity:</i> To provide a service-oriented, loosely coupled, open innovation platform for the mass tailoring of connectivity, content, context, and commerce services on demand for different industries and their various use cases. Dedicated virtual sub-networks and resources that can be offered as-a-service.</p> <p><i>Ways of serving the opportunity:</i> Meeting each user's diverse needs and preferences or a specialised 6G sub-network, whether a human, physical machine, or digital twin. To provide a structure, increase transparency and reduce complexity by providing a platform for stakeholders' communication and transaction. To enable low transaction costs and provide a cost-effective marketplace for matching and bridging resources' supply and demand.</p>
Value co-creation and co-capture	<p><i>Driver for scalability:</i> Efficient supply-side engineering platform. Value creation for its customers, grounded inside its selected verticals. Profiting from technology innovation in RAN and devices via SEP licensing.</p> <p><i>Boundaries of scalability:</i> Size of vertical cases served (number of customer cases, similarity of use cases served, degree of similarity across cases served). Availability and quality of content transmitted.</p>	<p><i>Driver for scalability:</i> Digital demand-side platforms turn previously disparate products into apps brought together on a single platform. Horizontalisation across many applications that used to be the end products of traditional verticals serve a wider value constellation.</p> <p><i>Boundaries of scalability:</i> Highly dependent on the supporting as-a-service platform infrastructure and complementors. Architectural management and orchestration capabilities to create vertical and horizontal network slices. Collaboration with third-party services and ecosystems such as cloud services, content distributors, and mobile payment/identification Platforms.</p>	<p><i>Driver for scalability:</i> Utilisation of a multi-sides platform that enables mass-tailoring for selected segments. Sharing economy antecedents, resources of third parties, and open-sourced effort. Network offered as a code for application developers. Processing-intensive radio functions implemented in custom silicon may continue to be specified by global standardisation.</p> <p><i>Boundaries of scalability:</i> Legitimation among developers. Availability and quality of data. The disparity of policies and legislation between the geopolitical groups influences technology development and innovation.</p>
Competitive advantages, exploration, and exploitation	<p><i>Sources of advantage:</i> Product mindset in core competences, as well as existing processes and resources. A firm controls its innovations, suppliers, distributors, or retail locations as part of its supply chain. Customer intimacy and capability of serving specialised needs.</p> <p><i>Sustainability of advantage:</i> The acquisition of business operations within the same vertical, strengthening its supply chain, reducing connectivity production costs, capturing upstream or downstream profits, and accessing new distribution channels. Services provided over the network's lifecycle, continuous tailoring to maintain/renew advantage.</p>	<p><i>Sources of advantage:</i> Ability to provide end-user experience through standardised as-a-service platforms. New control point at the edge cloud, the billions of transactional and control data points produced by networks.</p> <p><i>Sustainability of advantage:</i> Via growing size, creating economies of scale, increasing market power over distributors and suppliers, increasing product and service differentiation, expanding the company's market, entering a new market. Reduced competition may lead to monopoly positions within an industry or ecosystem.</p>	<p><i>Sources of advantage:</i> Value should be captured increasingly across multiple protocol layers and levels of the industry. Vertical cooperation in open architectures while competing horizontally to capture value across services. Platform that orchestrates and configures demand and supply in a segment to provide specialised services.</p> <p><i>Sustainability of advantage:</i> Depends on platform flexibility and competitiveness among SW developers. Policies and standards underlining the new reality of the ecosystem and its societal role.</p>

side and forms a multisided platform-of-platforms market or a sharing economy. Wide adoption and maturity of business-to-business marketplaces are emerging for enterprises and IT in hyperscale cloud ecosystems. Cloud native design, open source, and standards drive openness in networks' and operations' architectures, while enabling technologies such as hyper-specialised virtualisation and slicing, abstracted data, and analytics capabilities provide the right building blocks. These developments will define the traction for telco exposure and abstraction with mobile in moving towards hybrid *oblique* business models. The oblique business model views 6G as the general-purpose technology and the network as a code for developers. A loosely coupled oblique business model [114], [115] can be seen to follow the rationales of open innovation [116] and the timely concept of a sharing economy in which resource efficiency plays a crucial role [117]. Oblique business models consider the opportunities for value sharing to concurrently complement open innovation-enabled co-creation and co-capture through the simultaneous provisioning and utilisation of resources. Firms cannot build their business models in one-sided technology or industry silos, because it will be essential to consider the lifecycle stage of complementors, customers, and partners in the ecosystem. To be competitive in a value-sharing economy, a firm turns customers' and ecosystems' underutilised assets into more efficient or better use, leveraging a cumulative, open-sourced effort of a community of developers. For example, service-oriented web-scale companies have employed an oblique model to date for fast-to-market strategies, utilising the resources of third parties in their business [116], [118]. Stakeholder interactions are no longer based on customer-supplier relationships, but firms interact to achieve common strategic objectives and eventually share a common fate [119] in the ecosystemic platform-driven 6G business.

C. DISCUSSION

Fig. 6 summarises the key findings. It utilises the conceptual value configuration–business model configuration framework from [45]. 6G can be characterised as a GPT, i.e. it is ubiquitous, enables continuous technical improvements, and empowers innovation complementarities across industry sectors through an open value configuration- and ecosystem-focused business model. Alternative business model configurations can range from closed supply-focused 4G engineering platforms with the vertical business model and a mixed demand-focused horizontal 5G business model to open ecosystem-focused oblique business models in which 6G is seen as a GPT.

Regarding the limitations of this research, in foresight-focused multimethod research that combines qualitative and quantitative data, external validity is challenging to control [120]. To control the external validity, the workshops were carefully arranged to engage practitioners from different parts of the ecosystem and researchers from different research disciplines. Other scholars could have interpreted the data differently. Moreover, the theoretical business model

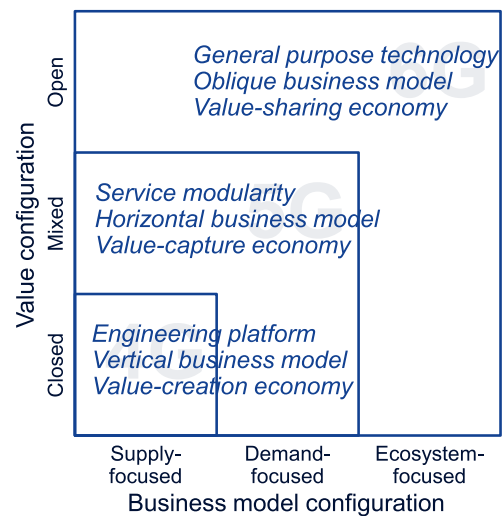


FIGURE 6. Alternative business models for 6G that transform business into open ecosystemic value configurations; conceptual framework adapted from [45].

frameworks and concepts used in the research were carefully calibrated to the context [108] to avoid limitations to generalisability. To increase the study's construct and external validity, we followed the cyclical process of research-oriented action research [120] over the research's two phases and four processes. The data for the research were collected in phases, starting with the future-oriented World Cafe workshops held at the 6G Wireless Summit in Levi in March 2019 [25] and followed by a set of virtual future-oriented Business of 6G white paper expert group workshops organised by the 6G Flagship [3], and white papers from adjacent 6G technology workshops [26], as Fig. 3 illustrates. All the systematically documented *qualitative* raw data from each workshop, such as scenario forces (trends and uncertainties), use cases, and business opportunities, were analysed, applying the causal layered analysis (CLA) and the integral futures four-quadrant frameworks widely used in futures research methodology to deepen the foresight and ensure the research's quality [122]. The data for the *quantitative* part of the study, exploring the current state of mobile communication intellectual property value, were based on the ETSI patent database [36]. Assuming the evolution of the standardisation from 5G to 6G will continue in the 3GPP era, the results of the current state of mobile communication intellectual property should be considered highly reliable.

Because 6G is still in the research phase and emerging as a technology, the results of the exploration of business opportunities, business models, and respective ecosystem alternatives remain to be seen. In particular, the foresight on the timing and sequence of markets, novel business models, and related stakeholders needs further research. As 2030 approaches, empirical research should be conducted to test the issues we have indicated in relation to the stage, scope, and scale of

ecosystemic value creation and capture via oblique business models and 6G as a general-purpose technology.

VI. CONCLUSION

This paper has characterised 6G as an emerging general-purpose technology that will fundamentally change how value creation and profiting from technology innovations will happen in the future. We have presented relevant 6G enabling technologies, examined related value-creation and value-capture mechanisms, and proposed new business models. Our findings on capturing value from technological innovations in 6G highlight the importance of appropriability (value-capture potential), complementarity, standardisation, and intellectual property. In 6G, appropriability may prove a challenge because of the anticipated role of 6G as a general-purpose upstream technology leading to a stronger downstream appropriability of the applications and services across industries, and an essential common economic contribution. 6G thus calls for a multidisciplinary approach with proactive business model innovations stemming from understanding the particularities of relevant complements, legitimising the novel innovations, and a supportive regulatory and policy environment. Specifically, regulators can support the legitimisation of the 6G ecosystem by establishing and enforcing rules and standards that underline the new reality of the ecosystem and its societal role. Complementary assets and embedded technologies lie at the core of 6G ecosystems structured around several competing and intersecting digital platform layers. Platforms and standardisation allow modularisation and autonomous innovation from different stakeholders. Open communities enable firms to convert a distributed resource like open-source software into a complementary asset in 6G. In addition, open architecture and modularity may challenge the ecosystem's ability to generate systemic innovation with the highest value-capture potential as the focus shifts to embedded technology enablers and applications. To ensure the path to the successful deployment of 6G around 2030, policymakers should pay attention to supporting the value capture of the emerging novel technology innovators. In expanding the circle of stakeholders and licensees, the introduction of 6G will lead to an increasingly complex licensing landscape and necessitate a novel, more precise rule for FRAND-compliant licensing. The systemic and complex converging 6G platform and ecosystem provide an exciting research context to study how to profit from innovation, particularly related to the open architecture and open source adopted in 6G.

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