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Multi-disciplinary Approach to 6G: Technology, Business, Regulation, and Sustainability Perspectives

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Abstract: 6G aims to address a number of societal challenges, while promising performance improvements over prior generations of international mobile communication technology. This calls for going beyond a traditional technology-driven approach in mobile communication system development and considering a wider set of values that are particularly driven by sustainability principles. In this 6G era, multi-disciplinarity, covering disciplines beyond telecommunications engineering, becomes an increasingly important approach to develop future-proof mobile communication technologies and services. This paper introduces a multi-disciplinary approach to 6G research and development (R&D) considering technology, business, regulation, and sustainability perspectives. Key topics and tools are introduced together with two case examples that illustrate how multi-disciplinarity, considering the proposed four perspectives, can bring new insights into practical topics relevant for 6G R&D.

Keywords: 5G, 6G, business, regulation, technology.

1. Introduction

6G is expected to play an important role in society in the 2030s, driving digitalization across different sectors and to address major sustainability challenges [1]. In particular, using information and communication technologies (ICTs) to solve sustainability challenges to maximize the positive handprint has become an important goal for digitalization, while ensuring that ICTs' own negative footprint impacts are minimized. Increasing attention in ICT and 6G research and development (R&D) is paid to values driven development [2], where the traditional performance driven technology design is complemented with values, spanning across a range of societal and business considerations. Yet, the topic of values driven technology design is in an early stage in telecommunications research [2], while the baseline concepts are more advanced in other fields of science including social sciences.

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Multi-disciplinarity and inter-disciplinarity, i.e., bringing together expertise from different fields of science to different extent, are fundamental tools for addressing complex problems in 6G R&D. Mobile communication research has been traditionally conducted in disciplinary siloes, where most effort has been on developing techniques within engineering disciplines. Some exceptions have occurred, including business and regulation sides of 5G and 6G [3]. Finnish 6G Flagship's research agenda has included technical, business, regulation, and sustainability perspectives in the 6G R&D from the beginning in 2018 [1], presenting a multi-disciplinary approach to developing future communications [3]. This multi-disciplinary approach, however, is not mainstream in 6G, where studies typically focus on specific technology development, see [4]. Consequently, a major challenge in the new values driven 6G research arises from the engineering community's tendency to work in silos with limited collaboration within the same field, across disciplines and/or across stakeholders. In the era of sustainability, this is no longer adequate, but a multi-disciplinary approach is needed. Indeed, to ensure sustainability in the 2030s, new global 6G framework introduces four overarching design principles: sustainability, connecting the unconnected, ubiquitous intelligence, and security and resilience to guide the R&D in [5].

In the 6G era, mobile communication aims to link digital, physical, and biological worlds [6]. As a general-purpose technology (GPT) platform [7], 6G will become the backbone of digitalization, impacting innovation and transactions across downstream and upstream value chains in different sectors of society [8–10]. The traditionally vertically integrated mobile communications industry, where mobile network operators (MNOs) have control over communication infrastructure and end users, is evolving towards horizontalized service-oriented business models grounded on service-based architectures and common application programming interfaces (APIs) defined across architectural layers and technology domains [9].

This paper introduces a multi-disciplinary approach to 6G considering technology, business, regulation, and sustainability perspectives to help scholars, industries and public sector stakeholders in their 6G R&D related activities. The paper expands authors' prior work on business, regulation and technology perspectives [11] and sustainability perspective [12] to present specific topics and tools for the four perspectives together with two illustrative case examples in 5G and 6G. The presented themes are collected into a frame for holistic multi-disciplinary 6G R&D, whose applicability is demonstrated with two case examples of global IMT-2030 (6G) framework development at the ITU-R [5] and MNO business model for 6G [13].

The rest of this paper is organized as follows. An overview of existing perspectives to 6G development is presented in Section 2. Section 3 presents our multi-disciplinary frame for 6G R&D. Case examples are presented in Section 4. Finally, conclusions are drawn in Section 5.

2. Overview of Perspectives to 6G Development

First, we review different perspectives relevant for 6G R&D including technology, business, regulation and sustainability perspectives, which are seen as important perspectives in [11,12].

2.1. Technology Perspective

Traditionally, research on mobile communication systems has focused on the development of new mobile communication technologies in a number of areas ranging from algorithm, service and hardware design to trialing and proof of concepts. In 5G, major technology developments took place in areas such as massive MIMO, beamforming, millimeterwave communications, cloud radio access network, energy efficiency, among others [14].

6G can be considered as a general purpose technology platform [9,10]. The way network services are being developed, delivered, and utilized in the 6G era will be increasingly built on open network architecture. In particular, the introduced exposure to network data, service, and transaction capabilities as northbound service application programming interfaces (APIs), operation APIs, and network APIs will allow developers to create new solutions and value via access to network capabilities, while providing the mobile network operators (MNOs) opportunities to capture value from their own network capabilities.

The vast majority of 6G R&D is around the technology perspective, similar to the prior generations of mobile systems. 6G technology development takes place around globally identified technology trends summarized in [4]. These trends and enablers include AI-native communications, integrated sensing and communications, device-to-device communications, convergence of communication and computing architectures, enhanced energy efficiency and lower power consumption techniques among others [4]. Significant research in these areas is ongoing, involving varying levels of multi-disciplinarity and collaboration within the same field, across disciplines and across stakeholders.

Mobile communication systems are typically defined in terms of minimum technical performance requirements, which for 6G are currently being defined at the ITU-R. For 5G (IMT-2020), the minimum technical performance requirements included peak data rate (bit/s), peak spectral efficiency (bit/s/Hz), user experienced data rate (bit/s), 5th percentile user spectral efficiency (bit/s/Hz), average spectral efficiency (bit/s/Hz), area traffic capacity (Mbit/s/m^2), latency (ms), connection density (number of devices per km^2), energy efficiency, reliability (success probability), mobility (mobility classes of km/h), mobility interruption time (ms), and bandwidth (MHz) [15].

6G discussions continue to use the same approach as prior generations and consider the 5G minimum technical performance requirements [15] as a starting point for improvements. Additionally, 6G work has introduced new values driven topics, including coverage, positioning, sensing-related capabilities, AI-related capabilities, sustainability, and interoperability [5]. The requirements for 6G will be defined by early 2026, setting requirements for the actual 6G technology development.

2.2. Business Perspective

Business perspective includes approaches to understand and characterize companies' business around mobile communication solutions and services and map and depict future business opportunities, use cases, and scenarios. There has been a growing interest in the telecommunications community to address the business aspects of mobile communications across the technology generations in terms of business models and business ecosystems, but still this research has remained limited.

Business model is a well-known but a debated concept for understanding and characterizing companies' operations, and it is widely used in different sectors. Business models describe how companies do business – by creating, delivering and capturing value – to exploit business opportunities. From the many definitions and approaches for business models, the approaches taken within mobile communication research are typically based on the original business model canvas [16].

More recently, platforms, ecosystems and stakeholders have gained attention in the business research on mobile communications for characterizing the complementing roles of different organizations in making business [6,11,17]. Stakeholders include individuals, groups, organizations or other entities that affect or are affected by a given theme such as 5G or 6G. Platforms – embodied in technologies, products, or services – form platform owner and complementor ecosystems that facilitate interactions between the supply and demand sides of a platform. Industrial digital platforms can be categorized into multisided transaction platforms that focus on facilitating exchange and interactions, and innovation platforms that help create value by enabling technological and service innovations. Ecosystems can be defined as value architectures based on value co-creation, delivery, and co-capture among ecosystem actors in co-specialized collaboration. For mobile communications, the delivery of services involves a number of stakeholders that form the ecosystem, especially when mobile communication is applied to a target environment in specific environments [6]. Research on 6G business models presents different options of value creation and capture in ecosystemic platform context for different stakeholders of the 6G ecosystem [3,13].

2.3. Regulation Perspective

Regulation perspective includes understanding and following of the laws, policies, rules, guidelines, and requirements governing the use of mobile communication technology to make business in different vertical sector application areas. Mobile communication sector is strictly regulated at national, regional and international levels. Spectrum regulation is a specific area within the telecommunication regulation with a lot of activity in different bodies having a big impact on the markets. Additionally, there are other generic regulations, such as AI, data, platform, cybersecurity and markets related regulations, as well as sector specific regulations in, e.g., healthcare, that need to be considered.

Regulation perspective involves analysis of existing and upcoming regulations and their impact on stakeholders, including

for example AI, data and platforms. Additionally, regulation perspective involves identifying change needs developing new proposals for regulations, based on future predictions of the technology and markets. Yet, there is not much work on analyzing the regulatory landscape and the existing regulations specifically for mobile communications. There is even less research on how regulations should evolve in the mobile communications sector.

An example within spectrum regulation is frequency bands for mobile communications which are defined at international level in ITU-R, technical conditions, and finally access rights at the national level. For mobile communications, regulation for example defines the different ways to access spectrum and awards rights to do business for companies, including recent local spectrum licensing approaches [18].

2.4. Sustainability Perspective

The fourth considered perspective includes sustainability, which is the principle of ensuring that our actions today do not limit the range of economic, social and environmental options open to future generations. 6G R&D has adopted sustainability as a key driver early on in the world's first 6G White Paper [1] from the Finnish 6G Flagship. Sustainable development has been structured around triple bottom line of environmental, social and economic perspectives already decades ago, which continues to be valid [3, 6, 12]. These three perspectives are often conflicting and need to be optimizing together, leading to complex trade-offs.

Environmental sustainability in mobile communications covers topics such as energy efficiency, energy consumption, carbon and other green-house gas emissions, e-waste, device duration, etc. [19]. Organizations' environmental sustainability is often assessed with scope 1–3 emissions, where scope 1 covers direct green house gas emissions from the organization, scope 2 covers organization's indirect emissions and scope 3 covers the whole value chain's emissions. The degree to which countries collect environmental sustainability information from ICT sector's companies varies a great deal in Europe, see [19]. A lot of effort in mobile communication R&D has been on energy efficiency improvements with the goal to develop energy efficient techniques as well as lower power consumption devices to reduce the overall energy consumption and resulting green house gas emission.

Social sustainability in mobile communications addresses the human and societal aspects typically through topics of digital inclusion, security, and trustworthinesss [6]. A specific goal in 6G is to connect the unconnected aiming at bringing access to everybody everywhere in a trusted manner [5]. However social sustainability considerations have received less attention in mobile communications R&D than environmental sustainability.

Economic sustainability in mobile communications targets long-term economic growth while respecting the conditions for environmental and social sustainability [20]. Important concepts includesustainable business models at corporate, ecosystem and societal levels [6], calling for systemic change, cross-sectoral collaboration, policy engagement, and impact assessment among others [21]. Circular economy driven operational models with new business opportunities from sustainability footprint reduction and handprint improvements are essential parts of economic sustainability. Circular business models encourage minimizing of consumption and waste and maximizing societal and environmental benefit, rather than prioritizing economic growth [22], highlighting the interrelations of the three sustainability perspectives to optimize operations across the entire value chain over lifetime.

3. Proposed Framing for Multi-disciplinary Approach to 6G

We next present our proposed framing for multi-disciplinary approach to 6G R&D. The proposed framing consists of technology, business, regulation and sustainability perspectives expanding prior work in [11, 12] and identifies key themes within these four perspectives. The framing aims to help scholars, industries and public sector stakeholders in their 6G R&D to identify influential factors across disciplinary borders to facilitate better collaboration across stakeholders with conflicting goals. The framing aims to guide researchers to expand existing research to multi-disciplinarity. The framing is presented in Figure 1, where the technology, business, regulation and sustainability perspectives build on top of the notion of 6G as a general purpose technology platform.

Our technology perspective consists of two elements: (1) enabling techniques and technical solutions, and (2) technical performance requirements and assessments. Thus, the technology perspective includes the development of the technical enablers and technology components to meet the technical performance requirements and their assessment.

Business perspective consists of two elements: (1) business models, and (2) business ecosystems and stakeholders, which build on platforms. The proposed business perspective results in the notion of platform-based ecosystemic business models with ecosystem level and stakeholder level analysis. Business perspective is closely linked to the technology perspective since a proper development of business models requires understanding of the capabilities and limitations of technology solutions.

Regulation perspective consists of two elements: (1) understanding of the impact of existing regulations, and (2) defining regulations for future technology solutions. Understanding of the existing regulations is needed for contextual awareness for technology and business development and potential need for refinements in regulations. Regulation perspective is closely related to technology and business perspectives, as regulations govern the

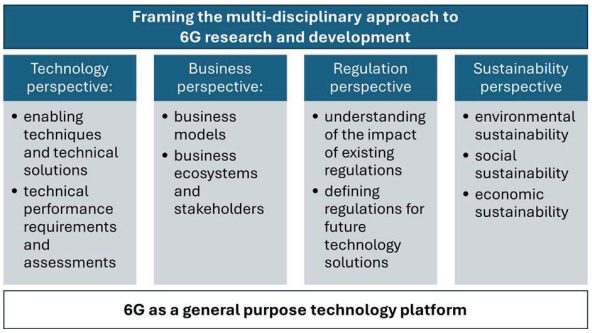

Figure 1.
Proposed framing for multi-disciplinary approach to 6G R&D.

use of technologies thus impacting their development and deployment, and ultimately business.

Finally, sustainability perspective consists of the triple bottom line: (1) environmental sustainability, (2) social sustainability, and (3) economic sustainability. These interrelated elements help to identify factors that influence 6G solutions' handprint and footprint effects over the life-cycle of end-to-end systems. The sustainability perspective is linked to technology perspective by driving sustainable technology development to solve major sustainability challenges. The sustainability perspective is linked to business perspective by redefining principles of making business around sustainability principles and circularity. Finally, the sustainability principle is closely linked to the regulation perspective as regulations on sustainability put requirements on organizations in terms of, e.g., green-house-gas reduction targets.

4. Case Examples

Next, we present two illustrative case examples of 6G, where several of the proposed perspectives are brought together to showcase the multi-disciplinary framing presented in Section 3. These examples include the global IMT-2030 framework for 6G developed at the ITU-R [5] and mobile network operator business model for 6G from [13]. The goal is to illustrate how a topic within mobile communications can be approached from the different perspectives in a coherent manner to discover interdependencies between the individual perspectives and how bringing them together helps to understand and further develop the entire concept.

4.1. Case Example 1: IMT-2030 Framework

The globally agreed framework for 6G is presented in ITU-R IMT-2030 framework recommendation [5]. At the high level, it consists of (1) trends and drivers including motivation and societal considerations and user and application trends, (2) usage scenarios, and (3) capabilities, which reflect performance and value related requirements, as shown in Figure 2.

When analysing the global framework for IMT-2030 (6G), presented in [5] and summarized in Figure 2, it is possible to distinguish that all four perspectives from our proposed framing presented in Section 3 are included, namely technical, business, regulation and sustainability perspectives.

Technical perspective is included in the IMT-2030 framework in the user and application trends, technology trends, usage scenarios, and capabilities parts, where enabling technologies as well as capabilities, which present performance requirements, are presented. In particular, a number of enabling technologies are presented in the technology trends part, which are further detailed in [4].

Business perspective is widely included in the motivation and societal considerations, user and application trends, and usage scenarios parts. Business perspective considers the potential benefits from the use of 6G and presents application areas for the new technology, including example use cases within the envisaged usage scenarios. Business perspective also considers stakeholders in the 6G ecosystem.

Regulation perspective can be considered to be included in motivation and societal considerations, spectrum considerations

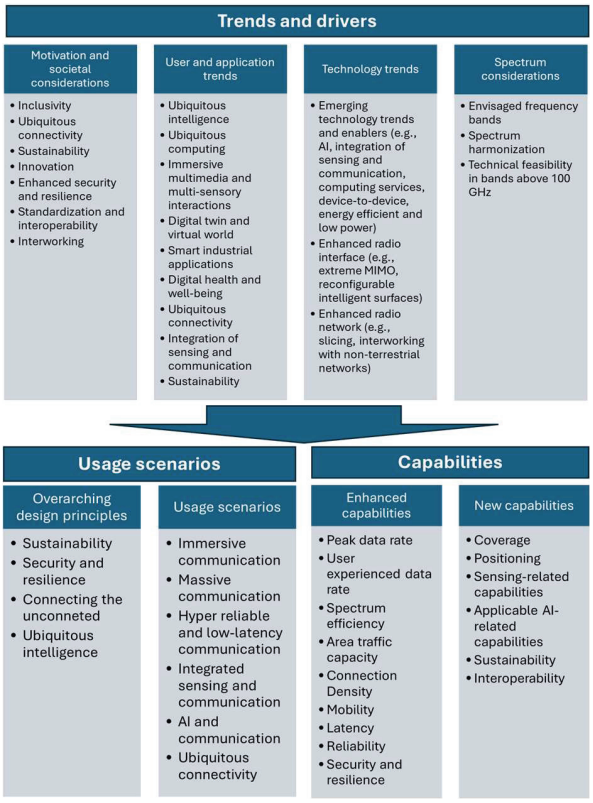

Figure 2.
Global framework for IMT-2030 (6G) based on [5].

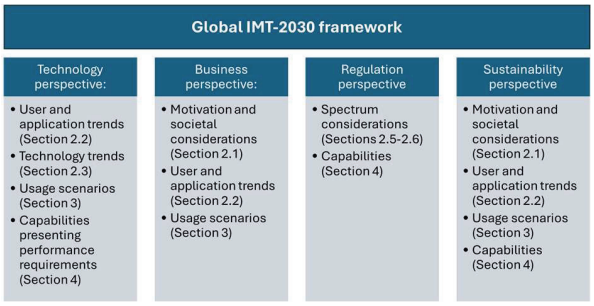

Figure 3.
Analysis of global framework for IMT-2030/6G from technology, business, regulation and sustainability perspectives.

and capabilities parts, showing what can be done and what cannot be done with the new technology. Furthermore, capabilities will be detailed in the future to present technical performance requirements for 6G as a requirement coming from regulation.

Sustainability perspective is included in motivation and societal considerations, user and application trends, overarching design criteria and capabilities, presenting a cross-cutting priority across the entire IMT-2030 framework. For example, in motivation and societal considerations, sustainability covers economic, social and environmental perspectives and highlights energy efficiency, low power consumption, reducing greenhouse gas emissions and use

of resources under circular economy to address climate change and contribute towards the achievement of sustainable development goals. Thus, the sustainability perspective in [5] considers environmental, social and economic sustainability perspectives from our framing in Section 3. Additionally, sustainability is presented as an overarching design principle for 6G, spanning across different usage scenarios of 6G together with the need for connecting the unconnected, which is a form of social sustainability requirement for 6G.

As a result, the global 6G framework presented in [5] has captured all four perspectives proposed in our framing, indicating the importance of considering the different perspectives in developing a future-proof communications system.

4.2. Example 2: 6G Mobile Network Operator Business Model

Next, a case example of an envisioned 6G business model for mobile network operators presented in [13] is analysed with respect to our proposed framing from Section 3. The considered 6G MNO business model is a vertical business model (BM), where an enterprise such as the MNO takes control over its suppliers, distributors, or retail locations as part of its supply chain. To be competitive, the company needs to create value for its customers, thereby living in a value-creation economy and being grounded inside its selected verticals.

The considered 6G MNO business model presented in [13] is an evolution of existing MNOs and built on end-to-end value chain controlled by the 6G MNO and supported by specialized firms that are connected to the 6G MNO's connectivity-centered platform. The 6G MNO business model aims to capture value by 'matching' the needs or 'bridging' the customers via the 6G general-purpose technology connectivity platform. Technical features, such as automated network slicing, will be used to offer differentiated services and service levels to different customer segments including closed and open customer groups. The future 6G MNOs are also expected to offer connectivity from a multi-technology platform that consists of a selection of connectivity platforms that vary from low-earth-orbit, drone, and terrestrial 6G to hyper-local networks with a special focus on components and interfaces in the system. 6G MNOs will rely on their existing infrastructure assets on top of which 6G is built.

From the technology perspective, the 6G MNO business model is built on the general-purpose technology 6G platform whose development has followed a global define-standardize-develop-deploy-use cycle of technology commercialization [13]. For a half-century, all major mobile technology providers have relied on licensing as technology value capture mechanism through European Telecommunications Standards Institute (ETSI) third generation partnership project (3GPP) that brings together national standards development organizations to develop technical specifications for mobile communications. ETSI has orchestrated the development and governance of standards, allowing technology contributors to make licenses available on a fair, reasonable, and non-discriminatory (FRAND) basis for a wide variety of implementers globally. This nonexclusive licensing model has enabled a combination of technological co-development and widespread global adoption of mobile communications technologies.

From the business perspective, in the same way as with 5G, the 6G MNO business model considers vertical supply-side incumbent connectivity platform business model, which is represented by the 6G MNO with vertically structured business ecosystem configuration [13]. The vertical model builds on connectivity and cloud technologies with specialized partners that are tightly tethered to the connectivity platform with a deepened value proposition and with an exploration strategy. The model is connectivity-centric and the stakeholders adopting it aim to grow toward supporting content services or acting as a dealer of content such as media.

In the considered 6G MNO vertical business model, the MNO controls its suppliers, complementors, and retailers as part of its supply chain. In the 6G era, MNOs utilize end-to-end value chain controlled by it and supported by specialized firms tethered to MNO's connectivity-centered platform. This model monetizes interaction by matching customer needs with the platform. MNOs are expected to have a multi-technology platform comprising anything from low-earth-orbit, drone, and terrestrial 6G to hyper-local networks. The platform-based 6G ecosystem is expected to include new types of stakeholders, apart from the traditional MNOs and local operators, network constructors, system integrators, developer ecosystems, content owners and dealers, device, equipment, and technology vendors such as semiconductor technology vendors, operating system providers, application interface developers, or human–machine interface providers, cloud platforms and data centers and marketplaces prevalent already in 5G.

From the regulation perspective, the considered vertical 6G MNO business model is built on the existing regulations for mobile communications, where the strong position of incumbent MNOs stems from auction-based spectrum licensing. Additionally, the business needs to take into account not only the existing telecommunication regulations but also new general regulations on data, AI, and security among others, as well as vertical specific regulations when using 6G in different sectors of society. The business model is restricted by a number of regulations, whose impacts on the business are significant.

Finally, the sustainability perspective is considered in the analysed vertical 6G MNO business model covering primarily the economic sustainability perspective in business model elements such as value, costs and revenues. Environmental and social sustainability perspectives are considered only indirectly, noting that MNOs have increasing interest to reduce their energy consumption and other environmental footprints.

To conclude our analysis, the framing proposed in Section 3 can be found in both considered examples covering all proposed four perspectives: technology, business, regulation and sustainability. The IMT-2030 framework [5] has specific parts considering technology, business and sustainability perspectives, while the regulation perspective is more embedded in the framework. The 6G MNO business model [13] focuses on business perspective and has clear linkages to technology and regulation perspectives, while the sustainability perspective is more embedded in the model.

5. Conclusion

6G R&D calls for a multi-disciplinary approach that brings together different expertise areas across disciplinary boundaries representing different stakeholders to develop future-proof telecommunication solutions for the next decade. Our proposed multi-disciplinary approach to 6G consists of technical, business, regulation and sustainability perspectives, which were brought together to form a holistic multi-disciplinary framing for 6G R&D. This paper has further illustrated the key elements of these four perspectives through case examples of the global IMT-2030 framework and 6G mobile network operator business model. Both analysed case examples cover the four proposed perspectives to different levels of depth, indicating the importance of considering multiple perspectives in developing future proof communications systems. Future work is needed to promote multi-disciplinarity and inter-disciplinarity in 6G R&D integrating these four perspectives, especially to properly address sustainability challenges of different sectors of society as well as of 6G itself. In particular, research expanding future business cases is needed.

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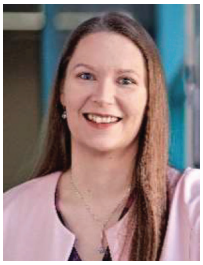

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