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Review

5G and 6G Networks and Economic Interactions Overview

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Abstract: Next-generation mobile networks, 5G and the emerging 6G, introduce transformative capabilities in connectivity, latency, and massive device support. While their technological innovations and service applications are well studied, the economic interactions among network stakeholders remain underexplored. This paper provides a comprehensive analysis of 5G and 6G ecosystems from an economic perspective, including a classification of service classes, applications, and enabling technologies. We map all relevant stakeholders, examine their interactions, and discuss business models and pricing strategies that generate revenue. The study also highlights regulatory frameworks that shape these dynamics and drive expected societal outcomes, offering insights into sustainable business strategies and policy development for next-generation communications.

Keywords: 5G, 6G, technologies, ecosystem, stakeholders, business models, economics, regulation

1. Introduction

Modern society is highly dependent on wireless communications, and networks are continuously evolving, with each new generation significantly enhancing connectivity, data transmission, and application capabilities. 5G networks follow this trajectory, with specifications defined by the International Telecommunication Union (ITU) under the framework *International Mobile Telecommunications-2020* (IMT-2020) [1]. According to [2], 5G networks aim to provide three primary service classes: enhanced Mobile Broadband (eMBB), ultra-Reliable Low-Latency Communications (uRLLC), and massive Machine-Type Communications (mMTC). These capabilities support a wide range of applications, including Augmented Reality (AR), Virtual Reality (VR), the Internet of Things (IoT), and autonomous driving, relying on enabling technologies such as network slicing, Massive MIMO, Millimeter Wave, Ultra-Dense Networks, among others [3]. Figure 1 illustrates some examples of emerging applications alongside the anticipated 5G service classes.

Looking further ahead, 6G networks are expected around 2030 to transform connectivity by providing more flexible and essential features, customizable to meet diverse needs across societal, industrial, and environmental domains. The ITU framework for 6G, IMT-2030 [4], introduces six new service classes: Immersive Communication (IC) [5], Hyper-Reliable and Low-Latency Communication (HRLLC) [6], Ubiquitous Connectivity (UC) [7], Massive Communication (MC) [8], artificial intelligence (AI)-integrated communication [9], and Integrated Sensing and Communication (ISaC) [10]. Figure 2 provides illustrative examples of emerging applications aligned with these 6G service classes.

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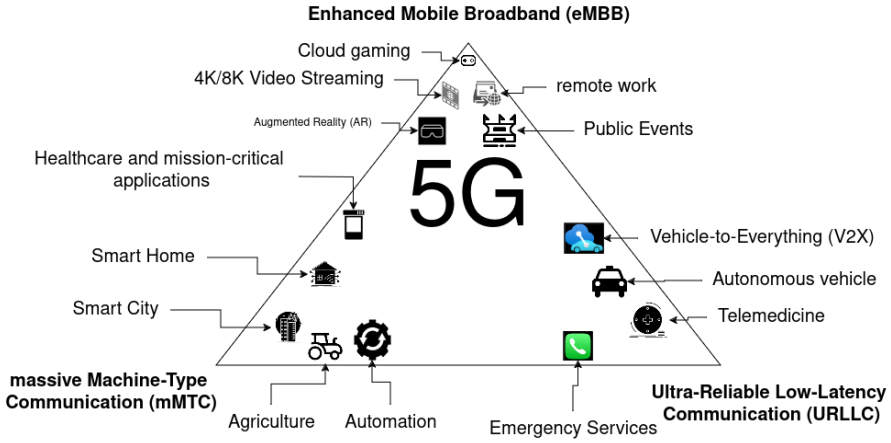


Figure 1. Usage scenarios of 5G networks

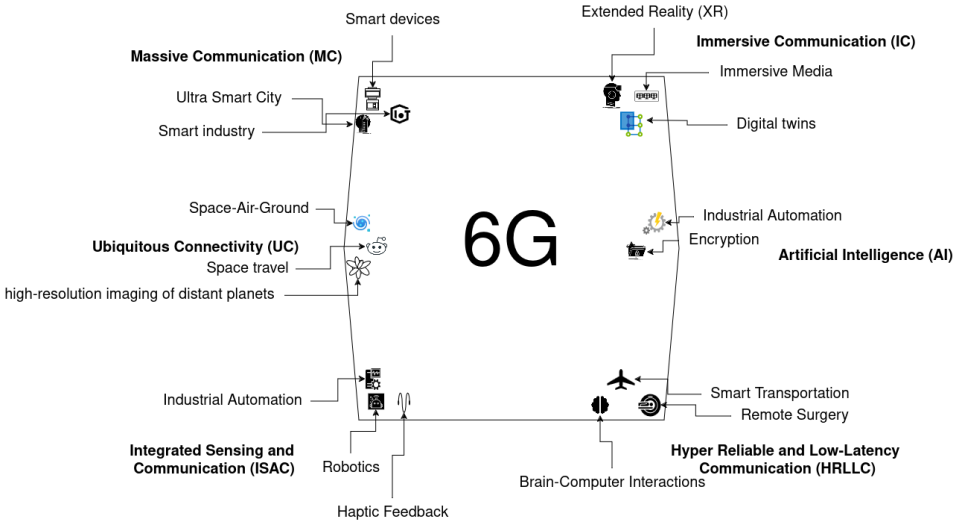


Figure 2. Usage scenarios of 6G networks

To meet these ambitious requirements, 6G leverages new technologies, including terahertz (THz) communication and ultra-massive Multiple Input Multiple Output (umMIMO) for enhanced data rates and network capacity, Non-Terrestrial Networks (NTNs) and Reconfigurable Intelligent Surfaces (RIS) for global coverage, and quantum communication and blockchain for secure large-scale data management.

The evolution to the next generation of networks also introduces new stakeholders and interactions, impacting existing actors and society at large. This is evident in the 5G/B5G era with the emergence of Non-Terrestrial Network Providers (NTNPs) delivering services via satellites or aerial platforms [11], Network Automation Providers (NAPs) offering AI-enabled cloud solutions, and Trust/Security Providers (TSPs) ensuring reliable operation of the 6G ecosystem [12]. These *evolving service providers* complement traditional roles already present in 5G, including Mobile Network Operators (MNOs), infrastructure and equipment providers, software vendors, regulatory bodies, content providers, and End-Users (EUs).

Understanding the full 5G and 6G ecosystems is critical for designing appropriate Business Models (BMs), economic relationships, and regulatory frameworks. The objective of this paper is to review the actors, key network and service characteristics from an economic perspective, and describe existing related business models. Such an analysis provides a foundation for future research on network economics, enabling the development of strategies to enhance revenue through

pricing models, service offerings, or regulatory interventions. Regulation may take the form of telecom-specific policies (e.g., net neutrality, spectrum allocation, mandated interconnection) or broader market-oriented measures (e.g., competition, trade, antitrust) [11]. There are numerous papers describing 5G and 6G networks and their specificities and capabilities. Some of them focus on classifying technologies. First, Akyildiz et al. [3] present how specifications in terms of data rates, latency, energy consumption, reliability, scalability, and security in 5G are fulfilled by ten technologies/applications designed to meet these requirements, including network slicing, millimeter wave, massive MIMO, ultra-densification, edge computing, software-defined networking, and network function virtualization. We separate technologies from applications such as IoT or green communication.

The authors of [13] discuss 5G by outlining its specifications, application trends, and technological advancements. ITU in [1] uses a similar description, adding a categorization of 5G service classes such as eMBB, URLLC, and mMTC. We also include this "service" classification in addition to technologies and applications, since services rely on technologies but do not directly specify their use cases.

Similarly, the authors of [14] describe 5G technologies and applications but do not consider service classes as we do. Reference [14] also includes an interesting historical perspective on network evolution across successive generations. Reference [15] also details network evolution, focusing on architecture, capabilities, applications, and technologies, still without introducing service types.

The same type of innovation description, but for 6G, can be found in the following articles. The author of [4] analyzes 6G evolution by providing 6G service classes (IC, HRLLC, MC, ISAC, UC, AI) and key technologies. The author of [7] adopts a similar classification of 6G service classes while also considering network evolution from 1G to 5G and discussing some challenges of 6G deployment. Our classification is close to that of [7].

In [8], Shamsabadi et al. explore only two specific 6G service classes (IC and HRLLC), along with related applications, key technologies, and network architecture. In [16], You et al. discuss 6G through its capabilities and applications: the authors classify 6G technologies into two groups aiming to meet these capabilities and applications.

6G additional capabilities are also described in [9, 17, 18], but still without distinguishing between services, technologies, and applications as we do. In [19], Shen et al. perform an in-depth analysis of one of the six 6G service classes (IC) by describing related applications, requirements, concerns, and potential solutions; our paper additionally provides a description of the five remaining service types.

However, none of the above works addresses the economic perspective, which is our main angle of analysis. Some economic views of 5G and beyond networks exist in the literature. In [11], the authors classify existing players in the 5G ecosystem and new entrants in 6G, describing their roles but without showing how they interact. They also discuss business opportunities in 5G and 6G and the evolution of regulation policies, without mentioning any specific pricing model.

Reference [20] follows a similar approach but adds the 5G value chain to the discussion, highlighting interactions between actors. In line with previous works, reference [21] analyzes actors in 3G networks, their roles, and interactions without addressing pricing models. The author of [22] follows the same idea for 5G mobile networks.

Thus, none of the above works tackles pricing methods between actors or analyzes the ecosystem as a whole, as we do. Reference [23], on the other hand, describes pricing schemes specifically for MNOs, focusing on static and dynamic pricing methods. We extend this approach to all actors in the ecosystem. In [24], Luong et al. focus on pricing strategies for network security issues only, while [25] is also limited in terms of the set of actors considered.

This paper extends our earlier preprint version available on HAL [26] as well as existing works, by providing a holistic analysis that encompasses all major actors of the 5G and 6G ecosystems. To the best of our knowledge, prior studies have not comprehensively examined how economic interactions among stakeholders are structured, nor how pricing mechanisms are designed across the different markets emerging within these ecosystems. The key contributions of this paper are:

• We propose a unified classification of 5G and 6G service classes, enabling technologies, and applications based on their use cases, technical requirements, performance metrics, advantages, limitations, and economic implications, including associated business models, stakeholder roles, and value creation mechanisms in Section 2.

• We then identify the key stakeholders involved and develop a comprehensive representation of the 5G/6G ecosystem, characterizing their roles, interactions, and positioning within the emerging value chain in Section 3.

• We highlight the relevant markets in the 5G/6G ecosystem, the actors operating within each market, their interdependencies, and the associated pricing mechanisms in Section 4. In particular, we provide a unified techno-economic framework that formalizes cost functions, revenue models, pricing schemes, utility functions, and integrates game-theoretic formulations across different business models in the 5G/6G ecosystem. We further characterize the business models within each market in terms of their advantages and limitations, enabling a systematic comparison of their economic efficiency and strategic trade-offs.

The remainder of the paper is structured as follows. Section 2 presents 5G and 6G networks, describing the innovations in service classes, applications, and key technologies. Section 3 introduces the network actors, with emphasis on new stakeholders in 5G and 6G. Section 4 examines economic interactions among all key players, highlighting their relationships and associated business models. Section 5 discusses regulatory policies affecting actors and interactions to promote fairness and order. Section 6 outlines future research directions in network economics for 5G, 6G, and beyond, and concludes the paper.

2. 5G and 6G networks technological innovations

Initially, mobile networks focused primarily on voice and data communication. However, with the advent of 5G and 6G, new markets have emerged, requiring tailored technical solutions. These solutions revolve around three service classes for 5G networks, as defined by IMT-2020: eMBB, uRLLC, and mMTC, and six additional service classes for 6G networks, as defined by IMT-2030: IC, HRLLC, UC, MC, AI-integrated Communication, and ISAC.

Based on these service classes, various technological solutions have been proposed to expand the boundaries of bandwidth, latency, and network capabilities in 5G and 6G, forming the foundation of their deployment. Furthermore, specific applications are developed by industries for companies or end-users, implementing these service classes and technologies to meet associated requirements for high data rates, ultra-high reliability, and ultra-low latency.

In the following subsections, we examine the service classes of 5G and 6G networks, identify the key enabling technologies, and present representative applications. For each element, we analyze the associated use cases, technical requirements, performance metrics, advantages, limitations, and economic implications, including how different stakeholders can create and capture value through emerging business opportunities. This comprehensive assessment provides the foundation for the subsequent analysis of actor roles, market interactions, and business models within the 5G and 6G ecosystems.

2.1 *Key service classes*

We specify in this subsection the service classes introduced by 5G and subsequently by 6G. A *service class* is defined by its performance characteristics that must be fulfilled. It is implemented through specific *technologies* in order to support various *applications*.

2.1.1 *5G service classes*

• **Enhanced Mobile BroadBand (eMBB):** eMBB represents the evolution of 4G broadband, focusing on high data rate transmissions up to 10 Gbps and supporting user-experienced data rates of up to 50 Mbps, even under high mobility conditions (up to 500 km/h), high reliability, and the ability to operate efficiently in dense user environments such as stadiums and urban areas. This service class is designed to support bandwidth-intensive applications such as virtual and augmented reality (VR/AR), ultra-high-definition (4K/8K) video streaming, and cloud gaming. It also enables seamless connectivity in high-mobility scenarios, including high-speed trains and connected vehicles. Economically, eMBB drives a significant increase in data consumption, enabling new revenue streams through premium data services and differentiated quality-of-service offerings with network slicing in network slicing market discussed later [1, 2]. However, eMBB imposes substantial infrastructure costs due to small cells deployment, limited coverage range, and increased battery consumption.

• **Massive Machine-Type Communications (mMTC):** mMTC is designed to support a vast number of connected devices, often in dense deployments with intermittent data transmissions, typical of IoT applications. Typical mMTC

applications include smart metering, environmental monitoring, smart agriculture, industrial sensors, and large-scale smart city deployments, where thousands to millions of devices operate simultaneously with limited data exchange. These use cases require ultra-high connection density, very low energy consumption to ensure long battery life, low device complexity, and the ability to handle intermittent traffic efficiently. According to the IMT-2020 vision, mMTC can handle up to 1 million wireless devices per km^2, maintain device battery lifespans of around 10 years, and achieve area traffic capacity of 10 $Mbit/s/m^2$ [1, 2]. mMTC enables large-scale IoT ecosystems where value is generated through the aggregation of massive numbers of low-data-rate devices, resulting in very low average revenue per device. However, mMTC deployments incur high operational complexity, including large-scale device management, signaling overhead, and the need for highly scalable and energy-efficient infrastructure, leading to a mismatch between costs and per-device revenue. Consequently, new ecosystem-driven business models are emerging, involving not only MNOs but also INEPs, CCPs, and InCs, who collectively capture value from data aggregation, analytics, and automation services in devices and cloud computing markets discussed later.

• **Ultra-Reliable Low-Latency Communications (uRLLC):** uRLLC aims to provide extremely low latency (as low as 1 ms) and very high reliability (up to 10^{-5}), ensuring secure and dependable connectivity for critical applications, such as autonomous vehicles, remote surgery, industrial automation, and smart grid control, where strict timing and high reliability constraints are essential, with strong potential for premium pricing also with network slicing business models. [2, 3] Key limitations are complex implementation, and reduction of network capacity due to high reliability.

Figure 3 illustrates the classification of the three main 5G service categories: eMBB (green), mMTC (blue), and uRLLC (red), together with their corresponding performance metrics and service requirements. Each service class is associated with distinct requirements that define its role within the 5G ecosystem. eMBB is characterized by high data rate and enhanced user experience requirements, focusing on throughput-intensive applications. mMTC targets massive device connectivity with relaxed data rate constraints but strict energy efficiency and scalability requirements. In contrast, uRLLC is defined by ultra-low latency and extremely high reliability, supporting time-critical applications with communication constraints. Overall, the figure highlights the inherent trade-offs between data rate, latency, reliability, and device density, showing that no single service class can simultaneously optimize all performance dimensions.

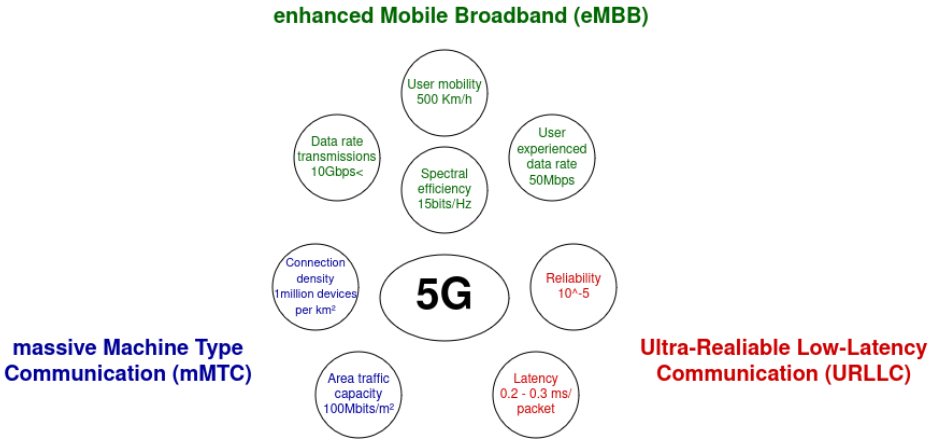


Figure 3. 5G key performance indicators: eMBB, uRLLC, and mMTC

5G service classes form the foundation for the next generation of networks. Enhanced Mobile Broadband (eMBB) delivers high-speed connectivity for applications such as streaming and immersive media. Ultra-Reliable Low-Latency Communication (uRLLC) supports mission-critical services like autonomous vehicles and industrial automation, while massive Machine-Type Communication (mMTC) enables connectivity for millions of IoT devices.

Building upon this foundation, 6G introduces an expanded set of service categories, designed to meet the demands of future applications requiring ultra-high data rates, extreme reliability, pervasive connectivity, and AI-driven intelligence.

2.1.2 *6G service classes*

• **Immersive Communication (IC):** IC is a core 6G service class designed to provide highly realistic and interactive experiences across physical, virtual, and hybrid environments. Typical use cases include holographic telepresence, extended reality (XR), digital twins, remote collaboration, and multi-sensory entertainment applications. These services require ultra-high throughput, ultra-low latency, precise synchronization, and seamless mobility to ensure a fully immersive quality of experience. According to the IMT-2030 vision, IC is expected to support peak data rates approaching 1 Tbps, user-experienced rates of 1 Gbps, and area traffic capacity of 1 Gbps/m^2. It also targets spectrum efficiency improvements of 100–1000× compared with 5G and mobility support up to 1000 km/h [5]. From a techno-economic perspective, IC enables new premium digital services and immersive content markets for MNOs and content providers, creating high-value revenue opportunities through differentiated quality-of-service offerings. However, its deployment faces significant limitations, including the need for next-generation hardware due to limited compatibility with current devices, extremely stringent latency and synchronization requirements, high bandwidth consumption, and the necessity of dense edge and network infrastructure, which may increase both capital and operational expenditures [27].

• **Hyper Reliable and Low-Latency Communication (HRLLC):** HRLLC extends 5G URLLC by targeting even stricter communication constraints, with ultra-low latency ranging from 25 μs to 1 ms and extremely high reliability levels up to 10^{-7}. It is intended for mission-critical applications such as industrial robotics, autonomous transportation systems, remote surgery, high-speed rail control systems, and smart grid protection systems, where communication failures or delays may cause severe operational or safety consequences. These use cases require deterministic communication, rapid response times, near-zero packet loss, efficient interference management, and scalable operation under highly dynamic network conditions. Achieving such performance demands advanced network management, intelligent resource orchestration, enhanced modulation and coding schemes, redundant transmission mechanisms, scalable AI-driven optimization, and reduced signal propagation delays through edge computing and distributed architectures [8]. Economically, HRLLC enables MNOs to operate significant investments in edge infrastructure, network redundancy, and specialized service-level guarantees, making it economically viable mainly for high-value industrial and safety-critical services with strong monetization potential. However, large-scale deployment remains constrained by high infrastructure costs, hardware complexity, stringent synchronization requirements, and the need for next-generation devices and reliable low-latency architectures.

• **Massive Communication (MC):** MC is the 6G evolution of 5G mMTC, designed to support real-time interactions among massive numbers of connected devices in large-scale IoT environments. It enables both device-to-server and device-to-device communications for applications such as smart cities, industrial sensing, connected logistics, and large-scale autonomous systems. These use cases require ultra-high connection density, scalable signaling mechanisms, low-power operation, and efficient coordination of heterogeneous devices. According to recent 6G visions, MC is expected to support up to 10 million devices per km^2, area traffic capacity of 1 Gbps/m^2, and network energy efficiency improvements of up to 100× compared with previous generations [6]. While the revenue generated per device remains limited, economic value is created through large-scale data collection in cloud computing market, automation services, and ecosystem-driven IoT platforms in AI-based market. However, MC also faces significant limitations, including signaling overhead explosion, scalability constraints in network orchestration, spectrum congestion in ultra-dense deployments, and increased energy consumption for massive device coordination.

• **Integrated Sensing and Communication (ISaC):** ISaC combines sensing and communication functionalities to enable connected devices to simultaneously transmit information and perceive their surrounding environment with high precision. It supports use cases such as augmented human sensing, indoor and outdoor localization, target tracking, gesture and posture recognition, environmental mapping, and real-time digital reconstruction of large-scale environments. These applications require fine spatial resolution (0.5 mm–0.5 m), high sensing accuracy (0.5 mm–0.1 m), ultra-high availability (up to 99.9999%), and fast update rates ranging from 1 ms to 1 s over coverage areas of approximately 200 m. These stringent requirements enable highly precise environment awareness and real-time interaction between humans, devices, and infrastructure [10]. ISaC enables new data-driven sensing services and environment-aware applications across multiple stakeholders, including MNOs, infrastructure providers, industrial sectors, and cloud service providers, and supports emerging markets such as cloud computing market, and AI-based market, where sensing data becomes a valuable resource

for service innovation and optimization. However, its deployment requires advanced radio hardware, tight integration between sensing and communication functions, and significant computational resources [28].

• **Ubiquitous Connectivity (UC):** UC aims to provide seamless and continuous network access to users regardless of location, device type, or mobility conditions, extending connectivity to underserved, rural, and remote areas through heterogeneous access technologies such as terrestrial networks, satellite communications, and aerial platforms (e.g., High-Altitude Platform Stations (HAPS) and Unmanned Aerial Vehicles (UAVs)). Its use cases include rural broadband access, disaster recovery communications, global maritime and aviation connectivity, and seamless handover between heterogeneous networks in highly mobile scenarios. These applications require wide-area coverage, high reliability, interoperability across access technologies, and adaptive resource management to maintain service continuity [4, 7]. UC enables new business models involving MNOs and NTNPs, fostering joint deployment and operation of terrestrial and non-terrestrial infrastructures within the satellite connectivity market. However, its deployment is constrained by high integration costs, complex interoperability requirements, and the need for infrastructure sharing and coordination mechanisms, particularly in low-density and remote areas where return on investment remains uncertain.

• **AI-integrated communication:** Integrating AI into 6G networks supports several use cases, including autonomous network management, predictive maintenance, intelligent resource allocation, virtualization, and context-aware service provisioning. These applications require real-time decision-making, scalability in large heterogeneous environments, and high reliability under dynamic network conditions. The performance of AI-enabled 6G systems is typically evaluated in terms of improved resource utilization, reduced latency, increased energy efficiency, and enhanced service quality [9]. AI integration reduces operational complexity by enabling automation of network management and predictive maintenance, thereby lowering operational expenditures and improving resource utilization. It also enhances infrastructure efficiency and enables scalable service deployment across multiple stakeholders, including MNOs, NAPs, and CCPs, forming an emerging AI-driven market ecosystem. However, it also introduces challenges related to implementation cost, data management and sharing, and model training complexity in highly dynamic network environments.

Figure 4 provides an overview of the main 6G service classes, including IC (green), HRLLC (red), MC (blue), ISaC (pink), UC (black), and AI-enabled networks (orange), together with their associated requirements and performance metrics. The figure illustrates how each service class targets a distinct set of capabilities within the 6G ecosystem, reflecting the diversification of network functionalities beyond traditional connectivity. IC focuses on immersive experiences requiring ultra-high data rates (up to 1 Tbps), high spectral efficiency, and high user mobility to support XR and holographic applications. HRLLC targets ultra-low latency (down to 1 μs) and extremely high reliability (up to 10^{-7}), enabling mission-critical services. MC is designed for massive device connectivity in ultra-dense environments, while UC ensures global coverage with connectivity across heterogeneous terrestrial and non-terrestrial networks. ISaC introduces joint sensing and communication capabilities, requiring high spatial resolution, high availability, high accuracy, high resolution and real-time environmental awareness. Finally, AI-native functionalities enhance all service classes by enabling autonomous optimization, adaptability, resilience and security. Overall, the figure highlights the strong heterogeneity of 6G service requirements and the trade-offs between data rate, latency, reliability, coverage, and intelligence, emphasizing that no single architecture can optimize all dimensions simultaneously.

To enable 5G and 6G networks to meet these stringent service requirements, specific enabling technologies must be developed. The next subsection addresses these technologies in detail.

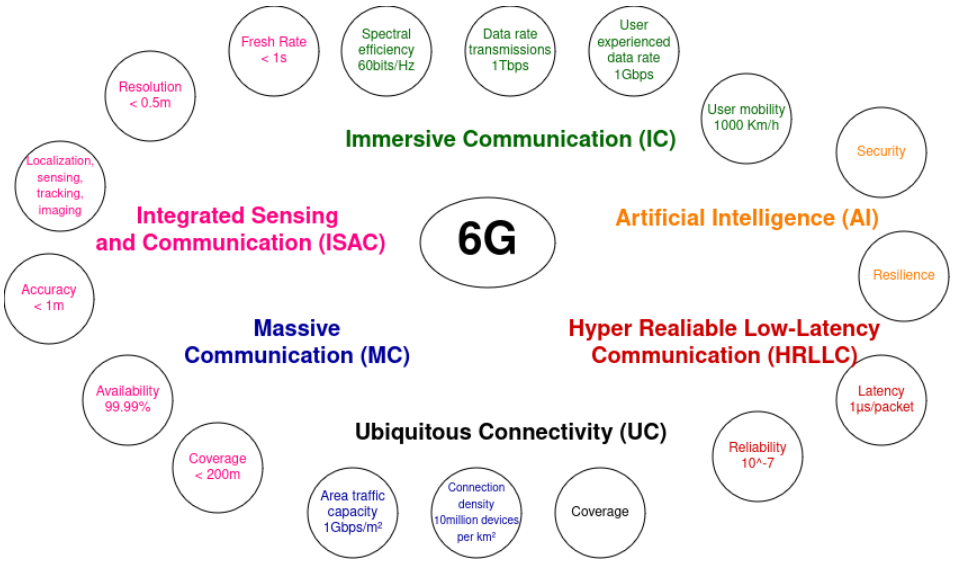


Figure 4. 6G key performance indicators

2.2 *Key service technologies*

Service technologies, focusing on 5G and 6G networks, are technical solutions that enable network functionalities and provide the infrastructure and capabilities required to support the previously described service classes. These technologies range from solutions that reduce latency, enhance data rates, and connect millions of devices, to those that extend network coverage. With 6G, certain 5G technologies will be further improved, while new technologies will emerge to meet additional requirements.

2.2.1 *5G technologies*

• **Network slicing:** Network slicing enables 5G networks to create multiple independent and logically isolated virtual networks over a shared physical infrastructure, each tailored to specific service requirements. It supports diverse use cases such as eMBB for high-data-rate services (e.g., video streaming and cloud gaming), URLLC for industrial automation and autonomous driving, and mMTC for smart city and environmental monitoring applications. Each slice is defined by distinct requirements, including high throughput for eMBB, ultra-low latency and high reliability for URLLC, and massive connectivity with low energy consumption for mMTC, along with strong isolation and scalable resource orchestration [2]. Network slicing offers significant advantages in terms of resource efficiency, service differentiation, multi-tenant infrastructure sharing, and support for heterogeneous applications, and allows MNOs to monetize the same physical infrastructure across multiple actors like MVNOs, CCPs, CPs, and even InCs in network slicing market as developed later, reducing per-service deployment and operational costs [29]. However, it also introduces challenges such as increased orchestration complexity, and inter-slice security risks, which may increase operational expenditures in the long term.

• **Massive Multiple Input Multiple Output (MIMO):** Massive MIMO enhances network throughput and spectral efficiency by deploying a large number of antennas at the transmitter and receiver sides, enabling highly directional transmissions and efficient spatial multiplexing [3]. It supports use cases such as eMBB in dense urban areas, stadiums, transportation hubs, fixed wireless access, and industrial environments requiring reliable high-capacity connectivity. These scenarios require high spectral efficiency, broad coverage, support for multiple simultaneous users, and robust performance under dynamic traffic conditions. Massive MIMO offers major advantages by increasing network capacity, improving signal quality, extending coverage, and reducing interference through beamforming techniques [29, 30]. Massive MIMO enables MNOs to monetize high-demand areas without proportionally increasing spectrum resources, while enabling INEPs to generate higher revenues from infrastructure sales, upgrades, and long-term maintenance services in infrastructure

market. However, its limitations are higher hardware costs, increased energy consumption, and complex channel estimation, which may raise deployment and operational costs for MNOs.

• **Millimeter Wave (mmWave):** mmWave technology leverages high-frequency radio spectrum to significantly increase network capacity and enable ultra-high data rate transmissions. The frequency spectrum is typically divided into sub-6 GHz bands for wide coverage and 24–100 GHz mmWave bands for high-capacity short-range communications [2]. It supports use cases such as dense urban hotspot connectivity, fixed wireless access, augmented and virtual reality services, and high-definition multimedia streaming. These applications require extremely high bandwidth and dense deployment of small cells due to the limited propagation range and high sensitivity to blockage, which are key limitations of mmWave technology. However, it remains well suited for short-range, high-capacity communications in dense urban environments [29]. From a economic overview, mmWave enables MNOs to increase network capacity in high-demand areas, monetizing premium high-speed services, while enabling INEPs to generate revenues from dense small-cell infrastructure sales inside infrastructure market described in Subsection 4.2.

• **Ultra-Dense Networks (UDNs):** To meet the high data demands of 5G, UDNs deploy a large number of small cells in densely populated areas to enhance coverage, capacity, and spatial reuse of spectrum. Small cells are typically categorized into femtocells (10–50 m), picocells (100–300 m), and microcells (250–1000 m) [2], enabling flexible deployment depending on traffic density and coverage requirements. These architectures support use cases such as dense urban hotspots, and indoor environments (shopping malls, stadiums, and offices), and require high site density, efficient interference management, and scalable backhaul connectivity [31]. With UDNs, MNOs increase capacity and revenue in high-traffic areas through improved service quality and user experience. At the same time, INEPs benefit from increased demand for small-cell deployments, site acquisition, and dense network rollouts. The limitations of UDNs are high deployment and maintenance costs due to network densification, increased interference management and operational complexity, and high energy consumption.

• **Software-Defined Networking (SDN) & Network Function Virtualization (NFV):** SDN separates the control plane from the data plane, enabling programmable and flexible network architectures, while NFV virtualizes traditional network functions such as load balancing and intrusion detection to optimize resource utilization and enable dynamic service deployment [2]. These technologies are widely applied in 5G core networks, network slicing, and edge computing environments, where scalable, programmable, and adaptive network management is required. They are designed to meet requirements such as high scalability, real-time orchestration, resource elasticity, and efficient service provisioning in highly dynamic and heterogeneous network conditions. Together, SDN and NFV provide significant advantages including improved network flexibility, efficient resource management, and support for rapid service deployment. From a economic overview, they reduce capital and operational expenditures through infrastructure virtualization and resource sharing, while enabling new service-oriented business models sush as network slicing-as-a-service [32] through network slicing market (Subsection 4.5), and On-demand NFV services through security market (Subsection 4.9). However, they also introduce limitations such as increased orchestration complexity, security vulnerabilities in virtualized environments, and implementation overhead in large-scale deployments.

• **Edge Computing (Multi-access Edge Computing, MEC):** MEC brings computation closer to the user or device, reducing latency and enabling local data processing instead of relying on distant centralized cloud servers [2, 3]. It supports use cases such as augmented reality/virtual reality applications, autonomous vehicles, industrial automation, smart surveillance, and real-time IoT analytics, where ultra-low latency and real-time decision-making are critical. These scenarios require stringent latency constraints, high bandwidth efficiency, and real-time processing capabilities at the network edge. By offloading tasks from centralized servers, Edge Computing improves response times, bandwidth efficiency, and operational performance compared to traditional cloud or fog computing. Edge Computing enables cloud computing market in Subsection 4.4 involving CCPs and MNOs, delivering computing resources for real-time video analytics and autonomous vehicles, while also introducing limitations such as high infrastructure deployment costs, limited edge computing resources, and increased orchestration and security complexity in distributed environments.

Figure 5 illustrates the relationship between key 5G enabling technologies and the three main service classes (eMBB, uRLLC, and mMTC), highlighting which technologies support each service requirement. The results show that SDN/NFV and network slicing provide full support across all service classes, as they enable flexible, programmable, and virtualized

network architectures capable of adapting to heterogeneous service requirements. In contrast, Massive MIMO, mmWave, and UDNs are primarily associated with eMBB and URLLC services due to their ability to provide high data rates, enhanced spectral efficiency, and low-latency communications in dense environments, while their applicability to mMTC is limited due to scalability and energy constraints. Finally, edge computing is strongly aligned with URLLC and mMTC services, as it supports low-latency processing and efficient handling of massive device connectivity, but its contribution to eMBB is less dominant. Overall, the figure highlights that no single technology satisfies all service requirements, emphasizing the need for an integrated multi-technology architecture in 5G networks.

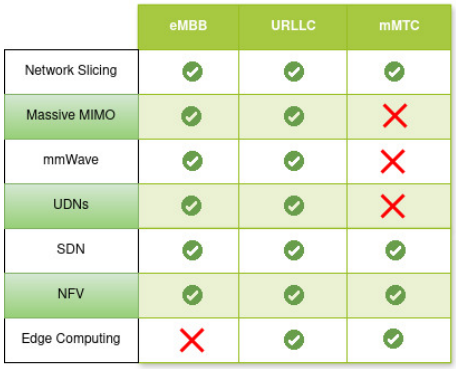


Figure 5. Relationship between updated 5G key technologies and service classes

2.2.2 *6G technologies*

Since 6G introduces new service classes beyond those of 5G, novel technologies are required to meet the associated quality-of-service demands. The following section lists these anticipated and emerging technologies that are expected to enable the next generation of mobile networks.

• **Terahertz (THz):** THz is an advanced wireless communication technology operating in the 0.1–3 THz frequency band [8], offering ultra-wide bandwidth and enabling multi-terabit-per-second wireless links. It supports use cases such as holographic communications, immersive extended reality (XR), ultra-high-definition content delivery, wireless backhaul/fronthaul, high-speed data kiosks, and real-time digital twin applications. These scenarios require extremely high throughput in terabits, ultra-low latency (10–100 μs), precise beam alignment, high reliability (99.99999%), and intelligent mobility management (more than 1000 km/h) [33]. THz provides major advantages including exceptional capacity, ultra-fast data transmission, and efficient spectrum exploitation beyond congested sub-6 GHz and mmWave bands. Key technologies supporting THz in 6G include Ultra-massive Multiple Input Multiple Output (umMIMO) and Reconfigurable Intelligent Surfaces (RIS), which improve signal gain, extend coverage, and enhance connection robustness.

1) **Ultra-massive MIMO (umMIMO):** An extension of 5G MIMO, umMIMO leverages THz frequencies to deploy a significantly larger number of antenna elements, enabling highly directional user-specific beams that improve spectral efficiency, spatial multiplexing, and coverage.

2) **Reconfigurable Intelligent Surfaces (RIS):** RIS consists of programmable reflecting surfaces that dynamically manipulate radio waves to improve signal quality, extend coverage, and mitigate interference. Strategic RIS deployment can allow MNOs to reduce the need for additional base stations, lowering energy consumption and infrastructure costs.

In infrastructure market described below, MNOs are responsible for deploying and commercializing THz-based connectivity services, monetizing premium ultra-high-speed consumer applications, while INEPs play a critical supporting role by supplying dense site locations, fiber backhaul, indoor hosting solutions, and shared passive infrastructure required for short-range THz deployments. As a result, THz networks strengthen the economic importance of infrastructure sharing and neutral-host business models.However, Thz large-scale deployment remains constrained by severe propagation losses, blockage sensitivity, short communication range, expensive next-generation hardware.

• **Quantum Communication (QC):** QC extends previous 5G computing technologies by exploiting quantum parallelism to process multi-dimensional and large-scale data more efficiently, enabling faster, more reliable, intelligent, and secure communications. It supports use cases such as large-scale network optimization, AI model acceleration, secure communications, quantum-enhanced intrusion detection, traffic prediction, and complex resource allocation in ultra-dense 6G environments. These applications require high computational capability, ultra-fast processing of complex datasets, strong security guarantees, low-latency decision-making, and integration with classical communication networks. QC offers major advantages by accelerating complex computations, improving network intelligence, strengthening cybersecurity, and enabling advanced optimization beyond classical computing limits [34]. Quantum Key Distribution (QKD) further enhances confidentiality for sensitive data exchanges, while quantum-based mechanisms can improve anomaly and intrusion detection [35]. From a economic perspective, QC enables premium secure communication services in trust and security market, and advanced AI-driven network management markets involving MNOs, CCPs, NAPs and TSPs. However, QC faces some challenges such as the requirement for cryogenic operating conditions close to absolute zero, which significantly increases infrastructure complexity and deployment costs; limited general-purpose applicability of current quantum computers, which restricts their integration into diverse network functions; high sensitivity to environmental disturbances (e.g., thermal fluctuations, electromagnetic fields, and cosmic radiation), leading to quantum noise and qubit instability; and the lack of mature quantum programming models and logical gate frameworks for large-scale and reliable system implementation [36].

• **Non-Terrestrial Networks (NTNs):** NTNs include satellites and aerial platforms such as HAPS and UAVs. They provide a sustainable solution to extend connectivity beyond terrestrial infrastructure and ensure coverage in rural, remote, and hard-to-reach areas [37]. They support use cases such as rural broadband access, maritime and aviation communications, disaster recovery and emergency response, military and border surveillance, and global IoT connectivity for remote sensing applications. These scenarios require wide-area coverage, high link reliability 99.99999%, seamless integration with terrestrial networks, adaptive mobility management (more than 1000 km/h), and efficient spectrum utilization (2–3 times) under dynamic channel conditions. NTNs offer key advantages such as global coverage, improved network resilience with AI techniques [35], rapid deployment in emergency scenarios, and enhanced connectivity in underserved regions. However, they face limitations including high deployment and maintenance costs, long propagation delays (especially for satellite links), limited bandwidth compared to terrestrial networks, mobility and handover complexity, and weather-dependent signal degradation for certain frequency bands [38]. Economically, NTNs enable satellite connectivity market described in Subsection 4.6 involving MNOs, and NTNPs. They support infrastructure sharing and hybrid terrestrial–non-terrestrial business models such as Direct to Customer (D2C) model, improving coverage efficiency while expanding service reach [39]. However, their economic viability is constrained in low-demand regions due to high capital expenditures, complex coordination between terrestrial and non-terrestrial networks, and uncertain return on investment.

• **Orbital Angular Momentum (OAM) technology:** OAM enhances channel capacity and spectral efficiency by exploiting wavefronts with helical phase structures, enabling the multiplexing and demultiplexing of multiple data streams over the same frequency resource [17]. It supports use cases such as ultra-high-capacity point-to-point backhaul links, indoor wireless hotspots, data center interconnections, short-range terabit communications, and line-of-sight high-throughput access scenarios. These applications require stable line-of-sight propagation, precise antenna alignment, low interference environments, and advanced signal processing for mode separation and channel estimation [40]. OAM offers key advantages including significant capacity enhancement, efficient spectrum reuse, and support for multi-stream parallel communications without requiring additional bandwidth. However, its performance is highly dependent on line-of-sight conditions and can be degraded by obstacles, atmospheric turbulence, misalignment, scattering, and mode crosstalk, which limit large-scale outdoor deployment [41]. From a economic overview, OAM enables specialized infrastructure market involving MNOs, and INEPs, particularly for indoor high-density environments and wireless backhaul applications.

• **Blockchain:** Blockchains provide secure, reliable, decentralized, and distributed networking support for 6G systems, enhancing trust management, privacy preservation, and spectrum utilization. Their integration with AI and Distributed Machine Learning (DML) enables automated and transparent resource coordination, efficient spectrum sharing, and protection of sensitive data through tamper-resistant records [17, 42]. They support use cases such as secure spectrum trading, decentralized identity management, roaming authentication, IoT trust management, smart contracts for network

slicing, and distributed data exchange among heterogeneous stakeholders. These applications require strong security guarantees, low-trust coordination among multiple parties, data integrity, auditability, and scalable consensus mechanisms. Blockchain technologies offer key advantages including decentralization, transparency, reduced dependence on centralized intermediaries, improved trust among ecosystem actors, and automated execution of service agreements through smart contracts. However, they also face limitations such as transaction delays, high computational and energy costs for some consensus mechanisms, storage overhead, privacy-management complexity, and scalability constraints in large-scale real-time network environments [43]. From a economic perspective, blockchains enable new digital trust and security markets (see Subsection 4.8) involving MNOs, and TSPs by facilitating secure multi-party transactions. They also support new BM such as smart-contract-based service monetization.

Figure 6 provides the correspondence between the main 6G enabling technologies and the proposed 6G service classes, which can be summarized as follows:

• **umMIMO:** Primarily supports IC through ultra-high throughput and beamforming gains, HRLLC through highly directional low-latency links, and MC through improved spatial multiplexing for dense device connectivity.

• **RIS:** Strongly related to HRLLC by improving link reliability and reducing blockage effects, UC through coverage extension, IC through signal quality enhancement, MC through better connectivity in dense deployments, and ISAC, since programmable surfaces improve sensing quality.

• **QC:** Mainly associated with AI for advanced optimization and secure intelligence, HRLLC for ultra-secure critical communications, and MC for large-scale optimization problems.

• **OAM:** Mainly supports IC by enabling ultra-high-capacity short-range links, partially HRLLC in controlled line-of-sight environments requiring reliable high-capacity transmission, and ISAC for advanced signal processing.

• **NTNs:** Strongly associated with UC through global and remote-area coverage, while also supporting MC for large-scale IoT connectivity, and AI for network resilience improvement.

• **Blockchain:** Primarily linked to AI through trusted distributed learning and automation, MC for secure IoT coordination, and UC for multi-operator roaming and identity management.

Overall, no single technology exclusively supports one service class. Instead, 6G service delivery relies on the complementary integration of multiple technologies within a unified intelligent architecture.

	IC	HRLLC	MC	AI	UC	ISAC
umMIMO	✓	✓	✓	✗	✗	✗
RIS	✓	✓	✓	✗	✓	✓
QC	✗	✓	✓	✓	✗	✗
OAM	✓	✓	✗	✗	✗	✓
NTNs	✗	✗	✓	✓	✓	✗
Blockchain	✗	✗	✓	✓	✓	✗

Figure 6. Relationship between key 6G enabling technologies and service classes

Nevertheless, these innovations are not only reshaping network operations but also unlocking new possibilities across a wide range of applications. In the following subsection, we examine how these advancements are applied in real-world scenarios, driving significant transformations across industries and enhancing end-user experiences.

2.3 *Key applications*

The ecosystems of 5G and 6G networks are designed to support a wide range of applications across different industries. Some applications require ultra-high data rates, ultra-low latency, and high reliability, while others demand high bandwidth,

strong security, or advanced automation. Below, we summarize the main anticipated new use cases enabled by these technologies.

2.3.1 *5G applications*

• **Augmented Reality (AR) and Virtual Reality (VR):** 5G supports AR and VR experiences ranging from immersive gaming and virtual tourism to remote training, collaborative design, telepresence, and industrial assistance. These applications rely on 5G capabilities such as high data rates (gigabit per second), ultra-reliable connectivity (99.999%), and low latency (less than 0.1 ms), enabled by technologies including edge computing, network slicing, SDN, and NFV. AR/VR services offer major advantages such as immersive user interaction, enhanced training efficiency, remote collaboration, reduced travel needs, and new digital entertainment experiences. However, they also face limitations including high bandwidth consumption, sensitivity to latency, expensive end-user devices, battery constraints for wearable equipment [44]. From a economic perspective, AR/VR creates new revenue opportunities for MNOs, CCPs, and CPs through premium immersive services, enterprise training solutions, gaming subscriptions, and virtual event markets, while INEPs benefit from the supply of AR/VR devices, edge infrastructure, and enabling hardware components.

• **Autonomous vehicles:** 5G enables ultra-reliable low-latency communication (1–10 ms), high mobility support (up to 500 km/h), seamless handover, and continuous connectivity under highly dynamic vehicular environments for autonomous driving, including Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) interactions. It supports collision avoidance systems, cooperative adaptive cruise control, intelligent traffic management, remote vehicle diagnostics, and autonomous fleet coordination. However, limitations include network coverage variability at high speeds, vulnerability to signal blockage in urban environments, high cost for infrastructure (sensors) deployment requirements for roadside units and edge nodes, and cybersecurity challenges [45]. The main 5G technologies involved in autonomous driving are Edge computing, which enables real-time edge processing close to vehicles; Network Slicing, which creates dedicated and isolated communication channels for automotive services; Massive MIMO and mmWave, which enhance capacity and data rates in dense traffic environments; and SDN/NFV, which provide flexible orchestration and dynamic resource management across vehicular networks. Economically, autonomous driving services create distinct revenue opportunities for automotive manufacturers (InCs) can monetize connected vehicles through diferentiated autonomous features, software updates, fleet solutions, and data-driven mobility services. MNOs can generate revenues through private 5G networks, V2X connectivity services, and dedicated network slices. CCPs can capture value by offering data storage, high-definition map management, AI model training, real-time analytics, and edge/cloud computing resources for autonomous vehicle platforms.

• **Smart cities:** 5G powers smart cities by connecting massive numbers of IoT devices to enable citizen-centric services such as public safety, smart healthcare, intelligent transportation, energy management, and digital education platforms. These applications require ultra-reliable connectivity 99.9999%, massive device density support (million devices per km^2), low-latency communication for critical alerts (1–10 ms), wide-area coverage, and scalable data aggregation across heterogeneous devices. Key advantages include improved urban efficiency, enhanced public safety, optimized resource utilization (e.g., traffic and energy), and better quality of life through digital services [46]. However, limitations include high infrastructure deployment costs, security and privacy risks due to large-scale data collection, network congestion in dense urban areas, and complexity in managing heterogeneous IoT devices [47]. From a economic perspective, smart city services represent a broad and emerging 5G market with strong long-term growth potential. They ensure for MNOs, and CCPs, in cloud computing market through IoT connectivity services, data analytics platforms, and smart surveillance solutions.

• **Remote healthcare and telemedicine:** Low-latency 5G connections facilitate advanced digital healthcare services such as high-quality video consultations, remote robotic surgeries, ambulance connectivity, AI-assisted diagnostics, and real-time health monitoring through wearable and medical IoT devices. These applications require ultra-reliable low-latency communication, secure transmission of sensitive medical data, high uplink and downlink throughput for medical imaging and video streams, continuous connectivity, and high service availability [48]. Key advantages include improved healthcare accessibility in remote areas, faster medical response, enhanced patient monitoring, reduced hospital workload, and more efficient use of medical resources. However, limitations include strict privacy and cybersecurity requirements, cases of

misdiagnosis, regulatory constraints for remote procedures, and high deployment costs for connected medical infrastructure [49]. Economically, 5G healthcare services can create distinct revenue opportunities accross many markets, for MNOs which can monetize telemedicine connectivity, private hospital networks, dedicated network slices, healthcare providers (EUs) through remote consultations, connected care services, digital treatment platforms, and subscription-based patient monitoring, and CCPs from medical data storage, AI-driven diagnostics, analytics platforms, and edge/cloud computing resources. The main 5G technologies involved are MEC for real-time local processing, Network Slicing for dedicated healthcare service channels, mmwave for high throughput necessary for imaging, and SDN/NFV for flexible and secure network management.

• **Smart homes:** 5G enhances connected home environments by enabling reliable, high-speed connectivity for smart appliances, wearables, voice assistants, surveillance cameras, energy meters, and home security systems [50]. These applications require reliable indoor coverage 99.9999%, low-latency communication for real-time control (1–10 ms), scalable connectivity for multiple simultaneous devices, secure data exchange, and efficient bandwidth management. Key advantages include improved convenience, enhanced home security, optimized energy consumption, better healthcare assistance for residents, and seamless integration of digital lifestyle services [46]. However, limitations include privacy and cybersecurity risks, interoperability issues among heterogeneous devices, dependence on stable broadband and indoor coverage, device management complexity, and the cost of upgrading legacy household equipment. From an economic perspective, MNOs monetize smart home connectivity subscriptions, bundled broadband-mobile offers, and dedicated IoT service plans; CCPs generate revenues through device management platforms, cloud storage, and home automation services; INEPs capture value from connected appliances, sensors, gateways, and maintenance or software upgrade services; and CPs benefit from premium streaming, cloud gaming, immersive entertainment, and personalized digital media services within smart home ecosystems. The main 5G technologies involved are MEC for local low-latency processing, Network Slicing for service differentiation, and SDN/NFV for flexible smart home service management.

The evolution from 5G to 6G will enhance these applications and introduce entirely new ones, enabled by technologies such as THz communications, ultra-massive MIMO, AI-native networks, and non-terrestrial platforms.

2.3.2 *6G applications*

• **Extended Reality (XR):** Immersive Communication enables ultra-high bandwidth and ultra-low latency connectivity for XR experiences, including immersive virtual travel, holographic telepresence, digital twins for real-world simulations, remote education, collaborative workspaces, industrial training, and multi-sensory entertainment. These applications require extremely high data rates (up GB/s), motion-to-photon latency below human perception thresholds (less than 0.1 ms), precise synchronization, seamless mobility, and highly reliable connectivity to preserve immersion and user comfort (99.9999%) [33]. Key advantages include realistic remote presence, reduced travel needs, improved training efficiency, enhanced collaboration, and the creation of new immersive entertainment ecosystems [50]. Although XR offers significant benefits for immersive work environments, several key challenges must be addressed before large-scale adoption. First, technical and network constraints remain critical, as XR applications require ultra-high bandwidth, ultra-low latency, and highly reliable connectivity, which are not always guaranteed in real deployments. Second, there is a lack of user skills and organizational readiness, since most users and enterprises are still unfamiliar with XR tools, requiring substantial training, IT support, and integration effort. Finally, high deployment and operational costs represent a major barrier, including investment in headsets, sensing devices, edge infrastructure, and content development [51]. From an economic perspective, XR creates revenue opportunities for MNOs and CPs, which deliver XR-as-a-Service (XRaaS) through differentiated immersive subscription models, while INEPs generate value through the production and sale of XR hardware and related enabling devices. The main 6G technologies enabling XR include THz technologies for ultra-high data rates and extreme low-latency, umMIMO for beamforming and capacity enhancement, and RIS for signal quality improvement.

• **Tactile internet:** Leveraging 6G with ISAC, the tactile internet enables real-time remote control of physical systems with haptic feedback, supporting applications such as remote robotics, industrial automation, teleoperation, healthcare assistance, and immersive touch-based human–machine interaction. These applications require ultra-reliable low-latency communication at the sub-millisecond level ($\leq$ 1 ms round-trip delay), deterministic networking behavior, precise synchronization between sensing and actuation, high availability ($\geq$ 99.99999%), and continuous bidirectional

feedback loops. Their performance is typically evaluated in terms of end-to-end latency, jitter, reliability, haptic feedback accuracy, and control loop stability [52]. Key advantages include safe and efficient remote operation of physical systems, improved industrial productivity, reduced human exposure to hazardous environments, and enhanced interaction realism in cyber-physical systems. However, limitations include extremely strict latency and jitter constraints, high dependence on edge computing infrastructure, sensitivity to network fluctuations, and significant deployment complexity for maintaining stable closed-loop control [53]. Economically, the tactile internet enables revenue opportunities for robotics manufacturers (InCs) through robotic hardware sales and subscription-based haptic control systems, for CPs through immersive applications subscriptions, for CCPs through remote operation platforms, and for MNOs and NAPs through connectivity services supporting industrial automation and ultra-reliable low-latency communications. The main 6G technologies enabling the tactile internet include ISAC for real-time sensing and environment awareness, QC for large-scale data processing, AI-based network optimization for adaptive resource management, SDN/NFV for network virtualization.

• **Super-smart society:** With billions of connected devices, 6G enables ultra-smart environments encompassing smart homes, smart cities, and fully automated transportation systems, with seamless integration of big data analytics, IoT, AI, and human-centric services to enable real-time coordination between digital intelligence and physical infrastructures [54]. These applications require ultra-high device density support (up to 10^6–10^7 devices/km^2), ultra-reliable low-latency communication with latency in the order of 1 ms down to sub-ms (e.g., $< 100\ \mu s$ for extreme cases), and reliability levels of 99.999%–99.9999%. They also require seamless mobility at speeds up to 500–1000 km/h, real-time data processing with end-to-end latency below a few milliseconds, and very high data rates ranging from 10–20 Gbps on average to 100 Gbps peak. In addition, these systems demand high spectral efficiency, improved energy efficiency (reduced energy-per-bit and multi-year IoT device lifetime), and large-scale integration of heterogeneous terrestrial and non-terrestrial networks ensuring continuous coverage, scalability, and efficient resource management [55]. Key advantages include enhanced personalized medicine and remote diagnostics in healthcare, precision farming for agriculture, improved learning systems, and optimized energy consumption in urban and transport systems. However, limitations include unemployment risks caused by automation, high deployment and maintenance costs, interoperability challenges among diverse technologies, and increased security and privacy risks due to massive data exchange [56]. From an economic overview, ultra-smart environments create revenue opportunities across multiple markets. MNOs monetize IoT connectivity and network slicing for smart city and autonomous services. CCPs monetize data processing, AI analytics, and digital twins for smart city management. INEPs capture value through edge-enabled infrastructure for low-latency distributed systems. InCs generate value via domain-specific applications (mobility, energy, urban services), while NAPs monetize industrial automation and platform services. These cross-sectoral interactions expand the ecosystem of ultra-smart societies, thereby increasing service diversity and enabling EUs to access a broader range of intelligent, context-aware solutions. These capabilities rely on key 6G enabling technologies such as QC for advanced optimization and security, THz communications for ultra-high capacity links, AI for intelligent automation and resource management, NTSs for global coverage.

• **Brain-Computer Interactions (BCI):** BCIs, which is designed to support biomedical applications like telesurgery, smart ambulance systems, continuous patient monitoring, enable direct communication between the brain and external devices, while requiring ultra-high data rates (up to 10 Tbps), ultra-low latency (evaluated in microseconds), and extremely high reliability (99.999%) to ensure accurate interpretation of neural signals and real-time interaction [57]. Key advantages include enhanced human—machine interaction, improved assistive technologies for healthcare and disability support, advanced neuro-rehabilitation systems, and new immersive interaction paradigms. However, key limitations include the extreme sensitivity of neural signal acquisition, stringent requirements on latency and reliability, high computational complexity for real-time signal processing, as well as significant ethical, privacy, and security concerns related to the collection and use of brain data [58]. Economically, BCIs create revenue opportunities across multiple stakeholders. MNOs and CCPs monetize connectivity, and large-scale neural data processing for neuro-health services, remote cognitive assistance, rehabilitation platforms, and brain-driven control systems. INEPs generate value through the development and sale of BCI devices, sensors, and wearable neurotechnology hardware, while healthcare providers invest in and adopt these solutions to deliver advanced medical services such as personalized neuro-therapy and remote patient monitoring to EUs. The main 6G technologies enabling BCIs include THz communications for ultra-high data rate neural signal

transmission, RIS for improving signal quality and coverage in sensitive environments, AI/ML for neural signal decoding and interpretation, and QC for real-time edge processing of brain data.

• **Industrial automation:** 6G empowers advanced AI and ML algorithms for real-time monitoring, predictive maintenance, intelligent decision-making, and fully automated operations across sectors such as manufacturing, logistics, and energy systems. These applications require large-scale data processing, ultra-low latency inference, high reliability, continuous connectivity, and efficient coordination between distributed edge and cloud resources under dynamic network conditions. Key advantages of industrial automation include increased production speed, enhanced operational efficiency through reduced downtime and 24/7 operation, and improved product quality and consistency due to reduced human error. Key limitations include high upfront investment costs for infrastructure and deployment, complex integration of heterogeneous systems, and the need for a highly skilled workforce for operation and maintenance. From an economic perspective, with industrial automation, NAPs are the key actors by providing AI-as-a-Service (AIaaS) platforms based on AI/ML techniques, enabling predictive maintenance, process optimization, and intelligent decision-making for manufacturing systems. MNOs support connectivity and low-latency communication for industrial IoT deployments, while CCPs provide large-scale cloud computing and data processing infrastructure for training and deploying AI models. INEPs supply industrial sensors, robotics, and edge devices enabling real-time data acquisition and automation at the physical layer. InCs generate value by deploying automated production systems and smart factories, and enterprises (EUs) benefit by integrating these solutions to improve productivity, reduce operational costs, and optimize supply chain efficiency. The main 6G technologies enabling these capabilities include AI-native networking for autonomous network optimization, edge computing or QC for real-time edge inference, SDN/NFV for flexible resource orchestration, NTNs for global industrial connectivity, and Thz technologies for improved coverage and reliability in distributed environments.

• **Space-air-ground integration:** 6G unifies terrestrial, aerial, and space-based networks, enabling seamless global connectivity across heterogeneous environments and supporting applications such as maritime and aviation navigation, Earth observation, disaster monitoring, remote sensing, and ubiquitous IoT connectivity. These applications require seamless global coverage across terrestrial, aerial, space, and marine domains, flexible and high-capacity network architectures to support high-speed user mobility, and efficient integration of heterogeneous networks for continuous service delivery. Key advantages include extended coverage to unserved and remote areas through satellite constellations, improved flexibility and deployment speed via low-altitude aerial networks, and enhanced long-range connectivity using high-altitude platform systems as relay nodes. They also enable improved system capacity through dense orbit satellites and support emerging user-centric and ultra-dense network architectures. However, key limitations include very high global deployment and operational costs, significant complexity in integrating terrestrial and non-terrestrial networks, and limited terrestrial THz coverage due to extremely small cell sizes. Additional challenges include spectrum management issues and uncertainty regarding the integration of underwater networks into future 6G architectures [33]. From an economic perspective, integrated 6G networks create major revenue opportunities for NTNPs direct satellite broadband access, remote IoT connectivity, maritime and aviation communication services, and Earth observation markets. In collaboration with NTN actors, MNOs can extend their coverage footprint and monetize hybrid terrestrial—satellite subscriptions, roaming services, and ubiquitous connectivity offers for underserved regions directly to their customers. The main 6G technologies enabling these capabilities include NTNs for satellite and aerial connectivity, AI for autonomous network optimization and resource management, THz communications for high-capacity links in specific scenarios, and 5G UDNs for capacity enhancement.

Table 1 presents a comprehensive mapping between emerging applications and their corresponding service classes, alongside the enabling technologies required for their implementation. Each application demands distinct network capabilities. Service classes, including uRLLC, HRLLC, ISaC, and others, have been defined based on application-specific requirements. Enabling technologies such as edge computing, network slicing, THz communications, RIS, Quantum Communication (QC), and umMIMO are aligned with these service classes to ensure performance, scalability, reliability, and low latency. This mapping highlights the evolving landscape of 5G and 6G networks, emphasizing the critical role of advanced technologies in supporting next-generation intelligent and immersive applications.

Table 1. Mapping of applications to service classes and enabling technologies

Applications	Service classes	Enabling technologies
Remote Healthcare and Telemedicine	eMBB, mMTC, uRLLC (5G), IC, MC, HRLLC (6G)	Edge Computing, Network Slicing, SDN/NFV (5G), THz Communications, RIS (6G)
Autonomous Vehicles	uRLLC, mMTC (5G), HRLLC, MC (6G)	Network slicing, mmWave, Massive MIMO, Ultra Dense Networks, edge computing (5G), THz, umMIMO, QC (6G)
Brain-Computer Interface (BCI)	HRLLC, ISAC, AI/ML	THz, QC, RIS
Tactile Internet	HRLLC, ISAC, AI	QC (6G), SDN/NFV (5G)
XR (Extended Reality)	HRLLC, IC	umMIMO, RIS, Thz
Space-Air-Ground	HRLLC, UC,AI	UDNs (5G) NTNs, THz, RIS
VR/AR	URLLC, eMBB	Network slicing, edge computing, NFV, SDN
Super-Smart Society	HRLLC, UC, MC, AI/ML	QC, THz, RIS, umMIMO
Full-Sensory Digital Sensing and Reality	ISAC	OAM

As 5G and 6G networks build upon decades of cellular innovation, they not only introduce new technical features but also reshape the competitive and operational dynamics among market players. The transformative capabilities of 6G extend beyond existing actors, influencing the nature and delivery of services across the ecosystem. In the following, we review the key market players in the evolving 5G ecosystem and those anticipated in 6G networks, aiming to characterize their roles, responsibilities, and positions within the emerging telecom value chain, as well as to highlight their evolving economic and technological interactions.

3. The set of economic actors and its evolution

In the traditional telecommunication ecosystem, multiple activities and processes are carried out by companies that produce and distribute value to their customers through products and services. The main established actors include Infrastructure and Network Equipment Providers (INEPs), Regulatory Bodies (RBs), Mobile Virtual Network Operators (MVNOs), and End-Users (EUs), all organized around Mobile Network Operators (MNOs), which play a central role in the ecosystem.

With the advent of 5G and beyond (B5G), networks are expected to provide capabilities far exceeding those of previous generations. This evolution gives rise to new actors, including Non-Terrestrial Networks Providers (NTNPs), Network Automation Providers (NAPs) [11], and Trust/Security Providers (TSPs), which we describe in this section.

3.1 *Traditional network stakeholders*

• **Mobile Network Operators (MNOs):** In 5G networks and beyond, MNOs play a pivotal role by providing network access and connectivity services to EUs, and enterprises. They manage licensed spectrum resources and a wide range of infrastructure components that enhance mobile coverage, optimize network operations, and support high-quality real-time services [20]. Beyond traditional voice and data offerings, MNOs increasingly enable advanced capabilities such as private networks, edge-enabled services, and network slicing for actors like MVNOs, CPs, and InCs through radio resource market or network sling market. Economically, MNOs capture value through subscription revenues, wholesale access, enterprise connectivity contracts, infrastructure sharing, and premium 5G/6G service offerings. Examples of MNOs include Orange, China Mobile, Deutsche Telekom, and Verizon.

• **Infrastructure and Network Equipment Providers (INEPs):** In the 2G/3G era, network infrastructure and equipment were exclusively owned and operated by MNOs. With the advent of 4G, 5G, and beyond, infrastructure

ownership has progressively diversified across multiple stakeholders. According to [20], INEPs supply core network and radio access equipment such as routers, switches, servers, RAN components, and base stations, as well as end-user devices. They also deploy and maintain physical infrastructure for MNOs, including cell towers, small cells, fiber backhaul, and rooftop installations, enabling large-scale network coverage. In addition, INEPs operate data centers that support storage, processing, and cloud interconnection services for CCPs. Economically, INEPs generate value through infrastructure leasing, long-term deployment contracts, co-location services, and one-time payments for EUs devices. Examples of INEPs include Huawei, ZTE, Ericsson, Cellnex Telecom, American Tower Corporation, Equinix, and Nokia.

• **Regulatory Bodies (RBs):** Implementing regulatory procedures, i.e., the application of laws and policies established by governmental and supranational institutions, can significantly influence interactions and activities among all stakeholders within the 5G and beyond ecosystem [11]. Regulatory bodies ensure fair competition, consumer protection, spectrum allocation, infrastructure sharing rules, and compliance across multiple levels: national (e.g., Telecom Regulatory Authority of India (TRAI), Ofcom, ARCEP), standardization bodies (e.g., European Telecommunications Standards Institute (ETSI)), and international organizations (e.g., International Telecommunication Union (ITU), World Trade Organization (WTO)). They also generate significant public revenues through spectrum auctions, where frequency bands are allocated to MNOs under competitive bidding mechanisms.

• **Mobile Virtual Network Operators (MVNOs):** Due to the limited availability of radio spectrum, which constrains the number of MNOs, MVNOs have emerged as a service-based business model enabled by network virtualization. MVNOs are companies that do not own spectrum or physical infrastructure but lease network capacity through wholesale agreements with MNOs, enabling them to provide wireless services such as voice calls, messaging, and data directly to EUs [59]. This arrangement allows MNOs to monetize excess network capacity through wholesale revenues, while MVNOs deliver differentiated and niche services. Examples of MVNOs include Lebara Mobile, Lycamobile, and Tracfone.

• **Cloud Computing Providers (CCPs):** CCPs establish public and private cloud infrastructures and provide on-demand computing resources such as processing power, storage, and platforms through cloud computing service models, including Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) [60]. These services are offered to organizations such as CPs and InCs, as well as directly to EUs over the Internet. CCPs also collaborate with MNOs to enable integrated cloud—network service delivery in 5G and beyond ecosystems. Economically, CCPs generate revenue through pay-as-you-go pricing models, subscription-based services, and long-term enterprise contracts for scalable and elastic resource provisioning, and revenue-sharing agreements with MNOs. Security and compliance considerations are critical, particularly for sensitive data storage and processing. Examples of CCPs include AWS, Google Cloud, Microsoft Azure, Alibaba Cloud, Tencent Cloud, and IBM Cloud.

• **Industrials Companies (InCs):** InCs are emerging as key transformative actors in the 5G ecosystem. With the rise of Industry 4.0, sectors such as manufacturing, energy, mining, logistics, and construction leverage 5G connectivity to enable automation, increase productivity, and support advanced use cases such as ultra-low-latency control, massive IoT integration, and high-reliability industrial operations. Leading industrial companies, including Siemens, Bosch, ABB, Schneider Electric, and Honeywell, collaborate with MNOs to deploy private 5G networks in industrial environments, enabling applications such as connected robotics, digital twins, predictive maintenance, and real-time quality control [61]. Economically, InCs generate value through the sale of industrial equipment and systems, deployment and integration of private network solutions, and service-based offerings such as industrial automation, monitoring, and predictive analytics platforms for enterprise customers.

• **Content Providers (CPs):** CPs have emerged as key actors in the digital ecosystem, developing and delivering content across multiple formats such as streaming media, online publications, gaming, social networks, and audiobooks [20]. These services are delivered directly to EUs over the Internet and are heavily dependent on underlying infrastructure provided by MNOs for connectivity and CCPs for scalable cloud and content delivery infrastructures (e.g., CDNs and edge caching). Economically, CPs generate revenue through subscription-based models, advertising services, freemium strategies, and in-app purchases, forming large-scale digital content monetization ecosystems. Examples of CPs include Netflix and Spotify (streaming), The New York Times and BBC (news), Facebook and Instagram (social media), and Steam and Epic Games (gaming platforms).

• **End-Users (EUs):** EUs represent the central actors in the 5G and beyond ecosystem, as they both consume and generate value within digital services. They use digital content provided by CPs, mobile connectivity offered by MNOs or MVNOs, devices supplied by INEPs, and cloud resources delivered by CCPs [11]. Beyond being service consumers, EUs also act as key data contributors enabling data-driven services and personalized applications. Economically, EUs participate in the ecosystem through subscription-based models, pay-per-use services, and data-driven value creation mechanisms. Their satisfaction, Quality of Experience (QoE), and adoption behavior are critical determinants of ecosystem growth and sustainability [20].

As the 5G/B5G landscape evolves, emerging technologies, capabilities, and innovative players are reshaping industry dynamics. The next subsection explores the impact of these changes by highlighting the new actors in the ecosystem.

3.2 *Emerging stakeholders*

• **Non-Terrestrial Networks Providers (NTNPs):** In the 5G/B5G era, NTNPs represent emerging actors that deliver communication services through non-terrestrial platforms such as satellites, HAPs, and drones directly to EUs. These systems extend connectivity beyond terrestrial coverage limits and can provide enhanced capacity, broad-area coverage, resilient communications, and low-latency services depending on the deployed architecture (e.g., Low Earth Orbit (LEO) constellations) [62]. NTNPs complement traditional MNOs by relying on different infrastructures and by serving remote, maritime, aerial, and underserved areas [63]. Economically, NTNPs generate value through direct broadband subscriptions, wholesale capacity leasing, backhaul services, IoT connectivity, and revenue-sharing partnerships with MNOs. Examples include SpaceX Starlink, Eutelsat OneWeb, and AST SpaceMobile. Illustrating this convergence, T-Mobile US and AT&T have partnered with Starlink and AST SpaceMobile, respectively, to expand mobile coverage using LEO satellite systems.

• **Network Automation Providers (NAPs):** B5G and 6G networks are expected to enable highly autonomous networking functions, including zero-touch management, monitoring, orchestration, and self-configuration. This evolution introduces a new class of actors, referred to as NAPs0, which develop software platforms integrating AI, data analytics, and automation capabilities such as machine learning, natural language processing, computer vision, and predictive analytics [11]. These technologies support network optimization, predictive maintenance, anomaly detection, security enhancement, and operational efficiency.

Economically, NAPs generate value through software licensing, subscription-based automation platforms, managed AI services, and enterprise integration contracts. Examples of NAPs include VMware, Juniper, and Puppet. Their customers include MNOs and NTNPs for network automation, CCPs for cloud resource orchestration, InCs for private 6G network automation [64], and CPs for media processing, transcription, and AI-enhanced service delivery.

• **Trust/Security Providers (TSPs):** B5G and 6G ecosystems are also expected to guarantee security, reliability, and privacy by design. This evolution introduces TSPs, which deliver solutions such as end-to-end encryption, post-quantum cryptography, federated learning, identity management, and AI-driven threat detection for enterprises and digital service providers [65]. Their services are particularly relevant for actors such as InCs and CPs in domains including industrial data processing, financial transactions, and digital content delivery.

TSPs may collaborate with MNOs and CCPs while leveraging technologies such as blockchain, dynamic security policies, and zero-trust architectures to enhance trust across distributed ecosystems [66]. Economically, TSPs generate value through cybersecurity subscriptions, managed security services, compliance solutions, enterprise protection contracts, and revenue-sharing agreements with MNOs and CCPs. Examples include Palo Alto Networks, CrowdStrike, and Hyperledger-based ecosystem providers, while institutions such as ENISA contribute to governance and cybersecurity standardization.

After classifying service classes and technologies of 5G and 6G networks in Section 2, and introducing the involved actors, we now describe in the next section the economic interactions between these actors, including the associated Business Models (BMs).

4. Economic ecosystem

Figure 7 illustrates the layered evolution of markets from 5G to 6G. Existing 5G markets are shown in blue and include:

- Radio resource market,
- Physical infrastructure market,
- Device market,
- Computing resources market,
- Network slicing market.

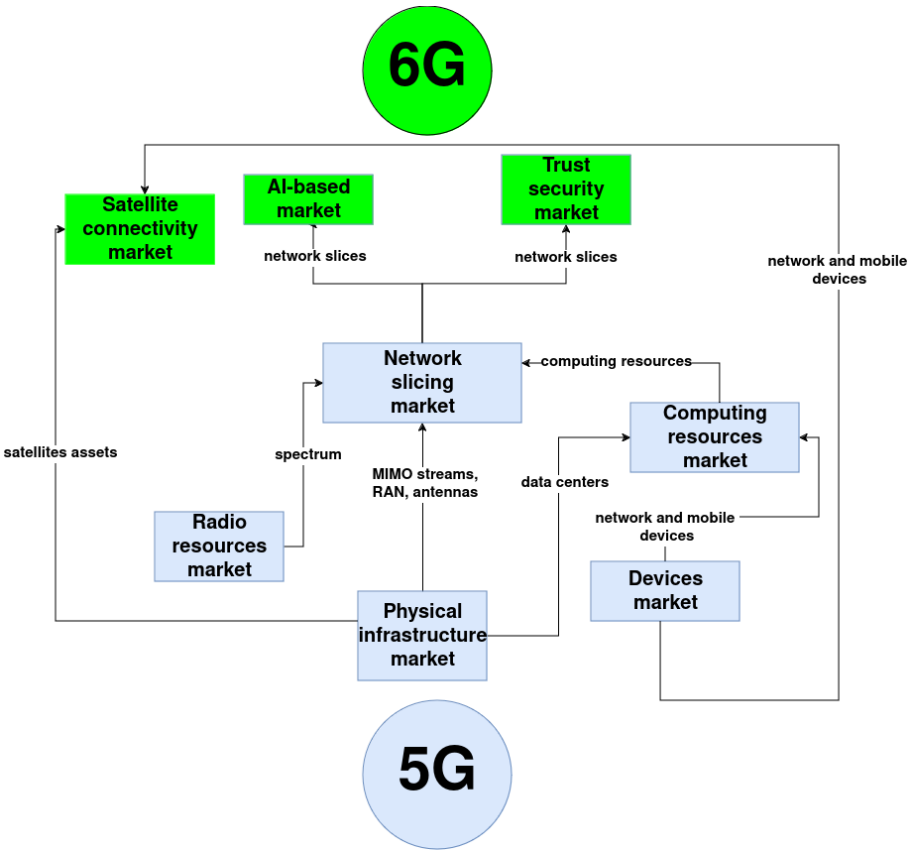


Figure 7. Layered evolution of markets from 5G to 6G

6G introduces additional markets, shown in green:

- Satellite connectivity market,
- AI-based market,
- Trust-Security market.

The markets can be conceptually organized in layers to highlight dependencies:

1) **Base layer:** Devices, radio resources, and physical infrastructure markets form the foundation necessary for all subsequent services.

2) **Intermediate layer:** Computing resources market leverages the base layer for scalable processing capabilities, while network slicing market enables flexible allocation of network resources to different tenants.

3) **Top layer:** Trust and security, AI-based, and satellite connectivity markets represent domains of differentiation and added value, enabling new services and revenue streams in 6G.

The staircase representation reflects these layered dependencies: higher-layer markets rely on resources and services provided by markets below. For example, network slicing depends on computing resources, which in turn depend on physical infrastructure and device availability.

Figure 8 provides a detailed mapping of the main stakeholders participating in the markets identified in Figure 7, and illustrates how value is created, exchanged, and monetized across the 5G and emerging 6G ecosystem. Light blue nodes denote established actors mainly associated with current 5G deployments, whereas light green nodes represent emerging actors expected to play a growing role in B5G/6G environments. Edges between nodes represent business relationships through which services, resources, data, or revenues are exchanged.

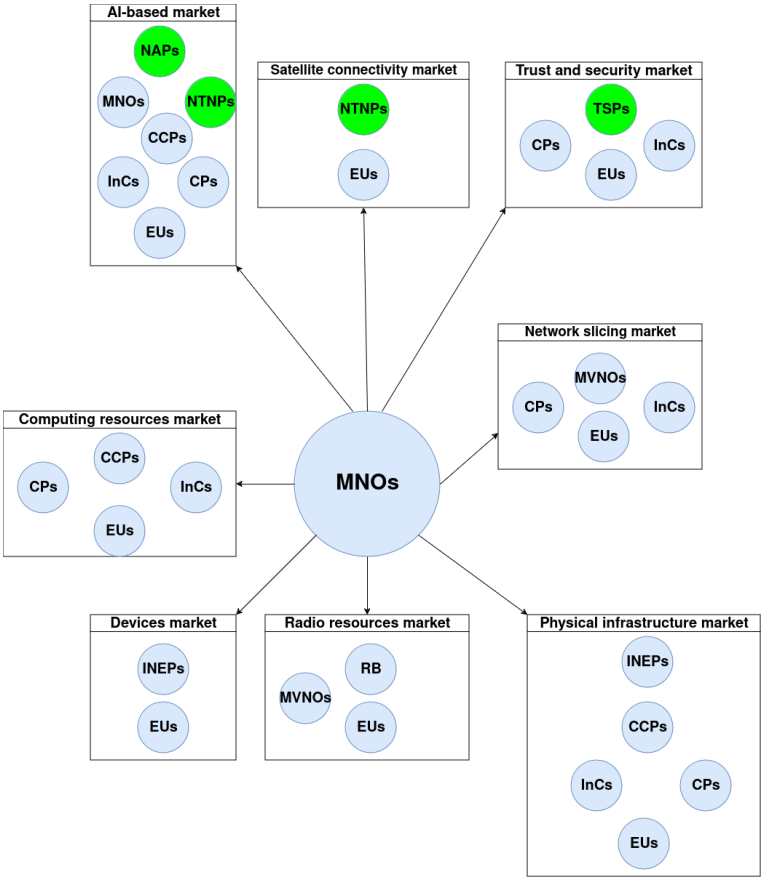


Figure 8. 5G and 6G value chain: markets and actors

The figure highlights the central position of MNOs, which remain the anchor actors of the ecosystem due to their control of licensed spectrum, radio access infrastructure, and connectivity services. MNOs interact upstream with INEPs in Physical infrastructure market for infrastructure deployment, equipment acquisition, tower leasing, fiber backhaul, and data center resources, but also in device market for devices sales directly to EUs, while downstream they provide connectivity and service access to EUs, enterprises, and MVNOs across Radio resource and Network slicing markets. Through wholesale agreements, MNOs enable MVNOs to deliver differentiated retail offers without owning full network infrastructure.

The figure also shows the increasing importance of digital, industrial, and cloud-based actors. CCPs provide storage, computing, edge processing, and AI resources to CPs, InCs, and other enterprises in Cloud Computing market. CPs leverage connectivity from Network slicing market and cloud resources from Cloud Computing market to deliver streaming, gaming, social media, and digital content services directly to EUs. In parallel, InCs exploit private networks provide

by MNOs in network slicing market, IoT platforms with computing resources provided by CCPs from cloud computing market, automation tools provided by NAPS from AI-based market, and security tools provided by TSPs from trust-security market to support vertical sectors such as manufacturing, logistics, healthcare, and energy.

Emerging 6G actors further expand the value chain. NTNPs complement MNOs by providing satellite, aerial, and remote-area connectivity, but also through partnerships with them for seamless coverage extension in Satellite connectivity market. NAPs contribute autonomous network management, orchestration, and AI-driven optimization services, while TSPs strengthen privacy, trust, cybersecurity, identity management, and regulatory compliance across AI-based market, and Trust-Security market.

Finally, the figure emphasizes that future 5G/6G ecosystems evolve from a traditional linear telecom supply chain toward a multi-sided and service-oriented platform economy, where infrastructure, connectivity, computing, intelligence, and trust are jointly combined to generate value across interconnected markets.

Note: To provide a possible quantitative modeling of economic interactions in the considered ecosystem, one may define representative utility and revenue functions for the different stakeholders in each market described below. These expressions are not intended to be solved in the present work, but rather to illustrate potential formulations that could be used in future optimization-based studies of network economics.

4.1 *Radio resources market*

First, in the radio resource markets, the RB frequently organizes spectrum auctions to assign specific capacity C_{MNO} (frequency bands) to MNOs, reducing the risk of interference. The main auction formats include the Simultaneous Multiple Round Auction (SMRA) [67], used in the UK 5G auction 2018, and the Combinatorial Clock Auction (CCA) [68], used in the Ofcom 5G auction 2021. In the United Kingdom, the rollout of 5G was made possible through two key spectrum auctions organized by Ofcom in 2018 and 2021, which allocated essential frequency bands to major mobile operators. In the first auction in April 2018, the four main operators—O2, Vodafone, EE, and Three—acquired spectrum in the 2.3 GHz and 3.4 GHz bands, which are crucial for 5G deployment. O2 secured the largest share, obtaining 40 MHz in both bands, while Vodafone acquired 50 MHz in the 3.4 GHz band, EE obtained 40 MHz, and Three secured 20 MHz. These allocations, worth hundreds of millions of pounds in total, provided a significant increase in network capacity. Overall, 190 MHz of spectrum were distributed, laying the foundation for the widespread deployment of 5G services across the UK (https://5g.co.uk/guides/5g-uk-auction/).

In the SMRA format, multiple spectrum lots are auctioned simultaneously over iterative bidding rounds, where MNOs place incremental bids on individual blocks, and pay a first-price equal to their winning bid. This model provides transparency and simplicity but may lead to exposure risk, where MNOs risk winning incomplete spectrum packages at suboptimal prices. In contrast, the CCA format allows package bidding through clock rounds and a supplementary round, with final allocations determined by a Winner Determination Problem (WDP) [69]. It adopts Vickrey–Clarke–Groves (VCG)-like pricing [25], improving allocative efficiency but increasing computational complexity and strategic bidding difficulty. These mechanisms define different pricing rules and can be interpreted as strategic allocation games between RB and MNOs, where MNOs compete to maximize their expected network utility under budget constraints while RB aims at efficient spectrum allocation and revenue maximization.

Once spectrum licenses are assigned, MNOs gain exclusive rights over all capacity, introducing flexible Spectrum Sharing (SS) through new business models. Co-Primary Spectrum Sharing (CoPSS) among MNOs enables cooperative use of underutilized spectrum to improve coverage and reduce costs, representing a co-opetition model. Its main advantage lies in improved spectral efficiency, reduced infrastructure redundancy and entry barriers for new and challenger MNOs, and enhanced network performance and capacity, while its limitation is the need for the availability of suitable spectrum and regulatory support, coordination mechanisms, uncertainty and risk potential, and conflicts over resource allocation. An example is Net4Mobility in Sweden (Telenor Sweden and Tele2 Sweden), a joint venture established to build, own, and operate a shared nationwide mobile network. Through this CoPSS arrangement, the two operators jointly utilize multiple frequency bands (including 700, 800, 900, 1800, 2100, 2600, and 3500 MHz) to provide extensive coverage reaching approximately 99.9% of the Swedish population (https://net4mobility.com/en/).

In contrast, spectrum sharing between MNOs and MVNOs follows a wholesale access model, where MVNOs purchase network capacity $C_{\text{MVNO}} \leq C_{\text{MNO}}$ from MNOs under wholesale agreements (often based on bundled capacity or usage), and compete at the service layer. This model enhances competition in voice services, reduces ARPU and retail prices, and increases service differentiation, leading to potential consumer welfare gains. However, its effects are asymmetric, with limited impact on data services, persistent structural dependency of MVNOs on MNO wholesale access, and inherent cost disadvantages due to infrastructure ownership by MNOs.

A concrete example from the study is the entry of MVNOs in the Czech mobile telecommunications market in 2013. Prior to this, the market was dominated by three mobile network operators (T-Mobile, Vodafone, and O2). Following the entry of MVNOs, which were primarily light MVNOs without full network infrastructure, competition intensified particularly in the voice services segment. The results show a significant reduction in the average price of voice calls (approximately 9.3% in the short term) and a decrease in ARPU of around 12.7% over the full period. However, no significant impact was observed on data prices or data consumption, indicating that MVNOs were unable to exert competitive pressure in the data services market. This case illustrates the asymmetric impact of MVNO entry, with clear benefits for consumers in traditional voice services, but limited effects in the more dominant and bundled data services segment [70].

Finally, interactions between MNOs/MVNOs and EUs are based on subscription-based pricing models, where users pay recurring fee for bundled services including voice, SMS, and data. These models generate stable and predictable recurring revenues for MNOs and MVNOs, enhance customer retention by encouraging long-term contracts, and enable flexible service differentiation. However, they also reduce user flexibility, exposes operators to churn risk if users switch providers after contract expiration, and lead to pricing pressure and margin reduction in highly competitive markets. EUs act as demand-side price takers, while their consumption behavior influences MNO spectrum acquisition and MVNO wholesale demand. From an economic overview, this hierarchical structure can be interpreted as a multi-level game where RB allocates spectrum, MNOs/MVNOs compete and optimize pricing strategies, and EUs select no service or service plans from MNOs or MVNOs based on utility maximization.

For a specific modeling of revenue functions, one might use the following form

$$\Pi_{RB} = \sum_{k} P_k - C$$

as it represents the RB revenue, where P_k denotes the payment from MNO k for total capacity C_{MNO} and C administrative costs.

On the other hand, the MNO revenue can be expressed as:

$$\Pi_{\text{MNO}} = Q_{\text{MNO}} D_{\text{MNO}} - P_k + W_{\text{MNO}}$$

where Q_{MNO} denotes the MNO subscription price, D_{MNO} denotes users demand for MNO service, and W_{MNO} is wholesale price paid by MVNO for capacity C_{MVNO}.

While, the MVNO revenue can be expressed as:

$$\Pi_{\text{MVNO}} = Q_{\text{MVNO}} D_{\text{MVNO}} - W_{\text{MNO}}$$

where Q_{MNO} denotes the MVNO subscription price, and D_{MNO} denotes users demand for MVNO service.

For a specific modeling of user utility functions, they might use the following formulations

$$\begin{cases} U_1 = \ln(1 + \frac{C_{\text{MNO}} - C_{\text{MVNO}}}{D_{\text{MNO}}}) - Q_{\text{MNO}}, & \text{For choosing MNO} \\ U_2 = \ln(1 + \frac{C_{\text{MVNO}}}{D_{\text{MVNO}}}) - Q_{\text{MVNO}}, & \text{For choosing MVNO} \\ U_0 = 0, & \text{For no service} \end{cases}$$

where $\frac{C_{\text{MNO}} - C_{\text{MVNO}}}{D_{\text{MNO}}}$ is the MNO service capacity per user mass unit, $\frac{C_{\text{MVNO}}}{D_{\text{MVNO}}}$ is the MVNO service capacity per user mass unit, and the logarithm in the valuation is a standard assumption representing diminishing returns.

Figure 9 illustrates the structure of the radio resource market and highlights the main finding that spectrum-driven connectivity in 5G/6G networks is governed by a hierarchical and multi-actor value chain rather than a single-layer service model. RB acts as the upstream allocator of scarce spectrum resources, assigning licenses to MNOs through regulated mechanisms, while ensuring interference control and efficient spectrum utilization. First, the figure shows that MNOs occupy a central intermediary position, transforming licensed spectrum into commercial connectivity services and redistributing network access through wholesale agreements with MVNOs. MVNOs, in turn, operate as service-layer competitors, differentiating their offerings while relying on MNO infrastructure. At the downstream level, both MNOs and MVNOs deliver subscription-based services (data, voice, SMS) to EUs, who represent the final demand and revenue source of the ecosystem. Second, the figure explicitly maps the bidirectional flows of services, resource rights, and monetary transactions across all actors, highlighting how value is created, transferred, and captured at different layers of the ecosystem. Finally, it further emphasizes the role of MNOs as strategic intermediaries between regulated spectrum markets and retail service markets.

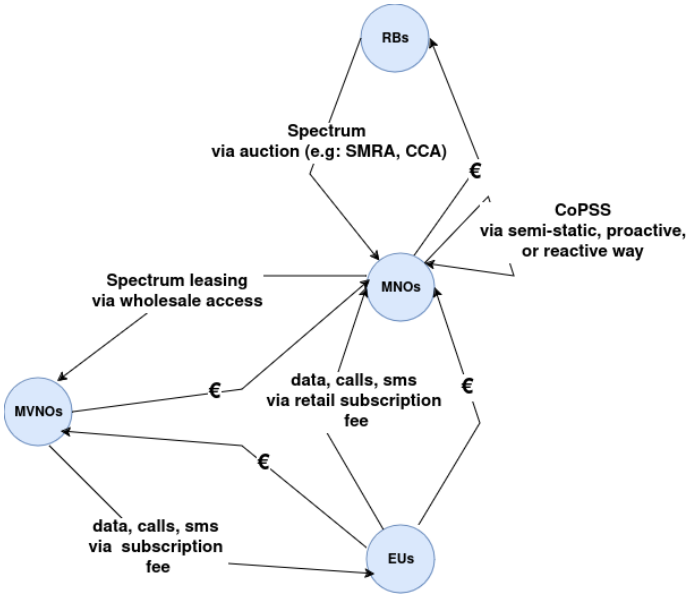


Figure 9. Radio resources market

4.2 *Physical infrastructure market*

Second, as mobile networks evolve from centralized hardware-defined architectures toward disaggregated, cloud-native, and software-driven deployments, the separation of infrastructure ownership between MNOs and INEPs gives

rise to a dedicated physical infrastructures market in 5G and beyond. In this environment, INEPs ow n multiple site j, and supply passive assets such as towers, rooftops, leasing them to multiple MNOs present ob site j at price ℓ_i through a neutral-host model [71]. This model reduces infrastructure duplication, lowers MNO capital expenditures, and accelerates network rollout, but may also create dependency on third-party pricing and reduced control over strategic sites. INEPs also lease at site j rack space in data center at price ℓ_c, to CCPs through a co-location model, enabling edge servers, micro data centers, and cloud outposts close to EUs [72]. This model improves reliability and security through controlled environments asset utilization for INEPs and allows CCPs to deploy services rapidly without owning local facilities, scalability and flexibility, although it may be constrained by high deployment costs, space, energy availability, and recurring lease costs.

A concrete example of neutral-host model is American Tower in the United States, which signed a new long-term lease agreement with Verizon in 2022 to support Verizon's ongoing nationwide 5G deployment across American Tower's extensive U.S. communications site portfolio. American Tower reported owning approximately 222,000 communications sites globally, together with a large U.S. data center footprint. Although the exact number of Verizon-utilized sites was not publicly disclosed, the agreement highlights large-scale access to a distributed portfolio of strategic tower locations (https://americantower.gcs-web.com/news-releases/news-release-details/american-tower-and-verizon-announce-new-long-term-agreement).

On the other hand, a representative example of co-location model is Cellnex Telecom, in partnership with Vapor IO, deploying edge colocation infrastructure in Europe through the Kinetic Grid platform, with the first deployment in Barcelona. This collaboration enables the hosting and integration of AWS Outposts at the edge of the network, bringing cloud computing and storage resources closer to end users. The resulting architecture supports ultra-low-latency applications such as real-time analytics, industrial robotics, autonomous vehicles, and computer vision, while also improving data residency compliance and reducing core network traffic (https://www.cellnex.com/news/vapor-io-expands-edge-computing-grid-europe-partnership-cellnex/).

In this ecosystem, MNOs use these assets to deploy radio equipment, base stations, and antennas, and monetize connectivity through subscriptions, wholesale contracts, and network slicing services delivered to EUs, MVNOs, CPs, and InCs in multiple markets described in Subsections 4.1 and 4.5. Similarly, CCPs provide computing and storage services to CPs and InCs in the computing resources market described in Subsection 4.4.

From an economic perspective, all the interactions (INEP-MNO) and (INEP-CCP) can be modeled as a Stackelberg game in which INEPs act as leaders by setting infrastructure prices (ℓ_c and ℓ_i), while MNOs observe ℓ_i and respond by optimizing leasing demand and retail pricing strategies in radio and network slicing markets, and CCPs observe ℓ_c and adapt deployment strategies in the computing resources market accordingly. For a specific modeling of revenue functions, one might use the following form

$$\Pi_{INEP} = \sum_j (\ell_i I_j + \ell_c C_j) - f$$

as it represents the profit of an INEP, where I_j is the number of MNO i at site j, C_j is the number of CCP c at site j, and f represents infrastructure deployment and maintenance costs.

Figure 10 illustrates the structure of the 5G physical infrastructure ecosystem and highlights the main finding that infrastructure provisioning and service delivery are governed by a layered, interdependent value chain rather than isolated bilateral relationships. INEPs occupy the foundational layer of the ecosystem by providing passive and semi-passive infrastructure resources such as data centers, rack space, towers, rooftops, ducts, and power through co-location and neutral-host models. First, the figure shows that MNOs and CCPs act as key intermediate infrastructure tenants, transforming these physical and computing resources into higher-level services, namely network slices and cloud-based services, which are then delivered to CPs and InCs under auction-based and on-demand usage-based pricing mechanisms. These actors further distribute value-added services to EUs through subscription-based business model, forming the final demand layer of the ecosystem. Second, the figure shows the explicit representation of both resource flows (infrastructure and services) and monetary flows (€), allowing a clear interpretation of how value is created, transferred, and captured across different

layers of the ecosystem. Finally, it highlights the dual role of INEPs as neutral infrastructure providers and pricing leaders, and the dependence of upper-layer actors on shared physical resources for service innovation and scalability.

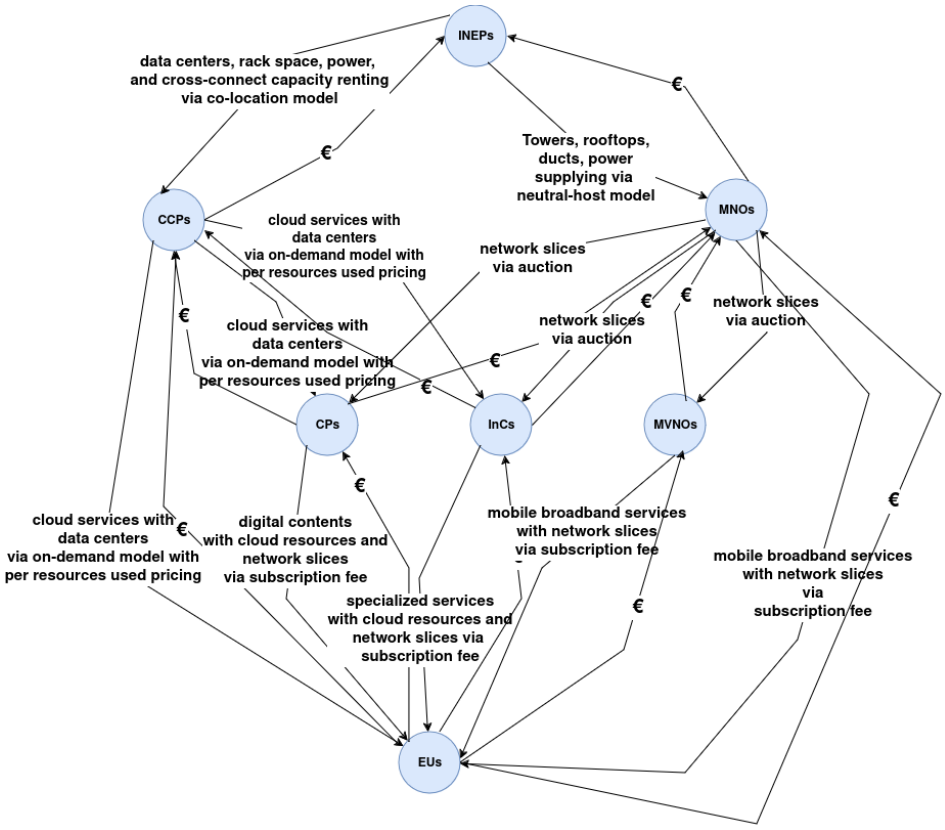


Figure 10. Physical infrastructures market

4.3 *Devices market*

Third, device provisioning constitutes an important supporting market within the 5G ecosystem. INEPs such as Samsung, Apple, and Huawei supply 5G-enabled smartphones, routers, wearables, and IoT devices directly to EUs, thereby shaping how users access and interact with network services [73]. This market is characterized by multiple business models, including direct retail sales [74] by INEPs and device resale models [75] through MNOs.

Under the direct retail sales model, EUs purchase devices through one-time payments or INEPs own financing options determined by device features, brand value, and technological capabilities. This model allows INEPs to directly control pricing strategies and maintain strong brand positioning, while EUs independently choose a MNO such as Orange or any other carrier for a separate mobile plan. The main advantages include high pricing flexibility, direct customer relationships, higher margins on premium devices for INEPs, and no contractual obligation for customers. However, its limitations include high marketing costs, strong competition, exposure to demand volatility and short product life cycles. A concrete case study supporting the direct retail BM is Apple selling the iPhone 15 directly to EUs without involving MNOs as the seller. Customers purchase the device from Apple's online store or Apple Retail Stores at the full retail price (for example, around €969 in Europe), either as a one-time payment or through Apple's own financing options (https://www.apple.com/fr/shop/buy-iphone).

MNOs also participate in the devices market through a bundling and resale model. Operators acquire devices from INEPs at a wholesale price w and offer them to EUs jointly with mobile subscriptions. The main advantages of this model include lower upfront costs for users, increased customer acquisition and retention, higher Average Revenue Per User

(ARPU), and long-term contract stability for MNOs. However, limitations include device subsidy risks, delayed return on investment, and customer churn exposure in case of early contract termination.

A concrete example is Verizon and the iPhone 15 sold in partnership with Apple. On Verizon's official website, the iPhone 15 is advertised as "0/month for 36 months" when the customer adds a new line on an eligible unlimited plan. Instead of giving the phone for free upfront, Verizon applies monthly bill credits that offset the device payment over time, meaning the customer must stay on the plan for the full 36 months to receive the discount. If the customer cancels early or changes to an ineligible plan, the remaining balance becomes due. This structure effectively allows Verizon to finance the device while locking in long-term service revenue from the customer (https://www.verizon.com/smartphones/apple-iphone-15/).

From an economic overview, these interactions can be modeled as a Stackelberg game where the INEP acts as the leader by setting wholesale device prices and direct retail device price, while the MNO acts as the follower by determining bundle pricing and subscription conditions. EUs then react by choosing the option (direct device purchases, bundled offers, or no service) which maximizes their utility, depending on price, and device quality. For a specific modeling of revenue functions, one might use the following form

$$\Pi_I = p_I N_I + w$$

as it represents the profit of an INEP, where p_I denotes the retail device price, N_I the quantity sold (number of EUs acquiring devices), and marketing, and w the wholesale price.

On the other hand, the profit of MNOs in this model can be expressed as

$$\Pi_M = (p_M + q_M)N_M - w$$

where p_M is the subscription fee, N_M the number of subscribers, and q_M the bundled device price.

For a specific modeling of user utility functions, they might use the following formulations

$$\begin{cases} U_1 = \ln(1+V) - p_I, & \text{For a direct device purchase} \\ U_2 = \ln(1+V) - (p_M + q_M), & \text{For a bundled offer} \\ U_0 = 0, & \text{For no service} \end{cases}$$

where V represents the device quality.

Figure 11 illustrates the structure of the devices market within the telecommunications ecosystem, involving INEPs, MNOs, and EUs. It highlights two coexisting distribution channels through which devices reach final users: (i) an indirect resale channel, where INEPs supply smartphones, routers, and IoT devices to MNOs at wholesale prices, and MNOs resell them to EUs bundled with connectivity services through recurring subscription fees; and (ii) a direct retail channel, where INEPs sell devices directly to EUs through one-time payments, bypassing operators. The main finding of the figure is that device provisioning is no longer exclusively controlled by MNOs, but increasingly relies on a dual-channel market structure in which manufacturers also compete directly for customer access.

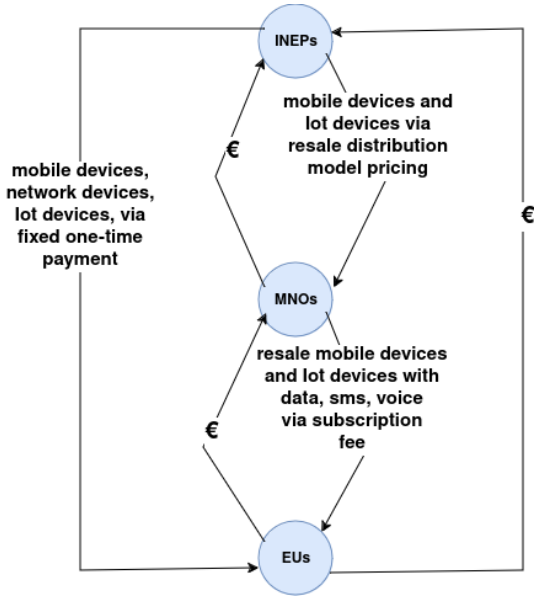


Figure 11. Devices market

4.4 *Computing resources market*

Fourth, 5G networks must handle a massive volume of service requests with stringent performance requirements, necessitating substantial computing and storage resources. This growing demand drives the emergence of a dedicated computing resources market. In this environment, CCPs deliver cloud services, including IaaS, PaaS, SaaS, IoT platforms [76], analytics [77], and orchestration tools [78], to Service Providers (SPs) (InCs and CPs), or directly to EUs through an on-demand usage-based model [79], where they only pay for what they use, with data centers often co-located on INEP infrastructure at leasing price ℓ_c. InCs leverage these cloud resources to design and operate private 5G networks for customized industrial services, while CPs use them to deliver high-quality digital content to EUs through subscription-based service provisioning, where EUs pay monthly or yearly recurring fee to access the service.

The main advantages of this model include cost efficiency through pay-as-you-use pricing, high scalability with virtually elastic storage capacity, and improved reliability through redundancy, backup, and automatic failover mechanisms. These benefits allow organizations to reduce upfront infrastructure investments while ensuring flexible and resilient data management. However, it also presents several limitations, including security and privacy risks related to unauthorized access or data breaches, dependency on network performance where bandwidth constraints and latency may degrade service quality, and long-term cost uncertainty when recurring usage-based charges exceed the cost of local ownership [80].

A concrete case study is Netflix's use of Amazon Web Services (AWS) for cloud storage, real-time analytics, and streaming infrastructure. AWS enables Netflix to rapidly deploy thousands of virtual servers and terabytes of storage resources within minutes, allowing seamless global service delivery. As a result, users can stream Netflix content worldwide across web, tablet, and mobile platforms following multiple subscription plans (https://aws.amazon.com/solutions/case-studies/netflix-case-study/).

From an economic overview, all these interactions can be modeled as a Stackelberg game where the CCP acts as the leader by setting computing resources unit price, while InC, or CP act as the follower by determining subscription fee. EUs then react by choosing the option (the CCP, one SP, CCP+SP, or no service] which maximizes their utility, depending on price, and service quality.

As CCPs are revenue-oriented actor, for a specific modeling of revenue functions, one might use the following form

$$\Pi_C = \sum_j \sum_i p_i x_{i,j} - c - \ell_c$$

as it represents CCP revenue, where i is the type of resource, p_i represents the unit price of computing resources (e.g., virtual machines, storage, or transcoding instances), $x_{i,j}$ denotes the consumed quantity by each customer j, and c is the total operational cost.

On the other hand, the SP j revenue can be expressed as:

$$\Pi_j = p_j d_j - \sum_i p_i x_{i,j}$$

where p_j is the SP j service price, and d_j denotes user mass choosing the service offered by SP j.

For a specific modeling of user utility functions, they might use the following formulations

$$\begin{cases} U_1 = \ln(1 + \sum_i x_{i,j}) - \sum_i p_i x_{i,j}, & \text{For choosing the CCP} \\ U_2 = \ln(1 + \frac{\sum_i x_{i,j}}{d_j}) - p_j, & \text{For choosing one SP} \\ U_3 = \ln(1 + \frac{\sum_i x_{i,j}}{d_j}) + \ln(1 + \sum_i x_{i,j}) - (p_j + \sum_i p_i x_{i,j}), & \text{For choosing CCP+SP} \\ U_0 = 0, & \text{For no service} \end{cases}$$

CCPs and MNOs can also be modeled as strategic players in a revenue-sharing model [81], where CCPs optimize resource allocation while MNOs provide network infrastructure and edge capabilities, leading to a cooperative game with the revenue obtained is shared between the businesses.

This model offers several advantages, including risk reduction through cost and revenue distribution among partners, stronger incentives for collaboration and joint innovation, and faster market expansion by combining complementary assets such as infrastructure, customer bases, or technological capabilities. However, it also presents limitations, including complex contract design regarding revenue allocation and performance responsibilities, potential conflicts of interest when partners have strategic objectives, and dependency risks where one actor's poor performance can directly reduce the revenues of the others.

A concrete example of MEC deployment is the partnership between Verizon and AWS through AWS Wavelength integrated with Verizon 5G Edge. This collaboration brings cloud computing and storage resources directly to the edge of the 5G Ultra Wideband network, enabling customers to deploy latency-sensitive applications closer to EUs. By reducing the distance between devices and application servers, the platform significantly lowers latency and improves real-time performance. It supports a wide range of use cases, including real-time analytics, IoT, autonomous systems, smart cities, and augmented/virtual reality (https://www.verizon.com/about/investors/runs-on-verizon/aws).

This interaction can be modeled as a cooperative game where the CCP and the MNO joint their resources to maximize a common revenue, which can be expressed by the CCP revenue described above.

Figure 12 illustrates the structure of the computing resources ecosystem and highlights the main finding that cloud-based service delivery in 5G/6G networks is organized through a multi-actor, interdependent value chain rather than a single-provider model. CCPs play a central role as resource providers, supplying computing, storage, and analytics services to CPs and InCs under a usage-based on-demand model, while also interacting with MNOs for resource coordination

and infrastructure support under revenue-sharing model. The figure shows that CPs and InCs act as intermediate service providers: CPs transform cloud resources into digital content services delivered to EUs via subscription-based model, while InCs use these resources to support industrial applications and private network deployments. EUs represent the final demand side, indirectly driving cloud consumption through their service usage. The figure also explicitly maps the bidirectional flow of (i) computing and network resources and (ii) monetary transactions across stakeholders, highlighting how value is jointly created and distributed. It further emphasizes the strategic collaboration between CCPs and MNOs, which enables efficient resource utilization, low-latency service delivery, and scalable cloud–edge integration.

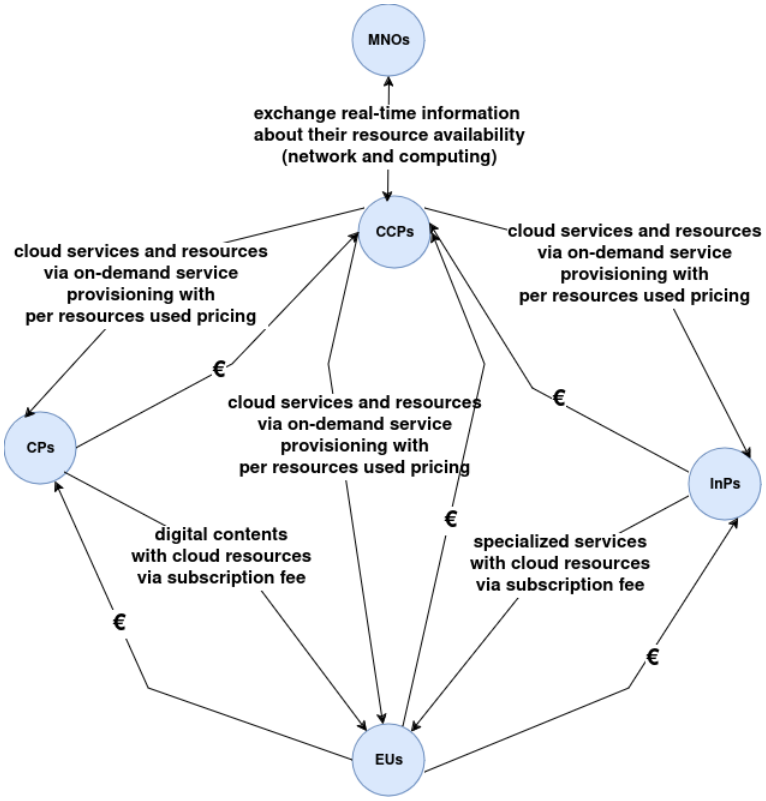


Figure 12. Computing resources market

4.5 *Network slicing market*

Fifth, in the 5G ecosystem, industries increasingly develop applications such as autonomous vehicles and HD streaming, driving demand for networks with specific performance requirements. Network slicing addresses this demand by enabling MNOs to create tailored virtual networks on a shared infrastructure, making it a key driver of the network slicing market and a crucial enabler of 5G monetization. In this environment, MNOs with total capacity $C \geq 0$, allocate customized bundles of radio [82], and computing resources [83] as network slices. These slices may be leased to external total tenants K such as MVNOs, InCs, and CPs through wholesale agreements (resource leasing), or internally reserved by MNOs to directly provide premium connectivity services to EUs (own services) [84]. Tenants k acquiring slices of capacity $C_k \leq C$ monetize them by offering differentiated services to EUs through subscriptions pricing. Network slicing creates a dual monetization model combining wholesale and retail revenues for MNOs.

The main advantages of the network slicing business model are: (i) efficient utilization of shared infrastructure through virtualization, (ii) new revenue streams via premium differentiated services, (iii) support for heterogeneous use cases with guaranteed QoS, and (iv) user welfare improvement. However, several limitations remain: (i) orchestration

and management complexity, (ii) SLA enforcement and security isolation challenges, and (iii) pricing uncertainty under fluctuating multi-tenant demand.

A concrete case study of the network slicing business model is provided by Hadjadj-Aoul et al., who analyze the economic viability of 5G network slicing through a Stackelberg game involving an Internet Service Provider (ISP), a Service Provider (SP), and end users. In their model, the ISP partitions network capacity into slices and sells premium resources to the SP, which then offers differentiated services to users under a Paris Metro Pricing scheme. The study derives optimal slice sizing and pricing strategies, and compares scenarios with slicing, no slicing, and vertical integration. Their results show that network slicing can improve user welfare and create additional revenue opportunities, although the benefits depend strongly on pricing regulation and market structure. This work provides a representative example of how slicing can be modeled as a monetizable techno-economic market rather than only a technical virtualization mechanism [85].

From an economic overview, these interactions naturally form a multi-level Stackelberg game in which the MNO acts as leader by setting slice prices and resource availability, tenants act as followers by choosing slice demand and retail pricing, and EUs determine final demand through utility maximization.

For a specific modeling of revenue functions, one might use the following form

$$\Pi_M = \sum_{k \in K} P(C_k) + q_M d_M - o,$$

as it represents MNO revenue, where $P(C_k) = \alpha C_k$ is the income from selling capacity to the tenant k, α is a decision variable, q_M denotes the retail subscription price, d_M is the user mass choosing the MNO, and o is the total operational cost of providing slice capacity.

On the other hand, as each tenant k is also revenue-oriented player, its profit can be expressed as

$$\Pi_k = q_k d_k - P(C_k),$$

where q_k denotes service price and d_k the user mass choosing the tenant k.

EUs select among available offers from the MNO, from the tenants, or no service which maximize their utility, according to price and service quality. For a specific modeling of user utility functions, they might use the following formulations

$$\begin{cases} U_M = \beta \ln(1 + \frac{C - \sum_{k \in K} C_k}{d_M}) - q_M, & \text{For choosing the MNO} \\ U_k = \theta \ln(1 + \frac{C_k}{d_k}) - q_k, & \text{For choosing the tenant } k \\ U_0 = 0, & \text{For no service} \end{cases}$$

where $\frac{C - \sum_{k \in K} C_k}{d_M}$ is the MNO service capacity per user mass unit, $\frac{C_k}{d_k}$ is the tenant k service capacity per user mass unit, θ the user sensitivity to the tenant k service quality, β the user sensitivity to the MNO service quality.

Figure 13 highlights the multi-sided economic structure of the 5G network slicing market, where MNOs transform shared infrastructure resources into monetizable virtual slices for multiple tenants, and clearly maps the flows of resources, services, and monetary transactions among all stakeholders. The main finding is that network slicing enables MNOs to serve heterogeneous actors such as MVNOs, CPs, and InCs through differentiated allocation and pricing mechanisms, while these tenants further monetize the acquired slices by delivering customized services to EUs. In addition, the figure

explicitly captures a direct MNO-to-EU relationship, where MNOs may also bypass intermediaries and provide retail connectivity services directly to end users using dedicated slices, highlighting the coexistence of wholesale and retail monetization strategies within the same infrastructure.

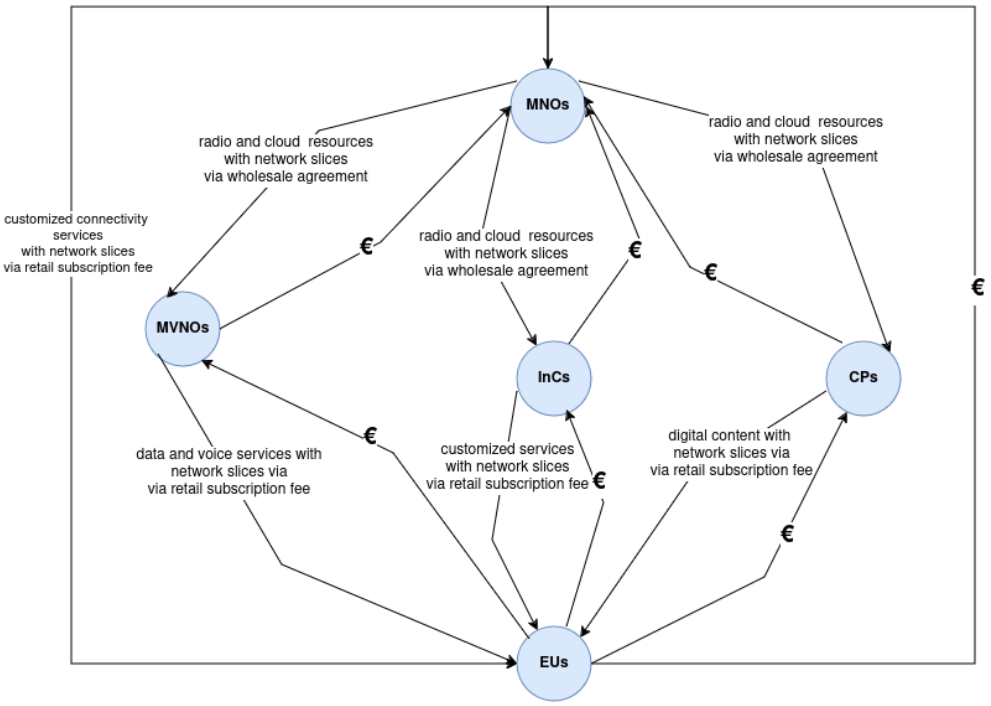


Figure 13. Network slicing market

4.6 *Satellite connectivity market*

With the advent of 6G, the ecosystem becomes significantly more complex and dynamic due to the growing number of actors and the convergence of terrestrial and non-terrestrial infrastructures. The architecture is more open, programmable, and AI-native, giving rise to a distributed and flexible economic structure. In this context, NTNPs gain a strategic role through the satellite connectivity market, complementing MNOs by extending coverage to remote, maritime, rural, and high-mobility areas [63].

A first business model is the direct retail subscription model, where NTNPs with a total capacity C_{NTNP} provide broadband connectivity directly to EUs using satellite assets such as LEO, MEO, or GEO constellations. Users typically pay a one-time equipment fee and recurring monthly or yearly subscription fee.

A representative case is Starlink, operated by SpaceX, offering high-speed satellite internet in the European Union through its Starlink Residential or Roam plans. After a one-time purchase of satellite reception equipment, users can subscribe monthly to either a 50 GB regional plan or an unlimited data plan for roaming services, with prices starting around €40 per month. Residential services are also available from €29 per month, depending on location. Roaming works across the country of registration and is supported temporarily in other EU countries for up to two months. Plans are flexible, cancelable at any time, and particularly suitable for travelers, digital nomads, or users in remote areas (https://www.starlink.com/).

From an economic perspective, this interaction can be modeled as a Stackelberg game in which the NTNP is the leader setting subscription price and physical hardware price, while EUs as followers choose the option (subscription to the NTNP, or no service) which maximizes their utility.

For a specific modeling of revenue functions, one might use the following form

$$\Pi_{\text{NTNP}} = (p_s + p_e)d - c_s$$

as it represents the profit of the NTNP, where p_s is the monthly subscription price, d the user mass choosing satellite connectivity, p_e the terminal equipment price, and c_s the fixed satellite deployment and operational cost.

For a specific modeling of user utility functions, they might use the following formulations

$$\begin{cases} U_1 = \ln(1 + \frac{C_{\text{NTNP}}}{d}) - (p_s + p_e), & \text{For choosing the NTNP} \\ U_0 = 0, & \text{For no service} \end{cases}$$

A second business model is the partnership model between NTNPs and MNOs as an integrated entity, based on revenue sharing agreements. In this case, NTNPs provide satellite capacity while MNOs manage customer acquisition, billing, and terrestrial integration to EUs through subscription-based fee, with a joint total capacity C_{NM}.

A concrete case study is the partnership between T-Mobile US and SpaceX, launched under the "Coverage Above and Beyond" initiative. In this model, T-Mobile contributes its licensed mid-band spectrum, nationwide customer base, and retail relationships, while SpaceX provides Starlink LEO satellites equipped with direct-to-cell payloads. The objective is to extend mobile connectivity to remote and uncovered areas without requiring users to purchase dedicated satellite equipment, since existing smartphones can connect directly to the service. The initial offering focuses on near-ubiquitous text messaging (SMS/MMS), with voice and data services planned in later phases. This case illustrates a hybrid revenue-sharing and infrastructure-sharing model that combines terrestrial spectrum assets with satellite capacity to create new value in the 6G non-terrestrial ecosystem (https://www.t-mobile.com/news/un-carrier/t-mobile-takes-coverage-above-and-beyond-with-spacex).

From an economic overview, this interaction can be modeled as a cooperative-stackelberg game in which the NTNP and the MNO cooperate as an integrated actor to set the subscription price p_{nm} to maximize its common revenue, while EUs as followers choose the option (subscription to the integrated entity, or no service) which maximizes their utility.

For a specific modeling of revenue functions, one might use the following form

$$\Pi_{NM} = p_{nm} d_{nm} - c_{nm}$$

as it represents the joint profit, where p_{nm} denotes the integrated entity subscription price, d_{nm} represents the user mass choosing the integrated entity, and c_{nm} is the operational costs.

For a specific modeling of user utility functions, they might use the following formulations

$$\begin{cases} U_1 = \ln(1 + \frac{C_{NM}}{d_{nm}}) - p_{nm}, & \text{For choosing the integrated entity} \\ U_0 = 0, & \text{For no service} \end{cases}.$$

Figure 14 highlights the dual nature of the satellite connectivity market in 6G ecosystems, where NTNPs and MNOs simultaneously engage in competition and cooperation. The main finding is that NTNPs directly compete with MNOs in the residential internet market through subscription-based satellite services, while also forming strategic partnerships for Direct-to-Cell (D2C) services via spectrum and satellite resource-sharing agreements. This structure reveals a hybrid ecosystem in which competition drives service diversification, whereas cooperation enables coverage extension and

technical complementarity. The figure contributes by clearly mapping these interactions, showing how revenue flows, infrastructure sharing, and service provisioning coexist within a unified satellite connectivity value chain, ultimately enhancing service availability and user experience for EUs.

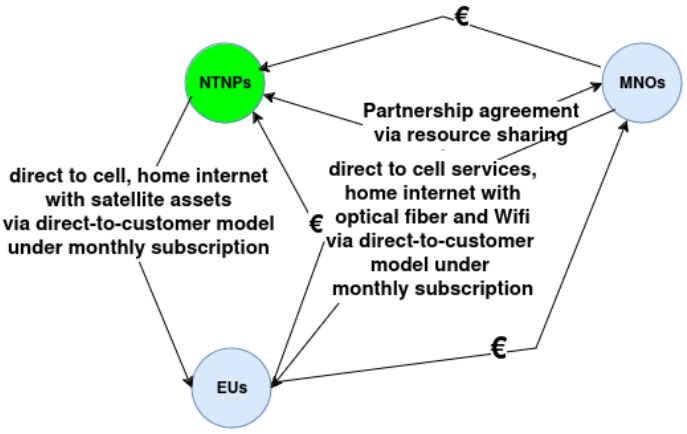


Figure 14. Satellite connectivity market

4.7 *AI-based market*

6G networks introduce a shift toward ultra-intelligent and fully automated ecosystems, where AI acts as a key enabler for real-time decision-making in routing, orchestration, resource allocation, and network optimization. This gives rise to a dedicated AI-based platform market, where NAPs provide AI/ML-driven services to manage complex 6G infrastructures.

In this market, NAPs offer orchestration and optimization services such as network slicing automation, dynamic resource allocation, traffic prediction, QoE optimization, and fault detection. These platforms operate under a platform-based business model (AI-as-a-Service (AIaaS) / Network Automation-as-a-Service (NAaaS)) [86], where pricing is typically defined per managed node or via subscription-based licensing. NAPs interact with multiple actors n in the ecosystem. In particular, MNOs use NAP services to automate network slicing and service provisioning for MVNOs, InCs, CPs, and for direct connectivity to EUs, in the markets described in Subsections 4.1 and 4.5 [87]. NTNPs rely on NAPs to optimize satellite-based network operations for EU connectivity as seen in Subsection 4.6 [88]. CCPs exploit AI-based orchestration to manage cloud resources for CPs and InCs in cloud-based market in Subsection 4.4 [89], while CPs and InCs use these platforms to improve service delivery, content optimization, and private network management [90].

The main advantages of this platform-based model are: (i) improved automation and reduced operational expenditure through AI-driven optimization, (ii) enhanced scalability for large-scale heterogeneous 6G networks, and (iii) improved QoE through predictive and adaptive control. However, key limitations include: (i) high computational and data requirements for AI training, (ii) dependency on centralized or semi-centralized intelligence platforms, and (iii) potential risks related to transparency, control, and interoperability across vendors [91].

A concrete case study is provided by Rodriguez et al., who analyze the ONAP-based deployment of a private and customized 5G network slice, as demonstrated in the literature. In this model, Open Network Automation Platform (ONAP) is used to automate the design, onboarding, instantiation, and lifecycle management of a network slice composed of virtualized core network functions deployed on shared cloud infrastructure. The slice is dedicated to an enterprise customer and provides tailored connectivity with specific QoS guarantees. This example illustrates a practical platform-based business model, where operators monetize slicing capabilities by offering on-demand, customized virtual networks to industrial customers, while reducing deployment time, improving flexibility, and accelerating time-to-market [92].

From an economic overview, the interaction between NAPs and stakeholders (MNOs, NTNPs, CCPs, CPs, InCs, and EUs) can be modeled as a hierarchical game in which NAPs act as leaders by setting pricing and automation policies, while

infrastructure and service providers act as followers optimizing their deployment, slicing, and service strategies under AI-driven orchestration constraints across all the markets in 5G/6G ecosystem.

For a specific modeling of revenue functions, one might use the following form

$$\Pi_{NAP} = \sum_{n \in \mathcal{N}} p x_n - C,$$

as it represents the profit of the NAP, where N represents the total number of actor, p is the unit price per node, and x_n is the number of managed nodes (e.g., slices, VNFs, cloud instances, or infrastructure elements) by actor n, while C captures operational and computational costs of AI-driven orchestration.

Figure 15 illustrates the economic structure of the AI-based platform market in 6G ecosystems, where NAPs emerge as strategic intermediaries supplying AI/ML-driven automation services to MNOs, CCPs, InCs, MVNOs, CPs, and NTNPs. The figure highlights that AI becomes a tradable resource monetized through subscription and per-managed-element pricing models. It further shows how each stakeholder leverages these automation capabilities across multiple other markets to improve resource allocation, orchestration, QoS/QoE, and operational efficiency before delivering services to EUs. A key contribution of the figure is to reveal the cross-market dependency created by NAPs, since one platform can simultaneously optimize terrestrial, satellite, cloud, enterprise, and content markets. Monetary flows (€) emphasize that value is generated not only from end-user services, but also from upstream sales of intelligence and automation tools.

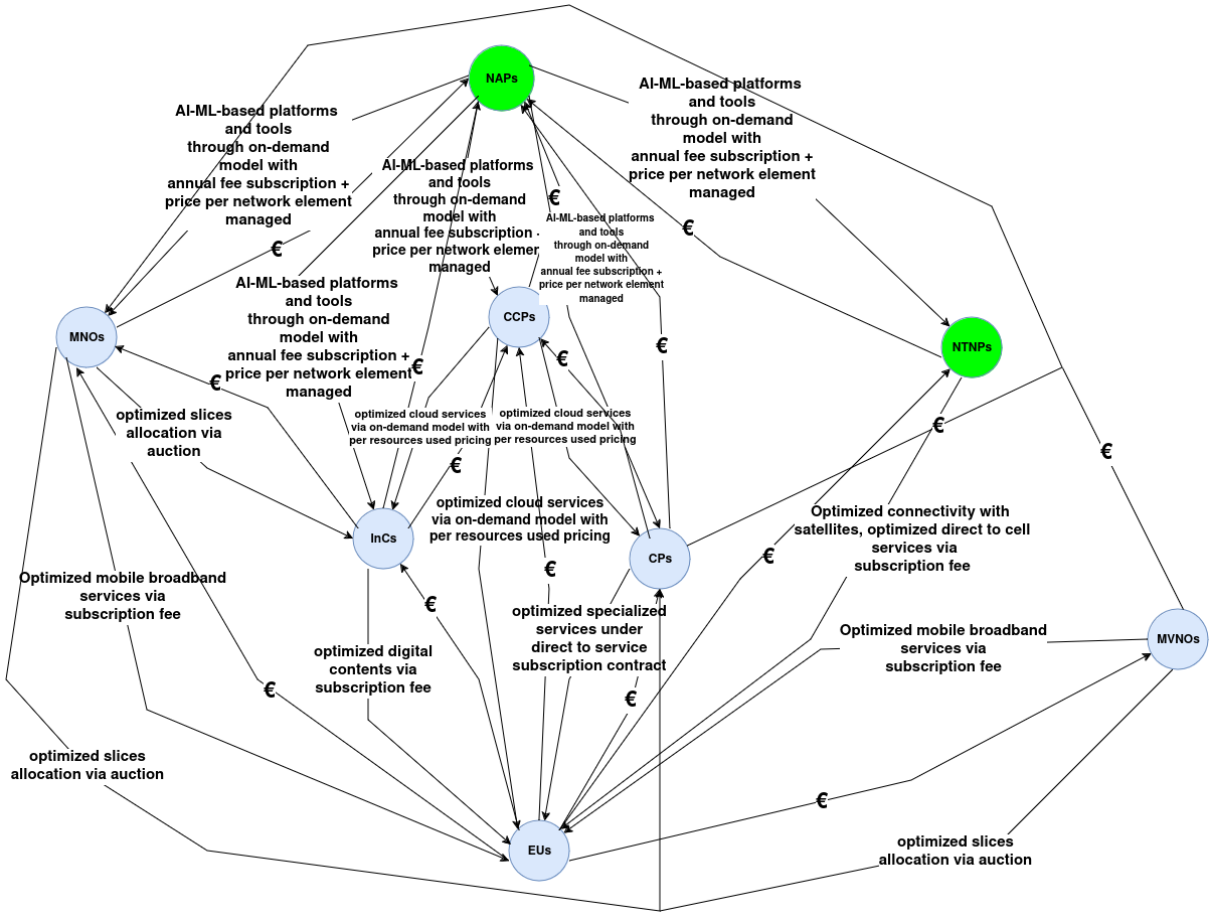


Figure 15. AI-based market

4.8 *Trust-security market*

Simultaneously, TSPs play a key role in addressing the security and trust requirements of software-defined and multi-stakeholder 6G ecosystems, where infrastructure, computing, and application layers are distributed across multiple providers. This increases exposure to risks such as unauthorized access, data leakage, identity spoofing, and slice-level attacks. In this context, TSPs provide CPs and InCs with security and trust services, including APIs, blockchain-based authentication, smart contracts, Identity and Access Management (IAM), encryption, network isolation, and compliance assurance, forming a dedicated trust and security market.

These services are offered under on-demand model, where pricing is typically defined through a combination of subscription-based contracts (monthly or yearly enterprise licensing) and usage-based mechanisms (e.g., per API call, per certificate issuance, or per security operation). CPs use these trust services to secure digital content delivery to EUs, while InCs rely on them to ensure secure IoT-based service provisioning.

A concrete case study is provided by Siemens' adoption of Microsoft 365 E5, which integrates advanced security and identity management tools such as Azure Active Directory, Microsoft Defender for Endpoint, and Conditional Access policies. In this model, security services are delivered under an enterprise subscription-based pricing scheme, typically charged on a per-user per-month basis, while access control and compliance enforcement are dynamically applied through Zero Trust policies (https://blog.siemens.com/2024/09/enabling-conditional-access-for-open-source-software/).

From an economic overview, the interaction between TSPs and stakeholders (CPs, InCs, and EUs) can be modeled as a hierarchical game in which TSPs act as leaders by setting pricing and security service policies, while service providers act as followers optimizing their service deployment and security integration strategies under trust and compliance constraints to deliver theirs services directly to EUs through subscription fee.

Similarly, TSPs may collaborate with MNOs under a cooperative game-theoretic framework to jointly secure network slices and APIs used in service delivery. The resulting value creation is captured through a revenue-sharing mechanism between both parties, where joint revenues are distributed according to predefined contractual agreements reflecting their respective contributions.

For example, Singtel (MNO), in collaboration with Palo Alto Networks (TSP), launched "Security-as-a-Slice" (SecaaS), which integrates AI-driven security functions such as Next-Generation Firewalls (NGFWs) [93] directly into 5G network slices. This solution enables identity-based and zero-trust security enforcement for mobile and IoT environments, leveraging a SASE-based architecture to provide real-time threat detection, traffic filtering, and secure access control within distributed networks (https://www.worldteleport.org/news/696038/Singtel-Palo-Alto-Networks-Launch-Two-Cybersecurity-Solutions-.htm).

For a specific modeling of revenue functions, one might use the following form

$$\Pi_{TSP} = \sum_{i \in \mathscr{I}} p_i x_i - C,$$

as it represents the profit of the TSP, where $i \in \mathscr{I}$ represents security service types (e.g., authentication requests, encryption services, API calls), p_i denotes the unit price of each service type, x_i is the demand from CPs, or InCs, or MNOs, and C captures operational, computational, and infrastructure costs associated with trust service provisioning.

Figure 16 summarizes the role of TSPs in the digital ecosystem, delivering security and trust services to CPs and InCs via on-demand pricing models based on fixed subscription fees or per-service usage, and indirectly to EUs. CPs and InCs provide secured digital content and specialized services through fixed retail subscription fees. Additionally, TSPs collaborate with MNOs via resource-sharing arrangements involving APIs for security and network elements, with internally shared revenue. Monetary flows (€) illustrate how trust services enable secure, value-added offerings across the ecosystem. The main findings of this figure are threefold. First, it highlights the central role of TSPs as enablers of security and trust services in the digital ecosystem, supporting CPs and InCs through hybrid pricing models combining subscription-based and usage-based mechanisms. Second, it reveals a hierarchical and interdependent ecosystem structure, where CPs and InCs depend on TSPs for security assurance while delivering services to EUs under retail subscription

models. Third, it shows that the interaction between TSPs and MNOs extends beyond simple service provisioning toward cooperative arrangements based on shared APIs and revenue-sharing mechanisms.

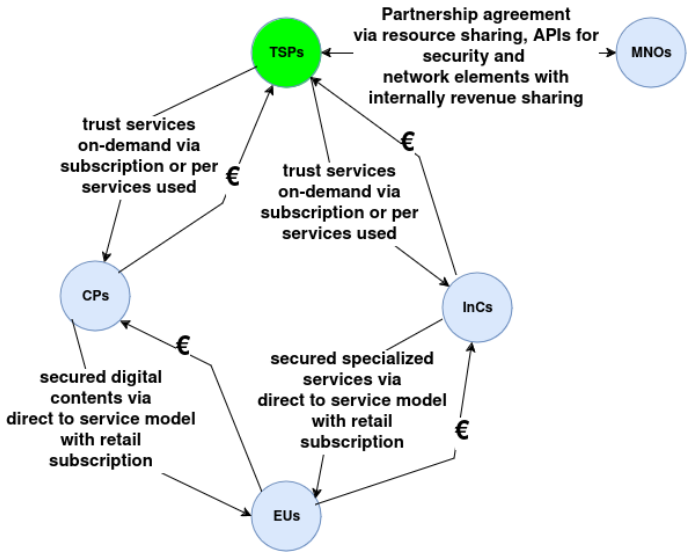


Figure 16. Trust and security market

Tables 2 and 3 jointly provide a structured comparative framework of the main business models considered in this paper. Rather than presenting independent summaries, they enable a systematic cross-model comparison across multiple economic and operational dimensions, including revenue generation mechanisms, cost structures, infrastructure ownership, pricing strategies, and service delivery modes. In particular, the comparison covers a wide range of paradigms such as direct retail and resale models, subscription-based services, wholesale and revenue-sharing agreements, auction-based resource allocation, infrastructure-sharing models (e.g., neutral-host and co-location), as well as advanced paradigms such as network slicing and platform-based AI-driven orchestration. This unified perspective highlights fundamental trade-offs between the different models. Retail and resale approaches typically provide higher revenue control and customer proximity but suffer from higher market competition and demand volatility. Infrastructure-sharing models, such as neutral-host and co-location, improve capital efficiency and deployment scalability, but reduce operational control and increase dependency on third-party pricing. Auction-based and wholesale mechanisms improve resource allocation efficiency and market transparency, but introduce complexity in pricing and strategic interactions. Finally, advanced paradigms such as network slicing and platform-based models enable high flexibility, improved QoS, and new revenue streams, but require higher orchestration complexity, stronger security guarantees, and significant computational and operational overhead.

Modeling multi-actor interactions in 5G and emerging 6G ecosystems requires moving beyond static resource allocation frameworks, adopting dynamic and strategic formulations. In 5G, the economic organization revolves around the MNO and its structured, though increasingly flexible, interactions with established entities. With 6G, the ecosystem becomes significantly more complex, introducing new actors, relationships, and forms of control, giving rise to new markets built atop existing ones. Future research must not only track how resources are traded and priced but also examine how decision rights are distributed, how roles evolve dynamically, and how economic and regulatory mechanisms can adapt to ensure efficiency, innovation, and fairness in this rapidly changing landscape. In the next section, we analyze the different regulatory rules that impact the evolution of BMs.

Table 2. Comparisons of different business models 1/2

Business Models	Advantages	Limitations
Direct retail sales	High pricing flexibility, direct customer relationships, higher margins on premium devices for INEPs, no contractual obligation for customers	High marketing costs, strong competition, exposure to demand volatility, short product life cycles
Resale	Lower upfront costs for users, increased customer acquisition and retention, higher ARPU, long-term contract stability for MNOs	Device subsidy risks, delayed return on investment, customer churn exposure in case of early contract termination.
On-demand usage-based	Scalability and Flexibility, Cost and Time Savings, Access to the Latest Hardware	Security Vulnerabilities, Downtime, Vendor Lock-In
Revenue-sharing	Risk reduction, stronger incentives for innovation, faster market expansion	Complex contract design, potential conflicts of interest, dependency risks to one actor's poor performance
Auction-based	transparency, allocative efficiency improvement	exposure risk, computational complexity, strategic bidding difficulty.
CoPSS	spectral efficiency, infrastructure redundancy and entry barriers reduction, network performance and capacity enhancement	Uncertainty and risk potential, conflicts over resource allocation, the need for the availability of suitable spectrum and regulatory support

Table 3. Comparisons of different business models 2/2

Business Models	Advantages	Limitations
Wholesale	ARPU and retail prices reduction, high service differentiation, high consumer welfare	Persistent structural dependency of MVNOs on MNO wholesale access, inherent cost disadvantages for MVNOs, limited impact on data services
Subscription-based	Stable and predictable recurring revenues for businesses, enhance customer retention by encouraging long-term contracts, flexible service differentiation	Churn risk, pricing pressure and margin reduction in highly competitive markets
Neutral-host	Reduction of infrastructure duplication, lowers capital expenditures, network roll out acceleration	Dependency on third-party pricing, reduction of control over strategic sites
Co-location	Improvement of asset utilization, Rapid services deployment without owning local facilities, scalability and flexibility	Recurring monthly expenses, regular operational maintenance, high initial deployment costs
Network slicing	Efficient utilization of shared infrastructure, new revenue streams via premium differentiated services, support for heterogeneous use cases with guaranteed QoS, improvement of user welfare	orchestration and management complexity, SLA enforcement and security isolation challenges, high initial deployment costs
Platform-based	Improved automation and reduced OPEX, enhanced scalability for large-scale networks, improved QoE through predictive and adaptive control	high computational and data requirements for AI training, dependency on centralized platforms, potential risks related to transparency, control, and interoperability across vendors

5. Regulatory implications of 5G and 6G

The ability of 5G and 6G networks to realize their ambitious potential in transforming society largely depends on the regulatory frameworks implemented. These rules operate at various levels: national, regional, and international [11], and include spectrum, pricing, security, privacy, AI, innovation, roaming, and net neutrality regulations. The goal of

regulation, except in authoritarian states, is to establish rules that ensure network design is beneficial for society and fair for all stakeholders. At the same time, regulations should ensure profitability for all actors while promoting competition and fostering innovation. Further details on these regulatory categories are provided below.

• **Spectrum regulation:** Spectrum regulation is designed to ensure the efficient and fair use of the radio-frequency spectrum without interference. At the international level, the ITU provides rights and obligations in spectrum use through the Radio Regulations (RRs), which are revised at the World Radiocommunication Conferences (WRCs) to optimize radio spectrum management. Regional bodies, like the European Conference of Postal and Telecommunications Administrations (CEPT), harmonize allocations and technical standards to facilitate interoperability, while at the national level, regulatory authorities, such as ARCEP, establish frequency allocation tables, assign licenses through auctions, monitor spectrum use, and enforce compliance to prevent harmful interference.

Spectrum regulation is essential for enabling 5G, which relies on a mix of licensed, unlicensed, and shared bands to support diverse services such as eMBB, URLLC, and mMTC. For example, in the US, the Federal Communications Commission (FCC) approved the Citizens Broadband Radio Service (CBRS) for licensed and unlicensed spectrum access [94], while the European Union adopted Licensed Shared Access (LSA), allowing sharing of spectrum between MNOs and non-MNOs, such as MVNOs, InCs, or CPs [95]. At the international level, 5G New Radio (NR) has been extended to unlicensed bands as NR-Unlicensed (NR-U) [96]. Although 5G spectrum policies generally improve utilization, they raise concerns regarding coordination and fairness, which 6G is expected to amplify through THz bands, NTNs, and AI-driven spectrum decisions.

These trends challenge existing regulatory paradigms and call for forward-looking policies. Such policies should enable the development of new licensed spectrum for THz bands and NTNs, while also increasing the availability of unlicensed spectrum to promote open innovation for non-traditional actors.

• **Pricing regulation:** Pricing regulations in mobile networks aim to ensure that services remain affordable without distorting competition. In the European Union, regulators actively cap retail and wholesale prices for services such as roaming and spectrum access. For example, the "Roam Like at Home" (RLAH) policy in 2017 [97] abolished retail surcharges for intra-European Union roaming and imposed wholesale pricing limits to prevent market failures. Further details are available here. Similarly, the Wholesale Access Regulation protects consumers and promotes fair competition by regulating spectrum access for MVNOs [98]. By contrast, in the United States, pricing is largely market-driven, with regulators intervening only to prevent anti-competitive practices, granting operators greater flexibility in setting wholesale and retail prices.

Furthermore, 5G introduces new pricing challenges through network slicing, shared infrastructure, and diverse QoS levels [85], while high deployment and spectrum costs require regulators to prevent excessive pricing without underpricing that could harm market sustainability [99]. With 6G, terahertz spectrum, AI-native networks, and non-terrestrial platforms will necessitate real-time, dynamic pricing frameworks that account for usage, spectrum value, and service differentiation. To address these challenges, regulators may adopt mechanisms such as cost-based pricing models [100] to prevent excessive profits, spectrum auction rules with long-term investment incentives that encourage operators to both pay for spectrum access and meet service obligations [101], and transparent slice allocation procedures to avoid hidden favoritism or price manipulation that could distort competition.

• **Net Neutrality (NN):** Net Neutrality (NN) mandates the equal treatment of all internet traffic. MNOs must provide equal and unrestricted internet access, ensuring that traffic is not altered based on content, user, platform, application, or device. For example, MNOs cannot slow down connections to video streaming applications such as Amazon Prime Video, nor can they prioritize their own favored streaming services, such as Netflix or Disney+. Most regulators recognize NN as a guiding principle; however, its implementation varies across jurisdictions. In the European Union, the Body of European Regulators for Electronic Communications (BEREC) enforces strict rules preventing blocking, throttling, or paid prioritization, whereas in the United States, the FCC has shifted between stricter and lighter approaches depending on the regulatory cycle. Further details are available here.

5G challenges NN through technologies such as network slicing and QoS differentiation, which enable tailored services for industries [102]. These capabilities risk creating "fast lanes" that could undermine neutrality principles if not

transparently regulated. 6G is expected to intensify these challenges due to AI-based traffic management, semantic-aware networking, and non-terrestrial systems, which can reduce transparency and accountability.

A recent work by some co-authors [102] also proposes an initial step toward conciliating 5G network slicing capabilities with net neutrality principles. Their framework suggests classifying traffic flows into categories based on QoE requirements, assigning slices accordingly, and ensuring neutrality within each slice while allowing objective differentiation across slices. This "class-based neutrality" approach seeks to balance fairness, user experience, and operator flexibility, as long as it is accompanied by robust transparency measures and regulatory oversight.

• **Roaming regulation:** Roaming regulations define the rules that MNOs apply when customers use their mobile devices abroad. At the international level, roaming depends on spectrum harmonization coordinated by the ITU, which facilitates device interoperability and cross-border frequency use. The European Union has pioneered strong roaming regulation through the "Roaming Like At Home (RLAH)" policy. By contrast, in the United States, roaming agreements are largely left to commercial negotiation, subject only to competition and consumer protection oversight. Further details are available here.

5G introduces ultra-low latency services, complicating regulation as they require accurate service mapping and cross-border quality guarantees. With 6G, roaming regulation must address even greater complexity, such as dynamic user-service associations across countries and platforms [103]. This increased complexity will require regulators to promote federated learning, enabling MNOs to share anonymized performance insights without sharing their customers' sensitive data, and to define Service Level Agreements (SLAs) for latency-sensitive applications across NTNs. These approaches aim to remove interoperability barriers, balance user experiences, and prevent conflicts between MNOs.

• **Innovation regulation:** Innovation regulation in telecommunications reflects varying regulatory philosophies across jurisdictions, balancing the need to foster new technologies with safeguards for competition, security, and equitable access. Balancing open innovation with the prevention of market concentration and vendor lock-in is a key concern for bodies such as the FCC and BEREC [104]. In the European Union, regulators often adopt proactive, principle-based frameworks that encourage innovation and experimentation rather than prescribing rigid compliance rules. One example is the use of regulatory sandboxes [105], which allow MNOs and industrial companies (InCs) to test 5G-enabled applications such as Industry 4.0. Another illustration is the EU's promotion of local and private 5G networks for industrial companies.

Innovation practices can be classified into two forms [20]: *modular innovation*, referring to improvements at the component level, and *architectural innovation*, involving fundamental reconfigurations of network design and operation. With 6G expected to integrate sensing, semantic communications, and fully autonomous networks, regulators face challenges regarding transparency, interoperability, and ethics in AI-driven infrastructures. They must support both modular and architectural innovation by allowing companies to deploy new components, such as Advanced Radios (ARs), AI schedulers, and edge computing modules, without regulatory hurdles, as well as entire architectures for 6G, including Open RAN (O-RAN) and service-based 6G cores, to maintain network robustness against threats.

• **Security, privacy and AI regulation:** Security, privacy, and AI regulation are central concerns in 5G networks due to massive data flows, real-time analytics, and decentralized architectures such as edge computing. Existing frameworks include the European Union's General Data Protection Regulation (GDPR), which safeguards personal data and ensures privacy in digital communications and is applied broadly across all sectors [106]; the U.S. California Consumer Privacy Act (CCPA), which, like GDPR, grants individuals rights over their personal data, including the ability to access, delete, and opt out of the sale of their information; and the Act on the Protection of Personal Information (APPI) in Japan [20].

However, 5G introduces complex scenarios involving dynamic data sharing, IoT integration, and AI-driven decision-making that strain current legal protections. AI systems in 6G, employed for traffic management, anomaly detection, and service personalization, raise concerns regarding algorithmic bias, data misuse, and explainability. Moreover, in 6G, intelligent automation, distributed ledger technologies, and ubiquitous sensing further obscure control over personal data and accountability.

Future regulations must address cross-border data flows, enforceable AI ethics, real-time compliance, and resilience against evolving cyber threats, while fostering innovation and trust. This will enable global interoperability, build trust with individuals, and reduce infrastructure vulnerabilities.

In the previous sections, we explored the foundational technological aspects of 5G and 6G networks, paying particular attention to the economic dimensions that influence their development, deployment, and global accessibility. In the next section, we examine the critical economic questions that must be addressed for 5G and 6G networks to realize their full potential.

6. Economic questions needing to be addressed

The evolution from 5G to 6G networks heralds large-scale, highly complex deployments, raising pressing economic research questions that require rigorous investigation.

Stochastic modeling of tokenized ownership. In the previous sections, we examined the basic business models for network resources. While these models are useful, all network assets entail some level of market risk: prices may fluctuate, and returns are not guaranteed. With blockchain, it is now possible to represent network assets, such as spectrum slices, physical infrastructures, or service rights, as *tokenized network resources* [107]. These resources can be divided into smaller units, traded, or leased in digital marketplaces, facilitating transactions and lowering entry barriers for new market participants.

However, tokenization also exposes investors to volatility and market uncertainty, as token values may fluctuate due to changes in demand, regulations, or technological developments. Modeling these concerns using stochastic processes, such as geometric Brownian motion [108], which captures continuous price variability driven by market demand, and jump-diffusion models [109], which capture sudden shocks like regulatory changes or unexpected large-scale outages, helps estimate risks and guide investment strategies.

Network slicing and NN. While network slicing enables differentiated services, it must coexist with NN principles, which are *a priori* in contradiction. On the one hand, when slicing allows operators to dedicate resources to specific use cases, NN requires that similar traffic flows be treated equally. A possible reconciliation lies in a class-based slicing model, which can be developed using queuing theory [110] and incentive-compatible mechanisms [102]: the principle is to organize applications into classes with similar (pre-established) quality requirements and to serve these classes using separate slices.

For example, *low-latency* slices could serve interactive applications such as cloud gaming or augmented reality, *high-throughput* slices could accommodate video streaming, and highly reliable but *low-bandwidth* slices could support IoT monitoring or emergency communications. Only the requirements relevant to each slice are considered, with similar flows treated equally. This should lead to higher user satisfaction (in terms of QoE) and greater benefits for providers (in terms of business opportunities), while also meeting regulatory fairness objectives.

In this way, research can contribute to reconciling user QoS requirements with policy constraints and provider profitability.

D2C models in terrestrial–non-terrestrial cooperation. The integration of terrestrial networks (RAN) with Non-Terrestrial Networks (satellites, HAPS) introduces complex challenges in coordination and resource sharing (spectrum and satellites), as well as in collaboration between MNOs and NTNPs. To address these issues, cooperative game-theoretic approaches [111] (e.g., Shapley value, Nash bargaining) and optimization methods [112] (deterministic, stochastic, multi-objective) can be employed to design fair revenue-sharing mechanisms, efficient cost-allocation strategies among all stakeholders, and effective resource allocation.

For example, cooperative models can support the determination of how MNOs and NTNPs share spectrum access fees in joint deployments, or how satellite backhaul capacity should be adjusted in real time under conditions of terrestrial network congestion. These models ensure profitability and service continuity across heterogeneous infrastructures, particularly in scenarios with limited terrestrial coverage, such as rural areas, maritime zones, or disaster recovery contexts.

BMs for 6G private networks. Private 6G networks are expected to play a central role in vertical industries such as healthcare, manufacturing, logistics, and smart campuses, enabling highly customized services with stringent performance guarantees. Research can assess viable BMs by studying revenue streams (service subscriptions, data-driven services, or premium low-latency applications), cost structures (spectrum licensing fees, infrastructure deployment, maintenance, and

energy consumption), and sustainability trade-offs (the carbon footprint of dense deployments and the use of renewable energy sources).

For instance, in manufacturing, private 6G networks could support digital twin-based operations and collaborative robotics, while in logistics, they could enable real-time fleet tracking and dynamic route optimization. The goal is to ensure tailored strategies that maximize revenues, ensure compliance with regulatory and environmental requirements, and also guarantee that private 6G networks are economically viable.

Analyze the impact of new actors. We have highlighted emerging actors in various network-based markets. A key challenge is to study and model the relationships with established actors. A typical example is the impact of tower companies: by providing passive network infrastructure (e.g., towers, sites, and energy supply), they lower entry barriers for new service providers and can alter the balance of power vis-à-vis MNOs. The presence of these actors can influence the outcome of market interactions, particularly when resource sharing (e.g., co-location models, spectrum pooling, or neutral host models) is allowed [71, 72, 113].

This raises important research questions: Should such practices be mandated through regulation, and if so, to what extent? How can mechanisms be designed to fairly allocate resources, prevent anti-competitive behavior, and at the same time encourage innovation? Understanding the impact of these emerging actors requires models that capture the interplay between cooperation and competition, while accounting for economic efficiency and policy objectives.

Strategies to optimize network management in terms of energy and encourage good practices. With the increasing awareness of the need to reduce carbon emissions, there is strong interest in modeling and analyzing novel techniques that align the energy consumption of next-generation networks with the growing share of variable renewable energy sources in electricity production. This can be achieved through QoS modulation (e.g., adjusting service levels during periods of energy scarcity) [114], dynamic pricing incentives [115] (e.g., encouraging operators to align their consumption with green energy availability), and the introduction of regulatory mechanisms across the markets described in the previous section.

For example, MNOs could schedule non-critical tasks such as software updates or data backups, during periods of abundant renewable generation, or temporarily reduce bandwidth for delay-tolerant applications during supply shortages. At a broader level, market mechanisms could reward stakeholders that demonstrate energy-efficient practices [116] or penalize excessive carbon use. Such approaches not only contribute to climate objectives but also create opportunities for cost savings and new sustainability-oriented business model

Customized security in network slicing. SecaaS can be built from network slicing by enabling MNOs to collaborate closely with TSPs. Instead of applying uniform security mechanisms across all services, policies can define the appropriate level of security for each slice. For instance, this can be achieved by differentiating the level of safeguards for healthcare data or financial services from lighter protection for entertainment services.

Revenue sharing models can ensure that both MNOs and TSPs benefit when higher levels of security are offered [117]. For example, slices with advanced security features could be priced at a premium, with additional revenue shared between TSPs and MNOs. These models ensure that all stakeholders benefit: MNOs can offer trusted services , while TSPs are rewarded for delivering stronger protections.

In this way, security is no longer merely a compliance requirement, but evolves into a value-added service [118] that builds user trust, creates new business opportunities, and enhances the resilience and profitability of next-generation networks.

Platform-centric BMs for 6G. In the 6G era, platform-centric business models are likely to become significantly more important, as networks move beyond providing connectivity to orchestrating entire ecosystems. Rather than merely delivering access, platforms can create multi-sided platforms where multiple stakeholders (e.g., MNOs, NAPs, CPs, and others) interact. The platform acts as a hub, offering not only connectivity but also services such as data analytics, edge computing, and AI-driven orchestration.

Analyzing platform-centric BMs [119] requires understanding how value is created and shared. At the same time, this raises important questions regarding governance, fairness, and regulation, including platform control, profit allocation, and the prevention of monopolistic behavior [120]. These platforms benefit from network effects: the more participants join, the more valuable the ecosystem becomes; however, they also require careful design to maintain interoperability, trust, and long-term sustainability.

7. Conclusion

This paper has analyzed the evolving economic dynamics of 5G and 6G networks, focusing on service classes, enabling technologies, and the shifting roles of key actors across technical and market layers. We show that 6G is not merely a technological enhancement but introduces a structural transformation in how digital infrastructures are monetized, accessed, and governed. Unlike in 5G, where MNOs remained central, 6G brings increased participation of NTNPs, NAPs, and TSPs, which creates a more disaggregated and multi-tenant economy. This shift challenges existing pricing, investment, and coordination models.

New economic paradigms are emerging through decentralized service provisioning, programmable infrastructure, and intelligent agents supporting operational and economic decision-making in real time. These developments raise critical questions regarding pricing mechanisms for programmable resources, platform competition, governance of AI-enabled decision-making, and secure, transparent inter-operator coordination. Regulatory frameworks must evolve to address not only traditional issues such as fair competition, but also emerging challenges including AI accountability, spectrum and compute resource sharing, and market concentration in orchestration platforms.

Our analysis underlines the need for future research in several directions: (i) designing distributed, incentive-compatible mechanisms for resource allocation; (ii) understanding the economic implications of delegation to AI agents in network operations; (iii) modeling decentralized economic coordination through tokenization of network resources; and (iv) examining how sustainability goals reshape cost structures and pricing strategies in 6G infrastructure. Addressing these challenges is critical to realizing 6G's potential as a trustworthy, inclusive, and economically viable digital ecosystem.

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Conflicts of interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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