IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 4 August 2022, accepted 17 August 2022, date of publication 8 September 2022, date of current version 15 September 2022.
Digital Object Identifier 10.1109/ACCESS.2022.3205011

SURVEY

5G Business Models for Mobile Network Operators–A Survey

LAURENCE BANDA[1], MJUMO MZYECE[1], AND FISSEHA MEKURIA[1,2]
[1]Wits Business School (WBS), University of the Witwatersrand, Johannesburg 2000, South Africa
[2]Council for Scientific and Industrial Research (CSIR), Pretoria 0001, South Africa

Corresponding author: Laurence Banda (1855961@students.wits.ac.za)

ABSTRACT Emerging Fifth-generation (5G) mobile networks and associated technologies are expected to provide multi-service wireless applications with diverse specifications intended to address not only consumer-based smartphone applications, but also the needs of various vertical industry markets (e.g., healthcare, education, energy, mining, agriculture, manufacturing, and so forth). This paper extends 5G networks' technology orientation towards attaining economic value for all key 5G stakeholders, including customers, mobile network operators (MNOs), equipment vendors, public institutions, private enterprises, digital business start-ups and other third parties. Although several surveys and tutorials have discussed business models in connection with 5G networks, there is no comprehensive study on business models for emerging 5G networks from the MNO's perspective. In this survey article, we present and investigate key advances on business models for 5G networks and 5G MNOs in particular, from industry, use cases and research community perspectives. The paper focuses the theoretical business model concept from both strategic management and technological innovation perspectives. Thereafter, we discuss conventional business models for MNOs before presenting particular disruptive business models which can be considered for rolling out 5G networks with an aim to improve business efficiency. Additionally, the paper explores the emerging network deployment concept of private 5G networks and their related business models. Finally, we present some of the open research challenges and provide possible guidelines for implementing 5G business models based on various countries' socio-economic status and relevant 5G use cases applicable in a specific context of emerging economies.

INDEX TERMS 5G, business model, business model innovation, disruptive business model, mobile network operators, private 5G networks.

I. INTRODUCTION

The Fifth-generation (5G) of mobile networks have been defined by the International Telecommunication Union (ITU) via its Radio-communication sector (ITU-R) under the umbrella name "International Mobile Telecommunication-2020" (IMT-2020) to support multi-service wireless applications by offering: higher data rates (20 gigabits/second peak data rate), a huge number of wireless connections (1 million connections per square kilometer), higher spectral efficiency (3 times higher than 4G networks), improved energy efficiency (100 times higher than 4G networks) and reduced communication latency (1 millisecond air interface transmission delay) [1]. Additionally, the 3rd Generation Partnership Project (3GPP) has played a pivotal role in the technical standardization of 5G technologies [2], [3]. Fig. 1 shows the enhancement of eight key performance capabilities from 4G (IMT-Advanced) to 5G (IMT-2020). According to [1], some of the capability parameters in Fig. 1 are targets aimed for research and investigation in the realm of IMT-2020 and expected to be further developed in future releases of ITU-R Recommendations.

Wireless cellular networks have been evolving since the 1980s and continue to introduce new network technologies addressing new use cases every subsequent decade including: First-generation (1G) analogue-based systems

The associate editor coordinating the review of this manuscript and approving it for publication was Nurul I. Sarkar.

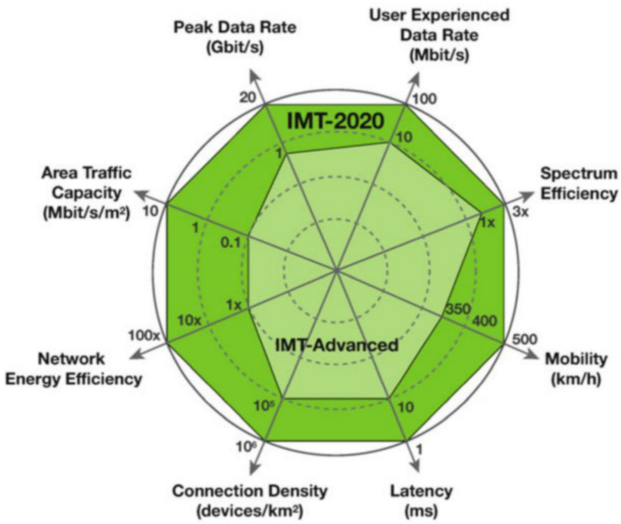

FIGURE 1. Enhancement of key capabilities from IMT-Advanced to IMT-2020 [1].

(e.g., Advanced Mobile Phone System (AMPS) and Total Access Communication System (TACS)); Second-generation (2G) digital systems (e.g., Global System for Mobile Communication (GSM)); Third-generation (3G) digital systems (e.g., Universal Mobile Telecommunication System (UMTS)); Fourth-generation (4G) digital systems (e.g., Long Term Evolution (LTE) - IMT-Advanced); and emerging 5G digital systems (e.g., New Radio) [4]. Fig. 2 depicts the evolution of wireless cellular networks.

A. MOTIVATION

With the standardization process of 5G technologies complete [2], [3], and commercial global deployment already underway, it is estimated that close to 65% of the global population will gain access to 5G superfast Internet access by the end of 2025 [5]. The current decade has already seen an exponential rise in mobile data traffic due to applications such as multimedia services, online gaming, high-definition video streaming, and mobile virtual reality. Moreover, the outbreak of the COVID-19 pandemic has spurred enormous demand for virtual interactions via video application platforms such as Zoom and Microsoft Teams, resulting in a gigantic rise in mobile data traffic. Furthermore, [6] predicts that by 2025, there will be 8.2 billion people on the planet and 100 billion connected devices, generating 180 zettabytes of data annually.

The vision for 5G networks is not only technology-oriented but is also focused on the creation, delivery and capture of business value for all key stakeholders such as customers, mobile network operators (MNOs), equipment vendors, device manufacturers, industry players and other third parties. From the business perspective, in order for 5G networks to be successfully deployed, there is a need for commercially viable and sustainable business models that can support the targeted vertical markets which include; healthcare, automotive, media and entertainment, agriculture, transportation, and public safety [7]. Moreover, successful and executable business models are likely to be the ones that can best address the economic disruptions and peculiarities underlying 5G wireless networks [8].

The business model concept can be approached from various angles including: strategic management which connects the business model concept with the company's business strategy [9]; organizational theory which focuses on the company's design, structure and architecture [10]; and technological innovation which views a business model as a technique that links a company's innovative technology to customers' needs [11]. This survey paper approaches the business model concept from two research perspectives: (1) strategic management by focusing on value proposition, value creation, value delivery and value capture activities within the 5G value chain; and (2) technological innovation by considering 5G networks as technology enablers for innovative 5G business models.

B. COMPARISONS AND MAIN CONTRIBUTIONS

Driven by the recent advances of wireless networks and business models, some research efforts have been made to review related works. Specifically, value creation and capture from technology innovation has been substantially outlined in [12]. The paper focuses mainly on 6G business models, although it does provide a comprehensive high-level summary of literature related to 5G and 6G business models as well as 3G and 4G business models. An in-depth review on 5G networks has been discussed in [13]. The article provides a detailed summary of 5G business models, use cases and cybersecurity. The study further, presents computer simulation methods and testbeds for the research and development of potential 5G network proposals. However, the work in [13] only addresses business models based on network slicing technology. A comprehensive survey in [14] discusses emerging trends in 5G techno-economic literature. The survey identifies six key topics for 5G techno-economic assessment (5G TEA) which include: use cases; technologies; modeling techniques; financial metrics; business models; and special focus. Nonetheless, authors in [14] only focused on theoretically formulated business models without incorporating the practical implementation aspect arising from the industry (e.g., MNOs, vertical markets, private 5G networks and regulatory policies). In [15], 5G slicing operational business models have been detailed. The discussed business models specifically target Internet of Vehicles (IoV) applications as well as Internet of Things (IoT) for maritime vertical applications.

Our survey is unique and complementary to current survey and review articles in that: (i) it goes in-depth and focuses exclusively on the 5G business models for MNOs in particular; (ii) it systematically highlights some of the key research issues related to specific aspects of 5G business models for MNOs; and (iii) it considers some of the key issues and implications outside the mainstream 5G markets, i.e., in emerging markets and developing countries context.

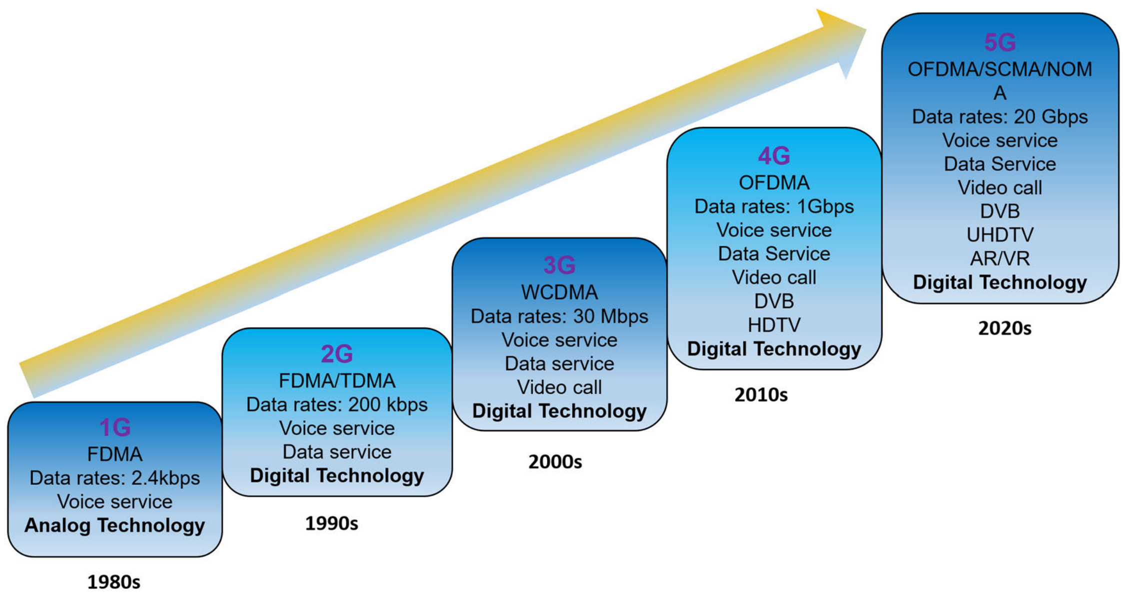

FIGURE 2. Wireless cellular networks evolution (1G to 5G).

Moreover, the fact that our survey paper incorporates both peer-reviewed and industry-based literature makes a unique contribution in comparison to other reviews.

This survey article explores and outlines the contemporary research progress which has been made on business models for emerging 5G networks and 5G MNOs. The main contributions of this paper are as follows:

i) Firstly, to put the paper in its technical context, we present an up-to-date overview of 5G technology, including the 5G network architecture, deployment modes, main service classes, key enabling technologies, and public and private 5G networks.
ii) We describe 5G global economic impacts, opportunities and benefits by highlighting the following critical aspects: the mobile industry's business goals for 5G networks; 5G market readiness; 5G economic benefits and investment opportunities; 5G global commercial deployment; 5G adoption strategies which MNOs can employ; and the impact of regulation on 5G deployment.
iii) We outline the theoretical aspects of the business model concept and their application to 5G networks. In addition, MNOs' current business models and their shortcomings are explained.
iv) Disruptive business models emanating from emerging 5G networks are explored. Additionally, several proposed business models for 5G MNOs as well as business models for the emerging private 5G networks are outlined.
v) The concepts of network slicing, digital platforms and industry verticals are discussed in the context of 5G business models.
vi) Lastly, we present open research challenges which will pave way for future research.

C. STRUCTURE OF THE SURVEY

The remainder of the article is organized as follows:

Section II presents an up-to-date overview of 5G wireless networks with respect to the 5G network architecture, use cases, key technologies, and public and private 5G networks. Section III describes the global economic impacts, opportunities and benefits in the 5G era by focusing on 5G market readiness, deployment status, adoption strategies, and impact of regulation on 5G deployment. Section IV discusses the theoretical concepts of business models, while Section V explains the existing business models of MNOs alongside the shortcomings of such business models. Section VI explores disruptive business models for emerging 5G networks and Section VII outlines several proposed 5G business models which MNOs can consider as well as business models for emerging private 5G networks. Section VIII narrates some of the key open research challenges which will form the basis for future research work. Section IX concludes the survey article.

II. OVERVIEW OF 5G WIRELESS TECHNOLOGIES

Emerging 5G networks are more than just an enhancement to current 4G networks. The 5G network is designed to meet the unique service requirements of specific vertical markets. Additionally, 5G networks should be accessible via various approaches, such as simultaneous use of licensed and unlicensed bands, intelligent spectrum management, and 5G New Radio (NR) to enable a range of different smart applications [16], [17], [18].

A. 5G NETWORK ARCHITECTURE

With the 5G requirements of sub-millisecond latency and the bandwidth limitations in conventional wireless spectrum, cellular networks in the 5G era are poised to shift towards cloud and edge computing technologies [17]. This can be achieved by the addition of applications implemented at the fundamental network level to fulfil user requirements. Thus, to meet the demands of the end-users and overcome the challenges that have been put forward in the 5G system, a drastic change in the strategy of designing 5G wireless networks is necessary [18]. The emerging 5G and beyond networks will be made up of heterogeneous radio cells consisting of high-powered large cells (e.g., macro cells and micro cells) for outdoor coverage extension as well as low-powered small cells (e.g., pico cells and femto cells) for capacity enhancement for both outdoor and indoor hotspots [19]. Fig. 3 illustrates the 5G cellular radio network architecture.

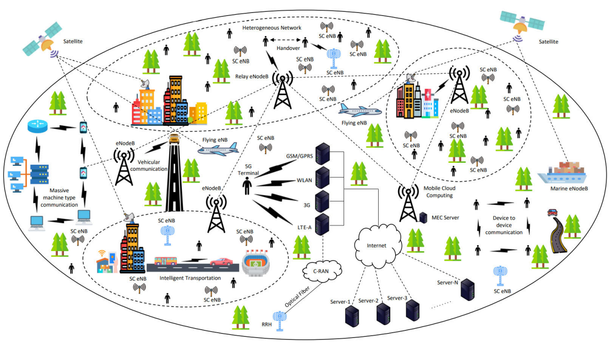

FIGURE 3. 5G radio network architecture.

B. 5G NETWORK DEPLOYMENT MODES

There are two main networking solutions, i.e., deployment modes, for 5G as defined by the 3GPP [2], [3]: the *Non-Standalone (NSA)* solution, which combines LTE and 5G New Radio (5G NR) access networks with the 4G evolved packet core (EPC); and the *Standalone (SA)* solution, which is based on the 5G NR access and the new 5G core network (5GC) running in parallel with the existing LTE network [20], [21].

1) NON-STANDALONE (NSA)

The existing LTE radio access network (eNodeB) is used as an anchor to the 4G core network (EPC) for the mobility management support of the 5G NR access network. This solution mainly focuses on eMBB services and enables operators to provide 5G services within short deployment timeframes and at a lower deployment cost.

2) 5G STANDALONE (SA)

The SA solution is a complete end-to-end (E2E) 5G network architecture consisting of the 5G NR access and the 5GC. Network slicing, virtualization, ultra-high data rates, ultra-low latency, and large data computation capability is natively built into the 5GC architecture. The SA solution supports eMBB, mMTC and uRLLC service applications.

Fig. 4 shows the NSA and SA 5G network deployment modes.

C. 5G SERVICE CLASSES

Mobile communications networks were initially designed for human-to-human communication to provide voice and data transmission [22]. However, in the 5G era, an extensive range of new and unique vertical industry markets have emerged [23]. To address the diverse vertical industries' technical demands for 5G wireless networks, the IMT-2020 vision has defined three main 5G use cases: enhanced mobile broadband (eMBB) (for ultra-high throughput applications); massive machine type communication (mMTC) (for ultra-large connection applications); and ultra-reliable and low latency communication (uRLLC) (for ultra-low latency applications) [1]. Fig. 5 illustrates the 5G main use cases and sample applications.

1) eMBB

The need to support the explosion in mobile data traffic is arguably one of the key drivers behind 5G [24]. eMBB traffic can be considered to be a direct extension of the 4G broadband service and the key objective of the eMBB service class is to fulfil the need for ultra-high data rate transmissions [25]. This is essential for many human-oriented applications, such as virtual reality (VR), augmented reality (AR), ultra-high definition (UHD) video streaming, intelligent CCTV, virtual presence and online gaming. The growing demand for increased data rates was the main motivation for the development of previous 3G and 4G mobile broadband cellular systems. Due to a further increase in mobile data demand to support new applications like extended reality (XR), 5G networks aim to offer peak data rates of 20 Gbps, cell edge user experience data rates of 50–100 Mbps and traffic density of 10 Mbps/m^2 [1].

2) mMTC

This service class is meant to support the connection of a large number of low-rate and low-power devices, referred to as machine-type devices (MTDs), within 5G cellular networks [2], [3], [26]. According to the IMT-2020 vision, mMTC is aimed at supporting 1 million wireless devices per km^2 and 10 years battery lifespan [1]. This service class will foster the realization of the mobile Internet of Things (IoT) by providing efficient Internet connectivity. mMTC applications include smart grids (energy sector), smart cities (public sector) and smart irrigation (agriculture sector).

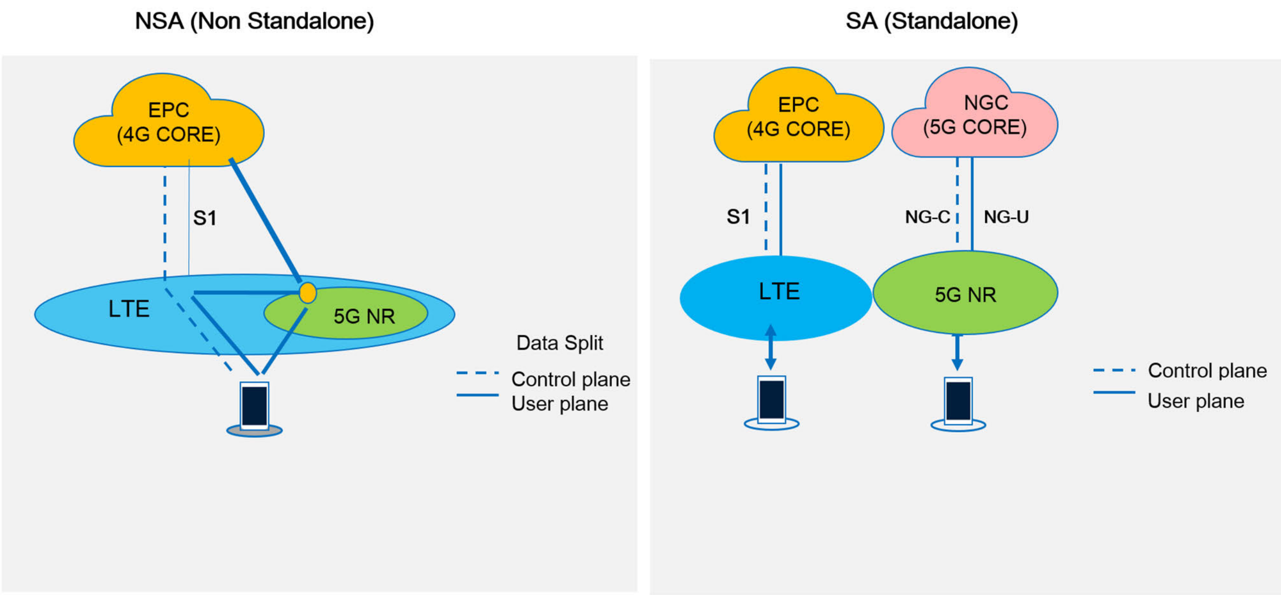

FIGURE 4. NSA and SA 5G network deployment modes.

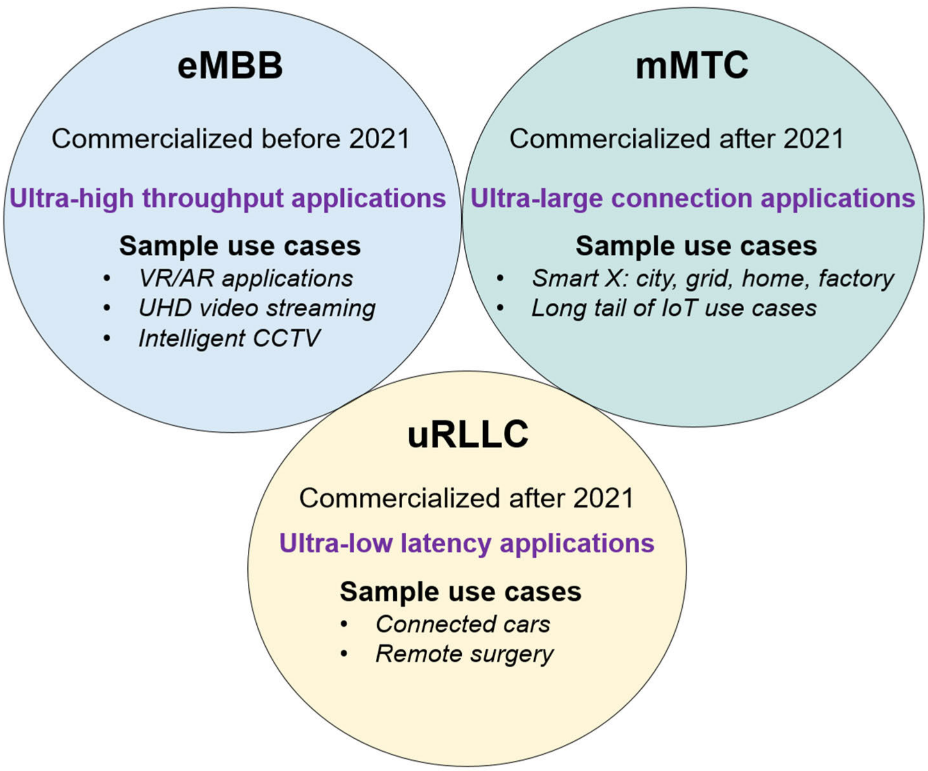

FIGURE 5. 5G main use cases and sample applications.

3) uRLLC

This service class is also referred to as mission-critical communications and requires extremely low latency (0.25–0.3 millisecond/packet) with very high reliability (99.999%) [2], [3], [27]. The uRLLC use case is essential for supporting many emerging mission-critical applications, such as industrial automation, remote surgery, robotics, drone applications and vehicular safety communications [27].

TABLE 1. IMT-2020 service class performance requirements.

eMBB	mMTC	uRLLC
Peak data rate: 10 to 20 Gbps; Minimum data rate: 100 Mbps	Supports high density of device connectivity(10^6 devices/km^2)	Provides ultra-responsive connections
Increases traffic capacity by 100 times	Supports long range and low data rate (1-100 Kbps)	Offers less than 1 millisecond air interface latency
Supports macro and small cells	Leverages benefits of ultra-low cost of M2M communication	Ultra-reliable and available 99.999% of the time
Supports high mobility of about 500 km/h	Ensures a battery life of 10 years for IoT	Provides low to medium data rates (50 Kbps - 10 Mbps)
Improves network energy savings by 100 times	Provides asynchronous access	Offers high speed mobility

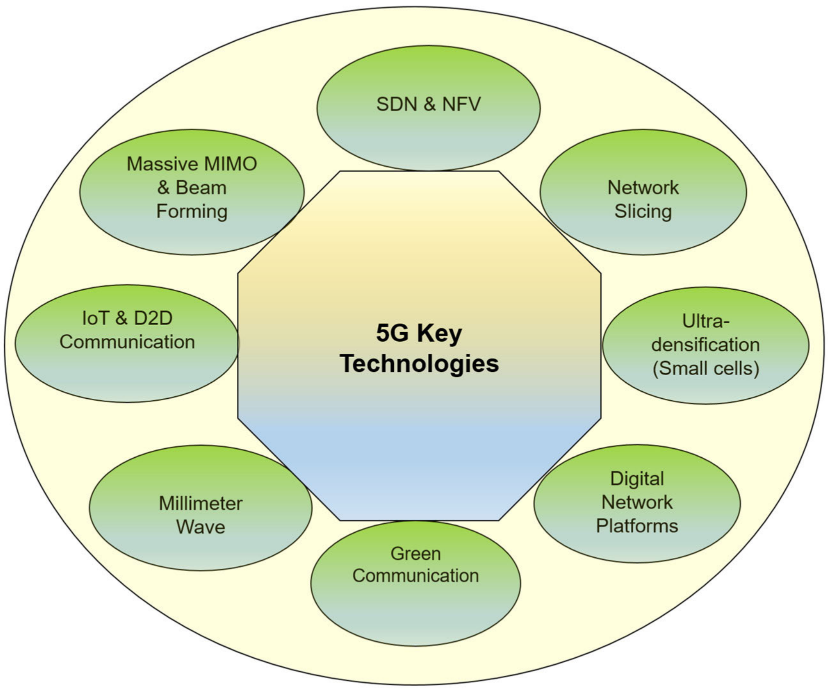

FIGURE 6. 5G key enabling technologies.

The IMT-2020 service class performance requirements are summarized in Table 1.

D. 5G KEY ENABLING TECHNOLOGIES

As a multi-service network technology, 5G needs to be accurately designed in order to provide enough flexibility to meet all the diverse requirements of the expected applications in an efficient and cost-effective manner [28]. A variety of emerging technologies are projected to be the key enablers for 5G networks. New air interface access techniques, higher-order modulation/demodulation schemes, complex channel coding algorithms and new radio frequency (RF) spectrums underpin the development and standardization of 5G key enabling technologies [29]. The technical capabilities and performance of 5G mobile networks transcend those of the existing 4G networks [1], [2], [3]. These next-generation mobile networks provide significantly higher capacity and support different types of emerging industrial applications that have stringent network quality of service (QoS) and end-users quality of experience (QoE) requirements [29], [30]. Fig. 6 summarizes the 5G key enabling technologies.

1) SOFTWARE DEFINED NETWORKING (SDN) AND NETWORK FUNCTION VIRTUALIZATION (NFV)

The previous commercial wireless broadband networks (i.e., 3G and 4G) were inherently hardware-based and relied on closed inflexible network architectures [31]. Software Defined Networking (SDN) is the separation of the control plane (signaling messages) from the user plane (data/traffic messages), thereby offering efficient and flexible resource management [32]. It guarantees MNOs with the flexibility to manage and control their networks with programmable software interfaces – called Application Programming Interfaces (APIs) – and allows for cloud network control and optimization.

Network Function Virtualization (NFV) is a crucial enabling technology for emerging 5G networks which offers an efficient platform for network providers and users to optimize resource utilization [33]. According to [32], NFV is the process of shifting functionalities such as load balancing or intrusion detection from integrated generic hardware to software components known as virtual network functions (VNFs). The key benefits of NFV include: simplified network functions, efficient installation and automatic upgrades. Moreover, NFV greatly reduces capital expenditure (CAPEX) required to buy hardware devices and saves operational expenditure (OPEX) by aggregating resources for VNFs that run on a centralized server pool [34].

SDN and NFV are complementary concepts that enable virtualization of the entire network functions that were initially tied to hardware to efficiently run on cloud infrastructure. However, the pitfall of such a network scenario is the exposure of the network functions to security threats. 5G network security is thus a crucial component in many critical network applications [32], [35].

2) NETWORK SLICING

Network slicing is a key technology which enables 5G and beyond networks to support composite services by transitioning from a ‘‘network-as-an-infrastructure’’ to a ‘‘network-as-a-service’’ platform [16]. According to [36], network slicing can be defined as the process of partitioning a physical network into multiple isolated logical networks (slices), each with its own service characteristics and performance requirements. Due to varying service class requirements, each network slice will require its own business model to meet its business targets in terms of economic value and profitability [37]. The 5G network slicing concept has been identified as a key driver to accelerate the creation of innovative digital businesses, and the associated service level agreements (SLAs) are aimed at enabling these digital businesses, as well as facilitating digital inclusion [38].

3) ULTRA-DENSIFICATION

Ultra-densification of the radio access network (RAN) is indispensable to efficiently support the exponentially growing mobile data traffic in the 5G era. Ultra-densification is a combination of different types of low transmit power radio sites with varying coverage radii including: femtocells (10–50 m radius); picocells (100–300 m) and microcell (250 –1000 m) [39]. Small cells are recommended for deployment in partial areas such as outdoor hotspots and indoor scenarios, thereby extending the network coverage and capacity [40].

4) MILLIMETRE WAVE (mmWave)

The rapid growth of mobile broadband traffic in the 5G epoch can be sustained via increased RF spectrum resources on the radio access network (RAN). The 3GPP [2], [3] has defined two main RF spectrum resources for 5G networks: *Frequency Range 1 (FR1)* consisting of sub-6 GHz frequencies (i.e., sub-3 GHz (e.g., 900 MHz, 1800 MHz and 2100 MHz) and C-band (e.g., 3.5 GHz and 3.7 GHz)); and *Frequency Range 2 (FR2)* consisting of millimeter wave (mmWave) spectrum (e.g., 26 GHz, 28 GHz, 39 GHz and 60 GHz) [28]. Due to the abundant availability of RF resources, the mmWave spectrum can support thousands of times more data and thus enhances capacity, as compared to the sub-6 GHz spectrum [41]. Typical applications for the mmWave spectrum include: UHD video applications, VR headsets, body scanning, 5G small cell concept, radar applications, automotive applications, medical applications (e.g., mmWave therapy) and satellite communication [42]. The disadvantage of mmWave spectrum is range limitations and possible radiation induced hazards, they are however suitable for high bandwidth and short distance communication requirement use cases.

5) DIGITAL NETWORK PLATFORMS

5G networks are expected to transform the wireless communication ecosystem from the current ‘‘network-for-connectivity’’ applications towards ‘‘network-of-services’’ applications which will be built on digital network platforms with massive data stocks/flows and complex algorithms [43]. Therefore, digital network platforms will require the application of big data techniques and machine/deep learning techniques [44]. In addition, since 5G and beyond networks are expected to disrupt the mobile ecosystem by full-scale introduction of ‘‘as-a-service’’ platforms and a shared economy approach, new entrants to the mobile market such as micro-operators, content providers, and app developers will be required to share the available resources [45]. Digital network platforms will certainly play a pivotal role in fostering the concept of a digital economy within a smart, inclusive and hyper-connected world.

6) GREEN COMMUNICATION

The rise in 5G network service applications (i.e., eMBB, mMTC and uRLLC) is accompanied by a corresponding rise in network energy consumption. Higher energy consumption may result in increased carbon dioxide (CO2) emissions within the environment which can in turn lead to harmful radiation effects to humans and other living organisms. To address the ecological and health concerns associated with the rise in CO2 levels, green communication is a key 5G technology to consider [46]. Energy harvesting technologies, which allow base stations and mobile devices to harvest energy from renewable energy sources (e.g., solar and wind) can provide green energy supply solutions to power 5G networks [47]. Furthermore, mMTC is particularly the 5G pillar use case that will benefit most from green network technology investments. Applications such as industrial IoT-based applications requiring network nodes to operate for years using green energy and energy-efficiency technologies being tested for

TABLE 2. 5G key technologies, service classes, performance targets and sample application scenarios.

5G Key Technologies	5G Service Classes	Performance Targets	Sample Application Scenarios
SDN & NFV	eMBB, mMTC, uRLLC	• Efficient and flexible resource management. • Reduced CAPEX & OPEX	• VR/AR for public service • Autonomous vehicles
Network slicing	eMBB, mMTC, uRLLC	• Improved resource utilization	• Ultra-high definition (UHD) video streaming • Real-time online gaming • Intelligent transportation system (ITS)
Ultra-densification	eMBB	• Higher data rates • Higher spectral efficiency	• Indoor and outdoor hotspots • Sport arenas • Dense urban areas
Millimeter Wave	eMBB	• Higher data rates	• Indoor and outdoor hotspots • Ultra-high definition (UHD) video streaming
Digital network platforms	eMBB, mMTC	• Massive data computation • Big data computation	• Smart meters • Smart grids • Traffic monitoring
Green communication	eMBB, mMTC, uRLLC	• Low CO_2 emission • Improved network efficiency	• e-health • Remote surgery • Smart factories
IoT & D2D communication	mMTC	• Large number of device connectivity	• Smart cities • Smart grids
Massive MIMO & Beamforming	eMBB	• Higher data rates • Coverage enhancement • Capacity maximization	• High rise buildings • Rural and sub-urban areas

5G networks [48], [49]. Other energy efficient mechanisms to attain green communication have been proposed in [34]. These include; power control and optimization in green communications, energy efficient hardware, energy efficient network architecture, and battery technology enhancements.

7) INTERNET OF THINGS (IoT) AND DEVICE-TO-DEVICE (d2d) COMMUNICATION

IoT technology envisions millions of simultaneous connections involving a variety of devices, automated machines, connected homes, smart grids and smart transportation systems [17]. IoT enables Internet connections and data interoperability for numerous smart objects and applications [50]. In traditional cellular networks, much of the wireless communication occurs between the base station and the device. The use of IoT in 5G networks has been triggered by emerging technologies such as device to device (D2D) communication [51] and machine to machine (M2M) communication [52]. D2D communications for 5G-enabled IoT applications can been employed in smart city development for the purpose of waste management, traffic management, water supply management, criminal tracking and environmental pollution monitoring [51], [53].

8) MASSIVE MIMO AND BEAMFORMING

Massive multiple-input multiple-output (MIMO), also referred to as full-dimension MIMO, is one of the key enabling technologies which has been standardized by the 3GPP aimed at increasing data throughput (particularly for cell edge users) and maximizing spectral efficiency [2], [3], [54]. Massive MIMO refers to a technology feature where base stations are equipped with antenna arrays consisting of a large number of antenna elements [55]. Massive MIMO increases costs and energy consumption of 5G network and end-user devices, hence it is always a compromise of technologies which is under consideration [56]. Conversely, the application of massive MIMO alongside beamforming (i.e., directionality of the propagation beams) ensures that cell edge coverage and capacity are enhanced. Additionally, beamforming increases the energy efficiency of the signals due to the formation of narrow beamwidths [57].

Based on the 5G key enabling technologies and the 5G service classes which have been presented in this article, Table 2 gives a summary of the 5G key enabling technologies in relation to the service classes, performance targets and sample application scenarios.

E. 5G DEPLOYMENT PHASES

5G networks are not just the next incremental update to the existing 4G communication standards. The services and network quality of service (QoS) expected from 5G networks rely on the seamless integration of many different elements such as 5G ecosystem partners, use cases, key technologies and performance measurement metrics [58]. Therefore, innovative and rigorous testing is crucial at every phase of 5G deployment, if MNOs are to ensure delivery of consistent

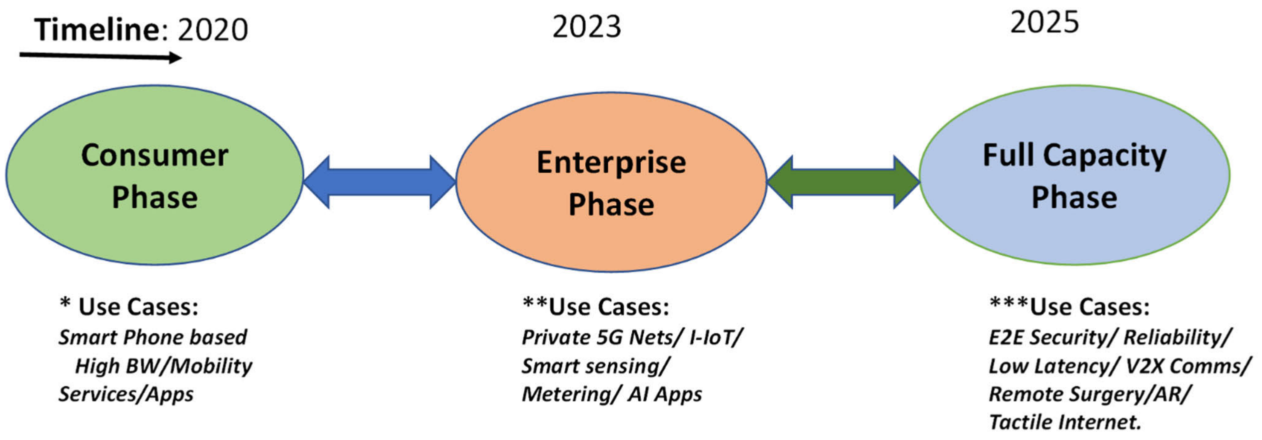

FIGURE 7. Possible 5G deployment phases.

performance that both applications and users demand [59]. However, the inherent complexity of 5G networks presents a number of challenges in the deployment process.

The 5G Alliance for Connected Industries and Automation (5G-ACIA) organization ensures that the interests and particular aspects of the industrial domain are adequately considered in 5G standardization and regulation. 5G-ACIA has been actively involved in promoting multiple industrial business applications for 5G and publishing white papers around them [60]. Fig. 7 illustrates the possible 5G deployment phases based on the examples of 5G connected and automated industries outlined by [60].

1) CONSUMER PHASE

The initial phase of 5G deployment which took place in 2020 and was more focused on individual end-users' smartphone-based eMBB throughput-sensitive applications.

2) ENTERPRISE PHASE

The second phase of 5G deployment and is likely to occur by 2023. It will focus on 5G small and medium enterprises. Sample use cases include: private 5G networks such as micro-operators; Industrial IoT, smart sensing such as smart grids, AI based applications and so forth.

3) FULL CAPACITY PHASE

The final deployment phase to be realized by 2025 and will incorporate eMBB, mMTC and uRLLC use cases. Moreover, end-to-end network security guarantees will be critical to 5G networks in this final phase of deployment. In this phase, all the vertical industry markets will be fully supported. These will range from financial institutions, educational institutions, government institutions, corporates institutions and many others

F. PUBLIC AND PRIVATE 5G NETWORKS

1) PUBLIC 5G NETWORK

A public 5G network is one where the MNO owns and operates the spectrum and the network infrastructure. In addition, generally all of the MNO's customers (apart from emergency or public safety organizations) have the same access rights to the network [61]. In a public 5G network, the management of services, infrastructure, technologies, value added services (VAS), and subscription charges are the responsibilities of the MNO. A MNO can be described as a licensed telecommunication company that owns and operates the network spectrum and infrastructure, delivers voice and data services to subscribers, provides devices, and controls the billing systems for the customers' usage [62].

2) PRIVATE 5G NETWORK

A private 5G network is a dedicated local area network with enhanced communication characteristics, unified connectivity, optimized services, and customized security within a specific area [63]. With private 5G networks, private organizations own, operate, or have some level of priority access to the network's infrastructure or spectrum. The amount of network infrastructure and spectrum owned and operated can vary greatly [64].

Private 5G networks are envisaged to offer agile solutions to effectively deploy and operate services with rigorous and diversified constraints in terms of availability, reliability, latency, re-configurability and re-deployment of network resources as well as issues related to governance and ownership of 5G network components and elements [65]. Non-public 5G networks are private 5G networks that are deployed for the sole use of a given business-to-business (B2B) customer such as a vertical [66]. Non-public 5G networks can be deployed in a wide variety of forms, depending on the vertical use cases to be supported as well as the established regulatory framework [67].

a: PRIVATE 5G NETWORK DEPLOYMENT MODES

Depending on spectrum and infrastructure availability as well as the level of network management and access control, private 5G networks can be deployed as either stand-alone (independent) mode or public network integrated (dependent) mode.

TABLE 3. Comparisons between public 5G and private 5G networks.

Comparison Item	Public 5G Network	Private 5G Network
Network accessibility and usage	• Everyone (i.e., consumers and businesses)	• Customized for specific organizations / enterprises
Coverage area	• Wide area network coverage (e.g., city, state, province or country)	• Limited to one specific locale (e.g., university campus, factory or hospital)
Spectrum options	• Licensed spectrum • Unlicensed spectrum	• Leased/rented spectrum • Dedicated private spectrum • Unlicensed spectrum
Service offering	• Diversified	• Specific
Network accessibility	• Less restricted	• Highly restricted and fully controlled
Deployment and operational costs	• High	• Independent private 5G: High • Dependent private 5G: Low
Network management and Maintenance	• Carrier MNO	• Independent private 5G: Organization/enterprise • Dependent private 5G: Carrier MNO

Stand-alone: A private 5G network is deployed as an isolated and independent system without relying on a public 5G network [63]. According to [68], in the stand-alone deployment mode, the 5G private network has the following characteristics: its own unique identifier, independent of the public network; the private 5G network is assigned its own spectrum resources; and a complete deployment of end-to-end 5G system (radio access, transport and core network domains) logically exists.

Public network integrated: A private 5G network is deployed anchored on the public network and thus, has lower customization, self-control, and security when compared with the stand-alone mode [63]. The public network integration mode can further be divided into following three categories [69]: (i) *Shared RAN* - where the private 5G network and the public network share part of the radio access network (RAN) while other network domains such as the core network remain separated, and all data flows of the private 5G network are restricted to the local area; (ii) *Shared RAN and Control Plane* - the private 5G network and the public network share part of the RAN and the network control tasks (signaling management) is implemented in the public network; and (iii) *Hosted by the Public Network* - the private network is entirely hosted and managed by the public network, despite regarding the two portions as parts of completely different networks in order to guarantee the isolation and independence of both portions.

b: PRIVATE 5G NETWORK SPECTRUM OPTIONS

Spectrum availability is one of the critical factors to consider when deploying private 5G networks. There are three spectrum options for private 5G networks [70].

Licensed spectrum: The MNO allocates a portion of its owned spectrum for private use by a non-public 5G network.

Dedicate private spectrum: A private 5G network obtains its own spectrum directly from the regulator, thereby enabling the private 5G network to operate independently from the public MNO.

Unlicensed spectrum: The spectrum is free of charge, thus the unlicensed spectrum option has the potential to enable the private 5G networks to expand rapidly. However, malicious jamming and external interference if not properly managed could cause service disruptions to some vertical industries [63].

Table 3 gives a high-level summary of the comparisons between public 5G networks and private 5G networks.

III. 5G GLOBAL ECONOMIC IMPACTS, OPPORTUNITIES AND BENEFITS

The information and communication technology (ICT) sector is a huge market that can stimulate the digitalization and growth of new smart industries through relevant use of emerging 5G and beyond technologies [71]. The continuous deployment of 5G networks is opening windows of opportunities for MNOs to move beyond connectivity and collaborate across vertical sectors to deliver rich new services to consumers and businesses [72]. 5G technologies will also offer an opportunity for industries, society and individuals to advance their digital skills and ambitions [73].

Despite the COVID-19 pandemic, 5G networks are being rolled out faster than expected, therefore service providers need to identify which areas to prioritise for future growth. Additionally, 5G investments, deployments and marketing efforts in most markets have been focused more on consumers, and this naturally has had an impact on 5G enterprise market potential which is yet to be fully exploited [71].

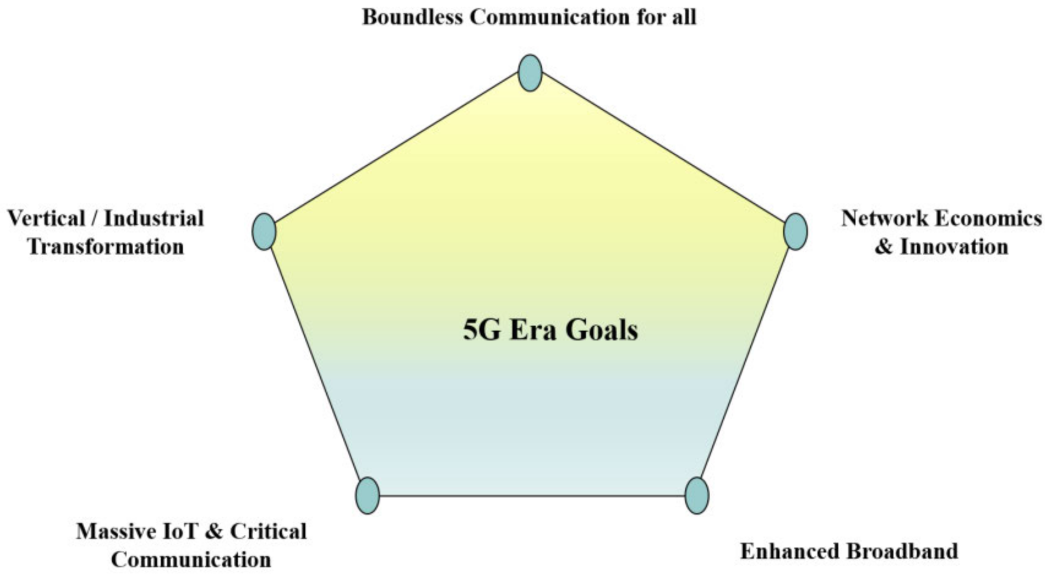

FIGURE 8. Mobile industry goals for the 5G era (source [83]).

A. MOBILE INDUSTRY GOALS FOR 5G NETWORKS

5G technologies are expected to shift the telecoms industry from a "horizontal" service delivery model, where services are defined independent of their consumers toward a "vertical" delivery model, where the provided services are tailored to specific industry sectors and verticals [74]. Additionally, 5G networks will disrupt the mobile telecommunication industry by opening the market to new entrants such as micro-operators, content providers and infrastructure owners through the expansion of the traditional mobile business ecosystem to meet vertical sector-specific requirements in a digital, smart and hyper-connected world [75].

The emergence of 5G technologies has offered a new way of enhancing economic growth in developing countries. Developing countries can tap the potential of 5G technologies by concentrating on the application layer in areas of their current economic activities [76], [77]. Additionally, tertiary education institutions are collaborating with communication companies in equipping graduates with technical expertise and entrepreneurial skills in 5G technology standards and use cases [78]. Thus, 5G could play a vital role in transforming education, including: 5G technology for AR and VR in education [79]; development of mobile applications that use VR for education [80]; sharing of online curriculum resources based on 5G and IoT [81]; and so forth. Indeed, some institutions like Obuda University in Hungary have already introduced 5G technology in their curriculum at both undergraduate and postgraduate levels [82].

According to research conducted by the GSMA [72], and as shown in Fig. 8 [83], the mobile industry has five main goals for the 5G era. These goals, which were arrived at following consultations with 750 operator CEOs in 2016/2017 and in line with the mobile industry's purpose to "intelligently connect everyone and everything to a better future" [72], are as follows.

1) BOUNDLESS CONNECTIVITY FOR ALL

Emerging 5G networks will co-exist with current 4G networks and other alternative wireless technologies to deliver fast, reliable and secure wireless services supporting a host of use cases to consumers.

2) VERTICAL/INDUSTRIAL TRANSFORMATION

5G will accelerate the digital transformation of industry verticals by providing network platforms for the digitalization and automation of industrial processes.

3) MASSIVE IoT & CRITICAL COMMUNICATION

The mobile industry envisions that during the 5G era, networks will support the large-scale rollout of intelligent IoT connections for various scenarios leading to widespread adoption of critical communication services.

4) ENHANCED BROADBAND

5G networks are aimed at transforming the end-users mobile broadband experience with data rates of up to 1 Gigabit per second and latency of less than 1 millisecond, and provide platforms for cloud and artificial intelligence-based services.

5) NETWORK ECONOMICS AND INNOVATION

In the 5G era, the mobile industry aims to cost-effectively deliver better quality networks either singly or via collaborative partnerships. This will require innovative technologies and the use of both licensed and unlicensed spectrum bands.

B. 5G MARKET READINESS

The pressure on MNOs to rapidly transition to 5G platforms and services is tremendous. However, the timing of 5G deployment is highly dependent on market readiness, and this varies by geographical markets [72]. The key factors affecting 5G market readiness for MNOs are: return on investment (RoI) on 4G networks, Fixed Wireless Access (FWA) and private industrial 5G networks [73], [83], [84]. The competitive environment going into the 5G era remains challenging in many markets globally. The competition among MNOs will remain a big 5G market force for the foreseeable future. Moreover, many operators are also increasingly competing with non-operator companies, such as TV and content services where operators have made acquisitions (e.g., AT&T's acquisition of Time Warner) as well as IoT where some operators aim to expand beyond connectivity and provide vertical solutions [85].

In addition, since telecoms is a capital-intensive industry, markets with sufficient scale can better influence the global trajectory of 5G development and are also able to achieve low unit cost of network rollout (i.e., economies of scale). These will create significant incentives for 5G deployment [72]. For example, according to the GSMA intelligence report [86], mobile operators in China and the US have higher scale than in the European Union. Thus, with sufficient scale, operators in China and the US have substantial financial capabilities to support 5G deployment and a large subscriber base, consequently reducing the cost per connection for 5G [72].

C. 5G ECONOMIC BENEFITS AND INVESTMENT OPPORTUNITIES

5G is projected to generate massive value for the global economy. This is underpinned by earlier studies conducted by the World Bank showing a strong relationship between broadband penetration and economic growth [87]. Further, the report in [88] estimates that 5G will provide key economic benefits of $22.2 trillion in global GDP and $588 billion in worldwide tax revenue cumulatively over the period from 2020 to 2034. A study by Ericsson [89] reveals that telecom operators have a potentially addressable 5G-enabled revenue opportunity of $619 billion by 2026 from ten industries: manufacturing, energy and utilities, public safety, healthcare, public transport, media and entertainment, automotive, financial services, retail, and agriculture. Another study by Huawei [90] explored the opportunities from their top-ten 5G use cases, showing for example, that there is an operator addressable market opportunity of $93 billion for Cloud AR/VR. Further studies conducted by IHS Markit [77] indicate that 5G will enable $12 trillion of global economic activities in 2035.

1) 5G KEY INVESTMENT BENEFICIARIES

The investment in 5G networks will benefit various key stakeholders in the 5G market value chain, including: *service providers* comprising traditional MNOs (primary carriers and secondary carriers like mobile virtual network operators (MVNOs)) and private service providers (such as micro-operators (μOs), content providers, platform providers, app developers and infrastructure providers); *industry partners* such as public/government institutions, private enterprises and vertical markets; and *network vendors* such as equipment manufacturers, device manufacturers and technology providers. Fig. 9 illustrates the anticipated key investment beneficiaries within the 5G market.

2) SHARE AND GROWTH RATE FOR GLOBAL 5G OPPORTUNITIES FOR SERVICE PROVIDERS

The 5G era is expected to spur digital transformation across diverse industries and sectors. By 2030, the expected industry digitalization revenues for ICT players globally across all industries are expected to amount to around $3.8 trillion, while the value in terms of investment opportunities driven by 5G across key vertical industries is expected to be around $1.5 trillion [91]. Furthermore, [71] projects that the total value of the global addressable 5G-enabled market for service providers across ten industries: manufacturing, energy and utilities, public safety, healthcare, public transport, media and entertainment, automotive, financial services, retail, and agriculture – will reach $700 billion in 2030, beyond mobile broadband. Fig. 10 illustrates the 5G-enabled revenue potential across the ten industries from the study conducted in [71].

The report in [71] has also provided the distribution of the expected 5G-enabled market opportunities for the ten industries across nine geographical regions as shown in Fig. 11. As illustrated in Fig. 11, most opportunities for service providers will occur in North America, North-East Asia and Western Europe due to huge economies of scale in those regions. Developing and emerging markets like Africa and India will have the least opportunities for service providers due to deployment challenges such as inadequate 5G network infrastructure, unavailability and unaffordability of 5G capable devices, unreliable power supply, and so forth.

D. GLOBAL 5G COMMERCIAL DEPLOYMENT

1) PROGRESS AND CURRENT STATUS

Despite the current COVID-19 pandemic and its associated economic constraints, the global commercial deployment of 5G networks has continued unabated [92]. As of April 2021, 68 countries (with 162 networks) out of the 193 UN-recognized countries in the world, had 5G networks commercially released [93]. These figures represent a Global 5G network index (i.e., the ratio of countries with commercial 5G networks to the entire countries in the world [94]) of 35%. In terms of connectivity, GSMA [95] predicts that the number of 5G connections will grow from 200 million in 2020 to 1.8 billion in 2025, thereby covering about one-third of the global population.

The GSMA predicts that Asia Pacific and Sub-Saharan Africa, the regions with the largest unconnected populations,

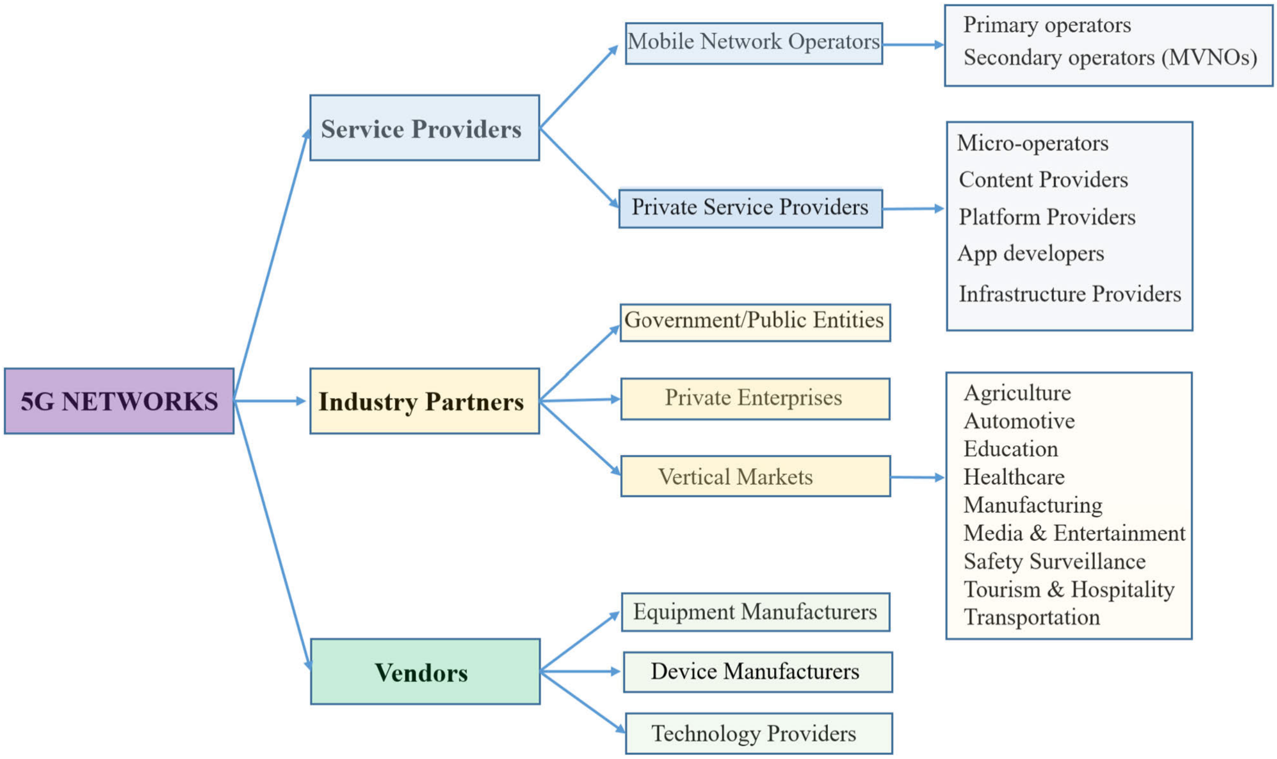

FIGURE 9. 5G key investment beneficiaries.

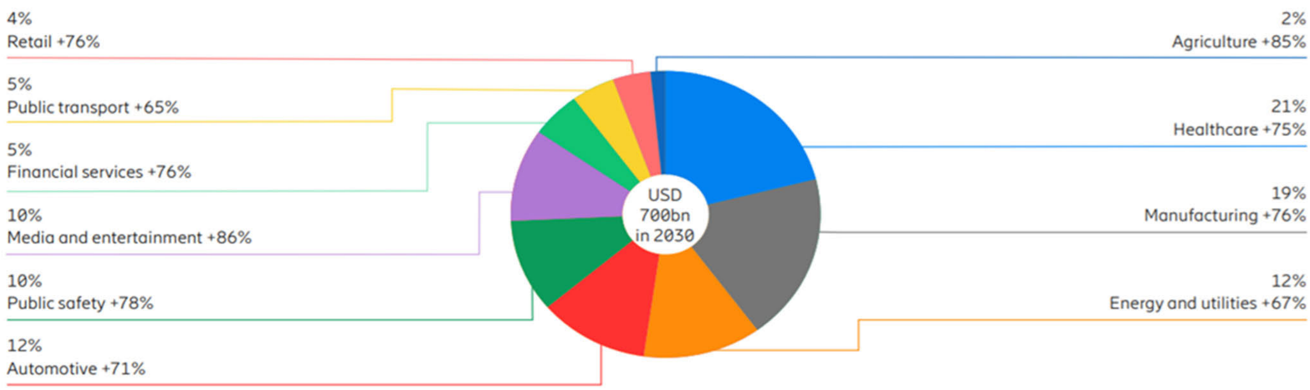

FIGURE 10. 5G-enabled revenue potential across 10 industries (Source: [71]).

will register the biggest growth in new mobile subscribers from 2020 to 2025 [86]. Nearly two-thirds of all new global mobile subscribers by 2025 will come from these two regions, with about 188 million from Asia Pacific and about 120 million from Sub-Saharan Africa [86]. With respect to global 5G connections by 2025, China alone will account for almost half (828 million) of all global 5G connections, while 5G adoption will be highest in North America and Developed Asia Pacific (Australia, Japan, Singapore and South Korea), at 51% and 53% respectively [86]. Globally, 5G adoption will average 21% of all connections in 2025, with the lowest 5G adoption being in Sub-Saharan Africa and Rest of Asia Pacific, at 3% and 5% respectively [86].

In readiness for the 5G network rollout, many MNOs have begun upgrading their existing legacy networks to multi-standard 5G-ready baseband and radio antennae which can handle multiple frequency bands. In addition, there is a need to build adequate transport (i.e., transmission, backbone or backhaul) network infrastructure mainly based on fiber. Mobile operators will also need to leverage the virtualization of network management systems through SDN and NFV, both of which are key enablers of network slicing [16], [45], [83].

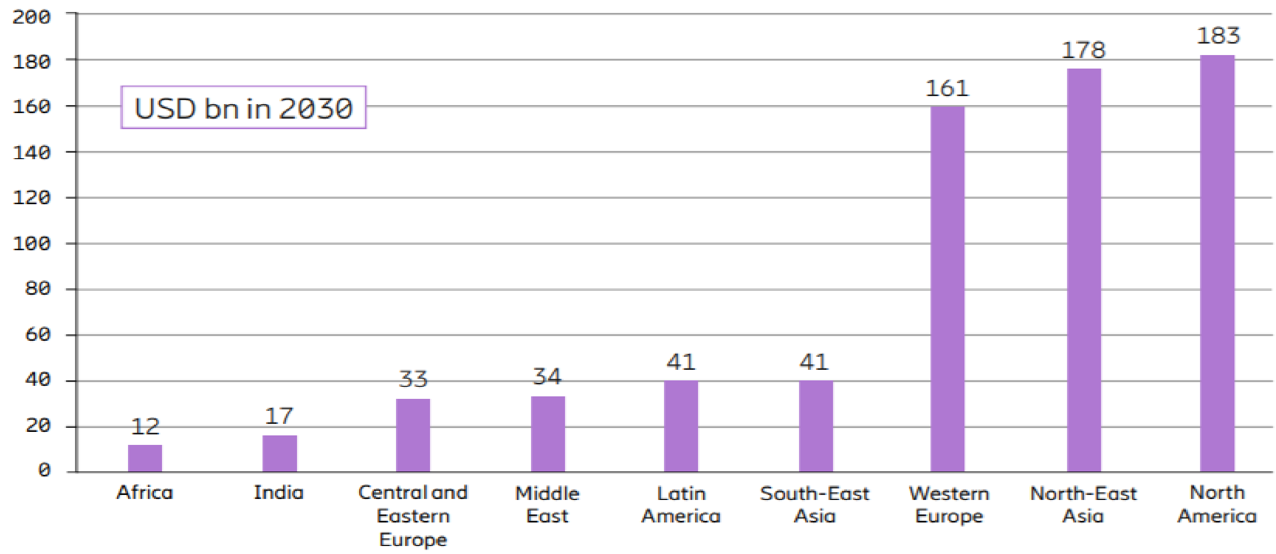

FIGURE 11. Regional distribution of the total service provider 5G-enabled opportunities across 10 industries (Source: [71]).

2) MOBILE OPERATORS' 5G DEPLOYMENT CHALLENGES

The challenges affecting the deployment of 5G networks by mobile operators are multifaceted. These challenges range from the business landscape, investment opportunities, political/governance atmosphere, and levels of technological advancement. The following are some of the challenges which have been discussed in the literature.

a: CURRENT 4G NETWORKS CAPABLE OF MEETING MOBILE BROADBAND SERVICE DEMANDS

The deployment of 5G is inevitable but not imminent in some developing regions because existing 4G technologies are capable of supporting current use cases and the demands for mobile Internet connectivity [73], [83]. Therefore, most mobile operators in such regions would rather exploit the untapped markets for 4G and maximize their ROI before upgrading to emerging 5G technologies.

b: EXORBITANT SPECTRUM PRICING

In developing and emerging markets such as Africa, Asia and Latin America, spectrum pricing has been dominated by regulations and policies that aim to maximize revenues for communication regulators. In countries like Nigeria, for instance, the spectrum prices are three times higher than in developed countries [96]. The inflated spectrum prices are influenced by various factors which are usually linked to expensive yet low quality mobile broadband services [45]. As a consequence, ROI for mobile operators is negatively affected. This can lead to reduced investment by mobile operators and higher service prices for consumers. 5G spectrum acquisition policies tend to be considered from either short-term or long-term perspectives by the regulatory authorities. Short-term considerations aim at maximizing the amount of money per spectrum band without adequate regulation, thereby promoting poor QoS, and with little or no regard for rural coverage and national technology benefits. On the other hand, long-term considerations accept lower yet reasonable amounts of money per spectrum band, while emphasizing that operators guarantee service quality and address rural coverage demands, and altogether incentivizing new services and smart industries to grow and benefit host countries.

c: UNAVAILABILITY AND UNAFFORDABILITY OF 5G CAPABLE DEVICES

Like other previous network generations, the deployment of 5G should be accompanied by 5G capable devices. However, the cost of 5G devices will remain prohibitively high for most consumers, especially in developing countries for the foreseeable future [92]. Due to the slow pace of 5G network rollout in most developing regions like Sub-Saharan Africa, the availability of 5G devices is limited as device manufacturers are skeptical with respect to making sales profits in these seemingly small markets.

d: INADEQUATE 5G NETWORK INFRASTRUCTURE

Most regions in the world, with the exception of North America, Western Europe, North-East Asia and Australia/New Zealand, have a relatively weak financial base, low human capital development and poor infrastructure including low broadband connectivity [83], [94]. These can cause potential investors' loss of confidence in deploying 5G networks in most countries.

e: LOW FIBER PENETRATION

The 5G backhaul network is predominantly supported by fiber transmission due to the low latency and higher bandwidth of optical fiber technology [97]. However, the low fiber penetration in most developing countries will be a key challenge to the deployment of 5G networks. For example, according to the report in [98], fiber penetration rate in Africa was at 10% (compared to 30%, globally) in 2017 and will only reach 15% (compared to 40%, globally) by 2025.

f: UNRELIABLE POWER SUPPLY

The energy requirements for 5G hardware equipment such as baseband units and RF components are higher than those of the predecessor technologies [1], [2], [3]. Many countries in developing and emerging regions such as Africa, Asia and Latin America are plagued by inadequate or intermittent power supply, or both. These power challenges mainly emanate from increased demand for power due to industrialization, urbanization and population growth. This has resulted in increased operators' OPEX as fuel-based generators and expensive batteries are used as backup power sources.

g: INACCURATE MOBILE SUBSCRIPTION DATA

The capturing of population data such as demographic profiles remains a challenge in most regions. Due to lack of consistent population census exercises in most countries, it is difficult for mobile operators to accurately anticipate the targeted subscriber base, resulting in inaccuracies in predicting their ROI. A prominent example is Africa, where mobile operators have tried to supplement this lack of accurate data using industry-based sources such as GSMA reports [72], [92], [98] and Ericsson reports [5], [45], [71].

h: REVENUE UNCERTAINTY

Most of the data compiled by mobile operators and industry bodies such as GSMA [92] is based on the current subscriber base (the majority of whom are urban dwellers) [76]. Thus, only limited data about the potential rural revenue opportunities is available. Moreover, based on the limited data available, it is hard for mobile operators to analyze key revenue parameters such as average revenue per user (ARPU) and subscriber adoption rate (SAR) which are critical in revenue modelling [99].

E. ADOPTION STRATEGIES FOR 5G TECHNOLOGIES

Commercial 5G networks are now operational in every region of the world, making 5G a truly global technology. However, adoption is proceeding at different speeds in different regions. As an emerging cutting-edge technology, the adoption of 5G should meet present and future needs, globally. This is critical in order to ensure that some regions are not left behind in terms of technological advancement and competences. Technologically advanced economies such as Western Europe, North America, and North-East Asia (i.e., China, Japan and South Korea) will be regarded as early-movers (pace setters) for 5G technology and have started adopting 5G through primary innovation [86]. Conversely, for developing and emerging markets which have low rates of 5G deployment and are facing the rollout challenges previously outlined, it would be appropriate to consider less advanced levels of adoption via secondary innovation [100]. Standards organizations such as the ITU and IEEE are suggesting new innovations and a scaled down version of the 5G standard meant to accelerate 5G adoption. For instance, the IEEE have developed a draft standard for a scaled down version of 5G standard known as P2061, also referred to as Frugal 5G [101]. P2061 describes a Draft 5G Standard Architecture for Low Mobility and Energy Efficient Network for Affordable Broadband Access. Frugal 5G will allow developing countries to start implementing 5G with lower capabilities and describes some of the use cases such as: basic connectivity to ICT infrastructure; economic opportunities (e.g., agriculture, small businesses and financial inclusion); human resource development and access to life-enhancing services (e.g., healthcare, education, entertainment, and support for safe water, sanitation and clean energy); and e-Governance and electronic delivery of citizen services [101].

Authors in [102] have demonstrated how latecomer firms, though disadvantaged in technological capabilities and market resources, can successfully introduce new and disruptive technologies from advanced economies into emerging economies through secondary business model innovation. With the comparatively slow pace of 5G deployment in Africa and other developing regions, mobile operators in such markets can be regarded as latecomers while operators in developed markets can be considered as first-movers for 5G adoption. As latecomers, mobile operators in developing countries will have two key advantages:

1) ADAPTING 5G IMPLEMENTATION STRATEGIES

The phenomenon of technological paradigm shifts opens a window of opportunities for latecomer operators to realize technological capabilities by importing and adapting 5G implementation strategies from developed countries.

2) COMPETITIVE POSITIONING

Operators can leverage initial competitive advantages, such as low adoption costs, to improve their competitive position within the 5G ecosystem.

F. IMPACT OF REGULATION ON 5G DEPLOYMENT

Regulation and policy makers are expected to continue playing a key role as the global 5G deployment intensifies. It is worth noting that regulatory policies may foster or inhibit the rollout of 5G networks. On a positive outlook, it is anticipated that the significant investments required for 5G deployment will be motivated by a stable, consistent and proportionate regulatory framework for all stakeholders [103].

5G has been regarded as a disruptive innovation, in that it has created new market values where new services and applications are emerging in an unexpected manner. Thus, policy makers will have to be prepared for significant challenges concerning 5G deployment in their respective countries [104]. Moreover, since the future development of 5G technologies and the related markets is open-ended, network implementation policies are being developed with incomplete knowledge and under conditions of uncertainty [105].

Regulators and policy makers should ensure that suitable spectrum is available in appropriate frequency bands, in sufficient amounts and with appropriate license conditions [103]. Maintaining a stable and predictable regulatory and spectrum management environment is critical for the long-term investments of operators into network infrastructure, innovative services and business models. The exclusive mobile licensed spectrum assignment methods will remain important for ensuring stability for long-term investments into networks and the underlying spectrum [106]. Support for a flexible and dynamic spectrum sharing and complementary heterogeneous networks, can also extend the reach and innovative potential of 5G networks [191].

5G technology has stimulated the adoption of local 5G networks within various vertical sectors [107]. Ensuring spectrum availability to these local 5G networks should be a key priority for regulators in 5G decision making as it requires adjustments to existing spectrum valuation approaches that are used as basis for spectrum assignment decisions [108]. Authors in [109] have identified spectrum management and spectrum fragmentation as key regulation issues in 5G implementation. According to [109], regulators are facing challenges in spectrum management especially for the local and specialized 5G providers such as private 5G networks and micro operators. Micro licensees might have to pay high charges to incumbent competitors in their area for backhaul or middle mile connectivity. Fragmentation of the spectrum is a challenge that it may cause interoperability problems among vendors and mobile operators and reduces the impact of 5G efforts. This should be considered in the market approach (e.g. spectrum trading) and controlled by regulators of spectrum licenses for new 5G spectrum releases to achieve a harmonized 5G spectrum [110].

Table 4 summarizes the 5G regulatory components, their roles in 5G and the associated challenges in implementing them.

IV. BUSINESS MODEL THEORETICAL CONCEPTS

Business models have been a hot topic of research in management-related disciplines for the past two decades or so. The business model concept gained popularity with the advent of the Internet in the mid-1990s, and it has become a key focus area within the research community since then [111], [112].

A. WHAT IS A BUSINESS MODEL?

Despite its extensive use in both management practice and the academic literature, the term ''business model'' lacks a formal standardized definition [112], [113], [114]. This is mainly due to the fact that diverse business models are applicable to different industry categories. Table 5 shows some selected definitions of a business model across different domains from the literature [115], [116], [117], [118], [119], [120], [121], [122], [123], [124], [125], [126], [127], [128]. In general, most of these definitions suggest that a business model articulates how a firm creates and delivers value to its customers, and how that value is appropriated. Due to the lack of a formal standardized definition of a business model, and based on the various definitions of the term in the literature, a business model in the context of this survey study is described as: ''The rationale of how a mobile network operator can create, deliver and capture value within the 5G networks' ecosystem by using interconnected elements such as customer relationships, value propositions (services), technology design, financial aspects and infrastructure management.''

B. BUSINESS MODEL RESEARCH AREAS

In their review paper, authors in [112] indicate that the business model concept has been employed to address three phenomena: e-business and use of information technology; strategic issues, such as value creation, competitive advantage, and firm performance; and innovation and technology management. The e-business phenomenon focuses on understanding the composition and structure of new Internet-based firms. Strategic issues consider: the networked nature of value creation; relationship between business model and firm performance; and distinction between business model and other strategy concepts such as product market strategy. In the innovation and technology management domain, a business model is viewed as a mechanism that connects a firm's innovative technology to customer needs [112].

On the other hand, [114] states that the three basic research streams on the business model concept are: information technology, organizational theory, and organizational strategy. The information technology context emerged from the area of management information systems [113], and the main focus of this stream is business modelling from which the business model ensues [114]. Organizational theory views a business model as an abstract representation of the company's structure and architecture [115]. The strategic management stream considers the relationship between the business model concept and business strategy and thus, views a business model as a source of information for implementing a company's strategy [114].

C. BUSINESS MODEL ONTOLOGY

A business model ontology (BMO) can be used to conceptualize, design and evaluate a business model [129]. BMOs can be regarded as standardized approaches to business models forming the theoretical basis on which business models in various fields can be developed, component by component. Currently, the most widely known and most commonly used BMO is the business model canvas which was created by Osterwalder and Pigneur [120].

Research in [130] describes a BMO as a conceptual tool that contains a set of elements and their relationships, and allows the expression of the business logic of a particular firm. Further, [130] translates four simple business pillars into four main business model blocks to make a BMO. These four pillars are: the 'what', the 'who', the 'how' and the 'how

TABLE 4. 5G regulatory components, roles in 5G and challenges.

Regulatory Component	Descriptions	Role in 5G	Challenges
Spectrum management	• Spectrum authorization granting of access rights to use frequency bands including rights and obligations (licensing models)	• New local licensing models will be needed to complement existing models to allow different stakeholders to establish local 5G small cell radio access networks with guaranteed quality.	• Spectrum fragmentation causes interoperability issues especially between public and private 5G networks.
Network access regulation	• Interconnection and interoperability requirement to allow access to infrastructure for operators (e.g., MVNO and private 5G operators) who do not own it.	• Network slicing and providing "network as a service" spans across multiple stakeholders and local 5G small cell radio access network deployments need to connect to other operator networks to ensure end-to-end connectivity	• Infrastructure owners may charge higher access fees. • Non-infrastructure owners have limited governance and management of the network.
Coverage and Quality	• Regulatory authorities should ensure that MNOs, enterprise operators, micro-operators and other service providers meet end-users coverage requirements with guaranteed quality of service (QoS).	• Network operators are encouraged to deliver more value to their existing customers and potentially new ones by contributing to cross-industry activity that benefit governments, enterprises, and consumers.	• Investment in coverage and capacity dimensioning to meet the target subscriber base can be capital-intensive for most operators. • For most MNOs, QoS guarantee is mostly focused on urban population where return on investment (RoI) is substantially higher than in rural areas.
Pricing regulation	• High quality services should be made available for end users with affordable prices. Retail and wholesale prices between operators need to be non-discriminatory and reasonable.	• Local and private 5G networks need to be allowed to connect to other networks with reasonable prices to ensure affordable prices for end users.	• Dependent local and private 5G operator tend to pay hefty connection fees to access MNOs' infrastructure. • Higher connection fees give rise to higher service prices for consumers
Competition management	• Holders of significant market power should not be allowed to abuse their dominant positions. • Incumbent and new market entrants should be treated fairly.	• Regulations should promote competition among MNOs, micro-operators and private operators to serve vertical sectors' specific needs in specific areas as well as the consumers.	• Heterogeneity among key stakeholders such as customers and partners pose a challenge for regulators to level the playing field as far as market dominance control is concerned.
Network security and user privacy	• Service providers need to safeguard the security of their services and protect the privacy and data of users as well as confidentiality.	• Role of data collection, analysis and usage will increase in 5G service provisioning which calls for regulatory actions to define rules for data ownership and exploitation.	• The massive device connectivity being championed mainly by industrial IoT is a challenge for both operators and regulators in ensuring network cyber-security and user privacy protection.
Taxation	• Network operators obliged to comply with national tax policy frameworks to avoid revocation of operational licenses.	• Regulatory authorities should ensure MNOs, micro-operators, private networks and other service providers are taxed fairly and at affordable rates to promote investment in 5G deployment	• In some countries, government regulators view taxation of network operators as their main source of revenue. This can lead to reduced investment by operators and higher service prices for consumers.

much' of a company. Specifically, these pillars allow us to express 'what' a company offers, 'who' it targets with this, 'how' this can be realized and 'how much' can be earned by doing it. The four business model pillars outlined in [130] are as follows:

1) Product (what?): What business the company is involved in, the products and the value propositions offered to the market.

2) Customer Interface (who?): Who the company's target customers are, how it delivers products and services to them, and how it builds strong relationships with them.

3) Infrastructure Management (How?): How the company efficiently performs infrastructural or logistical issues, with whom, and as what kind of network enterprise.

4) Financial Aspect (How much?): What is the revenue model, the cost structure and the business model's financial sustainability.

Nine building blocks of a business model have been identified in [131]. The building blocks are classified based on the four business model pillars discussed above [130]. Table 6 outlines the proposed business model building blocks in relation to the business model pillars. The nine business model building blocks are further elaborated by [120] and [130]:

1. *Value Proposition*: gives an overall view of a company's bundle of products and services.
2. *Target Customer*: describes the segments of customers a firm wants to offer value to, i.e., clients who are addressed by the value proposition.
3. *Distribution Channel*: describes various means the firm can utilize to get in touch with its customers as well as offer them the value proposition.
4. *Relationship*: explains the kind of links a company establishes between itself and its various customer segments.

TABLE 5. Selected definitions of a business model across different domains.

Author(s)	Business Model Definition
Al-Debei, El-Haddadeh & Avison [115]	• An abstract representation of an organization – of all core interrelated architectural, co-operational, and financial arrangements designed and developed by an organization now and in the future, including all core products and services that the organization offers or will offer, based on the arrangements that are needed to achieve its strategic goals and objectives.
Baden-Fuller & Haefliger [116]	• A system that solves the problem of identifying who is (or are) the customer(s), engaging with their needs, delivering satisfaction, and monetizing the value.
Teece [117]	• An architecture for how a firm creates and delivers value to customers and the associated mechanisms that are employed to capture a share of the created value.
Casadesus-Masanell & Ricart [118]	• The logic of the firm, the way it operates and how it creates value for its stakeholders.
Rao & Prasad [119]	• A company's plan on how it will generate revenues and make profit.
Osterwalder & Pigneur [120]	• The rationale of how an organization can create, deliver and capture value as part of the entire business strategy.
Fielt [121]	• The value logic of an organization in terms of how it creates and captures customer value and can be concisely represented by an interrelated set of elements that address the *customer*, *value proposition*, *organizational architecture* and *economics* dimensions.
Yunus, Moingeon & Lehmann-Ortega [122]	• A social business model has four interrelated components: *value proposition* (stakeholders & products/services); *social profit equation* (social profit & environmental profit); *value constellation* (internal value chain & external value chain); and *economic profit equation* (sales revenues, cost structure & capital employed ⇒ no economic loss, i.e., full recovery of capital).
Wirtz, Pistoia, Ullrich & Göttel [123]	• A simplified aggregated representation of the company's relevant activities indicating how customer value is created in order to achieve competitive advantage, coupled with business model evolution/innovation to adapt to changing internal and external circumstances.
Amit & Zott [124]	• A system of interconnected and interdependent activities that defines how the company interacts with its customers, partners and vendors. This *activity system* specifies the activities required to satisfy perceived customer needs, which parties (the company or its partners or its vendors) conduct which activities, and how these activities are interlinked.
DaSilva & Trkman [125]	• A specific combination of resources which through transactions generate value for both customers and the organization.
Johnson, Christensen, & Kagermann [126]	• A combination of the interlocking elements of *customer value proposition*, *profit formula*, *key resources* and *key processes* that when taken together create and deliver value.
Chesbrough [127]	• A business model articulates the *value proposition*, identifies a *market segment*, defines the *value chain structure* from raw materials to final customer, specifies *revenue generation mechanisms* and associated cost structure and profit potential, describes the position of the firm within the *value network (ecosystem)* and formulates the *competitive strategy* which gains and sustains an advantage over rivals.
Afuah [128]	• The set of activities that an organization performs to build and use resources to generate, deliver, and monetize benefits (embodied in products and services) to customers.

TABLE 6. Nine business model building blocks (based on [130]).

Business Model Pillar	Business Model Building Block
Product	Value Proposition
Customer Interface	Target Customer Distribution Channel Relationship
Infrastructure Management	Value Configuration Core Competency Partner Network
Financial Aspects	Cost Structure Revenue Model

5. *Value Configuration*: outlines the firm's arrangement of various activities and resources.
6. *Core Competency*: describes the competencies necessary to implement the firm's business model.

7. *Partner Network*: illustrates the cooperative agreements with other firms necessary to efficiently offer and commercialize value.
8. *Cost Structure*: sums up the monetary consequences of the means employed in the business model.
9. *Revenue Models*: describes ways a firm makes money through a variety of revenue flows.

V. CURRENT BUSINESS MODELS FOR MOBILE NETWORK OPERATORS

MNOs were purely voice and short message service (SMS) service providers until the introduction of 3G and 4G technologies when multimedia (voice, data and video) services were able to be delivered to end-users. With the emergence of disruptive 5G technologies, mobile operators will have to innovate their current business model in order to survive within the new business ecosystem [119].

A. CONVENTIONAL MOBILE NETWORK OPERATORS' BUSINESS MODELS

In the past two decades, conventional business models for MNOs have been more market-driven than technology-driven. This could be attributed to the fact that transition from 2G/3G to 4G has been more of an evolutionary enhancement with less technological disruption within the mobile communications industry. The following business models have been employed by MNOs prior to the emerging 5G networks.

1) OUTSOURCED AND MANAGED SERVICES BUSINESS MODEL

The rapid advancement in technology leads to frequent changes on the networks such as hardware upgrades and software updates. These network changes pose a challenge to MNOs on managing the technology and maintaining the network with minimal faults and outages. As a result, many operators have resorted to outsourcing the technology portion or the network maintenance part to equipment vendors who manage the outsourced portion through strict outcome-based service level agreements (SLAs) [119]. In such a model, the operators' focus is on market acquisition, customer experience management (CEM) and creation of multiple revenue streams through additional value-added services (VASs). This is a form of partnership in the network element outlined in [119], where through voluntary agreement, the equipment suppliers take portions of the value chain (e.g., access and backhaul networks) under an SLA.

2) MOBILE VIRTUAL NETWORK OPERATOR (MVNO) BUSINESS MODEL

MNOs can lease out, rent or sell their network capacity resources or infrastructure to secondary operators (referred to as mobile virtual network operators (MVNOs)) who do not have their own spectrum resources or network infrastructure. The MVNOs create their own service delivery platforms and manage customer service, billing and value-added services (VASs) to their own subscribers. MVNOs buy capacity from the primary operators and resell it with added value to MVNOs' dedicated sets of customers [132]. Thus, the MVNO can create and capture value through connectivity, content, context and commerce while relying on the primary mobile operator's network infrastructure and spectrum resources [72].

3) NEW MARKET ACQUISITION BUSINESS MODEL

Large and well-established MNOs tend to expand into new markets to address new customer segments as well as explore new market opportunities [132]. This could be due to market saturation or intense competition in the home markets. New markets are created via partnership ventures or acquisitions to enter new markets. A typical example is when India's Bharti Airtel entered the African market through the acquisition of Zain's African operations [133]. The market acquisition model aims at expanding into new markets by studying demands for the products and services to be offered. Key factors to be considered include: potential market offering for sales and growth opportunities, favorable regulatory and political/governance policies such as taxation, and an investment friendly atmosphere. The market acquisition business model can be described as a partnership network business model which is used to create joint ventures or strategic alliances to penetrate new geographical markets [119], [132].

4) MOBILE BROADBAND SERVICE BUSINESS MODEL

The current 3G and 4G technologies which are still undergoing deployment in most developing regions are a major source of mobile broadband/mobile Internet connectivity for most telco subscribers. Applications such as WhatsApp, Facebook, Twitter or Instagram which are offered on top of the mobile broadband networks have become popular. Initially, the mobile broadband model was a "flat-rate model" with fixed periodic rates [132]. However, due to the increased service consumption by end-users in recent years, various data utilization plans are being implemented by mobile operators. As a result, there has been a shift from the flat-rate model to demand-based models [119]. Ultimately, the end-users benefit from simple pricing strategies while mobile operators benefit from constant revenue streams.

5) INTEGRATED WLAN-CELLULAR BUSINESS MODEL

This business model emerged as the potential evolution for the wireless local area network (WLAN) hotspot concept aimed at providing wireless Internet connectivity to MNOs' subscribers [134]. In this model, the WLAN which is based on the IEEE 802.11 standard, is positioned as a complement to 3G/4G networks, and potentially as a substitute to the costly cellular network base stations. This model eliminates the process of upgrading from 3G to 4G, thereby minimizing deployment costs as well as operational costs.

B. CHALLENGES TO CONVENTIONAL BUSINESS MODELS OF MOBILE NETWORK OPERATORS

5G technologies require huge investments to cover deployment and operational costs, while the existing classical business models with subscription as the core element are not likely to produce enough revenues and profits to cover these costs [135]. Conventional business models are often faced with challenges from both the technological and socio-economic sides. The following key challenges have been identified.

1) EFFECTS OF OVER-THE-TOP (OTT) SERVICES ON MOBILE NETWORK OPERATORS' BUSINESS MODELS

As the behavior of end-users keeps changing due to higher data demands caused by digitalization, there has been an exponential rise of data consumption mainly driven by video content applications. This has seen the emergence of various over-the-top (OTT) services which are affecting the MNOs' business ecosystem, as OTT players can offer these services without owning, leasing or operating the network infrastructure [132]. OTT services are applications like social networks (e.g., Facebook, Twitter and Instagram), video content applications (e.g., YouTube), and messaging applications (e.g., WhatsApp) which are accessible on the Internet by riding on top of the mobile operators' network infrastructure [136]. MNOs' business models are impacted as their revenues are primarily dependent on data usage and not from OTT applications. Traditional mobile voice calls and SMS businesses are on the decline leading to lower revenue generation [119]. Consequently, conventional business models which are meant to support such services are proving to be inadequate to meet the end users' demands.

2) LIMITATIONS OF BUSINESS-TO-BUSINESS (B2B) AND BUSINESS-TO-CONSUMER (B2C) MODELS

Conventional MNOs' business models are simple to implement as they are usually two-dimensional business-to-business (B2B) models (e.g., mobile operators providing access services to enterprise firms) or business-to-consumer (B2C) models (e.g., mobile operators providing data or voice services to consumers) [137]. However, the increase in the number of key players (e.g., MNOs, private networks, and private/public enterprises) in the mobile communications industry has resulted in complex value chains. Thus, for MNOs to create and capture value through the provision of digital services in such complex business environments, traditional and simple B2B or B2C models are unlikely to succeed. Instead, innovative business-to-business-to-any (B2B2X) models are more likely to flourish.

3) EFFECTS OF DISRUPTIVE NON-CELLULAR TECHNOLOGIES ON MOBILE NETWORK OPERATORS' BUSINESS MODELS

MNOs operate under the assumption that the current 4G services and beyond will provide much of their revenue growth [138]. However, disruptive non-cellular technologies such as WiFi which operate in the unlicensed frequency bands presents a threat to existing business models for cellular technologies. Disruptive networks using the IEEE 802.11 standards in hotspots offer Internet access in public places and have the potential to cover the globe [138]. In addition, WiFi's deployment costs are much lower compared to cellular 3G or 4G and it offers higher data rates, albeit over a comparatively limited coverage range.

VI. EMERGING DISRUPTIVE 5G BUSINESS MODELS

The vision for 5G wireless communication networks is not only technology-oriented but is also focused on the creation, delivery and capture of business value for all key stakeholders such as MNOs, equipment vendors and other third parties. From the business perspective, in order for 5G and beyond networks to be successfully deployed, there is a need for commercially viable and sustainable business models that can support the targeted multi-dimensional vertical markets.

A. DISRUPTIVE BUSINESS MODELS

As part of a successful strategy, the business model plays an essential role in increasing the company's value through the creation of sustainable competitive advantage. Nonetheless, the sustainability and profitability of a business model in dynamic business environments is always limited in time, since progress and innovation not only promote competition, but also have the ability to make a business model obsolete [139]. Disruptive technologies like 5G mobile networks often alter the existing value chains and impact on the current ecosystem for MNOs, thereby rendering conventional business models inadequate [140]. Therefore, successful and executable business models are likely to be the ones that can best address the economic disruptions and peculiarities underlying 5G wireless networks [8].

The disruption of business models occurs when emerging technologies and innovation become critical in relation to an existing business model [141]. Disruptive business models arise to replace the existing business models, either by their reconfiguration or by designing new business models aimed at a specific value proposition from emerging technologies [141]. The delivery of differentiated value to customers, gaining of competitive advantage, opening of new markets, and the replacement of existing business models are characteristics of disruptive business models in the business environment [141]. Fig. 12 shows the relationship of business models, emerging technologies and innovation process with disruptive business models.

B. 5G DISRUPTIVE BUSINESS MODELS

5G networks can unequivocally be considered emerging and innovative technologies within the mobile communications sector. Therefore, MNOs are required to develop business models which are capable of addressing the economic and technological disruptions caused by 5G network technologies. Technological disruption due to 5G networks

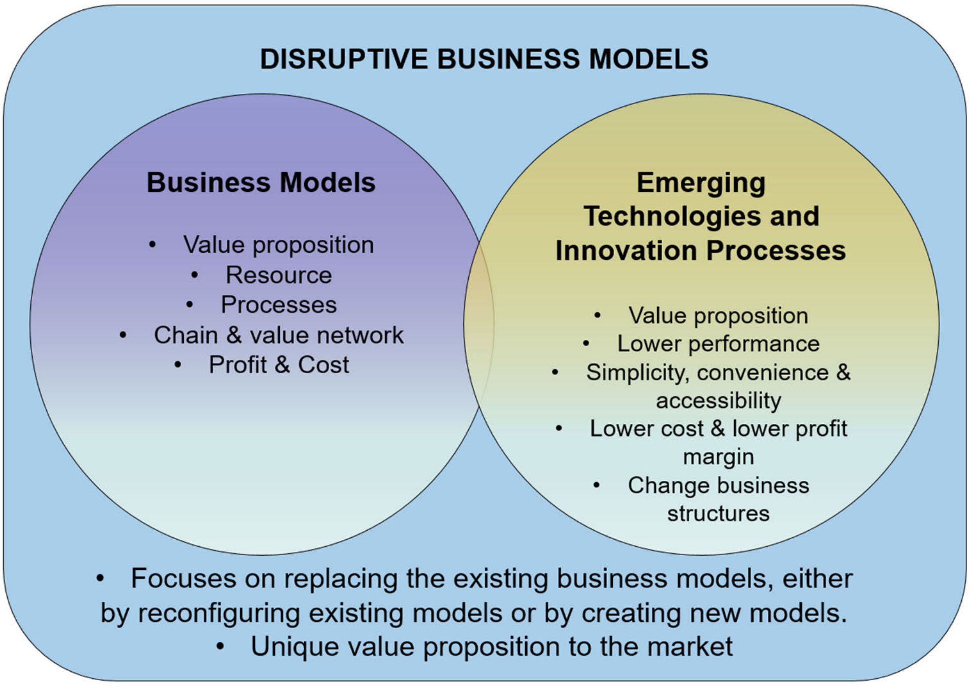

FIGURE 12. Disruptive business models [141].

if welcomed will result in positive and sustainable digital business models and increased revenue for MNOs. However, if these operators act too slowly and too rigidly towards 5G technological disruption, their existing business models will become obsolete with the emergence of new competitors such as private 5G networks, 5G content providers, 5G app developers, and so forth. The following five categories of 5G disruptive business models are found in the literature.

1) PARTNERSHIP BUSINESS MODELS

One of the leading innovations for 5G wireless technologies is the introduction of a new network architecture based on the latest technologies such as cloud computing, SDN, NFV, edge computing, artificial intelligence and machine learning. The emerging 5G and beyond networks will not only continue connecting people and objects, providing accessibility to demanded services, but will also be capable of providing specialized and competitive services to government departments, private enterprises and the vertical industry sectors [142]. New business models and the associated regulatory and policy strategies for 5G networks aimed at serving vertical industries such as healthcare, smart factory, media and entertainment, energy, and automotive have been proposed in [142]. However, [142] only outlines high-level business model proposals for various vertical markets without detailing the components such as relationships between the industry verticals and MNOs.

The following partnership business models have been discussed in the literature.

a: CONNECTIVITY PROVIDER BUSINESS MODEL

The connectivity provider business model for telecom operators and service providers has been presented in [119]. The basic connectivity business model which addresses the best effort Internet Protocol (IP) connectivity for wholesale and retail clients, as well as an enhanced connectivity business model where connection quality of service (QoS) is guaranteed, have both been described. The article further outlines the business models employed in cases where primary MNOs go into partnership with MVNOs or third-party providers. However, the proposed partnership business models do not consider the policy and regulatory framework which is key, especially during revenue sharing.

b: DIGITAL SERVICE PROVIDER BUSINESS MODEL

A business model for telecom operators as digital services providers has been proposed in [119]. The authors suggest that telecom operators should extend beyond providing the core connectivity services and venture into digital services like offering mobile TV/video content, financial services and smart homes. This transition is beneficial owing to the increasing CAPEX and revenue stagnation, as revenue does not increase in line with data growth [143]. The authors of [119] further outline the two available options for MNOs to offer digital services: (1) operator builds their own applications and decides whether to serve only their subscribed customers or to give open access to subscribers from other carriers; and (2) operator partners with an OTT provider and the operator get their OTT partner to build the applications. In their business model framework, [119] conclude that it would be beneficial for an operator to build its own digital services applications and provide open access to both paying and non-paying service subscribers, thereby expanding the target market. This could result in two revenue streams: direct revenue from own and other operators' subscribers (e.g., subscription revenue and advertisement revenue); and indirect revenue from own subscribers only (e.g., increased data users, improved customer retention and customer analytics).

c: ULTRA-LOW LATENCY SERVICE PROVIDER BUSINESS MODEL

Reference [144] claims to analyse the relevant 5G use cases that require ultra-low latency, from both technical and business perspectives. The paper is motivated by the following research question: "*Will it be cost-effective for telecom players to build ultra-low latency in 5G networks?*" The authors conducted a detailed study on the industry verticals that could benefit from low-latency technologies: healthcare, transportation, entertainment, and manufacturing. Data collection involved a combination of both primary sources (interviews, workshops, and collaborative research projects) and secondary sources (extensive literature review). In answering their research question, the authors in [144] concluded that telecom players can benefit from 5G ultra-low latency applications as long as new business models are created and strong partnerships with the industry verticals are established. Thus, the choice of new business models can determine the economic impact of 5G and the revenue of ultra-low latency applications. The contribution emphasizes revenue generation for 5G ultra-low latency services but does not outline the processes and parameters to employ in realizing the revenue. Additionally, the design of an appropriate revenue sharing mechanism between mobile operators and the industry verticals could benefit all stakeholders.

d: SMART CITY BUSINESS MODEL

The concept of a smart city business model and a practical framework for analysing it has been proposed in [145]. The authors outline the city model canvas (CMC) which is based on the firms' standard business model canvas [130]. The CMC addresses the research problem of how city governments can take ownership of smart city projects to ensure that they create value for their residents. The proposed CMC replaces several elements of the business model canvas with elements that are relevant to a public service context. The article in [145] indicates that the city of Bristol in England was selected as an appropriate context to apply the CMC because of its current smart city strategy. However, during the case study implementation, only Bristol City Council managers were consulted. The narrow consultation affected the validity and reliability of the analysis results, thereby hindering the attainment of a viable business case. Other key stakeholders in high-level decision-making positions such as politicians and politically appointed executives should have been approached. In addition, key partners such as citizen groups, non-governmental organizations and private entities that are involved in smart city development should have been consulted in order to enhance the results of the case study.

e: 5G DATA COMMUNICATION BUSINESS MODEL

The article in [146] focuses on the pricing policies and new business models for data communication in 5G networks. The paper discusses the importance of data pricing policies over the 5G network by taking into account the anticipated global exponential growth of mobile data traffic (i.e., 49 Exabytes per month and 6.2 billion smartphones and tablets by 2021 [147]). In an attempt to answer the research question "*What business models and what pricing policies will be appropriate for 5G networks?*", the article observes that the adoption of business models is related to the roles of key players: *asset provider business models* (i.e., X as a service (XaaS) and network sharing); *connectivity provider business models* (i.e., basic connectivity based on best effort IP and enhanced connectivity based on QoS); and *partners service provider business models* (i.e., operator offer enriched by partner and partner offer enriched by operator). Two pricing models are discussed: the *cost-based price model* (i.e., pricing based on operator's CAPEX and OPEX); and the *SBIFT model* (i.e., price differentiation based on the five dimensions of Scope, Base, Influence, F ormula and Temporal rights). The author in [146] concludes that there is no classic model of pricing which should be deemed as appropriate. However, since the study focuses on data services only, the discussed pricing policies have limited applications to the emerging multi-service (eMBB, mMTC, and uRLLC) 5G networks.

2) DIGITAL PLATFORM BUSINESS MODELS

5G wireless technologies are expected to transform the wireless communication business ecosystem from the current "network-for-connectivity" business models towards "network-of-services" business models which will be built on platforms with complex algorithms and massive amounts of data [43], [148]. This will require the application of big data techniques and machine/deep learning technologies. Platform-based ecosystemic business models will incorporate both technical (e.g., technological innovation) and economical (e.g., economies of scale and scope) aspects [149]. Furthermore, since 5G and beyond networks are expected to disrupt the mobile ecosystem by full scale introduction of "as-a-service" platforms and a sharing economy approach, new entrants to the mobile market such as micro-operators, content providers, and app developers will be able to share the available 5G network resources [45], [149].

The paper in [72] discusses the use of scenario-based business modelling in the quest to explore the market for 5G networks. Four scenarios that were developed in a collaborative effort among different actors in the market (Huawei, Ericsson, Nokia and academia) are presented. A novel approach to building business models that complements traditional techniques through the provision of a platform that integrates changes in technology, regulation, value-chain dynamics and value proposition evolution is proposed. The authors of [72] conclude that their approach is valuable in environments that are characterized by high levels of uncertainty and complexity. Nonetheless, the paper does not discuss the actual cost analysis and the revenue maximization strategies which are critical to capturing value by service providers.

3) NETWORK SLICING BUSINESS MODELS

Emerging 5G wireless technologies are developed in form of programmable platforms that offer services on an ''as-a-service'' basis [45]. Network slicing is a key technology which enables 5G and beyond networks to support composite services by transitioning from a ''network-as-an-infrastructure'' to a ''network-as-a-service'' platform [16]. Network slicing is the process of partitioning a physical network into multiple isolated logical networks (slices), each with its own service characteristics and performance requirements [36]. Due to varying service class requirements, each network slice requires its own business model to meet its business targets in terms of economic value and profitability.

The article in [150] focuses on the network slicing strategy and is based on a novel auction mechanism aimed at maximizing network revenue. The study addresses joint network resource and revenue optimization through a proposed auction-based model. The authors demonstrate that the proposed auction model can efficiently allocate network resources to network slices by providing higher satisfaction rate per slice as well as increased network revenue. Although the contribution in [150] comprehensively addresses the strategy of revenue maximization, it ignores the pricing policies which are critical to the successful practical implementation of the proposal.

Business models that are enabled by network slicing have been discussed and analyzed in [7]. In the *single domain business model of network slicing*, it is assumed that there are single hardware and virtual infrastructure providers and their resources enable the creation of end-to-end slices. The single domain model identifies the following business roles: physical infrastructure provider, virtual infrastructure provider, slice provider, slice template provider, slice function provider, slice tenant, slice customer, and service provider. These business roles are interconnected via a set of defined interfaces. The authors observe that the single domain model is unrealistic and does not fully exploit the potential of network slicing technology. To overcome these drawbacks, the article in [7] further proposes a *multi-domain business model of network slicing* which enables an ecosystem of multiple physical and virtual infrastructure providers as well as slice providers, and brokering of slice provisioning. The brokering mechanism in the multi-domain model adds several brokering business roles to the single domain model: infrastructure broker, slice broker, and service broker. In their analysis, the authors claim that the multi-domain concept supports multiple slice providers, who can be added dynamically, if the solution allows for the dynamic creation of slice orchestrators. However, the authors acknowledge that from an implementation standpoint, the proposed multi-domain model is incompatible with the standard NFV management and orchestration (MANO) framework, which is described in [151]. This lack of conformity with the standard MANO framework could therefore make MNOs reluctant to commercially adopt the proposed multi-domain model.

4) MICRO-OPERATOR BUSINESS MODELS

Micro-operators will be able to offer various services in their localized areas for specialized use cases in different 5G vertical markets. One way to realize this is for regulators and policy makers to ensure that spectrum acquisition by local 5G micro-operators is made possible at affordable costs [108].

The research in [152] focuses on business models involving micro-operators in small cell/indoor 5G environments. The paper defines a micro-operator as an entity that combines mobile connectivity with specific local services in spatially confined domains and dependent on appropriate spectrum resources. The authors conclude that micro-operators have a natural role in small cell/indoor scenarios and can complement incumbent MNOs' current offerings through co-opetitive business relationships (i.e., relationships combining cooperation and competition). Even so, currently, indoor wireless coverage and capacity solutions are mostly supported by WiFi which is based on the IEEE 802.11 standards. The authors in [152] did not discuss how their proposal would compete economically with existing indoor solutions such as WiFi which are easily accessible and affordable for most end users.

5) ECOSYSTEMIC BUSINESS MODELS

Ecosystemic business models – of which the 4C model (connection, content, context and commerce) is the classic example – focus on business models in business ecosystems in which multiple firms interact to create value in highly complex interdependent ways [153]. The 4C model has been used to define the framework of a future 5G business ecosystem as follows [153]. In this ecosystem, the *connection-oriented business model* focuses on monetizing connectivity services (e.g., infrastructure provisioning). The *content-oriented business model* is concerned with monetizing content services (e.g., video or audio). The *context-oriented business model* deals with monetizing the information that already exists on the Internet (e.g., user profiles, time and place) and contextualizing the content. The *commerce-oriented business model* monetizes any services related to connection, content and context. The proposed 5G ecosystem business model framework highlights potential implementations at each level, such as spectrum sharing (connection), vertical-specific data (content), contextual and location based services (context) and network slicing (commerce). However, the proposal does not take into account the implementation cost, nor does it discuss the actual means of how the monetization aspects would be achieved. Additionally, provision of the actual pricing mechanisms to employ would enhance the practicality of the proposed framework.

Business models for the smart-grid vertical market within the 5G ecosystem have been presented in [154]. The study introduces business models based on the logic of the networked and hyper-connected technological and business environment. A 4C ecosystemic model is developed in the context of smart-grid commercialization in the 5G era. The central research question of the study is: ''How can business models be applied in a co-opetition based value creation and capture in the context of a hyper-connected business ecosystem?'' The study employed an action-based research methodology for data collection within two techno-social collective innovation projects: 1) European Union level peer-to-peer (P2P) technical and market design of smart-grids; and 2) Finnish-American research co-operation on 5G networks key sector enablers. According to the paper in [154], the key contribution of the study lies in the discovery of the four dimensions of hyper-connectivity (namely, hyper-connectability, hyper-memorability, hyper-diffusibility, and hyper-scalability). Additionally, the empirical study which was conducted can serve as a building block when developing a stronger theoretical business model for hyper-connectivity. Nevertheless, the P2P concept had limitations as it could only evaluate 5G's potential in existing and known smart-grid applications. Thus, future applications that are yet to emerge cannot be examined. Apart from that, the study only concentrated on the technology design aspect and did not consider other business model elements such as infrastructure management and customer relationships. However, the findings in [154] can form the basis for future exploration within the emerging 5G smart-grid vertical market.

VII. BUSINESS MODELS FOR 5G MOBILE NETWORK OPERATORS AND PRIVATE 5G NEWORKS

Despite 5G networks being rapidly deployed around the world, MNOs seem to be undecided when selecting the optimal business models to support these networks. Therefore, as MNOs intensify their 5G network rollouts, viable and sustainable business models will play a pivotal role in ensuring that the targeted economic value is achieved.

A. 5G VALUE CHAIN COMPONENTS

In order for MNOs to develop viable and sustainable business models for 5G networks, the relationships among the 5G value chain components within the global market should be accurately established based on the business model ontology proposed in [130]. The following value chain components have been identified.

1) WHO?

Who are the target customer segments to which the MNOs will provide the proposed value? The ''Who?'' component of the value chain focuses on identifying the target customers, their specific needs and how differentiated services can be offered to guarantee customer satisfaction, thereby ensuring that customer value proposition is addressed. The customer segments can be categorized as government/public entities (e.g., public safety and smart cities), private enterprise (e.g., media and entertainment), verticals (e.g., energy and healthcare) and consumers.

2) WHAT?

What value does the MNO intend to provide to the target customer segment? The ''What?'' component of the value chain describes the MNO's service offering (value proposition) to a specific customer segment with the intention of delivering value (customer side) as well as capturing value (operator's side). For example, 5G services include eMBB (e.g., UHD video and VR/AR), mMTC (e.g., smart meters, smart energy grids, smart factories and smart cities) and uRLLC (e.g., driverless cars and remote surgery).

3) HOW?

How will the MNO create and deliver value to the target customer segment? This component of the value chain outlines the technology design, network infrastructure and network resources available to the operator in order to deliver the appropriate services to the intended customers. The ''How?'' component may include the following: i) 5G NSA and SA deployment modes; ii) 5G key enabling technologies such as ultra-densification, massive MIMO and beamforming, SDN/NFV, millimeter wave, green communication, IoT and D2D communications, digital platforms and network slicing; iii) site infrastructure sharing (e.g., tower space, baseband resources, radio resources, and antennas); iv) spectrum acquisition (e.g., sub-3GHz band, C-band, and mmWave band); and v) partner networks (e.g., equipment vendors, device manufacturers, and platform providers) as well 4C model participants (connection, content, context and commerce).

4) HOW MUCH?

How much value will the MNO capture from the target customer segment? This component of the value chain represents a blueprint of how an operator intends to maximize its profits while minimizing its costs within the 5G networks ecosystem. The ''How much?'' component consists of: 1) revenue structures (e.g., revenue streams, profit margins, and ROI); 2) pricing methods (e.g., pricing per slice and on-demand pricing); and 3) cost analysis (e.g., deployment costs, CAPEX, OPEX, and miscellaneous costs).

Fig. 13 depicts the relationships among the components of the 5G networks value chain.

B. BUSINESS MODELS FOR 5G MOBILE NETWORK OPERATORS

At present, mobile communications infrastructure is typically deployed, operated and maintained by MNOs. Because this is an extremely capital-intensive process, operators generally only deploy mobile networks where the ROI is high. As a result, rural areas are often neglected when rolling out new mobile technologies, thereby making these places digitally disadvantaged or disconnected from the rest of the world [155]. This poses a challenge for MNOs to realize their

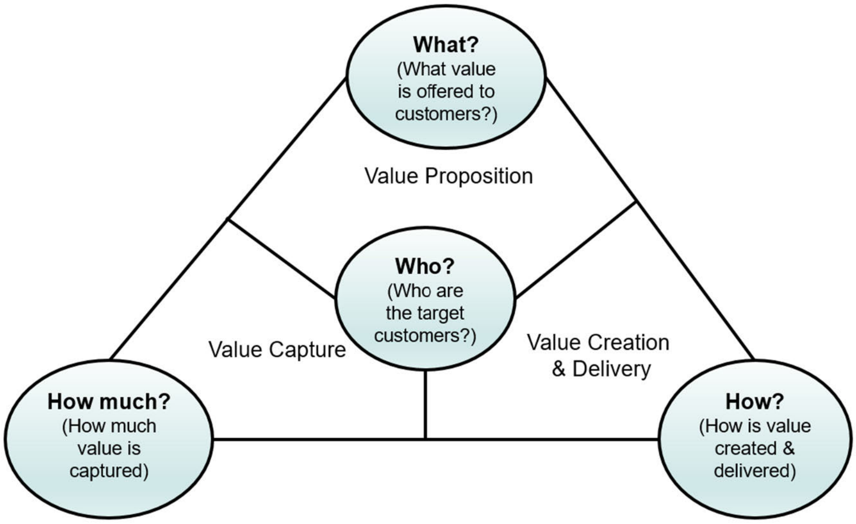

FIGURE 13. Relationships among the 5G value chain components.

ROI in regions such as Sub-Saharan Africa where the rural population is around 60% [83]. In addition to the disruptive business models for the emerging 5G networks presented in Section VI of this article, the following business models have been proposed for the initial 5G network deployment by MNOs.

1) VERTICAL MARKETS PARTNERSHIP BUSINESS MODELS

5G networks promise innovative business models that revolve around creating and capturing value through multi-partnership with vertical industries within a collaborative value system [156]. 5G will provide multiple and unique operators' value propositions to all customers consisting of consumers, enterprises, verticals and other partners at the same time [119]. The following vertical market partnership business models can be applicable for different use cases.

a: SMART LEARNING BUSINESS MODEL

MNOs can partner with the Ministries/Departments of Education, school districts, regulators, researchers and equipment vendors to provide smart learning via tele-education use cases [119]. This can be achieved through eMBB immersive real-time interaction using VR, AR and virtual presence applications with minimal visual or audio delays [157]. This could be substantively beneficial to both the learners and the educators, especially when classes with physical contact are not feasible, such as during COVID-19 outbreaks.

b: e-HEALTH BUSINESS MODEL

For the e-health business model, MNOs can partner with key stakeholders in the health sector, such as Ministries/Departments of Health, public or private medical insurers, medical device manufacturers, equipment vendors and researchers. Examples of 5G-enabled e-health business model uses cases and applications include: connected care, precision medicine, remote surgery and remote diagnostics [158]. Both during and after the COVID-19 pandemic, e-health will becoming increasingly critical for national and local governments, for instance to keep track of citizens who have been vaccinated [159].

c: SMART AGRICULTURE BUSINESS MODEL

5G technologies will also provide solutions for smart agriculture systems in countries whose economies depend on agriculture. IoT based on 5G will be the key driver to achieve smart agriculture via the mMTC service class [160]. For instance, multiple wireless sensors with 5G connectivity deployed in specific crop fields can help optimize the soil moisture content and ensure the efficient use of water and fertilizers through customized applications [161]. MNOs will be able to partner with the Ministries/Departments of Agriculture, commercial farmers, researchers, and agricultural scientists.

d: SMART GRID BUSINESS MODEL

The smart grid business model is targeted for smart end-to-end efficient power (energy) distribution networks with predictive big data analytics [162]. Key MNOs' partners could include: Ministries/Department of Energy, policy makers and regulators, public and private power utility companies, local municipalities, and researchers. With most emerging economies facing the challenges of unreliable power supply, MNOs have an opportunity to provide wireless sensor connectivity to enable power utility companies to effectively monitor and forecast energy demand and consumption via 5G networks [154].

e: SMART CITY BUSINESS MODEL

As managing cities in developed countries becomes more challenging and the rate of urbanization in developing economies grows, smart city concepts can be implemented to better support and serve urban communities [163]. MNOs can develop smart city business models by partnering with local governments, citizens groups, non-government organizations, city legislatures and policy makers, politically appointed executives, and researchers [119]. Potential 5G smart city services include: remote monitoring of roads and city infrastructure (e.g., parks, museums, etc.), smart meters/parking lots, water sanitation and waste management systems, among others [163], [164].

f: SMART TRANSPORTATION BUSINESS MODEL

Smart transportation systems will ensure flexible and adaptive public and private fleet management, such as optimized route planning to minimize traffic congestion and traffic accidents [165]. MNOs' potential for smart transportation system 5G business models include: Ministries/Departments of Transportation, municipal and local governments, transit system providers, and researchers. According to the World Health Organization and the World Bank [166], 90% of the world's fatalities on the roads occur in low-income and middle-income countries, even though these countries have approximately half of the world's vehicles. As such, 5G-enabled smart transportation business models have tremendous socio-economic potential. Besides, key industry players have formed the 5G automotive association (5GAA) whose objective is to connect the telecom industry and vehicle manufacturers to develop end-to-end solutions for future mobility and transportation services [167].

2) MOBILE NETWORK OPERATORS AS OTT/CONTENT PROVIDERS BUSINESS MODELS

One of the main challenges faced by MNOs is that OTT players and content providers offer video, voice and messaging services via the operators' network infrastructure without paying. Consequently, OTT players and content providers are directly competing with MNOs, but with no investment in infrastructure building [119].

a: VIDEO STREAMING SERVICES BUSINESS MODEL

Among the key drivers of the exponentially increasing demand for higher data rates are demand for various video applications (e.g., video on demand (VOD) services) and the proliferation of low-cost smartphones and other handheld devices. Video-based services offers an opportunity for MNOs to venture into adjacent digital businesses such as video streaming, especially in emerging markets like South Africa, Nigeria, Kenya and Brazil [45], [83]. As proposed by authors in [119], MNOs can develop 5G video streaming services business models via the following three options:

i) *MNO develops video streaming services targeting its own customers* – where direct and indirect revenues come from registered customers (i.e., consumers or enterprises) of the MNO.

ii) MNO develops video streaming services for open access – where direct revenue is captured from both registered and non-registered customers as well as indirect revenue coming from non-registered customers only.

iii) MNO partners with the OTT/Content provider for video streaming services – where the MNO provides video streaming services which are developed by specific OTT players or content providers. The revenue obtained is shared between the two parties.

3) REAL-TIME ONLINE GAMING BUSINESS MODELS

The online gaming industry is ready for disruption as we approach the wide-scale deployment of 5G. With augmented performance attributes such as higher data rates, lower latency, and increased capacity and reliability for enhanced player experiences, 5G bring many benefits to the online gaming industry [168]. MNOs can take advantage of the imminent opportunities within the 5G real-time online gaming market which will be supported by throughput-intensive eMBB applications like VR/AR [22]. The following two options for the real-time online gaming business models could be available to MNOs.

a: MNO BUILDS ITS OWN REAL-TIME ONLINE GAMING APPS

In this model, the MNO builds and manages real-time online gaming apps in-house and offers gaming services directly to consumers on its own.

b: MNO PARTNERS WITH REAL-TIME ONLINE GAMING APP DEVELOPERS

In this model, the MNO offers gaming services developed and managed by a third-party app developer under a revenue share agreement.

4) 5G-ENABLED INTERNET OF THINGS (5G/IoT) BUSINESS MODELS

Massive machine communication (MMC) in 5G networks will form the basis of Internet of Things (IoT) with a plethora of application fields including, automotive industry, public safety, emergency services, and medical field, each with specific business model requirements [18]. Recently, a rough distinction has been unfolding between consumer IoT (cIoT) and industrial IoT (iIoT), with implications on underlying technologies and business models [169]. Consumer IoT aims at improving the quality of people's life by saving time and money via the interconnection of consumer electronic devices, as well as virtual interactions with user environments such as homes, offices, and cities [170]. On the other hand, industrial IoT focuses on the integration between Operational Technology (OT) and Information Technology (IT) [171], and on how smart machines, networked sensors, and data analytics can improve business-to-business (B2B) services across a wide variety of market sectors and activities, from manufacturing to public services [169].

Research on the relationship between Internet of Things (IoT)-based real-time production logistics and real-time sensor networks respect to 5G business models for MNOs is steadily gaining ground. In the 5G era, sustainable business models may provide system transition value, resulting in the expansion of IoT-based real-time production logistics, refashioning of the energy markets, and asking customers to support a sustainable smart energy system [172]. Additionally, 5G networks will facilitate sustainable business models for smart product innovation with big data-driven technologies that can orient companies toward improving supply chain sustainability outcomes by use of circular economy criteria [173]. An empirical study to examine IoT-based real-time production logistics, cyber-physical process monitoring systems, and industrial artificial intelligence in sustainable smart manufacturing has been conducted in [174]. Cyber-physical production systems (CPPS) enable wireless sensor technologies to monitor manufacturing assets and networked production or logistics business operations in real time [175]. CPPSs inspect, supervise, and automate business operations, optimizing manufacturing and logistic processes across smart shop floor environments [176].

Furthermore, it has been observed that innovative applications of IoT technologies are not limited to developed countries. IoT technologies are gradually diffusing in developing regions such as Sub-Saharan Africa (SSA) and is being used as a tool for social and economic development in the region [177]. However, SSA region will only account for 1.19% of the global number of IoT connections by the year 2025 [178]. The low penetration rate of IoT enabled technologies could be attributed to inadequate infrastructure, low investment and uncertainties surrounding return on investment (RoI) [76], [83].

C. BUSINESS MODELS FOR PRIVATE 5G NETWORKS

A variety of business models can be employed when adopting 5G cellular network technologies for private 5G network purposes. The choice of business model varies depending on: the industry sector, specific use case, capital expenditure (CAPEX), operational expenditure (OPEX) and network scalability [179]. Private 5G networks are secure, fast, and easy-to-manage networks that can provide reliable voice or data services inside buildings or in remote areas. The following use cases and business models across different sectors can be supported by these networks [63].

1) SMART MANUFACTURING BUSINESS MODEL

Manufacturing vertical market has a variety of use cases which are mostly driven by 5G IoT [180]. According to [63], manufacturing business models can formulated for the following use cases: production line flexibility; machine to machine communications; automated guided vehicles; connected workers; end-to-end logistics; and multi-client serving facilities. Success stories of private 5G smart manufacturing use cases include: Ericsson's deployed 5G smart factory in Lewisville, Texas, USA [181]; US Department of Defense (DoD) smart warehouse developed with the technical assistance of Cisco and other technology companies [182]; and factory automation by Mitsubishi Electric Corporation [183].

2) SMART MINING BUSINESS MODEL

Mines are usually located in remote areas and miners often work underground where public cellular network coverage in not always available [63]. Private 5G technologies are required to conduct mining operations with greater safety and automation. Moreover, wireless sensor networks built on non-public 5G can be deployed in mines for monitoring the working environment, sensing mine disaster signals, and making early warning [63]. For instance, China Mobile, Yangquan Coal Group, and Huawei successfully built China's lowest underground 5G network at Xinyuan Coal Mine in Shanxi province [184].

3) SMART SEA PORTS BUSINESS MODEL

Private 5G network enabled smart sea ports are expected to be promising solutions [185]. This is critical as future ports are likely to face challenges regarding equipment downtime, congested port yards, worker safety, and environmental impacts. Four use cases for private 5G network-driven smart ports have been identified by [63]. These include: remote-controlled and automated cranes; automated guided vehicles (AGVs); condition monitoring; and unmanned aerial vehicles (UAVs). Nokia collaborated with the Hamburg Port Authority (HPA) and Deutsche Telekom on a successful 5G field trial at the Port of Hamburg in Hamburg, Germany [186].

4) SMART AIRPORTS BUSINESS MODEL

Private 5G networks can be employed in airports to optimize ground operations via automated boarding procedures, thereby improving passengers' experience [63]. Further, in the wake of the COVID-19 pandemic, non-public 5G networks can be used for automatic fever detection, facial recognition, access to passengers' travel records as well as passengers' vaccination status. For instance, 5G and AI-based boarding technologies accelerate check-in, constant security monitoring, luggage drop-off, and identity checks to minimize passengers waiting time. An outstanding example of smart airport design is Beijing's newest and largest airport in Daxing, China where Huawei has introduced a 5G-based automation system operated by China Unicom [187].

5) SMART RAILWAYS BUSINESS MODEL

Regular and high-speed trains require critical communication services for their scheduling and smooth operations. For instance, there is a need for secure and low-latency communication between train drivers and signaling controllers [63]. Moreover, train passengers also expect reliable and stable multi-media services when using onboard infotainment applications such as AR/MR applications, Video-on-demand (VoD) and UHD-video streaming. Thus, 5G private networks can provide high availability, high reliability, low latency, and customized QoS network coverage and capacity which are attractive solutions to railway networks [188].

TABLE 7. Summary of future research areas, challenges, drivers and mechanisms.

Future Research Areas	Challenges	Drivers	Mechanisms
Adaptive service-based business models	• Dynamic service-oriented technologies (e.g., network slicing and digital platforms)	• Variable and dynamic service demands from customers and consumers	• Dynamic service level agreements (DSLAs) • Dynamic pricing methods
Security-oriented business models	• Fulfilment of the IMT-2020 vision of 1 million devices per square kilometer • Increased number of 5G value chain key players	• Massive number of communication devices • Varying security requirement levels of 5G ecosystem players and consumers	• Modification and enhancement of current network security schemes (e.g., authentication, authorization and encryption) to fulfil security objectives
5G business model framework design	• Complex value chain for 5G networks • Disruptive nature of 5G networks	• Various business model research domains (e.g., organizational theory, strategic management, e-business & IT, technological innovation)	• Five interrelated components for the 5G business model framework: customer model, service model, technology model, infrastructure model, and finance model
Dynamic and shared spectrum business models	• Spectrum resource acquisition and utilization • Spectrum associated costs and fees • Growing and varying service demands from customers and consumers	• Ultra-densification of 5G access networks • Entry of local micro-operators and other specialized service providers into the 5G market	• Regulator-driven dynamic and shared spectrum techniques between licensed operators and micro-operators
Business models for 3D networks	• Integration of the UAVs (drones) within the 5G and beyond cellular networks	• Drone-based moving networks (i.e., moving base station and moving user equipment)	• Modification of the current static networks' business targets and performance metrics
Business models for 5G Green Communication	• Incorporating green communication and environmentally friendly technologies in 5G business model design	• Current dependence on traditional fossil fuel as a source of energy • Increase in CO_2 emission levels	• Alternative clean sources of energy (e.g., solar and wind) • Energy harvesting technologies for prolonged power conservation
Business Models for Network slicing and Digital Platforms	• Network connectivity • Network resource allocation	• Variable service requirements • Variable key performance indicators	• Appropriate platform components, interfaces, data algorithms • Accurate definition of network slice

VIII. OPEN RESEARCH CHALLENGES

There is a vast and ever-increasing literature on numerous aspects of 5G networks, particularly in context of the developed markets where they are currently being deployed. By contract, however, research on business models in emerging 5G networks, especially for MNOs, has received relatively little attention from the scholarly community. Consequently, there are still many open research challenges that need to be addressed. Below, we outline some of these key research challenges for 5G business models from the MNOs' perspective and summarize them in Table 7.

A. ADAPTIVE SERVICE-BASED BUSINESS MODELS

Some of the promising 5G technologies such as network slicing [16] and digital platforms [149] will require a wide variety of key players and partners to interact and provide consumers with various smart services. The present stand-alone rigid business models cannot support such dynamic service-driven technologies. MNOs and their partners must appropriately adapt to changes within the value chains while providing services to the target customers. Therefore, it is necessary to transition from product-based to adaptive service-based business models. This is crucial since consumer demands may change with time. The design of adaptive service-based business models can increase both the operators' and partners' profits as well as user satisfaction. These adaptive service-based business models will require dynamic service level agreements (DSLAs) [16] as well as dynamic pricing strategies [146].

B. SECURITY-ORIENTED BUSINESS MODLES

Research on 5G business models has focused more on the economic value aspects of key network performance metrics like data throughput, latency, reliability and device connectivity density with little regard for security objectives such as confidentiality, privacy and data integrity. However, since 5G networks will be enabled to fulfil IMT-2020's mMTC service class [1] by technologies like IoT and D2D communications, the effects of large-scale wireless connections and related security concerns should be incorporated in the design of business models. The involvement of a large number of role players in the 5G ecosystem, each with different security levels, increases the vulnerability to cyberattacks. Thus, existing MNO business models should be modified to security-oriented business models by integrating IoT forensics [189] and various other means of combatting 5G cyber threats [190]. Security-oriented business models should be capable of supporting the complex authentication, authorization and encryption mechanisms of the connected devices as well as users on the 5G networks in order to guarantee confidentiality, privacy and data integrity.

C. 5G BUSINESS MODEL FRAMEWORK DESIGN

Business models have been studied within various research streams, including: (1) organizational strategy focusing on companies' economic value, competitive advantage, and performance [112], [114]; (2) e-business and Information Technology (IT) focusing on understanding the composition and structure of new Internet-based firms [112], [114]; and (3) technological innovation where a business model is viewed as a mechanism that connects a firm's innovative technology to customer needs [112], [113].

The development of a 5G business model framework which is anchored on the theoretical concepts in organizational strategy, e-business and IT, and technological innovation could benefit MNOs when designing their unique business models for practical implementation. The 5G conceptual business model framework design can be formulated based on the ontologies outlined in [120], [126], [128], and [130]. In this survey article, we propose five interrelated components for a 5G business model framework: 1) *customer model* (for competitive advantage through increased market share); 2) *service model* (for value proposition); 3) *technology model* (for value creation); 4) *infrastructure model* (for value delivery); and 5) *finance model* (for value capture). Table 8 shows the 5G business model components, business targets within the value chain and examples of relevant research domains.

D. DYNAMIC AND SHARED SPECTRUM BUSINESS MODELS

The ultra-densification of the 5G network by the introduction of small cells (microcells, picocells and femtocells) [39], [40] will facilitate the possible entry of local and specialized service providers such as micro-operators who will require their own specific business models [107]. However, it is still undetermined if the rollout of 5G will create viable business opportunities for micro-operators, especially in rural communities. Micro-operators might have to pay hefty charges to incumbent licensed operators for spectrum resources. Moreover, if the spectrum is auctioned, the incumbent operators' dominance is likely to be perpetuated.

To meet the growing and varying demands of users, dynamic and shared spectrum allocation mechanisms between traditional mobile operators and micro-operators can be implemented. Regulators and policy makers should vigilantly oversee such a strategy to ensure that fairness, in terms of spectrum utilization and the associated costs among network operators is maintained [103], [109]. To motivate and accelerate new network operator entrants and improve inclusive digital businesses, independent communications sector authorities should identify underutilized spectrum bands and allocate them for use by micro-network operators, in a shared spectrum framework such as that developed by the CSIR [191]. Therefore, when developing business models, both traditional MNOs and new micro-operators should carefully consider the details of dynamic and shared spectrum mechanisms before going into partnership for their mutual economic benefits.

E. BUSINESS MODELS FOR THREE-DIMENSIONAL (3D) NETWORKS

Three-dimensional (3D) networks are designed by integrating unmanned aerial vehicles (UAVs) (also known as drones) into 5G and beyond cellular networks. The introduction of 3D networks is a promising solution to achieve safe UAV operation as well enabling diversified applications with mission-specific payload delivery [192]. Such networks are referred to as ''moving networks'' as they consist of a drone-based user equipment (UE) and a drone-based base station (BS) [193]. The study of business models for 3D networks could offer fruitful opportunities for future research. This is because the business targets and the network performance metrics requirements for 3D moving networks will be significantly different from the current networks.

F. 5G GREEN COMMUNICATION BUSINESS MODELS

To enable sustainable 5G networks, a number of green communication and low power network technologies have been proposed, with the aim to improve 5G systems' energy efficiency, and alternative energy powering of networks have been introduced to reduce dependence on traditional fossil fuels [47]. 5G techniques targeting reduction network energy consumption as well as minimizing carbon dioxide ($CO2$) emissions without sacrificing network quality of service (QoS) have been presented in [194], [195], and [196]. Additionally, energy harvesting technologies, which enable communication devices to harvest energy from various renewable sources have also been studied in the literature [197], [198], [199]. However, research on business models aimed at facilitating green communication within the 5G ecosystem has so far received very little interest from both academia and industry. The concept of improved business model efficiency for 5G networks using green communication technologies is most relevant for emerging economies where power supply is limited and low cost alternative energy resources are available abundantly, for powering 5G network equipment [45].

G. BUSINESS MODELS FOR NETWORK SLICING IN DIGITAL PLATFORMS

Despite the burgeoning literature on 5G developments, hardly any contributions have explored 5G network slicing in combination with digital platforms from the business model perspective. Various technical aspects of network slicing and digital platforms have been extensively studied in [16], [36], [37], [38], [43], [44], [200], [201], and [202], respectively. The study in [203] presents a sliced-based cost analysis for 5G eMBB video services by comparing two scenarios from the small medium and micro enterprise service

TABLE 8. 5G business model components, business targets & research domains.

5G Business Model Component	Business Target	Research Domain
Customer model	Competitive advantage	• Organizational strategy • 5G market segments
Service model	Value proposition	• Service design/innovation • 5G services classes
Technology model	Value creation	• Technological innovation • 5G resource management
Infrastructure model	Value delivery	• Operations/supply chain • 5G value chain/ecosystem
Finance model	Value capture	• Revenue/cost structures • 5G pricing schemes

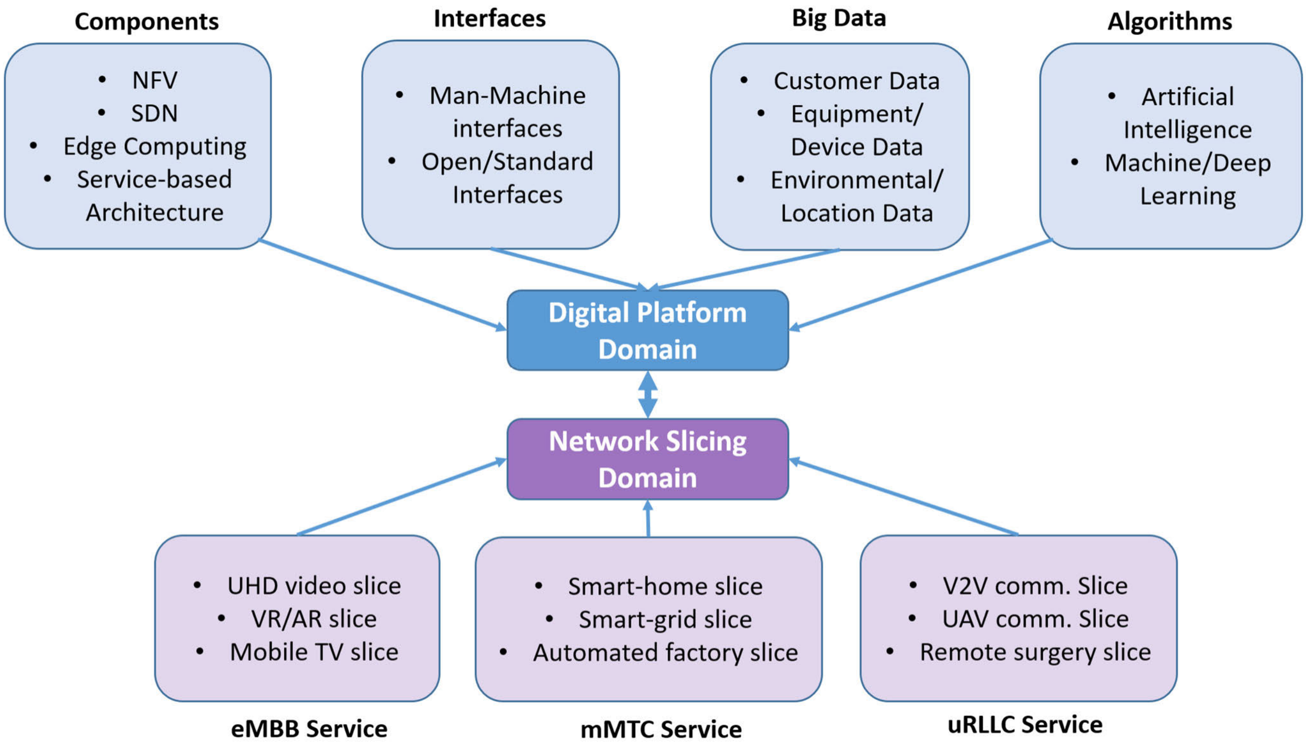

FIGURE 14. Network slicing and digital platform business model.

provider perspective, i.e., own slice implementation versus leased slice provisioning. The authors conclude that from the small business/entrepreneur's point of view, it is cost-effective to lease infrastructure to provide sustainable 5G eMBB services for rural populations.

The key salient feature of network slicing is the ability to customize the capabilities and functionality that a 5G network offers to business customers [200]. The customized service can consist of a combination of eMBB, mMTC and uRLLC use cases that are logically separated into distinct components: network connection service or network resources service. Platform-based ecosystemic business models will incorporate both the technical (e.g., technological innovation) and economical (e.g., economies of scale and scope) aspects [44]. An ecosystemic platform-based business model, consisting of components, interfaces, data and algorithms, has been studied in [43] and [202]. Therefore, business models based on network slicing in digital platforms should guarantee performance targets and connectivity as well as resource assignment. Fig. 14 shows the relationship between the network slicing and the digital platform domains of the business model.

In a network slicing and platform-based business model, the MNO can play key roles in the value proposition such as: ecosystem orchestrator (for partners offering services to their customers); value network orchestrator (for ICT, device OEM manufacturers and OTT providers); and innovation coordinator (for innovative value-sharing mechanisms with other partners) [203].

IX. CONCLUSION

In this article, we have presented a state-of-the-art survey on business models for emerging 5G networks and mobile network operators (MNOs). Based on the survey and discussion of various models, the paper recommends that novel disruptive and sustainable business models are absolutely necessary for consideration by MNOs who plan to or are in the process of deploying 5G network technologies to provide innovative services. The paper discussed the possible options that MNOs can employ disruptive and adaptive business models when rolling out 5G networks in relation to unique challenges of different markets within the global telecommunication sector. Disruptive 5G business models, which have been developed and used in advanced user markets, are discussed. The paper then presents viable and context based 5G business model concepts for MNOs in low- and middle-income countries, emulating successes in more developed and advanced regions of the world. Furthermore, the paper describes key value chain components within current 5G markets and presented a feasibility study on relevant use cases for 5G business models which MNOs could implement. In addition, emerging network deployment concepts of private 5G networks and their associated business models is discussed. Finally, the paper presents a few key open research challenges related to the problem of developing 5G business models in the context of MNOs in emerging economies.

A more concerted effort is required from industry (e.g., MNOs and vertical markets key partners), relevant government agencies (e.g., regulators and policy makers), academia and the research community to address the critical issue of appropriate business models to facilitate and stimulate 5G network deployments and harness applications for vertical industries. The paper makes a positive contribution towards this goal. In this respect, we recommend national 5G end-to-end testbeds for developing and testing context-aware innovative 5G services as well as generating supporting research-evidence for regulators and policy decisions regarding 5G spectrum allocation & technical regulations.

Future research and possible extension of the work presented in this article is on business models for beyond 5G networks, such as 6G. Two specific suggestions recently presented are to: (1) investigate the links between 6G enabling technologies and 6G business models [204]; and (2) perform a comprehensive techno-economic analysis of 6G, involving 6G business models and five other key ingredients (use cases, technologies, modeling techniques, financial metrics and spatial focus) [14].

REFERENCES

[1] *IMT Vision—Framework and Overall Objectives of the Future Development of IMT for 2020 and Beyond*, document ITU-R M.2083-0, International Telecommunication Union, 2015. [Online]. Available: https://www.itu.int/rec/R-REC-M.2083

[2] 3GPP. (2020). *3GPP Release 16*. Accessed: Mar. 23, 2021. [Online]. Available: https://www.3gpp.org/release-16

[3] 3GPP. (2021). *3GPP Release 17*. Accessed: Mar. 23, 2021. [Online]. Available: https://www.3gpp.org/release-17

[4] M. H. Alsharif, A. H. Kelechi, M. A. Albreem, S. A. Chaundry, M. S. Zia, and S. Kim, "Sixth generation (6G) wireless networks: Vision, research activities, challenges and potential solutions," *Symmetry*, vol. 12, no. 4, pp. 1–21, Apr. 2020.

[5] Ericsson. (2021). *This is 5G*. Accessed: Apr. 21, 2022. [Online]. Available: https://www.ericsson.com/49f1c9/assets/local/5g/documents/07052021-ericsson-this-is-5g.pdf

[6] Huawei. (2018). *Global Industry Vision 2025: Unfolding the Industry Blueprint of an Intelligent World*. Accessed: Apr. 21, 2022. [Online]. Available: https://www.huawei.com/en/giv/download-the-reports

[7] S. Kukliński, L. Tomaszewski, K. Kozłowski, and S. Pietrzyk, "Business models of network slicing," in *Proc. 9th Int. Conf. Netw. Future (NOF)*, Poznań, Poland, Nov. 2018, pp. 39–43.

[8] S. Moqaddamerad, "Visioning business model innovation for emerging 5G mobile communications networks," *Technol. Innov. Manag. Rev.*, vol. 10, no. 12, pp. 4–18, Dec. 2020.

[9] F. Newth, *Business Models and Strategic Management: A New Integration*. Hampton, NJ, USA: Business Expert Press, 2012.

[10] I. Lemus-Aguilar, G. Morales-Alonso, A. Ramirez-Portilla, and A. Hidalgo, "Sustainable business models through the lens of organizational design: A systematic literature review," *Sustainability*, vol. 11, no. 19, p. 5379, Sep. 2019.

[11] M. Dodgson, D. M. Gann, and A. Salter, *The Management of Technological Innovation: Strategy and Practice*. London, U.K.: Oxford Univ. Press, 2008.

[12] S. Yrjölä, P. Ahokangas, and M. Matinmikko-Blue, "Value creation and capture from technology innovation in the 6G era," *IEEE Access*, vol. 10, pp. 16299–16319, 2022.

[13] J. Aranda, E. J. Cabrera, D. Haro-Mendoza, and F. A. Salinas, "5G networks: A review from the perspectives of architecture, business models, cybersecurity, and research developments," *Novasinergia*, vol. 4, no. 1, pp. 6–41, Jun. 2021.

[14] E. J. Oughton and W. Lehr, "Surveying 5G techno-economic research to inform the evaluation of 6G wireless technologies," *IEEE Access*, vol. 10, pp. 25237–25257, 2022.

[15] E. Borcoci, A.-M. Drăgulinescu, F. Y. Li, M.-C. Vochin, and K. Kjellstadli, "An overview of 5G slicing operational business models for Internet of vehicles, maritime IoT applications and connectivity solutions," *IEEE Access*, vol. 9, pp. 156624–156646, 2021.

[16] L. U. Khan, I. Yaqoob, N. H. Tran, Z. Han, and C. S. Hong, "Network slicing: Recent advances, taxonomy, requirements, and open research challenges," *IEEE Access*, vol. 8, pp. 36009–36028, 2020.

[17] M. Agiwal, A. Roy, and N. Saxena, "Next generation 5G wireless networks: A comprehensive survey," *IEEE Commun. Surveys Tuts.*, vol. 18, no. 3, pp. 1617–1655, 3rd Quart., 2016.

[18] A. Gupta and R. K. Jha, "A survey of 5G network: Architecture and emerging technologies," *IEEE access*, vol. 3, pp. 1206–1232, 2015.

[19] E. Gures, I. Shayea, A. Alhammandi, M. Ergen, and H. Mohamad, "A comprehensive survey on mobility management in 5G heterogeneous networks: Architectures, challenges and solutions," *IEEE Access*, vol. 8, pp. 195883–195913, 2020.

[20] A. El Rhayour and T. Mazri, "5G architecture: Deployment scenarios and options," in *Proc. Int. Symp. Adv. Electr. Commun. Technol. (ISAECT)*, Rome, Italy, Nov. 2019, pp. 1–6.

[21] G. Liu, Y. Huang, Z. Chen, L. Liu, Q. Wang, and N. Li, "5G deployment: Standalone vs. non-standalone from the operator perspective," *IEEE Commun. Mag.*, vol. 58, no. 11, pp. 83–89, Nov. 2020.

[22] O. O. Erunkulu, A. M. Zungeru, C. K. Lebekwe, M. Mosalaosi, and J. M. Chuma, "5G mobile communication applications: A survey and comparison of use cases," *IEEE Access*, vol. 9, pp. 97251–97295, 2021.

[23] Malta Communications Authority. (2019). *5G Demand and Future Business Models: Towards a Feasible 5G Deployment*. Accessed: Apr. 21, 2022. [Online]. Available: https://www.mca.org.mt/consultations-decisions/5g-demand-and-future-business-models-towards-feasible-5g-deployment

[24] J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. K. Soong, and J. C. Zhang, "What will 5G be?" *IEEE J. Sel. Areas Commun.*, vol. 32, no. 6, pp. 1065–1082, Jun. 2014.

[25] P. Popovski, K. F. Trillingsgaard, O. Simeone, and G. Durisi, "5G wireless network slicing for eMBB, URLLC, and mMTC: A communication-theoretic view," *IEEE Access*, vol. 6, pp. 55765–55779, 2018.

[26] C. Bockelmann *et al.*, "Towards massive connectivity support for scalable mMTC communications in 5G networks," *IEEE Access*, vol. 6, pp. 28969–28992, 2018.

[27] A. Anand, G. de Veciana, and S. Shakkottai, "Joint scheduling of URLLC and eMBB traffic in 5G wireless networks," *IEEE/ACM Trans. Netw.*, vol. 28, no. 2, pp. 477–490, Feb. 2020.

[28] S. El Hassani, A. Haidine, and H. Jebbar, "Road to 5G: Key enabling technologies," *J. Commun.*, vol. 14, no. 11, pp. 1034–1048, Nov. 2019.

[29] P. Kaur and R. Garg, "A survey on key enabling technologies towards 5G," in *IOP Conf. Series: Mater. Sci. Eng.*, vol. 1033, no. 1, 2021, Art. no. 012011.

[30] D. Jiang and G. Liu, "An overview of 5G requirements," in *5G Mobile Communications*. Springer, Oct. 2017, pp. 3–26.

[31] I. F. Akyildiz, P. Wang, and S.-C. Lin, "Softair: A software defined networking architecture for 5g wireless systems," *Comput. Netw.*, vol. 85, pp. 1–18, Jul. 2015.

[32] C. Bektas, S. Monhof, F. Kurtz, and C. Wietfeld, "Towards 5G: An empirical evaluation of software-defined end-to-end network slicing," in *Proc. IEEE Globecom Workshops (GC Wkshps)*, Abu Dhabi, United Arab Emirates, Dec. 2018, pp. 1–6.

[33] S. Sridharan, "A literature review of network function virtualization (NFV) in 5G networks," *Int. J. Comput. Trends Technol.*, vol. 68, no. 10, pp. 49–55, Oct. 2020.

[34] I. F. Akyildiz, S. Nie, S.-C. Lin, and M. Chandrasekaran, "5G roadmap: 10 key enabling technologies," *Comput. Netw.*, vol. 106, pp. 17–48, Sep. 2016.

[35] J. Hasneen and K. M. Sadique, "A survey on 5G architecture and security scopes in SDN and NFV," in *Applied Information Processing Systems*. Singapore: Springer, 2022, pp. 447–460.

[36] X. Foukas, G. Patounas, A. Elmokashfi, and M. K. Marina, "Network slicing in 5G: Survey and challenges," *IEEE Commun. Mag.*, vol. 55, no. 5, pp. 94–100, May 2017.

[37] A. Alex, A. Ahmad, R. Mijumbi, and A. Hines, "5G network slicing using SDN and NFV: A survey of taxonomy, architectures and future challenges," *Comput. Netw.*, vol. 167, pp. 1–40, Feb. 2020.

[38] J. Noll, S. Dixit, D. Radovanovic, M. Morshedi, C. Holst, and A. S. Winkler, "5G network slicing for digital inclusion," in *Proc. 10th Int. Conf. Commun. Syst. Netw. (COMSNETS)*, Jan. 2018, pp. 191–197.

[39] F. Adachi, R. Takahashi, and H. Matsuo, "Challenges for beyond 5G: Ultra-densification of radio access network," *J. Commun.*, vol. 41, no. 11, pp. 1–11, Nov. 2020.

[40] X. Ge, S. Tu, G. Mao, and C. X. Wang, "5G ultra-dense cellular networks," *IEEE Trans. Wireless Commun.*, vol. 23, no. 1, pp. 72–79, Feb. 2016.

[41] S. D. Asha, "A comprehensive review of millimeter wave based radio over fiber for 5G front haul transmissions," *Indian J. Sci. Technol.*, vol. 14, no. 1, pp. 86–100, Jan. 2021.

[42] G. Chittimoju and U. D. Yalavarthi, "A comprehensive review on millimeter waves applications and antennas," *J. Phys., Conf. Ser.*, vol. 1804, pp. 1–7, Feb. 2021.

[43] S. Yrjola, "Technology antecedents of the platform-based ecosystemic business models beyond 5G," in *Proc. IEEE Wireless Commun. Netw. Conf. Workshops (WCNCW)*, Seoul, South Korea, Apr. 2020, pp. 1–8.

[44] M. Nuccio and M. Guerzoni, "Big data: Hell or heaven? Digital platforms and market power in the data-driven economy," *Competition Change*, vol. 23, no. 3, pp. 312–328, Jun. 2019.

[45] W. Coetzee, F. Mekuria, and Z. D. Toit, "Making 5G a reality for Africa," Council Sci. Ind. Res. (CSIR), Collaboration Ericsson, New Delhi, India, Tech. Rep., 2018. Accessed: Apr. 21, 2022. [Online]. Available: https://www.ericsson.com/assets/local/press-releases/africa/2018/5g-africa-report-11-2018.pdf

[46] P. Gandotra and R. K. Jha, "A survey on green communication and security challenges in 5G wireless communication networks," *J. Netw. Comput. Appl.*, vol. 96, pp. 39–61, Oct. 2017.

[47] Q. Wu, G. Y. Li, W. Chen, D. W. K. Ng, and R. Schober, "An overview of sustainable green 5G networks," *IEEE Wireless Commun.*, vol. 24, no. 4, pp. 72–80, Aug. 2017.

[48] Z. Yan, Z. Zhang, and Y. Meng, "Energy efficiency optimization for UAV-assisted mMTC networks with altitude differences," in *Proc. IEEE/CIC Int. Conf. Commun. China (ICCC)*, Jul. 2021, pp. 306–311.

[49] C. Kalalas and J. Alonso-Zarate, "Massive connectivity in 5G and beyond: Technical enablers for the energy and automotive verticals," in *Proc. 2nd 6G Wireless Summit (6G SUMMIT)*, Mar. 2020, pp. 1–5.

[50] G. Kumar, M. Lydia, and Y. Levron, "Security challenges in 5G and IoT networks: A review," in *Secure Communication for 5G and IoT Networks*. 2022, pp. 1–13.

[51] M. N. Tehrani, M. Uysal, and H. Yanikomeroglu, "Device-to-device communication in 5G cellular networks: Challenges, solutions, and future directions," *IEEE Commun. Mag.*, vol. 52, no. 5, pp. 86–92, May 2014.

[52] J. Kim, J. Lee, J. Kim, and J. Yun, "M2M service platforms: Survey, issues, and enabling technologies," *IEEE Commun. Surveys Tuts.*, vol. 16, no. 1, pp. 61–76, 1st Quart., 2014.

[53] G. S. Gaba, G. Kumar, T.-H. Kim, H. Monga, and P. Kumar, "Secure device-to-device communications for 5G enabled Internet of Things applications," *Comput. Commun.*, vol. 169, pp. 114–128, Mar. 2021.

[54] Q.-U.-A. Nadeem, A. Kammoun, and M.-S. Alouini, "Elevation beamforming with full dimension MIMO architectures in 5G systems: A tutorial," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 4, pp. 3238–3273, 4th Quart., 2019.

[55] D. Lopez-Perez, A. De Domenico, N. Piovesan, G. Xinli, H. Bao, S. Qitao, and M. Debbah, "A survey on 5G radio access network energy efficiency: Massive MIMO, lean carrier design, sleep modes, and machine learning," *IEEE Commun. Surveys Tuts.*, vol. 24, no. 1, pp. 653–697, 1st Quart., 2022.

[56] R. Chataut and R. Akl, "Massive MIMO systems for 5G and beyond networks—Overview, recent trends, challenges, and future research direction," *Sensors*, vol. 20, no. 10, p. 2753, May 2020.

[57] K. S. Mohamed, M. Y. Alias, M. Roslee, and Y. M. Raji, "Towards green communication in 5G systems: Survey on beamforming concept," *IET Commun.*, vol. 15, no. 1, pp. 142–154, Jan. 2021.

[58] M. Xie, A. J. Gonzalez, P. Gronsund, H. Lonsethagen, P. Waldemar, C. Tranoris, S. Denazis, and A. Elmokashfi, "Practically deploying multiple vertical services into 5G networks with network slicing," *IEEE Netw.*, vol. 36, no. 1, pp. 32–39, Jan./Feb. 2022.

[59] M. Femminella, M. Pergolesi, and G. Reali, "Simplification of the design, deployment, and testing of 5G vertical services," in *Proc. IEEE/IFIP Netw. Oper. Manag. Symp. (NOMS)*, Budapest, Hungary, Apr. 2020, pp. 1–7.

[60] 5G-ACIA. *Industrial 5G*. Accessed: Apr. 27, 2022. [Online]. Available: https://5g-acia.org/resources/whitepapers-deliverables

[61] R. He, C. Chang, G. Zhao, Z. Qin, and X. Qin, "Police security communication over public cellular network infrastructure," in *Proc. 7th IEEE Int. Symp. Netw. Comput. Appl.*, Jul. 2008, pp. 232–235.

[62] F. C. Bormann, S. Flake, and J. Tacken, "Business models for local mobile services enabled by convergent online charging," in *Proc. 16th IST Mobile Wireless Commun. Summit*, Jul. 2007, pp. 1–5.

[63] M. Wen, Q. Li, K. J. Kim, D. Lopez-Perez, O. Dobre, H. V. Poor, P. Popovski, and T. Tsiftsis, "Private 5G networks: Concepts, architectures, and research landscape," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 1, pp. 7–25, Jan. 2022.

[64] S. Guo, B. Lu, M. Wen, S. Dang, and N. Saeed, "Customized 5G and beyond private networks with integrated URLLC, eMBB, mMTC, and positioning for industrial verticals," *IEEE Commun. Standards Mag.*, vol. 6, no. 1, pp. 52–57, Mar. 2022.

[65] M. Maman *et al.*, "Beyond private 5G networks: Applications, architectures, operator models and technological enablers," *EURASIP J. Wireless Commun. Netw.*, vol. 2021, no. 1, pp. 1–46, Dec. 2021.

[66] X. Li, C. Guimaraes, G. Landi, J. Brenes, J. Mangues-Bafalluy, J. Baranda, D. Corujo, V. Cunha, J. Fonseca, J. Alegria, A. Z. Orive, J. Ordonez-Lucena, P. Iovanna, C. J. Bernardos, A. Mourad, and X. Costa-Perez, "Multi-domain solutions for the deployment of private 5G networks," *IEEE Access*, vol. 9, pp. 106865–106884, 2021.

[67] *5G IoT Private & Dedicated Networks for Industry 4.0—A Guide to Private and Dedicated 5G Networks for Manufacturing, Production and Supply Chains*, GSMA, London, U.K., Oct. 2020.

[68] J. Ordonez-Lucena, J. Folgueira Chavarria, L. M. Contreras, and A. Pastor, "The use of 5G non-public networks to support industry 4.0 scenarios," in *Proc. IEEE Conf. Standards Commun. Netw. (CSCN)*, Oct. 2019, pp. 1–7.

[69] *5G Non-Public Networks for Industrial Scenarios, White Paper*, 5G Alliance Connected Ind. Automat., 5GACIA, Frankfurt, Germany, Jul. 2019.

[70] W. Y. Poe, J. Ordonez-Lucena, and K. Mahmood, "Provisioning private 5G networks by means of network slicing: Architectures and challenges," in *Proc. IEEE Int. Conf. Commun. Workshops (ICC Workshops)*, Jun. 2020, pp. 1–6.

[71] Ericsson. (Oct. 2019). *5G for Business: A 2030 Market Compass—Setting a Direction for 5G-Powered B2B Opportunities*. [Online]. Available: https://www.ericsson.com/en/5g/5g-for-business/5g-for-business-a-2030-market-compass

[72] E. Obiodu. (Apr. 2019). *The 5G Guide: A Reference for Operators*. [Online]. Available: https://www.gsma.com/wp-content/uploads/2019/04/The-5G-Guide_GSMA_2019_04_29_compressed.pdf

[73] E. J. Oughton, N. Comini, V. Foster, and J. W. Hall, "Policy choices can help keep 4G and 5G universal broadband affordable," *Technol Forecasting Social Change*, vol. 176, Mar. 2022, Art. no. 121409.

[74] A. Banchs, D. M. Gutierrez-Estevez, M. Fuentes, M. Boldi, and S. Provvedi, "A 5G mobile network architecture to support vertical industries," *IEEE Commun. Mag.*, vol. 57, no. 12, pp. 38–44, Dec. 2019.

[75] S. Moqaddamerad, P. Ahokangas, M. Matinmikko, and R. Rohrbeck, "Using scenario-based business modelling to explore the 5G telecommunication market," *J. Futures Stud.*, vol. 22, no. 1, pp. 1–18, Sep. 2017.

[76] C. Najjuuko, G. K. Ayebare, R. Lukanga, E. Mugume, and D. Okello, "A survey of 5G for rural broadband connectivity," in *Proc. IST-Africa Conf. (IST-Africa)*, May 2021, pp. 1–10.

[77] K. Campbell, J. Diffley, B. Flanagan, B. Morelli, B. O'Neil, and F. Sideco, "The 5G economy: How 5G technology will contribute to the global economy," IHS Econ., IHS Technol., Landisville, PA, USA, Tech. Rep., Jan. 2017. [Online]. Available: https://cdn.ihs.com/www/pdf/IHS-Technology-5G-Economic-Impact-Study.pdf

[78] F. Liu, Q. Gong, and J. Zhou, "Reform of the practice teaching system of entrepreneurship education based on 5G fog computing in colleges and universities," *Sci. Program.*, vol. 2021, pp. 1–12, Oct. 2021.

[79] A. Baratè, G. Haus, L. A. Ludovico, E. Pagani, and N. Scarabottolo, "5G technology for augmented and virtual reality in education," in *Proc. Int. Conf. Educ. New Develop. (END)*, Jun. 2019, pp. 512–516.

[80] N. Virmani, S. Sampath, Y. Vasudeo, S. Shinde, S. Sharma, and A. Mathur, "Mobile application development for VR in education," in *Proc. 2nd Int. Conf. Recent Trends Mach. Learn., IoT, Smart Cities Appl. (ICMISC)*. Singapore: Springer, 2022, pp. 431–441.

[81] Y. Luo and K. K. Yee, "Research on online education curriculum resources sharing based on 5G and Internet of Things," *J. Sensors*, vol. 2022, Jan. 2022, Art. no. 9675342.

[82] G. Kún, R. Kovács, K. Mészáros, T. Wührl, S. Gyányi, L. Nádai, and P. J. Varga, "Introduction of 5G in education," in *Proc. IEEE 4th Int. Conf. Workshop Óbuda Electr. Power Eng. (CANDO-EPE)*, Nov. 2021, pp. 147–152.

[83] K. Okeleke, D. George, and E. Obiodu, "5G in sub-Saharan Africa: Laying the foundations," GSMA, London, U.K., Tech. Rep., Jul. 2019. [Online]. Available: https://data.gsmaintelligence.com/research/research/research-2019/5g-in-sub-saharan-africa-laying-the-foundations

[84] A. Aijaz, "Private 5G: The future of industrial wireless," *IEEE Ind. Electron. Mag.*, vol. 14, no. 4, pp. 136–145, Dec. 2020.

[85] B. R. Kumar, "AT&T–time warner acquisition," in *Wealth Creation in the World's Largest Mergers and Acquisitions*. Cham, Switzerland: Springer, 2019, pp. 121–129.

[86] GSMA Intelligence. (2021). *The Mobile Economy 2021*. [Online]. Available: https://www.gsma.com/mobileeconomy/wp-content/uploads/2021/07/GSMA_MobileEconomy2021_3.pdf

[87] World Bank. (2016). *Exploring the Relationship Between Broadband and Economic Growth*. [Online]. Available: https://openknowledge.worldbank.org/handle/10986/23638

[88] GSMA and TMG. (Dec. 2018). *Study on Socio-Economic Benefits of 5G Services Provided in mmWave Bands*. [Online]. Available: https://www.gsma.com/spectrum/wp-content/uploads/2018/12/5G-mmWave-benefits.pdf

[89] Ericsson. (Oct. 2017). *The 5G Business Potential*. [Online]. Available: https://www.ericsson.com/assets/local/networks/documents/report-bnew-17001714.pdf

[90] A. Wang, L. Yu, A. Mudesir, D. Zhu, B. Zhao, and T. S. Siew, "5G unlocks a world of opportunities: Top ten 5G use cases," Huawei Technol., Shenzhen, China, Tech. Rep., 2017. [Online]. Available: https://www-file.huawei.com/-/media/CORPORATE/PDF/mbb/5g-unlocks-a-world-of-opportunities-v5.pdf?la=en

[91] *The 5G Business Potential*, 2nd ed., Ericsson, Stockholm, Sweden, 2017.

[92] T. Hatt and P. Jarch. (Dec. 2020). Global mobile trends 2021: Navigating COVID-19 and beyond. GSMA Intelligence. [Online]. Available: https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=58621970&file=141220-Global-Mobile-Trends.pdf

[93] GSA. (Apr. 2021). *5G Market Snapshot: April 2021—Member Report*. [Online]. Available: https://gsacom.com/paper/5g-market-snapshot-april-2021-member-report/

[94] I. A. Adimula, A. O. Idowu, and G. I. Ojerheghan, "Radio propagation and the 5G network in Africa," *Int. J. Sci. Res. Eng. Develop.*, vol. 3, no. 6, pp. 1190–1195, Nov.-Dec. 2020.

[95] M. Iji, D. Nichiforov-Chuang, J. Joiner, and A. Hira, "Global 5G landscape, Q1 2021," GSMA, London, U.K., Tech. Rep., Apr. 2021. [Online]. Available: https://data.gsmaintelligence.com/research/research/research-2021/global-5g-landscape-q1-2021

[96] C. K. Agubor, N. Chukwuchekwa, and L. S. Ezema, "5G network deployment in Nigeria: Key challenges and the way forward," *Eur. J. Eng. Technol. Res.*, vol. 6, no. 3, pp. 16–19, Mar. 2021.

[97] M. Jaber, M. A. Imran, R. Tafazolli, and A. Tukmanov, "5G backhaul challenges and emerging research directions: A survey," *IEEE Access*, vol. 4, pp. 1743–1766, 2016.

[98] C. Handforth, "Closing the coverage gap how innovation can drive rural connectivity," GSMA, London, U.K., Tech. Rep., Jul. 2019. [Online]. Available: https://www.gsma.com/mobilefordevelopment/resources/closing-the-coverage-gap-how-innovation-can-drive-rural-connectivity/

[99] A. M. Cavalcante, M. V. Marquezini, and C. S. Moreno, "5G for remote areas: Challenges, opportunities and business modeling for Brazil," *IEEE Access*, vol. 9, pp. 10829–10843, 2021.

[100] Q. Xu and X. Wu, "A model of 'secondary innovation' process," in *Proc. Portland Int. Conf. Manag. Eng. Technol. (PICMET)*, Portland, OR, USA, Oct. 1991, pp. 617–620.

[101] *Draft Standard for Architecture for Low Mobility Energy Efficient Network for Affordable Broadband Access*, IEEE Mobile Communication Network Standards P2061/D1, IEEE Communications Society, Dec. 2021.

[102] X. Wu, R. Ma, and Y. Shi, "How do latecomer firms capture value from disruptive technologies? A secondary business-model innovation perspective," *IEEE Trans. Eng. Manag.*, vol. 57, no. 1, pp. 51–62, Feb. 2010.

[103] DotEcon and Axon Partners Group. (2018). *Study on Implications of 5G Deployment on Future Business Models*. [Online]. Available: https://berec.europa.eu/eng/document_register/subject_matter/berec/download/0/8008-study-on-implications-of-5g-deployment-o_0.pdf

[104] M. Suryanegara, "5G as disruptive innovation: Standard and regulatory challenges at a country level," *Int. J. Technol.*, vol. 7, no. 4, pp. 635–642, 2016.

[105] J. M. Bauer and E. Bohlin, "Regulation and innovation in 5G markets," *Telecommun. Policy*, vol. 46, no. 4, pp. 1–15, 2022.

[106] *5G Vision—The 5G Infrastructure Public Private Partnership: The Next Generation of Communication Networks and Services*, 5G Infrastruct. PPP Assoc., 5G-PPP White Paper, Feb. 2015.

[107] P. Ahokangas, M. Matinmikko-Blue, S. Yrjölä, V. Seppänen, V. H. Hämmäinen, R. Jurva, and M. Latva-Aho, "Business models for local 5G micro operators," *IEEE Trans. Cogn. Commun. Netw.*, vol. 7, no. 3, pp. 730–740, Sep. 2019.

[108] M. Matinmikko, M. Latva-Aho, P. Ahokangas, and V. Seppänen, "On regulations for 5G: Micro licensing for locally operated networks," *Telecommun. Policy*, vol. 42, no. 8, pp. 622–635, Sep. 2018.

[109] M. Taheribakhsh, A. Jafari, M. M. Peiro, and N. Kazemifard, "5G implementation: Major issues and challenges," in *Proc. 25th Int. Comput. Conf., Comput. Soc. Iran (CSICC)*, 2020, pp. 1–5.

[110] *5G Spectrum-Public Policy Position*, GSM Assoc., London, U.K., Nov. 2016.

[111] C. Goyal, K. Amit, M. Esposito, and S. B. Serji, "Understanding business model—Literature review of concepts and trends," *Int. J. Competitiveness*, vol. 1, no. 2, pp. 99–118, Jun. 2017.
[112] C. Zott, R. Amit, and L. Massa, "The business model: Recent developments and future research," *J. Manag.*, vol. 37, no. 4, pp. 1019–1042, Jul. 2011.
[113] D. J. Teece, "Business models, business strategy and innovation," *Long Range Planning*, vol. 43, nos. 2–3, pp. 172–194, Apr./Jun. 2010.
[114] B. W. Wirtz, *Digital Business Models: Concepts, Models, and the Alphabet Case Study*. Cham, Switzerland: Springer, 2019.
[115] M. M. Al-Debei, R. El-Haddadeh, and D. Avison, "Defining the business model in the new world of digital business," in *Proc. 14th Americas Conf. Inf. Syst. (AMCIS)*, Toronto, ON, Canada, Aug. 2008, pp. 1–11.
[116] C. Baden-Fuller and S. Haefliger, "Business models and technological innovation," *Long Range Planning*, vol. 46, no. 6, pp. 419–426, Dec. 2013.
[117] D. J. Teece, "Business models and dynamic capabilities," *Long Range Planning*, vol. 51, no. 1, pp. 40–49, Feb. 2018.
[118] R. Casadesus-Masanell and J. E. Ricart, "From strategy to business models and onto tactics," *Long Range Planning*, vol. 43, nos. 2–3, pp. 195–215, 2010.
[119] S. K. Rao and R. Prasad, "Telecom operators' business model innovation in a 5G world," *J. Multi Bus. Model Innov. Technol.*, vol. 4, no. 3, pp. 149–178, Sep. 2018.
[120] A. Osterwalder and Y. Pigneur, *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. Hoboken, NJ, USA: Wiley, 2010.
[121] E. Fielt, "Conceptualizing business models: Definitions, frameworks and classifications," *J. Bus. Models*, vol. 1, no. 1, pp. 85–105, Oct. 2013.
[122] M. Yunus, B. Moingeon, and L. Lehmann-Ortega, "Building social business models: Lessons from the Grameen experience," *Long Range Planning*, vol. 43, nos. 2–3, pp. 308–325, Apr. 2010.
[123] B. W. Wirtz, A. Pistoia, S. Ullrich, and V. Göttel, "Business models: Origin, development and future research perspectives," *Long Range Planning*, vol. 49, no. 1, pp. 36–54, Feb. 2016.
[124] R. Amit and C. Zott, "Creating value through business model innovation," *MIT Sloan Manag. Rev.*, vol. 53, no. 3, pp. 41–49, Mar. 2012.
[125] C. M. DaSilva and P. Trkman, "Business model: What it is and what it is not," *Long Range Planning*, vol. 47, no. 6, pp. 379–389, Dec. 2014.
[126] M. W. Johnson, C. M. Christensen, and H. Kagermann, "Reinventing your business model," *Harvard Bus. Rev.*, vol. 86, no. 12, pp. 59–67, Dec. 2008.
[127] H. Chesbrough, "Business model innovation: It's not just about technology anymore," *Strategy Leadership*, vol. 35, pp. 12–17, Nov. 2007.
[128] A. Afuah, *Business Model Innovation: Concepts, Analysis, and Cases*, 2nd ed. New York, NY, USA: Routledge, 2019.
[129] J. Gordijn, A. Osterwalder, and Y. Pigneur, "Comparing two business model ontologies for designing e-business models and value constellations," in *Proc. 18th Bled eConf.*, Bled, Slovenia, Dec. 2005, pp. 1–17.
[130] A. Osterwalder and Y. Pigneur, "Investigating the use of the business model concept through interviews," in *Proc. 4th Int. Conf. Electron. Bus. (ICEB)*, Dec. 2004, pp. 568–573.
[131] A. Osterwalder, Y. Pigneur, and C. L. Tucci, "Clarifying business models: Origins, present, and future of the concept," *Commun. Assoc. Inf. Syst.*, vol. 16, no. 1, pp. 1–25, 2005.
[132] S. K. Rao, "Socio-economic impact of 5G technologies," Ph.D. dissertation, Dept. Bus. Develop. Technol., Aarhus Univ., Aarhus, Denmark, 2018.
[133] S. Dhir, V. Ongsakul, Z. U. Ahmed, and R. Rajan, "Integration of knowledge and enhancing competitiveness: A case of acquisition of Zain by Bharti Airtel," *J. Bus. Res.*, vol. 119, pp. 674–684, Oct. 2020.
[134] P. Ballon, "Scenarios and business models for 4G in Europe," *Info*, vol. 6, no. 6, pp. 363–382, Dec. 2004.
[135] K. E. Skouby, "5G business models & trends in rural communication," *J. Mobile Multimedia*, vol. 17, nos. 1–3, pp. 1–12, Feb. 2020.
[136] C. Stork, H. S. Nwana, S. Esselaar, and M. Koyabe, "Over the top (OTT) applications & the internet value chain," Commonwealth Telecommun. Org., London, U.K., Tech. Rep., 2020. Accessed: Apr. 21, 2022. [Online]. Available: https://cto.int/wp-content/uploads/2020/05/CTO-OTT-REPORT-2020.pdf
[137] S. Iankova, I. Davies, C. Archer-Brown, B. Marder, and A. Yua, "A comparison of social media marketing between B2B, B2C and mixed business models," *Ind. Marketing Manage.*, vol. 81, pp. 169–179, Aug. 2019.
[138] M. M. Al-Debei and D. Avison, "Business model requirements and challenges in the mobile telecommunication sector," *J. Org. Transformation Social Change*, vol. 8, no. 2, pp. 215–235, Dec. 2011.
[139] D. Fasnacht, "The ecosystem strategy: Disruptive business model innovation," *Zeitschrift Führung Org.*, vol. 89, no. 3, pp. 168–173, Jun. 2020.
[140] J. Peppard and A. Rylander, "From value chain to value network: Insights for mobile operators," *Eur. Manag. J.*, vol. 24, nos. 2–3, pp. 128–141, Apr. 2006.
[141] G. S. Schiavi and A. Behr, "Emerging technologies and new business models: A review on disruptive business models," *Innov. Manag. Rev.*, vol. 15, no. 4, pp. 338–355, Oct. 2018.
[142] A. Kaloxylos, R. Peppe, and A. Gavra. (Aug. 2020). *Empowering Vertical Industries through 5G Networks—Current Status and Future Trends, 5GPPP White Paper*. [Online]. Available: https://5g-ppp.eu/wp-content/uploads/2020/09/5GPPP-VerticalsWhitePaper-2020-Final.pdf
[143] R. Gupta and S. Parida, "Challenges and opportunities: Mobile broadband," *Int. J. Future Comput. Commun.*, vol. 2, no. 6, pp. 660–664, 2013.
[144] M. A. Lema, A. Laya, T. Mahmoodi, M. Cuevas, J. Sachs, J. Markendahl, and M. Dohler, "Business case and technology analysis for 5G low latency applications," *IEEE Access*, vol. 5, pp. 5917–5935, 2017.
[145] K. Timeus, J. Vinaixa, and F. Pardo-Bosch, "Creating business models for smart cities: A practical framework," *Public Manag. Rev.*, vol. 22, no. 5, pp. 726–745, May 2020.
[146] I. Malolli, "Pricing policies and new business models for data communication over 5G networks," *J. Int. Sci. Publications, Econ. Bus.*, vol. 11, no. 1, pp. 398–406, 2017.
[147] R. Pepper. (Feb. 2017). *Cisco Visual Networking Index (VNI) Global Mobile Data Traffic Forecast (2016 to 2021)*. [Online]. Available: https://newsroom.cisco.com/c/r/newsroom/en/us/a/y2017/m02/cisco-mobile-visual-networking-index-vni-forecast-projects-7-fold-increase-in-global-mobile-data-traffic-from-2016-2021.html
[148] M. A. Cusumano, D. B. Yoffie, and A. Gawer, "The future of platforms," *MIT Sloan Manag. Rev.*, vol. 61, no. 3, pp. 46–54, Apr. 2020.
[149] S. Yrjola, P. Ahokangas, and M. Matinmikko-Blue, "Novel context and platform driven business models via 5G networks," in *Proc. IEEE 29th Annu. Int. Symp. Pers., Indoor Mobile Radio Commun. (PIMRC)*, Bologna, Italy, Sep. 2018, pp. 1–7.
[150] M. Jiang, M. Condoluci, and T. Mahmoodi, "Network slicing in 5G: An auction-based model," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Paris, France, May 2017, pp. 1–6.
[151] *Network Functions Virtualisation (NFV); Management and Orchestration*, Standard ETSI GS NFV-MAN 001, Version 1.1.1, Dec. 2014.
[152] P. Ahokangas, S. Moqaddamerad, M. Matinmikho, A. Abouzeid, I. Atkova, J. F. Gomes, and M. Iivari, "Future micro operators business models in 5G," *Bus. Manag. Rev.*, vol. 7, no. 5, pp. 143–149, Jun. 2016.
[153] S. Moqaddamerad, P. Ahkangas, M. Matinmikko, and V. Seppanen, "Toward the value-based business ecosystem model for 5G mobile communication networks," *Bus. Manag. Rev.*, vol. 9, no. 1, pp. 416–427, Jul. 2017.
[154] S. Moqaddamerad, Y. Xu, M. Iivari, and P. Ahokangas, "Business models based on co-opetition in a hyper-connected era: The case of 5G-enabled smart grids," in *Proc. 17th IFIP WG 5.5 Work. Conf. Virtual Enterprises (PRO-VE)*. Porto, Portugal: Springer, Oct. 2016, pp. 559–568.
[155] S. K. A. Kumar, R. Stewart, D. Crawford, and S. Chaudhari, "Business model for rural connectivity using multi-tenancy 5G network slicing," in *Proc. IEEE 17th Int. Conf. Smart Communities, Improving Quality Life Using ICT, IoT and AI (HONET)*, Charlotte, NC, USA, Dec. 2020, pp. 182–188.
[156] A. Rejeb and J. G. Keogh, "5G networks in the value chain," *Wireless Pers. Commun.*, vol. 117, no. 2, pp. 1577–1599, Mar. 2021.
[157] J. Lee and D. Kim, "A study on innovation in university education: Focusing on 5G mobile communication," *Proc. IEEE 17th Annu. Consum. Commun. Netw. Conf. (CCNC)*, Jan. 2020, pp. 1–4.
[158] N. Gupta, P. K. Juneja, S. Sharma, and U. Garg, "Future aspect of 5G-IoT architecture in smart healthcare system," in *Proc. 5th Int. Conf. Intell. Comput. Control Syst. (ICICCS)*, 2021, pp. 406–411.
[159] J. Hu, W. Liang, O. Hosam, M.-Y. Hsieh, and X. Su, "5GSS: A framework for 5G-secure-smart healthcare monitoring," *Connection Sci.*, vol. 34, no. 1, pp. 139–161, 2022.
[160] K. E. Khujamatov, T. K. Toshtemirov, A. P. Lazarev, and Q. T. Raximjonov, "IoT and 5G technology in agriculture," in *Proc. Int. Conf. Inf. Sci. Commun. Technol. (ICISCT)*, 2021, pp. 1–6.

[161] W. Tao, L. Zhao, G. Wang, and R. Liang, ''Review of the Internet of Things communication technologies in smart agriculture and challenges,'' *Comput. Electron. Agricult.*, vol. 189, Oct. 2021, Art. no. 106352.

[162] W. Zheng, D. Chen, J. Duan, H. Xu, W. Qian, L. Gu, and J. Yao, ''5G network slice configuration based on smart grid,'' in *Proc. IEEE 4th Adv. Inf. Manag., Communicates, Electron. Autom. Control Conf. (IMCEC)*, Jun. 2021, pp. 560–564.

[163] S. K. Rao and R. Prasad, ''Impact of 5G technologies on smart city implementation,'' *Wireless Pers. Commun.*, vol. 100, no. 1, pp. 161–176, 2018.

[164] B. Rusti, H. Stefanescu, J. Ghenta, and C. Patachia, ''Smart city as a 5G ready application,'' in *Proc. Int. Conf. Commun. (COMM)*, 2018, pp. 207–212.

[165] A. Gohar and G. Nencioni, ''The role of 5G technologies in a smart city: The case for intelligent transportation system,'' *Sustainability*, vol. 13, no. 9, p. 5188, 2021.

[166] World Health Organization and World Bank. (Feb. 9, 2004). *World Report on Road Traffic Injury Prevention*. [Online]. Available: https://www.who.int/publications/i/item/world-report-on-road-traffic-injury-prevention

[167] *5G Automotive Association (5GAA)*. Accessed: Apr. 14, 2022. [Online]. Available: https://5gaa.org/about-5gaa/about-us/

[168] D. Johnson. (2020). *5G: The Next Disrupter for Gaming and Mobile Networks*. [Online]. Available: https://www.samsung.com/global/business/networks/insights/blog/5g-the-next-disrupter-for-gaming-and-mobile-network-operators/

[169] M. R. Palattella, M. Dohler, A. Grieco, G. Rizzo, J. Torsner, T. Engel, and L. Ladid, ''Internet of Things in the 5G era: Enablers, architecture, and business models,'' *IEEE J. Sel. Areas Commun.*, vol. 34, no. 3, pp. 510–527, Mar. 2016.

[170] D. Bandyopadhyay and J. Sen, ''Internet of Things: Applications and challenges in technology and standardization,'' *Wireless Pers. Commun.*, vol. 58, no. 1, pp. 49–69, 2011.

[171] M. R. Palattella, P. Thubert, X. Vilajosana, T. Watteyne, Q. Wang, and T. Engel, ''6TiSCH wireless industrial networks: Determinism meets IPv6,'' in *Internet of Things*. New York, NY, USA: Springer, 2014, pp. 111–141.

[172] M. Kovacova and G. Lăzăroiu, ''Sustainable organizational performance, cyber-physical production networks, and deep learning-assisted smart process planning in industry 4.0-based manufacturing systems,'' *Econ., Manag., Financial Markets*, vol. 16, no. 3, pp. 41–54, 2021.

[173] M. Andronie, G. Lăzăroiu, M. Iatagan, I. Hurloiu, and I. Dijmărescu, ''Sustainable cyber-physical production systems in big data-driven smart urban economy: A systematic literature review,'' *Sustainability*, vol. 13, no. 2, pp. 1–15, 2021.

[174] G. H. Popescu, S. Petreanu, B. Alexandru, and H. Corpodean, ''Internet of Things-based real-time production logistics, cyber-physical process monitoring systems, and industrial artificial intelligence in sustainable smart manufacturing,'' *J. Self-Governance Manage. Econ.*, vol. 9, no. 2, pp. 52–62, 2021.

[175] E. Nica, C. I. Stan, A. G. Luţan, and R. Ş. Oaşa, ''Internet of Things-based real-time production logistics, sustainable industrial value creation, and artificial intelligence-driven big data analytics in cyber-physical smart manufacturing systems,'' *Econ., Manag., Financial Markets*, vol. 16, no. 1, pp. 52–62, 2021.

[176] G. Lăzăroiu, T. Kliestik, and A. Novak, ''Internet of Things smart devices, industrial artificial intelligence, and real-time sensor networks in sustainable cyber-physical production systemss,'' *J. Self-Governance Manag. Econ.*, vol. 9, no. 1, pp. 20–30, 2021.

[177] N. Kshetri, ''Economics of the Internet of Things in sub-Saharan Africa,'' *IT Prof.*, vol. 24, no. 1, pp. 81–85, Jan./Feb. 2022.

[178] GSMA. (2018). *The Internet of Things by 2025*. [Online]. Available: https://www.gsma.com/iot/wp-content/uploads/2018/08/GSMA-IoT-Infographic-2019.pdf

[179] W. Y. Poe, J. Ordonez-Lucena, and K. Mahmood, ''Provisioning private 5G networks by means of network slicing: Architectures and challenges,'' in *Proc. IEEE Int. Conf. Commun. Workshops (ICC Workshops)*, Jun. 2020, pp. 1–6.

[180] GSMA. (2020). *5G IoT Private & Dedicated Networks for Industry 4.0*. [Online]. Available: https://2020-10-GSMA-5G-IoT-Private-and-Dedicated-Networks-for-Industry-4.0.pdf

[181] Ericsson. *Ericsson USA 5G Smart Factory*. [Online]. Available: https://www.ericsson.com/en/about-us/company-facts/ericsson-worldwide/united-states/5g-smart-factory

[182] (2021). *DODs 5G-Powered Smart Warehouse Network Kicks Off*. [Online]. Available: https://gcn.com/articles/2021/02/19/marines-5g-smart-warehouse.aspx

[183] Mitsubishi Electric Cooperation. (2020). *Mitsubishi Electric Begins Demonstrating Local 5G System in Japan*. [Online]. Available: https://emea.mitsubishielectric.com/en/news/releases/global/2020/0518-a/index.html

[184] *China's First 5G Smart Coal Mine Launched in Shanxi*. [Online]. Available: http://en.sasac.gov.cn/2020/06/24/c5145.htm

[185] M. Zhong, Y. Yang, H. Yao, X. Fu, O. A. Dobre, and O. Postolache, ''5G and IoT: Towards a new era of communications and measurements,'' *IEEE Instrum. Meas. Mag.*, vol. 22, no. 6, pp. 18–26, Dec. 2019.

[186] A. Fellah. *5G Smart Sea Port: Hamburg Authority*. [Online]. Available: https://pf.content.nokia.com/t004f5-private-wireless-ports/use-case-5G-smart-sea-port

[187] B. R. Kumar, ''Case 9: Beijing Daxing international airport,'' in *Project Finance*. Cham, Switzerland: Springer, 2022, pp. 139–144.

[188] B. Ai, A. F. Molisch, M. Rupp, and Z. D. Zhong, ''5G key technologies for smart railways,'' *Proc. IEEE*, vol. 108, no. 6, pp. 856–893, Jun. 2020.

[189] I. Yaqoob, I. A. T. Hashem, A. Ahmed, S. A. Kazmi, and C. S. Hong, ''Internet of Things forensics: Recent advances, taxonomy, requirements, and open challenges,'' *Future Gener. Comput. Syst.*, vol. 92, pp. 265–275, Mar. 2019.

[190] J. F. Gomes, M. Iivari, P. Ahokangas, L. Isotalo, B. Sahlin, and J. Melén, ''Cyber security business models in 5G,'' in *A Comprehensive Guide to 5G Security*, M. Liyanage, I. Ahmad, A. B. Abro, A. Gurtov, and M. Ylianttila, Eds. Chichester, U.K.: Wiley, 2018, pp. 99–116.

[191] B. Somdyala, S. Rananga, L. Mfupe, M. Masonta, and F. Mekuria, ''Spectrum regulation for future internet networks in developing economies,'' in *Proc. IST-Africa Week Conf. (IST-Africa)*, Windhoek, Namibia, May/Jun. 2017, pp. 1–12.

[192] Q. Wu, J. Xu, Y. Zeng, D. W. K. Ng, N. Al-Dhahir, R. Schober, and A. L. Swindlehurst, ''A comprehensive overview on 5G-and-beyond networks with UAVs: From communications to sensing and intelligence,'' *IEEE J. Sel. Areas Commun.*, vol. 39, no. 10, pp. 2912–2945, Oct. 2021.

[193] M. Mozaffari, A. T. Z. Kasgari, W. Saad, M. Bennis, and M. Debbah, ''3D cellular network architecture with drones for beyond 5G,'' in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Abu Dhabi, UAE, Dec. 2018, pp. 1–6.

[194] M. A. Inamdar and H. V. Kumaraswamy, ''Energy efficient 5G networks: Techniques and challenges,'' in *Proc. Int. Conf. Smart Electron. Commun. (ICOSEC)*, Trichy, India, Sep. 2020, pp. 1317–1322.

[195] S. Jamil, Fawad, M. S. Abbas, M. Umair, and Y. Hussain, ''A review of techniques and challenges in green communication,'' in *Proc. Int. Conf. Inf. Sci. Commun. Technol. (ICISCT)*, Karachi, Pakistan, Feb. 2020, pp. 1–6.

[196] M. Masoudi *et al.*, ''Green mobile networks for 5G and beyond,'' *IEEE Access*, vol. 7, pp. 107270–107299, 2019.

[197] Y.-N.-R. Li, M. Chen, J. Xu, L. Tian, and K. Huang, ''Power saving techniques for 5G and beyond,'' *IEEE Access*, vol. 8, pp. 108675–108690, 2020.

[198] M. Eshaghi and R. Rashidzadeh, ''An energy harvesting solution for IoT devices in 5G networks,'' in *Proc. IEEE Can. Conf. Electr. Comput. Eng. (CCECE)*, London, ON, Canada, Aug./Sep. 2020, pp. 1–4.

[199] Y. Che, Y. Lai, S. Luo, K. Wu, and L. Duan, ''UAV-aided information and energy transmissions for cognitive and sustainable 5G networks,'' *IEEE Trans. Wireless Commun.*, vol. 20, no. 3, pp. 1668–1683, Mar. 2021.

[200] GSM Association. (2017). *An Introduction to Network Slicing*. [Online]: Available: https://www.gsma.com/futurenetworks/resources/an-introduction-to-network-slicing-2/

[201] P. Ahokangas, M. Matinmikko-Blue, S. Yrjölä, and H. Hämmäinen, ''Platform configurations for local and private 5G networks in complex industrial multi-stakeholder ecosystems,'' *Telecommun. Policy*, vol. 45, no. 5, pp. 1–15, Mar. 2021.

[202] S. Yrjölä, P. Ahokangas, and M. Matinmikko-Blue, ''Platform-based business models in future mobile operator business,'' *J. Bus. Models*, vol. 9, no. 4, pp. 67–93, 2021.

[203] A. Psyrris, A. Kargas, and D. Varoutas, "MNOs business models and roles enabled by 5G technologies and use cases: Transformation, challenges and strategies," in *Proc. 14th CMI Int. Conf. Crit. ICT Infrastruct. Platforms (CMI)*, Copenhagen, Denmark, Nov. 2021, pp. 1–11.

[204] M. Mzyece, "Enabling technologies and enabling business models for next generation wireless communications," in *Enabling Technologies for Next Generation Wireless Communications*, M. Usman, M. Wajid, and M. D. Ansari, Eds. Boca Raton, FL, USA: CRC Press, 2021, pp. 13–43.

LAURENCE BANDA received the B.Eng. degree in electrical and electronic engineering from the University of Zambia, Lusaka, Zambia, in 2006, the M.Sc. degree (by coursework) in electronics engineering from the EISEE-Paris, France, in 2012, and the M.Tech. degree (by research) in electrical engineering from the Tshwane University of Technology, Pretoria, South Africa, in 2013. He is currently pursuing the Ph.D. degree in technology and operations management (TOM) with the Wits Business School (WBS), University of the Witwatersrand, Johannesburg, South Africa. His research interests include business models, strategic management, technology and innovation management, and next-generation wireless networks.

MJUMO MZYECE received the Ph.D. degree in electronic and electrical engineering (mobile and wireless communications) from Strathclyde University, Glasgow, U.K., in 2004.

He is currently an Associate Professor of technology and operations management (TOM) at the Wits Business School (WBS), University of the Witwatersrand, Johannesburg, South Africa, where he conducts teaching, research, and has published widely on various aspects of TOM, business model innovation, digital business, and next-generation digital networks and platforms. Besides his academic work and expertise, he has extensive international experience in multiple industry, government and civil society organizations in various line, managerial and consulting roles.

FISSEHA MEKURIA received the Ph.D. degree in applied electronics (wireless communications and signal processing) from Linköping University, Linköping, Sweden, in 1993.

He is currently a Chief Research Scientist of the Next Generation Enterprises & Institutes, Future Wireless Technologies, Council for Scientific and Industrial Research (CSIR), Pretoria, South Africa, where he leads research on 5G and affordable broadband networks. Previously, he worked for ten years as a Senior Research Engineer at Ericsson Mobile Communications Research and Development Laboratory, Sweden, where he developed over 15 U.S./EPO patents. He is also involved in research and development and postgraduate supervision in wireless communications at a number of universities, including an Adjunct Professor appointments at both the Department of Electrical and Electronic Engineering Science, University of Johannesburg, and the Wits Business School, University of the Witwatersrand, South Africa. He has over 60 peer-reviewed research publications, including book chapters, journal articles, and conference papers.