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TOWARDS A DATA-CENTRIC FRAMEWORK FOR 5G AND BEYOND ECOSYSTEMS

Muhammad Asad Khan[*1], Mohsin Shah[2], Waqar Ishaq[3]

[*1,2,3]*Telecommunication Department Hazara University*
Mansehra, Pakistan

[*1]asadkhan@hu.edu.pk, [2]mohsinshah@hu.edu.pk, [3]waqarishaq@hu.edu.pk

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Corresponding Author: *
Muhammad Asad Khan

Abstract

The transformative potential of 5G and beyond technologies lies not only in enhanced connectivity but more importantly in enabling a data-driven digital ecosystem across diverse industries and end users. This paper presents a comprehensive data-centric perspective on the 5G and beyond ecosystem, detailing how data is generated, classified, shared, and utilized by key stakeholders, including telecom operators, vertical industries, equipment manufacturers, and end users. We explore the significant opportunities arising from data exchange—spanning sectors such as smart cities and healthcare—while critically addressing challenges related to data governance, security, privacy, and regulatory compliance. Through an in-depth case study of smart healthcare, the paper demonstrates how robust data management and governance frameworks can unlock value for individual players and foster holistic ecosystem success. These insights contribute to advancing the understanding of data-driven innovation and collaboration in next-generation network ecosystems.

INTRODUCTION

The leap to 5G represents more than just an advancement in speed and efficiency, in effect it is a profound catalyst for digital transformation [2]. The 5G's real value lies in the unprecedented scale, speed, and diversity of data it enables, weaving together billions of devices, sensors, systems, and users into a single, hyperconnected ecosystem. Data has become the backbone of innovation and automation, empowering real-time services, intelligent decision-making, and new digital business models [12].

By connecting billions of devices, 5G will boost the growth of smart cities, self-driving cars, and advanced healthcare. For businesses, 5G means faster, smarter operations with real-time data and seamless teamwork, no matter where people are. Its low delay and reliable connections will also enable critical uses like emergency response, remote surgeries, and automated factories. As industries move toward Industry 4.0, 5G will be the backbone supporting new ideas, services, and technologies, opening up possibilities we could only dream of before. Together, users and providers create a strong ecosystem that supports innovation and shapes a smarter, connected future [33].

The 5G ecosystem is a dynamic network of diverse players and technologies working together to unlock the full potential of 5G. It includes mobile network operators (MNOs) who operate the 5G network, device makers producing network equipment, smartphones, sensors, and IoT gadgets, as well as software and cloud service companies that manage data and applications. Beyond technology vendors, the ecosystem also involves industry verticals like healthcare, manufacturing, and automotive that use 5G to innovate and transform their operations [13]. This collaborative environment

promotes seamless integration of connectivity, computing, including cloud and edge computing. It also incorporates intelligence like AI and ML, allowing businesses and consumers to benefit from new services and smart solutions that drive economic growth and digital progress. The strength of the 5G ecosystem lies in its many specialized players working together, creating value that no single company could achieve alone.

This paper presents a comprehensive data-centric framework for understanding the 5G and beyond ecosystem, detailing how data is generated, classified, stored, shared, and utilized across diverse stakeholders including telecom operators, equipment manufacturers, cloud providers, standardization bodies, and vertical industries such as Smart Health. It identifies the distinct data roles and interdependencies among ecosystem players, illustrating how collaborative data exchange fosters innovation, operational efficiency, and seamless cross-sector integration.

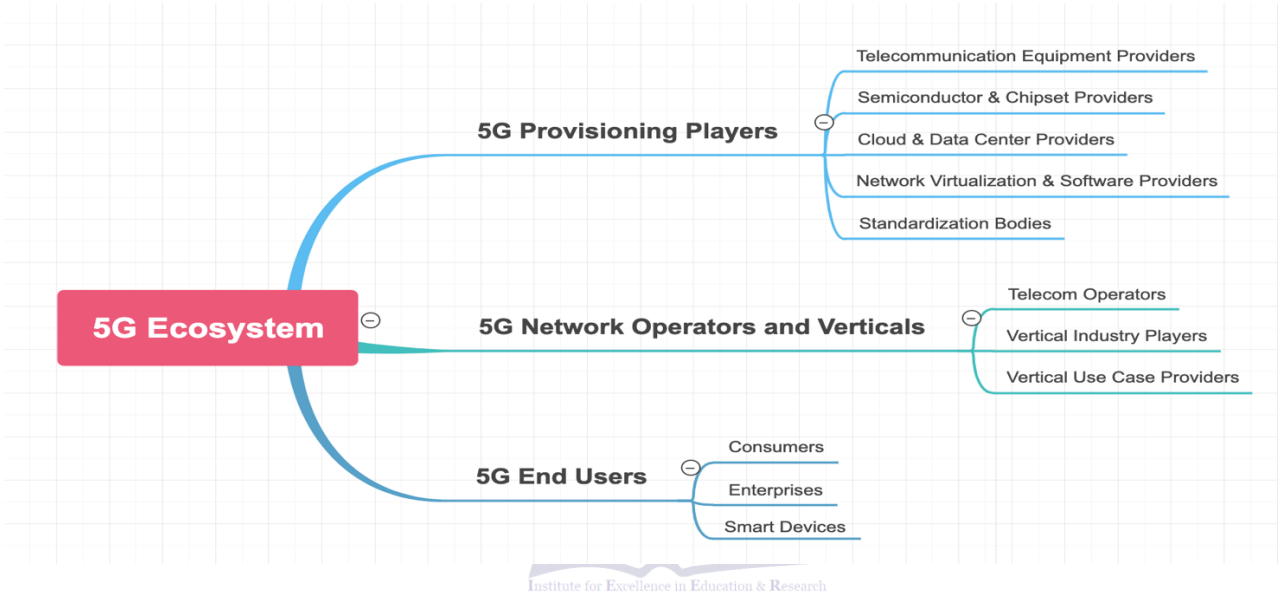

Figure 1: Key Stakeholders of 5G Ecosystem

In addition, the paper thoroughly addresses critical challenges related to data privacy, security, and regulatory compliance, emphasizing the importance of standardized protocols and governance to maintain trust and interoperability. Through an in-depth case study on Smart Healthcare, it demonstrates practical applications of the data-centric model, revealing tangible benefits enabled by 5G connectivity and advanced analytics. Overall, this research contributes both a conceptual and applied perspective that advances knowledge on managing complex, multi-stakeholder data flows in next-generation digital ecosystems, providing valuable insights to researchers, industry practitioners, and policymakers aiming to harness the full potential of 5G-enabled services.

The paper is organized as follows: Section 2 examines the 5G and beyond ecosystem, focusing on key players through the data lens. Section 3 delves into the data lifecycle within the 5G ecosystem. Section 4 highlights the data-centric opportunities enabled by the 5G ecosystem, while Section 5 discusses related data-centric challenges. Section 6 presents a case study on data flows in 5G-enabled smart healthcare. Finally, Section 7 concludes with key insights and recommendations.

5G and Beyond Ecosystem: Key Stakeholders and Data Lifecycle

"An ecosystem is a network of diverse actors collaborating to deliver a core value proposition, often creating more impact together than any single entity could achieve alone" [2]. In the context of 5G and beyond, the ecosystem includes multiple players that contribute not only to connectivity but also play critical roles in
generating, processing, sharing, and using data, fueling innovation and value creation throughout.

Key Stakeholders

The 5G and beyond ecosystem can be divided into three main groups of players and each having its sub-

components [1]. The main players and sub-components are presented in Fig. 1.

1. **Provisioning Players:**

The provisioning players in the 5G ecosystem are responsible for developing, maintaining, and advancing the infrastructure, hardware, and software that underpin 5G networks. They act as both data generators and consumers, facilitating essential data flows and processing that enable the entire ecosystem [34].

This group includes telecommunication equipment providers such as Huawei, Ericsson, and ZTE, who supply critical network components like base stations and antennas. These providers also drive innovations in areas such as Network Function Virtualization (NFV) and Software-Defined Networking (SDN). Supporting them are semiconductor and chipset manufacturers like Qualcomm and Intel, which design advanced chips that enable fast data processing and ensure reliable connectivity in both devices and network equipment [14].

Ecosystem Key Group	Category	Data Generation	Data Consumption	Data Importance & Usage
Provisioning Players	Telecommunication Equipment Providers	Hardware performance metrics, network element health data, signal quality logs	Network traffic patterns, QoS requirements from operators	**Critical for infrastructure health:** • Optimizes antenna/base station configurations • Predicts hardware failures • Enables real-time network tuning
	Semiconductor & Chipset Providers	Chipset efficiency data, processing latency metrics, power consumption analytics	Device performance feedback, network load data	**Foundation for device capabilities:** • Drives energy-efficient chip design • Enables low-latency processing • Supports AI/ML at edge devices
	Cloud & Data Center Providers	Resource utilization logs, edge computing performance data, storage access patterns	IoT sensor streams, real-time application data, network analytics	**Backbone for data processing:** • Enables real-time analytics for autonomous systems • Scales storage for massive IoT data • Powers edge AI decision-making
	Network Virtualization & Software Providers	SDN/NFV orchestration logs, network slicing performance, security threat analytics	Traffic flow data, service demand patterns	**Nervous system of 5G:** • Dynamically allocates network resources • Automates security responses • Enables QoS-based network slicing
	Standardization Bodies	Interoperability frameworks, compliance benchmarks, protocol specifications	Global performance data, security vulnerability reports	**Ensures ecosystem cohesion:** • Creates universal data exchange formats • Establishes security baselines • Enables cross-border data flows
Network Operators & Verticals	Telecom Operators & Carriers	Network traffic metadata, user location patterns, service quality metrics, device connectivity logs	Vertical industry IoT data, consumer usage analytics, cloud processing requirements	**Central data exchange hub:** • Optimizes network capacity planning • Enables SLA management • Provides latency-sensitive data routing for critical applications
	Vertical Industry Players (Healthcare, Auto)	Patient vitals (healthcare), vehicle telemetry (auto), machine sensor data (manufacturing), environmental metrics	Network QoS data, cloud-processed insights, consumer behavior data	**Domain-specific intelligence:** • Powers real-time remote surgery (healthcare) • Enables V2X communication (auto) • Drives predictive maintenance (manufacturing)
	Vertical Use Case Providers	Industrial automation logs, precision agriculture analytics, AR/VR content usage patterns	Network performance data, chipset capabilities, cloud resources	**Innovation catalyst:** • Creates data-driven vertical solutions • Optimizes industry-specific workflows • Generates new service revenue streams
End Users	Consumers	Personal device usage patterns, location data, content consumption habits, biometric data (wearables)	Personalized services, contextual advertising, cloud-based recommendations	**Demand driver:** • Shapes service development • Enables hyper-personalization • Generates behavioral insights for innovation
	Enterprises	Supply chain telemetry, industrial IoT streams, ERP system analytics, inventory tracking	Network performance reports, security threat intelligence, processed business insights	**Operational transformation:** • Enables real-time supply chain visibility • Powers automated decision-making • Optimizes resource allocation
	Smart Devices & Connected Systems	Real-time sensor streams (vehicles/homes), health monitoring metrics, environmental readings, usage telemetry	Control commands, firmware updates, cloud-processed analytics	**Autonomous ecosystem enablers:** • Facilitates machine-to-machine communication • Enables predictive self-maintenance • Creates closed-loop automated systems

In addition, cloud and data center providers—examples include AWS and Microsoft Azure—offer scalable storage and computing resources. They support massive data workloads through both centralized data centers and distributed edge infrastructures to achieve ultra-low latency. Meanwhile, network virtualization and software providers such as Cisco and VMware develop tools that automate, orchestrate, and manage dynamic, data-driven network services.

Finally, standardization bodies like 3GPP and IEEE play a crucial role in establishing protocols that ensure interoperability, data security, and regulatory compliance across global 5G networks. Together, these provisioning players form the backbone of the 5G ecosystem, enabling seamless data exchange and driving innovation [15].

2. Network Operators and Vertical Industry

This group includes telecom operators who deploy and manage 5G networks, as well as industry verticals that rely on these networks to enable specialized applications and data-intensive services. Telecom operators and carriers, such as Verizon and China Mobile, are responsible for managing the network infrastructure and optimizing data flows to accommodate the massive connectivity demands of modern applications. These operators enable critical use cases like private networks, edge computing, and low-latency applications, which are essential for sectors that require real-time data processing and high-speed connectivity.

Industry verticals, such as Tesla in the automotive sector and GE Healthcare in medical technology, are leveraging 5G to generate, exchange, and analyze large volumes of operational and IoT data [19][20]. Through the adoption of 5G, these companies are transforming their respective industries by enabling real-time decision-making and automated workflows. For example, Tesla uses 5G to enhance the connectivity and autonomy of its vehicles, enabling quicker data exchange between cars, charging stations, and centralized systems. Meanwhile, GE Healthcare utilizes 5G to improve the quality and efficiency of medical devices, enabling remote monitoring and rapid data transfer, which is vital for patient care.

Furthermore, vertical use case providers like Siemens and John Deere are developing specialized 5G-enabled solutions tailored to the unique needs of specific industries. Siemens, for instance, utilizes 5G for smart manufacturing, creating data-driven solutions that enhance factory automation, predictive maintenance, and supply chain optimization. John Deere, on the other hand, uses 5G to connect agricultural machinery and IoT devices, providing farmers with real-time insights that improve operational efficiency and yield predictions [21].

These vertical use case providers play a crucial role in accelerating data-driven innovation and facilitating the broader adoption of 5G technologies across diverse market segments. By offering specialized solutions, they help industries unlock the full potential of 5G, driving advancements in automation, real-time analytics, and operational intelligence. In doing so, they contribute significantly to the transformation of traditional industries, making them more agile, efficient, and data-centric.

3. End Users

Mobile network consumers generate vast amounts of personal and contextual data through devices such as smartphones, wearables, and home IoT systems. These users not only contribute to the ecosystem by generating data but also drive demand for immersive and high-performance services. With the advent of 5G, consumers now have access to richer, more dynamic experiences like augmented reality (AR), virtual reality (VR), and high-definition streaming, all of which require robust, low-latency networks to ensure smooth and uninterrupted service [16].

On the other hand, enterprises and businesses play a crucial role in the adoption and expansion of 5G technology by integrating it into their operations. These organizations deploy 5G networks for a variety of use cases, including automation, monitoring, and advanced analytics across multiple sectors such as manufacturing, healthcare, logistics, and retail. By doing so, they generate valuable operational data that helps optimize processes, reduce costs, and boost innovation. This data, combined with 5G's high speed and reliability, allows businesses to improve efficiency, streamline operations, and gain real-time insights into their workflows [17].

Additionally, smart devices—ranging from autonomous vehicles and health monitors to smart appliances—are critical players in the 5G ecosystem. These devices rely on real-time data exchange to perform complex, latency-sensitive functions. For instance, autonomous vehicles require continuous communication with their environment to process vast amounts of data from sensors and make immediate, safety-critical decisions. Similarly, health monitors must transmit real-time vital data to healthcare systems for immediate analysis and response. The ultra-reliable, low-latency capabilities of 5G networks enable these devices to operate seamlessly

and effectively, enhancing the performance and functionality of various smart systems [18].

In summary, the 5G ecosystem is dynamic and interconnected, with individual users, enterprises, and smart devices all contributing data and benefiting from the technology. This creates a feedback loop where data generation, enhanced services, and innovative applications continuously improve, driving the adoption of 5G and accelerating advancements across industries.

Data Lifecycle in the 5G Ecosystem

The data lifecycle within the 5G ecosystem encompasses several interrelated phases through which data is generated, collected, transmitted, processed, stored, and utilized to create value across various verticals and end-user scenarios [22]. By understanding these phases, we can better appreciate how data flows seamlessly among telecom operators, equipment manufacturers, cloud providers, vertical industries, and end users, enabling the 5G ecosystem to support innovations such as real-time analytics, automation, and immersive digital experiences. The lifecycle consists of the following phases [23]:

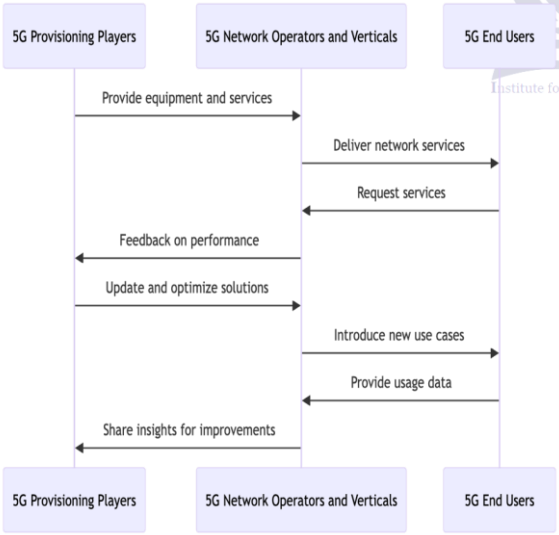

Figure 2: Data Exchange in 5G Ecosystem

- *Data Generation:* Each player in the 5G ecosystem generates vast and varied data types. Telecom operators produce network telemetry and performance data necessary for infrastructure optimization. End users, through devices like wearables and smartphones, generate personal data such as health vitals, location, and activity data. Industrial IoT systems and vertical industries (e.g., manufacturing, healthcare) contribute operational data, sensor readings, and machine-generated insights. Provisioning players (e.g., equipment manufacturers) generate data essential for ensuring network performance and operational efficiency [24].

- *Data Collection and Packaging:* Collected data is aggregated and processed at different levels. Edge computing allows for local data aggregation and immediate processing near the source, reducing latency for critical applications. Meanwhile, less time-sensitive data is routed to cloud platforms for further analysis and storage. Network virtualization and software solutions enable the efficient handling of this data by dynamically adapting to demand and quality of service requirements, ensuring seamless data flow.

- *Data Classification:* The data collected across various players is categorized based on several attributes:
  - Sensitivity (e.g., private health data vs. general usage statistics),
  - Format (e.g., structured data such as logs vs. unstructured data like video),
  - Time relevance (e.g., real-time critical alerts for autonomous vehicles vs. historical analytics for business intelligence),
  - Ownership (which dictates privacy policies and governance frameworks).

  This classification plays a vital role in managing data security, privacy, and compliance across the ecosystem.

- *Data Exchange and Sharing:* Secure, governed data flows between players underpin collaborative innovation. For instance, telecom operators may share network analytics with vertical industries, enabling them to optimize their applications (e.g., predictive maintenance in manufacturing). Vertical industries exchange IoT data with cloud service providers to optimize system performance and enhance user experiences. Additionally, end users' data are shared (with consent) to personalize services, such as delivering tailored content or optimizing smart home systems.

- *Data Utilization:* The processed data is leveraged to optimize network performance, enable intelligent applications like autonomous driving, and support

informed business decisions. AI and analytics platforms rely heavily on this data to generate actionable insights, automate processes, and power predictive models that enhance service delivery and user experiences.

Challenge	Description	Impact on the 5G Ecosystem
Data Sharing & Interoperability	Lack of standardized data formats, protocols, and communication methods across various platforms.	Hinders seamless data exchange, slows innovation, and limits application development.
Data Silos	Proprietary data systems within telecom operators, cloud providers, and vertical industries.	Slows innovation, limits usefulness of data, and impedes effective decision-making.
Data Privacy	The collection of personal data from connected devices without proper safeguards and privacy policies.	Increases risk of data exposure, requiring strict privacy regulations (e.g., GDPR).
Cybersecurity Risks	Exposure to cyberattacks, malware, and data breaches due to the interconnected nature of 5G networks.	Threatens critical infrastructure, data security, and could cause economic losses.
Regulatory Compliance	Complexity of complying with different regional laws (e.g., data protection, spectrum allocation).	Leads to operational inefficiencies and challenges in cross-border service deployment.

- *Feedback and Evolution:* Insights derived from data analysis feed back into network enhancements, service improvements, and the development of new applications. For example, the feedback from data analytics can be used to refine 5G network configurations, ensure optimal coverage, and foster the development of innovative applications that continuously drive ecosystem growth. This creates a feedback loop, ensuring constant improvement and adaptation within the 5G ecosystem.

In summary, the 5G ecosystem is interlinked through a dynamic data lifecycle, where data is not merely a byproduct of connectivity but an essential currency driving innovation, collaboration, and user value. By enabling seamless data exchange and fostering real-time, data-driven applications, the ecosystem thrives on collaborative growth and continuous innovation [25].

Unlocking Value through Data Collaboration

The 5G and beyond ecosystem nurtures a highly collaborative environment where a diverse set of stakeholders, including telecom operators, technology providers, enterprises, and end users—interact, cooperate, and collectively benefit by sharing capabilities, experiences, and data. This interconnectedness, illustrated in Fig. 2, leverages the integration of varied technologies and industries to unlock significant opportunities for mutual growth and innovation.

Enhanced Cooperation Across Industry Verticals

The 5G ecosystem acts as a powerful catalyst for collaboration between telecom operators and vertical industry players. For instance, telecom operators partner with automotive companies to develop autonomous driving technologies, and they collaborate with healthcare providers to enable advanced services such as remote surgeries and telemedicine [9]. The unparalleled speed and ultra-low latency provided by 5G networks make these innovative services feasible, significantly surpassing the capabilities of previous generations of networks.

Similarly, urban environments, utilities, and transportation systems work closely with cloud providers and IoT companies to implement comprehensive smart city initiatives. By combining the expertise of telecom operators, cloud platforms, and IoT developers, these interconnected systems optimize critical public services, including traffic management, waste disposal, and energy consumption.

Shared Knowledge and Innovation

The 5G ecosystem encourages close cooperation among technology providers, standardization bodies, and research institutions. For example, network virtualization companies such as VMware and Cisco collaborate closely with telecom operators to integrate Software-Defined Networking (SDN) and Network Functions Virtualization (NFV) technologies into 5G infrastructure. Meanwhile, standardization organizations like 3GPP and ITU develop global protocols that ensure interoperability, security, and operational consistency across the ecosystem. This solid foundation allows a wide range of participants—from equipment manufacturers to
software developers—to innovate freely while maintaining worldwide compatibility of their solutions. Such openness not only fosters competitive markets but also accelerates the development of scalable and robust technologies critical to the evolution of the 5G ecosystem.

Business Models and Revenue Sharing

The evolution toward 5G and future 6G networks presents new opportunities for telecom operators and cloud providers to develop collaborative business models based on the concept of 5G-as-a-Service. This model enables companies—including startups and smaller enterprises—to access high-performance 5G capabilities without requiring heavy investments in infrastructure. For example, an IoT company can leverage 5G connectivity offered by telecom providers alongside cloud-based platforms for real-time analytics, facilitating rapid scaling and fostering innovation.

Within the ecosystem, members such as telecom operators, equipment manufacturers, and software vendors can establish business arrangements that fairly share revenue generated from network usage, content delivery, and value-added services like edge computing. The entertainment sector, represented by companies like Netflix and Spotify, benefits from these collaborations by delivering low-latency streaming to users, supported by revenue-sharing agreements that align the incentives of all involved parties.

Social and Environmental Collaboration

5G and beyond technologies empower joint efforts involving telecom operators, technology firms, and environmental agencies to advance sustainability. Collaborations can target smart grids, sustainable agriculture, and real-time environmental monitoring, leveraging 5G's high-speed, low-latency data processing to optimize resource use and reduce waste. For instance, agricultural technology providers and farmers utilize 5G-enabled IoT solutions to monitor soil quality and irrigation, enhancing crop yields while minimizing environmental impact.

The ecosystem fosters partnerships among telecom operators, governments, and NGOs aimed at bridging the digital divide. Joint initiatives to deploy 5G connectivity in underserved rural and remote regions improve access to vital services, including education, healthcare, and financial inclusion, thereby promoting equitable growth and digital empowerment globally [11]. The 5G and beyond ecosystem creates an interactive environment where players across telecom, cloud computing, industry verticals, and user communities pool resources, expertise, and data.

CHALLENGES IN THE 5G ECOSYSTEM: Sharing, SECURITY, AND REGULATIONS

While the 5G and beyond ecosystem offers vast opportunities for innovation and collaboration, stakeholders face critical challenges in data management, privacy, security, and regulatory compliance. As telecom operators, technology providers, and other players increasingly share data, addressing these issues is vital to maintaining trust, ensuring efficient operations, and achieving seamless global interoperability for scalable 5G deployments [29].

A. Data Sharing and Interoperability Challenges

One of the major challenges in the 5G ecosystem is ensuring efficient and secure data sharing among various ecosystem players. With vast amounts of data being generated by IoT devices, connected vehicles, and smart cities, etc., it becomes critical to establish seamless systems for sharing and processing data across different platforms and services. However, the lack of standardized data formats, protocols, and communication methods often hinders the interoperability of systems. Achieving true data interoperability while maintaining the speed and performance expected from 5G networks can be technically complex and requires ongoing collaboration between stakeholders to create open and compatible data-sharing frameworks [30].

Another challenge is the potential for data silos within the ecosystem. Telecom operators, cloud providers, and various vertical industries may have proprietary data systems that prevent the free flow of information. This fragmentation can slow down innovation, limit the usefulness of collected data, and hinder the

development of new applications. To address this, stakeholders must work together to

Smart Health Data	Shared With	Utilization by Receiver	Benefits
Health data from connected devices (e.g., heart rate, blood pressure, glucose levels)	Network operators responsible for 5G infrastructure	- Network capacity planning: Predict peak usage times, adjust infrastructure. - Latency optimization: Ensure ultra-low latency for mission-critical services.	- Enhanced service reliability for critical healthcare applications like remote surgery and telemedicine.
Device performance data, usage patterns, health-related data traffic requirements	5G equipment manufacturers	- Performance analysis: Understand healthcare's impact on network performance (traffic, latency). - Design optimization: Improve 5G equipment for healthcare needs.	- Optimized, scalable network infrastructure that supports high-quality, real-time healthcare services.
Health data (patient vitals, clinical records, medical imaging)	Software developers	- Train algorithms for predictive health analytics, disease detection, and personalized care. - Predictive analytics to forecast health risks and improve outcomes.	- Optimized, scalable network infrastructure that supports high-quality, real-time healthcare services.
Patient treatment histories, clinical trial results, medication adherence data	Pharmaceutical companies	- Real-time monitoring of drug efficacy in clinical trials. - Develop personalized therapies based on patient responses.	- Innovative, personalized treatment options leading to better patient outcomes, with more effective medications and tailored care solutions.

models and open standards, adopt common data ensuring that data can be shared across systems and used effectively for decision-making, analytics, and innovation [24] [26].

B. Data Privacy and Security Concerns

With the proliferation of connected devices and sensors, data privacy becomes a significant concern in the 5G ecosystem. Personal data collected through smartphones, wearables, healthcare devices, and automated systems may be exposed to unauthorized access if proper privacy safeguards are not in place. Telecom operators, cloud providers, and vertical industry players must ensure that they follow strict data privacy regulations (e.g., GDPR) to protect user data. As 5G networks facilitate the exchange of more sensitive and real-time data, it becomes even more crucial to develop robust privacy policies that can address the growing complexity of data collection and usage [31].

The interconnected nature of the 5G ecosystem opens up new vectors for cyberattacks and data breaches [5]. The high volume of data exchanged between telecom operators, cloud providers, IoT devices, and enterprises makes networks highly susceptible to threats such as hacking, malware, denial-of-service attacks, and data interception. As a result, robust cybersecurity protocols are essential for securing the communication infrastructure, devices, and data within the 5G ecosystem [34]. Without these protections, malicious actors could exploit vulnerabilities to access critical infrastructure, leading to potential economic losses, privacy violations, and reputational damage [27].

As the 5G ecosystem expands, managing security at scale becomes a daunting task. Telecom operators, equipment manufacturers, and software providers need to work together to ensure consistent security practices across the entire infrastructure. The complexity of securing 5G networks, which include physical, virtual, and cloud-based elements, further amplifies the challenge. Ensuring compliance with global security standards while maintaining seamless performance in real-time applications requires continuous investment in advanced security technologies and protocols.

C. Compliance with Regulations and Standards

One of the major hurdles that members of the 5G ecosystem face is complying with diverse and complex regulations across different regions. Telecom operators and cloud providers must adhere to various local, regional, and international laws, such as data protection regulations, spectrum allocation, and network security [4]. These regulations can differ significantly across jurisdictions, leading to difficulties in operating cross-border services and ensuring legal compliance in all areas. For example, the rules governing spectrum management or data privacy may vary between Europe, North America, and Asia, making it difficult for global players to implement unified strategies [35].

Stakeholders Data	Shared With	Utilization by Smart Health	Utilization by Smart Health
Operational data (network traffic, bandwidth utilization, device connectivity)	Smart Health applications (e.g., remote monitoring, telemedicine)	- **Network usage insights**: Optimize network usage by scheduling tasks during low traffic. - **Latency & reliability optimization**: Adjust strategies based on network congestion.	- **Optimized healthcare services**: Avoid service disruptions and ensure reliable care for patients, especially in time-sensitive scenarios.
Information on network equipment performance,	Smart Health applications and healthcare providers	- **Infrastructure adaptation**: Plan deployment based on 5G network performance.	- **Enhanced service reliability**: Ensure Smart Health applications are deployed on

operational capacity, 5G coverage		- **Reliability monitoring**: Mitigate disruptions in remote monitoring and telemedicine.	the most reliable infrastructure, improving patient care and operational efficiency.
AI/ML algorithm outcomes, diagnostic insights, predictive analytics, and treatment suggestions	Smart Health applications, healthcare providers, and medical devices	- **AI-powered diagnostics**: Improve diagnostic accuracy, disease progression predictions, and personalized treatment plans. - **Predictive health monitoring**: Anticipate health risks and improve outcomes.	- **Personalized and proactive care**: Deliver personalized, data-driven solutions, improving patient outcomes and healthcare resource efficiency.
Data from clinical trials, patient outcomes, medication adherence, therapeutic efficacy	Smart Health applications and healthcare providers	- **Personalized medicine**: Recommend tailored medications and treatments. - **Clinical decision support**: Inform healthcare providers about the latest drug efficacy.	- **Improved treatment options**: Provide healthcare providers with cutting-edge treatment data, leading to better patient outcomes and more efficient care.

The ecosystem requires a more cohesive and collaborative approach to ensure that global standards are adopted uniformly to avoid fragmentation and incompatibility [32].

While organizations like 3GPP and ITU are responsible for setting technical standards for 5G, implementing those standards across different industries and countries remains challenging [3]. The lack of universal alignment on standards for 5G infrastructure, data protection, and IoT solutions can create roadblocks for companies looking to implement global solutions [28].

As 5G and beyond technologies evolve, so too will the regulatory landscape. Governments and regulatory bodies are likely to introduce new regulations concerning 5G deployments, data privacy, network neutrality, and security measures. Ecosystem members must stay agile and ready to adapt to evolving compliance requirements, which can be both costly and time-consuming. Additionally, new regulations may emerge in response to emerging technologies like 6G, AI, and quantum computing, creating further challenges for stakeholders in the 5G ecosystem. The 5G and beyond ecosystem offers vast potential for collaboration and innovation, but it also presents challenges that must be addressed to ensure the ecosystem's success. Efficient and secure data sharing, ensuring robust data privacy and security and navigating the complexities of regulatory compliance are key issues that must be overcome. Through continued cooperation, standardization, and adherence to ethical and legal standards, stakeholders can mitigate these challenges and unlock the full potential of 5G technologies, driving the evolution towards 6G and the next generation of digital connectivity.

CASE STUDY: SMART HEALTHCARE IN THE 5G ECOSYSTEM

This case study explores how Smart Healthcare functions as a key vertical within the 5G ecosystem, highlighting the flow of data among the various stakeholders, such as network operators, 5G provisioning players, AI/ML developers, and pharmaceutical companies [36]. The section is divided into two subsections:

- *Section 1* discusses how Smart Health data is shared across the 5G ecosystem and how it is utilized by stakeholders to enhance operational efficiency and optimize their services.
- *Section 2* focuses on how data from these ecosystem players is shared with Smart Health applications, improving healthcare delivery, patient care, and driving technological innovation across the ecosystem.

This case study demonstrates how the exchange of data benefits both individual players and the ecosystem as a whole, leading to improved services,

enhanced technologies, and a more efficient healthcare system.

Data Sharing: Smart Health to the 5G Ecosystem Stakeholders

The flow of smart health data through the 5G ecosystem benefits not only healthcare providers but also other key stakeholders, such as network operators, 5G equipment manufacturers, software developers, and pharmaceutical companies, etc. Table 2 summarizes how data produced by smart health is shared across these stakeholders and how it is utilized to improve operations, infrastructure, and services. Each stakeholder uses the health data in different ways to optimize their functions: Network operators use health data to adjust network capacity and reduce latency, ensuring the reliable delivery of critical healthcare services. On the other hand, 5G equipment manufacturers use device performance and data traffic information to enhance network design, ensuring that the infrastructure supports the demanding needs of healthcare applications. Software developers use patient data to train algorithms for predictive analytics, improving diagnostic accuracy and personalized care [7]. Similarly, the clinical and treatment data can be utilized by other verticals, like Pharmaceutical companies, to optimize clinical trials and develop targeted therapies, leading to innovative treatment options and improved patient outcomes.

These data exchanges not only improve operational efficiency within each sector but also contribute to the development of a more robust and interconnected healthcare ecosystem.

Data Sharing: 5G Ecosystem Stakeholders to Smart Health

Smart Health not only generates valuable data but also relies heavily on data from other key stakeholders within the 5G ecosystem. These stakeholders include network operators, 5G equipment manufacturers, software developers, pharmaceutical companies, cloud service providers, data security firms, insurance companies, and healthcare institutions. Each of these players contributes valuable data that enhances the functionality, reliability, and scalability of Smart Health applications.

Network operators provide data on network traffic, bandwidth utilization, and device connectivity patterns, helping Smart Health systems optimize network usage, reduce latency, and ensure reliable service delivery for time-sensitive applications like telemedicine and remote surgeries. 5G equipment manufacturers offer insights on network performance, operational capacity, and coverage areas, enabling Smart Health applications to plan and deploy services in locations with optimal network coverage and ensure infrastructure reliability for continuous healthcare monitoring.

Software developers contribute data from predictive analytics, diagnostic tools, and personalized treatment algorithms, which help improve diagnostic accuracy, early disease detection, and the proactive management of health conditions. Pharmaceutical companies share data on clinical trials, medication adherence, and therapeutic efficacy, enabling Smart Health applications to recommend personalized medications and targeted treatments, thus improving treatment outcomes.

Cloud service providers facilitate data storage, computing power, and cloud infrastructure that support the processing and storage of massive amounts of health data [10]. This enables Smart Health applications to scale efficiently and ensure that data is available for real-time

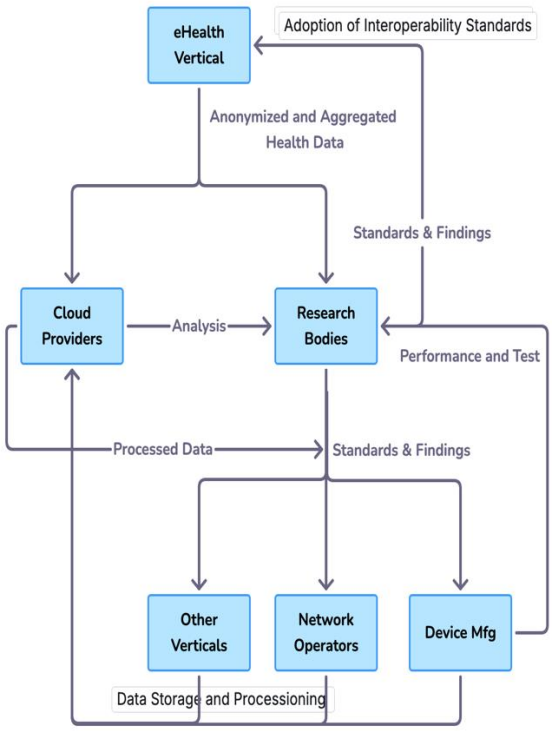

Figure 3: Data Sharing in the Ecosystem of Smart

decision-making, improving data accessibility and operational efficiency. Data security firms offer security protocols, encryption standards, and privacy regulations that ensure the protection of sensitive health data, helping Smart Health applications comply with legal requirements such as HIPAA and GDPR, thus ensuring data integrity and patient privacy [6]. Insurance companies provide data on patient risk profiles, policyholder health history, and claims data, helping Smart Health applications to integrate risk assessments and personalized care recommendations, enabling preventive care and optimized healthcare costs for both patients and providers.

Through these data exchanges, Smart Health can enhance service reliability, personalize treatments, optimize healthcare delivery, and improve patient care, driving innovation and efficiency across the ecosystem.

Conclusion and Discussion

This paper presented a comprehensive data-centric framework for understanding the 5G and beyond ecosystem, emphasizing the critical role of data flows among diverse stakeholders including telecom operators, device manufacturers, cloud providers, standardization bodies, vertical industries, and end users. By dissecting the generation, classification, sharing, and utilization of data within this complex ecosystem, we have highlighted how collaborative data exchange drives innovation, operational optimization, and enables new, intelligent services across multiple verticals such as smart healthcare, smart cities, and industrial automation.

The in-depth case study on smart healthcare illustrated practical examples demonstrating how real-time health data, combined with advanced analytics and 5G connectivity, can significantly enhance patient monitoring, predictive diagnostics, and treatment personalization. This reinforces the transformative potential of data as a central asset in driving digital health innovations while improving care quality and system resilience.

Despite these opportunities, the paper also underscores critical challenges that must be addressed to realize the full potential of the 5G data ecosystem. Privacy and security concerns surrounding sensitive health and personal data require rigorous governance frameworks, adherence to global and regional regulations, and adoption of standardized protocols to maintain trust and safeguard users. Moreover, interoperability and fragmentation issues persist due to disparate proprietary systems and inconsistent standard adoption, necessitating stronger collaboration among ecosystem players and standardized data models.

Looking forward, the evolution beyond 5G towards 6G and beyond will further amplify data volumes, heterogeneity, and latency demands, intensifying the need for robust data management, edge computing integration, and AI-driven orchestration within the ecosystem. Future research and industry efforts should focus on advancing adaptive governance models, enhancing cross-sector data sharing frameworks, and promoting sustainable and ethical use of data—ensuring that innovation does not come at the expense of privacy, security, or social inclusivity.

In conclusion, this data-centric perspective provides a holistic understanding of the interconnected data dynamics fundamental to 5G and beyond ecosystems. It offers valuable insights to researchers,

industry stakeholders, and policymakers aiming to architect scalable, secure, and collaborative data infrastructures that unlock new socio-economic benefits and drive the next generation of digital ecosystems.

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