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A Strategic Framework for Sixth-Generation (6G) Network Adoption in Libya: Challenges, Enablers, and Implementation Pathways

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Abstract

This study developed a context-specific strategic framework for the future adoption of sixth-generation (6G) networks in Libya, addressing the limited attention given to how developing and transitional countries can prepare for advanced networks under infrastructure, regulatory, institutional, financial, and human-capacity constraints. An evidence-based analytical approach was applied by synthesizing peer-reviewed 6G research, technology-adoption literature, academic evidence on Libya's digital-transformation environment, and a structured analysis of national readiness gaps. The analysis indicates that Libya should approach 6G as a gradual national readiness process rather than an immediate deployment objective. Initial priorities include improving existing 4G services, preparing for 5G and 5G-Advanced, expanding fiber and backhaul infrastructure, strengthening spectrum and regulatory governance, developing cybersecurity and digital trust, building cloud-edge and artificial-intelligence capabilities, and advancing specialized human and research capacity. Based on these findings, the study proposes a strategic framework comprising seven interrelated readiness dimensions and a three-stage implementation pathway progressing from foundation building to 5G and 5G-Advanced transition and, subsequently, selective 6G readiness. The framework contributes to the literature by translating global 6G developments into coordinated and practical priorities suited to Libya's national conditions. It also provides policymakers,

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regulators, telecommunications operators, and academic institutions with a structured basis for guiding long-term network modernization and future sector-based experimentation.
Keywords: 6G, Libya, digital transformation, strategic framework, national readiness, 5G-Advanced, phased adoption.

إطار استراتيجي لتبني شبكات الجيل السادس (6G) في ليبيا: التحديات، وعوامل التمكين، ومسارات التنفيذ

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الملخص

هدفت الدراسة إلى تطوير إطار استراتيجي ملائم للسياق الليبي لتبني شبكات الجيل السادس (6G) مستقبلا، استجابة لمحدودية الاهتمام بكيفية استعداد الدول النامية والانتقالية للشبكات المتقدمة في ظل القيود المرتبطة بالبنية التحتية والتنظيم والمؤسسات والتمويل والقدرات البشرية. واعتمدت الدراسة منهجا تحليليا قائما على الادلة، من خلال تجميع وتحليل الدراسات العلمية المحكمة حول الجيل السادس، وأدبيات تبني التكنولوجيا، والادلة الاكاديمية المتعلقة ببيئة التحول الرقمي في ليبيا، إلى جانب تحليل منظم لفجوات الجاهزية الوطنية. وأظهر التحليل أن على ليبيا التعامل مع الجيل السادس بوصفه عملية تدريجية لبناء الجاهزية الوطنية، وليس هدفا للتطبيق الفوري. وتشمل الاولويات الاولية تحسين خدمات الجيل الرابع، والاستعداد للجيل الخامس والجيل الخامس المتقدم، وتوسيع البنية التحتية للألياف والربط الخلفي، وتطوير حوكمة الطيف والتنظيم، وتعزيز الأمن السيبراني والثقة الرقمية، وبناء قدرات الحوسبة السحابية والطرفية والذكاء الاصطناعي، وتنمية القدرات البشرية والبحثية المتخصصة. واستنادا إلى هذه النتائج، اقترحت الدراسة إطارا استراتيجيا يتكون من سبعة أبعاد مترابطة للجاهزية، ومسارا تنفيذيا من ثلاث مراحل يبدأ ببناء الأسس، ثم الانتقال إلى الجيل الخامس والجيل الخامس المتقدم، وصولا إلى الجاهزية الانتقائية للجيل السادس. ويسهم الإطار في تحويل التطورات العالمية للجيل

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السادس إلى أولويات عملية ومتكاملة تتناسب مع الظروف الوطنية في ليبيا، كما يوفر أساسا منظما لصناع السياسات والجهات التنظيمية ومشغلي الاتصالات والمؤسسات الاكاديمية لتوجيه تحديث الشبكات والتجارب القطاعية المستقبلية.

الكلمات المفتاحية :الجيل السادس؛ ليبيا؛ التحول الرقمي؛ الإطار الاستراتيجي؛ الجاهزية الوطنية؛ الجيل الخامس المتقدم؛ التبني المرحلي.

1. Introduction

Sixth-generation (6G) networks are expected to represent a major stage in the evolution of mobile communication beyond 5G and 5G-Advanced. Their significance is not limited to higher transmission speeds or greater network capacity, but extends to the integration of communication, computing, sensing, artificial intelligence, automation, and energy-efficient operation within a more intelligent and adaptive digital environment. These capabilities may support advanced services in healthcare, transportation, industry, public administration, infrastructure monitoring, and remote connectivity. Consequently, 6G should be considered a component of future digital transformation rather than merely another mobile-network upgrade (Tataria et al., 2021).

Preparing for 6G, however, requires more than access to new telecommunications equipment. National readiness depends on the quality and reliability of existing networks, fiber and backhaul capacity, spectrum and regulatory governance, cybersecurity, cloud and edge computing, data management, investment capacity, research capability, and specialized human resources. These requirements are particularly important in developing and transitional economies, where the adoption of advanced technologies may be constrained by institutional, financial, infrastructural, and skills-related limitations. In such settings, a phased readiness process is more realistic than an immediate transition to large-scale 6G deployment.

Libya provides an important context for examining this issue. The country has growing digital-transformation needs and significant opportunities to use advanced connectivity in sectors such as oil and gas, healthcare, education, ports, public services, emergency

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response, and geographically remote areas. Nevertheless, research on digital transformation in Libya has identified persistent challenges related to telecommunications infrastructure, institutional coordination, regulatory implementation, funding, technical capacity, and specialized skills (Wynn et al., 2021). These conditions indicate that Libya's future preparation for 6G should begin with the modernization of its current telecommunications and digital foundations.

The main problem addressed by this study is the absence of a clear and context-specific framework that explains how Libya can prepare for future 6G adoption in a realistic, coordinated, and phased manner. Existing studies provide substantial knowledge about 6G technologies, network architectures, performance expectations, security requirements, and potential applications. However, less attention has been given to how countries facing infrastructure, regulatory, financial, and institutional constraints can translate these global technological developments into practical national readiness pathways. Without such a framework, future planning may become fragmented, investment priorities may remain unclear, and advanced network initiatives may be disconnected from national development needs.

Accordingly, this study aims to develop a strategic framework for the future adoption of 6G networks in Libya. It addresses the following central research question:

What strategic framework can support future 6G adoption in Libya in a realistic, phased, and context-specific manner? To answer this question, the study identifies the main readiness challenges, determines the technical and institutional conditions required for future adoption, and proposes implementation pathways that can guide Libya from current network modernization toward 5G and 5G-Advanced readiness and, eventually, selective 6G adoption.

The study adopts an evidence-based analytical approach based on peer-reviewed literature concerning 6G, technology adoption, cybersecurity, digital infrastructure, and network readiness, together with relevant academic evidence concerning Libya's digital-transformation environment. The analysis involves synthesizing

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global 6G requirements, interpreting them in relation to Libya's national conditions, identifying major readiness gaps, and converting the resulting findings into a strategic framework and phased implementation pathway. This approach is consistent with literature-based framework development, in which existing knowledge is systematically organized to establish conceptual relationships and produce practical guidance (Webster & Watson, 2002).

The study contributes scientifically by extending the discussion of 6G beyond technical architectures and advanced deployment environments to the readiness conditions of a developing and transitional national context. Practically, it provides a structured basis for policymakers, regulators, telecommunications operators, universities, and research institutions to coordinate future decisions concerning infrastructure, regulation, cybersecurity, investment, skills, and priority national applications. The proposed framework therefore positions 6G adoption in Libya as a gradual and evidence-based readiness process rather than an immediate nationwide deployment objective.

2. Literature Review

Sixth-generation (6G) networks are generally presented in the literature as a major transformation beyond 5G and 5G-Advanced rather than a simple improvement in transmission speed or network capacity. While 5G introduced enhanced mobile broadband, ultra-reliable low-latency communication, massive machine-type communication, and network slicing, emerging digital services will require deeper integration between communication, computing, sensing, intelligence, and automation. This development positions 6G as part of a broader digital infrastructure ecosystem capable of supporting more adaptive, reliable, and context-aware services (Tataria et al., 2021).

Research on 6G identifies several enabling technologies that may shape future network architectures, including AI-native networking, reconfigurable intelligent surfaces, integrated sensing and communication, terahertz communication, cell-free massive MIMO, non-terrestrial networks, cloud-edge integration, and network digital twins. These technologies are expected to support

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intelligent resource management, programmable network operation, and advanced services across industrial, public, and societal sectors. Their practical implementation, however, will depend on supporting infrastructure, computing capacity, reliable data systems, and specialized technical expertise (Wang et al., 2023).

Artificial intelligence is expected to play a central role in 6G by supporting resource allocation, traffic prediction, mobility management, anomaly detection, energy optimization, and automated service orchestration. This shift toward AI-native operation means that national readiness will depend not only on telecommunications infrastructure, but also on data governance, computing resources, algorithmic capabilities, and skilled professionals. At the same time, the integration of AI, cloud-edge platforms, connected devices, and critical services will create new security and privacy requirements, including identity protection, resilient network operation, incident response, and security-by-design mechanisms (Letaief et al., 2019, Porambage et al., 2021).

The literature also emphasizes that the value of 6G should be assessed through its contribution to economic and social development rather than through technological deployment alone. Potential applications include immersive communication, connected healthcare, intelligent transportation, industrial automation, digital education, energy management, public safety, and remote infrastructure monitoring. The relevance of these applications will vary across countries according to national priorities, institutional capacity, and the availability of supporting digital infrastructure (Strinati et al., 2019).

Future 6G systems may also integrate terrestrial, satellite, and aerial networks to improve connectivity in remote or underserved areas. Such integration may be particularly valuable for geographically dispersed countries, although its implementation will require effective spectrum coordination, interoperability, backhaul capacity, and financially viable deployment models. In parallel, increasing traffic volumes, distributed computing, and AI processing make energy efficiency and sustainable network planning essential considerations for future adoption (Giordani & Zorzi, 2021, Huang et al., 2019).

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Technology-adoption research indicates that advanced network adoption cannot be explained by technical availability alone. The Technology–Organization–Environment framework shows that adoption is shaped by the interaction between technological characteristics, organizational capabilities, and external conditions. Applied to national 6G readiness, this perspective highlights the importance of institutional coordination, regulatory capacity, investment conditions, market demand, and human resources. Spectrum governance is also central because future networks will require long-term planning, transparent licensing, refarming, monitoring, sharing arrangements, and coordination across different frequency ranges (Tornatzky & Fleischer, 1990, Alsaedi et al., 2023).

These requirements are particularly important for developing and transitional economies, where advanced-network adoption often occurs under infrastructure, financial, institutional, and skills-related constraints. Research on digital transformation in Libya has identified limitations in network infrastructure, organizational coordination, funding, technical capacity, and specialized human resources. Such conditions suggest that future 6G adoption should be preceded by improvements in existing mobile services, fixed broadband, fiber and backhaul infrastructure, cybersecurity, cloud computing, regulatory implementation, and professional capacity (Wynn et al., 2021).

Overall, the literature provides substantial knowledge on 6G technologies, architectures, security, sustainability, and potential applications. However, most studies concentrate on technical development and advanced deployment environments, while limited attention is given to how developing and transitional countries can convert these global directions into realistic national readiness pathways. This gap is particularly relevant to Libya, where future adoption must be aligned with existing telecommunications conditions, regulatory capacity, investment feasibility, institutional readiness, and priority national sectors. Accordingly, this study develops a context-specific strategic framework that connects global 6G developments with Libya’s challenges, readiness requirements, and phased implementation pathways.

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3. 6G Technical Requirements and Strategic Adoption Dimensions for Libya

Future sixth-generation network adoption requires translating emerging technical capabilities into practical national readiness dimensions. Unlike earlier mobile generations, 6G is expected to extend beyond conventional broadband connectivity by integrating communication, computing, sensing, artificial intelligence, automation, and sustainability within an intelligent and adaptive digital ecosystem. Therefore, national readiness cannot be assessed solely through radio-access deployment, data rates, coverage, or spectrum availability. It also depends on resilient infrastructure, distributed computing, secure network operation, enabling regulation, sustainable investment, and specialized human capabilities (Tataria et al., 2021, Wang et al., 2023).

The emerging 6G vision includes AI-native network management, cloud-edge integration, integrated sensing and communication, non-terrestrial connectivity, high-capacity spectrum use, advanced cybersecurity, and energy-efficient network design. AI is expected to support resource allocation, traffic prediction, anomaly detection, mobility management, service orchestration, and energy optimization, while cloud and edge computing will provide the distributed processing required for low-latency and data-intensive applications (Letaief et al., 2019, You et al., 2021). At the same time, increasingly distributed and intelligent network architectures will require stronger privacy, identity management, incident response, resilience, and security-by-design mechanisms (Porambage et al., 2021).

Future connectivity will also depend on the coordinated use of terrestrial and non-terrestrial networks, particularly where conventional infrastructure cannot provide sufficient coverage. Satellite and aerial network components may support remote and underserved areas, although their integration requires effective spectrum coordination, interoperability, backhaul capacity, and economically viable deployment models (Giordani & Zorzi, 2021). In addition, the expected growth of network traffic, computing demand, and AI processing makes energy efficiency, infrastructure

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sharing, intelligent power management, and sustainable network planning essential requirements for future adoption (Huang et al., 2019).

Spectrum and regulatory readiness are equally important. Future networks are expected to use combinations of low-, mid-, millimeter-wave, and potentially higher-frequency bands according to coverage, capacity, and service requirements. National preparation should therefore include long-term spectrum planning, transparent licensing, spectrum refarming, monitoring, sharing arrangements, international harmonization, and regulatory mechanisms that encourage investment and efficient infrastructure use (Alsaedi et al., 2023).

For Libya, these technical capabilities should be interpreted as strategic readiness requirements rather than immediate engineering specifications. Since 6G standards, architectures, equipment ecosystems, and commercial models are still evolving, national preparation should begin with the modernization of existing telecommunications and digital foundations. Research on digital transformation in Libya has identified persistent limitations related to infrastructure, institutional coordination, funding, technical capacity, and specialized skills, indicating that advanced network adoption must be gradual and linked to broader institutional and digital-development reforms (Wynn et al., 2021).

Accordingly, Libya should prioritize the improvement of current 4G services, preparation for 5G and 5G-Advanced, expansion of fiber, backhaul, and fixed broadband, development of cloud-edge infrastructure, strengthening of cybersecurity and spectrum governance, and investment in specialized human and research capabilities. Based on the reviewed literature, this study organizes these requirements into seven interrelated strategic adoption dimensions: infrastructure modernization, spectrum and regulatory governance, cybersecurity and digital trust, cloud-edge and AI readiness, investment and sustainability, human capacity and research ecosystem, and national use-case alignment. These dimensions provide the analytical basis for the subsequent gap analysis and proposed strategic framework, as summarized in Table 1.

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Table 1. 6G Technical Requirements and Strategic Adoption Dimensions for Libya

Technical Requirement	Strategic Adoption Dimension	Relevance to Libya
High-capacity, reliable, and scalable connectivity	Infrastructure modernization	Improve 4G performance, prepare for 5G and 5G-Advanced, and expand fiber, backhaul, and fixed broadband
Multi-band spectrum use and enabling regulation	Spectrum and regulatory governance	Strengthen spectrum planning, licensing, refarming, monitoring, quality-of-service regulation, and infrastructure sharing
Secure and resilient digital infrastructure	Cybersecurity and digital trust	Develop cybersecurity governance, incident response, data protection, identity management, and security-by-design policies
AI-native operation and low-latency processing	Cloud-edge and AI readiness	Develop data centers, edge nodes, cloud-native platforms, telecom data systems, and AI-enabled network capabilities
Energy-efficient and financially feasible deployment	Investment and sustainability	Support phased investment, public-private partnerships, infrastructure sharing, and energy-efficient network planning
Specialized technical and research capabilities	Human capacity and research ecosystem	Develop academic programs, professional training, applied research, experimental testbeds, and university-industry collaboration
Sector-driven advanced connectivity	National use-case alignment	Prioritize oil and gas, healthcare, education, ports, emergency response, public services, and remote connectivity

Source: Developed by the authors based on Huang et al. (2019), Letaief et al. (2019), Tataria et al. (2021), Giordani and Zorzi (2021), Porambage et al. (2021), You et al. (2021), Wynn et al. (2021), Alsaedi et al. (2023), and Wang et al. (2023).

Together, these dimensions establish a concise and structured basis for evaluating Libya's future 6G readiness. They do not imply immediate deployment, but identify the technical, regulatory, institutional, financial, and human foundations that should be developed progressively before selective 6G adoption becomes feasible.

4. Gap Analysis for 6G Adoption in Libya

This section analyzes the gap between the strategic adoption dimensions identified in the previous section and Libya's current readiness conditions. The purpose is not to assess immediate 6G deployment feasibility, because 6G standards, ecosystems, and commercial models are still evolving. Rather, the analysis identifies the readiness gaps that Libya should address progressively before future selective 6G adoption becomes realistic. The analysis is organized around seven dimensions: infrastructure modernization, spectrum and regulatory governance, cybersecurity and digital trust, cloud-edge and AI readiness, investment and sustainability, human capacity and research ecosystem, and national use-case alignment.

The first gap relates to infrastructure modernization. Future 6G-oriented services require high-capacity, reliable, scalable, and low-latency connectivity supported by strong mobile networks, fiber backhaul, fixed broadband, cloud-native cores, and resilient transport infrastructure. In Libya, existing research on e-government and digital transformation shows that digital service development is still constrained by inadequate information systems, weak network infrastructure, unreliable internet access, outdated technologies, limited technical capacity, funding constraints, and organizational weaknesses (Wynn et al., 2021). More recent research on Libya's e-government implementation also highlights infrastructure limitations, institutional coordination problems, digital skills gaps, and policy implementation challenges as major barriers to digital transformation (Shwehdy, 2025). This indicates that the infrastructure gap is not limited to future 6G radio equipment, but extends to the broader digital foundations required for advanced network services.

The second gap concerns spectrum and regulatory governance. Future 6G adoption will require long-term spectrum planning,

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transparent allocation, flexible licensing models, spectrum refarming, international harmonization, quality-of-service regulation, infrastructure-sharing mechanisms, and regulatory readiness for cloud, data, AI, and cybersecurity-related services. Spectrum governance research emphasizes that modern spectrum policy should move beyond traditional administrative control toward more flexible and multi-actor governance arrangements that support coordination, market development, and efficient spectrum use (Anker, 2017). For Libya, the main gap therefore lies not only in allocating frequency bands, but also in developing a future-oriented regulatory environment capable of supporting investment, competition, service quality, infrastructure sharing, and alignment with evolving international standards.

The third gap is related to cybersecurity and digital trust. Future 6G networks will support critical services, AI-enabled systems, massive connected devices, cloud-edge platforms, public-sector services, and non-terrestrial network components. This wider and more complex environment may increase exposure to cybersecurity and privacy risks, including identity attacks, data leakage, service disruption, attacks on distributed edge systems, AI-related vulnerabilities, and risks affecting network slicing and service continuity. Studies on 6G security show that future networks will inherit some vulnerabilities from earlier generations while also introducing new threat vectors linked to pervasive intelligence, advanced radio technologies, distributed infrastructures, and space-air-ground integrated networks (Nguyen et al., 2021, Porambage et al., 2021). Accordingly, Libya's readiness requires security-by-design principles, stronger cybersecurity governance, incident response capabilities, data protection mechanisms, identity management, secure digital-service environments, and resilience planning.

The fourth gap concerns cloud-edge and AI readiness. Future 6G networks are expected to depend on distributed computing, AI-native network management, local data processing, real-time analytics, and automated service orchestration. Edge intelligence research indicates that advanced 6G services will require closer integration between artificial intelligence, mobile networks, and

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edge computing in order to reduce latency and support adaptive service delivery (Xiao et al., 2020). AI-empowered wireless network research also shows that 6G will rely on AI for network design, optimization, and intelligent service management (Letaief et al., 2019). For Libya, this creates a major readiness gap because the country needs stronger data infrastructure, local computing resources, cloud and edge platforms, telecom data systems, and specialized AI-related skills before advanced 6G-oriented applications can be implemented effectively.

The fifth gap relates to investment and sustainability. Future 6G readiness will require long-term investment in telecommunications infrastructure, fiber networks, radio access modernization, cloud and edge facilities, cybersecurity systems, human capacity, and research environments. At the same time, advanced networks may increase energy demand and operational costs if they are not supported by energy-efficient planning, infrastructure sharing, renewable-energy options, and realistic deployment priorities. Green 6G research emphasizes that future networks should improve quality of service while also increasing energy efficiency and supporting more sustainable network architectures (Huang et al., 2019). In addition, research linking 6G with sustainable development highlights the need to align future network deployment with economic, social, and environmental objectives (Matinmikko-Blue et al., 2021). For Libya, the gap is therefore the absence of a clear investment and sustainability pathway that can support current modernization while preparing gradually for 5G-Advanced and future selective 6G adoption.

The sixth gap concerns human capacity and the research ecosystem. 6G readiness requires specialized expertise in telecommunications engineering, spectrum management, cybersecurity, AI, cloud and edge computing, data governance, digital policy, and sustainability planning. Studies on digital transformation in Libya indicate that limited skills, weak organizational capabilities, lack of funding, and insufficient technical specialization remain major barriers to advanced digital adoption (Wynn et al., 2021, Shwehdy, 2025). This means that future readiness should not be limited to infrastructure procurement. It should also include professional training, academic program development, applied research, certification pathways, telecom testbeds, and stronger collaboration between universities, telecom operators, regulators, and technology providers.

The seventh gap relates to national use-case alignment. Future 6G adoption should not be pursued as a technology objective in itself, but should be linked to Libya's development priorities and sectoral needs. Potential high-value use cases include oil and gas infrastructure monitoring, smart public services, connected healthcare, digital education, smart ports, emergency response, border and critical infrastructure monitoring, and connectivity for remote and underserved areas. Research on non-terrestrial networks shows that future 6G architectures may support wider coverage and connectivity beyond conventional terrestrial networks, but their adoption requires careful attention to latency, coverage, interoperability, spectrum coordination, and cost (Giordani & Zorzi, 2021). For Libya, the main gap is the limited integration between advanced network planning and sector-specific implementation priorities. A credible 6G pathway should therefore identify priority sectors, assess their readiness, and develop phased pilots before broader deployment is considered.

Table 2 summarizes the main readiness gaps identified in this analysis and links each gap to a strategic priority for Libya. The table synthesizes the analytical findings and provides the basis for the proposed strategic framework in the next section.

Table 2. Readiness Gap Analysis for Future 6G Adoption in Libya

Strategic Dimension	Main 6G-Related Requirement	Main Readiness Gap in Libya	Strategic Priority
Infrastructure modernization	High-capacity, reliable, scalable, and low-latency connectivity	Weaknesses in broadband quality, backhaul capacity, fixed connectivity, network reliability, and advanced infrastructure readiness	Upgrade 4G, prepare for 5G/5G-Advanced, expand fiber and backhaul, and strengthen fixed broadband

Strategic Dimension	Main 6G-Related Requirement	Main Readiness Gap in Libya	Strategic Priority
Spectrum and regulatory governance	Future-oriented spectrum planning and enabling regulation	Need for stronger spectrum governance, transparent licensing, regulatory enforcement, QoS rules, infrastructure sharing, and alignment with evolving standards	Strengthen spectrum planning, refarming, monitoring, licensing, infrastructure-sharing rules, and regulatory coordination
Cybersecurity and digital trust	Secure and resilient digital infrastructure	Need for stronger cybersecurity governance, incident response, data protection, identity management, and protection of critical digital services	Develop security-by-design policies, cyber governance, data protection mechanisms, and national incident response capacity
Cloud-edge and AI readiness	Distributed computing and AI-native network operation	Limited readiness in data infrastructure, local computing resources, cloud-edge capacity, telecom data systems, and AI-related skills	Develop data centers, edge nodes, cloud governance, telecom data systems, and AI-enabled network capabilities
Investment and sustainability	Sustainable financing and energy-efficient deployment	Need for realistic investment models, infrastructure sharing, public-private partnerships, and green network planning	Promote phased investment, PPPs, infrastructure sharing, energy-efficient deployment, and sustainability-oriented planning
Human capacity and	Specialized skills, applied research, and	Shortage of advanced telecom, AI, cybersecurity,	Develop academic programs, professional

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Strategic Dimension	Main 6G-Related Requirement	Main Readiness Gap in Libya	Strategic Priority
research ecosystem	experimental environments	cloud, spectrum, and 6G-related research expertise	training, certifications, research testbeds, and university-industry collaboration
National use-case alignment	Sector-driven adoption linked to national priorities	Limited linkage between advanced network planning and priority sectors	Prioritize oil and gas, healthcare, education, smart ports, emergency response, public services, and remote connectivity

Overall, the gap analysis shows that Libya's future 6G adoption should be approached as a phased readiness process rather than a direct deployment decision. The immediate priority is to strengthen current telecommunications infrastructure, prepare for 5G and 5G-Advanced, improve spectrum and regulatory governance, build cybersecurity and data capabilities, develop sustainable investment models, and strengthen human and institutional capacity. Only after these foundations are established can selective and context-specific 6G adoption become realistic, secure, and developmentally valuable.

5. Proposed Strategic Framework for 6G Adoption in Libya

Based on the literature review, the identified technical requirements, and the readiness gap analysis, this study proposes an integrated strategic framework for the future adoption of sixth-generation networks in Libya. The framework does not present 6G as an immediate nationwide deployment objective. Instead, it defines adoption as a progressive national readiness process through which existing telecommunications and digital foundations are strengthened before advanced experimentation and selective implementation are considered. This interpretation reflects the wider understanding of 6G as an intelligent ecosystem that integrates connectivity, computing, sensing, artificial intelligence, security, and sustainability rather than merely extending mobile broadband performance (Tataria et al., 2021, Wang et al., 2023).

The framework consists of seven interrelated dimensions: infrastructure modernization, spectrum and regulatory governance, cybersecurity and digital trust, cloud-edge and AI readiness, investment and sustainability, human capacity and research ecosystem, and national use-case alignment. These dimensions translate the technical and strategic requirements identified in the preceding sections into a unified model suitable for Libya's national conditions. They should not be treated as independent areas of intervention, because progress in each dimension is influenced by developments in the others.

As illustrated in Figure 1, future 6G adoption in Libya is positioned at the center of an interconnected readiness ecosystem.

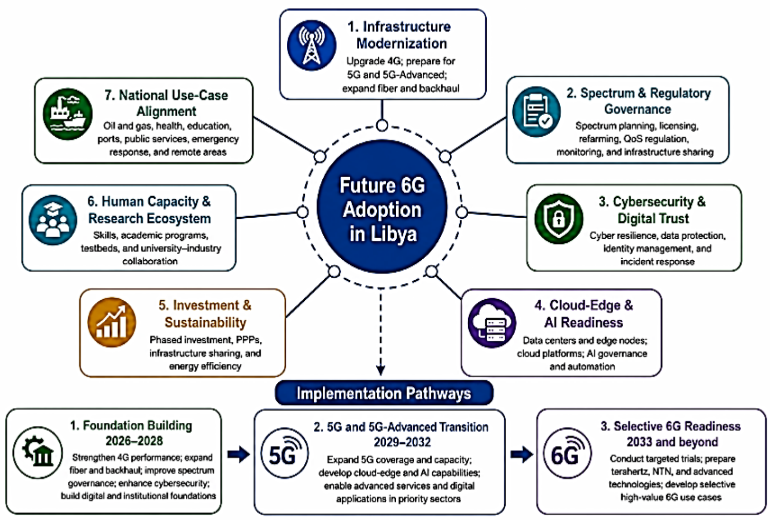

Figure 1. Proposed Strategic Framework for Future 6G Adoption in Libya

Source: Developed by the authors based on the literature synthesis and readiness gap analysis, drawing on Letaief et al. (2019), Huang et al. (2019), Tataria et al. (2021), Porambage et al. (2021), Wynn et al. (2021), Wang et al. (2023), and Alsaedi et al. (2023).

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Infrastructure modernization provides the foundation for advanced connectivity, while spectrum and regulatory governance establish the conditions for coordinated and efficient network development. Cybersecurity and digital trust protect future digital services, whereas cloud-edge and AI readiness enable intelligent and low-latency applications.

Investment and sustainability determine financial and operational feasibility, human and research capacity supports implementation and innovation, and national use-case alignment ensures that network development responds to practical economic and social priorities. The connections among the dimensions illustrate their interdependence and show that isolated initiatives are unlikely to produce effective national readiness.

The strategic logic of the framework is based on sequencing, institutional coordination, sectoral relevance, and sustainability. Libya should first improve current network performance, expand fiber and backhaul capacity, strengthen spectrum governance and cybersecurity, and develop cloud, AI, and specialized human capabilities. These foundations can support a subsequent transition toward 5G and 5G-Advanced services, followed by selective 6G experimentation when international technologies and national conditions become sufficiently mature. Implementation will also require coordination among regulators, telecommunications operators, public institutions, universities, research centers, cybersecurity bodies, and priority economic sectors.

The framework therefore converts the identified readiness gaps into an organized national pathway rather than a simple list of technical requirements. Its central contribution is to connect future network development with Libya's regulatory, institutional, financial, and developmental conditions while avoiding a technology-first approach. The following section translates this framework into phased implementation pathways for foundation building, 5G and 5G-Advanced transition, and future selective 6G readiness.

6. Implementation Pathways

The proposed strategic framework requires a phased implementation pathway that converts national readiness priorities into coordinated and practical action. Libya should not approach 6G

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as an immediate nationwide deployment objective, particularly while international technologies, standards, equipment ecosystems, and commercial models remain under development. A more realistic pathway begins with strengthening existing telecommunications and digital foundations, progresses toward 5G and 5G-Advanced capabilities, and moves later to selective 6G experimentation in sectors where advanced connectivity can generate clear national value. This sequencing reduces the risks of premature investment and links future network development to actual infrastructure, institutional, and economic readiness (Tataria et al., 2021, Wang et al., 2023).
As illustrated in Figure 1, the pathway is organized into three successive stages: foundation building, 5G and 5G-Advanced transition, and selective 6G readiness. Foundation building addresses the basic limitations that may prevent advanced network development, while the second stage introduces more programmable, intelligent, and service-oriented capabilities. The final stage focuses on targeted experimentation and selective adoption after international 6G technologies and Libya's national readiness conditions have reached sufficient maturity. The proposed periods are indicative planning horizons rather than fixed deployment deadlines and should be reviewed according to infrastructure progress, investment capacity, regulatory development, market demand, and the international maturity of 6G technologies. To make the implementation logic more explicit, Table 3 organizes the proposed pathway into three indicative stages and links each stage to its planning horizon, strategic purpose, priority actions, and expected outcome. In doing so, the table translates the strategic framework illustrated in Figure 1 and the readiness gaps identified in Table 2 into a practical sequence for future network modernization and selective 6G readiness in Libya.

The foundation-building stage should receive immediate priority because advanced-network development depends on reliable connectivity, adequate fiber and backhaul, effective spectrum governance, cybersecurity capacity, and specialized skills. Evidence concerning Libya's digital transformation environment indicates

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that infrastructure limitations, institutional coordination difficulties, funding constraints, and shortages of technical expertise remain important barriers to advanced digital development (Wynn et al., 2021).

Table 3. Phased Implementation Pathways for Future 6G Adoption in Libya

Phase	Indicative Horizon	Strategic Purpose	Priority Actions	Expected Outcome
Foundation Building	Short term: 2026–2028	Establish the basic telecommunications, regulatory, cybersecurity, and human-capacity foundations required for advanced-network readiness	Improve 4G performance and network reliability, expand fiber, backhaul, and fixed broadband, update spectrum planning, strengthen cybersecurity and data protection, develop technical and institutional capabilities	Stronger foundations for 5G, 5G-Advanced, and wider digital-service modernization
5G and 5G-Advanced Transition	Medium term: 2029–2032	Move from basic connectivity toward intelligent, programmable, and service-oriented networks	Deploy 5G and 5G-Advanced where technically and economically feasible, develop cloud-native telecom systems and edge computing, expand infrastructure sharing, strengthen quality-of-service regulation, introduce AI-assisted network management, launch sector-based pilots	Operational experience with advanced digital services and tested readiness for future 6G applications

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Phase	Indicative Horizon	Strategic Purpose	Priority Actions	Expected Outcome
Selective 6G Readiness	Long term: 2033 and beyond	Prepare for targeted experimentation and selective adoption in high-value national sectors	Conduct controlled trials, align spectrum planning with emerging international 6G standards, assess advanced AI-enabled, sensing, low-latency, and integrated terrestrial and non-terrestrial applications, prioritize strategically relevant use cases	Economically justified and nationally relevant readiness for selective 6G adoption

Source: Developed by the authors based on the proposed strategic framework and readiness gap analysis.

Progress during this stage should therefore be assessed before substantial investment is directed toward later phases.

Implementation will require a national coordination mechanism involving telecommunications regulators, network operators, digital-transformation authorities, cybersecurity institutions, universities, research centers, and relevant sectoral bodies. This mechanism should coordinate infrastructure investment, spectrum planning, security requirements, cloud-edge development, skills programs, and sector-based experimentation. Monitoring should focus on a limited set of measurable indicators, including network quality, fiber and backhaul expansion, spectrum-governance progress, cybersecurity maturity, computing capacity, trained specialists, research collaboration, and the performance of pilot applications.

Overall, the pathway operationalizes the framework presented in Figure 1 and responds to the readiness gaps identified in Table 2. It demonstrates that Libya’s future 6G adoption should proceed through evidence-based and periodically reviewed stages. The immediate objective is not 6G deployment itself, but the

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development of the technical, regulatory, institutional, financial, and human foundations required for Libya to adopt future network capabilities selectively and effectively.

7. Discussion

The analysis indicates that future 6G adoption in Libya should be understood as a progressive readiness process rather than an immediate nationwide deployment objective. The combined evidence from the readiness gaps presented in Table 2, the strategic framework illustrated in Figure 1, and the phased pathway summarized in Table 3 shows that advanced-network adoption depends on the coordinated development of technical, regulatory, institutional, financial, and human capabilities. This interpretation differs from a technology-first approach in which network deployment is treated as the primary indicator of readiness.

The gap analysis demonstrates that Libya's main challenge is not limited to telecommunications infrastructure. Although network modernization, fiber expansion, backhaul capacity, and service reliability remain essential, these improvements alone would not create sufficient readiness for future 6G applications. Advanced networks will also require effective spectrum governance, resilient cybersecurity systems, reliable data management, cloud-edge computing capacity, sustainable investment, and specialized expertise. This conclusion is consistent with the wider 6G literature, which presents future networks as integrated ecosystems combining communication, computing, intelligence, sensing, automation, and sustainability rather than as extensions of conventional mobile broadband

Figure 1 represents the main conceptual contribution of the study by translating these interconnected requirements into a framework adapted to Libya's national conditions. The seven dimensions are mutually dependent: intelligent services require cloud-edge infrastructure, secure data environments, and qualified professionals, while infrastructure modernization depends on investment, regulation, spectrum planning, and identifiable sectoral demand. The framework therefore suggests that isolated interventions, such as purchasing advanced equipment without parallel improvements in governance, cybersecurity, skills, and

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institutional coordination, are unlikely to produce sustainable readiness.

The implementation pathway presented in Table 3 further shows that sequencing is central to the proposed framework. Foundation building should precede the wider introduction of 5G and 5G-Advanced capabilities, while selective 6G experimentation should occur only after sufficient technical and institutional maturity has been achieved. This approach reduces the risk of premature investment and allows national readiness to be evaluated through measurable progress rather than technological ambition alone. It also enables later stages to be adjusted according to infrastructure development, investment capacity, regulatory progress, market demand, and the maturity of future 6G technologies.

The practical implication is that Libya should connect future network planning with clearly defined national priorities. Rather than treating 6G as a symbolic technological milestone, decision-makers should focus on use cases capable of producing identifiable economic and social value. Areas such as oil and gas infrastructure monitoring, ports, connected healthcare, emergency response, public-service modernization, critical infrastructure protection, and remote connectivity may provide suitable environments for future targeted experimentation. The integration of terrestrial and non-terrestrial connectivity may be particularly relevant to geographically remote areas, although its feasibility will depend on cost, interoperability, spectrum coordination, and supporting infrastructure (Giordani & Zorzi, 2021).

From a scientific perspective, the study extends existing 6G research by shifting attention from advanced technical capabilities to the readiness conditions required in a developing and transitional national setting. Its contribution lies in connecting global technological requirements with Libya’s infrastructure constraints, institutional capacity, investment feasibility, and development priorities. This is important because previous research on Libya’s digital transformation has identified continuing limitations in infrastructure, coordination, funding, implementation capacity, and specialized skills (Wynn et al., 2021). The proposed framework therefore provides a structured basis for examining how these

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limitations can be addressed before selective 6G adoption becomes realistic.

The study is nevertheless limited by its reliance on secondary evidence, literature synthesis, and strategic mapping rather than field surveys, expert interviews, or quantitative readiness measurement. The framework should consequently be regarded as an analytical and planning contribution rather than an empirically validated readiness index. Future research should test its dimensions through expert consultation, develop measurable indicators for national 6G readiness, compare Libya with other developing countries, and assess the technical and economic feasibility of specific sector-based applications.

8. Conclusion

This study developed a context-specific strategic framework for future 6G adoption in Libya. The analysis shows that an appropriate national approach should not begin with immediate technology deployment, but with coordinated readiness across infrastructure, regulation, cybersecurity, cloud-edge and AI capabilities, investment, human capacity, and priority use cases. Accordingly, the framework answers the study's central research question by proposing a multidimensional and phased pathway that progresses from foundation building to 5G and 5G-Advanced transition, followed by selective 6G readiness when technical, institutional, and economic conditions become sufficiently mature.

The main value of the framework lies in converting global 6G developments into practical priorities suited to Libya's current digital environment. It provides policymakers, regulators, telecom operators, universities, and other stakeholders with a structured basis for coordinating investment, governance, capacity building, and sector-based experimentation. The study therefore concludes that Libya's future ability to benefit from 6G will depend less on early equipment acquisition than on sustained improvements in national readiness and implementation capacity. Future research should empirically validate the framework and develop measurable indicators for assessing progress across its dimensions and implementation stages.

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