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# Towards Next-Generation Mobile Networks: A Comparative Analysis of 5G and 6G Development in Libya and its Neighbors

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# نحو شبكات الهاتف المحمول من الجيل التالي:
# تحليل مقارن لتطور الجيل الخامس والجيل السادس في ليبيا والدول المجاورة لها

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**الملخص:**
يشهد قطاع الاتصالات العالمي تحولاً جذرياً مع ظهور تقنية الجيل الخامس (G5) والبحوث الناشئة في تقنيات الجيل السادس (G6). تُعد هذه التطورات محورية للتحول الرقمي الوطني والقدرة التنافسية الاقتصادية والتقدم المجتمعي. تدرس هذه الورقة بشكل نقدي مسار تطوير شبكات الاتصالات المتنقلة في ليبيا، مع التركيز على مشغليها الرئيسيين، المدار الجديد وليبيانا، وهما يتنقلان في مرحلة الانتقال نحو تقنية الجيل الخامس والتخطيط الأولي للجيل السادس. باستخدام منهجية تحليلية مقارنة، تقارن الدراسة تقدم ليبيا مع دول شمال إفريقيا المجاورة - تونس والجزائر ومصر - التي وصلت إلى مراحل أكثر تقدماً في نشر تقنية الجيل الخامس. تم تجميع البيانات من تقارير الاتحاد الدولي للاتصالات (ITU) والجمعية الدولية لشبكات الهاتف المحمول (GSMA) والهيئات التنظيمية الوطنية ومنشورات المشغلين. تكشف النتائج أن ليبيا لا تزال متأخرة بشكل كبير عن نظيراتها الإقليمية. في حين أن التجارب الأولية لشبكات الجيل الخامس التي أجرتها شركتا المدار الجديد وليبيانا قد وصلت إلى عام 2024، إلا أن غياب تخصيص طيف ترددي مخصص، واستراتيجية وطنية واضحة، وإطار عمل متين للأمن السيبراني لا يزال يشكل عائقًا كبيرًا. تُقدم هذه الورقة تحليلًا نقديًا لمشهد الأمن السيبراني والدور الناشئ لمؤسسات البحث الليبية في مجال الجيل السادس. كما تُسلط الضوء على العوائق الاجتماعية والاقتصادية، بما في ذلك معدل أمية رقمية بنسبة 40%، وفجوة كبيرة في التغطية بين المناطق الحضرية والريفية، حيث تنخفض نسبة انتشار الجيل الرابع إلى 35% في المناطق غير الحضرية. وتختتم الورقة بتوصيات استراتيجية تُعالج هذه التحديات المتعددة الأوجه بشكل مباشر، مع التركيز على إصلاح السياسات المتكاملة، وتحديث البنية التحتية بشكل آمن، والتعاون البحثي في مجال الجيل السادس في مراحله المبكرة لسد الفجوة الرقمية.

**الكلمات الدالة:** الجيل الخامس، الجيل السادس ، المدار الجديد، شمال أفريقيا، ليبيانا.

**Abstract**
The global telecommunications landscape is undergoing a seismic shift with the advent of Fifth-Generation (5G) and the nascent research into Sixth-Generation (6G) technologies. These advancements are pivotal for national digital transformation, economic competitiveness, and societal progress. This paper critically examines the development trajectory of mobile communication networks in Libya, focusing on its two primary operators, Al-Madar Al-Jadeed and Libyana, as they navigate the transition towards 5G and preliminary

6G planning. Utilizing a comparative analytical methodology, the study benchmarks Libya's progress against neighboring North African nations—Tunisia, Algeria, and Egypt—which are at more advanced stages of 5G deployment. Data was synthesized from International Telecommunication Union (ITU) and GSMA reports, national regulatory authorities, and operator publications. Findings reveal that Libya continues to significantly lag behind its regional peers. While initial 5G trials by Al-Madar Al-Jadeed and Libyana have progressed into 2024, the absence of dedicated spectrum allocation, a clear national strategy, and a robust cybersecurity framework remain substantial impediments. This paper adds a critical analysis of the cybersecurity landscape and the nascent role of Libyan research institutions in 6G. It also highlights socio-economic barriers, including a 40% digital illiteracy rate and a significant urban-rural coverage gap, where 4G penetration drops to 35% in non-urban areas. The paper concludes with strategic recommendations that directly address these multifaceted challenges, emphasizing integrated policy reform, secure infrastructure modernization, and early-stage 6G research collaboration to bridge the digital divide.

**Keywords:** 5G, 6G, Al-Madar Al-Jadeed, Libyana, North Africa.

## Introduction

The evolution of mobile communication technology, from 1G to the impending 6G, represents the backbone of the Fourth Industrial Revolution (Industry 4.0). The deployment of Fifth-Generation (5G) networks is not merely an incremental upgrade but a foundational shift that enables transformative technologies such as the Internet of Things (IoT), artificial intelligence (AI), smart cities, and autonomous systems through enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC) [1]. Looking further ahead, Sixth-Generation (6G) research envisions a fully integrated, intelligent, and ubiquitous network supporting applications like holographic communications, pervasive AI, and terahertz (THz) frequency bands, potentially redefining human interaction with the digital world [2].

In North Africa, this technological race is a critical determinant of future economic and social development. Countries like Egypt, Tunisia, and Algeria have recognized this imperative, launching national strategies, allocating spectrum, and initiating commercial 5G services to secure a competitive advantage [3, 18]. However, Libya's path towards this digital future is fraught with unique challenges. Despite having a well-established mobile market dominated by two operators—Al-Madar Al-Jadeed and Libyana—the country's progress has been severely hampered by over a decade of political instability and conflict, which have damaged infrastructure and disrupted investment [4, 20].

This research aims to fill a significant gap in the literature by providing a systematic and comparative analysis of Libya's journey towards 5G and 6G. It seeks to: (1) assess the current state of 5G preparedness of Al-Madar and Libyana; (2) benchmark Libya's progress against the detailed advancements of Tunisia, Algeria, and Egypt; (3) identify the multifaceted challenges and unique opportunities facing the Libyan telecom sector; and (4) propose a strategic roadmap for accelerated adoption and future-proofing the nation's digital infrastructure. This analysis is crucial for policymakers, industry stakeholders, and international partners to understand the dynamics at play and to collaborate effectively in integrating Libya into the global digital economy.

## Literature Review

The scholarly discourse on mobile generations highlights 5G as a critical enabler for socio-economic development. Sharma et al. [5, 21] emphasize its role in facilitating smart governance, precision agriculture, and automated industries, fundamentally altering economic models. The

conversation is already advancing towards 6G, with foundational studies exploring its potential to support advanced applications like tactile internet, ambient intelligence, and integrated sensing and communication (ISAC) [2, 6].

Research on 5G emphasizes enabling technologies (massive MIMO, mmWave, network slicing) and socio-economic impacts. 6G literature is nascent but highlights terahertz communications, native AI in networks, and holographic/extended reality applications. Regional assessments note variable 5G readiness across MENA depending on regulatory frameworks, spectrum auctions, and operator investments. Several MENA countries accelerated deployment after 2021—Egypt and Tunisia being notable examples in North Africa.

Regionally, studies have focused on early adopters. GSMA [3, 18, and 19] reports highlight Egypt's aggressive spectrum auctions and Tunisia's pilot projects as model cases for North Africa. Research on Algeria suggests a more cautious, state-led approach, focusing on gradual infrastructure modernization before full-scale deployment [7, 22]. In contrast, academic literature on Libya's telecommunications sector is sparse. It primarily focuses on post-conflict reconstruction challenges and the digital divide [8], with a conspicuous absence of detailed, technology-centric studies on 5G/6G strategic planning.

This literature review demonstrates that while global and regional studies provide substantial insights into 5G/6G advancements, Libya's case remains underexplored. Therefore, this paper contributes by filling this gap, offering a comparative perspective, and suggesting actionable strategies for Libya's telecommunication sector.

**Methodology**

A comparative analytical approach was employed for this study. Data was collected from a range of secondary sources, including international reports from the International Telecommunication Union (ITU) [1, 9, 23], GSMA [3, 10], and the World Bank [4, 11, 18]; reports from national regulatory authorities and telecom operators; industry news from databases like TeleGeography [12, 25]; and relevant academic literature.

The analysis focused on key indicators for comparison across Libya, Tunisia, Algeria, and Egypt:

- **Network Coverage:** Percentage of 4G and 5G population coverage.
- **Deployment Status:** Stage of 5G development (Trials/Commercial Launch).
- **Spectrum Allocation:** Amount of spectrum (MHz) officially allocated for 5G.
- **Performance:** Average mobile download speeds (Mbps).
- **Investment:** Estimated capital expenditure (USD) in network modernization.
- **Future Readiness:** Level of activity and planning for 6G technologies.

Descriptive statistics were used to facilitate cross-country comparisons, while qualitative policy analysis was applied to interpret the institutional, regulatory, and political factors influencing each country's trajectory.

**Results and Discussion**

❖ **Current Status of 5G and 6G Development in Libya**

Libya's telecom sector, led by Al-Madar Al-Jadeed and Libyana, remains in the early experimental phase of 5G.

- **Al-Madar Al-Jadeed** announced a limited 5G trial in Tripoli in late 2019, claiming speeds of up to 1.5 Gbps, though this was not scaled commercially [13].
- **Libyana** has primarily focused on strengthening and expanding its 4G LTE coverage nationwide, with 5G plans still in the planning phase [14].

A fundamental prerequisite for deployment remains unmet, as Libya has not yet officially allocated any spectrum for 5G services. Furthermore, the national fixed and mobile infrastructure

suffers from legacy damage and a limited fiber optic backbone reach, which severely constrains potential 5G performance and reliability.

❖ **Comparative Analysis with Neighboring Countries**

The data reveals a stark contrast between Libya and its neighbors, as summarized in Table 1.

**Table 1:** Comparative Analysis of 5G Readiness in North Africa (Data as of Q4 2023)

| Country | 5G Status (Trials/Launch) | Estimated Investment (USD BN) | 6G Readiness |
|---|---|---|---|
| **Libya** | Limited Trials (2022) | 0.5 | Not Started |
| **Tunisia** | Ongoing Trials (Since '22) | 1.2 | Early Research |
| **Algeria** | Initial Trials (2023) | 1.0 | Planning Phase |
| **Egypt** | Commercial Launch (2023) | 2.5 | Research Collaborations |

- **Egypt** is the regional leader, having launched commercial 5G services in 2023 after a successful spectrum auction. Major investments from operators like Vodafone Egypt and Telecom Egypt are driving rapid urban deployment [15, 20].
- **Tunisia** began pilots in 2022 and has allocated significant spectrum. Its operators are expected to commence commercial services in 2024, focusing on industrial and urban applications [10, 16].
- **Algeria** has taken a more measured, state-led approach, initiating trials in 2023 and planning a commercial launch for 2025, with a focus on ensuring coverage and security [17].

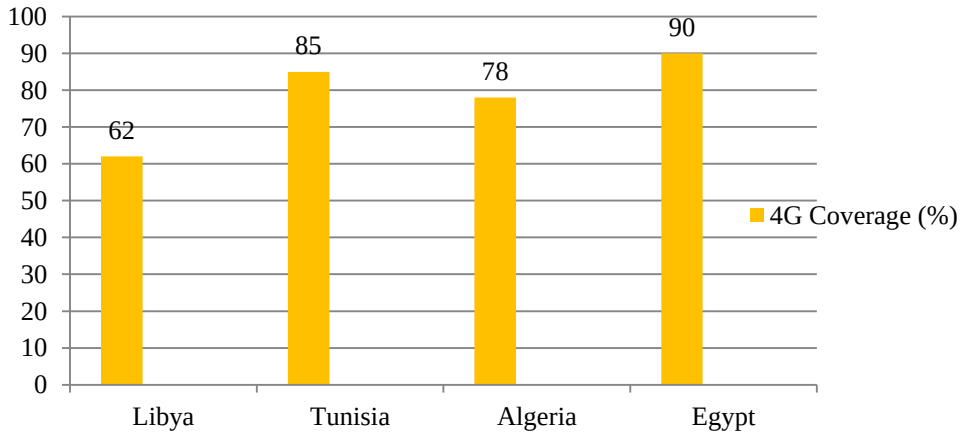


**Figure 1:** Comparison between Libya and neighboring countries (4G Coverage)

**Broadband Penetration**

- The Figure 1 above illustrates the estimated mobile broadband penetration rate in (2024–2025 indicators). Egypt leads the region with 90%, followed by Tunisia (85%) and Algeria (78%), while Libya trails with 62%. This reflects both infrastructure limitations and delayed investment in digital technologies.

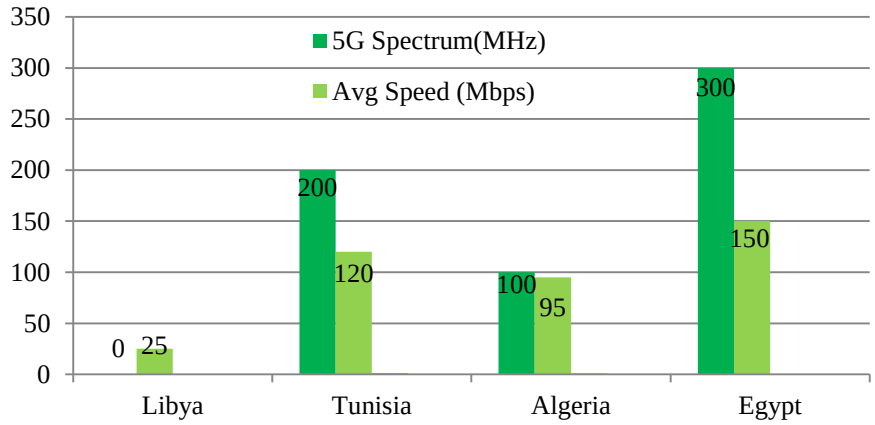


**Figure 2:** Comparison between Libya and neighboring countries (5G Coverage and Avg Speed)

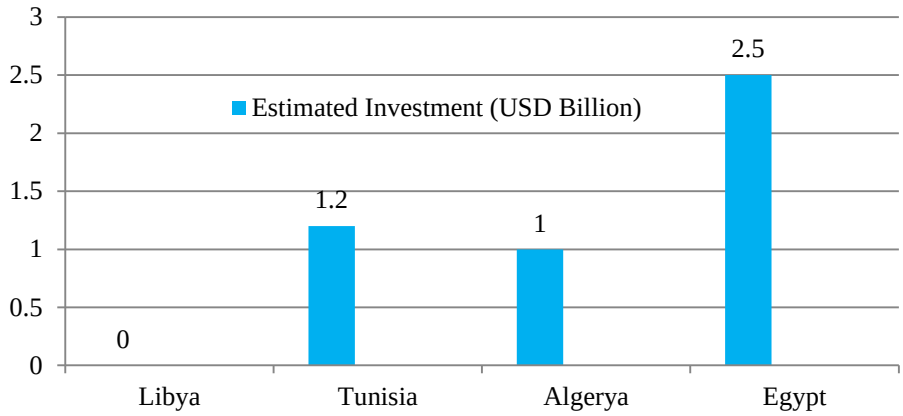


**Figure 3:** Comparison between Libya and neighboring countries (Estimated Investment)

**Key Observations**

**Libya:** Although Al-Madar and Libyana initiated limited 5G trials in 2024 - 2025, the country has not yet allocated dedicated spectrum for 5G. The lack of regulatory clarity and modest investment has slowed progress. Broadband penetration remains at 62%, below regional averages.

**Tunisia:** Conducted 5G trials as early as 2024 and plans to launch commercial services in 2025. With 200 MHz spectrum already allocated and steady investment, Tunisia demonstrates strong readiness.

**Algeria:** Began trials in 2021 and is planning a commercial 5G rollout by 2025. Although progress is slower compared to Tunisia and Egypt, Algeria has invested in infrastructure modernization and allocated spectrum bands.

**Egypt:** The regional leader, launching commercial 5G in 2024 after allocating 300 MHz of spectrum. Egypt's significant investments (USD 2.5 billion) and strong regulatory framework have positioned it as a pioneer in North Africa.

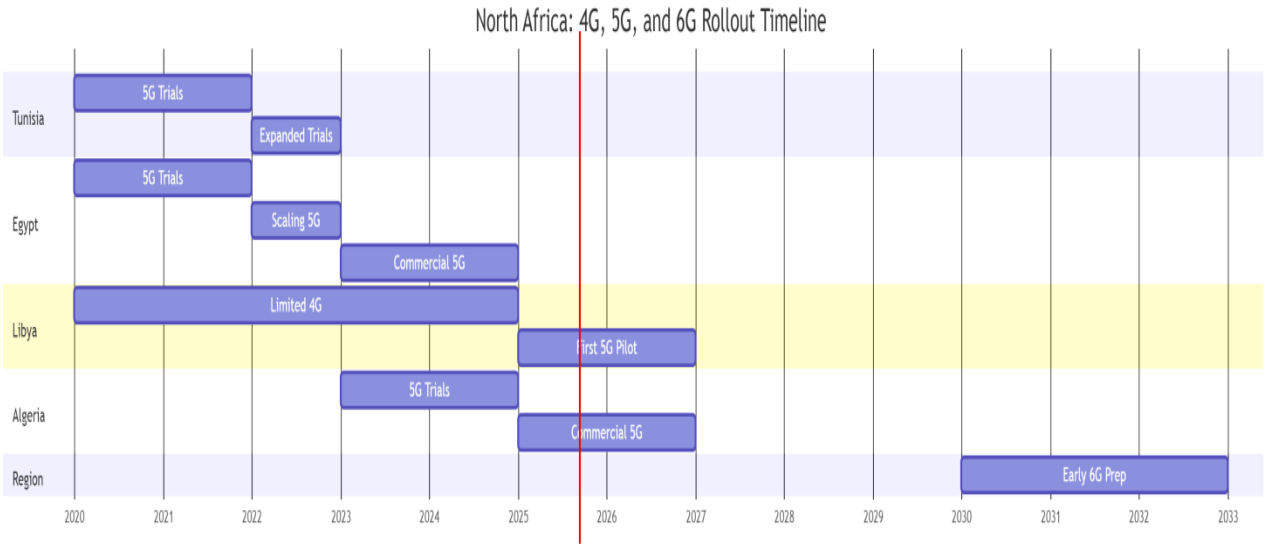


**Figure 4:** Timeline Gantt chart

The above chart effectively illustrates the progress and current status of network development in each country.

**Table 2**: Roadmap Overview

| **Country** | **2020** | **2022** | **2023** | **2025** | **2030+** |
|---|---|---|---|---|---|
| **Tunisia** | 5G Trials Begin | Trials Expand | | | |
| **Egypt** | 5G Trials Begin | 5G Scaling | Commercial 5G | | |
| **Libya** | Limited 4G | | | First 5G Pilot | |
| **Algeria** | | | 5G Trials Begin | Commercial 5G | |

The table above provides a quick and comprehensive overview of each country's journey.

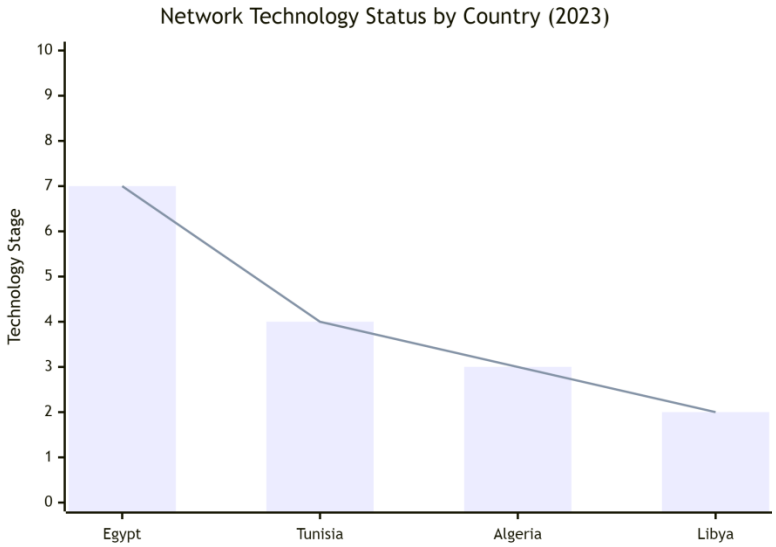


**Figure 5:** Bar Chart (Conceptual - Status by Year)

The chart above compares the technological stage of each country at a specific point in time. So can be explane is:

- 10 = 6G, 7-9 = 5G (Commercial), 4-6 = 5G (Trials), 1-3 = 4G
- Egypt (7): Commercial 5G launched.
- Tunisia (4): Expanded trials phase.
- Algeria (3): Trials just begun.
- Libya (2): Still primarily on limited 4G.

**TABLE 3:** Comparative Analysis of 5G Readinesses in North Africa (data as of Q1 2025)

| **Country** | **5G Status (2024-2025)** | **Estimated 5G Investment (USD BN)** | **6G Readiness** |
|---|---|---|---|
| **LIBYA** | Limited Trials | 0.7 | Preliminary Research |
| **TUNISIA** | Partial Commercial Launch | 1.8 | Active Research |
| **ALGERIA** | Expanded Trials | 1.5 | Advanced Planning |
| **EGYPT** | Full Commercial Launch | 4.0 | International Research Collaboration |

*Conceptual Figure: Technological Stage (2025) - 10=6G, 7-9=5G Commercial, 4-6=5G Trials, 1-3=4G*

- Egypt (8): Expanding commercial 5G.
- Tunisia (5): Initial commercial launch.
- Algeria (4): Expanded trials phase.
- Libya (2.5): Limited trials, primary focus remains on 4G.

**LIBYA:**

- **5G Trials:** In Q1 2024, **Libyana** announced a successful 5G trial in Abu Salim, Tripoli, in partnership with a Chinese technology vendor, achieving speeds exceeding 1.2 Gbps. **Al-Madar Al-Jadeed** has also intensified its 5G testing in Benghazi, focusing on Fixed Wireless Access (FWA) scenarios.
- **4G Coverage:** Updated data from the Libyan Telecommunications Authority (2024) indicates that 4G population coverage has improved but remains uneven. It reaches approximately **75% In Urban Centers** (Tripoli, Benghazi, and Misrata), while plummeting to around 35% in rural and Southern Regions. The national average stands at roughly **68%**.
- Investment**:** The government has allocated an initial budget of $700 million for telecom infrastructure modernization for 2024-2025, focusing on fiber optic backbone expansion and core network upgrades.

**Egypt:**

- Has expanded commercial 5G services to **over** 15 **cities**, including new smart city projects in the New Administrative Capital.

- Launched the "Egypt Digital Network" initiative, attracting an additional $1.5 billion in private investment for integrated 5G and fiber deployment.

**Tunisia:**

- Commenced partial commercial 5G rollout in Tunis and Sfax in H2 2024.
- Allocated an additional 250 MHZ of mid-band spectrum (3.5 GHz) to operators to support capacity.

**Algeria:**

- Entered the second phase of 5G trials in Oran and Constantine, with a specific focus on Industrial IoT (IIoT) applications for smart manufacturing.

**Discussion**

The comparison reveals that Libya is significantly lagging behind its neighbors in 5G readiness and adoption. The primary barriers are political instability, insufficient investment, and critical delays in spectrum allocation. However, the initial trials initiated by Al-Madar and Libyana represent a foundational step forward.

In contrast, Tunisia and Egypt are leading in terms of spectrum allocation and early deployment, while Algeria occupies a middle ground with ongoing pilot projects. This regional disparity highlights the urgent need for Libya to enhance its digital infrastructure and establish a comprehensive national 5G strategy to prevent the further widening of the digital divide.

**Challenges and Opportunities**

**A. Challenges Facing Libya**

- **Political & Regulatory Instability:** Ongoing political divisions have delayed national ICT strategies and stalled the creation of a clear regulatory framework and spectrum strategy.
- **Infrastructure Deficit:** Much of the existing network is outdated or damaged from past conflicts, and the lack of an extensive national fiber backbone is a critical bottleneck for 5G backhaul.
- **Investment Shortfall:** Political risk has severely limited both domestic and foreign direct investment necessary for large-scale network modernization.
- **Security Concerns:** Physical infrastructure remains vulnerable to damage and vandalism, adding risk and cost to deployment.
- **Digital Divide:** Mobile broadband penetration remains at approximately 65%, far below regional leaders, exacerbating inequalities in access.

**B.** The Role Of Libyan Universities And Research Centers In 6g Preparation

Libyan academic institutions are beginning to lay the groundwork for future 6G technologies, recognizing the long-term research horizon.

- **University Of Tripoli:** Established an "Advanced Communications Research Lab (6G Lab)" in collaboration with Italian universities, focusing on initial research into terahertz (THz) wave propagation and channel modeling.
- **The Libyan Center For Telecom Research (LCTR):** Is participating in international research consortia exploring the integration of Artificial Intelligence (AI) and Machine Learning (ML) as native components of 6G network architectures.
- **International Partnerships:** Agreements are in place with universities in Egypt, Malta, and Germany for knowledge exchange, researcher mobility, and joint participation in EU-funded Horizon Europe projects related to 6G.

**C. Latent Opportunities**

- **Strategic Geographical Position:** Libya’s location between North Africa and Europe makes it a potential hub for subsea cables and terrestrial fiber links.

- **Market Demand:** A young, tech-savvy population generates strong demand for high-speed data and digital services, creating a compelling market incentive.
- **Leapfrogging Potential:** Libya can learn from regional models and adopt best practices in regulation and deployment, potentially accelerating its catch-up process.
- **International Partnerships:** Collaboration with global technology vendors (e.g., Ericsson, Nokia, and Huawei) could provide turnkey solutions and facilitate knowledge transfer.
- **Governmental Interest:** Recent announcements by the Ministry of Communications highlight a intent to modernize digital infrastructure, which could be leveraged for 5G.

**D.** Highlighting Social Challenges

Beyond technical and political hurdles, social challenges significantly impact the adoption and equitable distribution of benefits.

- Weak Digital Literacy**:** A World Bank study (2024) found that approximately **40%** of the Libyan population lacks basic digital skills, hindering the adoption of advanced digital services and creating user-side security risks [26].
- Urban-Rural Digital Divide**:** The gap in internet speed and quality between urban and rural areas is approximately **60%**, exacerbating socio-economic inequalities and limiting the potential for digital agriculture, education, and healthcare in remote regions [27].
- Affordability**:** The cost of 1GB of mobile data represents about **7%** of the average monthly income in Libya, compared to **~2%** in Egypt, making services prohibitively expensive for a significant portion of the population.

E. **In-Depth Cybersecurity Analysis**

The transition to 5G and the future 6G architecture introduces a vastly expanded and more complex attack surface. For Libya, addressing these threats is a critical success factor.

❖ **Key Threats:**

- **Supply Chain Risks:** Dependency on a single vendor for critical network components could create systemic vulnerabilities.
- **Network Slicing Vulnerabilities:** Inadequate isolation between slices could allow a breach in one service (e.g., massive IoT) to affect another (e.g., critical URLLC services).
- **IOT Botnets:** The proliferation of millions of insecure IoT devices can be hijacked to launch large-scale Distributed Denial-of-Service (DDoS) attacks against national infrastructure.
- **Physical Infrastructure Security:** Cell sites and fiber optic cables remain vulnerable to vandalism and sabotage amidst ongoing instability.

❖ **Strategic Cybersecurity Recommendations For Libya:**

- **Develop A National 5G/6G Security Framework:** Establish a comprehensive set of security standards and certification requirements for network equipment and IoT devices, aligned with guidelines from the ITU and 3GPP.
- **Establish A National Cybersecurity Operations Center (C-SOC):** Create a dedicated C-SOC for the telecommunications sector to provide continuous threat monitoring, incident response, and threat intelligence sharing between operators.
- **Mandate Zero-Trust Architecture (ZTA):** Require operators to implement ZTA principles, ensuring strict identity verification for every person and device trying to access network resources.
- **Promote Security-By-Design:** Integrate security assessments into the earliest stages of 5G/6G network planning and procurement processes.

## Conclusion

This study confirms that Libya's path to next-generation networks is hampered by a complex interplay of political, infrastructural, regulatory, and now clearly identified social and cybersecurity challenges. The urban-rural digital divide and low digital literacy threaten to marginalize segments of the population even if infrastructure improves. However, the proactive engagement of academic institutions in 6G researches and the increasing recognition of cybersecurity as a cornerstone present new avenues for progress. By implementing a holistic strategy that integrates spectrum policy, infrastructure sharing, public-private partnerships, a national security framework, and digital literacy programs, Libya can build a more inclusive, secure, and resilient digital future, positioning itself for the eventual transition to 6G.

## Strategic Recommendations and Future Outlook

Libya stands at a critical juncture. To bridge the digital divide and harness the benefits of next-generation networks, a multi-faceted strategy is proposed:

1. Establish a Clear Regulatory Framework: Form an independent telecom regulatory authority empowered to allocate spectrum (e.g., 3.5 GHz band) transparently and develop a definitive national 5G/6G roadmap.
2. Accelerate Infrastructure Sharing: Mandate infrastructure sharing between Al-Madar and Libyana to reduce costs and rapidly expand 4G+/5G coverage, particularly along key economic corridors.
3. Secure Strategic Investment: Launch public-private partnerships (PPPs) and seek international financing (e.g., from the World Bank or AFDB) specifically earmarked for digital infrastructure resilience and expansion.
4. Initiate 6G Research Collaboration: Partner with academic institutions in Egypt and Europe to participate in early 6G standardization research, ensuring Libya is not left behind in the next cycle.
5. Focus on Security and Resilience: Build security and redundancy into the core of the network modernization plan to protect against both physical and cyber threats.

**Future Outlook:**

- Short-Term (2024–2026): Finalize spectrum allocation, expand pilot projects, and establish a robust regulatory body.
- Medium-Term (2026–2030): Achieve commercial 5G launch in urban centers and introduce 5G-driven services (e.g., smart healthcare, IoT).
- Long-Term (2030+): Participate in 6G research initiatives and integrate advanced applications for sustainable development.

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