Spectrum Allocation and Scarcity Analysis in West Africa: Toward Dynamic Management for 5G-Advanced and 6G

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Abstract

The rapid expansion of 5G-Advanced and emerging 6G technologies in West Africa faces acute spectrum scarcity, yet systematic data-driven analyses remain limited. This paper presents the first multi-country allocation study covering seven nations, including the three Alliance of Sahel States (AES) members Mali, Burkina Faso, and Niger, using regulatory data from 2020–2024. To address these challenges, a dynamic spectrum management framework is proposed specifically adapted to West African constraints, integrating database-assisted access, hierarchical licensing, and incremental deployment with potential for significant efficiency improvements. The framework leverages the recent political integration of AES countries as a coordination catalyst, enabling harmonized licensing, shared spectrum databases, and pooled regulatory capacity, addressing key implementation barriers in resource-constrained environments. This work establishes a foundational analysis and design framework for spectrum policy reform in West Africa, providing the first empirical evidence base while emphasizing contextual adaptation over algorithmic novelty.

Keywords

Spectrum management, 5G-Advanced, 6G, West Africa, Dynamic Spectrum Access

1. Introduction

The transition to 5G-Advanced and 6G wireless networks confronts a fundamental constraint: the finite nature of radio frequency spectrum [1]. While developed markets address this challenge through sophisticated dynamic spectrum management, developing regions face acute spectrum scarcity compounded by limited monitoring infrastructure, fragmented regulatory frameworks, and capital constraints [2].

West Africa presents a critical case study, particularly the Alliance des Etats du Sahel (AES) comprising Mali, Burkina Faso, and Niger formed in September 2023 [3]. This 60 million population bloc [4] faces the region's most significant 5G deployment delays (4–5 years behind regional leaders) yet offers unique opportunities: nascent regulatory frameworks enable harmonized spectrum policy from inception, potentially leapfrogging fragmentation observed in mature markets [5], [6]. The AES political integration provides a strategic window for coordinated spectrum management, though significant institutional barriers, heterogeneous regulatory capacities, the bloc's security focus, and withdrawal from ECOWAS must be overcome.

Despite substantial spectrum management research in developed markets [7], three critical gaps exist for West African contexts:

Gap 1: Data Scarcity. No prior work has systematically analyzed spectrum allocation across AES member states or examined how their political integration might inform coordinated spectrum policy.

Gap 2: Contextual Mismatch. Existing dynamic spectrum frameworks assume capabilities dense sensor networks, real-time database synchronization misaligned with resource-constrained African settings [7], [8], [9].

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Gap 3: Regional Coordination Mechanisms. No research has examined how sub-regional political integration might catalyze technical coordination in spectrum management [5].

To address these gaps, this paper makes three principal contributions:

Contribution 1: First Systematic AES-Focused Saturation Analysis. This paper presents the first data-driven spectrum saturation analysis for the AES bloc using regulatory data from Mali, Burkina Faso, Niger [10]–[12], complemented by comparative data from Nigeria, Ghana, Senegal, and Côte d'Ivoire (2020–2024).

Contribution 2: AES-Adapted Dynamic Spectrum Framework. Established dynamic spectrum techniques are adapted [7], [8], [13] to AES-specific constraints, emphasizing database-assisted allocation, hierarchical licensing, and AES-level coordination mechanisms.

Contribution 3: AES-Focused Validation Roadmap. A three-phase validation agenda is established positioning AES political integration as an accelerator for spectrum coordination.

The remainder of this paper is organized as follows. Section 2 presents related work on spectrum technologies and dynamic spectrum access, emphasizing African contexts; Section 3 presents the empirical analysis of spectrum allocation and saturation across seven West African countries; Section 4 introduces the context-adapted dynamic spectrum management framework; Section 5 concludes.

2. Background and Related Work

2.1. Mobile Network Evolution and Spectrum Demand

Table 1 summarizes the evolution from 4G to 6G, highlighting escalating spectrum demands. The transition to 5G-Advanced and 6G necessitates a heterogeneous spectrum approach (low-band, mid-band, mmWave) [7], placing unprecedented pressure on traditional spectrum management paradigms [1].

Table 1
Mobile Generation Evolution and Spectral Characteristics

Generation	Core Technologies	Frequency Bands	Peak Data Rate	Spectral Efficiency (bps/Hz)
4G	OFDMA, MIMO	700 MHz – 2.6 GHz	1 Gbps	~3.0
5G	mmWave, Massive MIMO	Sub-6 GHz, mmWave	20 Gbps	7.5–12
6G (Vision)	AI-native, THz, RIS	Sub-THz, Visible Light	1 Tbps	20–30

2.2. Dynamic Spectrum Access Technologies

Dynamic Spectrum Access (DSA) encompasses three main paradigms: database-assisted access, where secondary users query geolocation databases for available channels [7]; hierarchical licensing with cognitive radio capabilities [13]; and spectrum sensing for opportunistic access [14]. Database-assisted approaches have demonstrated up to 60% improvement in spectrum utilization density [7], while hybrid models show substantial gains in multi-operator environments [8]. However, sensing-based methods require dense sensor networks and sophisticated processing [15], making them challenging for resource-constrained settings.

2.3. African Context and Measurement Studies

Prior measurement studies in the DRC [16] have documented significant spectrum white spaces in African contexts, while regulatory analyses confirm that dynamic spectrum frameworks remain underdeveloped across the continent [17]. However, no systematic, data-driven saturation analysis exists for West Africa and particularly for the AES bloc representing the gap this work addresses.

3. Spectrum Allocation Analysis in West Africa

3.1. Methodology and Country Selection

The analysis employs a multi-method approach combining documentary analysis of national regulatory frameworks, quantitative assessment of allocated frequency bands, and comparative analysis of licensing procedures. Data were collected for seven representative West African countries Mali, Burkina Faso, Niger (Alliance des États du Sahel, AES), Senegal, Côte d'Ivoire, Ghana, and Nigeria selected for their geographic distribution, economic diversity, geopolitical significance, and varying stages of 5G deployment [3], [9], [18].

Data sources include national regulatory authority licensing databases and spectrum allocation tables (2020–2024) [10]–[12], [19], [20], [21], [22], published regulatory decisions, and industry reports from GSMA and regional telecommunications organizations [17]. The analysis focuses on regulatory allocations rather than real-time occupancy, due to limited public measurement data—a constraint particularly acute in the AES countries where security challenges limit infrastructure monitoring capabilities [23], [18].

3.2. National Allocation Status and Comparative Analysis

The analysis reveals significant disparities in 5G spectrum allocation across the region, as summarized in Table 2. The critical 3.5 GHz band shows varying stages of deployment, while mmWave spectrum remains largely unallocated [17]. The AES countries (Mali, Burkina Faso, Niger) exhibit the most nascent deployment stages: Mali remains in early planning with 40–60 MHz under consideration in the 3.5 GHz band and no formal mmWave plans [10]; Burkina Faso's three operators serve 27.36 million subscribers (Q2 2024) with confirmed 2G/3G/4G coverage but no 5G deployment [17]; Niger reported 16.38 million mobile subscribers (December 2024) with no active 5G service and a 4G network compliance rate of only 67% [24]. By contrast, Nigeria—the region's most advanced market—launched commercial 5G in 2022, yet 67.6% of its subscribers remained on 2G or 3G networks as of December 2023 [25].

Table 2-A
5G Spectrum Allocation Status in West Africa (2024) – Alliance des États du Sahel (AES)

Country	3.5 GHz Band	26 GHz Band	Licensing Model	Deployment Timeline
Mali	40–60 MHz under consideration	No formal plans	Administrative assignment	Early planning stage
Burkina Faso	Preliminary studies	No formal plans	Undetermined	Nascent stage
Niger	Preliminary studies	No formal plans	Under evaluation	Nascent stage

Table 2-B
5G Spectrum Allocation Status in West Africa (2024) – ECOWAS Advanced Deployment

Country	3.5 GHz Band	26 GHz Band	Licensing Model	Deployment Timeline
Nigeria	100 MHz allocated	Under consultation	Auction-based	Commercial launch (2022)
Senegal	100 MHz allocated	800 MHz in consultation	Beauty contest	Commercial launch Q4 2024
Côte d'Ivoire	100 MHz allocated	1 GHz planned for 2025	Multi-round auction	Limited deployment 2024
Ghana	80–100 MHz planned	Not yet allocated	Hybrid model	Trials ongoing, deployment 2025

Data compiled from national regulatory authorities [10]–[12], [19], [20], [21], [22] and industry reports [17], [23].

3.3. Sub-1 GHz Band Analysis

Table 3 details the allocation status of the three key sub-1 GHz bands most relevant to 5G deployment. Cross-referencing national frequency allocation tables [10]–[12], [19], [20], [21], [22] with GSMA regional data [17] consistently indicates that sub-1 GHz spectrum is heavily allocated across all seven surveyed countries, with legacy 2G/3G/4G services as the dominant occupants. A conservative lower-bound estimate of >80% sub-1 GHz regulatory allocation is adopted, consistent with broader regional surveys [17] and confirmed by GSMA (2024): "In sub-Saharan Africa, operators resorted to refarming existing spectrum bands [for 4G/5G deployment] as regulators released only a small quantity of new spectrum" [26].

Table 3
5G Sub-1 GHz Band Allocation Status in West Africa (2024)

Band	5G NR	AES Countries (Mali, Burkina Faso, Niger)	ECOWAS Leaders (Nigeria, Senegal, Côte d'Ivoire, Ghana)
700 MHz	n28	Assigned to 2G/3G or analog TV [24]; no 5G refarming initiated	Partial refarming (4G) underway; no 5G license issued for this band
800 MHz	n20	Fully assigned (2G/3G); no refarming plans	Fully assigned; refarming under regulatory review
900 MHz	n8	Fully assigned (2G/3G); no refarming plans	Fully assigned; 3G licenses renewed 2022 in Nigeria — no sunset plan [25]

Refarming status based on published regulatory decisions as of Q1 2024. Real-time occupancy may differ from regulatory assignment status.

3.4. Critical Assessment and Regional Implications

The documented deployment gap creates a strategic window for coordinated spectrum policy. The recent political integration of the AES bloc [3] enables four concrete coordination mechanisms:

harmonized licensing procedures, shared spectrum databases [5], pooled technical capacity for spectrum monitoring [5], and coordinated negotiation with international operators [6].

However, several institutional barriers must be acknowledged. The AES countries have regulatory authorities with significantly different capacities; harmonization requires capacity building, not just political will. Furthermore, the AES withdrawal from ECOWAS (January 2024) complicates the regional coordination framework proposed in Section IV.

1. Regulatory Diversity. Heterogeneous licensing approaches across the region (administrative assignment, auctions, beauty contests) create market uncertainty. The AES bloc's nascent frameworks offer an opportunity to adopt harmonized approaches from inception [5], establishing a unified 60-million-person spectrum market [4].
2. mmWave Delay and Coverage Prioritization. Limited progress on mmWave spectrum allocation across all countries suggests a regional focus on coverage-oriented 5G deployment rather than capacity-intensive applications [17]. Only Senegal and Côte d'Ivoire have concrete mmWave allocation plans [19], [22].
3. Sub-1 GHz Saturation. These findings underscore three critical imperatives: (1) coordinated spectrum refarming policy leveraging AES political integration as a catalyst for technical harmonization [5], [6]; (2) structured refarming strategies to reclaim sub-1 GHz bands currently locked in legacy 2G/3G services; and (3) dynamic management approaches to maximize efficiency of limited mid-band resources [7], [8].

4. Context-Adapted Dynamic Spectrum Management Framework

It is acknowledged that the framework presented here is conceptual and not quantitatively validated against the data in Section 3. Developing such validation is essential future work. The current contribution is to establish design principles and architecture informed by the empirical constraints documented earlier.

Given the documented saturation in West Africa (Section 3) and the well-known inefficiencies of static allocation [1], [7], [17], a framework adapting established dynamic spectrum techniques is proposed [8], [13], [15] to West African constraints.

4.1. Design Principles and Contextual Adaptation

The framework design prioritizes contextual adaptation to West African realities:

Principle 1: Database-Driven Over Sensing-Intensive. Given the infrastructure constraints documented in Section 1, geolocation database approaches [7] are prioritized over spectrum sensing. Database-assisted access requires only centralized repositories and modest computational resources, while sensing-based cognitive radio demands dense sensor networks and sophisticated signal processing. As Gamage et al. [14] demonstrate, database-based allocation delivers superior throughput and energy efficiency compared to sensing-only methods in comparable conditions.

Principle 2: Hierarchical Licensing Compatible with Existing Structures. The three-tier hierarchical model from Jiang et al. [13] is adopted, which preserves existing primary licenses while enabling secondary and tertiary access, minimizing disruption to incumbent operators.

Principle 3: Incremental Deployment Aligned with Capital Constraints. Phased deployment beginning with pilot zones is proposed in major cities, expanding gradually as technical capacity and regulatory confidence grow.

Principle 4: Regional Interoperability. An AES-level shared database with future ECOWAS-level interoperability is proposed as a long-term coordination objective, acknowledging the political obstacles following the AES withdrawal from ECOWAS.

4.2. Proposed Architectural Framework

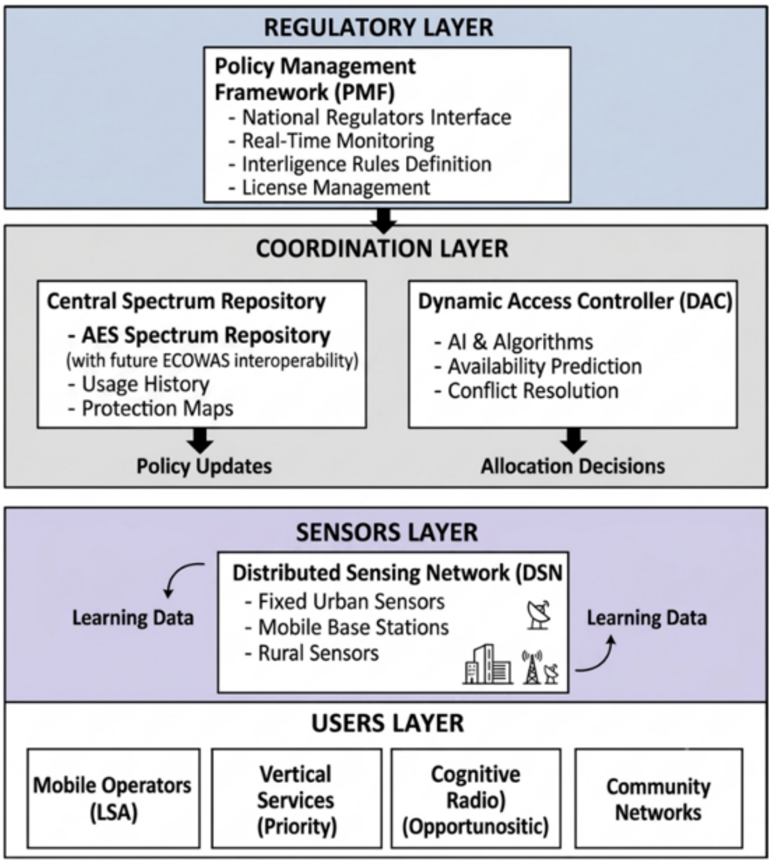

Figure 1: Proposed dynamic spectrum management architecture for West Africa

The framework integrates three core components:

Distributed Sensing Network (DSN): Network of spectrum sensors providing real-time utilization data, comprising fixed urban sensors in major cities (high density), mobile base station-integrated sensors (moderate density), and low-cost community sensors in rural areas [9].

Dynamic Access Controller (DAC): AI-based system making real-time allocation decisions, including availability prediction using historical data and machine learning, conflict resolution algorithms ensuring interference protection, load balancing across available spectrum resources, and priority management for different service classes.

Policy Management Framework (PMF): Regulatory oversight layer providing national regulator interfaces for policy updates, real-time monitoring and compliance verification, interference event detection and resolution, and license management and fee collection.

4.3. Implementation Roadmap and Migration Path

A three-phase implementation approach is proposed with measurable success indicators:

Phase 1 (2024–2026): Foundation and Piloting. Establish regulatory framework for spectrum sharing; deploy pilot DSA networks in 2–3 major cities (Bamako, Ouagadougou, Niamey). Success indicator: Functional shared database with 3 operators.

Phase 2 (2027–2029): Scaling and Integration. Expand DSA deployment to secondary cities; integrate DSA with 5G-Advanced network upgrades. Success indicator: 30% reduction in spectrum idle time measured in pilot zones.

Phase 3 (2030+): Full Integration and 6G Preparation. Full DSA integration across all network layers; preparation for 6G dynamic spectrum requirements. Success indicator: Regulatory framework adopted by all 3 AES members.

5. Conclusion

This work addresses a fundamental research gap by providing the first systematic spectrum saturation analysis for West Africa. Drawing on regulatory data from seven countries (Nigeria, Ghana, Senegal, Côte d'Ivoire, Mali, Burkina Faso, Niger) spanning 2020–2024, critical resource constraints are documented: Sub-1 GHz regulatory allocation exceeding 80% (conservative lower-bound estimate) and projected mid-band saturation in major urban centers by 2027–2030 under static allocation paradigms.

Building on this empirical foundation, a context-adapted framework is contributed that systematically addresses West African regulatory and infrastructure constraints through four design principles: database-assisted allocation prioritization, hierarchical licensing compatibility, incremental deployment alignment, and regional coordination. Extrapolating from documented performance of comparable systems [7], [8], the proposed framework has the potential to yield substantial efficiency gains relative to static allocation. However, context-specific validation through simulation or testbed deployment remains essential future work.

The analysis necessarily relies on regulatory licensing data rather than real-time occupancy measurements a data constraint common to developing regions [10]. The framework presumes regulatory receptivity to dynamic paradigms; actual implementation will depend on stakeholder negotiation and institutional capacity development. The analysis assumes that political integration can facilitate technical coordination, but significant institutional barriers are acknowledged: heterogeneous regulatory capacities, the AES's security-focused mandate, and tensions with ECOWAS.

Declaration on Generative AI

During the preparation of this work, the authors used Quillbot, DeepSeek, and Grammarly for the following activities: language refinement, grammar corrections, paraphrasing, and readability enhancement. After using these tools, the authors reviewed and edited all generated content as needed and take full responsibility for the publication's scientific integrity and content.

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