

From Technical Validation to Policy Implementation: A Dynamic Spectrum Sharing Framework for 6G Networks in West Africa

Dourahamane IDE BARKIRE, Benjamin KONÉ, Ahmed Dooguy KORA

E-INOV LAB, Ecole Supérieure Multinationale des Télécommunications (ESMT)

Dakar, Senegal

dourahamane.barire.etu@esmt.sn, benjikone@yahoo.fr, ahmed.kora@esmt.sn

Abstract— The transition toward 6G networks in West Africa; specifically, in the emerging Alliance of Sahel States or *Alliance des Etats du Sahel (AES)*, is probably going to be restricted by static approaches to spectrum management which results in significantly reduced efficiency of use of available spectra and significant economic waste. This research develops a comprehensive dynamic spectrum sharing framework that addresses both the technical potential of dynamic spectrum sharing and the need for implementation as it relates to the institutional and economic realities of West Africa. This is accomplished through a three-part framework which includes (1) collaborative spectrum pooling, (2) dynamic spectrum markets, and (3) public service spectrum banking based upon an assessment of existing regional spectrum allocations and identified saturation risks. A phased roadmap of implementation (2025-2030) is provided along with an assessment of the expected technical, economic, and social impacts, such as improved efficiencies in the use of available spectra, increased economic activity, and increased availability of broadband services. Through the combination of technical feasibility with practical policy design, this research identifies a viable path toward reforms in spectrum usage that will promote digital inclusion and the development of a sustainable 6G ecosystem throughout the AES and the broader West African region.

Keywords— 6G networks, dynamic spectrum sharing, cognitive radio, West Africa, regulatory framework, spectrum efficiency, telecommunications policy, digital transformation

I. INTRODUCTION

A. The West African Digital Transformation Challenge

West Africa and particularly the newly created Alliance of Sahel States (AES) is at an important turning point for their digital development. Their connectivity needs are increasing rapidly and they are adopting new technologies at an extremely fast pace. Mobile penetration rates have increased to over 80% in some of the most significant West African markets including Nigeria and Ghana [1]. This has led to record growth in data usage for this population which now exceeds 400 million people. The COVID-19 pandemic has also greatly contributed to the expansion of digitalization, with data traffic having grown from 2020 through 2024 by 35-50% in all of the largest West African countries. [2]. This remarkable digital progress, however, encounters a fundamental physical constraint:

artificial spectrum scarcity resulting from outdated allocation methodologies.

The prevailing spectrum management paradigm across West Africa, largely inherited from colonial-era regulatory frameworks designed for analog broadcasting services, demonstrates increasing inadequacy in supporting the heterogeneous, capacity-intensive applications that characterize modern digital economies [3]. Our systematic assessment reveals three interconnected systemic deficiencies that undermine spectral efficiency:

1) **Rigid Allocation Frameworks:** Static assignment models fail to accommodate temporal and spatial demand variations, resulting in substantial underutilization during off-peak periods and persistent scarcity in high-demand urban centers.

2) **Lack of Regional Coordination Mechanisms to Harmonize Strategies:** Disjointed national strategies make it impossible for regional countries to take advantage of the economies of scale that are possible when services can be delivered seamlessly across country borders.

3) **Constrained Secondary Markets:** Regulatory limitations inhibit efficient spectrum reallocation through secondary markets, perpetuating artificial scarcity despite measurable underutilization.

These structural deficiencies prove particularly consequential given West Africa's distinctive socio-economic landscape: extreme population density differentials between coastal urban centers and vast rural hinterlands, coupled with emerging market economies where spectral efficiency directly determines service affordability and digital inclusion [4]. These challenges are particularly acute for the AES nations (Mali, Burkina Faso, Niger), which are seeking innovative technological and regulatory pathways to accelerate their digital transformation and regional integration agendas.

B. Bridging Technical Potential and Policy Implementation

This research extends our established program in advanced networking architectures, building upon our previous work on quality of service (QoS) optimization in software-defined networks [5] and our technical validation of cognitive radio performance in West African propagation environments [6].

Technical evaluation of our investigations (including simulation-based analysis of cognitive radio architectures) show there is a considerable opportunity to improve the operational efficiencies of radio systems using dynamic spectrum access. The findings from our study match support well-established literature on cognitive radio systems [7], [8]; they also support literature on dynamic spectrum access architectures [9]. Our findings also demonstrate that the technology works at a regional level as it applies to some of the core ideas.

A significant "implementation gap" still exists between the technical validation of dynamic spectrum access technologies and their practical use within policies in developing regions. (These gaps will be examined in Section II) While recent developments in machine learning [10] and 6G vision documents [11] offer new opportunities to apply technology, these opportunities have been largely directed toward developed markets with well-established regulatory frameworks.

C. Research Contributions and Document Organization

This work delivers four principal contributions to the evolving discourse on telecommunications policy and 6G network deployment in developing regions: (1) Comprehensive Regional Assessment, (2) Tripartite Governance Framework, Phased Implementation Strategy, (4) Multidimensional Impact Framework.

The remainder of this paper proceeds as follows. Section II reviews relevant literature and positions our contribution within the broader research landscape. Section III analyzes current spectrum inefficiency challenges across West Africa. Section IV elaborates the tripartite dynamic spectrum sharing framework. Section V details the implementation roadmap. Section VI assesses anticipated impacts across multiple dimensions. Section VII examines implementation challenges and corresponding mitigation strategies. Section VIII concludes with policy recommendations and future research directions.

II. RELATED WORK

A. Dynamic Spectrum Sharing: Global Perspectives

Research has shown that Dynamic Spectrum Sharing is one of the most important enabling technologies for 6G Networks worldwide and there are many contributions to research in three different areas (technical, economic, policy).

While Mitola and Maguire's [7] initial work on the theory of Cognitive Radio Systems provided the foundation of research on the subject, later studies were published by Haykin [8] and Akyildiz et al. [9] which identified architectures for Practical Spectrum Sensing and Dynamic Access.

Most recent advancements include Machine Learning enabled spectrum management [12]; Blockchain based sharing mechanisms [10]; and Integration of Satellite Systems to enable global coverage [11].

However, it should be noted that all of these recent developments focus primarily on developed markets where the

Regulatory Frameworks are well established and Infrastructure Density is very High.

B. Spectrum Policy in Developing Regions

Studies regarding spectrum regulation in developing nations have identified common issues as a lack of regulatory capability [13], limitations due to infrastructure [14] and balancing efficiency against goals for universal access [15]. Cave and Webb [16] were among the first researchers to study the reform of spectrum usage in developing nations, which they noted required the development of institutions.

Blackman and Forge [17] studied spectrum sharing in emerging economies, and Sutherland [18] studied the challenges to regulatory harmony in Sub-Saharan Africa; however, both studies are based on current generation technology and do not consider forward-thinking 6G needs.

C. West African Telecommunications Policy

Research on telecommunications policy in West Africa has mainly focused on aspects of deregulation (market liberalization) [19], infrastructure growth (infrastructure development) [20], and closing the digital divide (digital divide) [21]. Kouty [3] studied the legal framework for digital trade, whereas Puplampu [4] examined the post-COVID-19 digitalization policies.

However, existing literature lacks comprehensive frameworks specifically addressing spectrum sharing for 6G deployment in the West African context. Our work fills this gap by combining technical validation with region-specific policy design.

D. Research Gap and Our Contribution

The literature review reveals three significant gaps: (1) Limited Regional Focus on developed markets, (2) Technology Generation Mismatch, and (3) a persistent disconnect between technical validation and policy Implementation.

Our research addresses these gaps by providing the first comprehensive framework specifically designed for 6G spectrum sharing in West Africa, combining technical validation with practical policy implementation guidance.

III. QUANTIFYING THE SPECTRUM INEFFICIENCY PROBLEM

A. Current Utilization Rates by Spectrum Band

Through an in-depth examination of primary spectrum band usage patterns, as described by both spatially-specific in our paper [6] we observe persistent trends of underutilization across all primary bands, which reinforces the observation of static allocations being inefficient for primary spectrum utilization.

The extent of underutilization in rural and low-frequency regions is stark compared to potential future saturation of mid-spectrum frequency bands within urban environments [22]; and thus provides strong evidence that the existing static allocation method is inherently unbalanced and inefficient. Therefore, it is necessary for the industry to migrate towards a dynamic model of spectrum use management, so that the imbalances between supply and demand for spectrum can be addressed throughout both space and time.

B. Economic Implications

Static Spectrum Management has numerous negative economic implications throughout West Africa's Digital Ecosystem due to the Technical Inefficiencies in how spectrum is currently allocated [23].

Opportunity Costs are generated by static spectrum management through multiple channels:

Consumer Welfare: Reduced consumer welfare is generated through reduced service availability, lower than maximum data allowances, and higher than competitive pricing [24] (due to artificially created spectrum scarcity).

- **Operator Cost Increases:** Operator cost increases occur from inefficiency in spectrum usage, early investment in infrastructure to reduce capacity limitations, and reduced returns on spectrum investments [25].
- **Delayed Innovation/Competitiveness in Digital Services:** Limited spectrum availability constrains the development and implementation of new emerging digital applications and uses [26].
- **Economic Growth Constrained:** The ability of the economy to be transformed digitally is reduced through limited opportunities in key sectors such as education, healthcare, agriculture, and financial services [27].

Although Economic Modeling of the total impact of the above listed impacts will be beyond the scope of this technical report, they collectively support the urgency needed to reform spectrum policies. Dynamic Spectrum Management is both an economic necessity to achieve digital development objectives and to create sustainable socio-economic benefits in West Africa, and a technical necessity to allow the networks to evolve.

C. Regional Variations and Implications

The level of spectrum management maturity and the condition of the market varies significantly between the West African nations that are part of this project; therefore, there needs to be a different approach to implementing the project across the region so as to maximize the efficiencies of the project. The three tiers of West African markets have been identified as follows.

Tier 1 Markets (Nigeria, Ghana, Senegal).

- Markets have the greatest economic impact because they have the largest market size and densest urbanizations.
- Markets also have the most developed regulatory infrastructure and institutional framework for telecommunications development.
- Markets also have the most sophisticated operators and investment capabilities.
- Markets will likely be among the first to adopt pilot projects for dynamic spectrum sharing.

Tier 2 Markets (Côte d'Ivoire...).

- Markets have moderate sized markets with rapidly growing digital economies.
- Regulatory frameworks for Tier 2 markets are developing but vary in terms of institutional capacity.
- Operator capabilities and the overall maturity of the market in Tier 2 markets is mixed.

- Markets will require support and capacity building for phased implementations of sharing systems.

Tier 3 Markets (the remaining ECOWAS countries specifically AES countries).

- Markets have smaller markets with many challenges related to covering rural areas.
- Markets have limited regulatory capacity and institutional barriers to telecommunications development.
- Markets will rely heavily upon coordination and knowledge transfer from regional organizations such as ECOWAS.
- Markets will require significant capacity building and technical assistance.

As previously stated these differences in Tier 1, 2 and 3 markets indicate the necessity for a multi-speed and flexible implementation approach. Advanced sharing systems may be pioneered by Tier 1 markets while Tier 2 and 3 markets would require simplified approaches with access to shared knowledge and capacity building programs supported by ECOWAS frameworks.

IV. THE TRIPARTITE DYNAMIC SPECTRUM SHARING FRAMEWORK

A. Framework Overview and Design Principles

Our tripartite framework addresses the diverse stakeholder needs and institutional contexts across West Africa through three complementary operational models designed to transition from static to dynamic spectrum management.

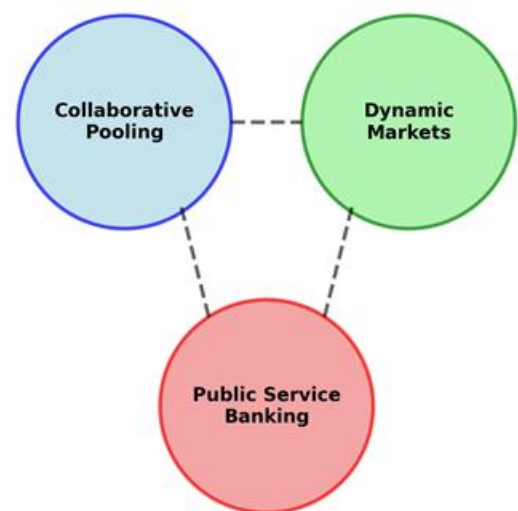


Figure 1. The Tripartite Dynamic Spectrum Sharing Framework showing the three complementary operational models and their interactions.

The framework is architected around five core design principles that ensure both technical robustness and contextual appropriateness. The five principles are: (1) Technical feasibility through the use of proven cognitive radio architectures; (2) Economic viability through competitive markets and incentives; (3) Regulatory flexibility through

adaptive governance that can be applied to various levels of institutional capacity; (4) Social equity through preservation of universal service obligation and access to rural areas; and (5) Regional harmony through the utilization of ECOWAS frameworks for cross border coordination and economies of scale. These five principles provide a balance between transitioning from static to dynamic spectrum usage throughout the region.

The three models work together in a complementary manner (Figure 1); spectrum is allocated dynamically based upon demand patterns, regulatory preference, and market condition

B. Model 1: Collaborative Spectrum Pooling

1) Operational Mechanism: The Collaborative Spectrum Pooling model is an operational mechanism to allow multiple licensed operators to share designated frequency bands using the same coordinated access rules, thus providing a virtualized spectrum resource which will adapt to temporal and spatial fluctuations in demand. Through this approach, licensees can maintain their right to use the spectrum they have been assigned; however, when there is high demand, or when specific locations become congested, operators can gain access to the shared capacity.

2) Technical Implementation:

- Centralized Control – In regional spectrum coordination centers, the allocation of pool rights and access rights are managed so that they provide an unbiased third party view and that they allocate resources efficiently.
- Real-Time Optimization – Algorithmically managed systems provide real-time optimization of spectrum allocations based upon predicted patterns of demand and actual usage of the spectrum.
- Interference Management – High-level coordination protocols and power management techniques ensure quality of service across the shared spectrum resource.
- Performance Monitoring – Systematic monitoring and reporting will be used to ensure that all parties accessing the shared spectrum resource have equal access and that the system remains at maximum efficiency.

3) Economic/Operational Principles: The collaborative spectrum pooling model is operated on a principle of contribution-based entitlement. The access rights of operators to the shared spectrum resource are directly proportionate to the amount of spectrum they contribute to the pool, with adjustments made for the effect of demand on usage. This provides direct economic incentive for operators to participate in the cooperative arrangement and ensures equitable distribution of the shared resource.

4) Target Applications:

- Urban Capacity Improvement: Temporary increase in capacity in densely populated urban areas during peak usage times.

- Emergency Communication: Shared coordinated access to the spectrum resource for emergency response and public safety applications.
- Cross Border Service: Seamless roaming and continued service for subscribers between member states of ECOWAS.
- Internet of Things (IoT) / Machine-to-Machine (M2M): Dedicated shared spectrum for machine type communication with guaranteed Quality of Service.

C. Model 2: Dynamic Spectrum Markets

1) Market Design and Rationale: A dynamic spectrum market is a mechanism for the most efficient use of resources. It will operate based on price (the value of each hour of spectrum). This model will provide a platform for companies to buy and sell spectrum in real time using automated auctions. This will create an incentive for users to utilize spectrum in its most effective way possible; by maximizing the use of the spectrum over space and time.

2) Multi-Layered Market Structure: The framework operates across multiple time horizons to accommodate diverse user needs:

- Primary Markets: Conventional spectrum auctions for long-term licensing, providing investment certainty and foundational rights.
- Secondary Markets: Medium-term trading platforms for predictable demand variations and capacity planning.
- Spot Markets: Real-time hourly auctions for immediate capacity needs and unexpected demand surges.
- Forward Markets: Advance reservation mechanisms for planned events and predictable peak periods.

3) Technology Infrastructure: The market ecosystem relies on several enabling technologies:

- Blockchain Infrastructure: Distributed ledger technology for transparent, immutable transaction recording and smart contract execution.
- Real-time Sensing: Spectrum monitoring systems for availability verification and interference management.
- Machine Learning: Predictive analytics for demand forecasting, price optimization, and anomaly detection.

4) Price Formation Mechanisms: the market clearing price will be determined by competitive bidding processes That take into account the following factors:

- Characteristics and propagation properties of each spectrum band.
- Temporal demand patterns and temporal scarcity conditions.
- Geographic location and the specific interference environment of each bid.
- Quality of Service (QoS) requirements and priority levels.

5) Target Applications:

- **Event-Based Capacity:** This includes temporary access to spectrum for large events such as concerts, sporting events, conferences and seasonal demand variances.
- **Vertical Industries:** This includes specialized access to spectrum for enterprise applications such as enterprise wide Wi-Fi networks, Internet of Things (IoT) devices and industrial automation systems.
- **Innovation Sandboxes:** This includes experimental access to spectrum for startup companies and research organizations developing new wireless technologies.
- **Multi-Operator Coordination:** Efficient resolution of temporary capacity imbalances among competing operators.

D. Model 3: Public Service Spectrum Banking

1) **Concept and Rationale:** Public service spectrum banking establishes a reserved spectrum capacity mechanism to safeguard essential services and universal access objectives. This model ensures that market-based allocation mechanisms do not compromise fundamental public interest requirements, particularly in rural areas and for critical national functions.

2) **Reservation Mechanisms and Allocation:** The banking framework comprises four dedicated spectrum reserves:

- **Strategic Emergency Reserve:** Dedicated spectrum for national security, disaster response, and public safety communications, ensuring availability during crises.
- **Universal Service Fund:** Allocations of radio frequency space that are committed to extend broadband to rural communities and bridge the digital divide in underserved communities.
- **Public Interest Broadcasting:** Radio frequency space reservation for broadcasting of non-commercial public service content, including education, culture, etc. to assist in developing digital literacy and preserving cultural heritage
- **Innovation and Research Sandbox:** Experimental spectrum for academic research, technology development, and startup innovation in wireless communications.

3) **Operational Principles:** The spectrum bank operates on several key principles:

- **Permanent Reservation:** Core allocations remain protected from commercial exploitation to ensure continuous public service availability.
- **Temporary Leasing:** When there is excess radio frequency space in a particular band that is assigned to a type of public service use (e.g., emergency communications), it may be leased temporarily to a commercial operator when such capacity is not being used by public service entities, providing a source of revenue to help support public service uses, while also allowing for the public service entity to retain its right to reclaim the radio frequency space for future public service uses.

- **Preemption:** Absolute priority for emergency services during crisis situations, with immediate access overriding commercial allocations.
- **Performance Monitoring:** Continuous assessment to ensure public interest objectives are met and resources are efficiently utilized.

TABLE 1. COMPARISON OF THE THREE OPERATIONAL MODELS

Aspect	Collaborative Pooling	Dynamic Markets	Public Banking
Primary Goal	Efficiency	Price Discovery	Universal Access
Time Scale	Medium-term	Real-time	Long-term
Governance	Multi-stakeholder	Market-based	Public Interest
Target Users	All Operators	Commercial	Public Services
Revenue Model	Contribution-based	Auction-based	Subsidized

4) **Banking Model and its Integration to Commercial Spectrum Models:** The banking model has a number of mechanisms to connect with commercial spectrum models that are commercially viable:

- **Cross-Subsidization:** The revenue generated by the short-term commercial leasing is used to support universal service obligations and the deployment of rural networks.
- **Incentive Structures:** Commercial operators receive incentives and regulatory benefits for providing services that meet public objectives (for example, through shared infrastructure or coverage commitments).
- **Hybrid Access:** Coordinated access protocols which allow the seamless transition from the use of commercial services to the use of public services based on their level of priority.

5) **Targeted Uses and Beneficiaries:**

- **Emergency Services:** Police, Fire, Medical and Disaster Response Agencies have guaranteed access to the spectrum.
- **Rural Communities:** Underserved populations benefit from universal service obligations and specific targeted coverage initiatives.
- **Educational Institutions:** Universities, schools and research institutions have access to the spectrum to use for academic and development purposes.
- **Cultural Organizations:** Public Broadcasters and Cultural Institutions can disseminate educational and heritage content.

V. IMPLEMENTATION ROADMAP (2025–2030)

A. Phase 1: Foundation Building (2025–2026)

1) **Regulatory Framework Development:**

- Establish legal basis for dynamic spectrum sharing through telecommunications law amendments in key pilot markets

- Develop technical standards aligned with International Telecommunication Union Radiocommunication Sector (ITU-R) recommendations and regional harmonization principles
- Create institutional frameworks for spectrum coordination centers at national levels
- Implement regulatory sandboxes for testing innovative sharing approaches in controlled environments

2) **Technical Infrastructure Deployment:**

- Deploy foundational spectrum monitoring systems in major urban centers
- Establish regional coordination centers in strategic locations (e.g., Lagos, Accra, Dakar)
- Implement cognitive radio testbeds for technical validation and protocol development
- Develop interference analysis and mitigation capabilities

3) **Stakeholder Engagement and Capacity Building:**

- Conduct comprehensive stakeholder consultation across participating countries
- Establish multi-stakeholder working groups for each operational model
- Develop capacity building programs for regulators and technical staff
- Create public awareness campaigns about spectrum sharing benefits and principles

4) **Success Metrics for Phase 1:**

- Legal frameworks established in a majority of pilot countries
- Technical infrastructure deployed in key metropolitan areas
- Stakeholder engagement programs reaching relevant institutional actors
- Pilot programs demonstrating measurable efficiency improvements over static allocation

B. Phase 2: Pilot Implementation (2026–2027)

1) **Collaborative Pooling Pilots:**

- Launch urban capacity sharing pilots in selected metropolitan areas (e.g., Lagos, Accra, Abidjan)
- Implement cross-border coordination pilots between adjacent countries (e.g., Ghana–Côte d'Ivoire corridor)
- Deploy emergency communications coordination systems using shared spectrum
- Test IoT spectrum sharing for smart city applications and sensor networks

2) **Market Mechanism Pilots:**

- Establish secondary spectrum trading platforms in markets with advanced regulatory capacity
- Implement spot market trials for event-based demand and temporary capacity needs
- Deploy automated auction systems for short-term spectrum leasing

- Test transaction transparency mechanisms using appropriate distributed ledger technologies

3) **Public Banking Pilots:**

- Launch rural coverage extension programs using banked spectrum allocations
- Implement emergency spectrum reserve activation protocols
- Deploy educational and public service broadcasting on shared spectrum
- Establish innovation sandboxes for 6G research and development

4) **Success Metrics for Phase 2:**

- Pilot programs demonstrating significant efficiency improvements over baseline measurements
- Market mechanisms showing effective price discovery and participation
- Public banking programs successfully extending coverage to unserved communities
- Technical systems achieving high reliability and operational stability
- Comprehensive lessons learned documentation for full-scale deployment

Prioritize the AES bloc for the implementation of cross-border coordination pilots, leveraging their contiguous geography and political alignment to demonstrate seamless roaming and interference management.

C. Phase 3: Scaling and Regional Integration (2027–2029)

1) **Geographic and Market Expansion:**

- Scale successful pilot programs to additional urban centers and secondary cities across participating countries
- Expand collaborative pooling systems to cover major economic corridors and urban clusters
- Establish secondary spectrum markets in markets demonstrating regulatory and technical readiness
- Strengthen public spectrum banking mechanisms to address coverage gaps in peri-urban and rural areas

2) **Advanced System Integration:**

- Integrate data-driven optimization techniques across all spectrum sharing models
- Deploy enhanced monitoring and coordination systems for cross-border interference management
- Implement automated compliance and reporting systems for regulatory oversight
- Develop integrated management platforms for multi-operator, multi-model coordination.

3) **Regional Harmonization:**

- Launch ECOWAS-wide coordination initiatives for spectrum harmonization
- Establish common technical standards and operational procedures across participating countries

- Implement seamless cross-border spectrum sharing for transportation and trade corridors
- Create regional dispute resolution mechanisms for spectrum coordination issues

4) **Success Metrics for Phase 3:**

- Significant expansion of geographic coverage and user base for shared spectrum services
- Measurable improvements in spectrum utilization efficiency across deployed areas
- Increased population coverage with quality broadband services through shared access
- High levels of stakeholder satisfaction and operational reliability
- Effective cross-border coordination and interference management

Formalize the AES as a harmonized regulatory zone, establishing a single set of rules and procedures for spectrum sharing across Mali, Burkina Faso, and Niger. This sub-regional success will serve as a core building block for broader ECOWAS integration.

D. Phase 4: Consolidation and Future Evolution (2029–2030 and beyond)

1) **System Optimization and Maturation:**

- Refine all operational models based on 3 to 4 years of operational experience and performance data
- Implement advanced optimization algorithms incorporating machine learning from operational patterns

- Develop migration paths for emerging wireless technologies and new spectrum bands
- Contribute to international standardization efforts based on West African implementation experience
- Prepare frameworks for integration with future network architectures (e.g., 6G requirements)

3) **Sustainability and Institutionalization:**

- Formalize funding mechanisms for ongoing operations and system maintenance
- Establish regional centers of excellence for spectrum management training and research
- Develop transition plans for technology refresh and system upgrades
- Create knowledge transfer programs for new market entrants and regulatory staff

4) **Success Metrics for Phase 4:**

- Demonstrated continuous improvement in spectrum utilization metrics
- High system reliability and stakeholder satisfaction maintained over time
- Successful integration of new technologies and spectrum bands into existing framework
- Established sustainable funding and governance models for long-term operations
- Recognition as regional best practice and contribution to international standards

5) **Performance Monitoring Framework:** Throughout all implementation phases, progress will be tracked through a balanced scorecard approach monitoring technical efficiency, economic impact, social inclusion, and regulatory effectiveness. Key monitoring dimensions include:

- Technical Efficiency: Spectrum utilization rates, interference levels, system reliability.
- Economic Impact: Market participation, investment levels, service affordability.
- Social Inclusion: Rural coverage expansion, universal service objectives.
- Regulatory Effectiveness: Compliance rates, stakeholder satisfaction, cross-border coordination.

Specific performance targets will be established iteratively based on pilot results and regional benchmarks, ensuring realistic and context-appropriate expectations.

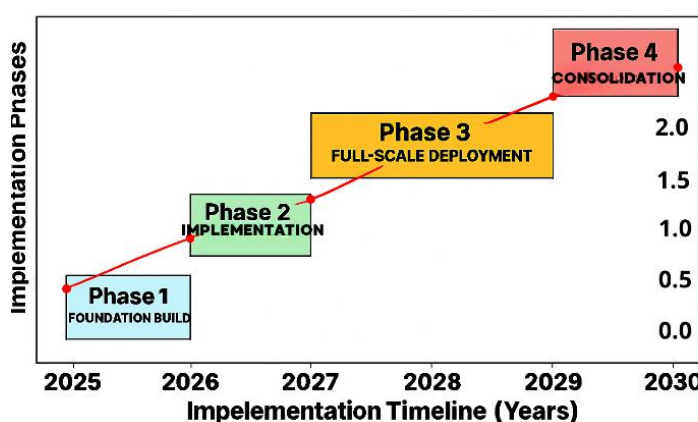


Figure 2. Implementation timeline showing the four phases of deployment from 2025 to 2030 with key milestones and success metrics.

- Enhance spectrum sensing and monitoring capabilities based on field experience
- Establish permanent governance structures and continuous improvement mechanisms

2) **Technology Evolution and Standards Development:**

- Integrate lessons learned into regional spectrum policy frameworks and technical standards

VI. ANTICIPATED IMPACTS AND STRATEGIC BENEFITS

This section outlines the multidimensional benefits expected from the transition to dynamic spectrum management, based on the technical framework presented and international implementation experiences.

A. Technical and Operational Improvements

The implementation of dynamic spectrum sharing is anticipated to deliver the following substantial technical enhancements.

Spectrum Utilization Efficiency:

- Significant improvement in overall spectrum utilization rates across temporal and spatial dimensions
- Enhanced capacity management in urban centers during peak demand periods
- Better utilization of spectrum resources in off-peak hours and rural areas
- More balanced distribution of spectrum access across geographic regions

Network Performance and Quality of Service:

- Improved latency and responsiveness for time-sensitive applications
- Increased network throughput and capacity for data-intensive services
- Enhanced service reliability and availability for critical communications
- Expanded geographic coverage through more efficient spectrum reuse

B. Economic and Market Benefits

The economic advantages span multiple stakeholder groups and economic sectors.

Operator Efficiency Gains:

- Reduced capital expenditure through more efficient spectrum utilization and infrastructure sharing
- Lower operational costs via dynamic resource allocation and interference management
- Enhanced revenue opportunities from new services and improved quality of experience

Consumer and Societal Benefits:

- Improved service affordability through more competitive market conditions
- Enhanced quality of experience across various applications and user scenarios
- Expanded service availability to previously underserved populations and regions

Broader Economic Impact:

- Positive contribution to economic growth through improved connectivity and digital services
- Productivity gains across sectors, leveraging enhanced telecommunications infrastructure
- Stimulation of innovation ecosystem through accessible spectrum for new entrants

C. Social and Development Outcomes

The framework supports key development objectives for West Africa.

Digital Inclusion:

- Meaningful expansion of broadband access to underserved communities
- Improved connectivity quality in rural and remote areas
- Enhanced affordability of essential communication services
- Targeted programs to address connectivity gaps for vulnerable populations

Capacity and Ecosystem Development:

- Development of technical expertise in advanced spectrum management
- Strengthened regulatory capacity across the region
- Growth of local innovation and technology development ecosystems
- Establishment of regional knowledge centers and research collaborations

Regional Integration:

- Facilitated cross-border services and seamless roaming experiences
- Enhanced digital trade infrastructure and economic integration
- Improved regional cooperation in telecommunications policy and regulation
- Strengthened emergency response coordination through spectrum sharing

D. Environmental Sustainability

The framework contributes to environmental objectives in several ways.

Energy and Resource Efficiency:

- Reduced power consumption through optimized network operations
- Lower carbon footprint of telecommunications infrastructure
- Enhanced support for renewable energy in network operations
- Contribution to sustainable development goals and climate objectives

Resource Optimization:

- Maximizing the utility of existing spectrum resources through sharing mechanisms
- Reduced need for duplicate infrastructure through collaborative models
- Extended lifecycle of existing equipment through efficiency improvements
- Minimization of electronic waste through shared infrastructure approaches

VII. IMPLEMENTATION CHALLENGES AND MITIGATION STRATEGIES

A. Technical Challenges

Challenge 1: Interference Management.

Problem: Dynamic spectrum sharing increases complexity of interference analysis and mitigation, particularly in dense urban environments and cross-border regions. Mitigation Strategies:

- Deploy advanced interference cancellation technologies
- Implement real-time monitoring and adaptive power control
- Establish coordination protocols for cross-border interference
- Develop machine learning algorithms for predictive interference management
- Create technical working groups for ongoing optimization

Challenge 2: System Integration Complexity.

Problem: Integration of multiple operational models with existing infrastructure requires significant technical coordination and standardization. Mitigation Strategies:

- Develop comprehensive technical standards aligned with international best practices
- Implement a phased integration approach with extensive testing
- Establish regional technical coordination centers
- Provide extensive technical training and support
- Create fallback mechanisms for system failures

B. Institutional and Regulatory Challenges

Challenge 1: Regulatory Capacity Limitations.

Problem: Many West African regulatory authorities lack the technical expertise and institutional capacity to oversee complex spectrum sharing arrangements. Mitigation Strategies:

- Implement comprehensive capacity-building programs with international support
- Establish regional centers of excellence for technical expertise
- Develop simplified regulatory frameworks for initial implementation
- Create peer learning networks among regulators
- Provide ongoing technical assistance and mentoring

Challenge 2: Cross-Border Coordination Complexity.

Problem: Harmonizing spectrum policies across 15 different national jurisdictions with varying legal and institutional frameworks. Mitigation Strategies:

- Leverage existing ECOWAS institutional frameworks
- Develop model legislation for national adaptation
- Establish bilateral agreements as stepping stones to regional coordination
- Create dispute resolution mechanisms for cross-border issues
- Implement pilot programs in willing countries before full regional rollout

C. Economic and Market Challenges

Challenge 1: Market Power Concentration.

Problem: Dominant operators may manipulate spectrum markets or resist sharing arrangements that benefit competitors. Mitigation Strategies:

- Implement strong competition policy enforcement
- Design market mechanisms that prevent manipulation
- Reserve spectrum allocations for smaller operators
- Monitor market behavior and intervene when necessary
- Create incentives for cooperative behavior

Challenge 2: Investment Uncertainty.

Problem: Operators may reduce investment due to uncertainty about future spectrum access rights and regulatory changes. Mitigation Strategies:

- Provide long-term policy certainty through clear roadmaps
- Implement grandfathering provisions for existing investments

- Create investment incentives for spectrum sharing infrastructure
- Establish transparent and predictable regulatory processes
- Develop risk-sharing mechanisms for early adopters

D. Social and Cultural Challenges

Challenge 1: Digital Divide Exacerbation.

Problem: Market-based spectrum allocation might prioritize profitable urban areas while neglecting underserved rural populations. Mitigation Strategies:

- Implement universal service obligations for spectrum sharing participants
- Reserve spectrum allocations specifically for rural coverage
- Create cross-subsidization mechanisms from urban to rural services
- Establish public spectrum banking for universal access objectives
- Monitor coverage and access metrics with corrective action triggers

Challenge 2: Stakeholder Resistance.

Problem: Various stakeholders may resist changes that threaten existing arrangements or require new capabilities. Mitigation Strategies:

- Conduct extensive stakeholder consultation and engagement
- Demonstrate clear benefits through pilot programs and case studies
- Provide transition support and capacity building

TABLE 2. IMPLEMENTATION CHALLENGES AND MITIGATION TIMELINE

Challenge Category	Priority Level	Mitigation Timeline
Technical	High	Phases 1–2 (2025–2027)
Regulatory	Critical	Phases 1–3 (2025–2029)
Economic	Medium	Phases 2–4 (2026–2030)
Social	Medium	Phases 1–4 (2025–2030)

VIII. CONCLUSIONS, RECOMMENDATIONS FUTURE RESEARCH DIRECTIONS

A. Conclusions, Recommendations

The focus of this study has been to close the major gap between the technical feasibility of dynamic spectrum sharing and actual policy implementation within the rapidly growing 6G ecosystem in West Africa.

The results from this comprehensive study illustrate how the current use of frequency bands represents significant economic lost opportunity, and the suggested tripartite approach can achieve significantly greater levels of efficiency than exist today.

Policy Recommendations, (1) For National Governments: Recognize Dynamic Spectrum Sharing as an Important Element of Digital Transformation (DT) for Development and Allocate Sufficient Resources and Political Will; Increase the Regulatory Capacity Building and Institutional Strengthening to Oversee Complex Spectrum Sharing Arrangements; Develop Regional Coordination Mechanisms to Develop

Policies That Support Harmonization Objectives of ECOWAS.

(2) For Regulatory Authorities: Build Technical Expertise in Spectrum Monitoring, Interference Analysis and Market Oversight; Develop Flexible Regulatory Frameworks That Can Be Continuously Refined Based On Experience From Operational Use; Foster Inclusive Stakeholder Engagement To Resolve Concerns and Optimize Implementation Outcomes.

(3) For Mobile Network Operators: Evaluate Opportunities for Cost Savings and Service Enhancement Through Collaborative Approaches; Invest In Technical Capabilities For Cognitive Radio Technologies and Dynamic Spectrum Management; Participate Actively In Pilot Programs To Gain Competitive Advantages and Influence Design of Framework

B. Future Research Directions

Priorities for Technical Research

- Integration With Emerging 6G Technologies And Network Architectures
- Development Of Advanced AI/ML Applications For Optimization of Spectrum Utilization and Management of Interference
- Security and Privacy Considerations For The Use of DS in DS Environments

Priorities for Policy and Implementation Research

- Cross-Regional Comparative Studies to Identify Adaptation Strategies
- Impact Evaluation Studies of Economic, Social, and Technological Effects of Implementation
- Innovation of Regulatory Approaches for Evolving Paradigms of Spectrum Sharing

REFERENCES

- [1] GSMA, "The state of mobile connectivity report 2024: West africa," London, 2024.
- [2] International Telecommunication Union, "Measuring digital development: Facts and figures 2024," Geneva, 2024.
- [3] M. Kouty, "Boosting the intra-african digital trade in the aicfta context: does regulatory framework matter?" *Digital Economy and Sustainable Development*, vol. 2, no. 1, pp. 15–32, 2024.
- [4] K. P. Puplampu, "Beyond the rhetoric: Digitalization policy for resilience in africa post-covid-19," in *International Political Economy Series*. Springer, 2023, pp. 45–68.
- [5] D. I. Barkire, B. Kone', and A. D. Kora, "Qosflow: Prioritizing flows in software-defined networking for enhanced quality of service," *IEEE Access*, vol. 12, pp. 65 432–65 445, 2024.
- [6] D. I. Barkire, B. Kone', and A. D. Kora, "Spectrum scarcity and saturation analysis in west africa: Towards dynamic management for 5g-advanced and 6g," Submitted to IEEE, 2025, under review.
- [7] I. Bala and M. M. Mijwil, "Unlocking the full Potential of Spectrum: A Comprehensive review of Cognitive Radio Technology," *Mesopotamian Journal of Computer Science*, vol. 2023, pp. 64–71, Apr. 2023, doi: 10.58496/mjcs/2023/020.
- [8] P. Chitralingappa and N. Shaik, "SEIZING THE SPECTRUM: COGNITIVE RADIO NETWORKS' PATH TO EFFICIENT COEXISTENCE," in *Futuristic Trends in Network & Communication Technologies*, 2024, pp. 233–245. doi: 10.58532/v3bbnc1p1ch20.
- [9] Z. Chkirbene and N. Hamdi, "A survey on spectrum management in cognitive radio networks," *International Journal of Wireless and Mobile Computing*, Apr. 2015, doi: 10.1504/IJWMC.2015.068618.
- [10] C. Zhang, P. Patras, and H. Haddadi, "Deep learning in mobile and wireless networking: A survey," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 3, pp. 2224–2287, 2019.
- [11] L. Song, B. Di, H. Zhang, and Z. Han, "Integrating Terrestrial-Satellite Networks into 5G and Beyond," in *Cambridge University Press eBooks*, 2023, pp. 269–293. doi: 10.1017/9781108936538.016.
- [12] P. Bhattacharya, F. Patel, V. Ralegankar, B. Thakkar, S. Tanwar, and M. Abouhawwash, "Trusted 6G-Envisioned Dynamic Spectrum Allocation: a reference Model, Layered Architecture, and Use-Case," in *Lecture notes in electrical engineering*, 2022, pp. 405–418. doi: 10.1007/978-981-19-0284-0_30.
- [13] B. Somdya, S. Rananga, L. Mfupe, M. Masonta, and F. Mekuria, "Spectrum regulation for future internet networks in developing economies," May 01, 2017, pp. 1–12. doi: 10.23919/istafrica.2017.8102342.
- [14] W. Lambrechts and S. Sinha, "Limitations of last mile internet access in developing countries," in *Lecture notes in networks and systems*, 2019, pp. 41–69. doi: 10.1007/978-3-030-20957-5_2.
- [15] M. Beck and T. R. Moore, "Is universal broadband service impossible?," 2022 IEEE 19th International Conference on Mobile Ad Hoc and Smart Systems (MASS), pp. 403–409, Oct. 2022, doi: 10.1109/mass56207.2022.00064.
- [16] M. Cave and W. Webb, "Spectrum management policy options," in *Handbook of Telecommunications Economics*, Volume 2. North Holland, 2006, pp. 619–678.
- [17] C. Blackman and S. Forge, "Spectrum management in developing countries," Geneva, 2012.
- [18] E. Sutherland, "Telecommunications regulation in africa," *Communications & Strategies*, no. 58, pp. 35–54, 2005.
- [19] O. Mothobi, "The impact of telecommunication regulatory policy on mobile retail price in Sub-Saharan African countries," *Information Economics and Policy*, vol. 58, p. 100963, Dec. 2021, doi: 10.1016/j.infoecopol.2021.100963.
- [20] B. Bado and S. Dunakhir, "The Role of Infrastructure in Driving Economic Growth: A Qualitative Literature study," *Formosa Journal of Multidisciplinary Research*, vol. 3, no. 11, pp. 4279–4288, Nov. 2024, doi: 10.55927/fjmr.v3i11.12352.
- [21] A. Cheshmehzangi, "Technology Availability and Accessibility: Dealing with the Issues of Digital Divide," in *Sustainable development goals series*, 2021, pp. 153–160. doi: 10.1007/978-981-16-4888-5_18.
- [22] M. Shahid et al., "Wireless spectrum in rural farmlands: status, challenges and opportunities," *arXiv (Cornell University)*, Jul. 2024, doi: 10.48550/arxiv.2407.04561.
- [23] M. Y. Sheik and Z. A. Warsame, "Enhancing spectrum management analysis to optimize economic value," *International Journal of ADVANCED AND APPLIED SCIENCES*, vol. 12, no. 9, pp. 1–12, Aug. 2025, doi: 10.21833/ijaas.2025.09.001.
- [24] O. Chillemi, S. Galavotti, and B. Gui, "The impact of data caps on mobile broadband Internet access: A welfare analysis," *Information Economics and Policy*, vol. 50, p. 100843, Nov. 2019, doi: 10.1016/j.infoecopol.2019.100843.
- [25] J. S. Marcus, "The economic impact of internet traffic growth on network operators," *SSRN Electronic Journal*, Jan. 2014, doi: 10.2139/ssrn.2531782.
- [26] A. G. Fanfalone, "Developments in spectrum management for communication services," *OECD Digital Economy Papers*, Oct. 2022, doi: 10.1787/175e7ce5-en.
- [27] E. Idowu, "ICT adoption in developing economies: Barriers and opportunities," *Preprints.org*, Jun. 2025, doi: 10.20944/preprints202506.0042.v1.



Ide Barkire Dourahamane is a PhD student in Telecommunications at the École Supérieure Multinationale des Télécommunications (ESMT), Dakar, Senegal, and Université Cheikh Anta Diop. He earned his master's degree in networks and telecommunications from ESMT in 2011, and he also holds a Diploma in Teleinformatics Engineering from ESMT. His research focuses on dynamic spectrum management. He is currently a department head for digital culture at the University of Dosso, Niger, and has worked in various academic and telecommunications roles, including as a contractual telecom department head at SGEM Telecom. He has also completed several internships in Niger and Senegal, contributing to his expertise in telecom and IT systems.



Benjamin Koné received his PhD in Mathematics and Computer Science with a Telecommunications specialization from Université Cheikh Anta Diop and Ecole Supérieure Multinationale des Télécommunications, Senegal, in 2023. His research focuses on the deployment of software-defined networks (SDN) and network function virtualization (NFV) to improve rural connectivity. He earned a master's degree in Networks and Telecommunications

from ESMT Dakar, with practical experience in RF planning, optimization, and quality of service for (2G -6G) / IA networks, intelligent Network and Autonomous System. Since 2024, he has been teaching telecommunications at private universities in Mali. He has contributed to multiple international conferences and has published research on network resource management and orchestration for virtualized networks. Currently, he is a co-founder and associate researcher at Find RD, where he focuses on innovation and rural connectivity solutions.



Ahmed Dooguy Kora is an IEEE Senior Member and a consultant for the International Telecommunication Union (ITU). He received a master's degree in Networks and Telecommunications from the Ecole Supérieure Multinationale des Télécommunications (ESMT) in 2003 and completed his PhD in Telecommunications at the University of Limoges, France, in 2007. He is currently a professor at ESMT,

where he serves as the head of teaching, training, and research. His research interests include communication and network system architecture (2G to 6G), free-space optics, fiber optics, quality of service, universal access, artificial intelligence, software-defined networking, Cloud RAN, and cognitive radio.