AI-Enabled Dynamic Spectrum Sharing in the Telecommunication Sector – Technical Aspects and Legal Challenges

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Abstract

Dynamic Spectrum Sharing (DSS), as part of Dynamic Spectrum Management, is already used in the telecommunication sector and is a critical technology for addressing spectrum scarcity in next-generation wireless networks, particularly when implementing 6G. Legacy statical spectrum management (designed for one user exclusively for a certain bandwidth for certain services) is no longer fit for purpose, as it does not allow the efficient use of the spectrum. By leveraging Artificial Intelligence (AI), DSS enables the real-time adaptive allocation of radio frequencies, thereby improving spectrum utilization and network efficiency. Although the integration of AI into DSS introduces complex technical and legal challenges. This paper aims to investigate the challenge of dynamic spectrum policy when using AI-enabled DSS and answer the question of why a flexible and new spectrum policy is desired. Some suggestions for refining the regulatory framework are also presented, which are long overdue in academic research. Recent research primarily focuses on technical issues, rather than specifically on legal ones. The closure findings underscore the need for standardized protocols, adaptive regulatory policies, and other legal frameworks to ensure equitable and efficient spectrum sharing.

Keywords

AI-Enabled Dynamic Spectrum Sharing, AI, spectrum sensing, spectrum right, spectrum regulatory framework

1 Introduction

The integration of Artificial Intelligence (AI) into Dynamic Spectrum Sharing (DSS) introduces technical complexities, such as computational demands and algorithm reliability (e.g., consistency, robustness, and accuracy), alongside legal challenges, including spectrum rights allocation, interference management, and dispute resolution. However, governance frameworks for AI-enabled DSS remain underdeveloped, requiring further exploration.

The rapid growth of wireless devices and data-intensive applications has heightened demand for radio frequency spectrum, a finite resource. Traditional static management often leads to underutilized frequency bands, with inflexible policies exacerbating inefficiencies beyond the spectrum's physical scarcity [1]. AI-enhanced DSS addresses this by enabling flexible, real-time allocation of resources, adapting to dynamic demands and environments while improving spectrum sensing, resource allocation, and interference mitigation.

This study briefly examines the technical and legal dimensions of AI-enabled DSS, identifying challenges and gaps in research. As an initial exploration, it evaluates significant prior work to lay the foundation for future investigations.

2 Technical Aspects of AI-Driven Dynamic Spectrum Sharing

AI-driven DSS leverage all sort of AI techniques to optimize spectrum utilization in dynamic, complex environments. [2, 3, 4].

2.1 Spectrum Sensing and Cognitive Radio

Spectrum sensing is the cornerstone of the DSS, enabling real-time detection of spectrum occupancy. AI-based techniques, such as convolutional neural networks (CNNs) and long short-term memory (LSTM) models, enhance spectrum sensing by analyzing signal patterns and predicting spectrum availability [5, 6]. CNNs are highlighted for their ability to extract features from spectral data, improving detection accuracy in noisy environments without relying on prior knowledge of signals. LSTMs are emphasized for their ability to handle sequential and time-series data..

In addition, deep learning-based spectrum sensing achieves up to 45% improvement in detection accuracy compared with traditional methods, which rely only on basic signal processing techniques to identify spectrum occupancy like energy detection [5]. Cognitive radio networks (CRNs) powered by AI allow users to opportunistically access unused spectrum bands without interfering with other users [3]. The challenges include, among others, the computational complexity of real-time processing and the need for robust datasets to train AI models. Studies highlight that AI models may struggle with unpredictable interference patterns, necessitating hybrid approaches that combine

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interpretable models (e.g., decision trees) with high-performing deep learning (DL) models [6].

2.2 Interference Management

Interference management is critical for ensuring reliable connectivity in the DSS. AI-driven techniques, such as multi-agent reinforcement learning (MARL), optimize power allocation and beamforming to minimize interference [6]. MARL is used for mitigating jamming attacks, where malicious entities disrupt spectrum utilization by interfering with communications Another example is reconfigurable intelligent surfaces (RIS) integrated with AI, which can dynamically adjust signal propagation to reduce interference in non-orthogonal CRNs [7]. RIS, also known as an Intelligent Reflecting Surface (IRS), is a passive, planar metasurface composed of a large array of low-cost, tunable unit cells that can dynamically manipulate incident electromagnetic waves. Unlike active devices like base stations or relays, RIS does not generate or amplify signals—it reflects, refracts, or absorbs them in a programmable way to shape the wireless propagation environment.

Research has demonstrated that AI-driven interference management achieves a spectrum utilization efficiency of up to 62.4% in urban environments, nearly double the utilization efficiency compared to traditional management [5]. Although challenges persist, including the scalability of AI models in large networks and the risk of unpredictable behavior in edge cases. Robust fallback mechanisms are necessary to address unpredictable AI behavior in edge cases, while standardized interfaces and protocols are essential for enabling seamless deployment and integration with existing network infrastructure [5].

2.3 Resource Allocation

AI enables dynamic resource allocation by predicting network traffic and allocating spectrum based on real-time demands. Machine learning algorithms, such as support vector machines (SVMs) and deep reinforcement learning (DRL), can forecast spectrum occupancy and optimize bandwidth allocation [8]. For instance, DRL-assisted virtual network embedding (VNE) in satellite networks enhances resource utilization by adapting to multiple coverage constraints [4]. Major obstacles include the need for energy efficiency and the requirement for real-world datasets to enhance prediction accuracy. The absence of standardized testbeds and benchmarks further complicates performance evaluation [2].

3 Regulatory Challenges in AI-Enabled Dynamic Spectrum Sharing

The deployment of AI-driven DSS raises significant regulatory challenges that must be addressed. According to recent research, regulatory issues arise, particularly in interference management, spectrum rights, and dispute resolution. Other legal and regulatory questions have, to the best of the author's knowledge, been completely overlooked or only superficially discussed.

3.1 Interference Management

Interference management in DSS requires regulators to ensure compliance with technical standards to prevent harmful interference. Those standards, when using AI, are missing. An example of such AI-driven systems to avoid interference is spectrum access systems (SAS) that use geolocation databases and sensing to manage the shared spectrum [9]. Simultaneously, the complexity of AI algorithms raises concerns about transparency and accountability when unwanted interference occurs. National regulatory bodies already emphasize the need for standardized protocols to ensure equitable access and interference mitigation [10, 11]. Regulators must strike a balance between innovation and the protection of incumbent users and their guaranteed rights to spectrum.

3.2 Spectrum Rights and Equitable Access

Regulatory authorities adopt the fixed spectrum access (FSA) policy to allocate different parts of the radio spectrum with a certain bandwidth to certain services. With such a static and exclusive spectrum allocation policy, only the authorized users, also known as licensed users, have the right to utilize the assigned spectrum, and the other users are forbidden from accessing the spectrum, regardless of whether the assigned spectrum is busy or not [3]. This could be seen as a direct opposition to the efficient use of the spectrum, where the use of the spectrum aligns with all available technical possibilities. Spectrum rights allocation is a contentious issue in DSS, as AI enables dynamic access by multiple users and challenges traditional licensing models. Spectrum right allocation is traditionally static – one user to a particular broadband. On the other hand, with shared access regimes, such as licensed shared access (LSA), regulators allow spectrum users to open spectrum bands while protecting incumbent users [12]. However, only a few countries have adopted this option, and it comes with numerous regulatory restrictions. For explanation, incumbent users are historically incumbent telecommunications operators, who paid a significant amount of fees for the licence to use the spectrum. Therefore, spectrum licenses are important assets for incumbent users. Nevertheless, AI-driven DSS raises concerns about monopolistic practices because dominant operators may leverage advanced algorithms to secure disproportionate spectrum access [13, 14. 15]. However, legal frameworks must evolve to address equitable access for smaller operators and license-exempt users while simultaneously protecting the guaranteed rights of incumbent users/operators. The absence of clear spectrum rights allocation policies risks exacerbating disputes and stifling innovation in the industry.

3.3 Dispute Resolution

Dispute resolution in DSS tackles conflicts over interference, spectrum access, and user priority. AI systems complicate this due to poor interpretability, obscuring decision processes [6]. AI-driven user prioritization can spark fairness disputes. National spectrum strategies propose interagency resolution processes [6, 10]. Explainable AI models (e.g., XAI) improve transparency, aiding dispute resolution [6]. Blockchain-based databases offer tamper-proof spectrum usage records, simplifying conflict resolution [6].

4 The Need for New AI-Enabled DSS Governance, Suggested New framework

As stated above, traditional regulatory frameworks designed for static spectrum licensing are ill-equipped to handle AI's autonomous and data-intensive nature of AI. The proposed regulatory framework should impose legal mechanisms to address more flexible licensing, privacy and data protection, interference management, security, and international coordination, ensuring compliance and fostering innovation. The objectives of the new framework, in the author's opinion, are: **Enabling Innovation**; **Ensuring Compliance**: that is, aligning with existing laws (e.g. national telecom regulations, Data Act, Artificial Intelligence Act etc.); **Promoting Fairness**, which means ensuring equitable spectrum access and accountability in AI decisions.; **Support Global Harmonization** to align with international standards (e.g., ITU, 3GPP); **Security and Cybersecurity**; Promoting **Regulatory Sandboxes,** to enable safe testing of AI-driven DSS.

4.1 Proposed Legal and Regulatory Framework

4.1.1. Dynamic Licensing Model

Replacing the current policy of static and exclusive spectrum with the Dynamic Licensing Model is a key principle, or, even better, the Dynamic Licensing Model should be prioritized. This could include a tiered access system (primary, secondary, and opportunistic users) managed by AI-driven Spectrum Access Systems (SAS) [3, 12, 9]. This means enacting laws defining tiered access rights, specifying priority levels, and usage conditions. For instance, extending the U.S. Citizens Broadband Radio Service (CBRS) model, where SAS dynamically assigns spectrum, with legal provisions for AI oversight and auditability. Refinements to the European Electronic Communication Code (EECC) [13]. to add AI spectrum management tools are another possible example. First, a definition of DSS should be added and represented. (e,g, in Art. 2). DSS can be defined as a primary shared use of the radio spectrum, enabling flexible, real-time allocation of spectrum bands among multiple users and designated services, when appropriate, adding tiered access rights. In spectrum management (Art. 45 EECC), the goal should also be, by default, to privilege AI-enabled DSS, adding appropriate certification. So, spectrum management could be flexible enough for new technologies and, at the same time, compliant as an exception to the technology and service-neutral principle, traditionally anchored in EECC, because general interest objectives are at stake and can be clearly justified and subject to regular review. From a practical point of view, mandating AI-predictive models for real-time allocation in "AI-harmonized" bands that require shared AI datasets could be discussed in future peer reviews. The neutral authorization regime for spectrum designation, with some exceptions, should move to the explicit inclusion of AI/ML, with possible certification for bias-free algorithms and energy metrics in an additional separate regulation, such as the Gigabyte Infrastructure Act (GIA), intended to simplify access to physical infrastructure in this sector. Art. 46 EECC is meant only to encourage shared access, while the default AI-driven DSS could drive spectrum sharing to another level.

The dynamic licensing model can use blockchain-based smart contracts to automate spectrum allocation, ensuring transparency and enforceability. Regulators should issue guidelines for AI algorithms to prioritize licensed users while optimizing opportunistic/dynamic access and imposing penalties for non-compliance.

4.1.2. Privacy and Data Protection

The goal is to require licensed users to implement privacy-preserving AI techniques (e.g., Federated Learning and differential privacy) to minimize data exposure. Minimal data exposure goes beyond personal data and should be extended to all processed data sets. AI systems in DSS are designed to process only the necessary data for the requested task. Memorized data, such as geolocation and traffic patterns, should be encrypted. Therefore, developing standards for anonymized data processing in DSS, with certification for compliant AI systems, is necessary. For instance, blockchain contracts and differential privacy could enhance efficiency in dense networks and align with the principle of minimizing sensitive data sharing. But on the other hand, all the relevant data for enabling AI-enabled DSS must be shared. Data Act of the EU could address this issue.

Privacy and data protection are strongly connected to the Right to Explanation (transparency). Therefore, it is necessary to mandate transparency in AI-driven spectrum decisions, allowing users to challenge allocations [6, 11]. Although the Artificial Intelligence Act of the EU requires high-risk AI systems (DSS component is legally interpreted as critical infrastructure) to face a strong transparency obligation, in the context of DSS, it needs to be technically detailed.

4.1.3. Interference Management, Liability and Dispute Resolution

Clear liability rules for AI-induced interference, balancing the responsibilities of operators, secondary users, and vendors, must be established. A shared liability model could be a solution. Operators as primary users could be liable for interference unless caused by secondary users or by the vendor/distributor/supplier AI errors, verified through forensic logs. The interference threshold must be introduced and known at the front. Legal limits for acceptable, e.g., signal-to-noise ratio standards, should be defined. The requirement for AI systems to maintain tamper-proof logs of spectrum allocation decisions, accessible when needed to stakeholders, is a good way to ensure the transparent operation of DSS. These logs can then be used as evidence at competent bodies in dispute resolution to resolve interference disputes, with AI decisions [5, 10].

4.1.4. International Standardization

Promoting harmonized standards for AI-driven DSS through international bodies like ITU and 3GPP is just one side of the remaining challenges, like interoperability. Negotiating bilateral and international treaties to align spectrum sharing protocols and data sovereignty rules is another issue. For instance, ITU's World Radiocommunication Conference (WRC) could develop model laws for national adoption, ensuring compatibility with global 5G and 6G standards [10, 14, 15]. Cross-border Coordination (e.g., Art. 4 EECC) could also be expanded, with the RSPG-led cooperation utilizing AI tools for interference resolution.

4.1.5. Security and Cybersecurity

A robust cybersecurity framework for AI-driven DSS systems is aimed at preventing attacks such as data poisoning. Cybersecurity standards for AI-Enabled DSS must still be developed. These standards will include encryption, intrusion detection, and regular security audits for AI systems, as well as reporting security breaches. Certifying AI systems for cybersecurity compliance, with the development of AI-enabled DSS [10, 14, 15].

4.1.6. Regulatory Sandboxes

Creating controlled environments to test AI-driven DSS without full regulatory constraints could be a way to overcome the development compliance. Sandbox legislation should define the scope, duration (e.g., 1-2 years), and liability exemptions for sandbox participants. Launching pilot programs with telecom operators and ensuring legal protections for experimental deployment are essential for the progress of AI-enabled DSS. After the test period, the transition to actual use in the real world would be enhanced because of a good testing foundation in a technological and regulatory sense. A good example is the Model on the UK's Ofcom sandbox, tailored for AI-driven 6G applications [10, 14, 15]. When it comes to regimes for authorization (e.g., Art. 47 EECC), introducing "AI-sandbox" authorizations for DSS testing accelerates innovation through pilots accompanied by authorization. This is also in line with the AI Act, where sandboxes represent well-documented risk mitigation and, as a result, transparency.

5 Conclusion

In this paper, the author examined AI-Enabled DSS from a technical and legal governance perspective. This is a notable achievement because there is a significant gap in research in this field.

This paper aimed to highlight some dimensions of the interaction between technological perspectives and the governance of AI-enabled DSS. After reviewing the adversarial and inherited technical challenges, such as resource allocation, interference management, and spectrum sensing, the legal issues of interference management, spectrum allocation, and equitable access, along with dispute resolution, are briefly discussed.

Moving into the future, a new possible regulatory framework is presented, including a dynamic licensing model, the implementation of privacy-preserving AI techniques in DSS, and a shared liability approach to interference management that could also contribute to dispute resolution. Briefly, the importance of international standardization and interoperability, as well as cybersecurity threats such as data poisoning and the lack of standardization, is mentioned. Lastly, creating regulatory not only technical sandboxes as controled testing environments is proposed.

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