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Article

Key guidelines to address technical and regulatory challenges in the adoption of cognitive radio in Mexico

Pautas clave para enfrentar los desafíos técnicos y regulatorios en la adopción de la radio cognitiva en México

Ortega-Laurel, Carlos*[a]

[a] Universidad Autónoma Metropolitana • LVQ-9127-2024 • 0000-0001-6072-8480 • 104250

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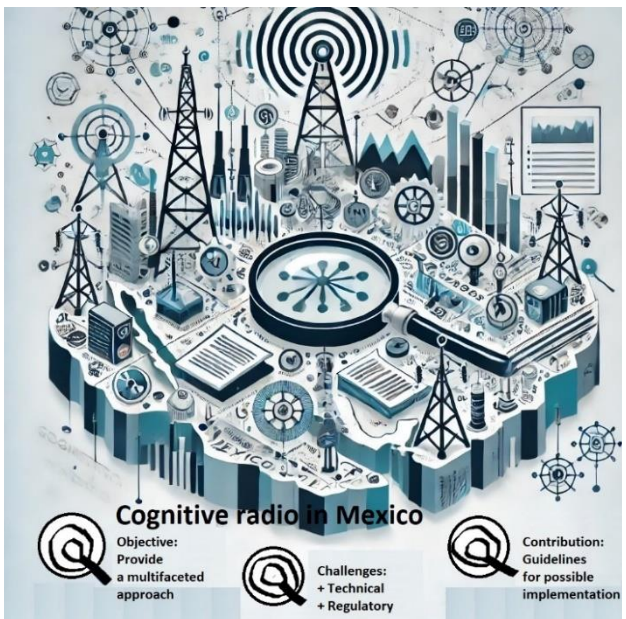
* [c.ortega@correo.ler.uam.mx]

Abstract

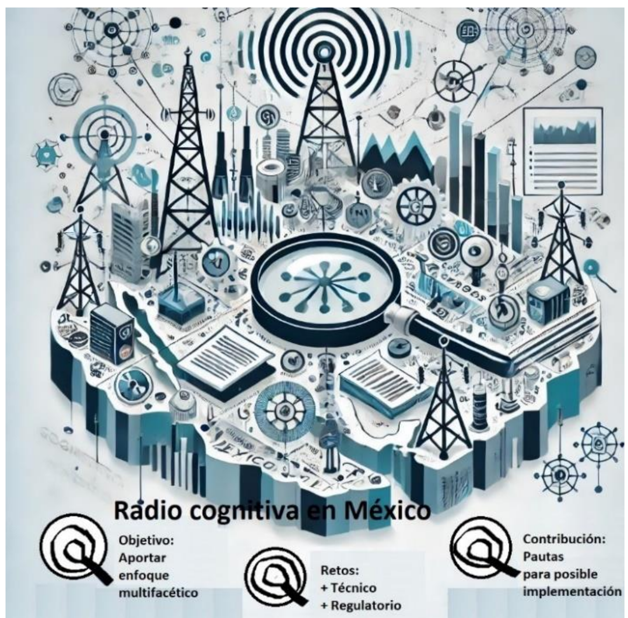
The main objective of this research is to provide a multifaceted approach to cognitive radio (CR) technology in Mexico, a technology that seeks to optimize the use of spectrum, ensuring more efficient and flexible wireless communication. CR faces significant technical and regulatory challenges in the world, with Mexico being no exception. These include the efficient management of the radio spectrum and the need for a regulatory framework adapted to emerging technology.



Cognitive, Radio, Technology

Resumen

El objetivo principal de esta investigación es aportar un enfoque multifacético de la tecnología de radio cognitiva (CR, por sus siglas en inglés) en México, tecnología que busca optimizar el uso del espectro, garantizando una comunicación inalámbrica más eficiente y flexible. La CR enfrenta desafíos técnicos y regulatorios significativos en el mundo, sin ser excepción México. Estos incluyen la gestión eficiente del espectro radioeléctrico y la necesidad de un marco normativo adaptado a la tecnología emergente.



Cognitiva, Radio, Tecnología

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Introduction

The concept of CR was introduced by Joseph Mitola III in 1999 (Mitola, 1999), defining it as an intelligent form of radio that can change its transmission and reception parameters based on interaction with the environment, interaction in which the availability of the radio spectrum is sensed.

General operation

1. Spectrum sensing

The CR continuously scans the spectrum to identify free bands and monitor occupied bands. It uses techniques such as energy detection, feature-based detection and cooperative methods (Yucek, 2009).

2. Analysis and decision

The collected data is analysed to assess spectrum availability, channel quality and other relevant factors. The CR controller makes decisions on spectrum usage based on these analyses (Akyildiz, 2009).

3. Assignment and access

The CR selects appropriate frequency bands and establishes communication using these bands. It employs spectrum access techniques to ensure that there is no interference with primary users (Zhao, 2007).

4. Adaptation and learning

The CR adapts its communication parameters (frequency, transmit power, modulation, etc.) in response to changes in the spectrum environment and learns from these adaptations to improve its future performance (Mitola, 1999).

The theoretical foundations of cognitive radio are therefore based on three main pillars:

1. Spectrum sensing:

Cognitive radio devices continuously monitor, quasi-permanently while active, the spectrum to identify available and used frequencies.

Spectrum monitoring: Cognitive radio devices continuously listen to the radio spectrum to identify available channels and avoid interference with other users (Haro, 2015).

2. Spectrum management:

Change from traditional fixed configurations to dynamic decisions in which it is determined which frequencies to use to firstly achieve communication, secondly to avoid interference, in order to optimise spectrum efficiency.

Dynamic spectrum: cognitive radio can detect frequencies that are not in use at a given time and adjust its transmission to those frequencies, which allows for a more efficient use of the spectrum (Márquez, 2014).

3. Adaptability and reconfiguration:

Dynamic modification - adjustment of parameters such as frequency, modulation and transmit power to achieve adaptability and reconfiguration, to improve the performance - use of the radio spectrum.

Adaptation: Cognitive radio systems can adapt their transmission parameters, such as transmit power and frequency, in response to environmental conditions (Rentería, 2011).

Other key features related to cognitive radio are:

4. Artificial intelligence and machine learning:

Advanced algorithms are used to analyse data collected from the environment and make decisions on how to operate more efficiently (Bezerra, 2024).

5. Interoperability:

Cognitive radio can communicate with different types of communication systems and networks, facilitating greater integration and cooperation between various wireless technologies (Haro, 2015).

Based on these generalities, a methodology is outlined, which is described in the following section.

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This is intended to ensure a comprehensive and rigorous approach to analyse the challenges and opportunities for the adoption of CR technology in Mexico, from a technical and regulatory perspective. As such, this report was drafted in sufficient detail to present the identified challenges, integrated analysis and recommendations.

Method

The research focuses on understanding, identifying and addressing the challenges facing the adoption of a specific technology in Mexico. To this end, two main lenses are used: technical and regulatory, based on the existing literature, in order to obtain a solid understanding of the technical and regulatory challenges documented in the literature.

The objectives are

a. Identify the technical challenges associated with technology adoption in Mexico.
b. Analyse the current regulatory framework and how it affects technology implementation.
c. Make recommendations to overcome the identified challenges.

Results

RC architecture

The CR architecture is an advanced wireless communication system that can dynamically adapt its operational parameters and communication strategies to optimise the use of the radio spectrum.

The main components of the CR architecture are:

1. Spectrum Sensing.

Detects available frequency bands and monitors spectrum usage to identify communication opportunities without interfering with Primary Users (PU) (Haykin, 2005).

2. Spectrum Management

Selects the best available frequency bands based on channel conditions and spectrum usage policies. This includes dynamic spectrum allocation and channel selection (Akyildiz, 2006).

3. Spectrum Sharing (Spectrum Sharing)

Coordinates spectrum usage among multiple cognitive users (Secondary Users, SU) to avoid collisions and ensure efficient communication. It implements mechanisms such as opportunistic spectrum access and coexistence with primary users (Zhao, 2007).

4. Spectrum Mobility

Allows cognitive users to switch frequencies without service interruption when the presence of a primary user is detected or when channel conditions change (Zhao, 2007).

5. Cognitive Radio Controller (CR Controller)

The core of the architecture, which integrates learning and decision-making functions (Mitola, 2002). It uses artificial intelligence and machine learning techniques to optimise real-time operation of the CR (Bezerra, 2024).

6. User Interface and Applications

Provides the means for users to configure and monitor the operation of the system. It allows the implementation of specific applications that leverage the capabilities of the CR.

The CR architecture represents the breakthrough achieved in wireless communications, which is significant in providing an intelligent and adaptive solution for the efficient use of the radio spectrum.

Benefits

1. Spectrum Efficiency

Improves spectrum utilisation by allowing opportunistic access to unused bands (Haykin, 2005).

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2. Interference Reduction

Minimises interference with primary users through accurate detection and dynamic frequency switching (Akyildiz, 2006).

3. Flexibility and Scalability

Adapts its operations to different environments and communication requirements, making it suitable for a wide range of applications (Mitola, 2002).

4. Improved Network Performance

Optimises quality of service and network efficiency by dynamically adjusting communication parameters (Yucek, 2009).

Challenges

1. Accurate Detection of primary users and identification of free bands are critical and can be complicated in noisy environments (Yucek, 2009).

Coexistence and Coordination

2. Efficient coordination between multiple cognitive radios and primary users is a challenge to avoid interference and maximise spectrum efficiency (Zhao, 2007).

Regulation and Policy

3. The implementation of cognitive radios must comply with the spectrum usage regulations and standards set by the competent authorities (Akyildiz, 2009).

Thus CR is a telecommunications technology that allows wireless communication devices to use the radio frequency spectrum more efficiently.

It is based on the idea that devices can ‘understand’ and ‘learn’ from the radio environment in which they operate in order to optimise their performance.

CR is a technology that allows wireless communication devices to dynamically identify and use available radio frequencies to optimise spectrum usage.

In fact, CR is an advanced technology that can allow wireless devices to automatically detect and use spectrum frequencies that are not in use at a given time, thus improving spectrum usage efficiency.

Given the characteristics CR has applications in diverse areas such as military and police communication (AllahRakha, 2024), mobile networks (Demeneghi, 2024), the Internet of Things (IoT) (El Akhdar *et al*., 2024), smart grids (Velasquez *et al*, 2024) and Artificial Intelligence (AI) (Espina-Romero *et al*., 2024) where efficient spectrum management is crucial for the performance and reliability of communication systems.

Given the attractiveness of the emerging technology, a number of countries where significant CR trials have been conducted or have sought to put into operation can be found in the literature:

1. The United States:

– The Federal Communications Commission (FCC) has been a pioneer in promoting CR. The FCC has authorised the use of ‘TV White Spaces’ devices, which are unused spaces in the television spectrum, for CR operations (Baykas, 2010).

– Several universities and technology companies in the US have conducted research and pilot tests in the area of CR. Researchers such as Mitola and Haykin have pioneered the development of CR concepts and technologies in the US (Mitola, 2002), (Haykin, 2005).

2. United Kingdom:

– Ofcom, the UK communications regulatory authority, has conducted trials of CR in TV White Spaces.

– Research projects such as the Cambridge TV White Spaces Consortium have explored the use of CR to provide Internet access in rural areas (Baykas, 2010).

3. Japan:

– Japan's Ministry of Internal Affairs and Communications has worked on developing regulations and testing for CR.

– Several universities and research centres in Japan have been involved in pilot projects and studies on CR.

Japan has been active in RC research and development, with organisations such as the National Institute of Information and Communications Technology (NICT) participating in experimental trials and deployments. Efforts in Japan have been crucial for the adoption of VC technologies in commercial applications (Akyildiz, 2009).

4. South Korea:

– South Korea has been a leader in the adoption of advanced wireless technologies and has conducted research and testing of CR.

– Academic institutions and technology companies have collaborated in the development of this technology (Baykas, 2010).

5. Finland:

– Finland has been a research hub for CR, with institutions such as the University of Oulu and the Technical Research Centre of Finland (VTT) leading projects in this field (Baykas, 2010).

6. China:

– China has shown a growing interest in CR, with research and testing conducted by universities and telecommunications companies.

– The Chinese government has supported research and development in this field as part of its technological innovation strategy (Fette, 2006).

7. Germany

Germany has conducted significant research in the field of RC through projects led by the Fraunhofer Institute and other research centres. These efforts have included field trials and prototype development to demonstrate the feasibility of RC in various environments (Fette, 2006).

These countries have been pioneers in the research and development of RC, conducting tests and establishing regulations that allow its use. The implementation of this technology has the potential to significantly improve the efficiency of spectrum use and provide better wireless communication services.

In Mexico, the Federal Telecommunications Institute (IFT) is the body in charge of regulating the radio spectrum. So far, the focus has been on spectrum release for mobile services and spectrum management for other telecommunications services (IFT, 2023). CR in Mexico has been only partially considered, little explored, and not at all implemented, but there is significant potential for its adoption, especially in rural areas and to improve the efficiency of spectrum use in urban areas (IFT, 2023).

Thus, radio spectrum regulation in Mexico, particularly in relation to CR, is a topic of ongoing discussion and criticism. In this sense, some criticisms and considerations on the current regulations in Mexico will be presented below.

Criticisms and Challenges

Lack of specific regulations: In Mexico, specific regulation on RC is still under development. The lack of clear and specific regulations may inhibit the implementation and development of this technology.

Therefore, the absence of a well-defined regulatory framework may generate uncertainty among operators and manufacturers of CR equipment at any given time.

Rigidity of the regulatory framework: Current regulations can be seen as rigid and not sufficiently adapted to the needs of emerging technologies such as CR.

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Traditional spectrum regulations, which assign fixed frequencies to specific services, do not align well with the dynamic and flexible approach of CR, and this is just what is in place in Mexico (IFT, 2023).

Interference and compatibility: The introduction of CR devices may cause interference concerns with existing radio services. Regulations must ensure that CR devices do not interfere with licensed transmissions.

From the above that compatibility between devices from different manufacturers and technologies is another challenge that needs to be addressed in regulation.

Licensing process: The spectrum licensing process in Mexico is complex and slow, and over-regulated, which can delay the adoption of CR technologies.

In fact, the need to obtain specific permissions for the use of certain spectrum bands in Mexico limits the flexibility and efficiency that CR promises.

Incentives for innovation: In Mexico there is a lack of clear incentives for innovation in spectrum use, which may discourage companies from investing in CR technologies.

Current Mexican regulations may not provide sufficient incentives for companies to develop and adopt advanced technologies that optimise spectrum use.

Discussion

To address the current technical and regulatory challenges of CR, a multi-faceted approach involving researchers, engineers, regulators and industry is essential.

The following are specific guidelines that the IFT should listen to in order to address these challenges:

Technical challenges, for the regulator, the IFT needs to ensure:

1. Promoting the development of advanced algorithms

To improve spectrum sensing through sensors: ensure the development of more accurate and efficient algorithms for the detection of available spectrum, using advanced techniques such as deep learning and artificial intelligence.

– Accuracy and efficiency: seek to develop and improve algorithms that detect with high accuracy the available frequency bands using machine learning and signal processing techniques.

– Collaborative sensing: seek to implement systems that use collaborative sensing between multiple devices to improve the accuracy of spectrum sensing.

– Optimisation of decision making: regularly implement decision making algorithms that balance spectrum efficiency and quality of service, leveraging predictive modelling and game theory.

– Game theory and reinforced learning: regulate the application of these approaches to optimise spectrum use decisions, balancing efficiency and interference minimisation.

– Predictive modelling: address the use of predictive modelling to anticipate spectrum availability and traffic load, enabling proactive planning.

Computational efficiency: encourage the design of algorithms that can run in real time with limited computational resources, especially for mobile and IoT devices.

2. Security and reliability

Protection against malicious interference: seek to develop techniques to detect and mitigate intentional or malicious interference, such as denial of service attacks.

– Detection and mitigation: arrange for the development of techniques to identify and mitigate jamming attacks, such as the use of spectral signatures and traffic pattern analysis.

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– Redundancy and resilience: demand the implementation of redundancy mechanisms to ensure continuity of service in the presence of interference.

– Authentication and authorisation: call for robust mechanisms to be implemented to ensure that only authorised devices can access and use the spectrum.

– Security mechanisms: call for the establishment of robust authentication and authorisation protocols to ensure that only legitimate devices can access and use the spectrum.

– Data integrity: provide for ensuring that data exchanged and decisions made by cognitive devices are reliable and not manipulable.

3. Interoperability

Open standards: promote the development and adoption of open standards to ensure that devices from different manufacturers can operate together.

– Development and promotion: work with standardisation bodies to develop and promote open standards that facilitate interoperability between devices from different manufacturers.

– Compatibility testing: seek comprehensive interoperability testing between devices from different vendors and in a variety of operating environments.

– Common test environments: create common test environments by the IFT to validate the interoperability and performance of CR devices.

Regulatory Challenges for the regulator, the IFT has to ensure:

Flexible policy development 2.

– Dynamic regulations: establish regulatory frameworks that allow for dynamic use of spectrum, adjusting frequency allocations in real time based on demand and availability.

– Dynamic use schemes: implement regulations that allow for dynamic spectrum allocation, adjusting to real-time needs.

Temporary licensing: implement temporary or secondary licensing schemes that allow CR devices to access spectrum opportunistically without interfering with primary users.

– Secondary spectrum access: establish temporary or secondary licensing schemes that allow opportunistic spectrum access without interfering with primary users.

2. International coordination

Global harmonisation: collaborate with international bodies to harmonise spectrum regulations and facilitate the use of CR globally.

– International collaboration: promote harmonisation of regulations at the global level to facilitate cross-border use of CR.

Information exchange: create platforms for the exchange of information on spectrum use and regulatory best practices between countries.

– Communication platforms: create platforms for the exchange of information and best practices between countries and regulators.

International cooperation: actively participate in international fora to share experiences and adopt best practices in spectrum regulation. International cooperation can provide valuable insights and help harmonise regulations with global standards.

Monitoring and enforcement

Monitoring systems: develop advanced spectrum monitoring systems to detect misuse and ensure compliance with regulations.

– Monitoring technologies: develop advanced spectrum monitoring systems to detect and record misuse.

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Sanctions and penalties: establish clear and effective sanctions for violations of spectrum regulations.

– Clear regulations: establish clear and effective penalties for violations of spectrum regulations to ensure compliance.

Collaboration and education the IFT is to ensure:

1. Promotion of research

Support for research projects: fund research projects in universities and institutes to advance CR technologies.

– Funding and grants: provide funding and grants for RC research projects in universities and research institutes.

Publications and conferences: to promote the dissemination of research results through academic publications and specialised conferences.

– Knowledge dissemination: encourage the publication of research and participation in specialised conferences to share advances and findings.

2. Training and awareness-raising

Training programmes: develop training programmes for engineers and technicians in new technologies and practices related to RC.

– Education and training: Develop training programmes for engineers and technicians on RC technologies and practices.

Awareness campaigns: conduct campaigns to inform the industry and the public about the benefits and challenges of RC.

– Informing the public: conduct campaigns to educate industry and the public on the benefits and challenges of RC, promoting wider and more conscious adoption.

Other considerations for improving technology regulation in general.

Developing specific regulations: It is essential to develop technology-specific regulatory frameworks that address the particularities and benefits of each technology. This includes clearly defining the conditions under which devices can operate and measures to avoid interference.

Flexibility in spectrum use: adopting a more flexible approach to spectrum allocation and use can facilitate the deployment of all types of emerging technologies. Regulations should allow, for example, for dynamic spectrum use and efficient frequency sharing.

Interference protection: implement monitoring and control mechanisms to ensure that devices of any technology do not interfere with licensed communications. This may include creating a regulatory environment that allows for the safe co-existence of multiple technologies.

Simplification of licensing: simplify and streamline the spectrum licensing process to facilitate the adoption of innovative technologies. A more accessible and less bureaucratic licensing system can accelerate the deployment of emerging technologies.

Encourage innovation: create incentives for research and development in the field of telecommunications technology in general. This can include subsidies, tax breaks, and collaborative programmes between government, academia and industry.

Implementing these guidelines will help overcome technical and regulatory challenges, facilitating the widespread and efficient adoption of RC, and technologies in general.

Implementing these guidelines will help facilitate the integration of CR into modern telecommunications. This comprehensive approach will not only improve spectrum management, but will also drive innovation in wireless telecommunications.

Conclusions

This paper highlights key guidelines for addressing the technical and regulatory challenges in the adoption of CR in Mexico, underlining the importance of a comprehensive approach that involves both technological advances and regulatory reforms.

In sum, a successful adoption of CR in Mexico will depend on a regulatory update that fosters innovation and investment in technological infrastructure to address the identified challenges.

To advance the implementation of CR in Mexico, it will be crucial to address the technical and regulatory challenges mentioned above, developing policies that support innovation and ensuring that new technologies can be safely and effectively integrated into the country's telecommunications ecosystem.

CR offers significant potential to improve the efficiency of radio spectrum use in Mexico. However, to fully exploit its benefits, regulations need to adapt and evolve. Current critiques highlight the need for a more flexible, targeted and innovation-oriented regulatory framework. Adapting regulations to address these challenges can facilitate the adoption of advanced technologies and optimise spectrum use for the benefit of all users.

Implementation of the outlined guidelines can result in a significant improvement in the efficiency of spectrum use, reducing interference and increasing the capacity of wireless networks. Advances in security algorithms and techniques will contribute to reliability and protection against attacks, while the adoption of open standards and compatibility testing will promote greater interoperability between devices. At the regulatory level, flexible policies and international coordination will facilitate more effective spectrum management, allowing more equitable and efficient access to radio frequency resources.

Together, these measures will not only optimise spectrum management in Mexico, but also drive innovation in wireless telecommunications, benefiting a wide range of applications, from mobile networks to the Internet of Things (IoT).

The CR represents a significant advance in telecommunications technology, offering an innovative solution for the efficient management of radio frequency spectrum. Through its ability to adapt and learn from the environment, it promises to improve the performance of wireless networks and meet the growing demand for bandwidth.

However, for its potential to be fully realised in Mexico, it is crucial to address existing technical and regulatory challenges.

Disclosures

Conflict of interest

The authors declare that they have no conflicts of interest. The authors have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Authors' contribution

Ortega-Laurel, Carlos: Contributed to the project idea, research method and technique.

Availability of data and materials

Please indicate the availability of the data obtained in this research.

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Abbreviations

Cognitive Radio (CR, for Cognitive Radio)

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Background

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