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A RESEARCH VISION

Technological surveillance study on TV White Spaces, focused on connectivity in rural areas in Colombia

Estudio de vigilancia tecnológica sobre TV White Spaces, enfocado a la conectividad en zonas rurales en Colombia

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ABSTRACT

The development of this research is aimed at knowing the most important aspects of TV White Spaces (TVWS) technology, operation, architecture, use cases, regulation and implementations in Colombia and in various parts of the world, as a starting point for evolution. of wireless communications in the rural sector.

The first step to know the current state of technology, the technological surveillance process (TW) is adopted, of which the planning, search and capture, and analysis and organization phases are applied. In the first planning phase, it is found that there is no existing study of technological surveillance of TVWS technology in Colombia and that we make way for factors that we can achieve with this study, such as early anticipation of technological changes, minimization of associated technological risks. to innovation and to expose the early detection of opportunities and technological cooperation. Next, it exposes the existing needs in Colombia and the critical surveillance factors of the TVWS, such as the technology that reduces this gap of non-connectivity.

As a general conclusion to this entire process of technological surveillance, it is to make known and recommend the use in Colombia of the base station-client architecture with georeferenced equipment that resolves which channels are available and achieves connectivity over long distances, overcoming interference and demonstrating advantages over other wireless technologies with reference to costs, infrastructure, uses, laws and regulations. It is disclosed that MESH topologies such as some of the existing wireless technologies (Wi-Fi, LTE, 5G) can be implemented in a hybrid way with TVWS technology for rural sectors with houses far from each other, where implementation with other technologies becomes unfeasible.

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RESUMEN

La elaboración de esta investigación va dirigida a conocer los aspectos más importantes de la tecnología TV White Spaces (TVWS), como: la operación, arquitectura, casos de uso, regulación e implementaciones en Colombia y en diversas partes del mundo, tomando como punto de partida en la evolución de las comunicaciones inalámbricas en el sector rural.

Se adopta el proceso de vigilancia tecnológica (TW), aplicando las fases de planeación, búsqueda y captación, y análisis y organización, empezando con el estado actual de la tecnología TVWS. En la primera fase de planificación se encuentra que no existe en Colombia ningún estudio existente de Vigilancia Tecnológica en la tecnología TVWS y que da paso a factores que se alcanzan con este estudio tales como la anticipación temprana de cambios tecnológicos, la minimización de riesgos tecnológicos asociados a innovación y a exponer la detección temprana de oportunidades y de cooperación tecnológica.

Seguidamente se exponen las necesidades en Colombia y los factores críticos en la vigilancia de la tecnología TVWS, evidenciando que esta tecnología reduce la brecha de la no conectividad.Como conclusión general se establece que este proceso de vigilancia tecnológica da a conocer y recomienda el uso en Colombia de la arquitectura estación base–cliente con equipos georreferenciados que resuelven que canales están disponibles y logran conectividad a largas distancias superando interferencias y demostrando ventajas sobre las demás tecnologías inalámbricas con referencia al costo, infraestructura, usos, legislaciones y regulaciones. Se da a conocer que las topologías MESH como algunas de las tecnologías inalámbricas existentes (Wi-Fi, LTE, 5G) se pueden implementar de manera hibrida con la tecnología TVWS para sectores rurales con viviendas distanciadas entre sí, en donde la implementación con otras tecnologías se vuelve inviable.

1. Introduction

In the broadcast of the television signal much of the bandwidth is underutilized, to avoid interference can be assigned blank channels that are known as TV White Spaces, TVWS technology, reusing the frequencies for more efficient use of the electromagnetic spectrum. The advantage of these spaces to transmit information is based on the wavelength of the TV band that is able to cover long distances, cross different obstacles and still have a complete signal; for this reason the use of TV bands of the UHF spectrum - Ultra High Frequency, is especially aimed to meet the needs of communicating the rural sector and allow links over long distances. [1].

The general interest and duty of the State is to promote efficient access and equal opportunities for rural inhabitants. Among the obligations to be fulfilled by the ICT ministry (Ministry of Information and Communication Technologies) and the Government are to generate opportunities for the production of goods and services under equal conditions in various fields (connectivity, education, content and competitiveness). [2].

In Colombia, several TW (Technology Watch) studies were identified for technologies such as nanotechnology, smart cities and agriculture and livestock, among others; however, no TW studies were found for TVWS technology. The National Rural Connectivity Plan. [2]. The proposed goal for the year 2030 is to meet Colombia's need to connect municipalities with rural areas.

1.1. Description of the current state of the art TV White Spaces technology

TV White Spaces (TVWS) technology is known as the frequency bands that are unoccupied in the VHF and UHF spectrum, whether it is an analog or digital signal [1]. In television broadcasting to avoid interference between television channels, blank channels are assigned, which are known as "TV White Spaces", hence the idea of frequency reuse for a more efficient use of the electromagnetic spectrum in rural areas, improving the signal quality without interference. The advantage of using the television broadcast spectrum to transmit information is based on the wavelength of the television band that is able to cover long distances, pass through different obstacles and still have an integrated and complete signal; for this reason the use of UHF television spectrum bands is especially aimed at meeting the needs of communicating the rural sector and allow links over long distances. [1].

The TVWS has a great boom and acceptance in several countries to provide connectivity in areas of difficult access, to low-income populations and in favor of improving the quality of life of the population. The following are some of them.

Mawingu White Space Internet Connection Project: Microsoft and Kenyan Internet service provider Indigo Telecom Ltd and wireless technology provider Adaptrum are delivering wireless broadband access using TVWS frequencies to schools and health centers near Nanyuki, Kenya. [3].

Central African Republic: Implementation of broadband link configurations between a farmer's home Internet connections and IoT (Internet of Things) farm with sensors for smart agriculture in rural areas that need specialized monitoring to be productive. [4].

Tanzania: Local Internet provider UhuruOne, Microsoft and the commission partnered in 2013 with TVWS technology, which provides wireless Internet access to students and faculty members of the University of Dar es Salaam. [3].

Limpopo: Study conducted to document the connectivity of five schools, evaluating performance, latency and finding as a differentiating factor that despite the long distances, viable connections are achieved using dynamic spectrum management and geolocated databases. [5].

Vietnam: Using TVWS to provide mobile broadband services for rural and mountainous areas effectively, following clear regulatory guidelines in Vietnam as measures to ensure the coexistence of TV and TVWS service. [6].

India: Considerations on TVWS and analysis in each of the frequency band ranges in order to guide and based on the results make determinations on adopting the technology and express the regulatory progress that the country should have for pilot projects. In India, it is proposed to adopt the TVWS technology with a proposed approach that avoids the limiting infringement of interference in TV reception for rural areas. [7].

China: Cognitive radio as a high-value alternative for wireless communication systems leveraging TVWS as an alternative to spectrum scarcity. First studies on the shared use of TVWS together with LTE technology and TV transmission systems in the 470 to 806 MHz band range have been conducted. [8].

Ofcom / UK: Innovative white space technology in the UK, among the first of its kind in Europe. Using white spaces between waves reserved for digital terrestrial TV transmission (470 MHz to 790 MHz). [3].

A clear example of the use of TVWS in the UK is related to a feasibility study of the use of the technology for railway communications applications, with the aim of considering emerging technologies as a solution to the inefficient use of spectrum and the low propagation characteristics of the currently used technologies. [9].

United States: Use of TVWS in video surveillance systems and transmission of clinical data to Hocking County Ambulances. [10].

Jamaica: Broadband access using TVWS, which is a project proposed by the United States Agency for International Development (USAID), NetHope and technical support from Microsoft to support educational projects, libraries and rural community areas. [11].

Montevideo, Uruguay: Microsoft has obtained an experimental license from Uruguay's telecommunications regulator to establish a TVWS network. [3].

Peru: Use of unmanned stratospheric balloons to provide service in underserved rural areas in the Andean and Amazon region of Peru following aviation regulations. [12].

Argentina: Transition from analog to digital TV which creates an opportunity to close the non-connectivity gap in rural areas. They are in a stage of exploration of available channels by ENACOM and Microsoft. [11].

Ecuador: spectral census by the regulatory control agency (ARCOTEL) evaluating the use of TVWS for data and video services, security services, internet of things, data meters and smart city applications. [11].

Implementations in Colombia

The National Spectrum Agency (ANE) through three pilot projects in Colombia implemented in 2016 the TV White Spaces technology in the following rural areas. [13]:

Pilot Aguadas - Caldas: Rioarriba Educational Institution (Vereda Rioarriba), number of students: 137, Link distance: 8.5km.

Pilot Pamplonita - Norte de Santander: Educational Institution Sede El Paramo (Pamplonita), number of students: 64, Link distance: 4km.

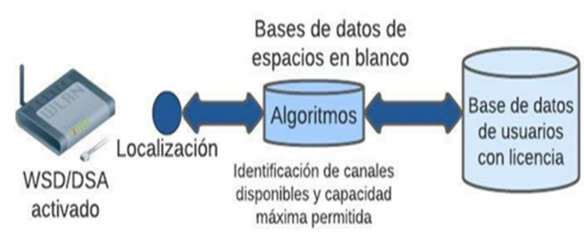
Pilot Dibulla - La Guajira: Educational Institution Punta de los Remedios, number of students: 56, Link distance: 5.5km. [13].

On the other hand, the Makaia Foundation, in October 2017 implemented and established connectivity of 5 coffee farms and 2 educational institutions in Mesetas-Meta, where the project "Technological Transformation: Improving the lives of coffee farmers in Colombia" was developed, demonstrated the need for a stage in the project that included the installation and adaptation of technology to provide internet access to farms and educational institutions in the area. [14].

1.2. TVWS operation

The model approved by the Federal Communications Commission (FCC) in the USA, grants access to clients in TVWS technology based on the enabling of a geolocalized database White Spaces Devices (WSD), is the one currently used in Colombia and regulated by the ANE. [15]. It is granted in the form of an established power and frequency band, based on its geographic location and other characteristic parameters of each WSD. [16].

Figure 1: TVWS database access method. [16].



The recommended architecture for a broadband system using TVWS frequencies requires. [17]:

- Centralized base station: Connected to a high-speed Internet backbone and a transmitting antenna 50 meters high that knows the location of the receiving antenna in advance.
- Client device: Antenna connected at the customer's location for service reception.
- Central database service: It is responsible for displaying TV channels available at the location of the implementation of this architecture, which depends on its geolocation.
- Network management equipment to configure and control the equipment connected to the TVWS infrastructure.

Using this type of architecture, any Internet Service Provider (ISP) could provide broadband access to the Internet. [3].

1.3. Technology Watch-TW

Technology Watch - TW is defined as a method of systematic provision and analysis of data from which forecasts can be made. Surveillance constitutes an active approach that provides the situation and possible trend at every moment that an innovation is generated [18].

The main advantage of the TW is to identify new market needs and the improvement of existing technologies. The TW provides information for the application and creation of new technologies and the evaluation of their impact in different environments, as in the case of communications in the rural sector. [19].

2. Technology Watch Phases

The TW requires the development of five phases: planning, search and capture, analysis and organization, and intelligence and communication. In the planning phase, needs are identified and the critical factors to be monitored are determined; in the search and capture phase, observation, discovery, detection and collection are developed; in the analysis and organization phase, the information related to TVWS is processed and stored; in the intelligence phase, the added value is given to the information; and finally, in the communication phase, the information is disseminated and the knowledge transferred. [20]-[22].

In the analysis phase, a study of the analysis of articles, patents, scientometric analysis, SWOT-CAME analysis, competitor profile analysis and competitiveness matrix is carried out. From the study of the analysis of articles and patents, we continue with the scientometric analysis that allows, by means of software tools, to organize and analyze publications, groups, institutions, countries, patents, authors and scientific production, allowing immediacy indicators. [20]-[22].

2.1 Identification of needs

Among the most notable needs in Colombia is technological inequality; in rural areas very few people have access to study, work or research work in the countryside. The government proposes in the **National Rural Connectivity Plan (2019)** as a main objective to contribute to the improvement of the quality of life giving two main pillars to achieve it.

- Promote access to information in all municipalities through high-speed networks.

Figure 2. TVWS architecture [3].

- Stimulate the use of the Internet in public community access for those who have neither the technological tool nor the connection. [2].

DANE [23] conducted a diagnostic survey where they defined percentages explaining the causes of not having access to the Internet, stated below:

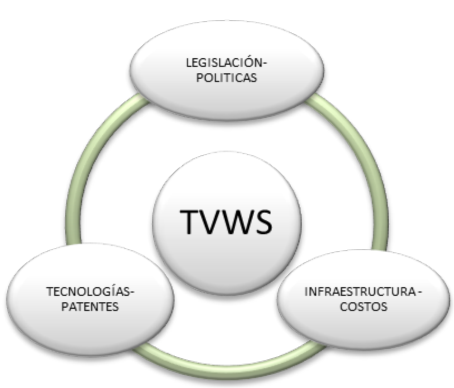
- High cost 49%
- Do not consider it necessary 37%
- Not having a device to connect 7%
- Not knowing how to use the Internet 5%
- No coverage 5%

Having identified the problems in Colombia in the literature review for real access to information, the critical monitoring factors were defined, proposing the study of TVWS technology, to know its current status, examine uses, types of connection, infrastructure and coverage for connectivity in the rural sector in Colombia.

2.2. Critical surveillance factors

Once defined the main need of this study, propose the TVWS surveillance study to know the current status of this technology in rural environments in Colombia. Standard UNE 166.002 [24]. The first phase of the study is the identification of the critical surveillance factors (FCV) in which will revolve around the surveillance of TVWS:

Figure 3: **Critical factors of TVWS technology.**



Identifying each of these FCVs, we start from them as a basis for a concise and truthful search, which identifies whether this technology can meet the needs of connectivity in rural areas in Colombia, technification of agricultural processes, inclusion in digital literacy and improvement of the quality of life of the farmer.

Each critical factor is comprised of information collected and will be discussed below:

- Infrastructure/Costs: Physical elements used to achieve connectivity in the rural sector and operating costs.
- Technologies/Patents: Wireless technology implementations and standards bodies and companies developing technological innovations involving TVWS.
- Legislation/Policies: Implementation standards, control bodies and sectors involved in TVWS.

2.3. Search and recruiting

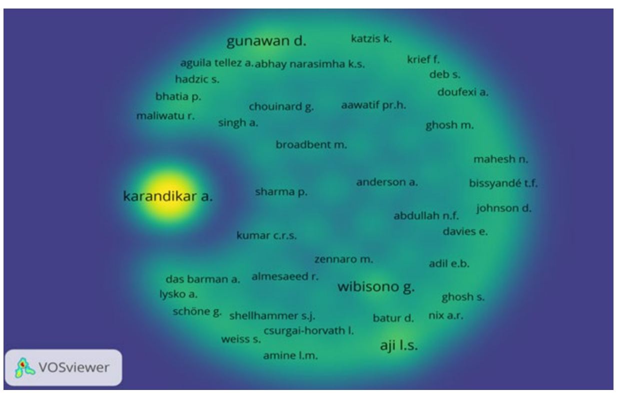
Different search equations are obtained that were executed with different search engines (Google, GoogleScholar, Carroy2, Yippy, etc.) and online libraries such as Scopus and IEEE, among others, additionally patents of the TVWS technology are listed. The steps to elaborate this search are carried out according to the Sánchez-Torres methodology [20]-[22]. The steps of a medium level and performing a structured search. Finally, the results are presented, which should provide answers to the questions based on the critical factors of FCV surveillance (legislation, policies, technologies, patents, infrastructure and costs), projecting TVWS technology as a feasible option for rural connectivity.

2.4. Analysis and organization

Once the search log is completed, an information corpus is developed. The analysis process of this study is carried out in several phases, which were developed as follows:

- Analysis of articles and patents (detailed reading of patents, extraction of information), taking into account the scientometric analysis in the VOSviewer software, where the concurrence of terms (authors, countries, common themes) is analyzed.
- Scientometric analysis, SWOT-CAME analysis, competitor profile and competitiveness matrix.
- Associate items with each of the FCVs defined in the planning phase.

Figure 4: Author analysis in VOSviewer software.



2.5. Recommendations for the use of TVWS in rural areas in Colombia according to the established phases

All regulatory bodies, associations and ministries in the Americas, Europe, Africa and Asia seek to plan efficiently the use of spectrum and in the case of TVWS technology, the development of a regulatory framework at country level, with the licensing of unlicensed spectrum. Users and service providers should agree on their role and responsibilities in the use of TVWS technology.

Involve ISPs in the adoption of TVWS technology in the services offered to customers. Not only internet service ISPs should be involved in spectrum innovation and management, but also mobile ISPs that can adopt scalable hybrid topologies with 5G or LTE, adopting minimum energy efficiency parameters.

The ANE, as a central axis, should support universities in the development, research and use of low-cost devices and achieve the connection with TVWS technology. To provide internet access in the last mile, the use of MESH (Mesh Network) topology is recommended, with the objective of reaching populations with homes at distant distances.

In response to the call of the ANE, where one of its strategies includes the spectrum public policy 2020, integration in spectrum management and flexibilization mechanisms, the conditions for the adoption of an assignment scheme are listed:

- Band E (71-76 GHz, 81-86 GHz) - ANE 450 of 2017.

- Reduction of consideration for point-to-point links - Resolution MinTic 1824 of 2018.

Research on the efficient use of spectrum and in the case of ANE to disable analog channels to avoid future interference with TVWS technology, should ensure the technical compatibility of adjacent devices and propose projects that can bridge the gap of technological inequality and bring connectivity to rural environments.

According to the SWOT-CAME analysis, which analyzes two external aspects (threats and opportunities) and two internal aspects (weaknesses and strengths), it is recommended:

- To reaffirm and maintain the strengths of TW's study in the direction of technology for rural connectivity projects that allow the use of combined architectures (LTE, 5G, C-RAN, TVWS) with Mesh topology for last mile access, without forgetting alternative energies to reduce energy costs.

Table 1. SWOT-CAME Matrix.

	Weaknesses/Corrections	Strengths/Maintain
Internal analysis	• It is necessary to develop projects that encourage the construction of low-cost TVWS devices that allow a feasibility of implementation in rural areas. • Development of combined methods of technologies to provide security and reliability in TVWS connectivity.	• Rural connectivity projects that allow the use of combined architectures (LTE, 5G, C-RAN and TVWS), and the use of Mesh topology for last mile access and that demonstrate low energy consumption supported by alternative energies.
	Threats/Confronting	**Opportunities/Exploit**
External analysis	• Working together with spectrum regulators and network device developers to include TVWS compatibility and eventually enable the licensing of TVWS mobile devices that bring better benefits to rural areas.	• TVWS connectivity with emerging technologies that can enable the development of rural areas such as: 1. IoT in the field. 2. Mesh networks for the creation of educational content networks. 3. Early warning and emergency systems. 4. Rural last mile connection alternatives. 5. Better reception cellular networks with combined technologies.

Source: Own.

- To exploit the opportunities of TVWS applicability with IoT and Mesh networks in the creation of educational content networks, in alert and emergency systems and in the improvement of cellular network reception, as a last mile TVWS alternative in rural areas. Correction of weaknesses with the development of projects that have a clear focus on the construction of low-cost devices for TVWS connectivity allowing lower implementation costs in rural areas.

- Addressing SWOT-CAME threats, which can be overcome with the teamwork of regulators and network equipment developers in order to generate compatibility with existing technologies and their regulation.

3. Conclusions

Through the tools in the exercise of TW technology watch, these have provided an overview of the current status of TVWS technology in Colombia and the world. Based on this overview, the various benefits in spectrum management and adherence to regulations in Colombia with the ANE are found.

The work done by government agencies with broadband has proven its benefits to the country's economy and with the help of these emerging TVWS technologies, it could bridge the technology gap and bring reliable connectivity to remote and hard-to-reach places.

The most widely used and recommended method of operation in Colombia is TVWS, which provides a method of access to databases of available channels that are generated by georeference and allow reliable connectivity without interference.

TVWS technology is prepared to work in WI-FI networks, in M2M usage modes, as mobile network coverage extenders and the most widely used due to the large amount of white spaces available in rural broadband TVWS.

In Colombia, pilots were achieved in several areas of the country to interconnect farms and rural schools in the departments of Meta, Guajira, Santander and Caldas between 2016-2018, which serve as a basis for expanding the different fields of action that benefit the Colombian countryside.

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