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Introduction of 5G Mobile Network in Colombia

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ABSTRACT

The implementation of the 5G mobile network is experiencing significant growth globally, providing commercially accessible services that enhance network performance metrics by reducing network latency in countries such as the USA, China, and Korea. Nevertheless, numerous countries worldwide are still in the experimental phase, endorsed and regulated by governmental bodies. Colombia is one such country where the allocation of the initial 5G spectrum is anticipated in the third quarter of 2021. By scrutinizing the outcomes of the trial phase and following the roadmap outlined by the Ministry of Information and Communication Technologies (MinTIC) in Colombia, we aim to identify key aspects influencing the deployment of 5G mobile technology and the strategies for transitioning from 4G networks to a stand-alone 5G network. This analysis holds relevance for other countries in Latin America and beyond. Consequently, our objective is to condense and disseminate crucial concepts of 5G mobile technology, including massive MIMO (multiple input/multiple output) antennas, RAN (Radio Access Network), C-RAN (Centralized-RAN), and frequency bands. We also assess the current status of its implementation in Colombia.

Keywords: *5G; extensive MIMO; 5G Colombia; O-RAN; 5G Latin America*

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Introducción de la Red Móvil 5G en Colombia

RESUMEN

La implementación de la red móvil 5G está experimentando un crecimiento significativo a nivel mundial, brindando servicios comercialmente accesibles que mejoran las métricas de rendimiento de la red al reducir la latencia en países como Estados Unidos, China y Corea. Sin embargo, numerosos países en todo el mundo aún se encuentran en la fase experimental, respaldada y regulada por entidades gubernamentales. Colombia es uno de esos países donde se espera la asignación del espectro inicial de 5G en el tercer trimestre de 2021. Al examinar los resultados de la fase de prueba y siguiendo la hoja de ruta delineada por el Ministerio de Tecnologías de la Información y Comunicaciones (MinTIC) en Colombia, buscamos identificar aspectos clave que influyen en la implementación de la tecnología móvil 5G y las estrategias para hacer la transición de las redes 4G a una red 5G independiente. Este análisis es relevante para otros países en América Latina y más allá. En consecuencia, nuestro objetivo es condensar y difundir conceptos cruciales de la tecnología móvil 5G, incluidas las antenas MIMO masivas (entrada/salida múltiple), la red de acceso por radio (RAN), la RAN centralizada (C-RAN) y las bandas de frecuencia. También evaluamos el estado actual de su implementación en Colombia.

Palabras clave: *5G; MIMO extenso; 5G Colombia; O-RAN; 5G América Latina*

INTRODUCTION

In recent years, the escalating surge in communication data volume has pushed the limits of existing 4G mobile communication systems. Projections indicate that wireless data traffic will surpass 131 exabytes per month by the close of 2024, with over 90% originating from cell phones. The advent of fifth-generation (5G) mobile networks signifies a substantial enhancement in network performance, ranging from 100× to 1000× compared to current technologies [1]. This improvement is achieved through heightened spectral efficiency, facilitating extensive connectivity, elevated transmission speeds, reduced latency, and decreased energy consumption [2]. 5G enables cloud-based applications, fostering the growth of technologies like virtual reality (VR), smart cities, and autonomous vehicle applications, adapting to the evolving landscape of the Internet of Things (IoT) and machine-to-machine (M2M) communication [3–6]. Simultaneously, software-driven network integration (SDN) and network functions virtualization (NFV) are recognized as effective solutions in optimizing the functionality of 5G networks with high scalability. Operating on a cloud-based architecture, they leverage the 5G core network architecture (5G-CN) model to provide versatile network traffic management through a distributed multi-controller structure that delivers a broad spectrum of services [7].

Our objective is to delineate the correlation between the 5G mobile network and multiple input/multiple output (MIMO) systems, millimeter-wave (mm-W) technology, frequencies ranging from 30 GHz to 300 GHz, and the Sub-6 GHz bands. We aim to expound on their principal advantages, challenges, and the supporting technology enabling higher data transfer rates compared to preceding 4G-based mobile networks. The source material for comprehending this topic was derived from a systematic search and review of the Scopus database. Additionally, information has been curated from official websites and documents of entities such as the Colombian Ministry of Information and Communication Technologies, the National Spectrum Agency of Colombia (ANE), the Global System for Mobile Communications (GSM Association), the Global mobile Suppliers Association (GSA), and mobile operators responsible for managing 5G mobile networks. Government resolutions have been incorporated to elucidate the steps undertaken by the Colombian government in implementing the 5G mobile telephone network and the present status of its deployment in Colombia.

Background

In the impending era of 5G mobile communication, designs for antennas in mobile terminals and base stations are being developed to accommodate higher transmission speeds, lower latency, and increased access speeds, presenting distinct advantages over 4G networks [8] and their predecessors (Table 1).

Table 1. Progression of mobile networks

	1G	2G	3G	4G	5G
Approximate date of implementation	1980s	1990s	2000s	2010s	2020s
Theoretical download speed	2 kbps	384 kbps	56 Mbps	1 Gbps	10 Gbps
Latency	N/A	629 ms	212 ms	60–98 ms	<1 ms

In the foreseeable future, the cumulative data rate in 5G wireless communication systems is anticipated to be 1000 times faster than 4G, accompanied by heightened wireless link reliability. A pivotal factor contributing to this achievement is the utilization of MIMO antennas. Unlike the preceding 2G, 3G, and 4G systems, which employed 2 and 4 element MIMO antennas in mobile terminals, the 5G system necessitates a more extensive array of MIMO antenna elements to meet the projected speed expectations [9].

The 5G new radius (NR) systems are founded on OFDM (Orthogonal Frequency Division Multiplexing) modulation, with each sub-carrier modulated using binary phase shift keying (PSK) schemes such as quadrature PSK (QPSK), 16-quadrature (16-QAM), 64-QAM, or 256-QAM amplitude modulation [10]. Furthermore, the adaptability of 5G NR enables support for multiple subcarrier separations, ranging from 15 to 240 kHz, contingent on the deployment scenario and application [11]. The initial 5G standard launch by 3GPP (3rd Generation Partnership Project) specifies three distinct usage scenarios based on applications: (i) massive machine type communications (mMTC), designed to connect one million devices per square kilometer, facilitating the development of smart homes, smart buildings, and smart cities; (ii) enhanced mobile broadband (eMBB) featuring maximum download speeds of 10 Gbps and a reliable user experience data rate of 100 Mbps in urban areas, with a user plane latency of 4 ms; and (iii) ultra-reliable low-latency communications (URLCC) ensuring less than 1 ms latency, very high availability/reliability, and security for supporting services like autonomous vehicles and mobile healthcare [12]. The summary of typical 5G application scenarios is outlined in Table 2, and Figure 1 illustrates these scenarios, including massive machine type communications (mMTC), enhanced mobile broadband (eMBB), and ultra-reliable and low-latency communications (uRLLC) [13,14].

Table 2. Common Application Scenarios for 5G Mobile Technology

Massive Machine Type Communications (mMTC)	Enhanced Mobile Broadband (eMBB)	Ultra-Reliable, Low-Latency Communications (URLLC)
IoT, asset tracking, smart agriculture, smart cities, energy control, smart homes, and remote monitoring.	Better quality broadband for both indoor and outdoor use, virtual, and augmented reality.	Autonomous vehicles, intelligent electrical networks, remote patient monitoring, and telehealth and industrial automation services.

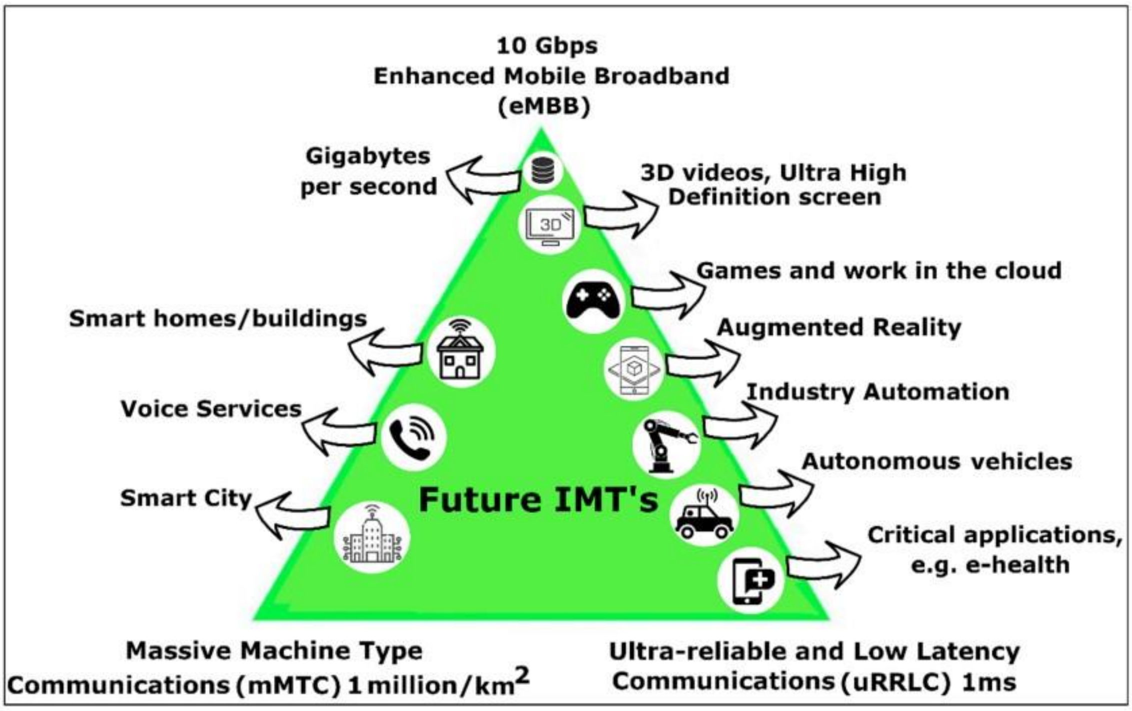

Figure 1. Anticipated Future of International Mobile Telecommunications (IMT) illustrating typical application scenarios for 5G communication technology [15,16].

Frequency Bands in 5G

One of the spectrum bands utilized for 5G network coverage is the Sub-6 GHz, employing macro cell bases for nationwide deployment, striking a balance between high transmission rates and low-latency for end-users [11,17]. The Sub-6 GHz band encompasses primarily the long-term evolution (LTE) bands 42, 43 (3.3~3.8 GHz), and 46 (5150–5925 MHz) [18,19]. The wavelength at 3500 MHz is 86 mm in free space, favoring the deployment of multiple antennas on mobile terminals [20].

Frequency bands within Sub-6 GHz are heavily populated and possess limited available bandwidth. Consequently, to meet the demands of 5G for high-performance data transfer and ultra-high-speed mobile broadband, several mm-W frequency bands have been proposed and authorized in most developed countries, including (24 GHz to 29.5 GHz), (37 GHz to 42.5 GHz), (47.2 GHz to 48.2 GHz), and (64 to 71 GHz) [21], with 57 to 66 GHz not necessitating a global license [12]. A key challenge in using mm-W in 5G is the design of low-cost, energy-efficient, high-gain broadband antennas capable of overcoming propagation losses [22]. Antennas operating at mm-W are primarily positioned along the side edge of the mobile device [23].

Advantages and Disadvantages in Frequency Bands mm-W and Sub-6 GHz in 5G

Millimeter waves (mm-W) enable high bandwidth [12], achieving a low-latency and high data rate network [1]. However, a significant drawback is their limited range without a line of sight (NLOS), poor diffraction capability, surface wave loss, metallic losses [24], and path loss due to the high frequency and short wavelength making them susceptible to atmospheric absorption, body absorption, and environmental blockage, such as raindrops, snow, and sand [1,6]. Implementing dense networks of small cells with numerous antennas (MIMO) is considered to counteract the effects of the mm-W channel [25] by enhancing coverage capacity through spatial multiplexing. Small cells, having reduced effective coverage, can be multiplied in a given area, thereby increasing the number of connected devices and enhancing data speeds per user. Nevertheless, small cells encounter challenges in supporting multiple operators and accommodating various services, such as 3G, LTE, 5G, etc., with each mobile operator needing to implement and manage its individual base station [12]. Table 3 summarizes the advantages and disadvantages of the frequency bands in 5G.

Table 3. Pros and Cons in 5G Spectrum Bands [26]

Band Frequency	Advantage	Disadvantage
<1 GHz	Greater coverage than higher frequencies (1 GHz–6 GHz), (mm-W bands up to 66 GHz)	Lower channel capacity than other frequencies (1 GHz–6 GHz), (mm-W bands up to 66 GHz)
1 GHz–6 GHz	Balanced combination of coverage and channel capacity for 5G services drives the first wave of 5G deployments	There are other mobile bands in the 1 to 6 GHz range, currently used for 3G and 4G services, which could be gradually reallocated for their use in 5G.
>6 GHz	Lower coverage than other frequencies (1 GHz–6 GHz) and (mm-W bands up to 66 GHz) Supports ultra-fast mobile broadband speeds envisioned for 5G technology Will include unlicensed mobile bands	Higher data rate than other frequencies (1 GHz–6 GHz), (mm-W bands up to 66 GHz)

Modern wireless communication systems are confronted with the challenge of accommodating an increasing number of subscribers concurrently demanding services. This trend underscores the widespread adoption of multiple input/multiple output (MIMO) systems, which play a pivotal role in enhancing data rates, expanding service coverage, and ensuring communication reliability without the necessity of additional radio frequencies [17]. Essentially, MIMO technology utilizes the multipath phenomenon, where data are received at the receiver with distinct time delays, to maximize channel capacity by minimizing envelope cross-correlation (ECC) between different antennas [23]. By employing MIMO technology, wireless systems can achieve multiple independent channels within the original spectrum through the diversity method, leading to a reduction in multipath fading and an improvement in data rates [27]. In essence, MIMO systems, featuring multiple antenna units on both the transmitter and receiver sides, leverage multipath components to enhance the overall performance of wireless communication systems.

Achieving desirable isolation for each antenna element within a compact size at future 5G terminals poses a formidable challenge. The mutual coupling of adjacent antennas, particularly in dual-band arrays, presents a pressing obstacle to overcome [28,29].

Comparison of MIMO in 5G vs. 4G

While 2 × 2 MIMO systems have proven successful in 4G mobile networks, the evolution to 5G communications necessitates the addition of a substantial number of antenna elements. Recent proposals for 5G MIMO smartphones include various types of antennas. For smartphones operating with several 5G MIMO antennas at frequencies Sub-6 GHz, the challenge lies in accommodating these antennas within a limited size environment and ensuring coexistence with frequency antennas used by previous generations. The typical scheme for 5G MIMO smartphone antennas involves incorporating four or eight antenna elements in separate regions of the antenna, where isolation is maintained by the distance between elements, resulting in low mutual coupling on unrelated channels. This task is particularly challenging for space-limited smartphones. As an illustration, the locations for the 3500 MHz 5G band antenna on mobile devices are typically along the two long edges of the chassis ground, given that 4G services, such as Long Term Evolution (LTE) and GSM 850/900, usually occupy space along the short edges. For instance, the primary antenna size for some 4G services is 45 × 15 mm, while the auxiliary antenna size for 5G is 19 × 15 mm [27,30].

MIMO and 5G

Given the valuable and limited nature of spectrum resources, the fifth generation of mobile communications, commonly referred to as 5G new radio (NR), seeks to enhance spectrum efficiency by increasing communication channel capacity. This improvement heavily relies on the integration of MIMO antennas in mobile terminals, showcasing multipath propagation with heightened data rates and link reliability—two pivotal features of 5G. MIMO, employing multiple transmitting and receiving antennas, constructs substantial information flows, thereby enhancing channel capacity with the benefits of high data rates and performance within the Gigabit/sec range. Importantly, this is achieved without the need for increased power, bandwidth expenditure, or additional retransmission devices, all while operating at frequencies of Sub-6 GHz [31]. Conversely, MIMO antennas demonstrate optimal performance when fully capitalizing on a rich dispersion environment. Numerous studies indicate that MIMO antennas at relay nodes play a vital role in 5G by extending coverage at cell edges and catering to indoor applications, even though they necessitate high bandwidth and high gain to mitigate atmospheric disturbances at millimeter frequencies [4,10,18].

Massive MIMO and 5G

The advent of the 5G network aims to facilitate the proliferation of applications relying on artificial intelligence and mobile computing, necessitating higher wireless data speeds. In 5G NR, this objective is realized through the adoption of massive MIMO and carrier aggregation (CA) with a wide channel bandwidth (BW) of up to 200 MHz [32]. Building on the traditional MIMO concept, massive MIMO takes it a step further by transitioning from tens to hundreds or even thousands of antennas at the base station (BS), serving a large number of autonomous terminals. This evolution is geared toward enhancing antenna gains through precise narrow beam-forming techniques, facilitated by accurate channel status information (CSI) [5]. As a wireless physical layer technology, massive MIMO bestows interference robustness, low latency, and security [3], while improving power output and system spectral efficiency [5]. Through spatial multiplexing, it ensures uniform quality of service in diverse environments, particularly in urban and suburban areas, thereby complementing or potentially replacing the densification process of the ultra-network [25]. This technology proves adept at supporting a large number of users [34] and exhibits compatibility with mm-W communications, where antenna gains offset the inherent propagation loss in the Very High Frequency (VHF) band [6]. Massive MIMO deployment at base stations can assume co-located or distributed configurations. Co-located massive MIMO concentrates all antennas in a compact area, boasting the advantage of low backhaul requirements. In contrast, distributed massive MIMO systems distribute antennas over a larger area, offering a significantly higher coverage probability than co-located massive MIMO (mMIMO) at the expense of increased backhaul requirements [35]. While the ideal bands for mMIMO are in the millimeter range (frequencies from 30 GHz upwards) [36], the Ministry of Information and Communication Technologies (MinTIC) currently plans to auction only up to the 3.5 GHz band [37].

Radio Access Network (RAN) in 5G

The predominant radio access network (RAN) architectures deployed for 5G include the C-RAN (centralized, clean, cloud, and collaborative RAN) and the distributed RAN (D-RAN), with the latter being the conventional deployment widely used in current mobile networks [38–40].

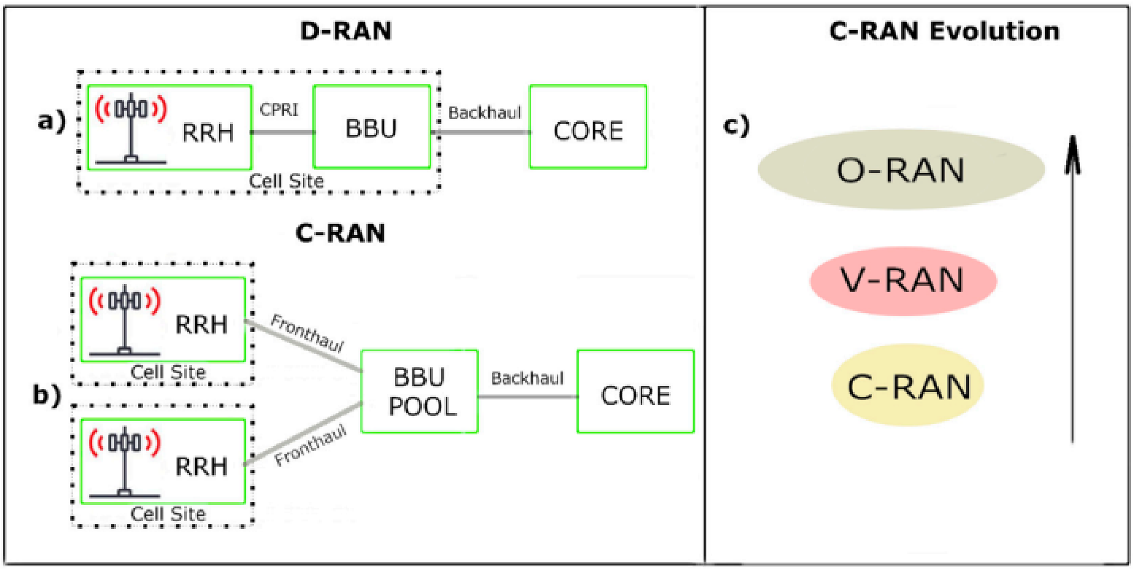

Figure 2 illustrates the schematic representation of different radio access network (RAN) architectures: (a) Distributed-Radio Access Network (D-RAN) architecture, (b) Centralized Radio Access Network (C-RAN) architecture, and (c) C-RAN evolution to V-RAN and O-RAN.

In the realm of C-RAN, as envisioned by the China Mobile Research Institute, a considerable portion of RAN functionalities is centralized within a resource pool housing Baseband Units (BBUs). This C-RAN approach splits the Base Station (BS) into BBUs and remote radio heads, relocating the BBU to a high-performance datacenter equipped with Digital Signal Processors (DSPs). The fronthaul transport network connects the BBU to the Remote Radio Heads (RRHs) using high-bandwidth optical fibers. The RRH, containing the local oscillator, converts the digital signal into an analog signal for transmission (refer to Figure 2b).

The C-RAN concept has evolved into Virtual RAN (V-RAN) and Open RAN (O-RAN) [45]. V-RAN involves virtualizing BBUs as vBBUs deployed on multiple Network Functions Virtualization (NFV) platforms using standard x86 hardware. These vBBUs are grouped in centralized data centers, while RRHs remain situated at their respective base stations. O-RAN, a key element of which is V-RAN, emphasizes openness through standardized and open interfaces. It also leverages intelligence, employing artificial intelligence and machine learning to automate operational network functions [45,48] (refer to Figure 2c).

5G Deployment Architecture Options from LTE (4G)

The deployment of the 5G mobile network from LTE (4G) encompasses two approaches: StandAlone (SA) and Non-StandAlone (NSA). The SA architecture involves 5G radio access without interacting with an existing 4G core. In contrast, NSA architectures provide 5G built over an existing 4G network. Service providers aiming to implement 5G speeds swiftly commence with NSA 5G networks, leveraging existing 4G infrastructure to amortize the 4G core networks. Once widespread 5G coverage is established, StandAlone 5G is implemented [49].

The NSA option 3 family, which doesn't necessitate the 5G Core, supports dual connectivity for legacy 4G devices and 5G devices [50,51]. This option facilitates wireless connectivity between the 5G base station (gNB) and the 4G base station (eNB) with the user equipment (UE). It comprises a master node (eNB), a secondary node (gNB), and a connection to the 4G Core (Evolved Packet Core—EPC) [51,53]. Control plane Option 3x involves the eNB being connected to the EPC, and the gNB collaborates with the eNB. In terms of user plane traffic, EPC can transmit/receive it from/to both the eNB and the gNB. The gNB can direct the received user plane traffic wirelessly to the UE directly or indirectly through the eNB [51].

5G Network Mobile Deployment in Colombia

Colombia adopts a technology neutrality scheme, indicating that while the spectrum orientation is for specific services, the government doesn't specify the type of technology to be used (4G or 5G). To enhance service quality, the government aims to acquire more spectrum, as it currently possesses only 30% of the spectrum recommended by the Organization for Economic Cooperation and Development (OECD). Consequently, the government's current effort prioritizes the spectrum auction to connect 70% of Colombians by 2022 and usher Colombia into the era of 5G.

The schedule delineated by the Ministry of Information and Communication Technologies (MinTIC) for the initial quarter of 2019 and the third quarter of 2021 is presented in Table 4, as per the details provided in Reference [54]. In the fourth quarter of 2019 (Q4-2019), MinTIC formulated and released the blueprint for the integration of 5G technology. Moving to the second quarter of 2020 (Q2-2020), the identification of frequency bands and spectrum requirements for 5G was undertaken. By the third quarter of 2020 (Q3-2020), MinTIC will actively encourage the development of 5G applications. Regulatory adjustments are slated for the concluding quarter of 2020 (Q4-2020). Following this, in the second quarter of 2021 (Q2-2021), the National Spectrum Agency (ANE) and MinTIC will embark on the regulatory framework for the designated frequency bands.

Table 4. MinTIC's Schedule for 5G Implementation in Colombia [37]

Development and Publication of the 5G Plan	ANE -MinTIC	ANE-MinTIC	Communications Regulation Commission (CRC)	Analysis of Frequency Band Management Mechanisms	MinTIC
Q4-2019	Q2-2020	Q3-2020	Q4-2020	Q2-2021	Q3-2021
MinTIC	- Identify radio spectrum requirements in accordance with the World Radiocommunication Conference (WRC-19) - Frequency Release Resolution	Call for the development of applications or use cases in 5G technology	Consult regulatory adjustment needs	ANE-MinTIC	3500 MHz band allocation.

Leveraging the capabilities of 5G technology and conforming to the International Mobile Telecommunications standard 2020 (IMT-2020), Colombia anticipates enhancing its wireless infrastructure to integrate with global society. This initiative aims to create new Information and Communication Technologies (ICT) markets, bridging the digital divide, and fostering innovative communication methods for content sharing across diverse devices and locations. The implementation of 5G is poised to revolutionize education by facilitating access to digital textbooks stored in the cloud, encouraging applications in e-learning, e-health, and e-commerce. Furthermore, it is expected to boost energy efficiency across various economic sectors, supporting machine-to-machine communications in smart grid solutions, as well as applications in video conferencing, logistics, and intelligent transport.

5G Pilot Tests in Colombia

The electromagnetic spectrum, considered a natural resource and public asset in Colombia, is subject to regulations and laws ensuring equitable access and preventing monopolies, thereby encouraging technological development and investment. In this context, a resolution [58] was enacted to announce the initiation of pilot tests for 5G technology. This initiative aims to gather preliminary information and assess potential challenges under real-world conditions. A total of 76 expressions of interest were received, involving more than 52 entities and 24 individuals.

Figure 3 provides a breakdown of the frequency bands requested during the call. Notably, the 3.3 GHz–3.7 GHz band attracted the highest number of interested parties (27) for configuring future 5G services in Colombia. Additionally, there were 56 applications for millimeter-wave (mm-W) bands, reflecting the intention to offer 5G technology services requiring high bandwidth, low latency, and increased data rates. Given mm-W's ample bandwidth, it has the capacity to accommodate numerous connected devices in a 5G deployment, promising not only greater speed but also enhanced quality of service.

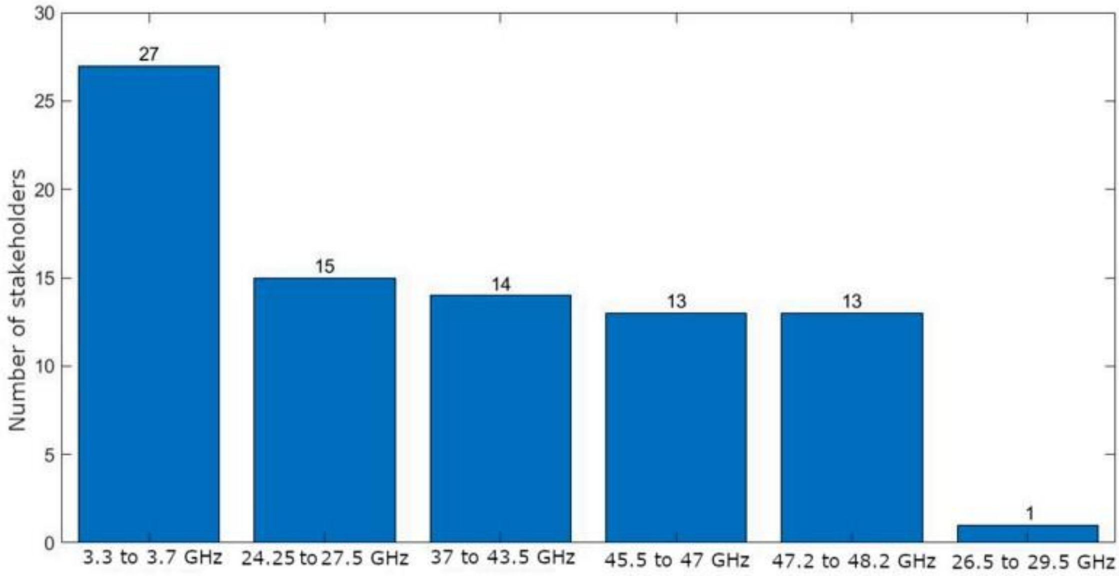

Figure 3. Distribution of stakeholders across frequency bands [58]

Licenses for the utilization of radio spectrum were issued for technical tests or equipment approval, valid for an initial 6-month period, with the option to extend for an additional 6 months.

The 5G mobile technology pilot tests in Colombia provide MinTIC, ANE, and CRC (Communications Regulation Commission) with valuable insights into aspects related to the effective utilization of frequencies for deploying 5G networks and services. These tests serve as a reference for potential measures associated with the implementation of these networks. Notably, the permits for 5G pilot tests are non-commercial in nature, adhering to the principle of non-interference and posing no risk to critical communications, including aeronautical radio navigation, radio astronomy, search and rescue operations, and mobile communications, among others. The resolution [59] outlined the schedule for requesting permits for pilot tests and establishing test environments for 5G mobile technology and use cases within specific frequency bands: 3.3–3.7 GHz, 24.25–27.5 GHz, 37–43.5 GHz, 45.5–47 GHz, and 47.2–48.2 GHz [56]. However, these dates were adjusted (see Table 5) due to the impact of the COVID-19 pandemic, as specified in the resolution [60].

Table 5. Timeline for the 5G network pilot testing procedure in Colombia

Activity	Date
Opening of the call process	As of the issuance of this resolution
Closing reception of applications	29 May 2020
Evaluation of applications, frequency studies, and requests for clarification	1 to 12 June 2020
Publication of the evaluation report on applications submitted	19 June 2020
Issuance of resolutions to grant permission to use the radio spectrum for 5G technical tests	23 to 30 June 2020
Publication of the assignment report	1 July 2020

Figure 4 illustrates the count of organizations involved in upcoming projects related to 5G that participated in the initiative. Smart Cities exhibited the greatest interest. A smart city is fundamentally a connected city, envisioning unrestricted connectivity for both objects and individuals, with 5G serving as the foundational standard for efficient management of security, transportation, or healthcare resources, thereby enhancing citizens' quality of life in terms of the economy, service accessibility, and territorial sustainability.

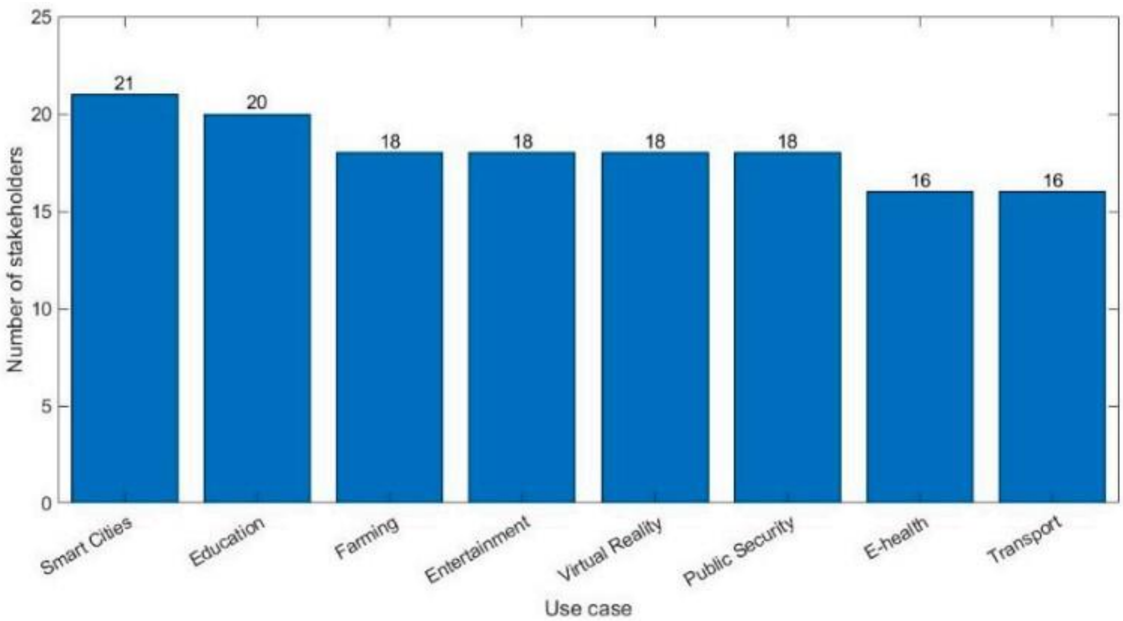

Figure 4 depicts the quantity of stakeholders associated with various use cases [58]

The licensed duration for the 3.5 GHz band is set at 20 years, with the possibility of extension for an additional 20 years [61]. Simultaneously, MinTIC is concentrating on the transition from 2G and 3G networks to 4G [62], extending coverage to 3658 locations across Colombia's 32 departments.

Moreover, MinTIC is advancing in 5G trials by authorizing six companies to conduct 42 pilot tests in Bogotá, Medellín, Cali, Barrancabermeja, and Tolú [63], conducting tests for mobile phone networks in the 3500–3600 MHz frequency range [64]. Concerning 5G pilot trials, the telecommunications operator Movistar conducted a trial at the Central Military Hospital in Bogotá, supporting ICU-COVID-19 patient care through videoconferencing equipment and rooms for medical remote consultations backed by a medical trolley and tele-triage. In this trial, they achieved a latency of less than 10 milliseconds and provided a throughput of 1.62 Gbps downlink (DL) and 176 Mbps uplink (UL) with an outdoor node in the 3.5 GHz band, along with a 5G Core [65,66]. The mobile operator Claro, in its private 5G network trial in the 3.5 GHz band at the Plaza Claro shopping centre in Bogotá, achieved throughputs of up to 864 Mbps in download and 103 Mbps in upload [67–69], utilizing the 3X scenario of the model 3GPP 5G Non-StandAlone [70]. Regarding the millimeter band, in January 2018, the company Claro demonstrated in Colombia in the 28 GHz band, reaching throughputs of 10 Gbps and latencies of less than 1 millisecond within the controlled environment of a laboratory [71]. In July of the same year, the telecommunications operator Telefonica and Ericsson achieved throughputs between 27 and 31 Gbps with latencies of 5 ms in the 28 GHz band at Ericsson's facilities in Bogotá [54,72,73]. Concerning the millimeter bands in Colombia, they are anticipated to be available for 5G use from 2027 (refer to Table 6), aligning with the experiences of other countries in the Latin American region. For example, Ericsson's 5G network deployments, operating in the 28 GHz mm-W band with beamforming functionalities in base station antennas, attain coverage of 300–400 m^2 in urban areas and up to 2 km in rural areas in Puerto Rico. These speeds exhibit variations inversely proportional to the distance from the base station, fluctuating approximately between 50 Mbps (at 2 km from the base station) and 2 Gbps (at 50 meters from the base station with a line of sight—LOS). In this context, mobile terminals employ Dynamic Spectrum Sharing [74], enabling interaction between the millimeter band used and other lower-frequency bands, ensuring superior signal strength quality and lower latency, ultimately ensuring improved speed rates.

Present Status and Future Rollout

The National Spectrum Agency (ANE) holds the responsibility of providing guidance to the Ministry of Information Technologies and Communications in developing policies, plans, and programs related to the radio spectrum [75]. In August 2020, ANE reported that the millimeter bands at 26 GHz and 38 GHz would be accessible from 2027 and 2028, respectively, while the 3500 MHz band is expected to be available in the third quarter of 2021. Additionally, the 700 MHz, 1900 MHz, 2500 MHz, and 3500 MHz bands are earmarked for the deployment and provision of 5G terrestrial mobile services in Colombia before the conclusion of the current national government, which is before September 2022 [63,76]. This information is condensed in Table 6. The 3500 MHz band is considered the "essential enabler" for the commercial implementation of 5G as it is globally allocated (harmonized) for this purpose [77]. Colombia possesses 400 MHz allocated within the 3300 MHz–3700 MHz range in the 3.5 GHz [61], with a recommended GSA (Global Mobile Suppliers Association) block of 80 or 100 MHz for each operator to optimize efficiency and affordability in the initial deployment phase [77]. This band, classified under the C-band for 5G (3300 MHz–4200 MHz), is scheduled for auction in the third quarter of 2021 (Q3-2021). Consequently, Colombia continues its exploration of 5G capabilities before its official launch for commercial use, aligning with similar roadmaps adopted by other nations globally, as illustrated in Figure 5.

According to estimations by 5G operators, during its commercial introduction, the radio access network in Colombia is expected to leverage certain elements of the existing 4G network to minimize costs, including the reuse of basebands. For instance, Ericsson-branded Baseband Units (BBUs) could be repurposed if they are within a 5-year age bracket, ensuring a significant portion of the capital investment in the radio and spectrum without necessitating a comprehensive network upgrade.

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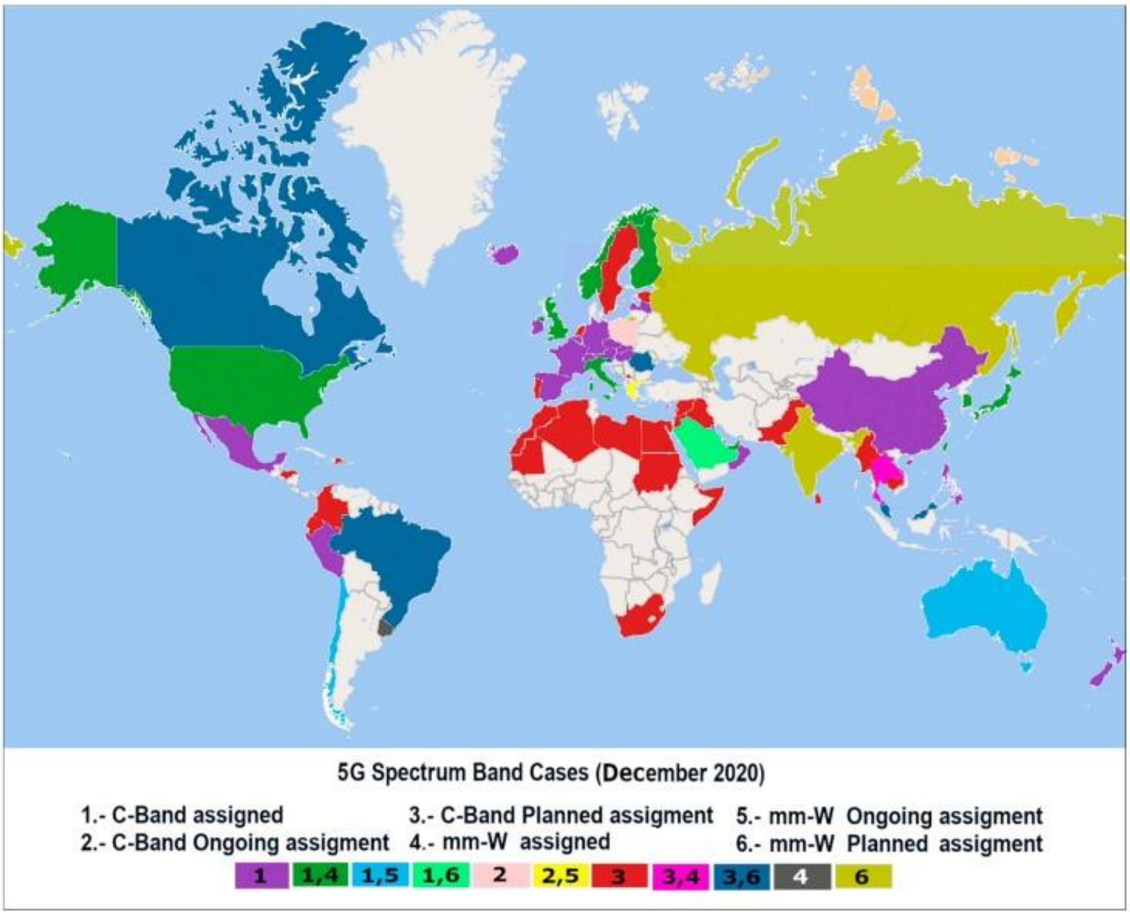

Figure 5 illustrates the global status of the C-Band for 5G (3300 MHz–4200 MHz) and mm-W band for 5G at 26/28 GHz as of December 2020 [78]

Most mobile operators in both Colombia and Latin America anticipate that, during the initial phase of commercial 5G network deployment, the majority, nearly 100%, will follow a Distributed-Radio Access Network (D-RAN) approach. However, they consider the possibility of implementing Centralized-Radio Access Network (C-RAN) in specific cases, such as industrial areas, constituting a small percentage of the overall 5G network. The adoption of C-RAN in Colombia and Latin America is in its early stages and is currently less efficient than D-RAN in terms of energy consumption and processing. Tests conducted in Ericsson laboratories indicate that transitioning distributed Baseband Unit (BBU) functions to Commercial Off-The-Shelf (COTS) X86 servers, which are presently the available resources in data centers, is not yet fully optimized for running telecommunications applications. Consequently, more servers are needed, leading to increased energy consumption to match BBU capacity, requiring 1.5 U (rack unit) per site to process multiple technologies simultaneously. Another potential approach involves establishing BBU-Hotels or BBU-Pool; however, limitations on

Fronthaul distance (10 to 15 km) between the Remote Radio Head (RRH) and the BBU must be considered to ensure latency of fewer than 100 microseconds and a minimum channel capacity of 10 Gbps. These latency and throughput requirements differ from the existing access network, and the associated costs per access point are expected to be higher, making it a less recommended alternative for widespread C-RAN deployments at present.

Table 6 provides information on the specific frequency bands allocated for 5G deployment in Colombia.

Band Frequency (MHz)	Total Free Spectrum in Band (MHz)	Spectrum to be Assigned Per Block (MHz)	Planned Auction Year/Available Band	Source
700	10	10	Before September 2022 (Auction). For 4G use, most of this frequency band was licensed in December 2019.	[62,82–86]
1900	5	5	Before September 2022 (Auction). For 4G use, most of this frequency band was licensed in December 2019.	[62,82–86]
2500	20	10	Before September 2022 (Auction). For 4G use, most of this frequency band was licensed in December 2019.	[62,81,83,84,86]
3500	400	80 or 100	Third quarter of 2021 (Auction).	[87,88]
26,000	1000	56 or 112	Available in 2027	[61,87]
38,000	1000	There are no ITU-approved channelisa-tions for this frequency band	Available in 2028	[87]

CONCLUSIONS

Colombia aims to roll out commercial 5G mobile phone services by the fourth quarter of 2021 (4Q-2021), aligning with the global plans of other nations. Similar to various European and American countries, pilot test phases have been initiated to assess the performance and robustness of the tested 5G networks.

To comprehend the efforts, costs, and challenges associated with the comprehensive deployment of 5G mobile networks for all stakeholders, we examined key issues and characteristics of 5G. This analysis contributes to achieving widespread penetration, enhancing coverage, and optimizing performance for the next generation of connected applications, including the Internet of Things, Telemedicine, and Industry 4.0.

In broad terms, the extensive deployment of 5G across higher and lower frequency bands, facilitated by Dynamic Spectrum Sharing, enhances access and coverage for mobile networks in both sparsely and densely populated areas. To address attenuation in the mm-W band, particularly in scenarios without a free line of sight over short and long distances, a combination of Dynamic Spectrum Sharing, mMIMO systems, and beamforming functionalities can be leveraged to provide an improved connectivity experience.

Finally, we shed light on stakeholders, future use cases, and advancements in the Colombian implementation, intending to serve as a reference point for researchers in the telecommunications field, particularly regarding the deployment of 5G mobile networks worldwide.

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