The 5G race: is Colombia lagging behind in implementation and information security?

La carrera 5G: ¿Colombia está rezagada en cuanto a implementación y seguridad de la información?

A corrida 5G: A Colômbia está atrasada em termos de implementação e segurança da informação?

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Abstract

Introduction: This article focuses on analyzing "The 5G Race: Is Colombia Lagging Behind in Implementation and Information Security?", through a literature review developed at the Universidad Distrital in 2023.

Problem: Despite successful pilot schemes, Colombia has not achieved large-scale 5G deployments like other nations. The following problematic question arises: How is Colombia faring in implementing successful 5G cases compared to other countries in terms of regulatory and information security aspects?

Objective: To compile up-to-date literature on the progress of 5G worldwide and contrast it with Colombia, to determine regulatory, pilot and security challenges.

Methodology: A search was conducted in academic and government databases such as Scopus, Web of Science, IEEE Xplore, SpringerLink, ScienceDirect and Google Scholar, focusing on identifying reports, case studies and articles on the current state of 5G worldwide and in Colombia. The keywords used in the search were: "5G", "5G regulation", "5G information security", "Colombia", "availability" among other related words.

Results: The comparative analysis allows us to identify gaps and challenges in Colombia for a comprehensive implementation of 5G.

Conclusion: The review suggests that Colombia is lagging behind in the adoption of 5G. Regulatory, infrastructure investment, and cybersecurity challenges remain.

Originality: This article provides an up-to-date comparative analysis between the state of adoption of 5G technology globally and in Colombia.

Limitations: Focuses on success stories and regulatory, safety and pilot aspects.

Keywords: 5G, regulation, information security, Colombia, availability

Resumen

Introducción: Este artículo se enfoca en analizar "La carrera 5G: ¿Colombia se está quedando atrás en implementación y seguridad de la información?", mediante revisión bibliográfica desarrollada en la Universidad Distrital en 2023.

Problema: Pese a pilotos exitosos, Colombia no ha logrado despliegues a gran escala de 5G como otras naciones. Surge la siguiente pregunta problemática: ¿Cómo está Colombia en la implementación de casos exitosos de 5G en comparación con otros países en términos de aspectos regulatorios y de seguridad de la información?

Objetivo: Recopilar literatura actualizada sobre avances de 5G y contrastarla con Colombia, para determinar desafíos regulatorios, pilotos y seguridad.

Metodología: Se realizó una búsqueda en bases de datos académicas y gubernamentales como Scopus, Web of Science, IEEE Xplore, SpringerLink, ScienceDirect y Google Scholar, enfocándose en identificar informes, estudios de caso y artículos sobre el estado actual del 5G a nivel mundial y en Colombia. Las palabras claves utilizadas en la búsqueda fueron: "5G", "regulación 5G", "seguridad de la informacion 5G", "Colombia", "disponibilidad" entre otras relacionadas.

Resultados: El análisis comparativo permite identificar brechas y desafíos de Colombia para una implementación integral de 5G.

Conclusión: La revisión sugiere que Colombia está rezagada en adopción de 5G. Persisten desafíos regulatorios, de inversión en infraestructura y ciberseguridad.

Originalidad: Este artículo proporciona un análisis comparativo y actualizado entre el estado de adopción de la tecnología 5G a nivel mundial y en Colombia.

Limitaciones: Se enfoca en casos exitosos y aspectos regulatorios, de seguridad y pilotos.

Palabras clave: 5G, regulación, seguridad de la información, Colombia, disponibilidad

Resumo

Introdução: Este artigo se concentra na análise "A corrida 5G: a Colômbia está ficando para trás na implementação e na segurança da informação?", por meio de uma revisão bibliográfica desenvolvida na Universidade Distrital em 2023.

Problema: Apesar dos projetos-piloto bem-sucedidos, a Colômbia não conseguiu implantações 5G em grande escala como outras nações. Surge a seguinte questão problemática: Como está o desempenho da Colômbia na implementação de histórias de sucesso 5G em comparação com outros países em termos de aspectos regulatórios e de segurança da informação?

Objetivo: Compilar literatura atualizada sobre os avanços do 5G e compará-la com a Colômbia, para determinar desafios regulatórios, pilotos e segurança. na Colômbia. As palavras-chave utilizadas na busca foram: "5G", "regulação 5G", "segurança da informação 5G", "Colômbia", "disponibilidade" entre outras relacionadas.

Resultados: A análise comparativa permite identificar lacunas e desafios na Colômbia para uma implementação integral do 5G.

Conclusão: A análise sugere que a Colômbia está atrasada na adoção do 5G. Persistem desafios regulamentares, de investimento em infraestruturas e de cibersegurança.

Originalidade: Este artigo apresenta uma análise comparativa e atualizada entre o estado de adoção da tecnologia 5G no mundo e na Colômbia.

Limitações: Concentra-se em casos de sucesso e aspectos regulatórios, de segurança e piloto.

Palavras-chave: 5G, regulação, segurança da informação, Colômbia, disponibilidade

1. INTRODUCTION

The implementation of 5G technology has sparked a great deal of interest globally due to the benefits and capabilities it provides, such as higher speeds, lower latency, and potential new applications. However, ensuring information security on 5G networks is a major concern that requires appropriate regulations and measures [1].

This article focuses on analyzing how Colombia is advancing in the implementation of 5G success stories compared to other nations in terms of information security. While Colombia has seen 5G pilot trials, large-scale deployments like those seen in foreign countries have yet to be achieved [1]. Previous papers have examined 5G deployments and cybersecurity in different countries separately [2]. However, there is a gap in the work that compares Colombia"s outlook with global trends.

Therefore, this article seeks to compile the works of the updated literature on the global advances of 5G and juxtapose it with the progress of Colombia. The methodology consists of reviewing global and national information on 5G deployments to determine the current state of the country. This comparative approach provides learnings on the challenges and next steps that are required in terms of regulations, testing, and information security to achieve a wider deployment of 5G.

2. METHODOLOGICAL FRAMEWORK

The research methodology consisted of a systematic review of the literature, focused on analyzing the implementation of 5G networks and their security in Colombia compared to the global context.

The variables of analysis were the state of commercial deployment of 5G networks, regulations on information security, and the challenges and advances in cybersecurity associated with this technology.

As research techniques, we searched the Scopus, Web of Science and IEEE Xplore databases using keywords on 5G and information security. The search focused on identifying case studies, technical reports, and scientific articles published between 2017-2023.

Inclusion criteria were: (1) articles in English or Spanish, (2) full text available, (3) published between 2017-2022, (4) focus on information security and regulations for 5G. Expert opinions, editorials and academic content were excluded.

Initially, 56 potentially relevant documents were identified. After applying the inclusion/exclusion criteria, 53 sources were selected for analysis.

For the fieldwork, the information extracted from the studies was classified and synthesized into analysis categories using a comparative matrix. This made it possible to contrast the findings between the global and national contexts.

In addition, official statistics from the Ministry of ICT and the CRC were used to complement the analysis of the Colombian context.

The analysis consisted of a triangulation of the findings found in the selected sources, contrasting the global and national situation regarding 5G deployments and their security. This made it possible to identify differences, gaps and opportunities for improvement.

3. LITERATURE REVIEW OR RESEARCH BACKGROUND

3.1 LITERATURE REVIEW OF CASES IN THE UNITED STATES

5G technology has generated a great deal of interest and anticipation in recent years due to its potential technical, economic, and social benefits. The United States is one of the leading countries in the race to deploy 5G networks, with several public and private players actively investing in the development of this technology. This section

presents a review of studies conducted specifically on the implementation of 5G in the United States.

One of the first papers published on the topic was presented by Lee et al. [3] in 2020, analyzing the challenges of wireless deployment and charging of 5G networks in the context of the United States. In their paper, Lee et al. [3] note that the high density of small cells required for 5G presents significant backhaul challenges, given the high cost of deploying the amount of fiber optics needed to provide the bandwidth and low latency demanded by 5G applications. Given this limitation in fiber availability, the authors seek in their study to assess the feasibility of using wireless charging for 5G devices as a viable alternative solution in cases where fiber deployment is not possible.

The proposal by Lee et al. [3] represents a novel approach to the 5G backhaul challenge for the United States, considering that the use of fiber optics for this purpose has traditionally been favored. As part of their research, the authors perform detailed theoretical models to analyze the performance of wireless charging systems taking into account key aspects such as power transfer efficiency, power consumption in mobile devices, and network interference management. They also present experimental results of a prototype wireless charging system operating in the 5 GHz band in the United States.

After an exhaustive theoretical and experimental analysis, Lee et al. [3] conclude that wireless charging is technically feasible to provide the bandwidth and low latency required in 5G backhaul, with the advantage of a lower deployment cost compared to fibre optic solutions. As such, they recommend that U.S. mobile operators seriously consider incorporating wireless charging into their 5G infrastructure deployment strategies, as an alternative or complement to fiber optics. This work is a clear example of applied research on real 5G deployment problems in the United States.

Another relevant work is the detailed book by Y. Yang [4] published in 2018, which analyzes the key technologies for 5G wireless systems with specific information for the United States. This book features contributions from dozens of international 5G experts and reserves an entire section for the particular 5G situation in the United States. In particular, the book discusses in detail the deployment plans announced at the time by the major U.S. mobile operators, AT&T and Verizon.

In addition, they study the different frequency bands that were being considered at the time in the United States for 5G, including millimeter wave spectrum and below 6 GHz, as well as the regulatory aspects of the use of these bands and the associated technical standards. In relation to the 5G network architecture for the United States, the book covers topics such as the use of dense small cells and usable technologies for backhaul, discussing the advantages and disadvantages of fiber optic and

microwave options. Finally, there are sections dedicated to key topics such as beamforming, massive MIMO antenna technologies, modulation, and other advancements considered essential to meet the technical requirements of 5G networks in the United States. In this way, this book offers a comprehensive view of 5G oriented specifically to the situation in the United States. [4].

Accelerating 5G in the U.S. [5]: This report emphasizes the importance of market-driven decisions in the implementation of 5G in the U.S., highlighting the need to accelerate spectrum reuse, remove regulatory hurdles, promote trust in the supply chain, counter predatory practices, redirecting export credits from the U.S. and its allies, making 5G security part of a broader cybersecurity strategy, increasing federal spending in support of 5G and 6G, allocating congressional funds, safeguarding the international standards process, and supporting the technology transition to O-RAN and 6G.

The U.S. is at the forefront of 5G rollout across the country, laying the groundwork for the launch of this new mobile broadband standard. With data speeds up to 20 times faster than 4G and 10 times higher connection density, 5G opens up significant opportunities for innovation and economic development, as well as a better consumer experience. [6]

The increased connectivity, speed, and lower latency of 5G are expected to create opportunities in sectors such as retail, agriculture, manufacturing, healthcare, and utilities. By supporting reliable and fast networks, 5G will power technologies such as advanced computing, artificial intelligence, and the Internet of Things. It is estimated that in the United States this could add up to $1.5 trillion to GDP by 2025 and generate millions of jobs. [6]

The market for 5G devices is growing, with the launch of new models from major brands. The demand for 5G functionality is increasing and prices are falling, making them more accessible. The government is auctioning licenses for 5G spectrum, vital to the network"s rollout. Speeds vary depending on a number of factors, but tests show substantial improvements over 4G. [6]

5G represents a great competitive and economic opportunity for the United States. A dramatic increase in adoption is expected as prices drop and coverage increases, benefiting consumers and driving innovation across multiple sectors. [6]

In the United States, these advances are expected to add $1.5 trillion to the nation"s gross domestic product (GDP) by 2025. The use of 5G is expected to generate $253 billion and up to 2.39 million jobs in California alone, and New York and Texas are also projected to add more than $130 billion. [7]

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The four major U.S. mobile operators (AT&T, Verizon, Sprint, and T-Mobile) have different plans for 5G deployment in terms of technology, business models, deployment timelines, and spectrum usage. Although only prototype 5G phones were initially available, the first consumer models arrived in 2019. Some carriers, such as Verizon, have already launched commercial 5G services, but using proprietary standards instead of the 3GPP standard. Speeds and coverage remain limited on these initial networks. Overall, the U.S. is moving toward some form of 5G mobile broadband rollout, but not necessarily in a coordinated or holistic way across different carriers. The reuse of LTE spectrum in UHF ranges appears to be significant in current strategies. [8]

According to an article by Frieden [9], the U.S. government has taken increasingly aggressive initiatives to unilaterally reallocate spectrum for 5G, before intergovernmental coordination at ITU is completed. Instead of seeking global consensus on spectrum allocations, the FCC has auctioned off large blocks of frequencies for 5G. The FCC argues for the need for accelerated action, but this unilateral approach has the potential to lead to high costs in the long run.

The article concludes that the costs and challenges for ITU will reduce the benefits of the FCC"s unilateral spectrum campaign. The U.S. must carefully weigh the risks of ignoring international coordination processes in the race to lead 5G.

In conclusion, the literature shows that research on 5G technologies and deployment strategies in the United States has focused on both the physical aspects of infrastructure deployment and application layer optimizations to maximize the benefits of 5G for end users.

More research is required to analyze the results and lessons learned from the large-scale 5G rollouts that major U.S. carriers such as Verizon, AT&T, and T-Mobile are currently running in several cities. As these deployments mature, case studies on the obstacles they face and the resulting best practices will be invaluable in guiding 5G deployments in other countries.

Another area of future research is to experimentally characterize the performance of edge computing platforms on real 5G hardware for various AI and machine learning algorithms. While authors such as Chen et al. have demonstrated the benefits of edge/airborne computing for IoT, more research is needed considering the different types of hardware that vendors like AWS and Microsoft are deploying at the edge of 5G networks. This would help to improve understanding on the strengths and limitations of distributed AI solutions specifically in 5G infrastructure in the United States.

In relation to 5G applications in the United States, there is room for future work that discusses in detail the requirements and characteristics of various verticals identified as key beneficiaries of 5G, such as manufacturing, automotive, healthcare, etc.

This will allow research and optimization efforts to focus on the specific needs of each industry in the context of 5G deployment in the United States.

In summary, the research reviewed so far has laid a solid foundation in several areas relevant to the deployment of 5G networks in the United States. There is room for future work to expand knowledge on specific topics of interest to different players in the 5G ecosystem in the United States.

After analysing the literature on cases of 5G deployment in the United States, studies focusing on the European context are examined below.

3.2 LITERATURE REVIEW OF CASES IN EUROPE

The introduction of 5G networks in Europe has gained momentum in recent years, with several countries carrying out rollouts and trials across the country. This section reviews studies on the implementation of 5G specifically in the European context.

The ITU Telecommunication Development Bureau (ITU-BDT) published one of the first documents in 2018, presenting a comprehensive technical report on the main issues and challenges related to the global deployment of 5G. The document includes a chapter dedicated to Europe, describing the European Commission"s first actions to stimulate research into 5G technologies through projects such as METIS and 5G PPP. It also discusses the radio spectrum requirements for 5G in Europe, analysing the different frequency bands identified for 5G services by European regulators. Another aspect addressed is the roadmap for the deployment of 5G in Europe, examining the economic motivations and potential associated risks. Finally, the regulatory challenges for the implementation of 5G in Europe and the role of government agencies in incentivizing its adoption are discussed. Therefore, this reference provides an overview of the state of 5G in Europe up to 2018.

Another relevant work is the one presented by the European Commission in 2016 [10], which quantifies the expected socioeconomic benefits of the introduction of 5G in the countries of the European Union. Using econometric methods, the study predicts that 5G networks will contribute €146 billion annually to the European economy and generate more than 2 million jobs by 2025. They also estimate that the capital investment needed is €56 billion. An important finding is that about 80% of the benefits would be concentrated in urban areas, while rural areas would receive only 20%. The document then warns of the risk of widening the digital divide, recommending that regulators implement policies to promote 5G investments in rural areas as well. This study exemplifies socio-economic research focused on measuring the impact of 5G in Europe. [10]

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While the benchmark provides a global overview of the state of 5G in Europe up to 2018, it is noted that it does not include the results and lessons learned from the large commercial 5G deployments that major European operators have carried out in recent years. As these networks mature, case studies on the challenges they face and best practices will be invaluable in guiding 5G deployments both in Europe and beyond.

The rollout of 5G technology in European countries has progressed unevenly, with divergences in the approaches taken by different Member States. [11]

In Spain, the auction of the 700MHz band was originally scheduled for March 2020, but the COVID-19 pandemic delayed the launch of this band that was used for digital terrestrial television. Subsequently, the auction was postponed until May 2020 and then until the first quarter of 2021. Finally, following an amendment to Spanish legislation in April 2021 to harmonize the duration of the licenses with the European Electronic Communications Code, the auction was postponed to the summer of 2021 and the 700MHz band was awarded in July of that year.

In Poland, the auction process for 5G frequencies was also suspended due to the COVID-19 pandemic. In March 2020, Poland had announced an auction for the 3.6 GHz band to be awarded by 30 June 2020, but following the outbreak of the pandemic the authorities decided to suspend all administrative procedures. As of September 2021, the auction process for this band had not yet been finalized. [11]

In Germany, meanwhile, the Information Technology Security Act 2.0, adopted in May 2021, provides for mandatory certification of critical components of 5G in order to authorize its use. However, the German mobile network operators interviewed stated that they would prefer the existence of a single European certification procedure under the auspices of ENISA, rather than having to go through multiple national certifications. German law also empowers the Federal Ministry of the Interior to prohibit the use of critical components if they may pose a threat to national security. [11]

Beyond these cases, there are generally divergences in the approaches of different EU Member States in relation to the use of equipment from suppliers considered to be high risk or in relation to the scope of the restrictions applied. [11]

For example, in October 2020, Sweden"s telecommunications regulatory authority imposed conditions for participating in the 5G spectrum auction that involved the exclusion of products from Chinese suppliers for new facilities and core network functions, as well as the phasing out by 2025 of any existing infrastructure from such providers. [11]

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By contrast, Hungary has not restricted any 5G providers so far and has refused to join the "Clean Network" program promoted by the United States to limit the presence of Chinese providers in 5G networks.

These divergences in national approaches to high-risk providers are related to the implementation of the EU 5G cybersecurity toolbox, which leaves a wide margin of discretion to Member States as these are non-legally binding measures. While 13 countries have recently adopted 5G security legislation based on the 5G toolkit, approaches remain different. For example, Germany focuses on the certification of critical components, while Sweden directly excludes suppliers. [11]

The European Commission has not yet assessed the impact that these divergent approaches could have on competition between operators operating in the single market or on cross-border security. Therefore, greater coordination between Member States is needed to harmonise the deployment of secure 5G networks. [11]

The European Commission and EU Member States carried out a coordinated assessment of the cybersecurity risks of 5G networks, the results of which were published in a report in October 2019. This risk assessment was a key action as part of the implementation of the European Commission"s Recommendation of March 2019, which aimed to ensure a high level of cybersecurity in 5G networks across the European Union. [12]

The report is based on the results of national cybersecurity risk assessments carried out by the 27 Member States. The report identifies the top security risks and threats, the most critical assets, technical and other vulnerabilities, and a number of strategic risks. [12]

The coordinated assessment concludes that with the implementation of 5G networks, an increase in exposure to cyberattacks, a greater criticality of certain network equipment, and a greater dependence of operators on single providers is expected. These challenges require a reassessment of the current policy and security framework for the telecoms sector, and it is essential that Member States take mitigation measures in a coordinated manner. [12]

The risk assessment serves as a basis for determining the mitigation measures to be implemented at national and European level to address the security challenges of 5G networks. [12]

In conclusion, the literature review shows that the adoption of 5G networks in Europe has advanced significantly in recent years, but with some divergences in the approaches of the different Member States. There are differences in spectrum auction schedules and processes, as well as in the policies applied to providers considered high-risk.

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While the European Commission has promoted coordinated cybersecurity risk assessments for 5G networks, there are still discrepancies between countries on the extent of restrictions and the level of discretion granted to national regulators. A key challenge is to harmonise regulatory frameworks between Member States to ensure cross-border security and fair competition in the European Digital Single Market.

More case studies on large-scale commercial deployments of 5G by major European operators are needed to extract lessons learned and best practices to help guide future deployments, both in the region and globally.

3.3 LITERATURE REVIEW OF CASES IN ASIA

Asia has established itself as a leading region in the deployment of 5G networks globally. Countries such as China, South Korea, and Japan are at the forefront, having launched commercial 5G services in 2019. [13]

China has set out a very ambitious roadmap for the rollout of 5G. The Chinese government plans to have more than 130,000 5G base stations in operation by the end of 2019. The country"s big three telecom operators, China Mobile, China Telecom, and China Unicom, are competing aggressively to lead the way in providing 5G services. [13]

South Korea commercialized 5G networks in April 2019, with services launched by its three dominant carriers at the same time. The South Korean government played a key role in ensuring the availability of radio spectrum for 5G and strongly supporting related research and development activities. [13]

Japan also joined the 5G race in 2019, although the initial rollout has focused on densely populated metropolitan areas. Compared to China and South Korea, Japan"s adoption of 5G has been more cautious. [13]

Key factors driving the rapid adoption of 5G in Asia include massive investments in research and development, supportive government policies, intense competition among operators, and the availability of a mature ecosystem of 5G devices. [13]

Given the highly favorable market conditions and focus on technology leadership, Asia is expected to continue to be at the forefront of the global deployment of 5G networks in the coming years. [13]

Beyond the leading countries (China, South Korea and Japan), several other Asian countries are making rapid progress in deploying 5G networks, albeit with some variations in approach. India held its first 5G spectrum auction in 2018, awarding airwaves in the 3.3-3.6 GHz and 24.75-27.25 GHz bands to operators such as Reliance Jio, Bharti Airtel and Vodafone Idea. These operators are testing 5G technologies in

Delhi, Mumbai, Hyderabad and other cities with plans to offer commercial coverage by 2020, focusing mainly on densely populated urban areas. [14]

Thailand represents one of the most advanced 5G markets in Southeast Asia, with operators AIS, DTAC and TrueMove testing 5G networks since 2018 and launching initial services in Bangkok in 2020. Malaysia is lagging behind, having auctioned off 3.5GHz spectrum in 2019, which will be used by operators such as Celcom, Digi, Maxis and U Mobile to roll out 5G with a focus on urban areas by 2022. In Taiwan, operators Chunghwa Telecom, FarEasTone and Taiwan Mobile received 3.5 GHz spectrum in 2019 and plan limited 5G services by 2020 in Taipei and other cities. Overall, Asia is expected to continue to lead the way globally in 5G network adoption over the next decade. [14]

Singapore has become a hub for technological innovation and is rapidly adopting 5G networks. The Singapore government began testing 5G technologies in 2018 in collaboration with operators such as Singtel, and planned a wider commercial rollout of 5G infrastructure by 2020/2021. Singapore was also investing heavily in local research on 5G applications in areas such as autonomous vehicles, industrial IoT, augmented reality, and smart cities. [15]

Indonesia represented a key emerging market for 5G in South Asia. The regulator was expected to hold a 3.5 GHz spectrum auction in the first quarter of 2020, allowing operators such as Telkomsel, Indosat Ooredoo, XL Axiata and Hutchison 3 Indonesia to start building 5G infrastructure across the country. Initially, 5G coverage would focus on the cities of Jakarta, Surabaya, Bali, and Bandung. [15]

The launch of 5G services in the Philippines was planned for 2020, although it would initially have a limited scope. Operators Globe Telecom and Dito Telecommunity were testing 5G technologies and planned to offer very basic coverage in metropolitan areas such as Manila, Cebu and Davao by 2020. The expansion was expected to accelerate by 2022, as more spectrum was freed up and prices for 5G equipment were reduced. The Philippines had the potential to adopt 5G applications in areas such as healthcare, education, and financial services. [15]

Li-Fi (Light Fidelity) technology represents an emerging solution in telecommunications that uses the visible light spectrum to transmit information wirelessly. Li-Fi emerges as an alternative to Wi-Fi in the face of the saturation of the radio spectrum and the new requirements for bandwidth and energy efficiency. A recent article by the Universidad Distrital Francisco José de Caldas analyzed the current status, advances and projection of Li-Fi through an extensive literature review [16].

In relation to Asia, the study highlights several important investigations that have been carried out in countries such as India, China and Japan for the development of

Li-Fi and its integration with Wi-Fi networks. Optimizations in modulation algorithms for visual communication systems and signal processing techniques in hybrid Li-Fi/Wi-Fi networks are highlighted, achieving improvements in spectral efficiency and interference mitigation. These developments are evidence of Asia"s interest in driving the development of Li-Fi as part of next-generation networks. [16]

In 2023, the implementation of 5G technology in Asia has been successful, leading the deployment of 5G networks in the region. [17]

Highlights:

Leadership in 5G deployment: Advanced markets in Asia-Pacific have been pioneers in 5G deployment. South Korea was the first country to roll out a nationwide 5G network in April 2019, followed by Australia, the Philippines, China, and New Zealand that same year. [17]

Asia overtakes Europe: Early 5G adopters in the Asia Pacific region have overtaken major European markets. Countries such as Malaysia and South Korea have achieved average download speeds above 500 Mbps, while in Europe only France has reached speeds above 200 Mbps [17].

Variability in 5G availability and adoption: 5G availability varies across the region due to factors such as population density, device affordability, and tariffs. Hong Kong stands out as the only country with 5G availability above 40%, while countries such as Australia and South Korea have availability rates of around 36.6%. [17]

Notable cities for 5G speeds: Seoul (South Korea) and Kuala Lumpur (Malaysia) are the leading cities for 5G download speeds in the Asia Pacific region, with average speeds above 500 Mbps.

India"s remarkable breakthrough: India has seen a significant breakthrough in mobile speed performance in the past year, thanks to the launch of 5G. The country has improved its ranking in the Speedtest Global Index™, moving from 119th to 47th place in August 2023. [18]

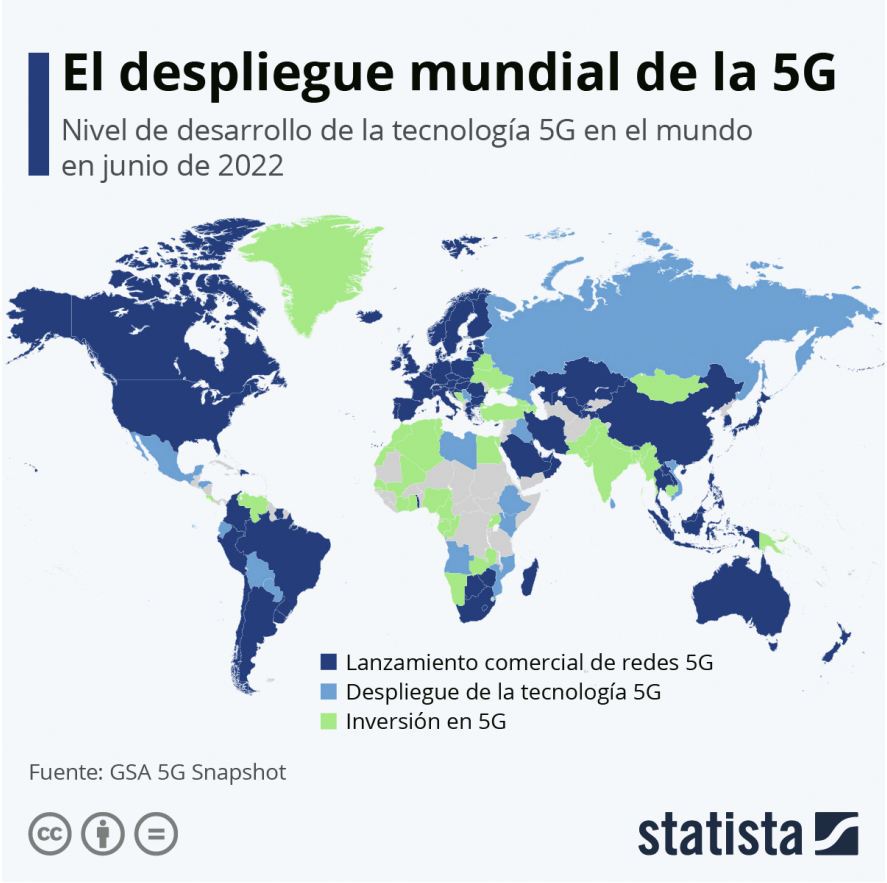
It is undeniable that Asia has positioned itself as a world leader in the deployment of 5G networks. Countries such as China, South Korea, and Japan have led the way since 2019, deploying 5G services before any other market.

There are compelling reasons for Asia"s success in deploying 5G. First, governments in the region have made massive investments in research and development of 5G technologies. They have also implemented effective supportive policies, such as the timely provision of radio spectrum for operators to build their networks.

Another decisive factor has been the fierce competition between the major telecom operators in these Asian markets. The eagerness to lead the technological race and gain a competitive advantage has led them to implement 5G technology in an accelerated and ambitious way.

Added to this is the early availability of 5G-enabled devices in the region, which has enabled rapid consumer adoption. Thanks to this, it"s no surprise that by 2023 the region will continue to lead the way globally, with countries like South Korea achieving 5G speeds higher than Europe.

Asia"s success in 5G can be explained by the vision of its governments, large investments, competition between operators, and enthusiastic adoption by users. These key factors ensure that the region maintains its leadership in the next decade of 5G network deployment.



[19] Fig. 1. Statista, "Graphic: The Deployment of 5G Around the World" [Online]. 27 Jul 2022.
Source: https://es.statista.com/grafico/23241/nivel-de-desarrollo-de-la-tecnologia-5g-en-el-mundo/. [Accessed: 28 Feb. 2023]

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3.4 LITERATURE REVIEW OF CASES IN LATIN AMERICA

The implementation of 5G networks in Latin America is at an incipient stage compared to other regions of the world. However, several countries in the region have begun to take important steps to enable the deployment of this technology. [20]

One of the most advanced cases is Brazil, which held a 5G spectrum auction at the end of 2021, committing investments of US$9,000 million. 90% of the value paid for the spectrum was converted into coverage obligations, school connectivity and fibre optic networks. There are currently four 5G networks operating commercially, and they should be available in all capitals by July 2022. Tariffs on the import of equipment have also been reduced. [20]

Chile is another of the leading countries, with three 5G networks operating after an auction held in 2020. Spectrum was allocated in the 700 MHz, AWS, 3.5 GHz and 26 GHz bands, totalling $450 million, including coverage commitments. [20]

Commercial operation began at the end of 2021 following regulatory approval. Deployment is currently underway in several cities and work is underway to reorganize the 3.4-3.6 GHz band. [20]

In Mexico, in 2021, the regulator formed a multisectoral Technical Committee to promote 5G. An auction is planned for 2022, while AT&T has already been offering commercial 5G services since December 2021. For its part, Telcel was authorized to operate 5G in certain bands where it already has concessions in force. [20]

Costa Rica has published a roadmap for 5G and a National Telecommunications Plan 2022-2027, which includes a schedule for spectrum tenders. However, in 2022 a conflict arose over possible breaches in the efficient use of certain previously allocated bands, which are key for 5G. [20]

Other countries such as Argentina, Ecuador, Peru and Uruguay are still defining roadmaps, reorganizing the current spectrum or conducting limited pilot tests. But several have taken steps to promote needed investments, such as extending licensing terms, lowering equipment fees, and simplifying regulations. [20]

In Colombia, while several successful 5G technology pilot schemes have been carried out in recent years in cities such as Bogota, Medellin, and Manizales, large-scale commercial deployment has yet to be achieved. [21]

According to a recent report by the CRC (Communications Regulatory Commission), 5G pilot schemes have made it possible to test the operation of use cases such as real-time video surveillance, telemedicine, virtual education, and industrial automation. These tests have been developed thanks to the assignment of temporary permits for the use of the spectrum by the Ministry of Information and Communications Technologies. [21]

The 5G pilot schemes have been carried out in Colombia since 2019, where Claro was the first operator to carry out tests in Bogotá and Barranquilla, followed by Tigo which tested its 5G network in Cali. In 2020, the country"s three largest mobile operators – Claro, Tigo, and Movistar – obtained permits to conduct 5G pilot schemes in cities such as Bogotá, Medellín, Cali, and Manizales. These pilot schemes were run in the 2.5 GHz band [21].

One of the most emblematic pilot schemes was the one carried out by Claro and Huawei at the Maloka Innovation and Technology Center (CIT) in Bogotá in September 2019. In this pilot scheme, a 5G NSA (non-standalone) network was successfully tested, reaching connection speeds of 1.2 Gbps indoors. Equipment such as 5G smartphones and 5G CPE terminals were used to make 8K video calls, cloud gaming, and remote augmented reality among the applications presented. [21]

Another relevant pilot scheme was the one carried out by Tigo and Ericsson in Cali in November 2019, covering the neighborhoods of Ciudad Jardín and San Antonio. With this pilot, download speeds of 1.7 Gbps were achieved and use cases such as real-time video surveillance, industrial automation, and augmented reality for predictive maintenance were tested. Among the 5G devices used were smartphones, fixed modems, and mobile hotspots. [21]

As for Movistar, in partnership with Nokia, it carried out 5G tests in Medellín in the 3.5 GHz band during 2020, achieving connection speeds of 600 Mbps. Additionally, it enabled a 5G station in Manizales in September 2020, reaching speeds of 200 Mbps and with plans to expand the initiative to other cities. [21]

Despite the success of these pilot schemes, the country faces some challenges for the mass deployment of 5G, especially in regulatory aspects, spectrum availability and infrastructure investments.

On the regulatory side, the frequency bands that will be used exclusively for 5G services have not yet been auctioned. Spectrum auctions that were originally scheduled for 2021 were postponed due to the pandemic. It is expected that during 2022 the Ministry of ICT will be able to auction the 700 MHz, 2.5 GHz and 3.5 GHz bands identified for 5G. [21]

Another regulatory challenge is the availability of supporting infrastructure such as fiber optics, given that 5G requires much more fiber than previous generations. Although Colombia has about 54,000 km of fiber installed, fiber penetration to homes is still very low (less than 10%), so it is necessary to expand last-mile coverage. [21]

In terms of spectrum availability, the Ministry of ICT needs to be able to release and allocate new bands such as 6 GHz, which allows wider channels for 5G. Expanding

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the availability of the licensed spectrum will also be key, as current pilot schemes use bands such as 2.5 GHz where 4G services coexist. [21]

Substantial investments in network infrastructure are also needed, especially in new antenna sites for small cells, which are critical in 5G given the use of higher frequencies. Many more 5G antennas are required than in 4G due to the shorter distance that millimeter waves can cover. [21]

5G smartphone prices also need to be made more affordable to drive mass adoption by users. Initially, the first 5G devices had very high prices, but it is expected that by 2023 there will be a mid-range of 5G smartphones below $500. [21]

Players in the telecommunications sector in Colombia agree on the need to create a regulatory environment that incentivizes these investments to deploy 5G infrastructure nationwide. Work should also be done on measures to promote the affordability of 5G devices and services for end-users. [21]

Overcoming these challenges will allow Colombia to move from the pilot stage to the massive deployment of 5G networks, delayed in part by the impacts of the pandemic.

The deployment of large-scale 5G networks will bring very relevant benefits to the country. It will drive digital transformation in key industries such as healthcare, education, manufacturing, entertainment, and e-commerce. It will also enable new use cases in the Internet of Things (IoT), connected vehicles, smart cities, industrial automation, extended reality, etc.

The higher bandwidth and low latency of 5G will bring huge improvements in productivity in sectors such as manufacturing, mining, and agribusiness. In medicine, it will accelerate the adoption of applications such as remote surgery, patient monitoring, and augmented reality for training. In education, it will promote remote and virtual digital learning solutions.

To take full advantage of these opportunities, Colombia will need to overcome regulatory, spectrum, infrastructure, and capacity challenges for the comprehensive deployment of 5G nationwide. This will allow it to make a leap towards hyperconnectivity and the new digital economy.

TABLE I. SPECTRUM ALLOCATION FOR 5G PILOT TRIALS

No.	NIT SOLICITANTE	Banda de Frecuencia
1 830.122.566-1	Colombia Telecomunicaciones S.A. E.S.P.	3500 MHz - 3600 MHz
2 800.153.993-7	Comunicación Celular S.A. Comcel S.A.	3500 MHz - 3600 MHz
3 899.999.115-8	Empresa de Telecomunicaciones de Bogotá S.A. E.S.P.	3500 MHz - 3600 MHz
4 900.278.364-4	ITICS S.A.S.	3500 MHz - 3600 MHz
5 900.981.128-7	Xiro Investment Group SAS	3300 MHz - 3400 MHz 587MHz – 592 MHz*

[22] Ministry of Information and Communications Technologies, "Spectrum Allocation Table for 5G Pilot Tests," in Spectrum Allocation Report for Pilot Test Use, 1 Jul. 2020. Source: https://mintic.gov.co/micrositios/plan_5g//764/articles-162293_recurso_1.pdf. [Accessed: 28 Feb. 2023].

Recently, in October 2023, Colombia"s Ministry of Information and Communications Technologies (MinTIC) carried out a radio spectrum auction process to boost the deployment of 5G networks in the country. This auction was carried out through Resolution Number 03947 of October 20, 2023, which established the procedure for granting permits for the use of the spectrum nationwide in the 700 MHz, 1900 MHz, AWS extended, 2500 MHz and 3500 MHz bands [23].

The auction included the allocation of 10 MHz in the 700 MHz band, 10 MHz in the 1900 MHz band, up to 30 MHz in the extended AWS band, up to 30 MHz in the 2500 MHz band and up to 320 MHz in the 3500 MHz band. Various auctioning mechanisms were employed for band-based spectrum allocation, including the Simple Upstream Clock Auction and the Upstream Multi-Round Simultaneous Auction [23].

The main objectives of this auction, according to the MinTIC resolution, are to maximize social welfare in access to the radio spectrum, reduce the digital divide, expand the coverage of mobile networks and promote the deployment of infrastructure to improve the provision of services to users [23].

Although the final result of the auction is not yet known given that the process is ongoing, it is expected that the assignment of these new frequency bands for 5G services will contribute to accelerating the commercial deployment of this technology in Colombia. This would provide mobile operators with the radio spectrum needed to expand their 5G networks beyond cities where pilot tests currently exist.

In this way, the spectrum auction organized by the MinTIC represents a key regulatory advance to materialize the benefits of 5G at the national level. The challenge now will be for mobile operators to make the infrastructure investments required to build robust 5G networks that take advantage of these new assigned frequency bands.

Contextualizing this 5G spectrum auction within the regulatory background in Colombia, it is worth mentioning that the Ministry of Information and Communications Technologies had previously issued Resolution 4543 of 2022 and Resolution 1505

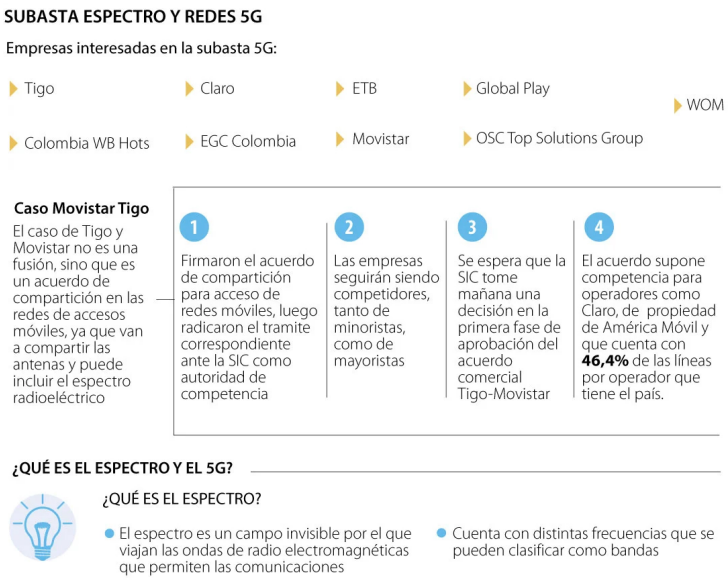
of 2023, through which it invited to express interest in participating in the process to grant permits for the use of the radio spectrum in some of the bands that were finally included in the October 2022 auction.

In response to this call, several actors in the telecommunications sector in Colombia expressed their interest in being part of the process, which made it possible to accredit compliance with the rule on verification of plurality of interested parties established in Law 1341 of 2009.

Resolution 03947 of 2023 of the MinTIC established the base value for each block of spectrum auctioned, which became the minimum price to bid for that block. For example, for the four 80 MHz blocks in the 3500 MHz band, a base value of COP $317,717 million each was set. A total of 70 MHz in bands below 1 GHz and 300 MHz in bands above 1 GHz were auctioned. [23]

Likewise, the resolution incorporates obligations aimed at expanding 4G and 5G mobile coverage in rural areas, as well as fiber optic connectivity in educational centers. A differential of this auction is that part of the value to be paid for the spectrum blocks can be covered by executing these obligations; up to 90% of the total. [23]

Once the spectrum blocks have been awarded to each winning participant, they will have 15 working days to complete their registration in the Single ICT Registry administered by the MinTIC. The issuance of the administrative acts for the final assignment of spectrum use permits is expected to occur in February 2024. [23]



[24] Fig. 2. L. República, "This is how the operators" fight for the spectrum and network is configured of 5G in Colombia," La República, 2022.

Source: https://www.larepublica.co/empresas/asi-esta-configurada-la-pelea-de-operadores-por-el-espectro-y-la-red-del-5g-en-colombia-3668374. Accessed on: Nov. 28, 2023.

On the other hand, before the auction, the Ministry of Information and Communications Technologies sent to the Superintendence of Industry and Commerce (SIC) the draft resolution for the assignment of permits for the use of the radio spectrum, in compliance with Article 7 of Law 1340 of 2009 on competition law.

The SIC issued a preliminary concept with some recommendations, among which it suggested that the Ministry of ICT consider differential measures aimed at promoting an effective competition dynamic in the mobile services markets in Colombia. However, the Ministry argued that it would not accept this specific recommendation under Law 1341 of 2009 and the legal objectives assigned for the granting of permits for the use of the radio spectrum [25].

Another recommendation of the SIC that was accepted was that the operator Claro could not choose its position in the 3500 MHz band based on the value of its offer, but would be assigned the location not chosen by other participants. This is in order to promote conditions of competition [25].

While the auction process represents a key regulatory milestone to accelerate the deployment of 5G in Colombia, once the spectrum is allocated comes the critical stage of infrastructure investments by operators to materialize the networks.

Substantial investments will be required by the winning operators to deploy the base stations, antennas and other infrastructure needed for 5G networks. It will also be key to expand fiber optic coverage as a backhaul of 5G networks, given the high requirements of this new standard, deploying 5G networks nationwide in Colombia will require a total investment of approximately COP $14 billion between 2022 and 2031. Between 16,000 and 19,000 new antenna sites would be needed to achieve coverage similar to the current 4G network.

In addition, higher infrastructure density is required due to the shorter distance that millimeter signals at frequencies above 6 GHz can cover compared to 3G or 4G. Therefore, the key will be for Colombian mobile operators to strongly accelerate their annual investments in 5G above current levels.

Another important challenge to realize the benefits of 5G in Colombia is to boost the adoption of the technology by users. While the first commercial 5G plans are already being offered in some cities, the penetration of 5G-compatible smartphones in the country is still very low, at less than 5%.

The high cost of 5G terminals is currently a barrier to entry. But prices are expected to start coming down to more affordable levels for a larger segment of the population in 2023 and 2024, as manufacturing of compatible devices increases.

Moving from 4G to 5G also poses significant challenges for mobile operators and infrastructure providers in terms of transforming their networks. Evolving to a

more flexible, software-defined, and automated architecture is required to support 5G innovations.

Likewise, the leap to 5G brings new cybersecurity challenges that Colombia must face. The massive increase in internet-connected devices with the expansion of the Internet of Things introduces new risks of cyberattacks and identity fraud that must be properly mitigated.

Both the MinTIC and the CRC will have a key role in the coming years; to monitor the winning operators of the auction and verify that they comply with their obligations of 4G and 5G coverage in rural areas. Likewise, they should invest adequately in the expansion of infrastructure so that the benefits of 5G reach more Colombians.

In this way, with the regulatory advances in the spectrum auction and the execution of the required investments, Colombia will be closer to the massive deployment of 5G networks and reap the expected benefits of this disruptive technology.

4. CURRENT CONTEXT OF 4G AND 5G TECHNOLOGY IN COLOMBIA IN TERMS OF INFORMATION SECURITY

In Colombia, considerable progress has been made through 4G network connectivity, as projects have been implemented to improve internet access in remote areas with limited coverage. This aligns with accelerated implementation efforts by MinTic, which achieved a coverage rate close to 80% nationwide throughout 2021, as specified in [26]. These services were mainly based on mobile phones, encompassing voice, messaging, and internet services, while also encompassing services provided through M2M (data exchange or communication between remote machines) and IoT devices.

Initiatives such as NavegaTic and the digital zones proposed by MinTic have contributed to social well-being in both urban and rural areas, reaching a total of 346,732 households with fixed internet access throughout the country.

4G was introduced with the aim of intensifying data transmission speeds, but, above all, to improve security compared to its predecessor networks, 3G and 2G. In the past, it was difficult to spy on traffic on those networks. However, today, the evolution to 4G LTE still has security weaknesses, as it comes with a number of vulnerabilities that allow attackers to intercept calls and messages sent by users, as well as track their location for potential cyberattacks.

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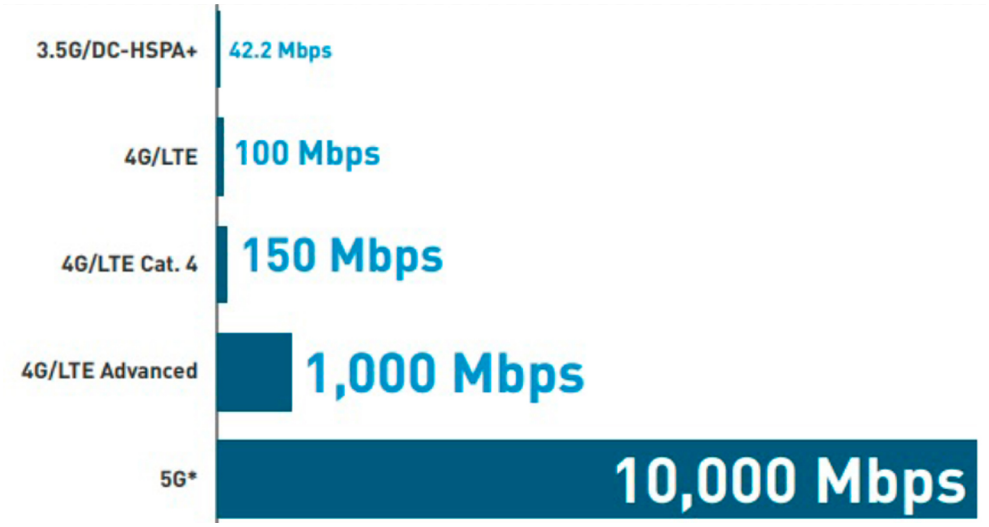
This vulnerability can be observed in any type of 4G network today. However, mitigating such impacts relies on a security system that kicks in when there is congestion in network traffic, causing traffic to be redirected to mitigate the damage. To protect against these attacks, users can either employ apps that offer end-to-end encryption or encrypt all traffic using a VPN, making the traffic indecipherable and harder to attack.



[27] Fig. 3. GEMALTO, "5G vs 4G Comparison Graphic," in What is 5G?, Q&A, Website, 2023-02-28.

Source: https://www.thalesgroup.com/es/countries/americas/latin-america/dis/movil/inspiracion/5g. [Accessed: 2023-02-28].

5. THE CONCEPT OF INFORMATION SECURITY IN COLOMBIA AND OTHER COUNTRIES

Information security is an ongoing process, as its risks are never completely eliminated, but they can be managed and mitigated as much as possible. It is important to note that the risks associated with security issues are not solely technological in nature and, for this reason, can never be completely eliminated [28]. Through the analysis of vulnerabilities and risks in information security, a set of standards available worldwide is established, which determine the responsibilities and rules to be followed in order to prevent or minimize the effects of these threats if they occur.

In the case of Colombia, we have the following regulations:

- Law 1273 of 2009: Focuses on the comprehensive preservation of systems that use information and communication technologies, among other provisions.
- Law 1341 of 2009: Defines principles and concepts related to the information society and the organization of information and communication technologies.
- BS 7799-3:2006: Provides guidance to support the requirements set forth by ISO/IEC 27001:2005 regarding all aspects to be covered in the risk management and analysis cycle when building an information security management system (ISMS).
- ISO/IEC TR 18044:2004: Provides advice and guidance on incident management for information security officers.
- Law 599 of 2000: Emphasizes copyright and incorporates some conduct indirectly related to computer crimes. It also states that abusive access to a computer system protected by security measures or against the will of the rightful owner may result in a fine [28].

On the other hand, the Ministry of Information Technology is responsible for promoting policies, plans and programmes in the field of information security. This is done through the information security and privacy model, which aims to preserve the confidentiality, integrity, and availability of information. As for its policies, information security events or incidents are handled in accordance with the Office of Information and Communications Technology"s Help Desk Security Incident Management Procedure.

In addition, this entity is responsible for assessing how information security incidents are events associated with non-compliance with security policies. These incidents are considered cybercrimes that violate current regulations and events that materialize dig

At a global level, we have the International Organization for Standardization (ISO) promoting a family of standards focused on information security, among which are the following:

- ISO 27000: This is the main standard in the series and contains the requirements for an information security management system. It originates from BS 7799-2:2002 [29].
- ISO 27001: Allows the assurance, confidentiality and integrity of data and information, as well as the systems that process them. It is mainly based on the identification and analysis of the main threats to information security [29].

- ISO 27002: Sets out best practices for information security. This standard is widely used as a reference to evaluate controls or verify compliance with various regulations and standards [29].
- ISO 27003: Serves as a manual for the implementation of an Information Security Management System and provides the necessary information for the implementation of the PDCA cycle [29].
- ISO 27005: Establishes guidelines for the management of information security risks. It is designed to support the general concepts specified in ISO 27001 and assist in the successful implementation of risk-based information security management [29].
- ISO 27011: This standard provides specific guidance for information security management for telecommunications. It has been developed jointly with the International Telecommunication Union [29].

6. REGULATIONS IN OTHER COUNTRIES COVERING THE IMPLEMENTATION OF 5G TECHNOLOGY VS. COLOMBIA

Since 2020, the European Union has developed a set of instruments to safeguard the security of the infrastructure and supply chain of 5G networks. These instruments include:

- Telecommunications and Cybersecurity Standard, which examines the implementing provisions relating to technical and organisational security measures [30].
- EU-wide certification under the EU Cybersecurity Regulation [30].
- Screening of foreign direct investment to protect the European supply chain of 5G networks [30].
- Competition rules, monitoring of the market to ensure competition, including possible situations of captivity [30].
- Public procurement, ensuring that security aspects are duly taken into account when awarding public contracts and through EU funding programmes [30].
- EU-wide incident response and crisis management frameworks to address large-scale cybersecurity incidents [30].

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In addition, Member States should ensure the integrity and security of public communications networks and that public communications networks or services take measures to manage security risks; The regulations also stipulate that national competent regulatory authorities have the power to issue binding instructions and ensure compliance [30].

Since March 2022, countries such as Spain have been using the "5G Cybersecurity Law", which consists of the minimum requirements to guarantee the security of electronic communications networks and services of this generation. This law, which has already been validated by the Congress of Deputies of the European Union, will allow the implementation of strategic measures to identify the main threats and vulnerabilities of the most sensitive assets and strategic risks in the deployment of 5G networks. The 5G cybersecurity law also establishes a procedure and criteria for classifying vendors as low, medium, and high risk; This means that operators cannot use equipment in the core of the network or in the management system [31].

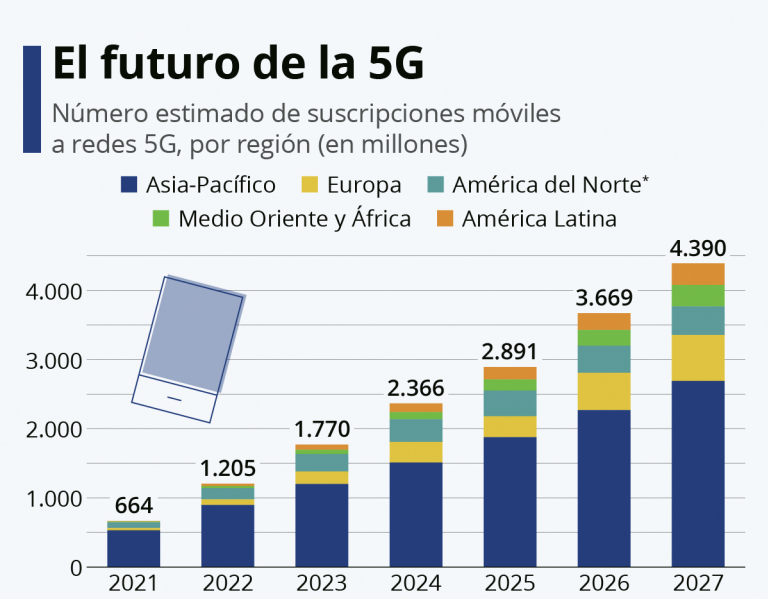
7. PROJECTION OF 5G COVERAGE WORLDWIDE AND IN COLOMBIA

According to a study by data analytics company Omdia, the first quarter of 2022 saw a 141% increase in 5G connections globally, with approximately 701 million people connected to this network. It is projected that by the end of 2026 there will be around 4.8 billion connections. Oceania, East and Southeast Asia, particularly China, are expected to continue to drive global trends, with this region accounting for 81.1% of total 5G subscriptions by the end of the first quarter of 2022. It is followed by North America, with the second-largest share of 5G subscribers at 11.7%," said Kristin Paulin, senior analyst at Omdia [32].

According to a report published by the Global Mobile Providers Association (GSA), 5G coverage is now available in more than 70 countries. This achievement has been reached in approximately 3.5 years since its launch, and it is expected to reach one billion connections in the year 2022. Compared to the 4G network, which took more than 4 years to reach the same milestone, and the 3G network, which took around 12 years, the growth of 5G has been significantly faster.

According to findings from Statista magazine, the United States and Europe are at the forefront of the implementation of 5G technology. However, Asia was a pioneer in this field. In Latin America, the countries that have invested the most in commercial launches are Chile, Uruguay and the Dominican Republic. Mexico and Bolivia have

moved from the investment phase to the deployment phase of this technology, according to the Global Association of Mobile Phone Providers (GSA) [33].



[34] Fig. 4. Statista, "Chart: 5G Could Surpass 1.2 Billion Subscribers This Year"
Source: https://es.statista.com/grafico/16309/numero-de-suscripciones-moviles-a-redes-5g/. [Accessed: 28 Feb. 2023].

8. 5G AND TECHNOLOGY LEADERSHIP

5G technology represents a significant breakthrough in telecommunications that will have a profound impact on the global digital economy. This new generation of mobile networks promises higher speeds, lower latency, higher capacity, and more reliable connectivity than previous generations like 4G or 3G [35]. According to Corral (2020), 5G opens up new opportunities in fields such as augmented reality, autonomous vehicles, telemedicine, digital education, among many others. It represents a real disruption that will change paradigms in the economy and society.

According to a Global Ecommerce Update 2021 report by eMarketer, by 2025 e-commerce is expected to account for 21.8% of retail sales globally, up from 14.1% in 2019 [36]. This forecast is based on factors such as internet penetration, the rise of digital shoppers, and market expansion in emerging countries. The exponential growth of e-commerce is closely linked to the development of telecommunications and, in particular, 5G technology.

China has shown great vision by developing a national plan to boost next-generation Artificial Intelligence, investing heavily in Research and Developmenet in this field [37]. The Made in China 2025 plan sets ambitious goals for China to be a global leader in artificial intelligence by 2030. It is estimated that by that date it could become number one worldwide, surpassing the United States [38]. 5G technology will be instrumental in supporting innovations in artificial intelligence, big data, IoT, and other emerging technologies.

In Latin America and the Caribbean, the adoption of 5G can contribute significantly to the region"s digital transformation, improving productivity, competitiveness, and well-being, according to a 2020 IDB report [39]. The study analyzes the potential of 5G in key sectors such as education, health, transportation, energy, digital government, among others.

Mexico and China have implemented strategies to incentivize e-commerce and the digital economy, although China leads the way in terms of vision and investment in these technologies [40][41]. González (2020) and González and Salamanca (2016) analyse the progress and challenges of both countries in the adoption of e-commerce and the path to 5G.

The race for leadership in 5G has not only economic, but also geopolitical implications. The United States considers 5G technology to be a matter of national security and has expressed concern about China"s dominance in this field, which has led to a "technological cold war" between these powers [42][43]. Donahue (2019) and Kania (2019) analyze the tensions in the U.S.-China relationship around 5G leadership.

Globally, it is recognised that 5G can play a key role in improving public health systems, for example in responding to pandemics such as COVID-19 [44]. A report by Deloitte (2020) analyzes 5G use cases in telemedicine and remote patient monitoring. It will also have applications in manufacturing, transportation, energy, among many other sectors [45]. Some use cases include autonomous vehicles, remote surgery, augmented reality, among others [46].

In conclusion, 5G technology represents a new era of connectivity that will transform the digital economy. Its early adoption by China will give it a potential competitive advantage, but leadership in 5G will have broader geopolitical implications [47] [48]. The United States will have to carefully define its strategy so as not to be left behind in this technological race [49].

9. VISION AND TRENDS TOWARDS 6G WIRELESS NETWORKS

Cellular networks have evolved rapidly over the past few decades, moving from 1G to 5G. Now, the research is focused on the next generation: 6G. Several recent papers look at the vision, requirements, applications, enabling technologies, and new paradigms of 6G networks [50]

An overview of 6G is presented in [50], describing use cases such as high-fidelity holographic communications, the tactile internet, the highly interconnected society, and integrated communications between Earth and space. 6G is expected to provide higher spectral and power efficiency, higher data rates (up to 1 Tbps), lower latency (up to 0.1 ms), and higher connection and mobility density (up to 1000 km/h). New frequency bands, such as millimeter waves and terahertz, will provide the necessary bandwidth. Artificial intelligence (AI) will play a key role in automating the network. Four new paradigms are identified: global coverage, full spectrum usage, full applications and integration with AI, and network security.

The authors in [51] present a speculative study on key technologies for 6G, including quantum communications, smart surfaces, fluid antennas, visible light communication, and wireless power transfer. They identify use cases such as augmented and virtual reality, remote surgery, autonomous vehicles, and Industry 4.0. Challenges include providing data rate Tbps, integrating terrestrial and satellite networks, and securing the network.

Candidate technologies for 6G at the physical and access layers are discussed in [52]. New waveforms, modulation, channel coding, massive MIMO systems, non-orthogonal multiple access, and optical communications in free space are explored. Propagation channels in different frequency bands and scenarios are also reviewed. Finally, challenges in real-time signal processing and RF transceiver design are discussed.

On the other hand, [53] focuses on the fundamental changes needed in transport and backbone networks to support 6G use cases, proposing a significant reduction of the current transport architecture to meet stringent latency requirements. Virtualization of centralized network functions as on-demand-enabled microservices is also discussed.

In short, 6G poses major challenges both at the physical and access layer and in backbone networks. Breakthroughs in all areas will be required to make the ambitious use cases and technical requirements a reality. Candidate technologies include terahertz-band communications, massive MIMO systems, more efficient network

protocols, and artificial intelligence. Much work remains to be done before 6G becomes a reality.

10. DISCUSSION AND CONCLUSIONS

This article has analyzed the current state of the implementation of 5G technology in Colombia compared to other regions, as well as the associated information security aspects. The most relevant findings are then discussed and conclusions are presented.

A first key aspect highlighted in the review is, while several successful 5G pilot schemes have been carried out in Colombia since 2019, large-scale deployment has not yet been achieved as has been seen in other countries. Pilot tests have made it possible to validate the operation of 5G technology and some innovative use cases such as video surveillance, remote education and industrial automation. However, the massive commercial phase is delayed, in part due to the impact of the pandemic on the original spectrum auction plans that were due to take place in 2021.

Another important conclusion is that regulatory barriers persist to the comprehensive implementation of 5G in Colombia. While the Ministry of ICT has promoted the pilot schemes and has plans to auction bands such as 700MHz and 3.5GHz, the regulatory roadmap that strongly incentivizes the necessary investments in 5G infrastructure at the national level has not yet been finalized. Aspects such as facilitating the deployment of small cells, the availability of more licensed spectrum, and the expansion of fiber optics for transport support require priority attention.

In terms of information security, a key finding is that Colombia has a robust cybersecurity regulatory framework, but effectively protecting future 5G networks poses significant challenges. The high connectivity, virtualization, automation, and new types of data that 5G technology will bring will require strengthening existing security measures and incorporating new capabilities.

On a positive note, the CRC regulator and the Ministry of ICT are mandated to impose strict cybersecurity requirements on operators, allowing them to require deployed 5G networks to have robust safeguards in place. This is key considering that 5G will enable critical services in sectors such as healthcare, transportation, energy, and finance.

However, a major challenge is to ensure the continuous updating of security measures and the training of specialized talent, given that cyber threats are constantly evolving. Colombia will have to invest in Research and Development, 5G cybersecurity and public-private coordination to proactively identify and mitigate new risks.

In the international context, the review allows us to conclude that Colombia is lagging behind in the race for 5G adoption compared to other regions. Leaders such as South Korea, China, Japan, and the United States launched 5G networks years earlier. Even in Latin America, Chile and Brazil are currently more advanced in commercial deployments.

This relative backwardness is partly explained by Colombia"s budgetary and market scale constraints vis-à-vis world powers. But it also reflects the need for a more aggressive vision and comprehensive plans that accelerate execution. Defining clear roadmaps, allocating sufficient resources, and facilitating the necessary investments in infrastructure should be priorities.

If proactive measures are not implemented, Colombia risks falling further behind in the adoption of 5G, missing out on the opportunities for economic growth and social development that this technology offers. On the positive side, the country has strong institutions and a growing innovation ecosystem that can be leveraged strategically.

In summary, based on the analysis carried out, the following key recommendations are made:

- The recent 5G spectrum auction carried out by the MinTIC through Resolution 03947 of 2023 represents an important regulatory advance to accelerate the deployment of 5G networks in Colombia.
- This objective selection process will allow the allocation of valuable spectrum slots in the 700MHz, 1900MHz, 2500MHz and 3500MHz bands to national mobile operators under different auction mechanisms.
- A positive aspect is that the auction seeks to maximise social welfare in access to spectrum, establishing obligations for 4G and 5G coverage in rural areas, as well as fibre optic connectivity in educational centres.
- The fact that up to 90% of the payment for spectrum blocks can be made by executing these obligations will accelerate the reduction of the digital divide.
- It is also the first time that Mobile Virtual Network Operators (MVNOs) have been allowed to participate in the spectrum allocation process in the country, which could promote greater competition.
- However, once the radio spectrum has been allocated through the auction, the main challenge will be for operators to make the large investments necessary to deploy the dense infrastructure of antennas, fiber optics and other platforms required by 5G networks.

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- It will also be key to overcome challenges such as boosting the adoption of 5G smartphones by users and strengthening cybersecurity in the face of new risks associated with this technology.
- In conclusion, the MinTIC"s 5G spectrum auction lays solid regulatory foundations to accelerate the deployment of next-generation networks in Colombia. But the main challenges lie ahead in terms of investments, mass adoption and management of new technological risks by all the actors involved.
- Strengthen public-private coordination on cybersecurity by creating a high-level committee focused on 5G. This will facilitate the exchange of threat information and the definition of joint mitigation measures.
- Promote the training of human talent specialized in 5G networks and associated cybersecurity through relevant technical and university programs. This will ensure that the necessary capabilities are in place.
- Encourage the development of innovative applications that take advantage of 5G functionalities, in areas such as telemedicine, digital education, industrial IoT, autonomous vehicles and entertainment.
- Conduct mass communication campaigns to inform citizens about the advantages of 5G. This will help drive adoption and demand for 5G services when the commercial phase begins.
- The implementation of these recommendations will require close coordination between the Ministry of ICT, the CRC, telecommunications operators, academia and other relevant actors in the 5G and cybersecurity ecosystem in Colombia.
- Executing a clear roadmap for the deployment of 5G networks nationwide should be a public policy priority. This technology represents a crucial platform for the country"s digital transformation over the next decade. Making the most of its benefits will depend on the strategic vision and effective execution of plans by decision-makers.
- Colombia has the necessary capabilities to implement 5G as an enabler of economic and social development. But it will require building on the foundations already established with deliberate execution, targeted investments, and a comprehensive roadmap that brings together all players in the 5G ecosystem. This will make it possible to maximise the opportunities offered by this innovative technology.

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