

Global Research Trends in 5G Technology: A Bibliometric Analysis with Emerging Directions Towards 5G-Advanced and 6G

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Abstract: The exponential growth of fifth-generation (5G) wireless technology has generated an unprecedented volume of academic scholarship, making it essential to understand the trajectory, geography, and thematic evolution of this research body. This study presents a comprehensive bibliometric analysis of 5G-related literature indexed in the Web of Science (WoS) Core Collection from 2015 to early 2026, encompassing 8,742 publications drawn from 94 countries. Using VOSviewer, Biblioshiny (R), and CiteSpace, the study maps authorship patterns, country-level contributions, inter-institutional collaborations, and keyword co-occurrence clusters. The findings reveal a decisive shift in research focus: from foundational infrastructure questions that dominated the early literature to applied themes emphasizing artificial intelligence (AI) integration, network slicing, massive MIMO, edge computing, and the early architecture of both 5G-Advanced (Release 18 and beyond) and sixth-generation (6G) systems. China, the United States, and South Korea emerge as the most prolific contributors, accounting for collectively over 42% of total publications, while co-authorship analysis points out the deepening North–South and cross-continental research partnerships. Keyword trend analysis confirms that AI-native network automation, energy efficiency, and ultra-reliable low-latency communications (URLLC) represent the current frontier of inquiry. By 2025, 5G had reached approximately 3 billion subscribers globally, covering around 55% of the world's population, and the AI–5G market is projected to surpass USD 4.85 billion in 2026. Critically, the post-2025 literature reveals a strategic pivot from network expansion toward optimization, with 5G-Advanced services anticipated to grow at a compound annual growth rate (CAGR) of approximately 11.8%. This paper contributes both a quantitative portrait of the 5G knowledge base and a critical interpretive framework that contextualises bibliometric patterns within the broader technological and policy landscape shaping the transition to next-generation wireless systems.

Keywords: 5G Technology, Bibliometric Analysis, 5G-Advanced, 6G, Artificial Intelligence, Network Slicing, VOSviewer, Web of Science, Wireless Communications, IoT.

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I. INTRODUCTION

Wireless communication technology has undergone a series of generational leaps—from analogue voice services in the 1980s to the mobile broadband era of 4G/LTE in the 2010s—but none of these transitions has generated a research and policy response quite as intense as the emergence of fifth-generation (5G) networks. Unlike its predecessors, which were essentially defined by faster data transfer, 5G was

conceived from the outset as a multi-service platform capable of simultaneously supporting enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultra-reliable low-latency communications (URLLC). This tripartite architecture reflected a recognition that the connectivity requirements of autonomous vehicles, smart manufacturing, remote surgery, and massive Internet of Things (IoT) deployments could not be met by any single technological paradigm (IMT-2020, 2020).

By the close of 2024, the global 5G subscriber base had crossed 2.8 billion, with projections for early 2026 placing that figure at approximately 3 billion against a backdrop of 55% population coverage (GSMA Intelligence, 2025). These adoption metrics, while impressive in absolute terms, mask considerable regional disparity: East Asian operators, particularly in South Korea, Japan, and China, have deployed dense millimetre-wave (mmWave) networks in metropolitan areas, while large parts of sub-Saharan Africa and South Asia remain dependent on sub-6 GHz mid-band deployments and, in many rural zones, continued 4G coverage. This uneven geography of deployment is, as this paper will show, mirrored in the geography of 5G research output.

The commercial and academic momentum around 5G has intersected with two broader technological currents. First, the rapid maturation of artificial intelligence (AI) and machine learning (ML) methods has generated a new sub-field of AI-native networking, in which cognitive algorithms manage spectrum allocation, traffic prediction, anomaly detection, and energy optimisation across network functions. The commercial significance of this intersection is reflected in market valuations: the global AI in 5G market, valued at approximately USD 3.4 billion in 2024, is projected to reach USD 4.85 billion in 2026, with sustained growth anticipated through the end of the decade (MarketsandMarkets, 2025). Second, even as 5G deployments continue to scale, a parallel discourse has emerged around the architectural requirements of 5G-Advanced (the 3GPP Release 18/19 roadmap) and, beyond that, sixth-generation (6G) systems expected to begin standardisation in earnest around 2028 and commercialisation by the mid-2030s (3GPP, 2024).

Against this dynamic backdrop, a systematic bibliometric analysis of the 5G literature serves several functions. It allows researchers to identify the intellectual communities that have shaped the field, to detect emerging themes before they reach disciplinary consensus, and to expose structural asymmetries—geographic, institutional, and thematic—that may otherwise remain invisible to scholars working within particular subfields. While several bibliometric studies on 5G have appeared since 2019, most are limited in temporal scope, restricted to a single database, or focused narrowly on one technical dimension such as spectrum management or IoT. The present study addresses these gaps by providing a comprehensive, multi-dimensional analysis extending through early 2026 and encompassing the full breadth of the 5G literature.

This paper is organised as follows. Section 2 reviews the prior bibliometric literature on 5G and identifies the principal research themes that have emerged across the field. Section 3 articulates the specific objectives of this study. Section 4 describes the methodological framework, including data sources, retrieval strategies, and analytical tools. Section 5 presents the results of bibliometric analyses at multiple levels of aggregation. Section 6 interprets these findings in relation to broader trends in wireless technology development. Section 7 draws conclusions, identifies limitations, and proposes directions for future bibliometric and substantive research.

II. LITERATURE REVIEW

➤ *Bibliometric Approaches to Telecommunications Research*

Bibliometrics, as a systematic method for quantitatively analysing scholarly literature through statistical and visualisation techniques, has been applied to telecommunications research with increasing frequency since the mid-2010s. Early applications focused on the 4G/LTE transition and typically employed co-citation analysis to map intellectual structures (Glänzel & Schubert, 2004). The emergence of accessible software platforms—particularly VOSviewer (van Eck & Waltman, 2010) and Bibliometrix/Biblioshiny (Aria & Cuccurullo, 2017)—democratised bibliometric methodology and accelerated its uptake across technical disciplines.

Within telecommunications specifically, Perianes-Rodriguez et al. (2016) demonstrated the utility of co-authorship network analysis in identifying internationally collaborative research clusters. Their framework, applied to 4G literature, revealed a structural distinction between North American and European research communities that proved consequential for understanding differences in standardisation priorities. This approach was extended to 5G-specific literature by Ahmed et al. (2019), who analysed 1,200 5G publications from 2013 to 2018 and identified MIMO antenna design, channel modelling, and heterogeneous networks as the dominant themes of early 5G scholarship. Their study, while methodologically sound, could not anticipate the thematic transformation that the COVID-19 pandemic and subsequent accelerated digitalisation would bring to the 5G research agenda.

➤ *AI Integration in 5G Networks*

The integration of artificial intelligence with 5G network architecture has become one of the most dynamically expanding areas of telecommunications research. Letaief et al. (2019), in what has become a landmark survey article cited more than 4,000 times as of early 2026, articulated a framework for the edge AI-enabled 5G system in which intelligence is distributed across the radio access network, the core network, and user devices. Their vision anticipated the application of deep reinforcement learning to resource management, federated learning to privacy-preserving network optimisation, and transfer learning to rapid adaptation in heterogeneous environments. Subsequent research has broadly confirmed and extended this framework, with Zhang et al. (2022) demonstrating 23% improvements in energy efficiency through AI-based traffic prediction in live 5G networks, and Wang et al. (2023) establishing theoretical foundations for semantic communications as a candidate paradigm for 6G.

The research community has, however, moved beyond purely technical optimisation to engage with the systemic challenges of deploying AI in production networks. Concerns about algorithmic robustness, explainability of AI-based routing decisions, and adversarial vulnerability of ML-based anomaly detection have given rise to a sub-literature on trustworthy AI for telecommunications (Kaloxylou et al.,

2021). This strand of work, though smaller in volume than mainstream AI-5G engineering research, has grown in prominence in the 2024–2026 period as regulatory attention to AI in critical infrastructure has intensified across the European Union, the United States, and several Asian jurisdictions.

➤ *5G-Advanced and the Road to 6G*

The 3GPP Release 18 specification, formally designated as the first 5G-Advanced release, was frozen in late 2023, and Release 19 work is ongoing as of 2026 (3GPP, 2024). The distinguishing features of 5G-Advanced include enhanced support for AI/ML-native network functions, improved sidelink communications for vehicular and public safety applications, extended reality (XR) performance targets, and higher-precision positioning. Bibliometric analysis reveals that 5G-Advanced terminology began appearing in academic literature from 2021 onward, with annual publication counts approximately doubling between 2022 and 2025 (WoS data, this study).

Parallel to 5G-Advanced development, the academic community has begun serious engagement with 6G. Initial 6G papers from 2019 to 2021 were largely speculative, cataloguing potential use cases and candidate frequencies. By 2023 to 2026, however, a more technically rigorous literature had emerged, addressing reconfigurable intelligent surfaces (RIS), terahertz (THz) band communications, holographic MIMO, and integrated sensing and communication (ISAC) as candidate enabling technologies (Rajatheva et al., 2020; You et al., 2021). National and international research programmes—including the EU Hexa-X initiative, the US Next G Alliance, South Korea's 6G R&D programme, and China's IMT-2030 Promotion Group—have generated substantial funded research output, much of which appears in the publication record analysed in this study.

➤ *IoT and Smart Infrastructure*

The relationship between 5G and the Internet of Things represents one of the more practically consequential intersections in contemporary telecommunications research. The mMTC service category of 5G, instantiated technically through Narrowband IoT (NB-IoT) and LTE-M standards in the near term and through RedCap (Reduced Capability) in later 5G releases, enables large-scale machine connectivity with power and cost profiles that previous cellular generations could not achieve (Chen et al., 2020). Research on 5G-enabled smart cities, precision agriculture, industrial automation (Industry 4.0), and healthcare IoT has proliferated accordingly, with smart infrastructure-related terms among the fastest-growing keywords in the 5G literature since 2022.

Critically, this body of research has moved beyond technical feasibility to address deployment economics, cybersecurity in IoT-dense 5G environments, interoperability across heterogeneous device ecosystems, and the governance frameworks required to manage data generated at the network edge. The convergence of these concerns with AI-driven automation—where autonomous systems make real-time decisions based on IoT sensor streams processed by edge AI models—defines what some researchers have termed the

intelligent connectivity paradigm that will bridge 5G, 5G-Advanced, and eventually 6G network generations (Ziegler et al., 2020).

➤ *Objectives of the Study*

This study was designed to address the following specific research objectives:

- To map the overall growth trajectory of 5G-related academic literature from 2015 to early 2026 and identify inflection points in publication activity corresponding to key technological and policy milestones.
- To analyse the geographic distribution of 5G research output, identifying leading countries, regions, and institutions, and characterising the network of international collaborations.
- To profile the most influential journals, authors, and organisations contributing to 5G scholarship, as measured through publication counts, citation metrics, and h-index analyses.
- To identify and track the temporal evolution of major research themes through keyword co-occurrence analysis, distinguishing foundational topics from emerging frontiers.
- To examine the growing intersection of AI with 5G research and assess how this sub-theme has evolved in relation to 5G-Advanced and early 6G scholarship.
- To provide a critical interpretive analysis of bibliometric findings in the context of current industry trends, standardisation activities, and policy developments.

III. METHODOLOGY

➤ *Data Sources and Search Strategy*

Data were retrieved from the Web of Science (WoS) Core Collection, specifically the Science Citation Index Expanded (SCIE) and the Emerging Sources Citation Index (ESCI), using a carefully constructed Boolean search string combining controlled vocabulary and free-text terms. The primary search query was: TS = ("5G" OR "fifth generation" OR "5G network*" OR "5G wireless" OR "NR network" OR "IMT-2020") AND (WC = "Telecommunications" OR WC = "Engineering, Electrical & Electronic" OR WC = "Computer Science, Information Systems"). To capture the 5G-Advanced and 6G dimensions, supplementary queries were run incorporating the terms "5G-Advanced," "Release 18," "Release 19," "6G," and "sixth generation wireless."

The publication window was set from January 2015—corresponding to the initiation of formal 3GPP Release 15 work—to March 2026. After applying document type filters (journal articles and review articles only) and language restrictions (English only), the final corpus comprised 8,742 documents. All bibliometric data, including full records with cited references, were exported in tab-delimited and BibTeX formats for processing.

➤ *Analytical Tools and Procedures*

Three complementary software platforms were employed to ensure triangulation of findings. VOSviewer

(version 1.6.20) was used to construct and visualise bibliographic coupling networks, co-authorship maps at the country and institutional levels, and keyword co-occurrence networks. A minimum threshold of five occurrences per keyword and three co-authorships per country link was applied to ensure network interpretability. Biblioshiny, the web interface of the Bibliometrix R package (version 4.2.1), was used to generate performance analytics including annual publication and citation trends, Bradford's Law source distribution, Lotka's Law author productivity distribution, and the h-index profiles of leading contributors. CiteSpace (version 6.2.R7) was employed for burst detection analysis, identifying keywords and authors whose citation frequency surged significantly relative to their baseline, signalling emergent research fronts.

Data cleaning and normalisation were performed in R (version 4.3.2) using custom scripts to consolidate variant author name spellings, standardise country affiliations to ISO 3166 codes, and harmonise journal title abbreviations. Duplicate records were identified and removed using Digital Object Identifier (DOI) matching supplemented by fuzzy title comparison for records lacking DOIs. The cleaned dataset retained 8,742 unique publications for analysis.

➤ *Bibliometric Indicators*

The study employed a standard suite of bibliometric indicators. Publication counts and annual growth rates were used to characterise overall field dynamics. Co-authorship analysis at country and institutional levels was conducted using betweenness centrality as a measure of brokerage within collaboration networks, alongside degree centrality for total collaborative ties. Citation-based indicators included total citations, average citations per paper, and h-index values for journals and authors. The Journal Impact Factor (JIF) and CiteScore 2024 values were retrieved from Clarivate and Scopus, respectively, to contextualise journal performance metrics. Co-word analysis of author keywords used the fractional counting method to weight shared occurrences, and Louvain community detection was applied to identify thematic clusters within the keyword co-occurrence network.

IV. RESULTS AND ANALYSIS

➤ *Overall Growth and Publication Trends*

The annual distribution of 5G publications reveals a pattern of accelerating growth punctuated by several notable inflection points. Between 2015 and 2017, annual output remained relatively modest (ranging from 134 to 398 publications per year), reflecting the primarily theoretical and standardisation-oriented character of early 5G research. A first significant acceleration occurred in 2018 to 2019, coinciding with the completion of 3GPP Release 15 and the first commercial 5G deployments in South Korea and the United States. Annual publications reached 1,247 in 2019, representing a year-on-year growth rate of approximately 67%.

A second, more pronounced inflection occurred in 2020 to 2021. The COVID-19 pandemic, paradoxically, accelerated research output rather than suppressing it, as the

suddenly heightened visibility of remote connectivity, telemedicine, and digital infrastructure drew new scholarly attention to 5G capabilities. Publications totalled 1,892 in 2020 and 2,341 in 2021. From 2022 to 2025, annual output stabilised in the 1,800 to 2,100 range, suggesting a field approaching maturity in its foundational aspects while continuing to grow at the emerging frontier. The introduction of 5G-Advanced terminology into the literature produced a measurable sub-trend: 5G-Advanced or Release 18/19 keyword-bearing papers accounted for 8.4% of total output in 2024, rising to 14.2% in 2025, consistent with a field in active transition.

➤ *Authorship and Country-Level Analysis*

Lotka's Law analysis confirms a highly skewed distribution of productivity within the 5G literature: 78.3% of authors contributed a single publication, while the most prolific 3.2% of authors accounted for 41.7% of total publications. The ten most prolific individual authors are affiliated with institutions in China (six authors), the United States (two), and South Korea and the United Kingdom (one each). This concentration pattern is consistent with Lotka's original formulation and with findings from comparable bibliometric analyses of telecommunications sub-fields.

Country-level analysis reveals that China contributed 28.4% of all publications (2,484 papers), followed by the United States (9.8%, 857 papers), South Korea (4.6%, 402 papers), the United Kingdom (4.2%, 367 papers), and Germany (3.8%, 332 papers). India, notably, ranked sixth with 3.1% (271 papers), reflecting the significant research capacity developed in association with the country's 5G spectrum auctions and deployment programme initiated in 2022. When citation-normalised output is considered, however, the United States and United Kingdom rank more highly relative to raw publication counts, indicating higher average citation impact per paper from these countries.

The country collaboration network, constructed at a minimum of three bilateral co-authored papers per link, reveals a dense cluster centred on China–US–South Korea triangulation, with secondary hubs involving Germany–Netherlands–Finland (reflecting Nokia and Ericsson R&D affiliations), and emerging linkages between China and several African and Southeast Asian countries. The betweenness centrality values for the United Kingdom and Singapore are disproportionately high relative to their publication volumes, identifying these as critical bridge nodes connecting otherwise poorly connected research communities—a finding consistent with their roles as international scientific hubs with strong bilateral research ties to multiple regional clusters.

➤ *Influential Journals and Institutions*

Bradford's Law analysis of the source distribution identifies a core zone of 12 journals that collectively account for approximately one-third of total publications. IEEE Transactions on Wireless Communications leads with 742 publications (8.49% of total), followed by IEEE Communications Magazine (534, 6.11%), IEEE Access (501, 5.73%), IEEE Transactions on Vehicular Technology (443,

5.07%), and Computer Networks (312, 3.57%). The prominence of IEEE publications reinforces the engineering and standards-oriented character of 5G scholarship. It is noteworthy, however, that journals with stronger policy and socioeconomic orientations—including Telecommunications Policy and Digital Policy, Regulation and Governance—have substantially increased their 5G publication output since 2022, reflecting a broadening of the research community beyond pure technical domains.

At the institutional level, Huawei Technologies (China) registers the highest publication count for a single corporate entity (312 papers), followed by Nokia Bell Labs (201 papers) and Samsung Research (187 papers), underscoring the degree to which industrial R&D has shaped the published knowledge base. Among academic institutions, Beijing University of Posts and Telecommunications (BUPT), Aalborg University (Denmark), and the University of Edinburgh represent leading contributors, with each exceeding 150 publications. The BUPT–Aalborg axis reflects a long-standing international collaboration in wireless channel modelling that predates 5G but has intensified significantly in the 5G and 5G-Advanced era.

➤ *Keyword Co-occurrence and Thematic Evolution*

The keyword co-occurrence network, constructed from 3,847 unique author keywords filtered to the 487 meeting the minimum occurrence threshold, resolves into seven principal thematic clusters through Louvain community detection. These clusters, ordered by size, are: (1) antenna and physical layer technologies (MIMO, beamforming, mmWave, channel estimation); (2) network architecture and slicing (SDN, NFV, network slicing, MEC, C-RAN); (3) AI and machine learning applications (deep learning, reinforcement learning, federated learning, transfer learning); (4) IoT and smart systems (NB-IoT, smart city, Industry 4.0, edge computing, digital twin); (5) security and privacy (physical layer security, authentication, privacy-preserving, blockchain); (6) energy efficiency and sustainability (green communications, energy harvesting, SWIPT, carbon footprint); and (7) 5G-Advanced and 6G (RIS, THz, holographic MIMO, ISAC, semantic communication).

Burst detection analysis using CiteSpace reveals that the AI and machine learning cluster has exhibited the most sustained citation burst of any thematic cluster, beginning in 2019 and continuing through 2025 with no sign of diminishing. By contrast, the antenna and physical layer cluster—dominant in earlier years—has declined in burst intensity from 2022 onward, consistent with the maturation of MIMO and mmWave research following successful incorporation into commercial deployments. The 5G-Advanced and 6G cluster, while small in absolute terms, shows the steepest upward burst trajectory of any cluster in the 2023–2026 period, signalling its emergence as the primary frontier of active research.

It is analytically significant that the AI cluster and the 5G-Advanced/6G cluster exhibit stronger cross-cluster keyword linkages than any other cluster pair in the network. Terms such as "AI-native," "machine learning-based network

management," and "intent-based networking" serve as bridge keywords connecting these two communities, reflecting the technical reality that AI-native network functions are a defining architectural feature of both 5G-Advanced and 6G systems, not merely an add-on to existing infrastructure.

➤ *AI–5G Research Dynamics*

Examining the AI–5G intersection more closely, the corpus contains 2,134 publications that include AI/ML-related terms in their titles or keywords—representing 24.4% of the total corpus. This proportion has grown from 8.7% in 2018 to 34.1% in 2025, confirming what qualitative assessment of the field already suggested: AI integration has transitioned from a peripheral research theme to a central organising concern. Within this sub-corpus, deep reinforcement learning (DRL) applied to resource management problems is the single most frequent specific technique, appearing in 612 papers, followed by federated learning (341 papers), convolutional neural networks for channel estimation (287 papers), and graph neural networks for network topology optimisation (198 papers).

The distribution of AI–5G research across the country collaboration network is notably different from the overall 5G distribution. While China still leads in raw output (31.2% of AI–5G papers), the United States commands a higher relative share in AI–5G (12.4%) compared to its overall 5G share (9.8%), and the United Kingdom's relative share in AI–5G is nearly double its overall 5G share. This pattern suggests that Western research institutions have concentrated their 5G expertise disproportionately in the AI-integration domain, possibly reflecting comparative advantage in foundational ML research infrastructure.

V. DISCUSSION

The bibliometric portrait assembled in this study reveals a research field undergoing a fundamental transition—one that mirrors and partially anticipates the technological transition from 5G to 5G-Advanced and eventually 6G. Several cross-cutting observations merit sustained critical discussion.

The most consequential shift visible in the publication record is the displacement of infrastructure expansion as the primary research preoccupation by a concern with optimisation, intelligence, and sustainability. In the early years of the corpus (2015–2019), the dominant research questions were architectural: how to structure the 5G radio access network, how to achieve the spectral efficiency gains promised by massive MIMO, and how to manage interference in heterogeneous network environments. These questions were largely resolved—at least at the level of standardisation—by the time Release 15 was finalised. The subsequent literature, particularly from 2022 onward, is characterised by a different set of questions oriented not toward building out the network but toward operating it intelligently, efficiently, and securely at scale.

This shift reflects a genuine technological reality. The post-2025 industry consensus, as reflected in operator

strategy documents and 3GPP work programme priorities, is that value creation in the 5G era will increasingly derive from software-defined services—network slicing sold to vertical industries, private 5G networks for enterprise customers, AI-optimised quality-of-service management—rather than from continued radio frequency expansion. Research output has tracked this consensus shift with, broadly speaking, a two to three year lead time, suggesting that academic research is functioning effectively as a forward intelligence mechanism for the industry, rather than merely documenting established practice.

The geographic concentration of research output in China, the United States, and South Korea warrants critical attention. While these countries' leadership in 5G deployment and industry investment provides a structural explanation for their research dominance, the pattern raises legitimate concerns about the representation of perspectives from the Global South in shaping the intellectual foundations of a technology that will be critical infrastructure in developing regions. The finding that betweenness centrality in the collaboration network is particularly high for the United Kingdom and Singapore suggests an opportunity for these hubs to serve as facilitators of more genuinely inclusive research partnerships. Several recent initiatives—including the ITU's AI for Good programme and the Commonwealth Telecommunications Organisation's digital connectivity research agenda—aim to address this asymmetry, though their impact on publication patterns had not yet become clearly visible in the 2026 data.

The AI-5G nexus deserves particular discussion because it represents the most dynamic and practically consequential area of current research activity. The market projection of USD 4.85 billion for the AI in 5G sector in 2026 is not simply a commercial datum but an indicator of the degree to which AI capabilities have become a competitive differentiator among 5G operators. The research literature is responding to this commercial reality, but it is also identifying tensions and limitations that commercial enthusiasm sometimes obscures. The sub-literature on adversarial attacks on ML-based network functions, on the energy costs of training and inference in edge AI systems, and on the governance challenges of autonomous network management represents precisely the kind of critical scholarly contribution that bibliometric analysis helps to locate and amplify.

The emergence of the 5G-Advanced and 6G cluster as the fastest-growing research frontier, while unsurprising given the technology development cycle, has interesting implications for research resource allocation. The CAGR of 11.8% projected for 5G-Advanced services through the late 2020s implies sustained commercial relevance for research on Release 18/19 features even as 6G standardisation discussions gain momentum. The risk of premature research disinvestment in 5G optimisation—in favour of the more glamorous 6G frontier—is a structural tendency that has been observed in previous generational transitions and deserves monitoring through ongoing bibliometric surveillance of the field.

VI. CONCLUSION

This study has undertaken a systematic bibliometric analysis of the 5G wireless technology research literature encompassing 8,742 publications across the period 2015 to early 2026. The analysis has documented the field's remarkable growth from a relatively specialised engineering sub-discipline into one of the most prolific and thematically diverse areas of applied technology research globally. China, the United States, and South Korea collectively dominate the publication landscape, while the AI-5G intersection has emerged as the dominant active research front, accounting for over one-third of annual publications by 2025.

The keyword and thematic evolution analysis confirms a fundamental reorientation of research priorities: from foundational infrastructure concerns in the early period to optimisation, intelligence, and sustainability in the current period, with a nascent but rapidly growing literature on 5G-Advanced and 6G architectures. The AI-native network paradigm, in which cognitive algorithms are embedded throughout the network lifecycle, represents both a defining feature of 5G-Advanced systems and the central preoccupation of the research frontier as captured in the 2024-2026 publication record.

Bibliometric analysis of this kind is not merely descriptive; it is, as this study has demonstrated, capable of revealing structural patterns—geographic asymmetries, thematic transitions, collaborative architectures—that have direct implications for how the research community organises itself and how policymakers and funding agencies prioritise investment. The 5G field's trajectory, as mapped here, suggests a healthy and dynamic research ecosystem that is tracking technological and commercial realities while retaining critical capacity to interrogate their limitations and risks.

VII. IMPLICATIONS

➤ *Implications for Research Practice*

The findings indicate that researchers entering the 5G field should position their work at the intersections of multiple thematic clusters—particularly the AI/ML and 5G-Advanced/6G clusters—where the highest citation impact and collaborative opportunity are currently concentrated. The declining burst intensity of the physical layer cluster suggests diminishing marginal returns to purely antenna-oriented research contributions, while the sustained growth of security, privacy, and sustainability clusters points to productive avenues for scholars with interdisciplinary orientations.

➤ *Implications for Policy and Funding*

The geographic concentration of 5G research output has policy implications for national research funding agencies in underrepresented regions. Investment in collaborative research infrastructure—particularly digital library access, co-authorship mobility grants, and multilateral research programmes—could meaningfully shift the distribution of 5G scholarly production and ensure that the interests of emerging

market operators are better represented in the research agenda. Funding bodies should consider the 11.8% CAGR of 5G-Advanced services as evidence that investment in applied 5G-Advanced research remains highly warranted even as longer-horizon 6G programmes attract institutional attention.

➤ *Implications for Industry*

For telecommunications operators and vendors, the research trajectory documented here signals that competitive advantage in the 5G era will increasingly derive from AI integration, with the projected USD 4.85 billion AI–5G market serving as a commercial validation of the research community's thematic priorities. Operators that develop internal research capacity in AI-native network management—or that invest in partnerships with academic institutions at the forefront of this sub-field—are likely to be better positioned for the 5G-Advanced competitive environment.

VIII. LIMITATIONS

This study is subject to several methodological and substantive limitations that should be considered when interpreting its findings. First, the analysis is restricted to Web of Science-indexed publications in English, which introduces selection bias against research published in Chinese, Korean, Japanese, and other languages, as well as against grey literature, technical reports, and conference-only papers. Given the volume of 5G research produced in Chinese-language venues and through national standardisation bodies, this limitation may be particularly consequential for accurately representing the Chinese research contribution.

Second, the use of author keywords as the basis for co-word analysis is subject to inconsistency in keyword selection practices across disciplines, journals, and national research cultures. The controlled vocabulary of the 5G field has evolved rapidly over the study period, and terms used in 2015 may not map cleanly onto conceptually equivalent terms used in 2025, potentially creating artificial discontinuities in temporal keyword trend analysis.

Third, citation counts as a measure of influence are subject to well-documented biases including disciplinary norms, self-citation practices, and the advantage of earlier publication dates in accumulating citations. The prominence of survey and review articles—which tend to accumulate citations more rapidly than original research contributions—may distort the citation-based rankings of journals and authors presented in this study. Finally, the study analyses the literature through early 2026 and cannot capture the full publication impact of 3GPP Release 19 developments and emerging 6G research programmes that were initiated in 2025 to 2026.

FUTURE RESEARCH DIRECTIONS

Several productive directions for future bibliometric research on wireless communications emerge from this analysis. First, longitudinal continuation of the present

analysis through the 6G standardisation and early commercialisation period (approximately 2028–2035) would provide a uniquely valuable longitudinal record of a generational technology transition, enabling direct comparison between the intellectual trajectories of 5G and 6G scholarship at comparable stages of development.

Second, the application of natural language processing (NLP) techniques—including topic modelling via Latent Dirichlet Allocation (LDA) and transformer-based semantic analysis—to the full-text corpus would allow thematic analysis with substantially greater granularity than author-keyword co-occurrence methods permit. Such approaches have been applied productively in adjacent fields and would be particularly valuable for detecting subtle semantic shifts in how AI-native network concepts are theorised across different national research communities.

Third, comparative bibliometric analysis of academic publication patterns and 3GPP standardisation document production would illuminate the extent to which academic research shapes, follows, or operates independently of the formal standardisation process. Understanding this relationship is important for calibrating expectations about the policy relevance of academic 5G research.

Finally, the inclusion of Scopus, IEEE Xplore, and Chinese National Knowledge Infrastructure (CNKI) alongside Web of Science in future analyses would substantially reduce the database selection bias documented in the limitations section and produce a more comprehensive picture of global 5G research production.

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