Research status and Frontier hotspots of 5G technology based on visualization

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Abstract. The 5G era has come, Scholars' research focuses on 5G technology and applications. Based on the 5G technology-related literature data collected by the WOS, Derwent Innovations Index, this article uses CiteSpace V visualization software to find and explore research hotspots and frontier trends through keyword clustering analysis, mutation detection. Based on the above analysis, it is intended to provide theoretical reference for scholars in this field.

1. Introduction
With the continuous development of information and communication technology, mobile wireless networks have become an indispensable part of our lives, studies, and work. While the technology itself is constantly being updated, mobile communications are constantly evolving and developing, from 2G to 3G to 5G at this stage. In the fierce international competition, the information and communication industry can only seize the commanding heights of the market and control the voice of the industry only through innovation and development. This article identifies and trend detection of core technologies in 5G technology research, and then captures the latest international trends and cutting-edge research directions.

2. Research methods and data sources
Due to the variability of research frontiers, how to track, mine, and capture the latest international trends and cutting-edge research issues from massive, complex, and unstructured information intelligence poses a serious challenge to researchers in related fields. Under the premise of grasping the characteristics of frontier information, different approaches and methods should be adopted to find important information in different research fields. The combination of qualitative and quantitative analysis can complement and verify each other, so as to make the frontier research dynamics comprehensive and accurate.

This article uses the 5G technology research literature in the WOS core collection database, the Derwent Innovations Index database as the data source to construct the English search formulas and set the relevant search conditions. After screening and deduplication, the results are obtained 6884 related English documents, 20032 patent documents.

3. Analysis of 5G technology research hotspots
The mining of research hotspots is a complex task, and it is constantly changing with the development of research fields and time. Keywords can reflect the research objects and research intentions of
researchers, and are a high-level generalization and summary of the subject of the literature. Analyzing the frequently occurring keywords can quickly and effectively lock the hot issues and major issues in this field. Aiming at the subject scope and evolution method involved in the 5G technology research field, CiteSpace software is used to perform co-occurrence analysis and cluster analysis on keywords in the literature.

3.1. Keyword co-occurrence analysis

Run the CiteSpace software to perform a statistical analysis on the keyword information of the literature. A total of 864 keywords appeared in 6884 English literature, with a cumulative frequency of 29174 times. Analyze the frequency of keywords. In addition to the general high-frequency keywords of 5G, the frequency of 5G keywords is network, system, design, and resource allocation in the range of 500-1000. Judging from the top 10 keywords in the frequency ranking in Figure 1, the English literature focuses on 5G networks, system design, resource allocation, optimization, mimo, wireless networks as the main research directions. It can be seen that a lot of research has been done on the basic work of 5G, including 5G theoretical research, system architecture, system design, etc.

![Knowledge map of keywords co-occurrence in English literature on 5G technology research.](image1)

![Knowledge map of keywords co-occurrence in Patent literature on 5G technology research.](image2)

Analyzing the patent information with common words, there are 197 nodes in Figure 2. Based on the frequency of occurrence and the size of betweenness centrality, the top 10 key technologies are...
selected for analysis. The nodes in the 5G patent key technology co-occurrence knowledge graph are Derwent manual codes, and the size of the ring and the number of connecting lines reflect its importance. The top 5 technologies in the comprehensive ranking are W01-A06C4 (wireless connection), W02-C03C1L (wireless communication system), W01-C01D3C (portable handheld device), T01-S03 (software copyright patent), W02-C03G1 (resource allocation technology). The patented technology with the highest frequency and the most co-occurrence is “W01-A06C4”, and the corresponding field is wireless connection.

3.2. Keyword cluster analysis
Perform cluster analysis on keywords in English literature to form 10 cluster labels, representing 10 research hotspots. See Figure 3 for details. Select the LLR algorithm and automatically identify the keywords. When the clustering module value (Q value) is greater than 0.3, the cluster structure is significant. When the cluster average contour value (S value) is greater than 0.5, the clustering result is reasonable 0.7 means that the results are convincing[1].

![Figure 3. Clustering diagram of English keywords for 5G technology research.](image)

The Q value and S value in the English keyword cluster map in Figure 3 are 0.4999 and 0.7433 respectively, so the map is reasonably usable. The 10 research hotspots in English literature are multi-server architecture, 5G applications, resource allocation, NOMA system, PAPR (peak-to-average ratio) reduction, deep learning, polar codes, design challenges, 5G framework, and battery radiation. Here is a brief analysis of the top three research hotspots:

(1)The multi-server architecture has a total of 254 members as the largest cluster, and the profile value is 0.63. Regarding the research of multi-server architecture, Monserrat, Jose F. et al. proposed the concept of METIS system in 2015, explained the main functions of its architecture, and discussed the challenges faced by future research work[2]. Panneerselvam, John et al. proposed the Mobilouds architecture solution in 2016 to solve the energy consumption faced by the emergence of mobile cloud computing (MCC)[3]. The most active research is the exploration of 5G heterogeneous networks with the Internet of Things as the research object of Chettri, Lalit[4].

(2)The second-ranked cluster in 5G application research has a total of 225 members with a profile value of 0.838. As early as 2014, Wunder, Gerhard and other scholars began to explore the transmission technology faced in the 5G application process[5], and then global authors conducted research on specific applications such as the Internet of Things, the Internet of Vehicles, public safety, and smart cities. The cluster is the most Active research is the high-diversity gain ultra-wideband single-band notch analog antenna technology suitable for a variety of wireless applications.

(3)Ranked third is the NOMA system, with a total of 205 members and a profile value of 0.704. NOMA is a non-orthogonal multiple access technology. Compared with OMA, it has higher spectrum efficiency and flexibility in quasi-synchronous transmission. Combined with it, it can achieve a large
number of accesses and a high edge throughput, which meets and meets 5G The explosive data growth and access demand of the times have attracted the favor of many researchers.

4. Frontier analysis of 5G technology research
Mutations refer to significant changes in keywords or phrases. 43 mutations in the 5G technology research field in English literature have been detected through CiteSpace software. Figure 4 clearly shows the evolution of the research frontier from 2010 to 2020.

| Keywords | Year | Strength | Begin | End | 2010 - 2020 | Keywords | Year | Strength | Begin | End | 2010 - 2020 |
|----------|------|----------|-------|-----|-------------|----------|------|----------|-------|-----|-------------|
| 5G       | 2010 | 9.24     | 2001  | 2020| 2010 - 2020 | cellular prison | 2010 | 7.12     | 2010  | 2020| 2010 - 2020 |
| energy efficiency | 2010 | 9.35     | 2001  | 2020| 2010 - 2020 | energy efficiency | 2010 | 6.34     | 2016  | 2020| 2010 - 2020 |
| evolution | 2010 | 12.74    | 2001  | 2020| 2010 - 2020 | full duplex | 2010 | 5.13     | 2016  | 2020| 2010 - 2020 |
| wireless | 2010 | 6.03     | 2001  | 2020| 2010 - 2020 | fiber | 2010 | 4.97     | 2017  | 2020| 2010 - 2020 |
| technology | 2010 | 14.03    | 2001  | 2020| 2010 - 2020 | capacity | 2010 | 7.51     | 2017  | 2020| 2010 - 2020 |
| lta | 2010 | 17.64    | 2001  | 2020| 2010 - 2020 | lta | 2010 | 5.03     | 2017  | 2020| 2010 - 2020 |
| heterogeneous network | 2010 | 9.44     | 2015  | 2020| 2010 - 2020 | carrier aggregation | 2010 | 7.49     | 2017  | 2020| 2010 - 2020 |
| network | 2010 | 0.11     | 2015  | 2020| 2010 - 2020 | directional antennas | 2010 | 6.97     | 2017  | 2020| 2010 - 2020 |
| bandwidth | 2010 | 11.25    | 2015  | 2020| 2010 - 2020 | bandwidth ratio | 2010 | 4.97     | 2017  | 2020| 2010 - 2020 |
| mobile | 2010 | 10.13    | 2015  | 2020| 2010 - 2020 | mobility | 2010 | 5.30     | 2017  | 2020| 2010 - 2020 |
| interference management | 2010 | 0.74     | 2015  | 2020| 2010 - 2020 | mobile communication | 2010 | 6.01     | 2017  | 2020| 2010 - 2020 |
| fastTrack | 2010 | 9.95     | 2015  | 2020| 2010 - 2020 | fastTrack network | 2010 | 6.01     | 2017  | 2020| 2010 - 2020 |
| small cell | 2010 | 14.43    | 2015  | 2020| 2010 - 2020 | 5G | 2010 | 7.25     | 2017  | 2020| 2010 - 2020 |
| grant | 2010 | 13.49    | 2015  | 2020| 2010 - 2020 | grant | 2010 | 5.12     | 2017  | 2020| 2010 - 2020 |
| hetnet | 2010 | 0.5      | 2015  | 2020| 2010 - 2020 | stochastic geometry | 2010 | 6.11     | 2017  | 2020| 2010 - 2020 |
| heterogeneous small cell network | 2010 | 17.08    | 2015  | 2020| 2010 - 2020 | cancellation | 2010 | 6.29     | 2017  | 2020| 2010 - 2020 |
| radio | 2010 | 5.15     | 2015  | 2020| 2010 - 2020 | cross run | 2010 | 9.12     | 2017  | 2020| 2010 - 2020 |
| cognitive radio | 2010 | 6.91     | 2015  | 2020| 2010 - 2020 | spectrum | 2010 | 6.65     | 2017  | 2020| 2010 - 2020 |
| future | 2010 | 5.94     | 2015  | 2020| 2010 - 2020 | user | 2010 | 4.99     | 2017  | 2020| 2010 - 2020 |
| stochastic geometry | 2010 | 7.45     | 2016  | 2020| 2010 - 2020 | complexity | 2010 | 6.79     | 2017  | 2020| 2010 - 2020 |
| 5G small cell | 2010 | 5.41     | 2016  | 2020| 2010 - 2020 | reinforcement learning | 2010 | 5.33     | 2017  | 2020| 2010 - 2020 |
| cooperation | 2010 | 5.9      | 2016  | 2020| 2010 - 2020 | cooperation | 2010 | 5.59     | 2017  | 2020| 2010 - 2020 |

Figure 4. Major mutation words in 5G research field from 2010 to 2020

For the research on 5G technology, new mutation words were generated every year from 2014 to 2019 and gained continuous popularity. For example, the mutation duration of the word 5G was 2011-2020. From Figure 4, it can be found that the mutation words are mainly distributed in 2015-2017. In the past two years, the number of mutation words totaled 28, accounting for 65.12% of the total number of mutation words. Global scholars began to conduct large-scale research on 5G technology in 2015, and the enthusiasm for investment and the expansion of research fields continued until 2017. In 2018 and 2019, mutation words were relatively reduced. After the explosive initial stage, research topics and directions have basically stabilized, and new research fields have not yet been involved on a large scale for the time being. Due to the short period of time in 2020, the mutation words cannot be detected. Combining the latest research in 2020, the cutting-edge topics in the field of 5G technology research in the past two years are mainly distributed on the user side, low-complex systems, big data analysis and reinforcement learning.

(1) User. The research on the user side mainly focuses on the research on the mobility, connectivity and security of the user side. Nawaz, Syed Junaid; Sharma, Shree Krishna, etc. proposed a novel framework based on QC assistance and QML, and pointed out the challenges and potential performance of the framework on the user side[6]. As users’ demands for continuous connections and better service quality increase, scholars such as Zhang Hongtao, Dai Lingcheng, Tabassum Hina, Salehi Mohammad have adopted Markov chains, hidden Markov models, artificial neural networks, Bayesian networks, and Research on the accurate prediction of user mobility in mobile networks based on data mining of different types of knowledge[7, 8]. Faced with serious storage and security issues during data transmission, Wu Tsu-Yang, Lee Zhiyuan, etc., proposed new improvements to the user authentication and user security issues in the multi-server (M0S) architecture and reached higher security standards[9]. Khan Hamza, Elgabli Anis, etc. use machine learning tools to study the
connection problem of car network terminals, especially distributed deep reinforcement learning (DDRL) and asynchronous participant critic algorithm (A3C). It can be seen that the research of 5G user terminals by global scholars combines practical applications such as AI, VR technology, Internet of Vehicles, social networks, smart manufacturing, smart cities, smart medical care, home entertainment and other directions. Specific research plans and results can further optimize and improve user-side performance.

(2) Complexity. 5G is not just a communication system. With the introduction of the Internet of Things and virtualized network architecture, 5G networks are facing many complex challenges in the era of big data. 5G networks will coexist with multiple networks for a long time, posing huge challenges to subsequent network construction. In order to support 5G and ensure good network performance, new technologies such as Massive MIMO, mmWave, UDN bring high complexity. The 5G core network constructed by the concept of virtualization and cloudification has new features of diversification of network elements and interfaces, and requires higher requirements for unified network scheduling management. New business scenarios and differentiated requirements further increase the complexity of network operations.

In the face of the above-mentioned problems, the current research of global scholars is mainly focused on how to reduce the complexity of heterogeneous networks, OFDM signal propagation, millimeter wave MIMO systems and so on. They use optimization algorithms, mobile edge computing, AI assistance and other means to improve performance in network planning, business assurance, energy saving and efficiency, and security protection.

(3) Big data analysis and reinforcement learning. The 5G network must be able to adapt to the rapid growth of mobile data traffic in the context of the big data era, while supporting an increasing density of mobile users involving various services and applications. At the same time, for increasingly dense, heterogeneous, decentralized and self-organizing networks to achieve different goals, such as high throughput and low latency, it is necessary to design and optimize resource allocation accordingly. Through the use of artificial intelligence reinforcement learning and in-depth learning, the performance of dynamic and uncertain wireless network services is further improved. The latest research direction is to explore a variety of algorithms, in highly mobile millimeter wave communications, dynamic access control in wireless networks, resource management in network slicing, radio resource control, virtual networks, mobile edge computing service deployment, mmWave networks, heterogeneous Optimize the online antenna tuning and VR broadband broadcasting in the cellular network.

5. Summary

By tracking and mining 5G technology-related literature information, conclusions can be drawn: The research hotspots shown in English literature include 5G theoretical research, specific architecture, system design, etc. The cutting-edge topics of 5G technology in the past two years are mainly distributed in user terminals, low-complexity systems, big data analysis. It can be seen that as the main direction of the development of new generation mobile communication technology, 5G has shifted from the exploration stage to the landing stage and gradually penetrated into various fields.

There is still a lot of room for improvement in the field of 5G technology research around the world.

(1) 5G involves many basic disciplines such as mathematics, physics, chemistry, materials, information. As communication technology is gradually approaching the limits of Shannon's Law and Moore's Law, the development of mobile networks in the future urgently needs a breakthrough in basic scientific research.

(2) At this stage, although 5G and cloud computing, big data, artificial intelligence, blockchain, holographic technology, human-computer interaction and other technologies have achieved certain results, they are far from industrial Internet, car networking, cultural creativity, smart medical care, smart energy, etc. There is still a big gap in mature applications in the industry.
(3) Focus on core technologies such as edge computing enhancement (MEC), network slicing enhancement, network intelligence and architecture enhancement, and non-public network enhancement research (eNPN) to solve a series of related problems.

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