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Fifth Generation Antennas: A Bibliometric Survey and Future Research Directions

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Abstract: As the 5G technology is going to be deployed soon, so the research on the 5G antennas as a part of communication devices becomes an important aspect. One of the important components of the 5G communication system is an antenna that is essential for the transmission and reception of the 5G signals. The international telecommunication union (ITU) has provided different specifications for the 5G communication system. The 5G antenna should operate at frequency range 1 and 2 (FR1 and FR2) specified by the ITU. The proliferation of various 5G antenna designs is surveyed in this bibliometric paper. The bibliometric survey aims to throw light on several types of antenna employed in various 5G applications like smartphone, base stations, and the IoT based devices that support 5G communications. The Scopus database from January 2015 to 14th October 2020 is used to perform this

bibliometric survey on 5G antennas. This paper also presents various future breakthroughs in 5G applications.

Keywords: Scopus; Antenna; Bibliometric; 5G Applications; Survey

1. Introduction

The 4G technology is hindering current communication technology. It cannot meet the various demands of mobile users like high data rate, good quality of service (QoS), and enhanced spectral efficiency (Zhu et al. 2018). Such an ever-increasing user's demands can be satisfied by using 5G technology that also provides evolutionary and revolutionary services (Zhu, Liu, and Wen 2019). The 5G technology can unleash new opportunities for social benefits. This 5G technology not only supports smartphones but also the internet of things (IoT) devices (Shafique et al. 2020). Hence the 5G technology has the ability to use information technology in the field of education, health-care, industry, agriculture, finance, and many more for ushering a remarkable societal transformation. The different 5G applications are smart-phones, wrist-watches, base stations, and IoT based devices. Three usages scenarios of 5G communication are explained below (ITU-R 2017):

- **Enhanced Mobile Broadband (eMBB):** It consists of new applications in addition to existing mobile broadband applications for seamless user experience. It also supports high user mobility in trains and aircraft. It provides high data rates of 2 Gbps and 20 Gbps for outdoor and indoor use respectively.
- **Ultra-reliable and Low Latency Communications (uRLLC):** It provides low latency and low packet loss as a result of this, 5G supports various wireless applications such as emergency response, intelligent transportation, drones, tactile internet, collaborative robotics, e-Health, and public safety.
- **Massive machine type communications (mMTC)**: It is categorized by a large number of IoT based connected devices to provide a very high density of connectivity. It provides many applications like smart power grids, smart cities, smart farms, etc.

The various requirements of 5G technology are specified by the International Telecommunication Union (ITU) as shown in figure 1 (ITU-R 2015)(Huang 2018)(Hong et al. 2017). The 5G technology should provide low latency of less than 1 millisecond, an ultra-high data rate of 2 to 20 Gbps, spectrum efficiency up to 9 bit/s/Hz, connection density of 1 million/km^2, and mobility of more than 500 km/h. To achieve an enhanced quality of service, beam division multiple access (BDMA) and filters bank multicarrier (FBMC) access technologies are used. To recover the received signal effectively and in a short duration period, low density parity check (LPDC) forward error correction code is used. Out of these specifications, one of the most important specifications is frequency bands. The 5G technology should operate at various frequency bands which are in the range from 24 GHz to 71 GHz and to achieve this important specification, an antenna is required to be designed.

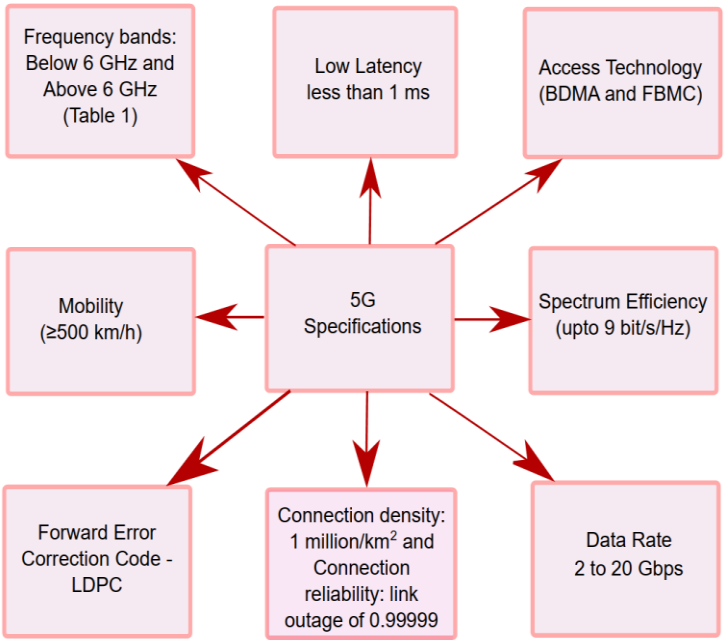

Figure 1. Specifications of 5G technology (Kumar et al. 2020)

After doing intensive an literature study, it is found that there is a proliferation of an antenna design for 5G applications. Several researchers have developed various types of antenna like monopole antenna (H. Ullah and Tahir 2019), dipole antenna (Esmail et al. 2020), Magneto-Electric Dipole Antenna (Li et al. 2017), loop antenna (A. Zhao and Ren 2019), inverted F antenna (IFA) (Liu et al. 2019), planar inverted F antenna (PIFA) (Chattha 2019), fractal (H. Ullah and Tahir 2020) and antipodal Vivaldi antenna (Dixit and Kumar 2020b)(Dixit and Kumar 2020c). Moreover, a single antenna

may not fulfill 5G requirements and hence many researchers have designed antenna array (Mao et al. 2019) and multiple input multiple output (MIMO) antenna (Parchin et al. 2019). Further, various antenna performance enhancement techniques can be deployed in an antenna to improve its performance parameters like gain, efficiency, front to back ratio, bandwidth, and radiation pattern (Dixit and Kumar 2020a). In the MIMO antenna, as the distance among antennas is less, isolation between two antennas is an important issue. This isolation problem can be alleviated by using various isolation improvement methods like a metamaterial, decoupling networks, neutralization lines, etc. (Nadeem and Choi 2019). In this paper, a bibliometric analysis of this emerging new 5G technology is done to elaborate on the amount of work done on the 5G antenna as well as the further scope of work.

The bibliometric analysis means measuring researches in books, universities, countries, and journals (Patil and Kumar 2020). This is the first time to perform such a bibliometric analysis on the 5G antenna. For this bibliometric study, the authors have used the Scopus database available from 2015 to 14th October 2020. Various metrics of 5G antenna research are elaborated such as number of publications per year, number of publications in various reputed journals, document type, and country-wise the amount of research done on 5G. This bibliometric study will serve as a pool of knowledge to the new researchers on the 5G antenna to understand the amount of research done and the scope of research in this 5G antenna field. After the introduction section, the detailed bibliometric analysis based on the Scopus database is done. Next network analysis on 5G antenna is done and then the paper is concluded. The different acronyms used in this paper are listed in figure 2.

Sr. No.	Acronyms	Full Form of Acronyms
1	5G	Fifth Generation
2	ITU	International Telecommunication Union
3	IoT	Internet of Things
4	eMBB	Enhanced Mobile Broadband
5	uRLLC	Ultra-reliable and Low Latency Communications
6	mMTC	Massive machine type communications
7	AVA	Antipodal Vivaldi Antenna
8	IFA	Inverted F Antenna
9	PIFA	Planar Inverted F Antenna
10	ME	Magneto-electric
11	SISO	Single Input Single Output
12	MIMO	Multiple Input Multiple Output
13	FR1	Frequency Range 1
14	FR2	Frequency Range 2
15	QoS	Quality of Service
16	BDMA	Beam Division Multiple Access
17	FBMC	Filters Bank Multicarrier
18	LDAC	Low Density Parity Check
19	D2D	Device to device

Figure 2. Summary of Acronyms

2. Classification of 5G Antennas

As per the intense bibliometric study, various researchers have designed various types of 5G antennas as shown in figure 3. Figure 3(a) shows 5G antenna classification based on its structure and figure 3(b) is the 5G antenna classification based on the number of input-output ports.

2.1. Structure Based 5G Antenna Classification

Depending upon the structure of an antenna 5G antennas are classified as follows:

- **Dipole Antenna:** It can be in the form of wire or printed on a substrate form that has a length of λ/2 where λ is the wavelength of resonating frequency. The dipole antenna feeding is provided at its center. It is easy to design and fabricate but it provides low gain and bandwidth (Hussain et al. 2020).

- **Monopole Antenna:** It is also available in the form of wire or printed on the substrate and it is of λ/4 length. It is easy to design and implement but it gives a poor performance in bad weather conditions (L. Zhao, Chen, and Wang 2019).
- **ME Dipole:** It consists of vertical magnetic dipole and horizontal electric dipole planar antenna elements. It provides a high front to back ratio and wide bandwidth but its design is complex (Yin et al. 2019).
- **Loop Antenna:** It is in the form of a ring that can be of circular, rectangular, or square shape. It enhances the channel capacity but its gain is low (Sharawi, Ikram, and Shamim 2017).
- **Antipodal Vivaldi Antenna (AVA):** It consists of two metal patches that are mirror images of each other and they are present on opposite sides of the substrate. It provides wider bandwidth and gain at the cost of larger antenna size (Ojaroudiparchin, Shen, and Pedersen 2016).
- **Fractal Antenna:** To design this antenna mathematical rule is used for repetition of the same structure. Some structures of fractal antennas are leaf, hexagon, rectangle, triangle, and star. It alleviates the antenna size but the design complexity increases after the third iteration (Darimireddy, Reddy, and Prasad 2018).

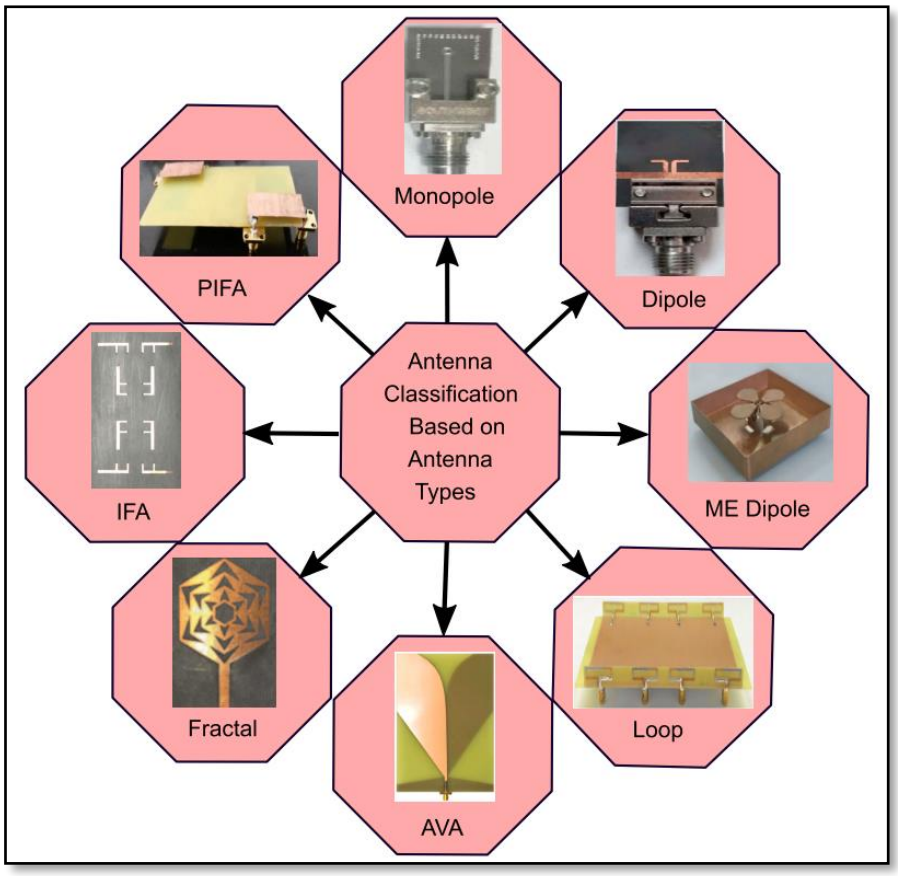

Figure 3. (a) 5G antenna classification according its structure (Kumar et al. 2020)

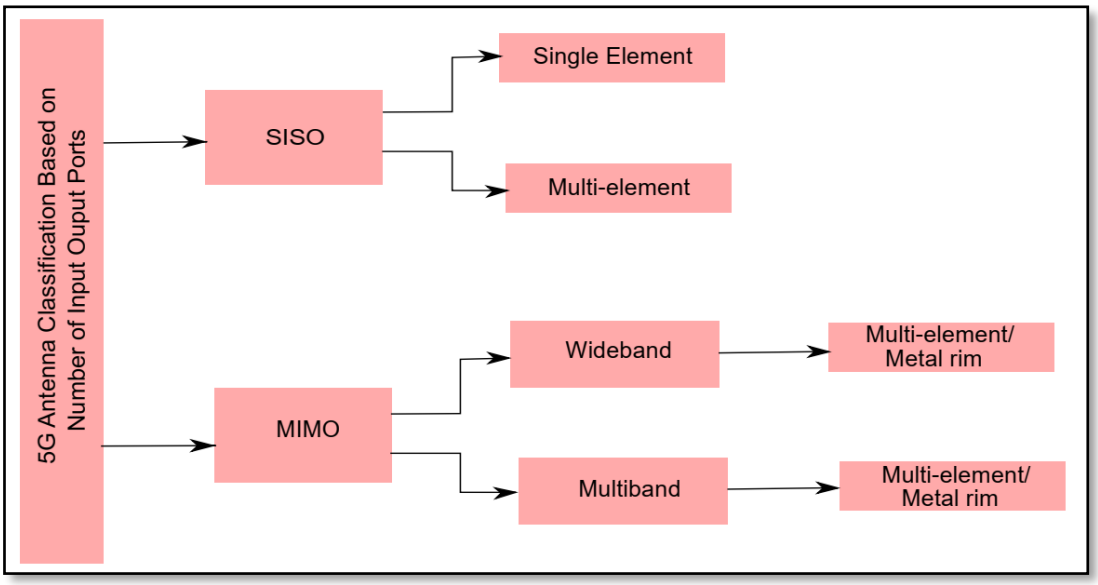

Figure 3. (b) 5G antenna classification according to the number of I/O ports

- **Inverted F Antenna (IFA):** The monopole antenna is bent at one side so that there will be two arms one should be of a longer size and the other arm should be of smaller size. Further, feeding is provided to the long arm and parallel to the smaller bent arm. This structure results in inverted F and hence the name is inverted F antenna (IFA). As the feeding is provided at the intermediate point, there is good impedance matching but it provides low gain (Deng et al. 2017).
- **Planar Inverted F Antenna (PIFA):** It is a multilayer antenna. At the top it has a radiator, the middle layer is air and at the bottom, it has a ground layer. It is a compact antenna because it requires only λ/4 space but it provides less gain (Chattha 2019).

2.2. Input/ Output Port Based 5G Antenna Classification:

Another way to classify a 5G antenna is based on the number of input/ output ports as shown in figure 3(b) which is explained below:

- **Single Input Single Output (SISO):** This is the simplest type of 5G antenna in which feeding is provided at one point and only one signal is transmitted or received at a time. Such an antenna can be divided into single elements and multi-element i.e. array antenna. The SISO antennas are suitable for IoT based devices for 5G applications. As the array antenna provides higher gain and stable radiation pattern, it is more preferable as compared to a single patch antenna (Tiwari and Rama Rao 2017).
- **Multiple Input Multiple Outputs (MIMO):** As the name suggests it consists of more than one feeding port and copies of the same single are transmitted or received. As multiple copies of the same signal are received at the receiver, the received signal can be reconstructed effectively which in turn improves the quality of services (Wani, Abegaonkar, and Koul 2018). Moreover, many researchers have designed wideband and multiband MIMO antennas for 5G applications. Both of these wideband and multiband MIMO antennas are further classified into a multi-element antenna with or without metal rim. The metal rim antenna provides mechanical strength to the device (Kurvinen

et al. 2019). The daunting task in MIMO design is to reduce the interactions among antenna elements and it is called mutual coupling. Several techniques have been proposed in the literature to reduce this mutual coupling (Nadeem and Choi 2019).

3. Bibliometric Analysis of 5G Antennas

This section explains briefly various bibliometric analyses done on antennas for 5G applications. The required database is taken from Scopus for the duration of 2015 to 14th October 2020. The main aim of this study is to understand the amount of work done on 5G antennas, the scope of work, and to find the best resources for this 5G antenna design.

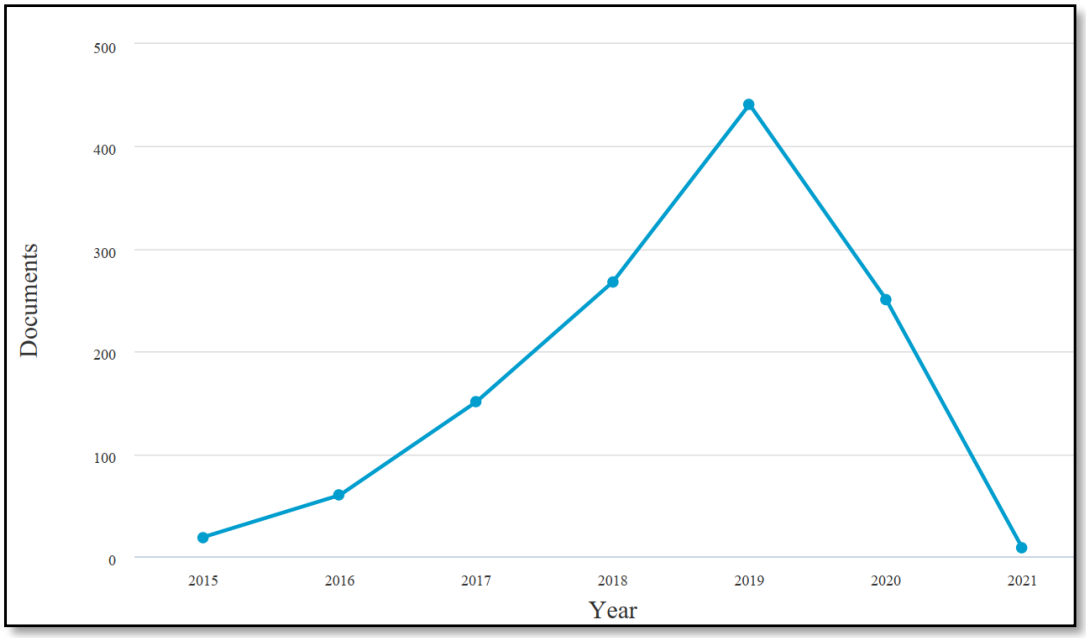

Figure 4. Number of documents published per year

The increasing curve of figure 4 depicts the gravitational pull of 5G antenna i.e. 5G applications. It is the graph of the number of publications on 5G antenna per year. The research on the 5G antenna is started with 19 publications in 2015 after announcing the specifications of 5G communication by ITU. Hence, we have done this bibliometric analysis in the period of 2015 to 14th October 2020 and it is found that 1198 documents are published in Scopus. The highest numbers of documents with a count of 441 are published in 2019 and still, rigorous research is going on 5G antenna in 2020.

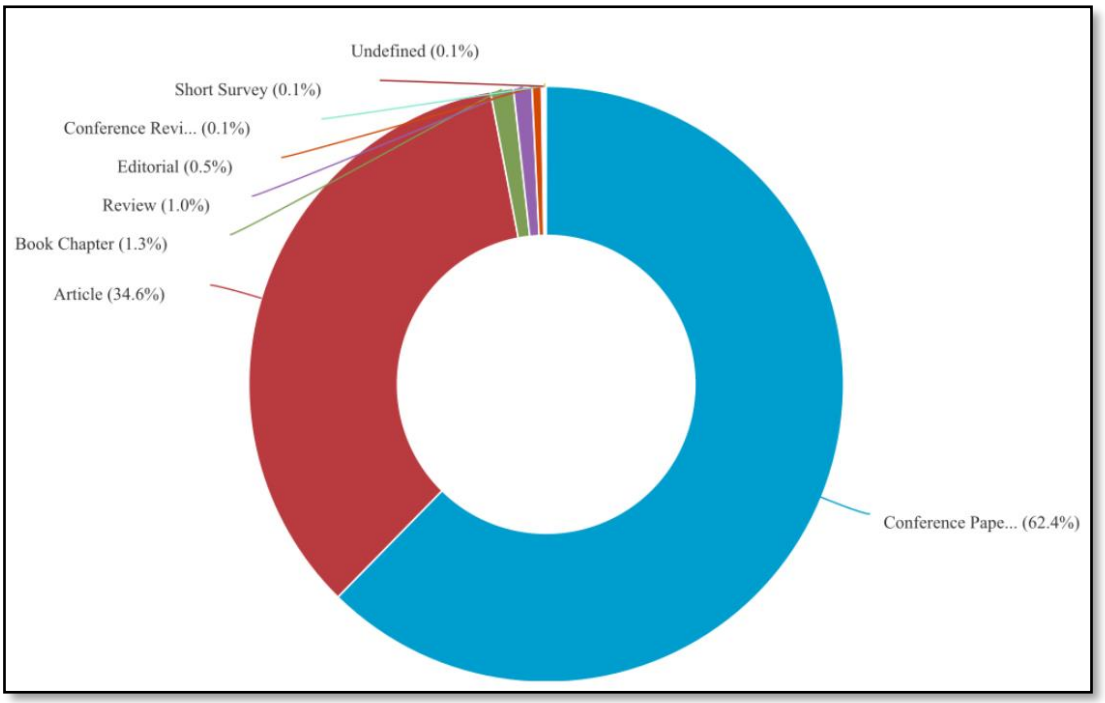

Figure 5. Distribution of 5G antenna documents by its type

Figure 5 shows the distribution of 5G antenna documents by its type. According to this figure, 62.4\% are conference papers and 34.6\% are research articles. Only 1\% of review papers are published on the 5G antenna. Hence, this paper will be very useful for the new researchers on the 5G antenna to throw light on research gaps in the area of 5G antenna designs.

Figure 6 is the bar chart of documents published by top universities in the field of 5G antennas and the corresponding table is shown in table 1. It shows that University Teknologi Malaysia is the leading university in 5G antenna designs. As per the database of Scopus, 160 universities from all over the world have given their valuable contribution to the research area of the 5G antenna.

The number of documents published per year in the top five journals is shown in figure 7. Out of these journals, the IEEE access journal is at the top since 2018 (more than ten research papers per year). Moderate numbers of documents are published in IEEE transactions on antennas and propagation as well as a microwave and optical technology letters. Further, a few numbers types of research have used IEEE MTTS international microwave symposium digest and IEEE antennas and wireless propagation letters for their research article publication.

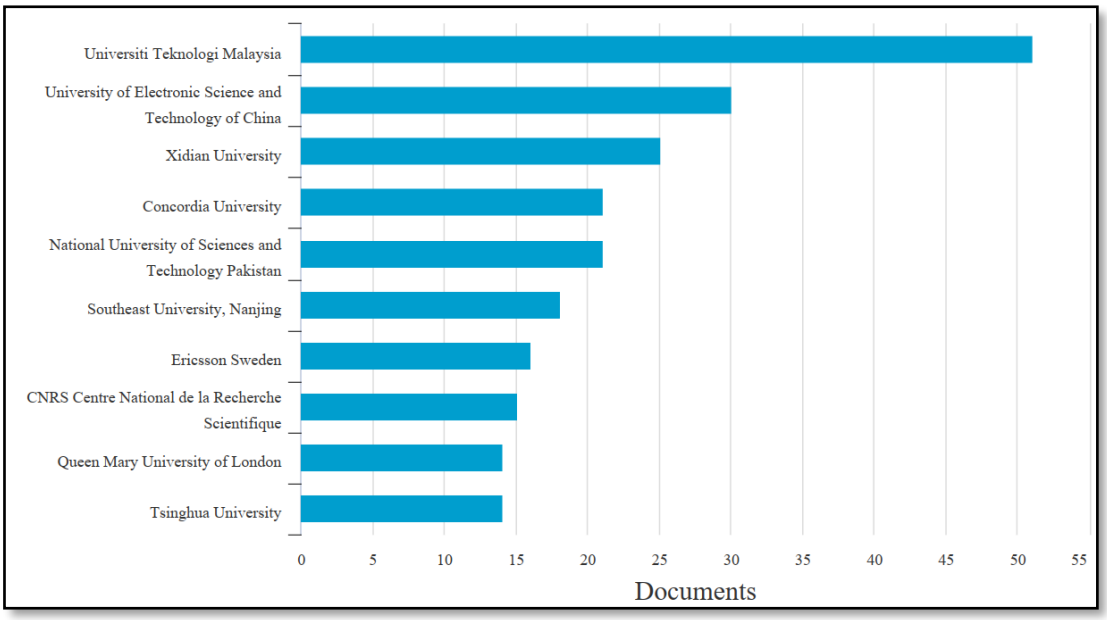

Figure 6. Bar chart of number of documents published by top ten universities

Next, the map of the world depicting the number of publications on 5G antenna in various countries is shown in figure 8. This map is created by using Google sheets. The faint green color indicates the fewer number of publications and the dark green color indicates more number of publications. This figure proves that the highest numbers of documents are published by China followed by India.

Table 1. Number of documents published by top ten universities

Sr. No.	University Name	No. of Papers Published
1	University Teknologi Malaysia	51
2	University of Electronic Science and Technology of China	30
3	Xidian University	25
4	Concordia University	21
5	National University of Sciences and Technology Pakistan	21
6	Southeast University, Nanjing	18
7	Ericsson Sweden	16
8	CNRS Centre National de la Recherche Scientifique	15
9	Queen Mary University of London	14
10	Tsinghua University	14

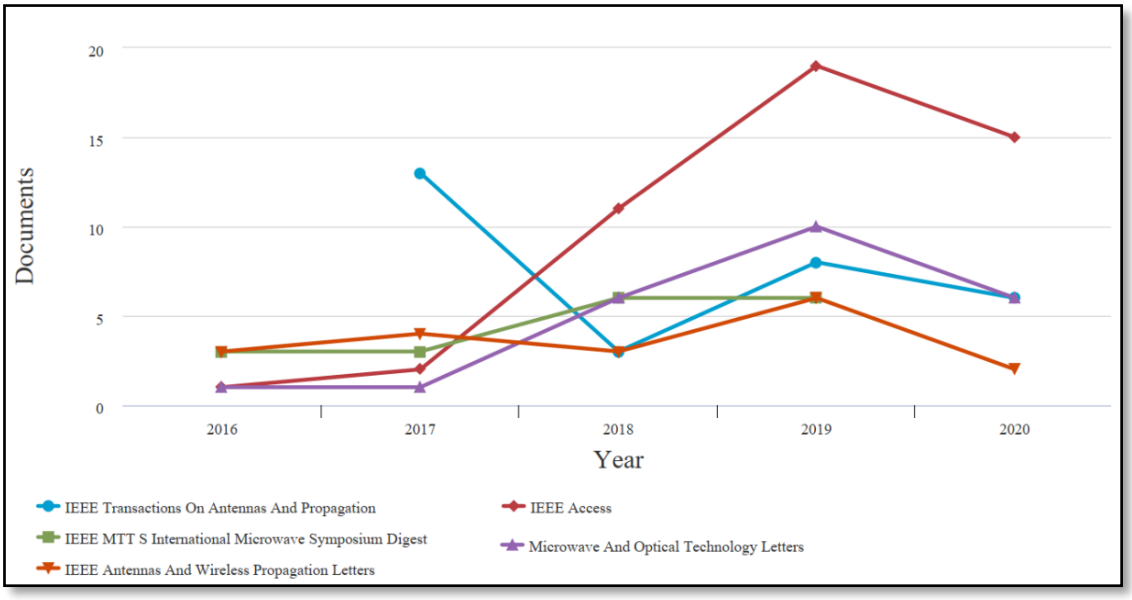

Figure 7. Number of documents published per year by various journals

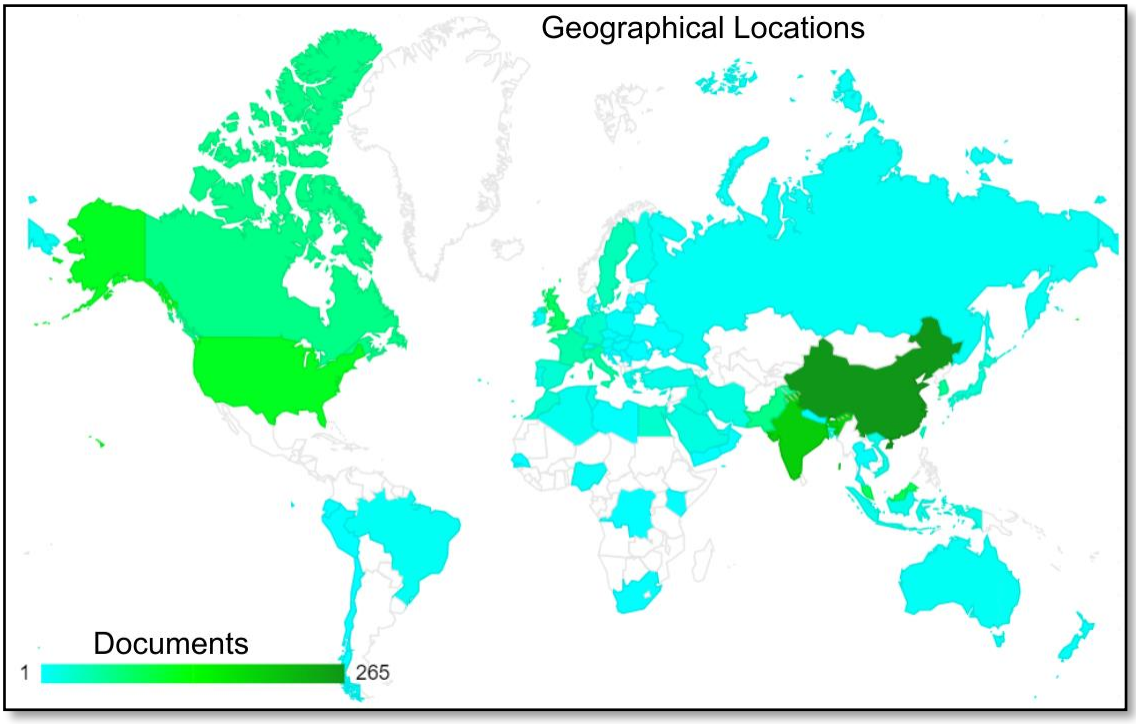

Figure 8. Country wise details of research done on 5G antenna

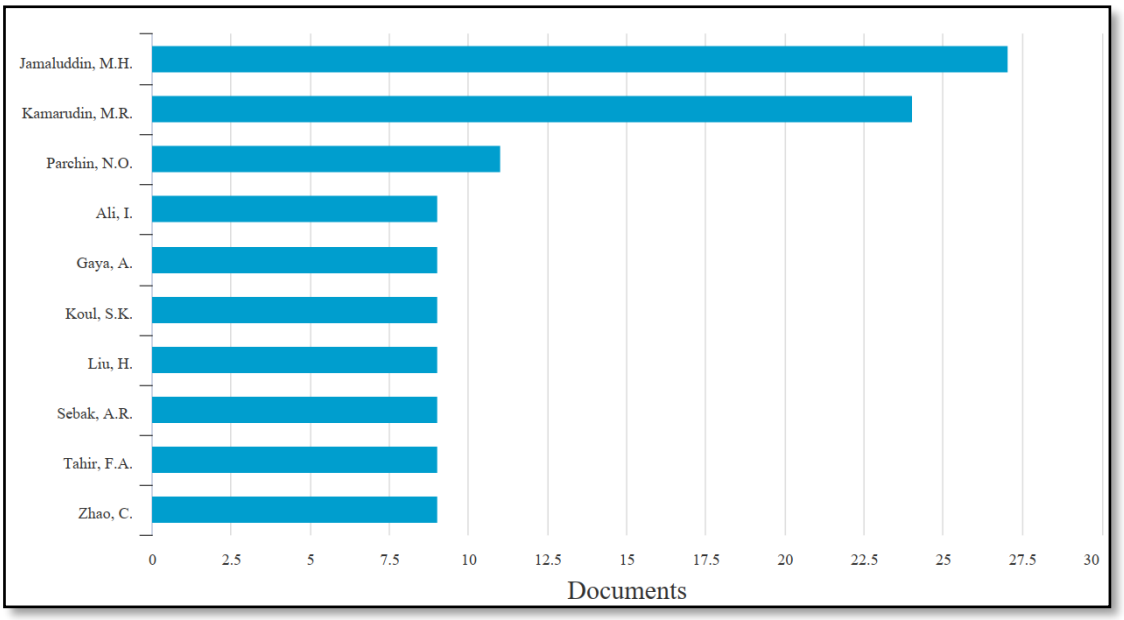

Figure 9. The bar chart of research contribution by top ten authors

The contribution of the top ten authors in the area of 5G antenna design is summarized in figure 9 and table 2. A total of 159 researchers have worked on antenna design for 5G applications. Out of these, Jamaluddin, M.H. has published a maximum number of documents which are 27 documents followed by Kamarudin, M.R. with a count of 24 documents.

Table 2. Details of number of documents published by top ten authors

Sr. No.	Author Name	No. of Documents Published
1	Jamaluddin, M.H.	27
2	Kamarudin, M.R.	24
3	Parchin, N.O.	11
4	Ali, I.	9
5	Gaya, A.	9
6	Koul, S.K.	9
7	Liu, H.	9
8	Sebak, A.R.	9
9	Tahir, F.A.	9
10	Zhao, C.	9

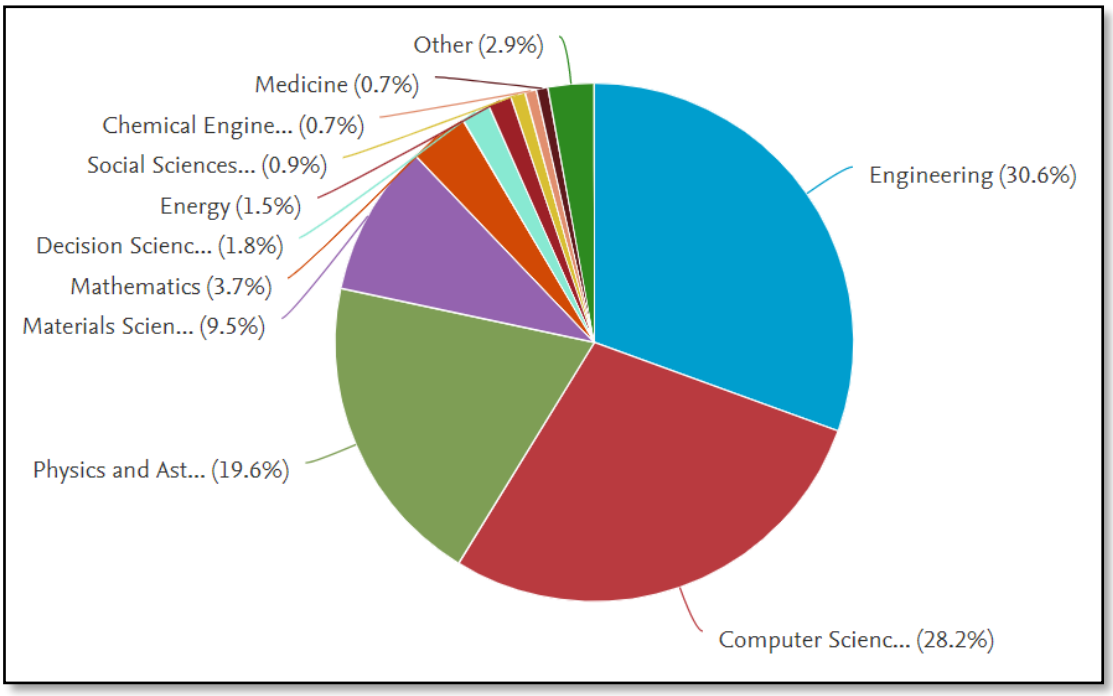

Figure 10. Distribution of documents by subject area

The percentage-wise distribution of 5G antenna documents in various subject areas is shown in figure 10 that depicts 5G antenna design mainly comes under engineering and computer science subject areas as they cover 30.6% and 28.2% of all subjects respectively. Physics and astronomy subject contributes 19.6% while material science includes 9.5% of research work on 5G antenna. Other subject areas merely are involved in the 5G antenna designs.

Further, a cluster of document titles and their corresponding year is depicted in figure 11. This cluster figure is drawn with the help of the NodeXL tool in which the publication year and publication title are represented by nodes. The density of the cluster represents the number of publications in the corresponding year. This figure represents that more research on 5G antenna is done in 2019 followed by the 2018 year.

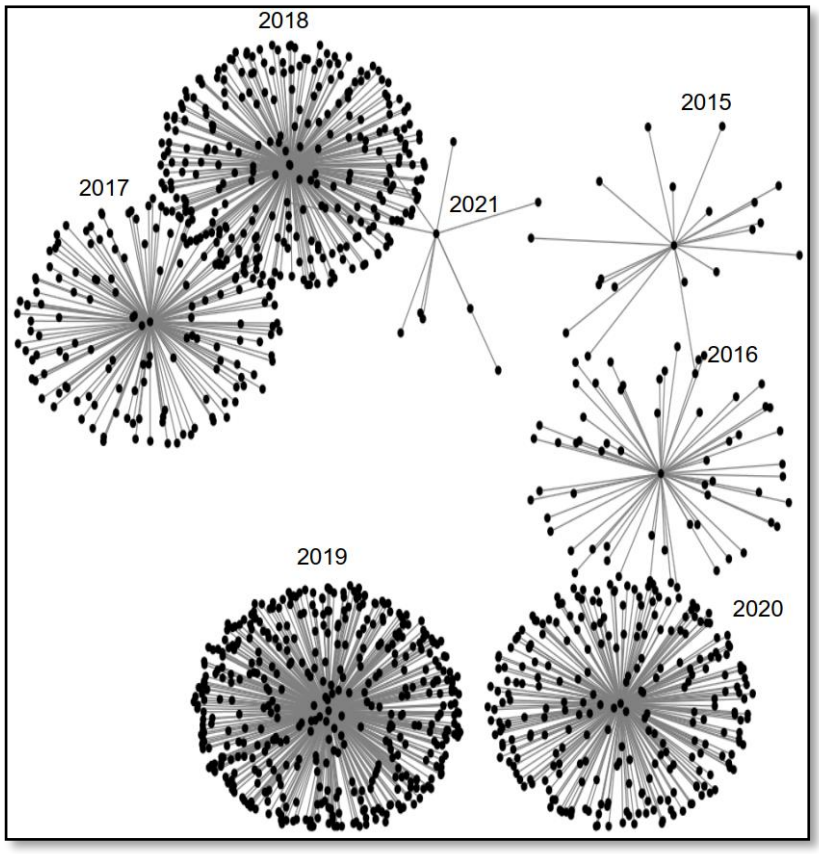

Figure 11. Cluster of publication year and article titles

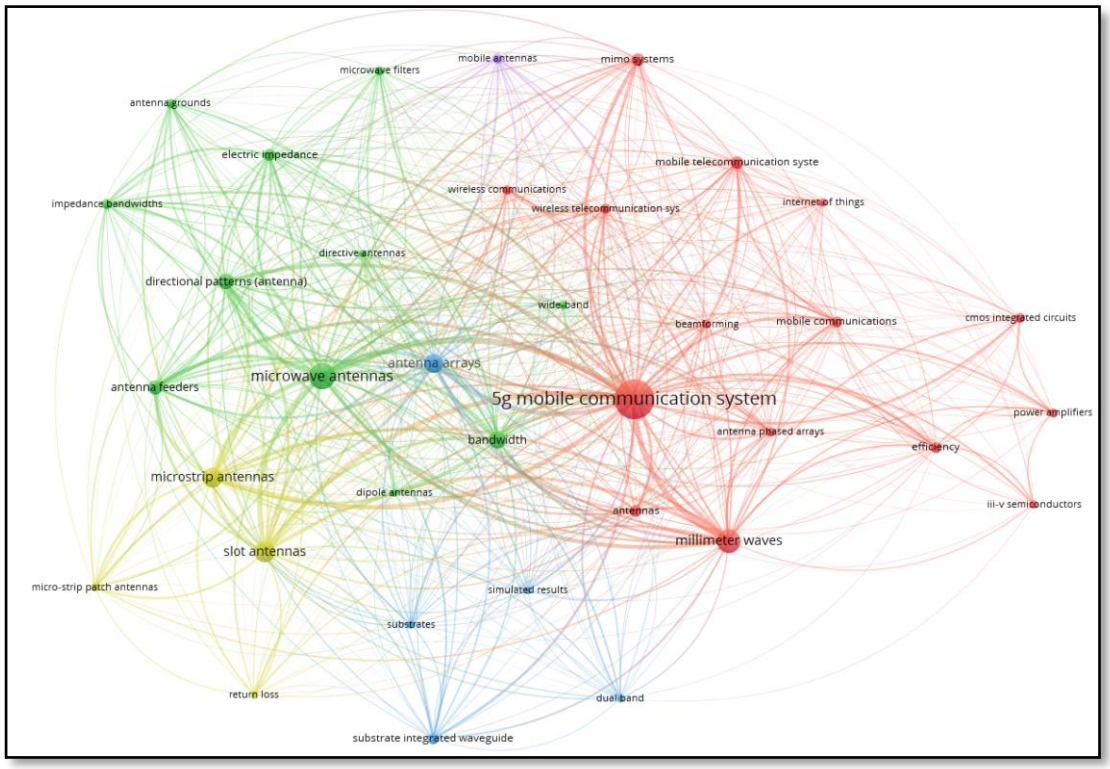

Figure 12. Network visualization depicting the inter linkage of indexed keywords

The VOSviewer tool is used to obtain figure 12 which represents the network map containing interconnections between keywords and source titles. The circles in the network represent various keywords of the source titles. The size of the circle represents the number of occurrences of that keyword in the source title for example; the circle representing the 5G mobile communication system is of the largest size as it has the highest count of a repetition. Next, the distance between two keywords is directly proportional to the association between those keywords. As shown in figure 13, bandwidth and antenna phased arrays are more closely related to the 5G mobile communication system. Hence, these figures are very useful to understand the important keywords of the 5G antenna and their relations.

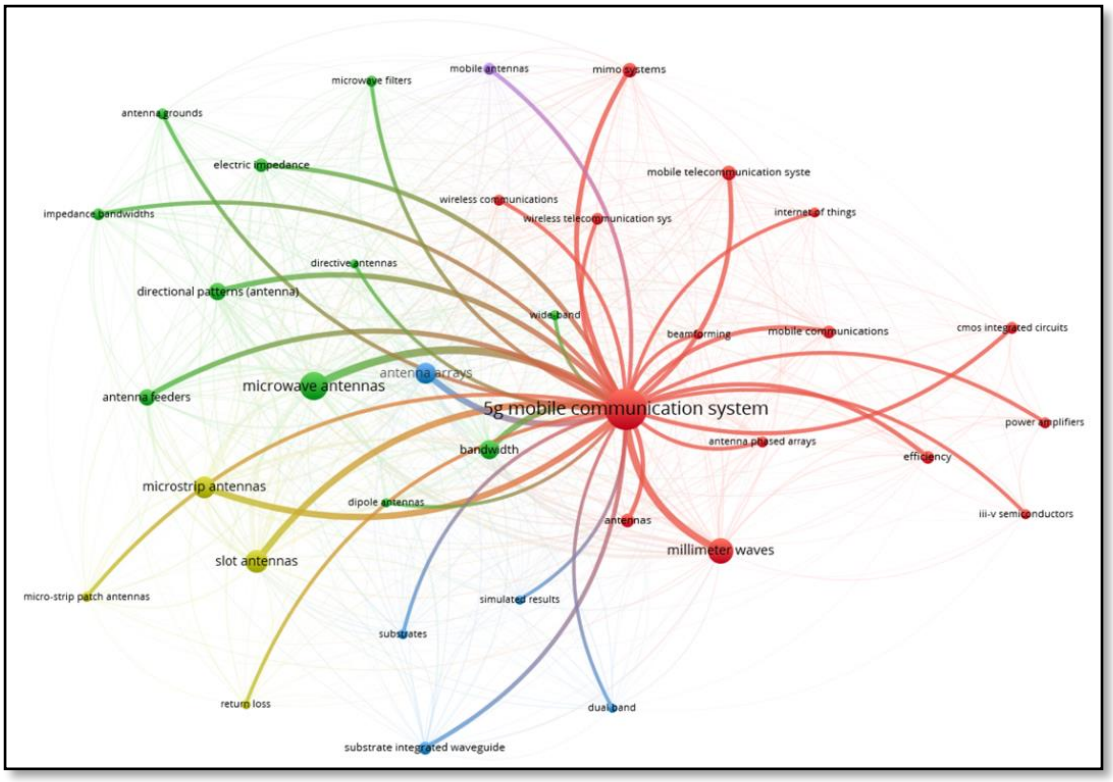

Figure 13. Network visualization depicting the inter linkage of 5G mobile communication system keyword with other keywords

Figure 14 provides the details of the top five documents that are highly cited in the field of 5G antenna. All documents are from IEEE and IEEE Transactions on Antennas and Propagation journal is the leading source for 5G antenna design. Out of these five documents, three documents are research articles, one is a conference paper,

and another is a magazine. A research article of Hong et al. is at the top and cited by 146 times followed by a research article of Sadhu et al. which is cited by 145 times. The research article of Hong et al. elaborates overview and experimental set up of 5G antenna for a smartphone application.

Sr. No.	Document Title	Authors	Year	Source	Citation Count
1	Millimeter-Wave 5G Antennas for Smartphones: Overview and Experimental Demonstration	Hong, W., Baek, K.-H., Ko, S.	2017	IEEE Transactions on Antennas and Propagation	146
2	A 28GHz 32-element phased-array transceiver IC with concurrent dual polarized beams and 1.4 degree beam-steering resolution for 5G communication	Sadhu, B., Tousi, Y., Hallin, J., (...), Friedman, D., Valdes-Garcia, A.	2017	Digest of Technical Papers - IEEE International Solid-State Circuits Conference	145
3	5G communications race: Pursuit of more capacity triggers LTE in unlicensed band	Al-Dulaimi, A., Al-Rubaye, S., Ni, Q., Sousa, E.	2015	IEEE Vehicular Technology Magazine	141
4	Radio access for ultra-reliable and low-latency 5G communications	Johansson, N.A., Wang, Y. P.E., Eriksson, E., Hessler, M.	2015	2015 IEEE International Conference on Communication Workshop, ICCW 2015	131
5	A 28-GHz 32-Element TRX Phased-Array IC with Concurrent Dual-Polarized Operation and Orthogonal Phase and Gain Control for 5G Communications	Sadhu, B., Tousi, Y., Hallin, J., (...), Friedman, D., Valdes-Garcia, A.	2017	IEEE Journal of Solid-State Circuits	123

Figure 14. Details of top five highly cited documents

4. Future Breakthroughs

5G technology is the panacea of the increasing demand for higher data rates with a faster and secure network. The use of ultra-small cells can make 5G networks more flexible. The deployment of 5G technologies in smartphones will make it possible to use various advanced facilities like smart cities, smart agriculture, health care, etc. at anytime and anywhere. The future breakthroughs of 5G antennas are explained with the help of the following applications:

- **Smartphones:** The multiband MIMO antenna is the best antenna for 5G smartphones but it is a daunting task to design such antenna in a compact space. Many researchers have suggested using monopole, IFA, and PIFA because of their compactness and they are easy to integrate into smartphones (R. Ullah 2019)(Chen 2019).
- **Base station:** 5G Base station should use massive MIMO antennas which is a group of antennas working together to enhance the throughput and spectrum efficiency. The massive MIMO also increases channel capacity and reduces the latency. These antennas also offer beamforming which means that the direction of maximum antenna directivity can be changed to send the signals to the intended user only (Zhang et al. 2020).
- **5G - IoT:** The 5G technology supports millions on IoT based devices. This also supports faster device to device (D2D) communication. This important application will bring revolutionary and evolutionary changes in the various social sectors. Some important applications are automated industry controls, smart cities, public safety, e-health, smart farm, etc. As 5G technology provides very low latency, remote control operations are also possible. Additionally, IoT with artificial intelligence (AI) and cognitive radio will play a vital role in 5G technology (Kaur, Kumar, and Baliyan 2018) (Shevada et al. 2020)(Raut et al. 2020).

5. Conclusion

This bibliometric study is carried out to enlighten the amount of work done on the 5G antenna and its corresponding future scope. It provides the details of publication counts in various journals, countries, subject areas, and documents per year.

Importantly, the analysis done on the number of publications per year indicates that still there is lots of scope in the area of 5G antenna design. The authors have also elaborated on network analysis on keywords to explain the linkage between different keywords. It will serve as guidelines to new researchers to refer to the research work of various authors according to their number of publications or citation count. Also, this bibliometric survey makes it easy to find the journals with abundant details of the 5G antenna and to target the journals for work publications. Moreover, it is proved from the bibliometric analysis that China is leading in 5G antenna designs followed by India. The future breakthroughs illustrate the importance and need of research in 5G antenna area. This bibliometric survey is very useful for new upcoming researchers to find the research gap in the field of 5G antenna design.

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