Graphene-based antenna for 5G wireless communications - a bibliometric-thematic analysis and future directions

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Graphene-based antenna for 5G wireless communications – a bibliometric-thematic analysis and future directions

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Abstract: This manuscript provides a bibliometric and thematic analysis of research on graphene-based antennas for 5G wireless communications. Recently, graphene-based antennas have gained popularity. Currently, research is underway to design and develop compact antennas using graphene material. This study presents an analysis of graphene antennas for 5G communication from a bibliometric and thematic viewpoint. A literature search was carried out on the Scopus database documents related to 5G communication using graphene antenna. To conduct this study, total 56 research articles from 2014–2021 were reviewed. Bibliometrix (R package) and SciMAT software were used to conduct this review in terms of bibliometric and thematic analysis. The analysis presents results as contributing authors and co-authors, main affiliations, leading contributing countries, main relevant sources and major themes. The derived results provide insight into the limitations and scope of collaborative research in the area of 5G antenna design utilising graphene material.

Keywords: bibliometric analysis; communication; graphene; wireless; thematic analysis.

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1   Introduction

Terahertz frequency band in the range of (0.1–10 THz), is found to be one of the potential resources for 5G wireless communications (Petrov et al., 2016). Terahertz band has numerous unique properties such as large channel bandwidth, high data rates, propagation by reflection, etc. (Vettikalladi et al., 2019). At such small dimensions, conventional copper antennas are incapable to function due to their limitations in installation and fabrication (Bozzi et al., 2015). A variety of planar antennas such as microstrip for 5G communication are available in the literature (El-Hakim and Mohamed, 2023; Jain et al., 2023; Kumaran et al., 2023). However, graphene material which is 2-dimensional crystalline allotrope of carbon, found suitable for antenna design in Terahertz domain due to its excellent thermo-electro-mechanical properties. It is light weight, flexible and fabrication is inexpensive (Hu et al., 2021). It is also claimed in one

of the research papers that graphene can be used in upcoming broadband plasmonic antennas operating in the Terahertz range (Dash and Patnaik, 2018).

In this study, a bibliometric analysis is accomplished using biblioshiny of Bibliometrix (R package) to provide a comprehensive overview of the research developments, publication trends and global associations in the field of graphene antenna for 5G wireless communication (Aria and Cuccurullo, 2017). This is the unique review to quantitatively analyse the use of graphene antenna for 5G communication. Bibliometrics is a way to analyse research publications in a certain field quantitatively using indicators such as most productive authors, countries, affiliations, current trends and partnership patterns, etc. (Derviş, 2019; Meschede, 2020; Sharma et al., 2024, 2023). Further to analyse the available documents qualitatively, thematic analysis is also performed using SciMAT software. According to the literate survey it is found that bibliometric analysis on 5G exists in Aslam et al. (2020) and Verma and Verma (2021) but no analysis from bibliometric and thematic view on research focused on graphene antenna for 5G is available. To highlight the contribution of researches working in the domain of designing graphene antenna for 5G this current analysis is performed. The presented study discovers the contribution of researchers working world wide in the domain of 5G communication and also provides significant direction for researchers planning to work in this emerging domain.

In business and management, the development and adoption of 5G networks can have significant implications for operations, productivity, and innovation. Furthermore, the implementation of 5G networks can also lead to new and innovative applications and services, such as virtual and augmented reality, which can have implications for businesses in various industries, such as entertainment, marketing, and customer experience. Graphene-based antennas can potentially improve the performance of these applications and services, leading to better customer experiences and increased revenue for businesses. Additionally, the management of the development and implementation of 5G networks can also have significant implications for businesses. The successful deployment of 5G networks requires coordination between various stakeholders, including telecommunication companies, government agencies, and businesses. The allocation of spectrum, the deployment of infrastructure, and the development of standards and regulations are all important factors that can impact the success of 5G networks and the businesses that rely on them.

One potential application of graphene-based antennas in business and management is in the development of internet of things (IoT) devices. IoT devices rely on wireless communication to function, and the performance and reliability of wireless connectivity can impact the efficiency and effectiveness of these devices. Graphene-based antennas can potentially improve the performance and reliability of wireless communication, leading to more efficient and effective IoT devices. This can have implications for businesses in areas such as supply chain management, logistics, and automation. Graphene-based antennas can also potentially improve the performance and reliability of autonomous vehicles and drones, which also rely on wireless communication to navigate and operate. This can have significant implications for businesses in industries such as transportation, logistics, and delivery. Recent research on graphene-based antennas for 5G wireless communication highlights the growing interest and potential for this technology. A review of graphene-based antennas for Tetrahetz, highlighting the potential benefits and challenges associated with this technology are described in Correas-Serrano and Gomez-Diaz (2018). An analysis of the state of research on 5G

flexible antennas for communication and its potential applications are discussed by Riaz et al. (2023).

This bibliometric and thematic analysis is performed on Scopus database available from 2014–2021. The idea behind conducting this analysis to find the answers of following questions:

Q1 How has an article on 5G communication using graphene antenna evolved?

Q2 Which journals are the most well-known in this field?

Q3 Which authors are the most prominent in this field?

Q4 Which organisations and countries have written most of the research articles, and what is the country wise collaborative research scenario?

Q5 What is the research focus of this field's researchers?

The rest of the paper is organised as follows – Section 2 explains about the collected data type and flow diagram of whole process. Results and discussion of bibliometric analysis are highlighted in Section 3. Thematic analysis findings are explained in Section 4 followed by conclusions in Section 5.

2 Materials and methods

To find answers to questions proposed in the Introduction section, research articles on graphene-based antenna for 5G communication from the Scopus database for the year 2014–2021 were collected. Key search items include graphene and antenna and 5G communication. The collected data was analysed using bibliometric mapping (Aria and Cuccurullo, 2017). The procedure of bibliometric mapping analysis comprises data collection, extraction, filtering and synthesis. For this study, data from Scopus database were exported in BibTex format, which was imported into biblioshiny of bibliometrix tool (Agbo et al., 2021). It is found that a total of 59 documents comprising 23 articles, two books, 25 conference papers, seven conference review and two review papers were published in 53 different sources. From the Scopus database, 59 documents from 53 sources were extracted for the analysis. For conduction of this study relevant research articles were included. Research articles not written in English as well as duplicate documents were excluded. It is found that the average number of publications each year is 2.75. Each document receives an average citation of 3.763 and the average citation per document per year is 1.018. As far as the collaboration is considered, the collaboration index is 3.28. The main information about the collected data is given in Table 1 and type of data in Table 2.

The collaboration index is a quantitative measure that assesses the degree of collaboration among researchers. This metric calculates the average number of authors per article or document, assuming that a higher number of authors imply a higher level of collaboration. The collaboration index offers valuable insights into the extent of collaboration among researchers working within a specific field or on a particular topic. It is a widely used tool for assessing the collaborative nature of scientific research across various disciplines.

Table 1   Main information about the data

Sources (journals, books, etc.)	53
documents	59
Average years from publication	2.75
Author appearances	241
Authors per document	2.61
Co-authors per documents	4.08
Collaboration index	3.28

Authors per document refer to the average number of authors in a particular document or article, calculated by dividing the total number of authors by the total number of documents or articles. In documents or articles, 'co-authors per document' refers to the average number of co-authors. It is determined by dividing the total number of co-authors by the total number of documents. Co-authors are the individuals who have collaborated with the primary author in producing a specific document or article. Therefore, while 'authors per document' measures the average number of authors per document, 'co-authors per document' measures the average number of co-authors per document.

Table 2   Type and count of relevant documents

Document type	No. of papers
Article	23
Book	1
Conference paper	25
Conference review	7
Review	2

We collected data from Scopus in the form of a bibliographic information file. The exported data consist of

a   item type

b   authors

c   titles

d   publisher information

e   abstract

f   keywords

g   publication year

h   affiliation

i   ISSN/ISBN

j   languages

k   DOI.

The recent developments in the emerging area of graphene antenna for 5G communication are analysed using bibliometric analysis. In this work, results are presented in terms of top contributing countries, active affiliations, most relevant keywords, contributing authors and publishing domains. The visualisations are extracted from 'Biblioshiny'.

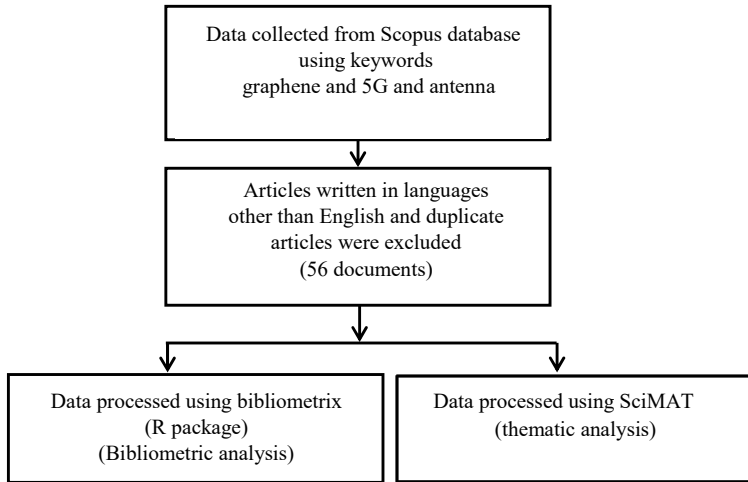**Figure 1** Flow diagram of analysis process

Figure 1 displays the flow diagram of the whole process which comprises data collection from Scopus database, filtering and processing through Bibliometrix of R package and SciMAT. The processed results are displayed in the form of figures and tables.

3 Results and analysis

Bibliometric analysis results and discussion of research documents available in the year 2014–2021 are presented in this section.
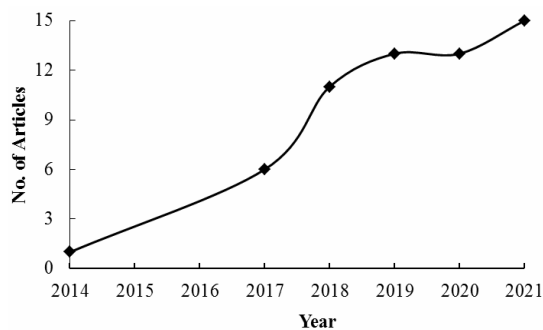
Figure 2 Annual production plot

Figure 2 displays the distribution of publications refers to research that is associated with graphene, antenna and 5G communication from 2014 to 2021. Since 2014, there is an increase in research in the field of Graphene antenna for 5G communications (*Q1*). A constant phase is observed during 2019 and 2020 while, peak has been achieved in the year 2021. Research papers published in 2021 are mainly focused on graphene patch array antenna design for 5G communication and IoT (Song et al., 2021; Lu et al., 2019; Xia et al., 2018; Mittra, 2018).

Figure 3   Research articles published by the top 20 sources (see online version for colours)
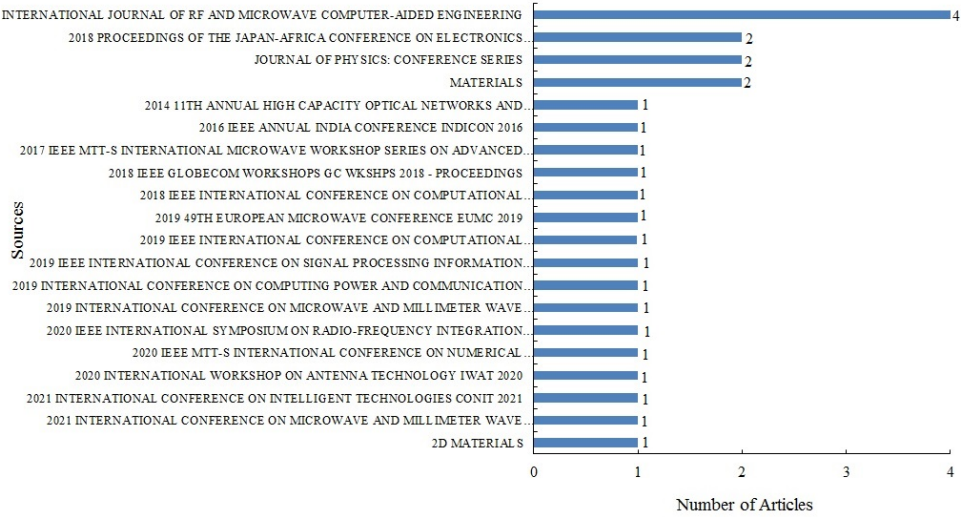
The various sources publishing the research articles are shown in Figure 3. The highest numbers of papers are published in the *International Journal of RF and Computer Aided Engineering* (Elsheakh, 2020; Song et al., 2019). Most of the research papers are published in international conferences on communication and journals related to material study (*Q2*).

Figure 4   Top contributing countries that are involved in the research (see online version for colours)
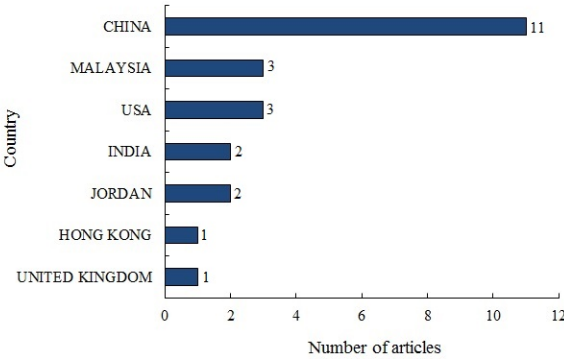
The top occurring countries are depicted in Figure 4. About 47.8% (11/23) articles are published by China followed by Malaysia and USA with 13% (3/23) overall contribution (*Q4*).

Figure 5 Collaborative research country wise (see online version for colours)
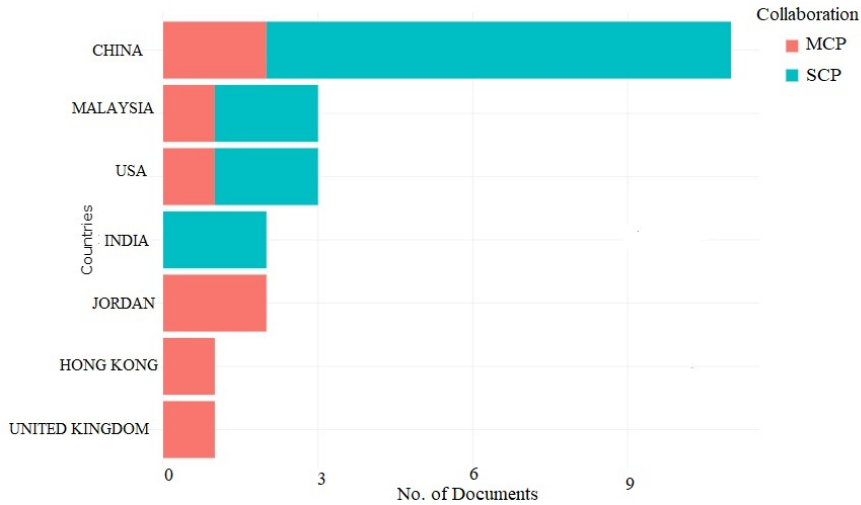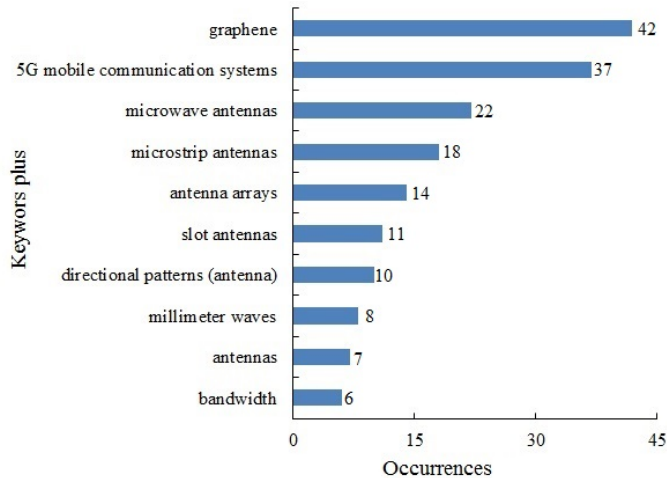

Figure 6 Most relevant keywords (see online version for colours)

The collaborative research in terms of single country publication (SCP) and multiple country publication (MCP) is presented in Figure 5. The top productive countries in this field are China, Malaysia and USA (Cherevko and Morgachev, 2021; Sa'don et al., 2019; Han et al., 2018). Most of the countries have performed independent research. The above stated collaborative results are also presented in tabular form in Table 3.

Table 3   Top contributing countries

Country	Research articles	Frequency	SCP	MCP	MCP_Ratio
China	11	0.4783	9	2	0.182
Malaysia	3	0.1304	2	1	0.333
USA	3	0.1304	2	1	0.333
India	2	0.087	2	0	0
Jordan	2	0.087	0	2	1
Hong Kong	1	0.0435	0	1	1
United Kingdom	1	0.0435	0	1	1

Figure 7   Top contributing authors with minimum of three publications (see online version for colours)
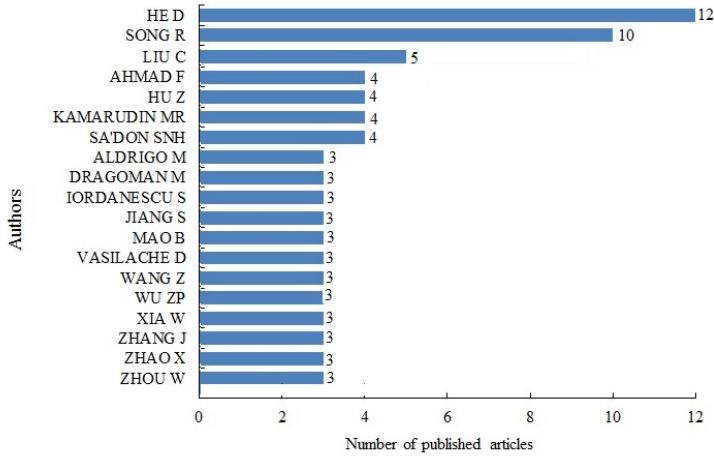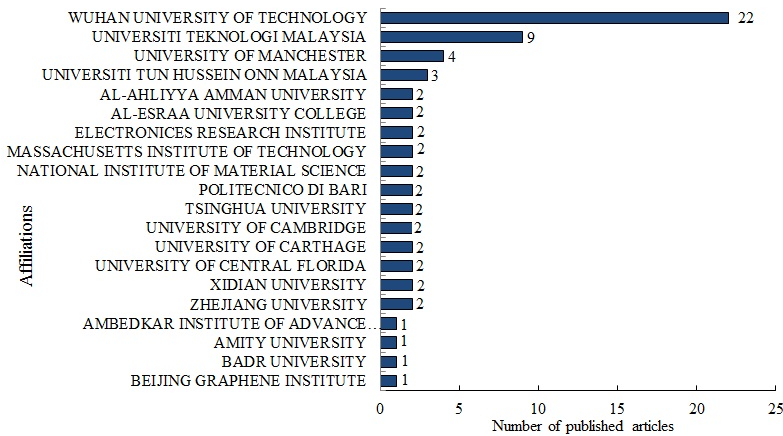

Figure 8   Top contributing affiliations (see online version for colours)

During the study it is found that most frequently used keywords are graphene, 5G mobile communication, microwave and microstrip antennas as represented in Figure 6. It is found that most of the antennas designed for 5G communications are wideband array antennas with directional patterns using graphene material (Shree et al., 2018; Grande et al., 2018; Zainud-Deen et al., 2018).

Figure 7 depicts the main contributing authors in the field of graphene-based antenna for 5G communication (*Q3*). Daping He and Rongguo Song are professors at Wuhan University of Technology, working extensively in the related field with the highest number of publications as shown in Figure 8.

4 Theoretical structure and thematic analysis

Thematic analysis is a method of analysing data qualitatively. Researchers use SciMAT, which implements science mapping exploration within a longitudinal structure (Cobo et al., 2012). SciMAT visualises the major themes in two ways – strategic diagrams and thematic networks (Herrera-Viedma et al., 2020). In a strategic diagram, the vertical axis shows density and the horizontal axis shows centrality, as shown in Figure 9(a). The centrality deals with the degree of interaction between various themes, whereas the density measures the internal strength among them (Kılıç and Uyar, 2022). The research themes are classified into four major clusters – motor themes (these are major driving themes); greatly established and isolated themes (these are well developed but less critical); developing or declining themes (these are weakly developed and either emerging or diminishing), and basic and transversal themes (these are relevant for the research but not fully developed) (Martínez et al., 2015). Figure 9(b) shows the thematic evolution of the topic over two periods.

**Figure 9** (a) Strategic diagram, (b) Thematic evolution
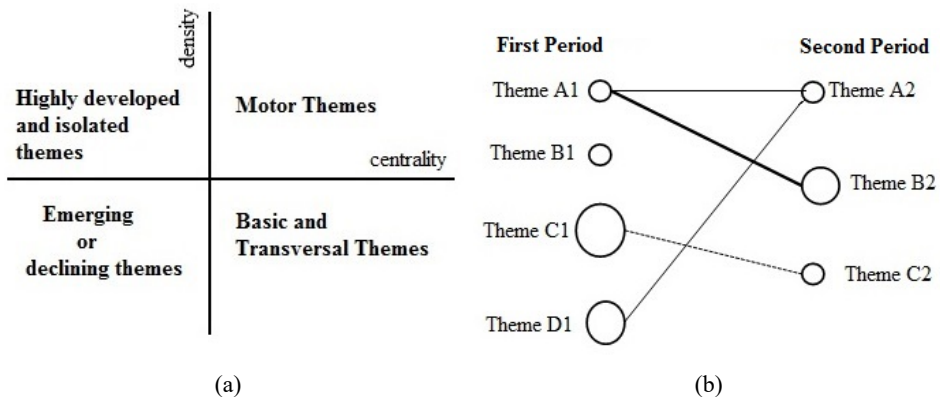
To investigate the scientific evolution of 5G communication using graphene-based antenna the entire period that is 2014–2021 is divided into two phases: 2014–2019 and 2020–2021. The reasons behind this unequal periodisation are

a   to have almost equal number of papers in both the phases

b   to understand the research trend before and after COVID-19.

The nodal size in thematic evolution is relative to the number of documents published in each theme. The links indicate co-occurrence among the clusters of different periods. Clusters with solid lines share common themes, while clusters with dashed lines do not share common themes.

Figure 10   Strategic diagram displaying the performance of the themes for first period 2014–2019 (see online version for colours)
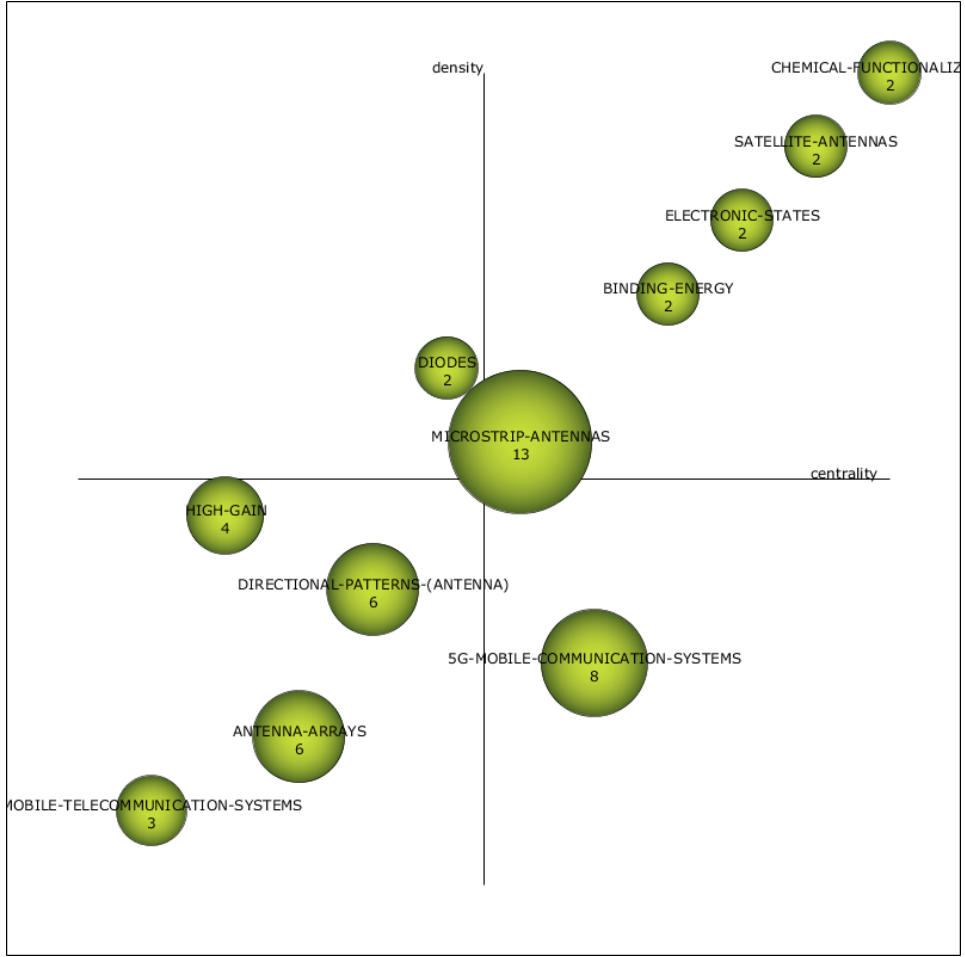

4.1   First period (2014–2019)

The strategic diagram in Figure 10 depicts a total eleven themes were used out of which five are the motor themes. The microstrip-antenna theme is well developed, highly connected and has a maximum number of documents in comparison to the others (*Q5*). Diode theme is developed but isolated from other themes related to 5G communication using graphene antennas. High gain, directional pattern, antenna array and mobile communication are developing themes. The 5G mobile communication system is the

basic theme which is relevant to the present research study and around which a lot of development is going on.

4.2   *Second period (2020–2021)*

This period is the latest one where the majority of themes are placed in 1st and 3rd quadrant as depicted in Figure 11. Here, microstrip-antenna is the motor theme with the highest number of documents. Dielectric resonators and silicon are the emerging themes.

Figure 11   Strategic diagram displaying the performance of the themes for second period 2020–2021 (see online version for colours)
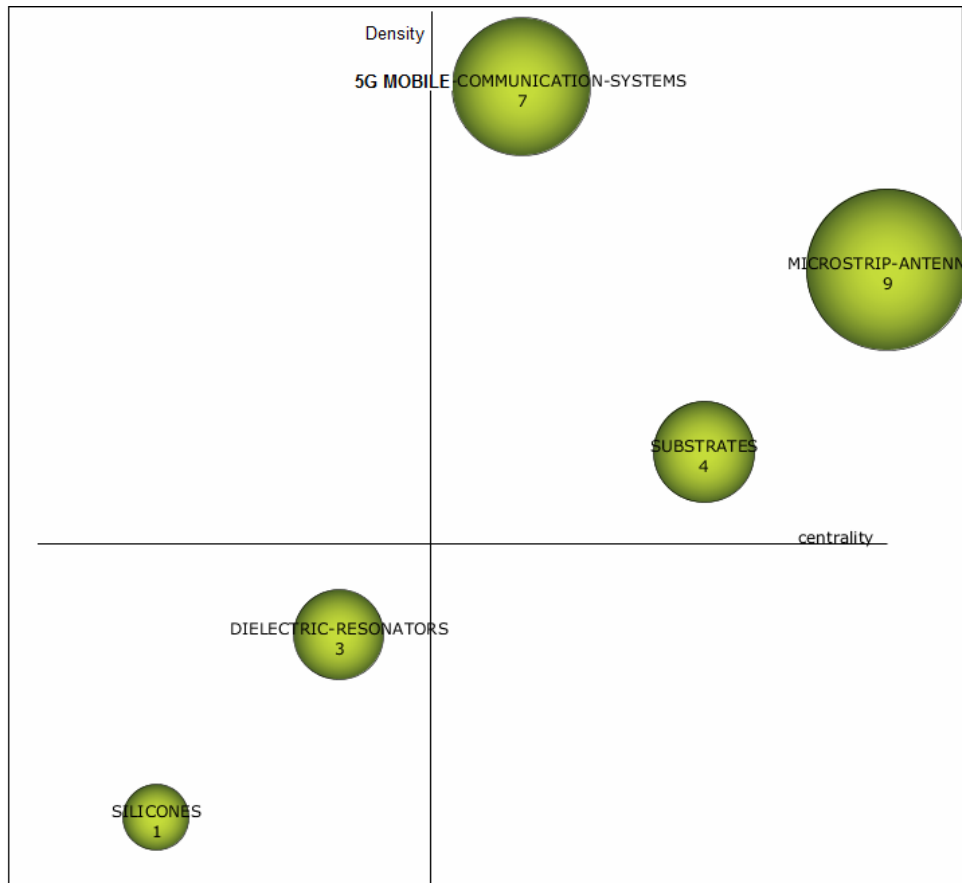

According to Figure 12, Microstrip-antenna is strongly connected to graphene, coplanar-waveguides, impedance bandwidth and electric impedance. A number of documents are available on graphene-based microwave and microstrip antennas with wide impedance bandwidths.

The thematic evolution of themes over the time is displayed in Figure 13. The evolution process eliminates diodes, binding-energy, electronic-states, satellite antenna, chemical functionalisation and mobile telecommunication system. Microstrip antenna theme from the first period was carried over to the second period. A strong theme

connection is found between directional patterns and dielectric resonators. However, high gain and 5G mobile communication shares weaker linkage over the period.

Figure 12   Thematic network of microstrip-antennas (see online version for colours)
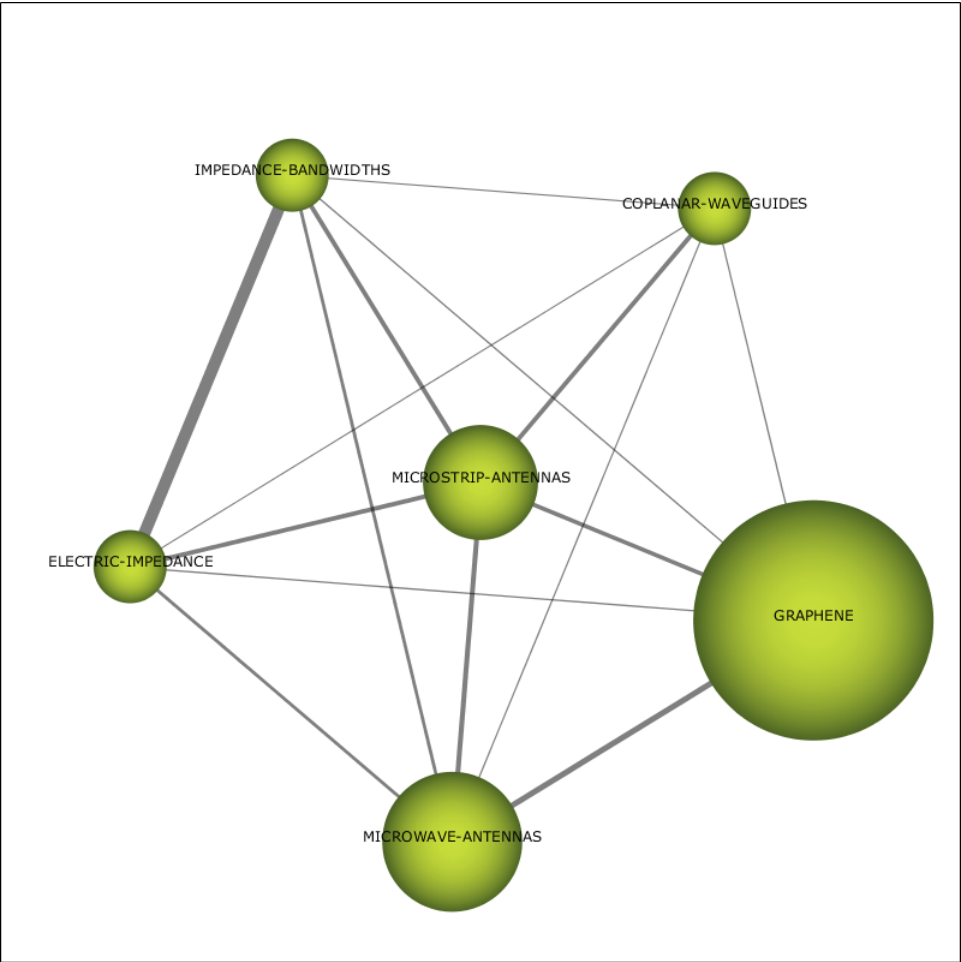
Overlay graph in Figure 14 shows the stability of themes between the successive periods.

In the first period a total of 246 keywords were used out of which 205 were deleted and 41 were carried forward to the next period. With 186 keywords added in the second period, the total keyword count now stands at 227. The total numbers of keywords are indicated inside the circle and the similarity index is 0.18. The inward arrow shows the emerging themes whereas the outward arrow shows the disappearing themes.

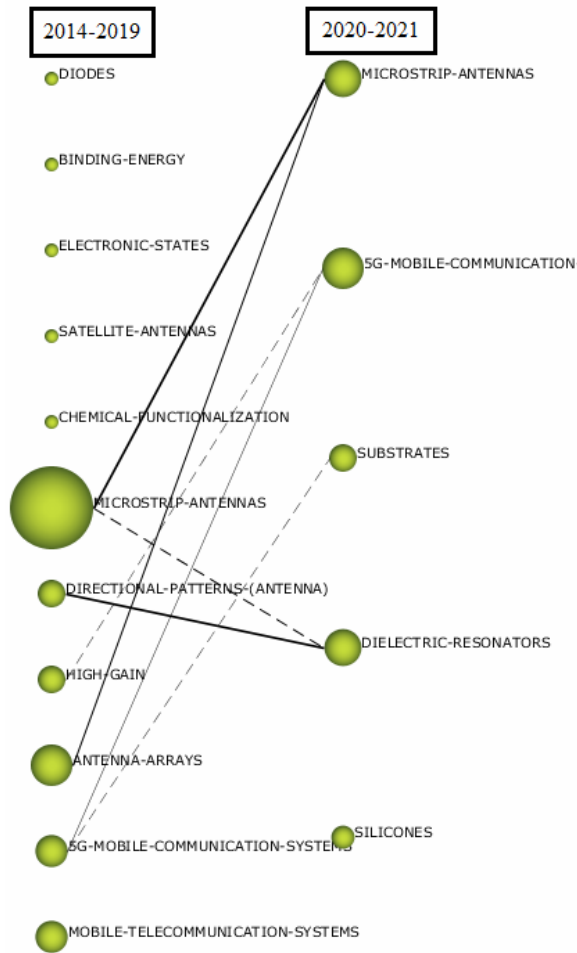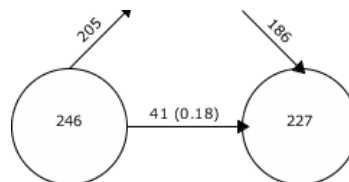**Figure 13** Evolution map (see online version for colours)

Figure 14 Overlay graph

5   Conclusions and future scope

Bibliometric analysis of graphene antenna for 5G communications provides an overview of global research efforts and performance within specific topic areas. In this study, certain keywords were used to extract the most significant papers from the Scopus database from 2014 to 2021. Through Bibliometric analysis, we identified significant countries, authors and affiliations in the related field. In literature there are 59 research articles available in the field of graphene-based antenna for 5G communication. Most of the research papers address the design of array antennas using graphene material for 5G communication. It is also claimed that with the usage of graphene, compact and low-profile antennas can be designed.

According to this analysis China, Malaysia and USA are the most productive countries in terms of the highest number of published papers worldwide. Collaborative research is also going on in this emerging field. *International Journal of RF and Microwave Computer-Aided Engineering* is the top leading journal with the highest number of publications. As 5G is not just an incremental expansion of previous generations, diverse materials other than conventional copper are required. Conventional antennas are not capable of supporting high frequencies required for 5G; therefore, there is a need for research in the direction of designing graphene-based antennas. This bibliometric – thematic analysis also suggests that there is a wide opportunity of research in designing and developing graphene-based antenna 5G communication. In this current study, academic literature and scholarly communication in the targeted field is analysed qualitatively and qualitatively. In addition, it also offers valuable directions and findings to the academic researchers working on antenna design and development using graphene for 5G communications. In addition to Scopus, this study can be extended to Web of Science databases in the related research area.

The use of graphene-based antennas in 5G wireless communication has the potential to revolutionise various industries, leading to improved efficiency, safety, and customer experiences. Continued research, development and collaboration in this area can potentially lead to significant benefits for businesses and management, making it an important area of study for both researchers and practitioners for further exploration. The results highlight the increasing interest and potential of graphene-based antennas for improving the performance and efficiency of 5G networks. Furthermore, the adoption of graphene-based antennas for 5G wireless communications can have important implications for businesses and management, including increased innovation and competition in the telecommunications industry, potential cost savings and improved network performance, and the development of new applications and services that rely on 5G networks.

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