The Role of 5G and IoT in Smart Cities

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Abstract

Smart cities, one of the key application areas of 5G and IoT technologies, have at their core the goal of improving quality of life, creating collaborative solutions, and addressing resource constraints. Examples of some of the many services integrated into the network of a typical smart city are related to smart health, smart transportation, smart buildings, smart hotels, smart industry, smart universities, etc. The new era of wireless mobile telecommunication technology and the IoT ecosystem is driving the opportunities for smart cities to not only solve existing problems but also create new services and functionalities that are out of the box and invisible to the end user. The main objective of this paper is to explore the role of 5G and IoT in smart cities. The market environment, key business developments, and trends related to the key smart cities' enablers, IoT and 5G, are presented. An in-depth literature review followed by a discussion is substantiated with synthesised research findings on the current development, 5G coverage, use and deployment of IoT in smart cities, and forecasting the evolution of its application in smart cities.

Keywords: mobile technology; 5G; Internet of things (IoT); smart cities; smart tourism
JEL classification: O31, O32, O33, Z19, Z32
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Introduction

The main goal of cities today is sustainable development with smart features, mainly due to the overuse of resources, increasing pollution, and better public services (Suciu and Petre, 2019). According to the UN, 55% of the world's population now lives in urban areas, which is expected to increase to 68% by 2050 (UN, 2018). This major population shift from rural to urban areas poses a major challenge for all urban areas. Continued population growth in urban areas is a major challenge for all cities. Today, the number of residents in urban areas is increasing significantly compared to the rural population, and this trend is expected to continue in the coming years (Akhunzada, Islam, and Zeadally, 2020). In the face of urbanisation, population growth, and resource scarcity, cities will turn to a new modern technology known as smart city solutions in the coming years (IoT and smart city technologies, 2022).

How people live in smart cities has changed dramatically with the growth and development of technology (Yang et al., 2022). To make life easier for residents of urban areas, many cities have decided to adopt new or available technologies. One of the technologies developed to cope with the continuous growth of data and connectivity in today's world is called 5G. The increasing coverage of the 5G network is gradually changing the way we live and connect. According to Setyawan et al. (2020), smartphone users will reach 5.9 billion by 2025. The smart city concept represents a vision of urban development that enables sustainable management of urban resources on the one hand and a higher quality of life for citizens through the advanced application of technology on the other.

The Internet of Things (IoT) is a revolutionary communication paradigm that aims to create an invisible and innovative framework for connecting various digital devices to the Internet (Mehmood et al., 2017). In the last decade, new and disruptive technologies emerged in the ICT field - Big Data, Big Data Management, the Internet of Things, 5G, artificial intelligence applications, etc. For the implementation of the "smart" concept in a smart city, IoT technologies, ICT solutions, and corresponding service delivery models should be integrated with the underlying wireless access technologies (Šuman, Poščić, and Gligora Marković, 2020; Musa, 2018; Taleb, Afolabi, and Bagaa, 2019).

The main objective of this paper is to highlight the role of 5G and IoT in smart cities. The publications of the last decade in this field are reviewed in the largest databases, Scopus and Web of Science. The analysis of abstracts and keywords in most related publications in the research area aims to highlight the most related terms and expressions in the field of smart city development.

The research focused on the need to consider and think of Smart Cities and the development of IoT and 5G.

The following section provides an overview of the market environment, key business developments, and trends related to the key smart city enablers, IoT and 5G. The methodology section explains a method for targeted literature search and text processing of relevant publications. In the results and discussion, the current developments and trends from the relevant publications are presented using tables, graphs, and figures. Finally, the prerequisites for the deployment of IoT in smart cities and the importance of 5G coverage are summarised.

Theoretical background

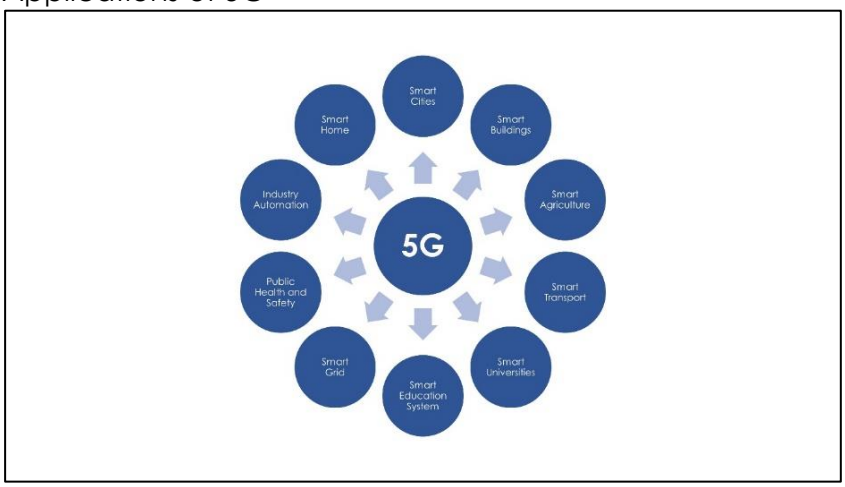
5G network

5G represents a generation of mobile broadband that will replace or at least improve upon 4G LTE connectivity. The 5G network will enable exponentially faster download and upload speeds. Latency, the time it takes devices to communicate with wireless networks, will also drop dramatically. In addition, the 5G and 6G eras will ensure continuity and, with huge simultaneous connections, the ubiquity of the network at any time and place (Akhunzada, Islam, and Zeadally, 2020).

The main applications of 5G in the industry are shown in Figure 1.

Figure 1

Applications of 5G



Source: Authors adapted from (Alam, 2019)

All of this is a potential opportunity to develop and design smart city strategies that leverage the 5G network to expand the use of data, sensors, and other smart devices to improve city operations and the lives of citizens. 5G will be an innovative mobile communications solution for smart cities consisting of very high carrier frequencies with a wide bandwidth (mmWave), extreme node and device density (ultra-density), and a large number of Massive Multiple-Input Multiple-Output (MIMO) antennas. (Gupta and Jha, 2015). In many cities, 5G networks are being deployed or have already been deployed, which will certainly change the lives of citizens (Yang et al., 2022).

According to Statista 2022, China and the United States lead in the number of cities with 5G network deployments, with a total of 356 and 296 cities, respectively, where 5G is available. Among European countries, the cities with an available 5G network are Spain (71), Italy (65), and Germany (58). In addition, the economic impact of 5G will increase the United States' gross domestic product (GDP) by $484 billion by 2030 (in 2019 value). In China, 5G will increase GDP by $220 billion by 2030 (Statista- 5G in cities by country, 2022) (Statista - 5G contribution to GDP by 2030, 2022).

Internet of Things (IoT)

The Internet of Things - an ever-growing network of connected devices that communicate with a central server and each other - is becoming more than just connectivity (Car, Pilepić Stefanich, and Šimunić, 2019).

Internet of Things (IoT) systems imply a "thing" or "machine" (microcontrollers are often used, which is why the "thing" is considered intelligent) that can communicate

with an agreed protocol, collect data from the environment with appropriate sensors, and influence the environment with appropriate actuators. The "thing" is usually an embedded system that performs the intended functionality. In this context, data is generated and collected from many networked devices.

The following data shows the continued growth and impact of IoT-related projects and applications (IoT_Analytics, 2022):

- IoT-related public cloud services accounted for $5.3 billion in 2020 in a public cloud market of $109 billion.
- IoT cloud (IaaS and PaaS) spending is expected to grow 37% annually to $37 billion by 2026.
- 87% of smart building projects are successful and have a positive return on investment (only one of 26 use cases has an ROI below 50%).
- Local incentives and increasing user satisfaction are the strongest drivers of the smart building initiative.
- Today, 613 IoT platform vendors are in the market, a 1% decrease from the 620 IoT platforms identified two years ago.
- In 2020, $5 billion was spent on IoT platforms, while the market is expected to grow to $28 billion by 2026.

IoT technologies enable resource management optimization for many areas related to urban quality of life, such as smart transportation systems, energy consumption, smart buildings, space and occupancy management, pollution monitoring, resource monitoring, and sensing, physical security, sustainability, and the green environment (Minoli and Occhiogrosso, 2019).

Smart cities

The most comprehensive definition of a smart and sustainable city is given by ('ITU-T Y.4900/L.1600', 2016): "A smart, sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, the efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations concerning economic, social, environmental as well as cultural aspects."

In recent years, the rapid development of technology has led many cities to consider the concept of a smart city. Urban environments increasingly rely on smart solutions to provide citizens with a more comfortable and better quality of life. Population inflation in cities and the ongoing depletion of resources are putting a strain on people's lives in terms of providing the most basic services. As a result, most of the world's cities have transformed into smart cities that play an important role in providing direct services to citizens through the optimal use of ICT (Habeeb and Weli, 2020) (Habeeb and Weli, 2020).

Smart cities have six main dimensions (Santos *et al.*, 2018):

- smart economy,
- smart mobility,
- smart environment,
- smart people,
- smart living and
- smart governance.

Another industry that is greatly affected by the development of ICT and smart cities is tourism: tourism businesses, hotels, bookings, transportation, service quality, etc. "A smart tourism city is an urban transformation that aims to provide basic services to citizens and tourists through technology" (Habeeb and Weli, 2020).

Tourism cities become smart and sustainable through the appropriate and comprehensive use and implementation of modern technologies. In this way, a smart, sustainable city becomes an innovative tourism city that improves the quality of life for citizens and tourists, the efficiency of city operations and services, and competitiveness, while meeting the needs of current and future generations. (Habeeb and Weli, 2020). Therefore, many stakeholders should continuously collaborate in smart city projects for mutual benefit.

Research Methodology

One of the paper's objectives was to explore the interconnection of 5G and IoT in smart cities. To observe the evolution of the underlying technologies for the realisation of Smart Cities, the publications of the last decade in this field are analysed. Two major abstract and citation databases, Web of Science Core Collection and Scopus, were used to search for the related topic. The keywords used in creating the search strings were: Smart City and Smart Cities ("smart cit*), Internet of Things or IoT, and 5G. Several strings were created to represent the past, present, and future trends of smart cities, IoT, and 5G technologies. In this research, we examined the title field in both databases for the frequency of publications, while keywords and abstracts were analysed in the text processing section. The search strings were formulated differently following the syntax of the WoS and Scopus search expressions. The results are presented in Graphs 1 to 4.

The methodology is divided into two phases: 1) the creation of an effective search string for the scientific database to capture relevant literature, 2) the processing of the obtained records according to the most frequent words and expressions (each record is a publication with specific attribute fields such as title, authors, abstract, keywords, etc.). 3) Visualisation of results.

Multiple search strings were created in both databases for the Title field for English-language publications during the last decade:

a) Observation of the frequency of the expression "smart cit*" in both databases
b) Observation of the frequency of the expression "smart cit*" with "Internet of things" OR "IoT" OR "5G."
c) Observation of the frequency of the expression "smart cit*" AND ("Internet of things" OR "IoT") AND "5G".

The number of publications referring to 2022 was highlighted in red - because the period was limited to 01 Jun 2022 (less than half a year). The most relevant and important findings for our research were those with Smart Cities* and IoT and 5G as the main basic requirements for developing Smart Cities. Therefore we examined both databases, merged them, reduced them, and presented them in Graph 4 (only publication type: article, conference paper, or review).

To gain insight into the relevant literature that emerged from the specific search of the two databases, text processing was performed using software (RapidMiner) for the abstracts and keywords sections.

Several text processing models were created:

1) The most recent 2000 publications with the term "smart city*" in the keywords (for the years 2020 and 2021), targeting the most common related terms and expressions in the keywords (also using the option of n-gram detection, max n=3),
2) the most recent 2000 publications with the term "smart city*" in the keywords (for the years 2020 and 2021), targeting the most frequent related terms and expressions in the abstracts (also using the option of n-gram detection, max n=3),

3) Abstracts of the most recent publications from the last decade all have "smart cit*" AND (Internet of Things OR IoT) AND (5G) in the title (expression in keywords (for the years 2020 and 2021), aiming to find the most frequent related terms and expressions (also using the option of n-gram detection).

All text processing models were built using standard RapidMiner software operators, such as Tokenize, Filter Stopwords (English), Transform Cases (in lower), and generation of n-grams (max n=3). The Stem operator was mostly not applied to get a more readable representation of the results. Before processing the documents from the CSV files, the data for the observed fields (abstracts or keywords) were converted from nominal to text. The results are depicted in Graphs 5, 6, and 7 in the Results and Discussion section.

Results and Discussion

As mentioned in the Methodology section, the search strings were formed in the WoS and Scopus databases, and the frequency distribution over the years was very similar (see Graphs 2 and 3). Therefore, only data from Scopus (a larger database) are presented in Graphs 4 and 5.

Figure 2
Number of publications TI=(„smart cit*") from 2012, Scopus

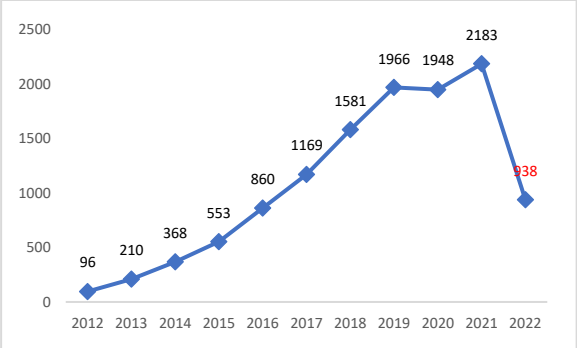


Figure 3
Number of publications Title ("smart city*"), WoS

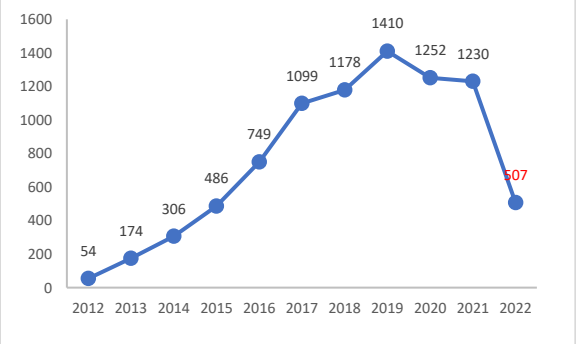


Figure 4
TITLE (smart AND cit*) AND (TITLE (internet*of*things) OR TITLE (IoT) OR TITLE (5g), Scopus

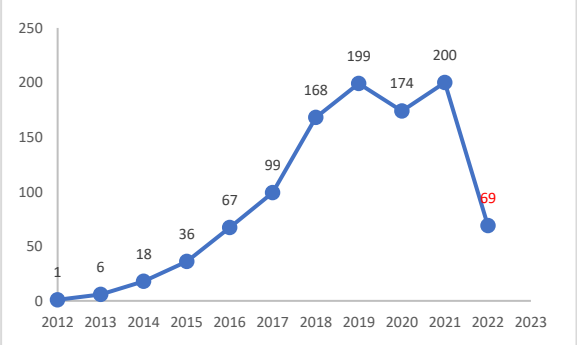
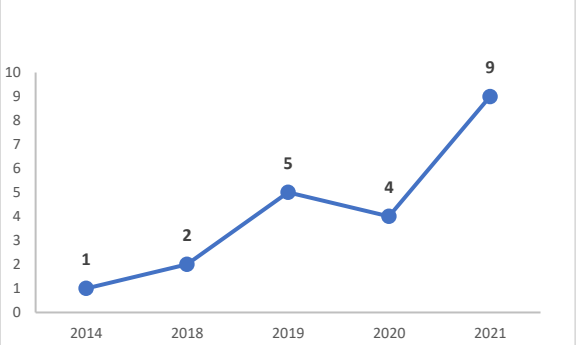


Figure 5
TITLE („smart cit*“) AND TITLE ("Internet of Things" OR "IoT" OR "Internet-of-Things") AND TITLE ("5G"), Scopus



Source: Author´s work

Publication titles containing only the term "smart cit*" have peaked in the last three years, and the same dynamic is seen for publications containing "smart cit*" and one or more of the following terms/expressions: "Internet of Things", "IoT" or "5G". Looking at the period of observed results up to 01 Jun 2022, the number of publications in all practical search terms is expected to remain similar or slightly decrease in 2022 if the trend continues. Although IoT and 5G technologies are

driving the development of smart cities, there are only a few publications (18 in Scopus and 13 in WoS CC) in the last decade that include all three practical terms/expressions: Smart City, IoT, and 5G (Graph 4).

The publications that contain all three terms/expressions (smart cit*, Internet of Things OR IoT, and 5G) in the title are listed in Table 1. Most of the publications have a highly specialized topic, except for (Minoli and Occhiogrosso, 2019) (Hsu et al., 2021) (Milovanovic et al., 2019) (and Alfa et al., 2018). As an intense development of IoT and Smart Cities related applications with the necessary 5G and even 6G coverage is expected currently and shortly, there is a need for more publications addressing all these topics together.

Table 1
Publications containing in titles all three terms/expressions

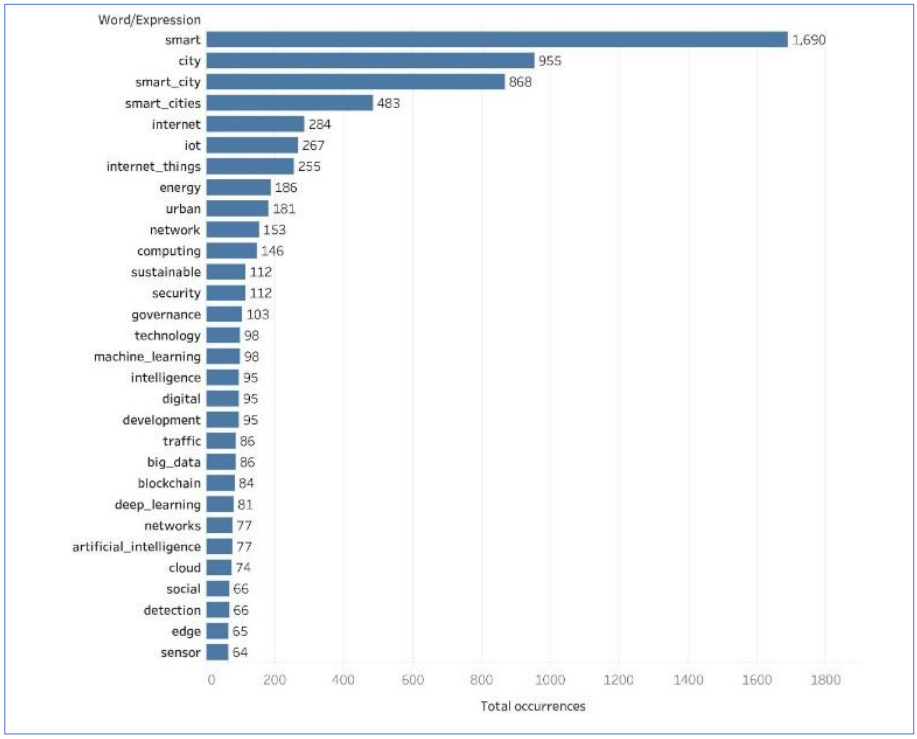
Authors	Publication Title	Indexed
(Liu, Guo, and Lee, 2021)	Promoting smart cities into the 5G era with multi-field Internet of Things (IoT) applications powered with advanced mechanical energy harvesters	Web of Science, Scopus
(Alcaraz-Calero et al., 2020)	5G IoT System for Real-Time Psycho-Acoustic Soundscape Monitoring in Smart Cities with Dynamic Computational Offloading to the Edge	Web of Science, Scopus
(Zhao, Askari and Chen, 2021)	Nanogenerators for smart cities in the era of 5G and the Internet of Things	Web of Science, Scopus
(Cui et al., 2020)	A Novel Additively 4D Printed Origami-inspired Tunable Multi-layer Frequency Selective Surface for mm-Wave IoT, RFID, WSN, 5G, and Smart City Applications	Scopus
(Serrano, 2021)	The Blockchain Random Neural Network for cybersecurity IoT and 5G infrastructure in Smart Cities	Web of Science, Scopus
(Sharma et al., 2021)	A Compact Multiband 2x2 MIMO Antenna For 5G 28GHz/38GHz IoT and Smart City Applications	Scopus
(Hsu et al., 2021)	Research on Shanghai Smart City Evaluation System in the Era of 5G Internet of Things	Scopus
(Sánchez-Cano et al., 2021)	Review of Methods to Reduce Energy Consumption in A Smart City Based On IoT and 5G Technology	Web of Science, Scopus
(Vivekanandan, N and U, 2021)	BIDAPSCA5G: Blockchain based Internet of Things (IoT) device-to-device authentication protocol for smart city applications using 5G technology	Web of Science, Scopus
(Cui et al., 2020)	Additively Manufactured RF Devices for 5G, IoT, RFID, WSN, and Smart City Applications	Scopus
(Yan et al., 2020)	UHF RFID handset antenna design with slant polarization for IoT and future 5 G-enabled smart cities applications using CM analysis	Web of Science, Scopus
(Hayes and Omar, 2019)	End-to-End VANET/IoT Communications A 5G Smart Cities Case Study Approach	Scopus
(Uddin et al., 2019)	IoT for 5G/B5G applications in smart homes, smart cities, wearables, and connected cars	Web of Science, Scopus
(Milovanovic et al., 2019)	Advanced human-centric 5G-IoT in a smart city: Requirements and challenges	Web of Science, Scopus
(Minoli and Occhiogrosso, 2019)	Practical Aspects for the Integration of 5G Networks and IoT Applications in Smart Cities Environments	Web of Science, Scopus
(Nizzi et al., 2018)	Evaluation of IoT and video surveillance applications in a 5G Smart City: The Italian 5G experimentation in Prato	Web of Science, Scopus
(Alfa et al., 2018)	The role of 5g and IoT in smart cities	Scopus
(Skouby and Lynggaard, 2014)	Smart home and smart city solutions enabled by 5G, IoT, AAI, and CoT services	Web of Science, Scopus
(Dutkiewicz, 2016)	Radio Spectrum Research for Emerging IoT and 5G Networks: Applications to Smart Buildings and Smart Cities	Web of Science

Source: Author´s work

As mentioned in the methodology, several text-processing models were created for the abstracts and keywords of the publications:

- After processing the latest 2000 publications with the term "smart cit*" in the keywords (for the years 2020 and 2021) and searching for the most frequently related terms and expressions in the keywords (also using the option of n-gram detection, max n=3), the subsequent distribution is obtained (see Graph 6). It shows the interconnection and inseparability of the domains related to Smart Cities.
- The same text processing model was built for the latest 2000 publications with the term "smart cit*" in the keywords (for the years 2020 and 2021), identifying the most frequently related terms and expressions in the abstracts (also using the n-gram detection option, max n=3), and is shown in Graph 7.
- Finally, text process analysis of the 18 abstracts of the latest publications from the last decade, all having "smart cit*" AND (Internet of Things OR IoT) AND (5G) in the title (expression in keywords (for the years 2020 and 2021), is shown in Graph 8.

Figure 6
Text analysis of the 1

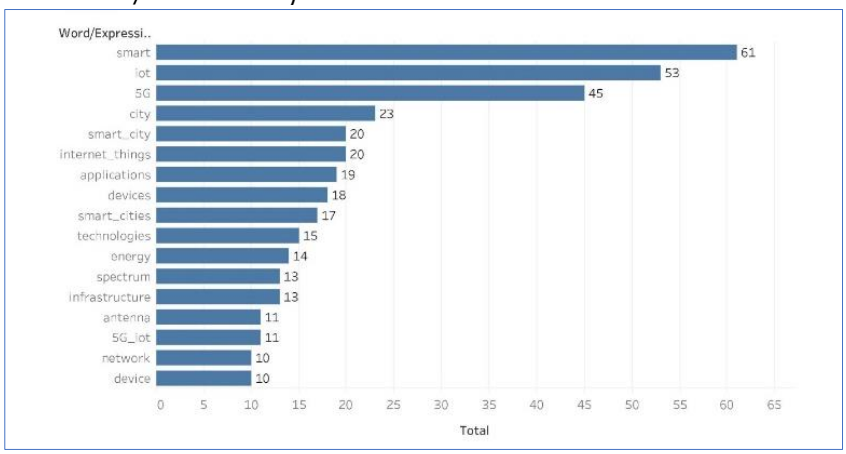


Source: Author´s work

Figure 7
Text analysis of the 2

Source: Author´s work

Figure 8
Text analysis of the 3)



Source: Author´s work

Conclusion

The rapid growth and development of technology will shape the times ahead. There is already talk of the 6G network, which will enable better, faster, and more efficient connectivity of numerous devices on an even larger scale. As mentioned in this paper, the technology has numerous benefits that have found application in urban areas. Not only have they enabled the smooth growth and development of urban areas, but they have also made life easier and increased the quality of life for citizens. When we talk about 5G and increasing 6G transmission technology, the fact should not be overlooked that these technologies are the reason for the growing number of networked (smart) devices, which are called by one name - the Internet of Things (IoT).

This paper aims to highlight the role and importance of the 5G network and the Internet of Things, as well as their growing impact on the development of smart cities. One of the biggest advantages of 5G networks and IoT is the ability to connect "everyone to everyone" and the speed at which large amounts of data can be transmitted. Because of the ever-increasing population growth in cities, city governments or governments no longer have a choice because doing business without high-speed Internet and ICT is almost unthinkable today. So if all cities want

to be and become "smart," they must constantly follow technological trends with the goal of quality of life for citizens/tourists on the one hand and sustainability of the city(ies) on the other.

State art in smart city networking and the development and implementation of underlying and fundamental technologies is shown by the frequency of related publications in the two abstract and citation databases, Scopus and Web of Science Core Collection. The research focused on the need to consider and think about Smart Cities and the development of IoT and 5G. Results from the last decade show that after a sharp increase in publication numbers from 2012 to 2019, there has been some stagnation in the last two to three years. Moreover, in the largest database Scopus, only a few publications have the title Smart City with IoT and 5G. The text analysis of abstracts and keywords showed the most related terms and expressions in the field of smart city development. The findings in this paper can be used for related and further research and provide an overview of the most related areas in the context of smart cities. The main limitation of the research is the focus on only three areas: smart city, IoT, and 5G, but the authors believe that they are the most important pillars for smart city development.

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