Transdisciplinarity and the Future of Engineering
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Transdisciplinary Technology Mining of Advanced 6G Satellite Communication Innovations

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Abstract. This research focuses on using natural language processing text mining approaches to make knowledge induction from the patent corpus within 6G satellite communication technologies. The domain ontology, that describes the transdisciplinary features of the knowledge taxonomy, is derived and organized in a hierarchical schema. The trends of innovation distributions within the ontology are further analyzed to discover the transdisciplinary R&D requirements. The technology mining process discovers that the advanced satellite infrastructure and its hardware/software integration are the enabler for seamless and high-speed communication network connectivity on land, sea, and sky. Seven main parts of "6G satellite communication" ontology schema and the taxonomy are text-mined from relevant patents and literature. 2357 domain patents (all with highly transdisciplinary nature) are collected and analyzed. During macro-analyses, trend of inventions, the leading assignees, and the distribution of technology categories are depicted. The micro-analyses discover the innovations of technological themes, technology function matrix showing R&D hot-spots and cold-spots, and the most critical sub-technologys' lifecycle maturities. The ultra-goal of this research is to discover the main trends and the potentials of satellite communication-related technologies through smart technology mining techniques, especially those requiring transdisciplinary R&D. Finally, the strategic research plan for technical-savvy countries (e.g., Taiwan focusing on semiconductor and IT design and manufacturing sectors) is presented, highlighting the necessary transdisciplinary R&D efforts for mobile telecommunication industry.

Keywords. 6G satellite communication, Non-terrestrial network, NLP text mining, Transdisciplinary R&D

Introduction

With the growing applications of Internet of Things (IoT) and AI machine learning utilizing the massive data, mobile devices (or "things" such as smart cars, smartphones, etc.) are expected to connect to each other and the cloud, so that allows people and

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machines to access real-time information and make dynamic decisions. To achieve the above tasks, communication technology must meet the performance goals of low latency, high speed, etc. Hence, many countries are developing their 5G network, e.g., Taiwan promoted commercial use of 5G since mid-2020. It is also important to look forward Beyond 5G (B5G) and 6G. Usually, it takes several years to develop and test new technologies in telecommunication, many companies have already published their whitepaper and released their visions of 6G. Since it will be a whole new era in telecommunication, governments have to develop criteria in the decade ahead for all companies to follow. With the vigorous development of science and technology in the future, 6G is expected to become the foundation of all industries and social development in 2030, it will not only connect people but also things [1].

To achieve 5G network, high density of base station installations is a major task. However, installing many base stations is costly and may not guarantee comprehensive global digital connectivities. In order to meet the demanding 5G requirements both in large throughput and global connectivities, satellite communications provide a valuable resource to extend and complement terrestrial networks [2]. 5G (terrestrial) and satellite (off ground) connectivities will integrate by 2025 according to third-generation partnership project (3GPP) Release-18. Satellites can be launched into many types of orbits. Compared to geostationary earth orbit (GEO), and medium earth orbit (MEO), Low earth orbit (LEO), is the closest orbit to the earth, which is more suitable to develop 6G network with its high network coverage and low latency characteristics. Recently, many low earth orbit operators have already started deploying their LEO satellite constellations (e.g., SpaceX, OneWeb, and Amazon), their current projects are Starlink, OneWeb, and Kuiper, respectively. According to the United Nations' Outer Space Objects Index, more than 1,200 and 1,800 LEO satellites launched respectively in 2020 and 2021. Obviously, satellite communication is a trending technology of 6G. This research proposes to analyze the patents about 6G satellite communication, which global patents are retrieved from a patent leading platform, Derwent Innovation.

A patent is an exclusive right granted for an invention, which provides state-of-the-art knowledge [3]. Through patent retrievals and analysis, this research discovered all the leading technologies related to 6G satellite communication. With all the relevant patents collected, we further analyze the text semantics of the patents by using natural language processing (NLP). This method requires transdisciplinary knowledge with the understanding of satellite communication, patent retrieval and analytical methods, and machine learning for NLP. The research demonstrates the comprehensive technology mining results with transdisciplinary R&D nature.

Specifically, in this research, latent Dirichlet allocation (LDA) ontology matching, k-means clustering, technology function matrix (TFM) for exploring hot and cold patenting spots, and s-curve of the technological maturity lifecycle are applied in patent analyses. Through patent analysis, the research provides a better understanding of 6G satellite communication technologies ontology schema and taxonomy, with ICT-related R&D potential technologies discovered. Last, the future perspective for Taiwan is analyzed.

1. Methodology applied in this research

In order to fully investigate B5G technologies portfolio and its R&D trend, this research deploys a comprehensive patent search and analyses procedure as described in the following sub-sections.

1.1. Patent search strategy and preliminary results

In this research, patent search is conducted using boolean search approach. First, three most important phrases, embedded in the domain articles of satellite communication, are identified. They are low earth orbit satellite (p1), communication (p2), and non-terrestrial networks (p3). Further, twelve keywords, w1~w12, listed in Table 1, are also found in the most relevant domain articles. Thus, the boolean formula for the comprehensive patent search is expressed as Eqn (1).

$$\wedge\ (\wedge\ (p1\ \ p2\ \ p3)\ \vee\ (w1\, w2\ \dots\ w12)) \tag{1}$$

where, ∧ is boolean "and" and ∨ represents boolean "or."
The publication years are set from 2008 to 2021. A total of 2357 global patents is retrieved by applying the above search strategy.

Table 1. Keywords in satellite communication.

B5G	Radio Access Network	Satellite
Free Space Optical	Satellite Broadcasting	Sub-Terahertz
C-RAN	O-RAN	Satellite Communication
NTN	MMWAVE	Millimeter-Wave

1.2. Keyterm extraction

A keyterm extraction is an approach to analyze the important word in a document. Term frequency-inverse document frequency (TF-IDF) is a method for text mining common weighting techniques. Normalized term frequency-inverse document frequency (NTF-IDF) is a statistical approach for text mining, it considers the length of each patent and the frequency of keyterms. In this research, we calculate term frequency by using NTF-IDF [4].

1.3. Technology function matrix (TFM)

TFM consists of technology and function indicators which is an approach to patent analysis. TFM is a patent map that helps visualize quantitative patent information with respect to the technical and functional features in the patent landscape [5]. Building a technology function matrix is based on domain knowledge. First, do the literature review and patent study to have a landscape of the domain. Next, construct domain ontology for a given domain, and define technology and function to finish TF matrix construction. Last, analyze patents and fill them into TFM cells. E-technology function matrix (eTFM) generates TFM through computer-aided. The expert can verify domain's correctness and consistency by eTFM. The principle behind eTFM is doing text mining twice to cluster the patents, then automatically generating analysis results with computer-supported. In eTFM, calculate term frequency and find key terms for each technology and function by using normalized term frequency (NTF). The higher the NTF values are, the more significant the term is. If the similarity meets default threshold, the patent will fill into the corresponding TF field. Sometimes a patent can be filled into more than one TF cell, because patent meets more than one TF cell requirement. The summation of the patents in eTFM will be greater than original input patent number.

2. Analyses of 6G patents and literatures

This chapter will introduce the definitions of 6G satellite domains according to ontology explored by keyword extraction, topic modeling, and clustering algorithm.

2.1. Ontology Construction

The domains of the 6G satellite can be separated into two sub-domains, including satellite communication and applications. Satellite communication represents the communication technologies and infrastructure in 6G satellite. Applications represent varieties of applications that can be realized in 6G satellite. There are six parts in satellite communication, including transmission, transmission protocol, cellular network, terminal, spatial network, and communication link.

Fig. 1 shows the six domains which belong to satellite communication. Transmission protocol is the standard needed to follow when the signals are transmitted in two systems. The transmission protocol in satellite communication for 6G system includes a framework with IAB, PDU, and layer [6]. Cellular network has been a significant communication way since 1st generation. This technology is constantly evolving. Satellites and UAVs can make signals distribute everywhere, especially in the sky and remote regions. RAN is the communication architecture that built connections with equipment and core network. Transmission contains the method and frequency used in satellite communication. The frequency of millimeter waves falls in 20 GHz~60 GHz and Terahertz falls in 300 GHz~10 THz [7]. Free space optical communication system is one of the optical transmission methods, and the characteristic of it is the transmission channel contains atmosphere, space, or vacuum. Terminal shows the components used in the user end, ground station, and any communication node. Antenna is an important part of satellite communication. The different arrangements of the antenna array can achieve diverse functions such as GPS or reducing noise.

Spatial network contains the technology of the terrestrial network and non-terrestrial network. Non-terrestrial network involves any flying objects, including satellite system, high altitude platform, and UAV [8]. Providing air-to ground network can expand signal propagation distance [9]. Ground station can receive the signal from the non-terrestrial network. VSAT is the most common ground station used in the world [10]. Communication link include the technology that uses in the signal transmission in satellite systems and terrestrial network [11]. It has four parts, core network, inter satellite link, ground-to-satellite link, and routing [12]. These four parts construct a communication network between satellites.

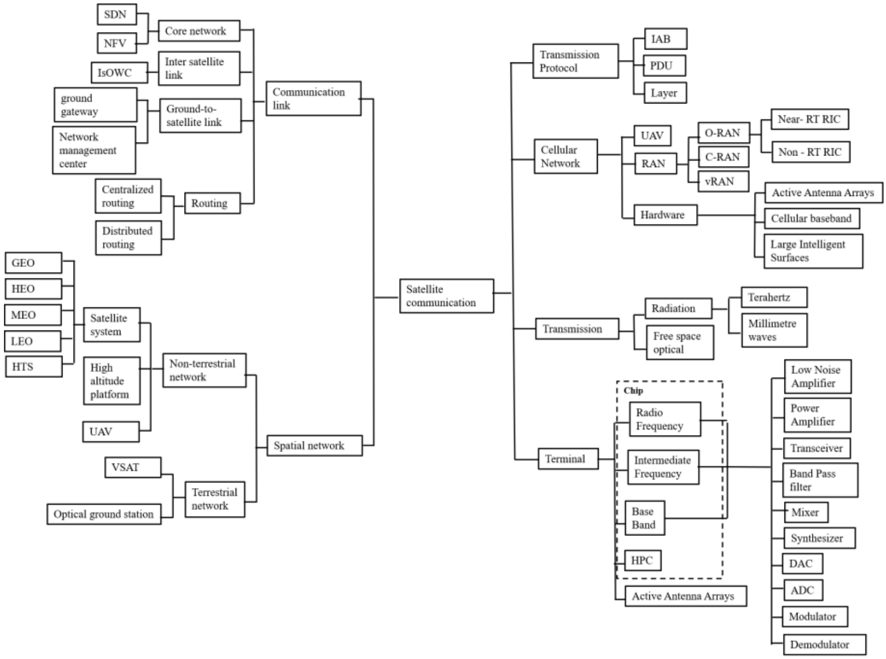

Figure 1. 6G satellite communication technology ontology.

Fig. 2 illustrates the applications with the 6G satellite communication. Autonomous car is a vehicle that can operate without controlling by sensing the environment. The 6G network provides a high transmission data rate and the satellite provides the sensing data from space [13]. Broadcasting is the basic function of satellite, integrating the high data rate and high coverage can be more powerful. Providing the data to the user quickly and accurately. Cloud applications virtualize conventional computing, storage, and networking by adding satellite information resources. Improving the accessibility of data in any place and at any time [14]. IIOT is the combination of industrial and IoT which are more convenient to operate a factory. Collect data from the machine by installing the sensor. IIOT constructs a network to monitor or manage the efficiency of the manufacturing process. Remote sensing is a method to get the target information captured by the satellite. HFT is high-frequency trading. Satellite networks can provide a more secure and faster link for trading [15].

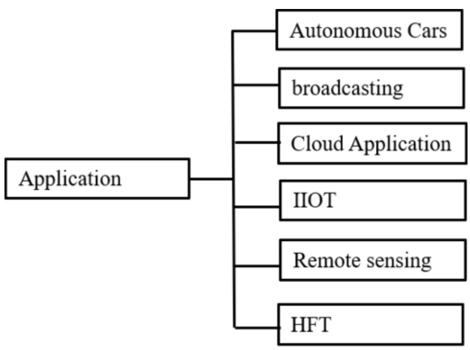

Figure 2. 6G satellite applications.

2.2. Macro-data analysis

After statistical analyses, the number of 6G satellite patents from 2012 to 2021 indicate a steady growth in patent published. By observing the top assignees in 6G satellite communication, the main assignees are Qualcomm, Hughes Network System, Directv, and Viasat. We can find that most of the top assignees are related to satellite technology. They are the equipment vendors and infrastructure providers that build up the satellite communications, such as chips, beamforming, and so forth. These companies develop the necessary basic components for satellite communications and then become the providers of standard technologies.

According to the results in Fig. 3, the current 6G satellite patents are mainly concentrated in several technologies and applications. These technologies and applications include user equipment, wireless communication, uplink, indication information, and so on. And the research fields that the top three assignees are fully engaged in are highly overlapped with these technologies.

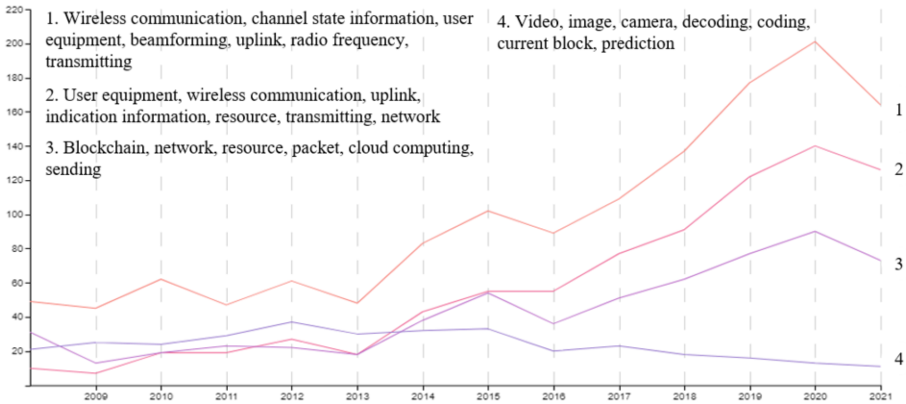

Figure 3. Main technological field in 6G satellite (top 4).

Table 2 shows the technology categories and related technologies that the top three players are focusing on. All three companies are fairly committed to the development of class A. Class A is mainly composed of satellite system signal, access technology, global navigation satellite system signal, and other technologies. In addition, Qualcomm also put emphasis on the development of class B. Class B includes technologies such as multiple access system, division multiple access system, etc. While Directv is particularly focused on the development of class C, referring to web service, database, and rate allocation chart.

Table 2. Main research fields of top 3 players in 6G satellite.

Qualcomm	Hughes Network System	Directv
Class A Satellite System Signal, Access Technology, Radio Access Technology, Global Navigation Satellite System Signal	Class A Satellite Terminal Gateway, Satellite Gateway, Receiver Station	Class A Uplink Signal, Downlink Signal, Satellite Communication System
Class B Multiple access system, Division multiple access system	Others Report, Small Aperture, Allocation, Request, Interface	Class C Web Service, Database, Rate Allocation Chart

2.3. Micro-data analysis

There are 7 topics discovered in LDA [16]. Keywords for each topic are listed in Table 3. Some of the topics have overlapped with another topic. It shows that the technologies in the satellite communication system are related to each other domains, and provide domain combination in the topic. Terminal, communication link, and spatial network are listed in two domains simultaneously in Table 3. It shows that the technology in 6G satellite communication combines the different domains. In order to reach some functions, we integrate the advantages from another domain.

Table 3. LDA topic keywords.

Domain	Topic	Keywords
Transmission protocol Communication principle	Topic 1	channel, mobile, broadcast, group, component, processor, serve, sub, interval
Terminal (analog signal & equipment)	Topic 2	message, apparatus, reference, scheme, multi, layer, sequence, computer, phase, generate
Non-terrestrial network	Topic 3	matrix, cell, rf, beacon, mode, spatial, frequency, channel, uav, field
Antenna	Topic 4	mimo, antenna, equipment, circuit, beam, array, port, orthogonal, fourth, couple
Communication link	Topic 5	symbol, stream, input, precoding, wireless, feedback, value, radio, transmission, bit
Communication link Terminal (digital signal)	Topic 6	node, wireless, multiple, network, user, terminal, information, request, access, parameter
Terrestrial network	Topic 7	ue, transmitter, resource, station, interference, relay, location, modulation, detect, instruction

K-means clustering is a clustering algorithm that is an unsupervised machine learning algorithm. The aim of the K-means algorithm is to divide M points in N dimensions into K clusters so that the within-cluster sum of squares is minimized [17]. In Fig. 4, the ground station, user end is the biggest clustering result. The technologies in the cluster are talking about analog signal processing methods and equipment used in the transmission. How to transmit the signal in the long-distance and make sure its reliability is an important part of satellite communication. Especially in the 6G satellites, it uses the higher frequency signal to transmit data. The faster speed it has the more difficult technology it has to use. The second domain in topic 1 is communication principle, which is the basic part of any communication technology. Technology in the past can give us a basic frame of transmission. Communication principle is talking about how transmission can be achieved from the physical perspective. All of the communication networks have to start from this. Others are almost the same amount of numbers. They are still parts of the important domains in communication.

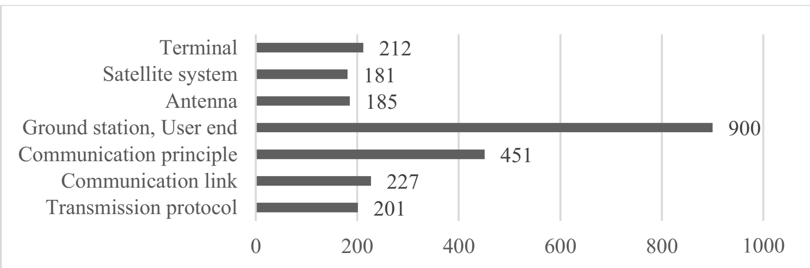

Figure 4. Satellite communication clustering result.

Fig. 5 shows the s-curve of 7 clusters. Growth data of every cluster over the years is drawn by applying logistic method and Gompertz method. Fig. 5 shows that cluster 1 entered the introduction period around 2003. However, there is a turning point in the slope in 2010. The patent publication numbers begin to increase and officially entered the growth period. The inflection point occurs around 2020. Although the number is still growing, the slope become relatively smooth. This also makes the growth rate become lower. By around 2040, cluster 1 related technologies will develop to the limit. The number of patents will converge to about 50 patents. However, cluster 1 will enter the decline period; Cluster 5 and cluster 6 are similar to cluster 1. They enter the introduction period around 2003 and enter the growth period in 2009. The inflection point appears around 2021. So, the growth rate will become smaller, and enter the maturity period. Finally, cluster 5 and cluster 6 will enter the decline period around 2038. As for clusters 2, cluster 3, and cluster 4, these clusters have entered the maturity period in terms of patent publication numbers in recent years. Finally, cluster 2 and cluster 3 will converge to 50 patents and 70 patents. While cluster 4 is converge to 200 patents. Cluster 7 is now in the early stages of growth. It will enter the maturity stage around 2028 and eventually converge to 70 patents. For now, cluster 1, cluster 3, and cluster 4 have entered into the maturity stage (partially shown in Fig. 5). While cluster 2, cluster 5, cluster 6, and cluster 7 (also shown in Fig. 5) are still in the growth stage. In short summary, transmission protocol, communication principle, and ground station related technologies are matured, widely applied, and are gradually moving towards a saturation state where the R&D is slowing down.

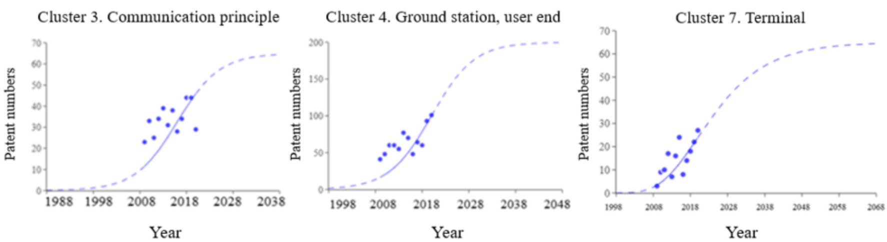

Figure 5. s-curve of 7 clusters.

In Fig. 6 technology function matrix, four major technologies and eleven sub-technologies based on satellite communication ontology are defined, also, six important communication indicators are defined in the function. The threshold of 25 percent is set in TFM analysis. Very small aperture terminal (VSAT) and inter-satellite link (ISL) are mentioned 1,311 times and 923 times, respectively. Among all the technologies, VSAT and ISL are hot topics of the technologies. VSAT is an integral element in satellite communication for applications, such as home users, private companies, and emergency responses. The potential business opportunities of VSAT (belonging to Cluster 4) are tremendous due to its matured development. However, fewer numbers of patents in high altitude platforms (HAPs) and core network (CN) indicate that HAPs and CN are newer and prominent for future research. As indicated in function dimension, "high coverage" and "high reliability" are certainly the most important functional features in 6G satellite communication innovations, as shown in Fig. 6's column 4 and 6.

Technology	Function	High Data Rate	High Reliability	Low Latency	High Coverage	Low Cost	Security	**SUMMATION**
Non-Terrestrial Network	Satellite System	53	192	66	248	62	45	666
	High Altitude Platform	51	20	18	28	32	14	163
	UAV	45	13	80	15	5	81	239
Terminal	Anteena	44	212	37	150	19	18	480
	Chip	121	84	38	77	16	20	356
Communication Link	Inter-satellite Link	86	257	128	312	78	62	923
	Core Network	53	13	14	16	35	28	159
	Ground to Satellite link	47	68	44	78	34	47	318
	RAN	56	17	57	16	6	54	206
Terrestrial Network	VSAT	238	278	222	351	52	170	1311
	Optical Ground Station	69	188	67	240	42	51	657
	SUMMATION	863	1342	771	1531	381	590	

Threshold:25

Resource:2357 >10%

Figure 6. TFM shows the distribution of patents in various technology and function categories.

2.4. Future perspective for Taiwan

According to the report of Satellite Industry Association (SIA), ground equipment segment was worth $135.3B revenue in 2020, which was 50% of global revenue in the satellite industry [18]. Taiwan is well known for its advanced semiconductor design and fabrication. Semiconductor is the key part of communication systems and, thus, will be a major contributor for developing chip-level advanced global navigation satellite system equipment (GNSS), particularly for its ground communication equipment. Further, as a leading country for ICT hardware manufacturing, companies have high technical capability to produce consumer and network equipments (e.g., VSAT, gateways) will focus on advanced B5G network technology development, e.g., core network (CN).

3. Conclusions

This paper integrates transdisciplinary knowledge, including patent retrieval and analytic methods, 6G satellite communication domain knowledge, and advanced natural language processing techniques to discover the feasible technology landscape and trends. We retrieve 2357 highly related patents in 6G satellite communication and construct a full landscape ontology for 6G satellite communication technologies and applications. Both patent macro-data and micro-data analyses are conducted in the paper to identify the major technology leaders and the matured and growth sub-clusters of technologies. Finally, the strategic directions of Taiwan's semiconductor and ICT industries are depicted in terms of their R&D potentials for the ground equipment chip development and core network (CN) technology development. For the future research, 6G satellite communication integrating AI technologies will become a powerful trend for many applications encompassing high coverage and high reliability of Internet connectivity and intelligent decision supports. We will study further into the extended applications and sectors in details, e.g., manufacturing industry, service sectors, agriculture, education, and UAV in various applications.

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References

[1] H. Saarnisaari, S. Dixit, M.-S. Alouini, A. Chaoub, M. Giordani, A. Kliks, M. Matinmikko-Blue, N. Zhang, A. Agrawal, M. Andersson, V. Bhatia, W. Cao, Y. Chen, W. Feng, M. Heikkilä, J.M. Jornet, L. Mendes, H. Karvonen, B. Lall, M. Latva-aho, X. Li, K. Lähetkangas, M.T. Masonta, A. Pandey, P. Pirinen, K. Rabie, T.M. Ramoroka, H. Saarela, A. Singhal, K. Tian, J. Wang, C. Zhang, Y. Zhen and H. Zhou, 2020, *Arxiv a 6G White Paper on Connectivity for Remote Areas,* https://arxiv.org/abs/2004.14699 , accessed: 07.03.2022.

[2] O. Kodheli, A. Guidotti and A. Vanelli-Coralli. Integration of Satellites in 5G through LEO Constellations, *IEEE Global Communications Conference*, Singapore, 2017, pp. 1-6.

[3] World Intellectual Property Organization, 2022, *Patents*, https://www.wipo.int/patents/en/, accessed: 16.05.2022.

[4] C.V. Trappey, T.M. Wang, S. Hoang and A.J.C. Trappey, Constructing a Dental Implant Ontology for Domain Specific Clustering and Life Span Analysis, *Advanced Engineering Informatics,* 2013, Vol. 27, pp. 346-357.

[5] A.C. Jhuang, J.J. Sun, A.J.C. Trappey, C.V. Trappey and U.H. Govindarajan, Computer Supported Technology Function Matrix Construction for Patent Data Analytics, *IEEE 21st International Conference on Computer Supported Cooperative Work in Design (CSCWD),* Wellington, 2017, pp. 457-462.

[6] D. Yang, Y. Zhou, W. H and X. Zhou, 5G Mobile Communication Convergence Protocol Architecture and Key Technologies in Satellite Internet of Things System, *Alexandria Engineering Journal,* Vol. 60, 2020, pp. 465-476.

[7] M. Giordani and M. Zorzi, Satellite Communication at Millimeter Waves: a Key Enabler of the 6G Era, *International Conference on Computing, Networking and Communications (ICNC),* Big Island, 2020, pp. 383-388.

[8] X. Lin, S. Rommer, S. Euler, E.A. Yavuz and R.S. Karlsson, 5G from Space: an Overview of 3GPP Non-Terrestrial Networks, *IEEE Communications Standards Magazine,* Vol. 5, 2021, pp. 147-153.

[9] F. Rinaldi, H.L. Maattanen, J. Torsner, S. Pizzi, S. Andreev, A. Iera, Y. Koucheryavy and G. Araniti, Non-terrestrial Networks in 5G & Beyond: a Survey, *IEEE Access,* Vol. 8, pp. 165178-165200.

[10] S. Chen, S. Sun and S. Kang, System Integration of Terrestrial Mobile Communication and Satellite Communication—The Trends, Challenges and Key Technologies in B5G and 6G, *China Communications,* Vol. 17, 2020, pp. 156-171.

[11] I. Leyva-Mayorga, B. Soret. M. Röper, D. Wübben, B. Matthiesen, A. Dekorsy and P. Popovski, LEO Small-satellite Constellations for 5G and Beyond-5G Communications, *IEEE Access,* Vol. 8, 2020, pp. 184955-184964.

[12] N. Saeed, H. Almorad, H. Dahrouj, T. Y. Al-Naffouri, J.S. Shamma and M.-S. Alouini, Point-to-Point Communication in Integrated Satellite-Aerial 6G Networks: State-of-the-Art and Future Challenges, *IEEE Open Journal of the Communications Society,* Vol. 2, 2021, pp. 1505-1525.

[13] A.G.C. Guerra, A.S. Ferreira, M.J. Costa, D. Nodar-López and F.A. Agelet, Integrating Small Satellite Communication in an Autonomous Vehicle Network: a Case for Oceanography, *Acta Astronautica,* Vol. 145, 2018, pp. 229-237.

[14] Z. Zhang, W. Zhang and F.-H. Tseng, Satellite mobile edge computing: Improving Qos of High-speed Satellite-terrestrial Networks Using Edge Computing Techniques, *IEEE Network,* Vol. 33, 2019, pp. 70-76.

[15] S. Liu, Z. Gao, Y. Wu, D.W.K. Ng, X. Gao, K.-K. Wong, S. Chatzinotas and B. Ottersten, LEO Satellite Constellations for 5G and Beyond: How Will They Reshape Vertical Domains?, *IEEE Communications Magazine,* Vol. 59, 2021, pp. 30-36.

[16] D.M. Blei, A.Y. Ng and M.I. Jordan, Latent Dirichlet Allocation, *The Journal of Machine Learning Research,* Vol. 3, 2003, pp. 993-1022.

[17] J.A. Hartigan, and M.A. Wong, Algorithm AS 136: A K-means Clustering Algorithm, *Journal of the Royal Statistical Society. Series C (Applied Statistics),* Vol. 28.1, 1979, pp. 100-108.

[18] Satellite Industry Association, 2021, *State of the Satellite Industry Report,* https://sia.org/news-resources/state-of-the-satellite-industry-report/ , accessed: 07.03.2022.