The Research Development Track of Internet of Things in the Application Area of Communication Technology

Chia-Yu Wu[1,2], Sheng-Tsung Tu[1], Shu-Juan Chen[3], Sheng-Chieh Chen[4]*

[1] Department of Radio and Television, Ming Chuan University, Taiwan
[2] Ph.D. Program in Communication Studies, Shih Hsin University, Taiwan
[3] Department of Public Policy and Management, I-Shou University, Taiwan
[4] College of Management, Yuan Ze University, Taiwan
wcy12@mail.mcu.edu.tw, shengtsung@yahoo.com, happylive2222@gmail.com, sanjain270@gmail.com

Abstract

Computer networks, mobile media, and information and communication technology (ICT) have grown progressively, and the development of communication technology is closely connected with that of ICT. This study explored the role played by the Internet of Things as ICT develops. Accordingly, through main path analysis and keyword co-occurrence network analysis, this study was designed to learn the major research development track, cluster status, and future research and development of the Internet of Things in the application area of communication technology.

Keywords: Internet of Things, Communication technology, Main path analysis, Keyword co-occurrence network analysis

1 Introduction

Each emergence of a new media type is accompanied by the development of new technologies, and such emergence also brings about changes to society. For instance, printing drove the development of books, newspapers, and other print media; radio boosted the development of broadcasts; and technologies related to imaging bolstered the progress of film and television. The fourth revolution in communication technology, marked by the advent of the first personal computer, Altar, in 1975, and the introduction of the World Wide Web (WWW) concept by Tim Berners-Lee in 1980, has arrived alongside the information society [1].

The International Telecommunication Union (ITU) released its annual network report, with the theme of the Internet of Things (IoT), in 2005. The core concept was that in IoT, people can contact each other through the Internet and obtain information. In addition, information can stay in an interconnected network environment based on the Internet protocol. From the perspective of trends, the development of IoT can be grouped into the three dimensions of time, place, and thing, and covers people and people, people and things, and things and things (as shown in Figure 1) [2].

This study explored the role played by the Internet of Things (IoT) as ICT started to influence the development of media. Accordingly, through main path analysis and keyword co-occurrence network analysis, this study investigated the following problems:

1. What is the major research development track of IoT in the application area of communication technology?
2. What are the clusters in the research development track of IoT in the application area of communication technology?
3. What is the research development track of IoT in the application area of communication technology?

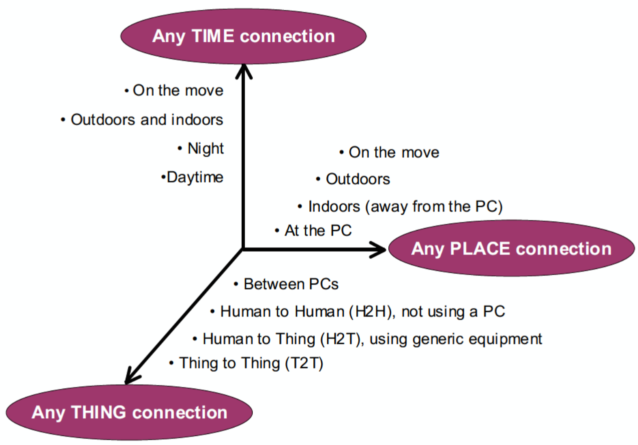

Figure 1. Three dimensions of the development of IoT [2]

2 Main Path Analysis

Main path analysis, combined with bibliometrics and social network analysis, is a literature citation analysis which can find the track of knowledge diffusion by the citation relationships between papers. On the basis of the principle of researchers citing relevant papers, knowledge may be spread to the citer through the papers cited. Papers that are cited many times have a greater impact in their relevant field. When relevant papers are scarce, authors may present and understand the network cited. On the other hand, when

*Corresponding Author: Sheng-Tsung Tu; E-mail: shengtsung@yahoo.com
DOI: https://doi.org/10.70003/160792642024092505010

there are thousands of papers or more, the significance is difficult to determine, even though authors can describe the content. Thus, Garfield, Sher and Torpie [3] launched their analysis through the concept of a literature citation network and described the history of knowledge evolution in the DNA sector. Later, Hummon and Dereian [4] put forward the concept of main path analysis for the first time. Taking the research field of DNA as an example, the network relationships fostered through researchers citing the literature of each other during the development of this research were applied to validate the path or development track of technical knowledge, by which the main axis of the industrial technology was mastered. After that, academics borrowed this concept to conduct a literature review in many areas [5].

In the academic and patent areas, many studies have been conducted by improving on previous research results. To have an understanding of the development of such previous results, the concept of citation relationships was developed for analyzing large amounts of cited literature data in a quantitative manner, and is referred to as citation analysis. In the network cited, the connections among nodes are the places through which knowledge diffusion passes. From the starting point to any of the intermediate nodes, there are many paths available for searching, and the main path is the essential one among all search paths.

In the network cited, the original node for the path of knowledge dissemination is the source node, while the terminal node is the sink node [5]. Conventional main path analysis is used to find the most critical and important path among all possible paths from the source node to the sink node, and the base of this search is the traversal count between the connections among nodes. From the viewpoint of Batagelj [6], the foundation of traffic is cited literature that has been published previously, and the main path can probe into the skeleton of changes in a time series on the network. Multiple methods for computing weights have been proposed, thereby offering more choices for path tracking. However, [5] deemed that conventional main path analysis fails to cover all the connections of the maximum weights. Therefore, they posted the analyses of the global main path and key-route main path, which enables the main path analysis to explore more abundant phenomena of knowledge diffusion. To be specific, the key-route main path not only hints at the most important literature but also implies the metaphor of the main path of knowledge flow in the field, and the key-route main path can be extensively applied to miscellaneous subjects [7-8].

Main path analysis can be divided into two steps. First, calculate the information flow (Traversal Count) of the links. The algorithms commonly used are SPC (Search Path Count), SPLC (Search Path Link Count), and SPNP (Search Path Node Pair) [4, 6]. Then, it involves tracing the main path. Starting from the Priority-First Search algorithm proposed by Hummon and Doreian [4], the development has led to the identification of three types: Local Main Path, Global Main Path, and Key-Route Main Path [5, 9-10].

The stepwise main path focuses on developing step by step, starting from the source node, each node only seeks the node with the highest weight value to proceed, and will not go back to find other paths. Through the stepwise main path, it is possible to find the academic knowledge evolution under the mainstream knowledge context. However, when the academic field is quite mature and there are rarely new publications, the main path obtained cannot clearly see the overall development of the academic field. The difference between the global main path and the stepwise main path lies in that the global main path focuses on the overall main axis overview, and can thereby find the path trajectories that are more influential to the overall development. Both the stepwise main path and the global main path have the problem of not being able to include all high-weight quality paths, while the key-route main path solves this problem. The key-route main path is to find all the paths with high weight values, and then based on these high-weight paths, to search for the path with the highest total weight value, thus finding the key-route main path of the academic topic [5].

In this study, the global main path and key-route main path were adopted to explore the development track of IoT in the application research of communication technology. Additionally, the free software, Pajek, was utilized to visually display the main path, through which the combining and disjunction phenomenon of the relevant development could be seen.

3 Keyword Co-occurrence Network Analysis

The Keyword Co-occurrence Network analysis method links cluster analysis, keyword extraction in text mining, and applications like KH Coder3 to develop an analysis method with block connections. In research, cluster analysis keywords can quickly uncover association rules hidden in large databases. Main path analysis is commonly used to identify the most significant paths in citation network graphs, clearly depicting the trajectory of scientific development and having identified numerous cross-disciplinary development frameworks in the past. Conversely, the Keyword Co-occurrence Network analysis method can bridge and construct a new citation network, organizing the main development context and knowledge diffusion paths of the discipline. This facilitates a deeper understanding of the field's application scenarios, critical research issues, and potential future development directions through visualization.

The Keyword Co-occurrence Network analysis method utilizes several free software applications to apply text mining to the associations of citations using keywords. Through structurization, it links keywords from different clusters to find potential textual associations for visual map analysis. Specifically, using KH Coder3 to process text mining results, a temporal sequence keyword network map is constructed with the free software VOSviewer, displaying visual associations and shared relationships. As shown in Figure 2, red squares represent structured clusters, orange circles indicate important keywords within each cluster, which can vary in number, and green circles represent the shared keyword relationships between clusters, signifying important common keywords among them.

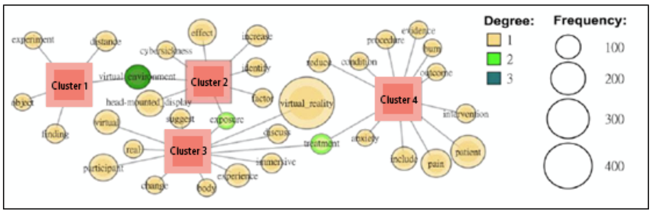

Figure 2. Example of a keyword co-occurrence network analysis

Thus, this method can supplement main path analysis by addressing its shortcomings in cluster analysis. It efficiently identifies highly correlated, valuable, and precise association rules, including both single and compound words, in a short time frame. By utilizing the frequency of text and keyword occurrences for statistical analysis, it uncovers the inherent relationships, new connections, and research focal points among the literature, offering scholars accurate interpretations from various perspectives.

4 Research Track of IoT in the Application Area of Communication Technology

In this study, a number of journals, including SCI, SSCI, and Arts & Humanities Citation Index (AHCI), and literature related to the study subject were retrieved based on the WOS academic database, with the keywords being *IoT* AND *technology* AND *media* OR *communication* OR *information*. Regarding information collation, a total of 3,667 pieces of literature related to the subject of this study were acquired and used for the follow-up analysis.

4.1 Main Path Analysis

A total of 1,687 pieces of literature were identified as having a citation relationship and were leveraged for the main path analysis, after which the development track of IoT in the application research of communication technology was drawn using Pajek based on the analysis result of this study (as shown in Figure 3). The source nodes of IoT in the application research of communication technology were HanJFA2013 [11] and DingJRH2013 [12]. Although there have been 30 pieces of related literature published since 2006, HanJFA2013 and DingJRH2013 mainly focus on proposing new plans for improvement based on IoT, and the two articles were the source nodes of the relevant studies.

Following the foundational analyses conducted by HanJFA2013 and DingJRH2013, XuHL2014 [13] provided a comprehensive retrospective on the evolution of the Internet of Things (IoT), systematically cataloging the industry's most advanced IoT technologies available at that time. Subsequently, LeHIKCJ2016a [14] explored the integration of cloud computing, IoT, and software-defined networking (SDN) within the context of 5G networks. Building on this line of inquiry, JawadNGJI2017b [15] examined the application of IoT's wireless sensor networks (WSNs) in precision agriculture (PA), aiming to leverage IoT for enhancing agricultural practices.

Beginning with the study by GermaniMBRF2019 [16], and extending through the works of LeonardiLBP2020 [17], LavricPCP2020 [18], SilvaNORCBZN2021 [19], LimaMOCZR2021 [20], CheikhASSR2022b [21], IdrisKF2022 [22], a significant emphasis has been placed on research related to the Internet of Things (IoT) technologies within the context of Long Range (LoRa) Low Power Wide Area Networks (LPWAN). Beyond foundational research on LoRaWAN's applicability in IoT, these contributions also explore advancements in communication technologies and power networks. Thus, it is discernible that the main trajectory of this research path primarily centers on the investigation of foundational communication technologies within the IoT framework.

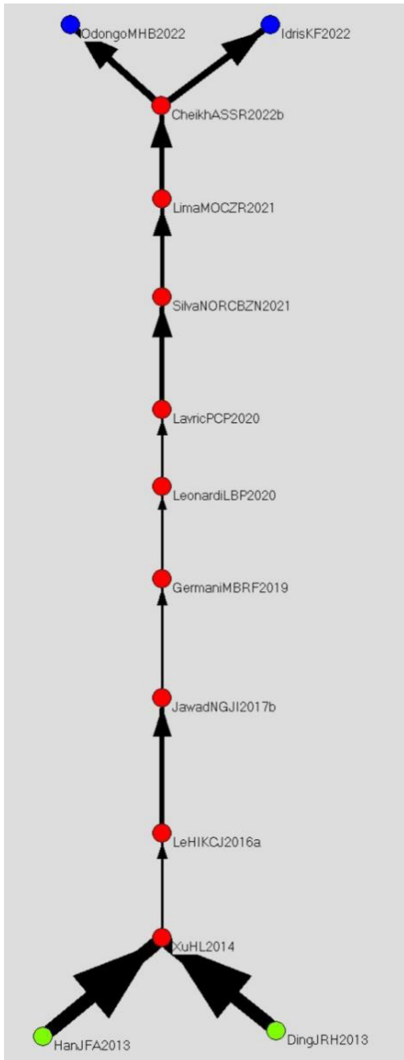

Figure 3. Global 1 main path regarding the research development track of IoT in the application of communication technology

Reviewing the Key-Route Main Path (as shown in Figure 4) reveals that the source node is identified with the study by HaxhibeqiriVMH2017 [23]. This initial research thoroughly investigates the applications of Internet of Things (IoT) technologies in fields such as machine learning, artificial intelligence (AI), information technology, smart cities, smart grids, and power distribution. Beginning with the study of

LoRaWAN, this path progressively expands to include a comprehensive exploration of IoT applications within the framework of smart cities.

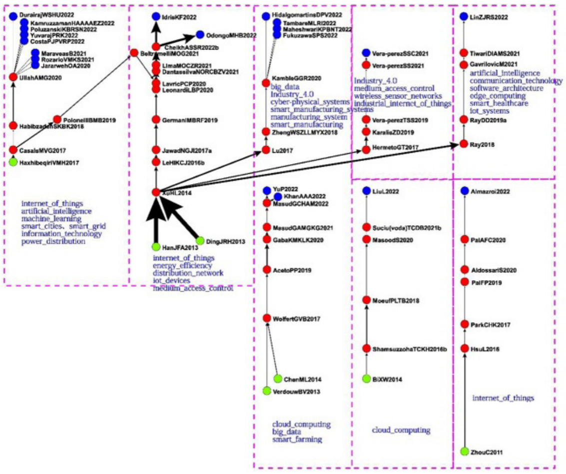

Figure 4. Global key-route 20 block description regarding the development track of IoT in the application of communication technology

The second path, congruent with the Global 1 main path, focuses on investigations pertaining to IoT devices, media access control, and LoRaWAN. This path significantly impacts three distinct areas, rooted in the seminal studies by Lu2017 [24], HermetoGT2017 [25], Ray2018 [26].

The section sourced from Lu2017 [24] extensively explores research related to the Internet of Things (IoT), encompassing areas such as big data, manufacturing systems, smart manufacturing, cyber-physical systems, and Industry 4.0. This exploration initiates with an analysis of the interplay between Industry 4.0 and IoT, advancing to a discussion on Smart Manufacturing Systems (SMS) and the transformative impact of IoT-driven Industry 4.0 on production methodologies. The section sourced from HermetoGT2017 [25] focuses on the Industrial Internet of Things (IIoT), specifically highlighting research on wireless sensor networks and media access control within the IoT framework. This section underscores the pivotal contributions to understanding the applications and implications of IIoT technologies in enhancing connectivity and functionality in industrial environments. The section sourced from Ray2018 [26] concentrates on application-oriented research in the Internet of Things (IoT), covering topics such as artificial intelligence (AI), communication technology, smart healthcare, and IoT systems. It commences with an evaluation of the latest advancements in IoT frameworks, subsequently exploring the detailed research on the software and hardware architectures that underpin the IoT infrastructure.

Finally, in addition to the three pathways that extend from the second path block, there are paths with VerdouwBV2013 [27] and ChenML2014 [28] as sources, as well as those that sources from BiXW2014 [29] and ZhouC2011 [30]. The segments associated with VerdouwBV2013 [27] and ChenML2014 [28] concentrate on big data within IoT, paralleling the path from Lu2017 [24]. However, these pathways primarily investigate from the standpoint of IoT's supply chains, progressing through smart farming and Industry 4.0, and advancing to the Internet of Medical Things (IoMT). The pathway with BiXW2014 [29] as the source discusses the impact of IoT on manufacturing enterprise systems (ESs), the influence of Industry 4.0 on SMEs' industrial management, and concludes with IoT services that incorporate AI. The path that begins with ZhouC2011 [30] explores multimedia applications within IoT, further delving into the importance of trust and security risks in smart home environments and wearable platforms, in addition to other IoT applications.

4.2 Keyword Co-occurrence Network Analysis

Through keyword co-occurrence network analysis (as shown in Figure 5), this study identified that the application research of IoT in the area of communication technology could be classified into four parts:

Part 1 focused on the Internet, including IoT, medium access control, the Internet of medical things (IOMTs), smart cities, medium enterprises, LoRaWAN networks, communication technology, and the technology acceptance model.

Part 2 focused on IoT facilities, including IoT devices, energy efficiency, smart healthcare, the industrial Internet of things (IIOTs), and medium access.

Part 3 focused on intelligent systems, including intelligent transportation systems, edge computing, artificial intelligence, power distribution, smart grids, and distribution networks.

Part 4 focused on smart cities, including smart cities, IoT systems, software architecture, smart manufacturing, cyber-physical systems, Industry 4.0, big data, smart farming, cloud computing, enterprise systems, manufacturing systems, digital transformation, wireless sensors, and information technology.

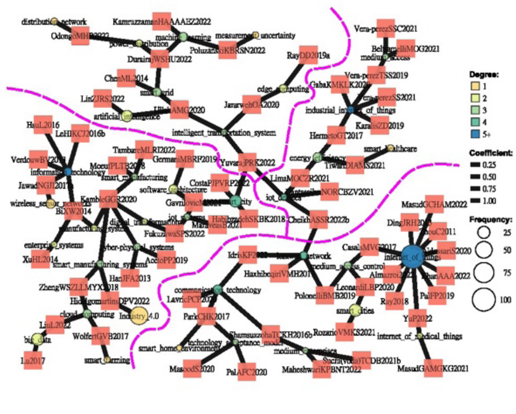

Figure 5. Keyword co-occurrence network relationships regarding the development track of IoT in the application research of communication technology

4.3 Analysis of the Growth Curve

The application of IoT in communication technology is a new research area. Since Tuters and Varnelis released a study on locative media in 2006, a total of 1,687 relevant studies were identified through main path analysis, and 10,305 researchers were found to have participated in studies in relevant fields.

This study took the logistic growth model as the basis, with time as the horizontal axis and cumulative quantity as the vertical axis. Through the Loglet Lab website and algorithm, the development trend toward the quantity of relevant articles was depicted, as shown in Figure 6. Also, the saturation, inflection point, and growth time concerned were calculated.

In the topic of this study, the relevant papers have passed the inflection point and are entering the growth period, which means that the quantity of newly published papers is expected to increase in the next few years. The growth time of papers is 7.5 years with 6,327 as the saturation. This study found that by mid-2028, the number of studies on IoT in the area of communication technology will reach 6,327 and thus enter a stable period.

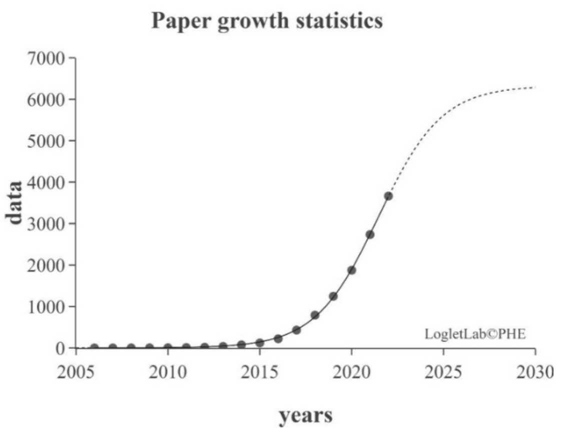

Figure 6. Growth curve of the number of articles on IoT in the application research of communication technology

From the overview of the development directions of research on IoT in the field of Communication Technology in the past five years, it could be identified that IoT has developed towards intelligent technology networks in the areas of smart cities, industry 4.0, intelligent manufacturing, smart medical treatments, and cloud computing.

In 2018, the center of attention was on cyber-physical systems, manufacturing, cloud computing, smart manufacturing, and IIOTs; in 2019, this focus switched to medium access control, wireless sensor networks, edge computing, and software architecture. In 2020, the focus was on IoT, industry 4.0, smart cities, the technology acceptance model, and intelligent transportation systems, while IoT systems, information technology, smart healthcare, IoT devices, medium access, IOMTs, energy efficiency, and IIOTs received greater attention in 2021. Most recently, IoT, big data, distribution networks, AI, power distribution, and LoRaWAN networks received attention in 2022.

5 Conclusions

This study reviewed the application research of IoT in communication technology and retrieved data using *IoT* AND *technologies* AND *media* OR *communication* OR *information* as the keywords. In the modern era where computers, networks, and mobile media develop rapidly, media technology and information technology are bound to be referred to when communication technology is mentioned. Therefore, only when these two keywords of media technology and information technology are listed can all of the relevant studies be identified. The major findings of this study were:

1. The development track of IoT in the application research of communication technology shows that the major development of applications is on IoT and networks. At the early stage of the development, studies on how to integrate the 5G network into the technologies at that time were carried out, upon which a number of studies on the WSNs of IoT were presented. Those studies focused on LPWANs with LoRa related to IoT.
2. The major subjects summarized through the keyword co-occurrence network analysis were the Internet, IoT facilities, smart systems, and smart cities.
3. Analyzing the Global Key-Route 20 block's description of the development trajectory of the Internet of Things (IoT) in communication technology applications reveals a focused interest in smart healthcare, artificial intelligence (AI), and IoT systems within IoT. Therefore, it can be inferred that these three domains are poised to be the predominant research development directions for IoT applications in the realm of communication technology.

References

[1] I. de Sola Pool, *Technologies Without Boundaries: On Telecommunications in a Global Age*, Harvard University Press, 1990.

[2] ITU, *The Internet of Things*, International Telecommunication Union, November, 2005.

[3] E. Garfield, I. H. Sher, R. J. Torpie, *The Use of Citation Data in Writing the History of Science*, Institute for Scientific Information, Philadelphia PA, December, 1964.

[4] N. P. Hummon, P. Dereian, Connectivity in a Citation Network: The Development of DNA Theory, *Social Networks*, Vol. 11, No. 1, pp. 39-63, March, 1989.

[5] J. S. Liu, L. Y. Y. Lu, An Integrated Approach for Main Path Analysis: Development of the Hirsch Index as an Example, *Journal of the American Society for Information Science and Technology*, Vol. 63, No. 3, pp. 528-542, March, 2012.

[6] V. Batagelj, *Some Mathematics of Network Analysis, Department of Sociology*, University of Pittsburgh, January, 1991.

[7] H. Park, C. L. Magee, Tracing Technological Development Trajectories: A Genetic Knowledge Persistence-Based Main Path Approach, *PLoS ONE*, Vol. 12, No. 1, pp. 1-18, January, 2017.

[8] Y. Xiao, L. Y. Y. Lu, J. S. Liu, Z. Zhou, Knowledge diffusion path analysis of data quality literature: a main path analysis, *Journal of Informetrics*, Vol. 8, No. 3, pp.

594-605, July, 2014.
[9] J. S. Liu, L. Y. Y. Lu, W. M. Lu, B. J. Y. Lin, Data Envelopment Analysis 1978-2010: A Citation-Based Literature Survey, *Omega-The International Journal of Management Science*, Vol. 41, No. 1, pp. 3-15, January, 2013.
[10] J. S. Liu, L. Y. Y. Lu, W. M. Lu, B. J. Y. Lin, A Survey of DEA Applications, *Omega-The International Journal of Management Science*, Vol. 41, No. 5, pp. 893-902, October, 2013.
[11] C. Han, J. M. Jornet, E. Fadel, I. F. Akyildiz, A cross-layer communication module for the Internet of Things, *Computer Networks*, Vol. 57, No. 3, pp. 622-633, February, 2013.
[12] Y. S. Ding, Y. L. Jin, L. H. Ren, K. R. Hao, An Intelligent Self-Organization Scheme for the Internet of Things, *IEEE Computational Intelligence Magazine*, Vol. 8, No. 3, pp. 41-53, August, 2013.
[13] L. D. Xu, W. He, S. C. Li, Internet of Things in Industries: A Survey, *IEEE Transactions on Industrial Informatics*, Vol. 10, No. 4, pp. 2233-2243, November, 2014.
[14] N. T. Le, M. A. Hossain, A. Islam, D. Y. Kim, Y. J. Choi, Y. M. Jang, Survey of Promising Technologies for 5G Networks, *Mobile Information Systems*, Vol. 2016, pp. 1-25, December, 2016.
[15] H. M. Jawad, R. Nordin, S. K. Gharghan, A. M. Jawad, M. Ismail, Energy-Efficient Wireless Sensor Networks for Precision Agriculture: A Review, *Sensors*, Vol. 17, No. 8, Article No. 1781, August 2017.
[16] L. Germani, V. Mecarelli, G. Baruffa, L. Rugini, F. Frescura, An IoT Architecture for Continuous Livestock Monitoring Using LoRa LPWAN, *Electronics*, Vol. 8, No. 12, Article No. 1435, December, 2019.
[17] L. Leonardi, L. Lo Bello, F. Battaglia, G. Patti, Comparative Assessment of the LoRaWAN Medium Access Control Protocols for IoT: Does Listen before Talk Perform Better than ALOHA?, *Electronics*, Vol. 9, No. 4, Article No. 553, April, 2020.
[18] A. Lavric, A. I. Petrariu, E. Coca, V. Popa, LoRa Traffic Generator Based on Software Defined Radio Technology for LoRa Modulation Orthogonality Analysis: Empirical and Experimental Evaluation, *Sensors*, Vol. 20, No. 15, Article No. 4123, August, 2020.
[19] F. S. D. Silva, E. P. Neto, H. Oliveira, D. Rosario, E. Cerqueira, C. Both, S. Zeadally, A. V. Neto, A Survey on Long-Range Wide-Area Network Technology Optimizations, *IEEE Access*, Vol. 9, pp. 106079-106106, May, 2021.
[20] E. Lima, J. Moraes, H. Oliveira, E. Cerqueira, S. Zeadally, D. Rosario, Adaptive priority-aware LoRaWAN resource allocation for Internet of Things applications, *Ad Hoc Networks*, Vol. 122, No. 1, pp. 1-11, November, 2021.
[21] I. Cheikh, R. Aouami, E. Sabir, M. Sadik, S. Roy, Multi-Layered Energy Efficiency in LoRa-WAN Networks: A Tutorial, *IEEE Access*, Vol. 10, pp. 9198-9231, January, 2022.
[22] S. Idris, T. Karunathilake, A. Forster, Survey and Comparative Study of LoRa-Enabled Simulators for Internet of Things and Wireless Sensor Networks, *Sensors*, Vol. 22, No. 15, Article No. 5546, August, 2022.
[23] J. Haxhibeqiri, F. Van den Abeele, I. Moerman, J. Hoebeke, LoRa Scalability: A Simulation Model Based on Interference Measurements, *Sensors*, Vol. 17, No. 6, Article No. 1193, June, 2017.
[24] Y. Lu, Industry 4.0: A survey on technologies, applications and open research issues, *Journal of Industrial Information Integration*, Vol. 6, pp. 1-10, June, 2017.
[25] R. T. Hermeto, A. Gallais, F. Theoleyre, Scheduling for IEEE802.15.4-TSCH and slow channel hopping MAC in low power industrial wireless networks: A survey, *Computer Communications*, Vol. 114, No. 1, pp. 84-105, December, 2017.
[26] P. P. Ray, A survey on Internet of Things architectures, *Journal of King Saud University-Computer and Information Sciences*, Vol. 30, No. 3, pp. 291-319, July, 2018.
[27] C. N. Verdouw, A. J. M. Beulens, J. G. A. J. van der Vorst, Virtualisation of floricultural supply chains: A review from an Internet of Things perspective, *Computers and Electronics in Agriculture*, Vol. 99, pp. 160-175, November, 2013.
[28] M. Chen, S. W. Mao, Y. H. Liu, Big Data: A Survey, *Mobile Networks & Applications*, Vol. 19, No. 2, pp. 171-209, April, 2014.
[29] Z. M. Bi, L. D. Xu, C. G. Wang, Internet of Things for Enterprise Systems of Modern Manufacturing, *IEEE Transactions on Industrial Informatics*, Vol. 10, No. 2, pp. 1537-1546, May, 2014.
[30] L. Zhou, H. C. Chao, Multimedia Traffic Security Architecture for the Internet of Things, *IEEE Network*, Vol. 25, No. 3, pp. 35-40, May-June, 2011.

Biographies

Chia-Yu Wu is an assistant professor in the Department of Radio and Television at Ming Chuan University, with a Ph.D. in Technology and Service Innovation from Yuan Ze University. His research focuses on big data mining, data visualization, main path analysis, and communication technology. Contact him at wcy12@mail.mcu.edu.tw

Sheng-Tsung Tu is an associate professor and chair of the Department of Radio and Television at Ming Chuan University. He holds a Ph.D. in Political Science from National Taiwan Normal University, specializing in big data mining, new media, and digital communication. Contact him at shengtsung@yahoo.com

Shu-Juan Chen is the Director of the Penghu County Health Bureau and an adjunct assistant professor in the Department of Public Policy and Management at I-Shou University. She holds a Ph.D. in Technology and Service Innovation from Yuan Ze University, specializing in main path analysis, technology management, and health care management. Contact her at happylive2222@gmail.com

Sheng-Chieh Chen is a Ph.D. student in the Technology and Service Innovation program at Yuan Ze University's College of Management. His research focuses on technology management, new product/ service development, technology forecasting, data frequency analysis, and main path analysis. Contact him at sanjain270@gmail.com