Message querying telemetry transfer on IoT applications to enhance technology: a systematic review

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ABSTRACT

More things are connected to the Internet, making the internet of things (IoT) develop significantly. But IoT also has weaknesses in communication, one of which can be overcome by utilizing message querying telemetry transfer (MQTT) because there are too many benefits of MQTT. Because there have been many published studies regarding MQTT, this study aims to conduct a review utilizing preferred reporting items for systematic reviews and meta-analyses (PRISMA) on the application of MQTT in IoT applications to enhance technology. The results of using PRISMA were 57 papers selected from this process, which starts from the identification stage, screening, eligibility, and included. The last author found components that can be discussed to enhance technology. In this discussion, several topics will be used to enhance technology, such as; smart technology, security, MQTT performance for IoT, monitoring systems, MQTT comparison, enhancement or optimization. This paper is expected to help academia and industry related to MQTT research that can help IoT to enhance technology quality.

Keywords:
Internet of things
Monitoring system
MQTT
PRISMA
Smart technology

1. INTRODUCTION

There have been enough uses for the internet of things (IoT) devices because they have lightweight capabilities and affordable prices. Many of their applications in IoT devices can connect and communicate with each other using the Internet because they have the services needed by most people. This technology develops through things related to the Internet, so its application is easy and fast. These technologies sometimes have additional reasons for being “smart”, usually having relationships such as home automation, smart agriculture, smart cities, health systems, smart gardening, smart grids, smart vehicles, and smart culture. A British technology pioneer named Kevin Ashton 1999 gave terms by naming the "internet of things" [1]. The "things" principle is currently developing very significantly. The main goal is to make information by sensing without anyone's help. In the IoT, it is predictable that the integration of all "things" is realized by building intelligent interfaces between the functions of device utilization. IoT can utilize IoT gateways to connect points between applications and smart IoT devices for connection. Smart for sensing and collecting data from the environment is the task of the IoT. This evolution continues to grow, especially those that utilize; actuators, sensors, and other micro components [2].

People rapidly push towards IoT based on increasing the quality of life through connections for everything, starting from many personal devices to other devices out there, for example, medical devices (e.g. medical aids), burglar alarms, car fire alarms and massive sensor use. The many facilities that IoT can use
have weaknesses and advantages that must be re-studied or appropriately resolved. Because any technology has a new face to always enhance and improvise [3]. In its utilization, IoT is widely used in; smart farming [4] [5], smart health [6], [7], smart building [8], [9], and smart cities [10], [11].

Many have used IoT [12] devices, from researchers to industry, because it is one of the tools for the industrial revolution. Energy savings [13], are needed because the number of devices increases, especially when it connects with communication. One of the important components sent IoT is communication. Many communication protocols focus on providing low power (lightweight). One of them can take advantage of message querying telemetry transfer (MQTT) [14]. The MQTT protocol adheres to the principle system of IoT or device-to-device association. Some of the main causes behind the rapid development of MQTT are to provide communication bandwidth and reduce battery failure [15].

However, building a suitable model for MQTT because it has the advantage of several brokers is a new challenge. The difference between using MQTT, such as having security in a distributed architecture, is different from using a centralized distribution, one of which is how data is sent from publishers. They are mainly connected to two different brokers because a traditional MQTT is very concerned about the authentication mechanisms [16]. After learning about IoT and its functions using MQTT, motivation author to provide assistance to conduct a review of this study. Completing surveys is very important because it opens new minds for researchers to innovate and update in terms of technique.

There are many studies to review for technology. But some studies only focus on the usefulness of IoT and have not conducted a study that directly examines the improvement of IoT when using MQTT. This protocol is very light and suitable for lightweight technologies such as IoT. Still, a rare systematic review focused on how MQTT for applications enhance technology. The aims of this study such as; systematic review and meta-analyses on MQTT for IoT applications to enhance technology, identification of recent papers (2019-2022), and discussion of existing issues about the recent paper.

Due to this, the author aims to conduct a systematic review that focuses on IoT applications utilizing MQTT to focus on its manufacture to enhance the quality of technology. The scope of the systematic review does not discuss other communication protocols. It only focuses on MQTT as the protocol that will create. Usually, systematic reviews can utilize [17], [18], preferred reporting items for systematic reviews and meta-analyses (PRISMA). But the function of these two methods has their respective advantages. In this study, the author will focus on PRISMA. This method is also very transparent and complete to perform a systematic review.

Therefore, the author will carry out a systematic review utilizing PRISMA, which has explained the basics and knowledge of MQTT for IoT applications in part 1. Part 2 will describe some systematic reviews to see similar research studies and their differences. Part 3 is the method that will be used in PRISMA. Part 4 is the result and discussion of the results of PRISMA. The last is section 5 for conclusions on the current results and their descriptions.

2. CONCEPTS

2.1. Related topics

Many studies have reviewed MQTT applied in IoT, some of which will be discussed in this section. Beniwal and Singhrova [2], present a systematic review focusing on IoT gateways. Jahantigh et al. [19], conduct an in-depth investigation of cloud computing and IoT, with its problems and challenges. Yan et al. [20], recently focused on the smart gateway, especially in the second generation. The study investigates further and classifies them into several categories. Hintaw et al. [21], because MQTT is a protocol often used in IoT applications, there are problems such as disclosing information, identity spoofing, denial of service, increased data tampering, and increased privileges. Many studies suggest various security mechanisms and techniques for this problem. But in this systematic review, the authors are not focused on improving it but on how MQTT can enhance IoT quality. Kurdi and Thayananthan [16], the study focuses on reviewing and challenging the use of security, authentication mechanisms, and the procedures required for implementing MQTT. In contrast to this systematic review, it is not focused on security but on what MQTT can apply to study for improvement in the IoT field. Mishra and Kertesz [22], conducted a quantitative evaluation by presenting some important things about the protocol of the MQTT. The authors compared such as superior, main, and weaknesses in the MQTT protocol. Few studies have carried out systematic reviews and have been carried out in recent years. Another thing is that few studies have reviewed MQTT to enhance technology and use systematic reviews. This study uses PRISMA for several studies focusing on MQTT for IoT applications to enhance technology. The author will discuss the stages of conducting PRISMA research to carry out several stages in the next stage.
2.2. MQTT and IoT

In a communication on the IoT deploy several radio technologies such as (IEEE 802.11), RFID, (IEEE 802.15), (IEEE 802.16), (IEEE 802.3), and others, which are used in the most basic of communication [23]. Figure 1 is an image of several protocols used based on TCP/IP Model. Figure 1 shows several communication protocols used in the TCP/IP Model, which, in basic communication, there are still other communications using LoRaWAN, SigFox, or Cellular/4G/5G [22]. Which MQTT is publish/subscribe protocol. This protocol has a client/server model that can create a client to communicate with the endpoint. In this protocol, there are two types of clients have been identified. A client sent a message is called the publisher. While on other Clients who work as recipients are called subscribers. But these two types of clients did not communicate directly. Both clients use a central point that functions as a server and is called a broker for exchanging messages. The broker here helps receive messages sent by publishers and pass them on to the subscribers [24]. MQTT widely uses IoT applications because they have evolved, especially in MQTT brokers, reflecting recent moves, especially in IoT systems [22].

![MQTT and IoT Protocols](image.png)

Figure 1. IoT protocols [23]

2.3. PRISMA method

At this stage in achieving the goals, this study will focus on PRISMA, a recommended framework to help carry out a systematic review and report [18]. As a new strategy, researchers conducted in January 2022 a focused search on MQTT utilizing a search focused on scientific articles. After that, in March 2022, a new search was carried out in the same place using the MQTT database to search for papers published in 2019-2022. Sorting this database must look at its relevance and scope so that it can affect the academic world because this database must focus on publishers such as IEEE, ACM, and MDPI. Besides being widely used in the systematic review.

In this study, search for the term "Search String" in several fields ("MQTT" OR “message queing telemetry transport”) AND ("internet of things" OR "IoT") AND ("internet of things applications" OR “IoT applications”) AND ("enahcne technology" OR “improve technology). The advanced stage (following the pattern of [25]) is that papers are validated so that they are considered valid if: i) the paper taken is not a study, review, or challenge in the future, case studies that are considered if appropriate to the topic; ii) are closely related to the topic and research objectives; iii) presents an improvement in technology by utilizing MQTT on IoT Applications; and iv) published papers must be in English. By utilizing the PRISMA model [18], using PRISMA, here find a meta-analysis of several existing studies.

This systematic review method does not use statistical models, only searches based on recent reviews. Figure 2 shows the results of the first PRISMA Flow identification, which got 2,488 papers carried out at the identification stage. The screening was carried out to get 1,247 papers, then the eligibility stage with 249 results, then the final stage, which got selected articles in this study in the form of 57 study papers that can be done as a study that will enhance technology in IoT applications. The flowchart of PRISMA [18], (pattern inspired by previous [25]) is presented in Figure 2.

3. RESULTS AND DISCUSSION

3.1. PRISMA result

This section is the result of the selected paper (see Figure 2) and will be explained by classifying the obtained studies as shown in Table 1. Then, where did this study come from in Table 2 (focus on the first author). The last is the distribution of years presented in Table 3. Furthermore, Table 4 explains the distribution of articles by year (2019-2022) (in research results, there are still those paper that uses the constraint application protocol (CoAP), but the focus remains on the results of using MQTT on IoT).
As shown in Table 1, several topics have been discussed in 2019-2022, such as smart technology, security, MQTT performance for IoT, monitoring systems, MQTT comparison, enhancement or optimization. The author will further explain these topics in the discussion section. The results of this presentation are also useful in viewing articles about MQTT on IoT applications.

Furthermore, Table 2 shows the distribution (focus on the first author) of research on MQTT on IoT applications to enhance technology from papers mostly from India, as many as 10 papers. These results show that a lot of research conducted in the area can be used for academics and industry in conducting research benchmarks there. Table 3 shows publishers’ distribution because most came from the IEEE and then continued with MDPI, ACM, and ScienceDirect. So that many related articles can be published in IEEE publishers. This indicates that the articles prefer IEEE articles in publishing related articles. Table 4 also

| No | Topic                                           | References |
|----|-------------------------------------------------|------------|
| 1  | Image notifications                             | [26]       |
| 2  | Smart technology                                | [27]-[32]  |
| 3  | Security (DoS attack or intrusion detection)    | [33]-[46]  |
| 4  | Positioning system                              | [47]       |
| 5  | MQTT performance and evaluation for IoT         | [48]-[53]  |
| 6  | Interoperability solution                       | [54]       |
| 7  | MQTT for healthcare                             | [55], [56] |
| 8  | Overhead analysis                               | [57]       |
| 9  | Monitoring system                               | [58]-[66]  |
| 10 | Geographical IoT                                | [67]       |
| 11 | MQTT comparison, enhancement or optimization    | [68]-[71]  |
| 12 | Surveillance system                             | [72]       |
| 13 | QoS IoT using MQTT                              | [73]       |
| 14 | Development of modbus                           | [74], [75] |
| 15 | ICN system                                      | [76]       |
| 16 | Design and implementation                       | [77], [78] |
| 17 | Authentication scheme                           | [79], [80] |
| 18 | Machine learning techniques                     | [81]       |
| 19 | Routing based protocol                          | [82]       |
presents the distribution by year, and for the 2019-2022 period, the most research was still in 2019, but it can also be seen that for 2022, which is currently ongoing, many studies have been published.

Table 2. The articles based on country

| Country     | Number of publications |
|-------------|------------------------|
| India       | 10                     |
| Italy       | 7                      |
| Indonesia   | 6                      |
| UK          | 4                      |
| Brazil      | 3                      |
| Japan       | 3                      |
| Taiwan      | 2                      |
| USA         | 2                      |
| Germany     | 2                      |
| Pakistan    | 2                      |
| China       | 2                      |
| France      | 2                      |
| South Korea | 1                      |
| Saudi Arabia| 1                      |
| Romania     | 1                      |
| Norway      | 1                      |
| Turkey      | 1                      |
| Thailand    | 1                      |
| Egypt       | 1                      |
| Serbia      | 1                      |
| Spain       | 1                      |
| Bulgaria    | 1                      |
| UAE         | 1                      |
| Malaysia    | 1                      |
| Total       | 57                     |

Table 3. The articles based on publisher

| Database     | Result |
|--------------|--------|
| IEEE         | 37     |
| MDPI         | 11     |
| ACM          | 7      |
| ScienceDirect| 2      |
| Total        | 57     |

Table 4. The articles based on year published

| Database | Result |
|----------|--------|
| 2019     | 29     |
| 2020     | 18     |
| 2021     | 5      |
| 2022     | 5      |
| Total    | 57     |

Suppose the author compares with similar research papers [5], which utilize PRISMA as a systematic review. In that case, this paper presents a summary of related research (IoT and MQTT). The results presented are more detailed and easier to use as references for related academics or industries. Results can also be used to enhance research or find related results supporting existing research.

### 3.2. Discussion

In this section, there will be a discussion on the most researched topics (see Table 1). The growing trend in the number of papers on IoT applications utilizing MQTT in technology improvement and those observed since 2019 will be outlined in several discussions regarding the findings. Obtained from PRISMA. The author gives some snapshots like glossaries for the IoT and MQTT. In this discussion, several papers that have been widely researched and received attention for technological developments (see Table 1) by study in 2019-2022 based on Figure 3. As shown in Figure 3, the author will describe the topic in more detail by dividing it into several sections described in the following sub-chapters.
3.2.1. Smart technology

The concept of IoT that can connect several objects, and other things and be integrated with the Internet is an attraction in itself. In many studies, MQTT helps IoT in "smart" concepts like smart agriculture and smart cities. Many studies have focused on smart technology because of its nature that can automate and facilitate other things. This concept has indeed become a material that researchers and industry often use. This is part of a technological improvement that has been successfully enhanced by utilizing the MQTT protocol. Apart from improving its quality, it also helps users implement the "smart" concept. Research on smart technology that utilizes MQTT is found in [27]–[32].

3.2.2. Security

MQTT is a protocol that is often used because it is lightweight and effortless to use if operated remotely. Because MQTT is widely used due to minimal bandwidth and low memory consumption, but also has some drawbacks stemming from several types of attacks [46]. Then there is a study on external attacks such as denial-of-service (DoS) [38], and intrusion is some examples of attacks on brokers [43]. Therefore a lot of research on security (DoS, intrusion detection) [33]–[46].

3.2.3. MQTT performance for IoT

Knowing performance is very important because IoT requires excellent performance compared to the lightweight nature of MQTT. Protocol research has been carried out by measuring the quality of service (QoS). Looking at the version of MQTT, it can also be seen that operations at different QoS levels can impact latency when sending data [48], because it feels MQTT is needed to measure its performance in helping IoT. Another performance measurement can also be made for smart cities [49]. MQTT performance is also considered in NB-IoT smart meter [50]. Then many other studies focus on analyzing the performance of MQTT [48]–[53].

3.2.4. Monitoring system

Monitoring is an important thing used in IoT because monitoring is real-time. It needs a supporting protocol to maximize IoT performance. In addition to utilizing sensors, IoT also uses MQTT. This protocol, for example, can be used for radon gas monitoring [58]. And also, can be used in soil humidity monitoring [59]. Furthermore, many more studies regarding monitoring systems [58]–[64].

3.2.5. MQTT comparison, enhancement or optimization

Performing comparison, enhancement, or optimization is made by several methods, protocols, and even technologies. Comparisons, optimizations, and enhancements are used to find out the improvements or changes to workability, especially MQTT, which should help IoT as a lightweight protocol. MQTT can perform message routing algorithms for optimizing communication between cloud microservices [68]. MQTT also enhances transparency among MQTT brokers [69]. Several other studies can compare, enhance or optimize MQTT [68]–[71].

4. CONCLUSION

This study seeks to review research on MQTT in IoT applications to enhance technology. This study conducted a systematic review using PRISMA, this method is very good and traceable in conducting a systematic review, but its use can be different. This paper focuses more on presenting results than is needed for academia and industry in conducting experiments and further systematic reviews. This method uses four stages: identification, screening, and feasibility, incl. At the identification stage to look for the latest papers (2019-2022), around 2,488 scientific papers were obtained, then the screening stage was 1,247, and the next stage was the feasibility of 249 papers. Finally, the authors get 57 papers that are eligible to be used in the
ficial stage. Recent articles often discuss topics in MQTT studies, such as smart technology, security. MQTT performance for IoT, monitoring systems, MQTT comparison, enhancement or optimization. This study has drawbacks because it does not provide statistical study methods. Further research is planned by looking for related studies by offering statistics on recent papers.

REFERENCES
[1] K. Ashton, “That ‘internet of things’ thing,” RFID journal, vol. 22, no. 7, pp. 97–114, 2009.
[2] G. Beniwal and A. Singhrova, “A systematic literature review on IoT gateways,” Journal of King Saud University - Computer and Information Sciences, 2021, doi: 10.1016/j.jsuci.2021.11.007.
[3] H. Anwer, F. Azam, M. W. Anwar, and M. Rashid, “A model-driven approach for load-balanced MQTT protocol in internet of things (IoT),” in Conference on Complex, Intelligent, and Soft Computing Intensive Systems, 2019, pp. 368–378, doi: 10.1007/978-3-030-22354-0_33.
[4] M. S. Farooq, S. Riaz, A. Abid, K. Abid, and M. A. Naeem, “A survey on the role of IoT in agriculture for the implementation of smart farm,” IEEE Access, vol. 7, pp. 156237–156271, 2019, doi: 10.1109/ACCESS.2019.2949703.
[5] M. H. Widianto, I. Andimansyah, H. I. Pohan, and D. R. Hermanus, “A systematic review of current trends in artificial intelligence for smart farming to enhance crop yield,” Journal of Robotics and Control (JRC), vol. 3, no. 3, 2022, doi: 10.18196/jrc.v3i3.17360.
[6] A. Ahad, M. Tahir, M. A. Sheikh, K. I. Ahmed, A. Mughees, and A. Numani, “Technologies trend towards 5G network for smart health-care using iot: A review,” Sensors, vol. 20, no. 14, p. 4047, Jul. 2020, doi: 10.3390/s20144047.
[7] L. Xiong, Y. Zhong, X. Liu, and L. Yang, “A small file merging strategy for spatiotemporal data in smart health,” IEEE Access, vol. 7, pp. 14799–14806, 2019, doi: 10.1109/ACCESS.2019.2939282.
[8] D. Minoli, K. Kohraby, and B. Occhiogrosso, “IoT considerations, requirements, and architectures for smart buildings-energy optimization and next-generation building management systems,” IEEE Internet of Things Journal, vol. 4, no. 1, pp. 269–283, Feb. 2017, doi: 10.1109/JIOT.2017.2647881.
[9] C. K. Metallidou, K. E. Psannis, and E. A. Egyptiadou, “Energy efficiency in smart buildings: IoT approaches,” IEEE Access, vol. 8, pp. 63679–63699, 2020, doi: 10.1109/ACCESS.2020.2984661.
[10] R. O. Andrade, S. G. Yoo, L. Tello-Quendo, and I. Ortiz-Garcés, “A comprehensive study of the IoT cybersecurity in smart cities,” IEEE Access, vol. 8, pp. 228922–228941, 2020, doi: 10.1109/ACCESS.2020.3046442.
[11] A. Kirimtат, O. Krejcar, A. Kertesz, and M. F. Tasgireen, “Future trends and current state of smart city concepts: a survey,” IEEE Access, vol. 8, pp. 86448–86467, 2020, doi: 10.1109/ACCESS.2020.2992441.
[12] M. H. Widianto and R. Aryanto, “Performance evaluation of an IoT device using a cognitive radio in GLRT approach,” in 2020 International Conference on Information Management and Technology (ICIMTech), Aug. 2020, pp. 6–10, doi: 10.1109/ICIMTech50083.2020.9211222.
[13] M. H. Widianto, A. Madanath, A. Triseyarso, and E. Abdurachman, “Energy saving on IoT using LoRa: a systematic literature review,” International Journal of Reconfigurable and Embedded Systems (IJRES), vol. 11, no. 1, pp. 25–33, Mar. 2022, doi: 10.11591/ijres.v11.i1.pp25-33.
[14] Z. Kegenbekov and A. Saparova, “Using the MQTT protocol to transmit vehicle telemetry data,” Transportation Research Procedia, vol. 61, pp. 410–417, 2022, doi: 10.1016/j.trpro.2022.01.067.
[15] S. V. V. A. and S. Pattar, “MQTT based secure transport layer communication for mutual authentication in IoT network,” Global Transitions Proceedings, 2022, doi: 10.1016/gtp.2022.04.015.
[16] H. Kuri and V. Thayananthan, “Authentication mechanisms for IoT system based on distributed MQTT brokers: review and challenges,” Procedia Computer Science, vol. 194, pp. 132–139, 2021, doi: 10.1016/j.procs.2021.10.066.
[17] A. Liberati et al., “The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration,” Journal of Clinical Epidemiology, vol. 62, no. 10, pp. e1–e34, Oct. 2009, doi: 10.1016/j.jclinepi.2009.06.006.
[18] D. Moher, A. Liberati, J. Tetzlaff, and D. G. Altman, “Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement,” Journal of Clinical Epidemiology, vol. 62, no. 10, pp. 1006–1012, 2009, doi: 10.1016/j.jclinepi.2009.06.005.
[19] M. N. Janahitgh, A. M. Rahmani, N. J. Navimipour, and A. Rezaee, “Integration of internet of things and cloud computing: a systematic survey,” IET Communications, vol. 14, no. 2, pp. 165–176, 2020, doi: 10.1049/iet-com.2019.0537.
[20] W. Yan, Z. Wang, H. Wang, W. Wang, J. Li, and X. Gui, “Survey on recent smart gateways for smart home: systems, technologies, and challenges,” Transactions on Emerging Telecommunications Technologies, 2020, doi: 10.1002/ett.4067.
[21] A. J. Hintaw, S. Manickam, M. F. Aboal, and S. Karuppayah, “MQTT vulnerabilities, attack vectors and solutions in the internet of things (IoT),” IET Journal of Research, pp. 1–30, 2021, doi: 10.1080/03772063.2021.1912651.
[22] B. Mishra and A. Kertesz, “The use of MQTT in M2M and IoT systems: a survey,” IEEE Access, vol. 8, pp. 201071–201086, 2020, doi: 10.1109/ACCESS.2020.3035849.
[23] N. Naik, “Choice of effective messaging protocols for IoT systems: MQTT, CoAP, AMQP and HTTP,” in 2017 IEEE International Systems Engineering Symposium (ISSE), Oct. 2017, pp. 1–7, doi: 10.1109/SysEng.2017.8088251.
[24] A. Velinov, A. Mileda, S. Wendzel, and W. Mazurecky, “Covert channels in the MQTT-based internet of things,” IEEE Access, vol. 7, pp. 161899–161915, 2019, doi: 10.1109/ACCESS.2019.2951425.
[25] E. Navarro, N. Costa, and A. Pereira, “A systematic review of IoT solutions for smart farming,” Sensors, vol. 20, no. 15, p. 4231, Jul. 2020, doi: 10.3390/s20154231.
[26] S. Nazir and M. Kaleem, “Reliable image notifications for smart home security with MQTT,” in 2019 International Conference on Information Science and Communication Technology (ICISCT), Mar. 2019, pp. 1–5, doi: 10.1109/ICISCT.2019.8777403.
[27] S. V. Mukherji, S. Ritesh, S. Basak, and S. P. Kar, “Smart agriculture using internet of things and MQTT protocol,” in 2019 International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (Com-IT-Con), Feb. 2019, pp. 14–16, doi: 10.1109/COMITCon.2019.8862233.
[28] K. Jaikumar, T. Brindha, T. K. Deenapalakshmi, and S. Gomathi, “IoT assisted MQTT for segregation and monitoring of waste for smart cities,” in 2020 6th International Conference on Advanced Computing and Communication Systems (ICACCESS), Mar. 2020, pp. 887–891, doi: 10.1109/ICACCESS48705.2020.9074399.
[29] C. D’Ortona, D. Tarchi, and C. Raffaelli, “Open-source MQTT-based end-to-end IoT system for smart city scenarios,” Future Internet, vol. 14, no. 2, p. 57, Feb. 2022, doi: 10.3390/fi14020057.
[30] A. Munshi, “Improved MQTT secure transmission flags in smart homes,” *Sensors*, vol. 22, no. 6, p. 2174, Mar. 2022, doi: 10.3390/s22062174.

[31] K. L. Raju and V. Vijayaraghavan, “IoT and cloud hinged smart irrigation system for urban and rural farmers employing MQTT protocol,” in *2020 5th International Conference on Devices, Circuits and Systems*, Mar. 2020, pp. 71–75. doi: 10.1109/ICDCS48716.2020.243351.

[32] H. W. Yoon, D. J. Kim, M. Lee, C. Weon, and A. Smith, “L&M Farm: A smart farm based on LoRa MQTT,” *2020 International Conference on Omni-layer Intelligent Systems (COINS)*, 2020, pp. 1–6. doi: 10.1109/COINS49042.2020.9191387.

[33] A. Thantharate, C. Beard, and P. Kankariya, “CoAP and MQTT based models to deliver software and security updates to IoT devices over the air,” in *2019 International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom)* and IEEE Smart Data (SmartData), Jul. 2019, pp. 1065–1070. doi: 10.1109/IOTINGS/GREENCOM/CPSCOM/SMARTDATA.2019.00183.

[34] T. L. Liao, H. R. Lin, P. Y. Wan, and J. J. Yan, “Improved attribute-based encryption using chaos synchronization and its application to MQTT security,” *Applied Sciences*, vol. 9, no. 20, Oct. 2019, doi: 10.3390/app9204454.

[35] C. Patel and N. Doshi, “A novel MQTT security framework in generic IoT model,” *Procedia Computer Science*, vol. 171, pp. 1399–1408, 2020, doi: 10.1016/j.procs.2020.04.150.

[36] W.-T. Su, W.-C. Chen, and C.-C. Chen, “An extensible and transparent thing-to-thing security enhancement for MQTT protocol in IoT environment,” in *2019 Global IoT Summit (GIoTS)*, Jun. 2019, pp. 1–4. doi: 10.1109/GIOTS.2019.8766412.

[37] K. Sahlmann, V. Clemens, M. Nowak, and B. Schnor, “MUP: simplifying secure over-the-air update with MQTT for constrained IoT devices,” *Sensors*, vol. 21, no. 1, Jan. 2021, doi: 10.3390/s21010010.

[38] G. Potrino, F. de Rango, and A. F. Santamaria, “Modeling and evaluation of a new IoT security system for mitigating DoS attacks to the MQTT broker,” in *2019 IEEE Wireless Communications and Networking Conference (WCNC)*, Apr. 2019, pp. 1–6. doi: 10.1109/WCNC.2019.8885553.

[39] A. Shalaginov, O. Semeniuta, and M. Alazab, “MEML: resource-aware MQTT-based machine learning for network attacks detection on IoT edge devices,” in *Proceedings of the 12th IEEE/ACM International Conference on Utility and Cloud Computing Companion*, 2019, pp. 123–128. doi: 10.1145/3368235.3368876.

[40] E. Cãlabakkal, A. Donmez, M. Erdemir, E. Suren, M. K. Yilmaz, and P. Angin, “ARTEMIS: an intrusion detection system for IoT attacks in internet of things,” in *2019 38th Symposium on Reliable Distributed Systems (SRDS)*, Oct. 2019, pp. 369–371. doi: 10.1109/SRDS47363.2019.00053.

[41] M. Hussain et al., “Preventing MQTT vulnerabilities using IoT-enabled intrusion detection system,” *Sensors*, vol. 22, no. 2, Jan. 2022, doi: 10.3390/s22020567.

[42] M. A. bin Ahnadon, N. Yamaguchi, and S. Yamaguchi, “Process-based intrusion detection method for IoT system with MQTT protocol,” in *2019 IEEE 8th Global Conference on Consumer Electronics (GCCE)*, Oct. 2019, pp. 953–956. doi: 10.1109/GCCE46687.2019.9015252.

[43] M. A. Khan et al., “A deep learning-based intrusion detection system for mqtt enabled IoT devices,” *Sensors*, vol. 21, no. 21, Nov. 2021, doi: 10.3390/s21217016.

[44] D. Dinculeană and X. Cheng, “Vulnerabilities and limitations of MQTT protocol used between IoT devices,” *Applied Sciences*, vol. 9, no. 5, p. 848, 2019, doi: 10.3390/app9050848.

[45] R. A. Nathi and D. Sutar, “Object security scheme based on access policies using MQTT protocol for IoT devices,” in *2019 10th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*, Jul. 2019, pp. 1–6. doi: 10.1109/ICCCNT45670.2019.8944432.

[46] M. Sâlîgean and D. Zinca, “IoT applications based on MQTT Protocol,” in *2020 International Symposium on Electronics and Telecommunications (ISET)*, Nov. 2020, pp. 1–4. doi: 10.1109/ISET50328.2020.9301055.

[47] K. Mekki, E. Bajic, and F. Meyer, “Indoor positioning system for IoT device based on BLE technology and MQTT protocol,” *IEEE 2019 5th World Forum on Internet of Things (WF-IoT)*, Apr. 2019, pp. 787–792. doi: 10.1109/WF-IoT.2019.8767287.

[48] D. Borsatti, W. Cerroni, F. Tonini, and C. Raffaelli, “From IoT to cloud: applications and performance of the MQTT protocol,” in *2020 22nd International Conference on Transparent Optical Networks (ICTON)*, Jul. 2020, pp. 1–4. doi: 10.1109/ICTON51198.2020.9203167.

[49] D. L. de Oliveira, A. F. da Veloso, J. V. V. Sobral, R. A. L. Rabelo, J. J. P. C. Rodrigues, and P. Solic, “Performance evaluation of mgmt brokers in the internet of things for smart cities,” in *2019 4th International Conference on Smart and Sustainable Technologies (SpiTech)*, Jun. 2019, pp. 1–6. doi: 10.23919/SPLITECH.2019.8783166.

[50] B. Khan and C. Pirak, “Experimental performance analysis of MQTT and CoAP protocol usage for NB-IoT smart meter,” in *2021 9th International Electrical Engineering Congress (IEECON)*, Mar. 2021, pp. 65–68. doi: 10.1109/IEECON51072.2021.9440273.

[51] R. Zitouni, J. Petit, A. Djoudi, and L. George, “IoT-based urban traffic-light control: modelling, prototyping and evaluation of MQTT protocol,” in *2019 International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom)* and IEEE Smart Data (SmartData), Jul. 2019, pp. 182–189. doi: 10.1109/IOTINGS/GREENCOM/CPSCOM/SMARTDATA.2019.00051.

[52] M. Michaeledes, C. Sengul, and P. Patras, “An experimental evaluation of MQTT authentication and authorization in IoT,” in *Proceedings of the 15th ACM Workshop on Wireless Network Testbeds, Experimental Evaluation & Characterization*, 2022, pp. 69–76. doi: 10.1145/3477086.3480838.

[53] D. B. C. Lima, R. M. da B. Silva Lima, D. D. F. Medeiros, R. I. S. Pereira, C. P. de Souza, and O. Biaocchi, “A performance evaluation of raspberry pi zero W based gateway running MQTT broker for IoT,” in *2019 IEEE 10th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*, Oct. 2019, pp. 76–81. doi: 10.1109/IEMCON.2019.8936206.

[54] M. Dave, J. Doshi, and H. Arolkar, “MQTT - CoAP Interconnector: IoT interoperability solution for application layer protocols,” in *2020 Fourth International Conference on 5SMAC (IoT in Social, Mobile, Analytics and Cloud) (1-5MAC)*, Oct. 2020, pp. 122–127. doi: 10.1109/5SMAC49090.2020.9243377.

[55] E. Eldin, N. H. Shaker, and M. A. Sobh, “A secure MQTT protocol, telemedicine IoT case study,” in *2019 14th International Conference on Computer Engineering and Systems (ICCES)*, Dec. 2019, pp. 99–105. doi: 10.1109/ICCESS48960.2019.9068129.

[56] R. Priyamvada, “Temperature and saturation level monitoring system using MQTT for COVID-19,” in *2020 International Conference on Recent Trends in Electronics, Information, Communication & Technology (RTEICT)*, Nov. 2020, pp. 17–20. doi: 10.1109/RTEICT49044.2020.9315637.
A. Fauzan, P. Sukarno, and A. A. Wardana, “Overhead analysis of the use of digital signature in MQTT protocol for constrained device in the internet of things system,” in 2020 3rd International Conference on Computer and Informatics Engineering, IC2IE 2020, Sep. 2020, pp. 415–420. doi: 10.1109/IC2IE50715.2020.9274651.

A. Medina-Pérez, D. Sánchez-Rodríguez, and I. Alonso-González, “An internet of thing architecture based on message queuing telemetry transport protocol and node-red: A case study for monitoring radon gas,” Smart Cities, vol. 4, no. 2, pp. 803–818, May 2021. doi: 10.3390/smartcities4020041.

I. K. A. A. Aryanto, R. R. Huizen, and K. Y. E. Aryanto, “Design of soil humidity monitoring system using the internet of things concept and MQTT,” in 2020 International Conference on Smart Technology and Applications (ICoSTA), Feb. 2020, pp. 1–6. doi: 10.1109/ICOSTA48221.2020.915061115.

A. F. Okillas, R. Zulfahmi, Ermatita, and A. P. Jaya, “Temperature monitoring system based on protocol message queue telemetry transport (MQTT),” in 2019 International Conference on Informatics, Multimedia, Cyber and Information System (ICMICS), Oct. 2019, pp. 61–66. doi: 10.1109/ICMICS48181.2019.8985356.

M. Quamara, B. B. Gupta, and S. Yamaguchi, “MQTT-driven remote temperature monitoring system for IoT-based smart homes,” in 2019 IEEE 8th International Conference on Consumer Electronics (GCCE), Oct. 2019, pp. 968–970. doi: 10.1109/GCCCE6687.2019.9015603.

A. Huang, M. Huang, Z. Shao, X. Zhang, D. Wu, and C. Cao, “A practical marine wireless sensor network monitoring system based on LoRa and MQTT,” in 2019 IEEE 2nd International Conference on Electronics Technology (ICET), May 2019, pp. 330–334. doi: 10.1109/ELTECH.2019.8839464.

N. K. Bharti, M. D. Dongargaonkar, I. B. Kudkar, S. Das, and M. Kenia, “Hydroponics system for soilless farming integrated with android application by internet of things and MQTT broker,” in 2019 IEEE Pune Section International Conference (PuneCon), Dec. 2019, pp. 1–5. doi: 10.1109/PuneCon46936.2019.9105847.

F. Masykur, A. Prasetyo, I. Widaningrum, A. F. Cobanporto, and M. B. Setyawan, “Application of message queuing telemetry transport (MQTT) protocol in the internet of things to monitor mushroom cultivation,” in 2020 7th International Conference on Information Technology, Computer, and Electrical Engineering (ICTACEE), Sep. 2020, pp. 135–139. doi: 10.1109/ICTACEE50144.2020.9239118.

P. Perleoni et al., “IoT solution based on MQTT protocol for real-time building monitoring,” in 2019 IEEE 23rd International Symposium on Consumer Technologies (ISCT), Jun. 2019, pp. 57–62. doi: 10.1109/ISCTE.2019.8901024.

A. K. Saputro, A. R. Andiitsa, M. Ulum, H. Sukri, R. Alfita, and A. F. Ibaddillah, “Application of LoRa (long range access) in optimizing internet of things using MQTT (message queuing telemetry transport) for fish feed monitoring,” in 2020 6th Information Technology International Seminar (ITIS), Oct. 2020, pp. 224–228. doi: 10.1109/ITIS0018.2020.9321021.

R. Kawaguchi and M. Bandai, “Edge based MQTT broker architecture for geographical IoT applications,” in 2020 International Conference on Information Networking (ICON), Jan. 2020, pp. 232–235. doi: 10.1109/ICON48656.2020.9016528.

M. Matic, M. Antic, I. Papp, and S. Ivanovic, “Optimization of MQTT communication between microservices in the IoT cloud,” in 2021 IEEE International Conference on Consumer Electronics (ICCE), Jan. 2021, pp. 1–3. doi: 10.1109/ICCE50685.2021.9427602.

M. Markovic, “Enhancing transparency of MQTT brokers for IoT applications through provenance streams,” in Proceedings of the 6th International Workshop on Middleware and Applications for the Internet of Things, 2019, pp. 17–20. doi: 10.1145/3366610.3366899.

A. Almheiri and Z. Maamar, “IoT protocols - MQTT versus CoAP,” in Proceedings of the 4th International Conference on Networking, 2021, pp. 1–5. doi: 10.1145/3454127.3456594.

N. Nikolov, “Research of MQTT, CoAP, HTTP and XMPP IoT communication protocols for embedded systems,” in 2020 XXIX International Scientific Conference Electronics (ET), Sep. 2020, pp. 1–4. doi: 10.1109/ETS0336.2020.9238208.

A. Nordrine, Z. Kasmi, K. Ahmed, C. Motzko, and J. Schiller, “MQTT-based surveillance system of IoT using UWB real time location system,” in 2020 International Conferences on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData) and IEEE Comos Conference on Cybermatics (Cybermatics), Nov. 2020, pp. 216–221. doi: 10.1109/ITHINGS-GREENCOMM-CPSCOM-CYBERMATICS50389.2020.00050.

A. S. Sadeq, R. Hassan, S. S. Al-Rawi, A. M. Jubair, and A. H. M. Aman, “A Qos approach for internet of things (IoT) environment using MQTT protocol,” in 2019 International Conference on Cybersecurity (ICoCsec), Sep. 2019, pp. 59–63. doi: 10.1109/ICOCSEC47621.2019.8971097.

C. R. M. Silva and F. A. C. M. Silva, “An IoT gateway for modbus and MQTT integration,” in 2019 SBM/IIEEE MTT-S International Microwave and Optoelectronics Conference (IMOC), Nov. 2019, pp. 1–3. doi: 10.1109/IMOC43827.2019.9317637.

C. Sun, K. Guo, Z. Xu, J. Ma, and D. Hu, “Design and development of modbus/MQTT gateway for industrial IoT cloud applications using raspberry Pi,” in 2019 Chinese Automation Congress (CAC), Nov. 2019, pp. 2267–2271. doi: 10.1109/CAC48633.2019.8977492.

K. Terada, S. Ohno, H. Mukai, K. Ishibashi, and T. Yokotani, “An ICN system focusing on distributed MQTT brokers for IoT services,” in 2019 7th International Japan-Africa Conference on Electronics, Communications, and Computations (JAC-ЕЕС), Dec. 2019, pp. 28–31. doi: 10.1109/JAC-ЕЕС48896.2019.9501132.

T. Zeybek, C. H. Chang, and Z. Yang, “An IoT implementation for manufacturing using Wi-Fi, 6LoWPAN, and MQTT,” in Proceedings of the 2019 International Conference on Embedded Wireless Systems and Networks, 2019, pp. 362–366.

A. Zainudin, M. F. Syaifuin, and N. Syahroni, “Design and implementation of node gateway with MQTT and CoAP protocol for IoT applications,” in 2019 4th International Conference on Information Technology, Information Systems and Electrical Engineering (ICITSEE), Nov. 2019, pp. 155–159. doi: 10.1109/ICITSEE48480.2019.9003573.

F. Buccafurri and C. Romolo, “A blockchain-based OTP-authentication scheme for constrained IoT devices using MQTT,” in Proceedings of the 2019 3rd International Symposium on Computer Science and Intelligent Control, 2019, pp. 1–5. doi: 10.1109/ISCSIC50364.2019.3389095.

F. Buccafurri, V. de Angelis, and R. Nardone, “Securing MQTT by blockchain-based OTP authentication,” Sensors, vol. 20, no. 7, p. 2002, Apr. 2020. doi: 10.3390/s20072002.

I. Vaccari, G. Chiola, M. Aiello, M. Mongelli, and E. Cambiazzo, “MQTTS-based secure channel for constrained IoT devices,” Sensors, vol. 20, no. 22, p. 6578, Nov. 2020. doi: 10.3390/s20226578.

P. Arivuban and K. Prem, “The routing-based protocol technique for enhancing the performance metrics using MQTT in the internet of things,” Materials Today: Proceedings, 2020. doi: 10.1016/j.matpr.2020.11.070.
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