Systematic Review on Security and Privacy Requirements in Edge Computing: State of the Art and Future Research Opportunities

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ABSTRACT Edge computing is a promising paradigm that enhances the capabilities of cloud computing. In order to continue patronizing the computing services, it is essential to conserve a good atmosphere free from all kinds of security and privacy breaches. The security and privacy issues associated with the edge computing environment have narrowed the overall acceptance of the technology as a reliable paradigm. Many researchers have reviewed security and privacy issues in edge computing, but not all have fully investigated the security and privacy requirements. Security and privacy requirements are the objectives that indicate the capabilities as well as functions a system performs in eliminating certain security and privacy vulnerabilities. The paper aims to substantially review the security and privacy requirements of the edge computing and the various technological methods employed by the techniques used in curbing the threats, with the aim of helping future researchers in identifying research opportunities. This paper investigate the current studies and highlights the following: (1) the classification of security and privacy requirements in edge computing, (2) the state of the art techniques deployed in curbing the security and privacy threats, (3) the trends of technological methods employed by the techniques, (4) the metrics used for evaluating the performance of the techniques, (5) the taxonomy of attacks affecting the edge network, and the corresponding technological trend employed in mitigating the attacks, and, (6) research opportunities for future researchers in the area of edge computing security and privacy.

INDEX TERMS Edge computing, edge computing attacks, systematic review, security and privacy requirements.

I. INTRODUCTION

Edge computing paradigm is developed with the intention of overcoming the drawbacks associated with cloud computing. In the edge computing, the edge network stands between the cloud and the end-users, thereby, bringing cloud resources very closed to the end-users [1]. This consequently provides tremendous real-time data analysis, reduce latency, low operational cost, high scalability, and improve the quality of services. The most challenging problem affecting the success of edge computing is a breach in the security and privacy of most of the components associated with it. This survey study
considers eight security and privacy requirements of a typical edge computing network. Security and privacy requirements can be referred to as the measure of the capabilities and functions that a system should achieve for eliminating the security and privacy vulnerabilities [2]. When the requirements are satisfied, the system complies successfully with the imperative private and secure targets, as well as relevant regulatory guidance [3]. The requirements include Privacy-Preservation, Confidentiality, Authenticity, Attack Detection, Integrity, Availability, Nonrepudiation, and Reliability. The detail of each requirement will be discussed in section III.

Many survey studies discussed the security and privacy issues in edge computing; however, most of these previous studies systematically overlooked the investigation on the security and privacy requirements in the edge computing network. In addition, research on the state of the art curbing techniques with the corresponding technological methods was also missing in the previous survey studies. In [4], Zhang et al. presented a survey on security and privacy issues in edge computing, however, only cryptography-based technologies that considered confidentiality requirements were highlighted. In [5], Rodrigo and his team analyzed and surveyed the security threats associated with the various edge computing related paradigms, such as fog computing, and mobile edge computing. However, the survey considered techniques related to authenticity requirement, whereas, less attention was given to other requirements. Guan et al. [6] discussed the main data flow in the energy sector, nevertheless, their survey work focused only on security and privacy issues in the area associated with the application of edge computing in the electricity sector. Rapuzzi and Repetto [7] likewise, reviewed the limitations of current cyber-security paradigms associated to the evolving fog/edge schemes. The survey work aimed at representing a basics for the design of innovative cyber-security methods, nonetheless, a thorough investigation of the security requirements was missing. Shirazi et al. [8] in another survey highlighted the need to come up with new security curbing strategies in the emergent area of edge/fog computing, and to investigate them in their new computing applications.

The various survey studies have laid a tangible foundation in understanding security and privacy issues in edge computing. However, most of these studies provided limited information with respect to the security and privacy requirements in the edge computing network. Besides, most of the work rather discussed partially or conducted the review when the problem was at an early stage. This review work will recapitulate the existing state of the art security and privacy requirements, as well as the trend of the technological methods employed by the techniques for curbing the associated threats in the edge computing for future researchers to follow. A systematic review protocol that will specify all the relevant stages necessary for achieving the aim and objectives of the study will be developed and considered from the initial stage before starting the process of data abstraction. This process will ensure impartial data search and retrieval. The contribution of this review work will be attained by answering the following research questions:

1) What are the categories of security and privacy requirements in the edge computing network?
2) What techniques are proposed for ensuring the requirements identified?
3) What trend of the technological methods are employed by the identified techniques?
4) What are the suitable evaluation metrics employed in assessing the performance of the techniques?
5) What are the categories of attacks affecting edge computing networks, together with the corresponding mitigating technologies?
6) What are the future research opportunities available for researchers working in the area of security and privacy of edge computing?

The remaining part of the paper is categorized as follows: Overview of edge computing similar paradigms (Post-Cloud Computing Paradigms) will be given in Section II, the overview of security and privacy requirements in edge computing will be stated in Section III, Section IV will highlight the methodology for conducting the systematic literature review, Data analysis will be given in Section V, the discussion of the reviewed result will be given in Section VI, Section VII will highlight the research open issues, and conclusion will be finally given in Section VIII.

II. OVERVIEW OF EDGE COMPUTING SIMILAR PARADIGMS

This section will introduce the edge computing similar paradigms, which are otherwise known as post-cloud computing paradigms. This includes Edge computing, Fog computing, Mobile Edge Computing (MEC), Cloudlet computing, Mist computing, and Dew computing. The post-cloud computing paradigms are used interchangeably by most researchers, although, they are not exactly the same. Therefore, this section compares and contrasts between the post-cloud paradigms, and clarify the similarities and differences that are ignored by most researchers. The post-cloud paradigms are all developed with the intention of overcoming the weaknesses of cloud computing for not satisfying the requirements of internet-of-things (IoT) and next-generation 5G networks. The most important requirements include real-time and distributed data processing, low latency, mobility support, quick response of wireless sensors and actuators, etc. Although the post-cloud computing paradigms have been developed by different organizations with different ideas, the principle of bringing cloud services closer to the end-user (network edge) is common. Table 1 summarizes the similarities and differences between the post-cloud computing paradigms.

In all of the post-cloud computing paradigms, end-users and other IoT devices are the main target for security and privacy breaches, because of their inability to establish explicit trust for other devices, and also their inability to establish a trustworthy connection. Generally, security and privacy need
to be provided in every layer of the post-cloud computing networks [4]. Barika Pace, a research director highlighted that “Each IOT device in post-cloud computing network is configured in a different way which leads to having a different version with different vulnerabilities, and consequently causes problems” [9]. Another issue that leads to the security
and privacy breach of the post-cloud computing paradigms, with the exception of MEC is that the data and computational tasks of end-users are communicated through a decentralized edge network.

According to Duncan Pauly, a CTO at Edge Intelligence, “The security and privacy risks associated with post-cloud
computing paradigms are quite different from a cloud environment, because all the data in the cloud are stored or process in a single or small number of locations, whereas in post-cloud computing paradigms, data is decentralized” [9]. Thus, sensitive data associated with end-user can be compromised. Furthermore, the offloaded data and other complex computational tasks together with some cloud resources are stored at the network edge, which is more vulnerable than the cloud itself [10].

Shane MacDougall, a senior security engineer at networking and cyber-security services company Mosaic452, argued that “The best practice for ensuring security and privacy in post-cloud computing networks is to provide an equal amount of protection to all of the edge/Fog and other related nodes as the remaining part of the network” [9]. In another hand, the worst practice of ensuring post-cloud computing security and privacy is to employ the traditional security controls, for example, using only antivirus and firewalls to protect the edge devices. Joseph Carson, the chief security scientist at Thycotic, an access management technology provider said, “In post-cloud computing, the organization’s data are no longer flowing through their internet connection, nor via their corporate firewall, so there is a need to secure and protect each edge device as if it is a door to their network” [9].

Another poor practice for ensuring security and privacy in edge computing is employing cloud-based security models. Therefore, for proper handling of security and privacy in the post-cloud network, certain security and privacy requirements need to be considered in the process of enabling smooth operation of the entire network. This review work will concentrate only on the edge computing security and privacy requirement, which will be discussed in section III.

The typical architecture of edge computing is illustrated in Fig. 1, while the architectures of the other edge similar paradigms are illustrated in Fig. 2. More details on the post-cloud computing paradigms and their comparison can be found in the work of Yousefpour et al. [11]. Fig. 1 depicts the typical 3-layer architecture of an edge computing paradigm. The edge layer stands in between the cloud and the end-devices layer. It can be seen from the Fig.1 that the latency decreases significantly from an edge network layer to an end-devices layer when compared to that of the cloud layer and end-devices layer. This is an important feature of an edge computing paradigm. The security decreases drastically when moving away from the cloud layer to an edge layer and then to an end-device layer, which is as the result of distributed nature of the edge network. It can also be observed
that the storage capacity decreases drastically from the cloud layer to the edge layer and then to the end-device layer. The real-time processing decreases dramatically when moving from end-devices to an edge layer and then to the cloud layer. Data flows from end-devices to edge layer for storage or processing, then to the cloud layer when long term storage is required. Requests in the edge computing network flow in two directions, as depicted in Fig. 1.

Similarly, in Fig. 2, fog computing consists of fog nodes that are distributed over geographical locations, very close to end-user devices. The overall computation process is done at the edge of the network, very close to the data sources [12]. The architecture of mobile edge computing (MEC) is also depicted in Fig. 2. As shown, the MEC computing consists of MEC servers that are located in the vicinity of the mobile users. Thus mobility is highly supported, and latency is relatively lower than the remaining post-cloud computing paradigms. Fig. 2 also illustrates the architecture of the cloudlet computing. As shown in Fig. 2, cloudlet computing consists of a relatively small mobility support cloud called cloudlet located close to the mobile end-users. The cloudlet is connected to the faraway cloud, and it brings computational resources directly into mobile devices with relatively low latency. Cloudlets are installed on distributed virtual machines servers connected together by the LAN network, on which mobile devices can upload high computational tasks. Cloudlet does not have to be fixed infrastructures close to the end-devices, but may rather be accessible through the wireless LAN network.

The architecture of Mist computing is also shown in Fig. 2. As depicted in the figure, data processing is at the extreme edge of the network because fog nodes stand between the cloud layer and the mist layer, resulting in less network delay, reduced latency, as well as bandwidth utilization, when compared to the remaining post-cloud paradigms. Thus, it can be said that, in Mist computing, computation is pushed further to the network edge. Therefore, devices at the edge, such as sensors and actuators are involved in the computing process, which is not the case when compared to the other post-cloud computing paradigms. This allows the computation to be performed by microcontrollers of the embedded nodes [27].

Fig. 2 also shows the architecture of the dew computing paradigm. It can be seen that the dew computing consists of dew servers that allow the cloud information to always be available on end-devices, connected to the nearby dew server, so that cloud data will be available even in the absence of internet service [28], [33]. Unlike cloudlet computing, dew computing employed relatively high-level servers, which provide services similar to that of cloud and also synchronizes its database to the database of the cloud [34]. Thus providing services independent to the cloud, and also in collaboration with the cloud [29].
III. OVERVIEW OF THE SECURITY AND PRIVACY REQUIREMENTS IN EDGE COMPUTING NETWORK

In the traditional way, security and privacy requirements are categorized into three main groups referred to as CIA-Triad [35]. They include Confidentiality, Integrity, and Availability. However, due to the insufficiency of CIA-Triad to address new threats in the shared security environment (like edge computing), a comprehensive list of security and privacy requirements called IAS-Octave was formulated [36]. IAS-Octave can be utilized in edge computing due to its ability to address new threats in the shared environment. In the IAS-Octave categorization, Accountability, Auditability, Trustworthiness, Nonrepudiation, and Privacy-Preservation security requirements are added to the CIA-Triad, thus making a total of eight requirements. Considering the fact that Accountability and Auditability lead to Trustworthiness [37], [38], and also, Trustworthiness is highly related to Authenticity requirement [39], the three requirements can be merged together to form Authenticity. Additionally, the security and privacy requirements of edge computing, which are not included in the IAS-Octave when compared with the reviewed studies under the edge computing perspective are Attack Detection and Reliability. Therefore, in this paper, edge computing security and privacy requirements are proposed. They include Confidentiality, Integrity, Availability, Privacy-Preservation, Nonrepudiation, Authentication, Attack Detection, and Reliability. Table 2 illustrates the description of the proposed edge computing security and privacy requirements, which will be considered in the review work. Similarly, Fig. 3 illustrates the development of the security and privacy requirements from CIA-Triad to the proposed requirements.

IV. METHODOLOGY

This review work employs a systematic review to ensure accurate and impartial data search and retrieval. A review protocol that specifies the search strategy, devising of inclusion and exclusion criteria in the selection of the articles to be considered or ignored respectively, and plan for analyzing the

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**TABLE 2. Description of the security and privacy requirements.**

| S/N | REQUIREMENTS | DESCRIPTION |
|-----|--------------|-------------|
| 1   | Confidentiality | It ensures that only genuine data owners and intended receivers have the right to access private information or data in the edge computing environment. |
| 2   | Integrity     | This requirement ensures the delivery of data and information only to authorized edge devices without any form of modification. |
| 3   | Availability  | It ensures that all the edge computing participants, including the edge nodes and end users are able to access all the services at any moment in time. |
| 4   | Privacy-Preserving | This requirement ensures that all the secret information for end users are kept undisclosed under trust and monitoring. |
| 5   | Non-Repudiation | It ensures occurrence or nonoccurrence of any task. It guarantees that a user or edge node did not deny any accomplished action. |
| 6   | Authenticity  | This requirement ensures careful monitoring, verification of edge computing participants’ identity, and also establishment of trust among them. |
| 7   | Attack Detection | It ensures that the attacks associated with edge computing network are detected and eradicated accordingly. |
| 8   | Reliability   | This requirement ensures that the genuine communicating edge computing entity believes with other genuine entity under sufficient and credible evidence |
SELECTED ARTICLES WAS DEVELOPED FROM THE INITIAL STAGE BEFORE BEGINNING THE SEARCH PROCESS OF LITERATURE AND DATA EXTRACTION. THE PROTOCOL WAS APPROVED BY ONE OF THE AUTHORS PRIOR TO ITS IMPLEMENTATION. THE STEPS INVOLVED IN THE METHODOLOGY OF THE REVIEW WORK ARE ILLUSTRATED IN FIG. 4.

A. DATA SEARCH STRATEGY

A thorough search was conducted on all studies that focus on security and privacy issues in edge computing including both review and technical studies. The entire search was carried out through six prominent online electronic databases, which include: Scopus, Web of Science, IEEE-Explore, Science Direct, Springer, and Wiley. This is because they encompass publications from the major journal and conference proceedings, and as such, a reasonable sample that will represent the current state of knowledge in the area of edge computing privacy and security will be obtained. Restricting the search on the four mentioned online electronic databases implies that only a sample of the literature on the intended review is targeted.

Also, limiting the search to only computer science and information, computer science and theory, and engineering subject areas were made in order to limit the boundary of the review work. The initial search was made by filtering only conference, technical and review journal articles that were published between 2015 to November 2019. The search tip used in retrieving the articles include:

1) “Security and Privacy” AND “Edge Computing” OR “Security” AND “Edge Computing” AND “Privacy” OR “Privacy” AND “Edge Computing” OR “Trust” AND “Edge Computing” OR “Security” AND “Trust” AND “Edge Computing” OR “Privacy” AND “Trust” AND “Edge Computing” OR “Privacy” AND “Trust” AND “Edge Computing”

2) “Security” AND “Privacy” OR “Privacy” AND “Trust” OR “Trust” AND “Edge Computing” OR “Privacy” AND “Edge Computing” OR “Trust” AND “Edge Computing”

A total of 273 articles from Scopus, 271 from Web of Science, 1328 from IEEE-Explore, 354 from Science Direct, 371 from Springer, and 405 from Wiley were obtained. A total of 3,002 articles were found. A scan was made on the title and abstract of the searched articles. After the scan, 2,730 articles found to be either beyond or not even related to the scope of the review work, and were completely removed. Inclusion and exclusion procedures were then applied to the remaining 272 articles for further selection. An article is considered for inclusion if it satisfies the inclusion requirements highlighted in Table 3, and it is excluded if it satisfies the exclusion criteria. After the full-text review of the remaining 272 retained articles, 96 fulfilled the inclusion requirements.

TABLE 3. INCLUSION AND EXCLUSION CRITERIA

| INCLUSION CRITERIA                                                                 | EXCLUSION CRITERIA                                                                 |
|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| • An article is considered for inclusion if it is either a Journal or Conference  | • An article is considered for exclusion if it is not focusing on security and     |
| paper to achieve the highest level of significance                                | privacy issues in the edge computing area                                          |
| • An article is considered for inclusion if it is published between 2015 to       | • An article is considered for exclusion if it is not fully accessible from the     |
| November 2019, to include the latest techniques employed in solving security and  | online electronic databases (Scopus, Web of Science, IEEE-Explore, Science Direct, |
| privacy issues in edge computing                                                  | Springer, and Wiley)                                                              |
| • It is written in English                                                        |                                                                                   |
Again, duplicate articles are extracted and discarded, leaving a total of 78 articles. The distribution of the retained articles according to their respective databases is depicted in Fig. 5.

B. DATA EXTRACTION

Relevant data that will answer the research questions were exhaustively abstracted from the 78 articles that fulfilled the inclusion criteria. The following items were documented: Authors, Year of publication, type of the article, the technique under a specific category of security and privacy requirement, the category of the technological methods employed, performance metrics used in evaluating the performance of the proposed technique, and the attacks considered by the techniques. Additionally, research opportunities are derived from the weaknesses of each identified techniques.

V. DATA ANALYSIS

In this section, all the studies that fulfilled the inclusion criteria will be systematically analyzed. The steps of the general data analysis will be described in sub-section A. Also, the analysis based on the proposed security and privacy requirements, which will answer the research questions will be given in sub-section B.

A. GENERAL DATA ANALYSIS

The review work examined 78 articles from various journals and conference proceedings across the four different electronic databases. Fig. 6 illustrates the percentage of journal articles and conference papers published between 2015 to November 2019. Based on the review findings, there is no visible journal publication between 2015 and 2016, which may be regarded as research on security and privacy on edge computing only gain popularity in the year 2016. 50% and 48% of 2017 and 2018 publications journal articles respectively. This may be due to the fact that researchers lately start developing interest in security and privacy issues in edge computing. In the year 2019, 100% of the publications from the review work are from journal articles. This may be because additional interests are diverted to the area of security and privacy in edge computing. However, conference papers may also be available in other electronic databases.

Fig. 7 shows the distribution of the articles according to the different journals spanning a broad range of disciplines. The majority of the articles were from the IEEE Access Journal (32%), followed by the journal of the Future Generation Computer System (30%). The next most prevalent journals are the Journal of Parallel and Distributed Computing, while IEEE Internet of the Thing Journal and Journal of System Architecture, Edge Computing, and Edge Cloud Journal, and Journal of Distributed Sensor Network are having 5% each. However, Hindawi Mobile Information System Journal, the
Journal of Computers, Transaction and Industrial Informatics Journal, Journal of the Selected Area in Communication, and Journal of Transaction in Multimedia are all having 1% each.

B. DATA ANALYSIS BASED ON THE PROPOSED SECURITY/PRIVACY REQUIREMENTS

Subsection B(1) aimed at answering the research question 1 (RQ1) that focused on the classes of the security and privacy requirement in edge computing network, research question 2 (RQ2) that deliberates on the techniques proposed for ensuring the identified requirements, research question 3 (RQ3) that concentrates on the trend of the technological methods employed by the identified techniques, and, research question 6 (RQ6) that emphasizes on the research opportunities (gaps) for future researchers working in the area of security and privacy in edge computing. Research question 4 (RQ4) that focuses on finding the employed evaluation metrics assessing the performance of the identified techniques will be answered in Sub-section B (2). Similarly, research question 5 (RQ5) that highlights the attacks affecting edge computing network, with the corresponding technological curbing techniques will be explored in Sub-section B (3).

1) DATA ANALYSIS TO ANSWER RQ1, RQ2, RQ3, AND RQ6

In this section, the identified techniques that considered a specific category of security and privacy requirements are classified as depicted in Fig. 8. Additionally, Fig. 9 and Fig. 10 illustrate the classification of the techniques that consider more than one requirement, and the techniques that did not specify any of the proposed requirements respectively. Similarly, a summary of technique ideas under a given requirement is given in tables. In the tables, the description of the methodology, the technology employed, the used performance evaluation analysis, the advantages, and the disadvantages/gaps are given.

Table 4 reviews the techniques under Confidentiality requirement, Table 5 recapitulates the techniques under Privacy-Preservation requirement, Table 6 analyses the techniques under Authenticity requirement, Table 7 explores the techniques under Attack Detection requirement, Table 8 summarizes the techniques that considered the combination of both Authenticity and Privacy-Preservation, Table 9 reiterates the techniques that considered more than two requirements, and Table 10 summarizes the techniques that did not specify any of the proposed requirements.

Based on the review work, a technique that considers the Integrity requirement alone could not be established, except in combination with other techniques. Furthermore, findings show that only one study considered the availability requirement. Authors in [40] applied both block-chain and game theory methods to overcome the attack on edge servers by mobile devices in the edge computing network. A punishment scheme based on the active record of a Block-Chain
was proposed. A block-chain security game is formulated by considering the interaction between the edge server and the mobile devices. The mobile devices either send a request to the server to obtain a real-time service or to launch an attack. Nash equilibrium is employed to determine the exact intention of the mobile device of either service request or attack. The scheme improved the network security performance by decreasing the attack rate of the server by 66.7% as compared to other similar techniques. Mathematical analysis is employed in evaluating the performance of the block-chain security game. Furthermore, according to the review work, a technique that considered Nonrepudiation requirement either alone or in combination with other requirements is not found.

Likewise, a technique that considers the Reliability requirement alone is also not found, except in combination with Authenticity requirements. Han, B., and his colleague in [41] devised an edge computing security technique based on the Markov model. The objective is to propose a decentralized authentication scheme that can provide flexible and low-cost authentication, which is aware of the context information of user devices and other network elements. They introduced trust architecture with cognitive access management. A context-aware mechanism, which synchronizes and reduces the backhaul network traffic, was designed. A simulation was conducted to validate the effectiveness of the technique. The proposed scheme was successful in maintaining the balance between network operating costs and
TABLE 4. Summary of the confidentiality techniques.

| REFERENCE | DESCRIPTION | TECHNOLOGY EMPLOYED | PERFORMANCE ANALYSIS METHOD | ADVANTAGES | LIMITATION/GAP |
|-----------|-------------|---------------------|-----------------------------|------------|----------------|
| [45]      | To provide access control over encrypted data in the edge computing environment, the authors focused on ensuring confidential channels for key distribution in edge computing. They proposed Proxy-Aided Cipher Text-Policy ABE (PC-CPABE) that affords the majority of the decryption computation to the trusted edge data centers so that no channel will be needed for key distribution. | ABE policy hidden methods | Prototype Implementation | No channel is needed for key distribution | A method that will reduce the computational overhead associated with ABE policy hidden technique needs to be designed. |
| [46]      | The objective of the study is to revoke users’ secret keys after being compromised and to minimize communication and computation overheads to attain lightweight requirements. The authors proposed Cipher Policy-ABE (CP-ABE) that ensures the confidentiality of users’ private information when shared within the edge computing network. Every authorised user is assigned with an ID, and the total IDs of the users are embedded in the private key that will be used for data decryption. Therefore, the only user whose ID corresponds to the ID set can decrypt the ciphertext. In any event, when the ID of a user is compromised, the data owner simply removes the ID of the affected user from the ID set and encrypts the information again. Thus, any compromised user will be automatically removed without affecting other users. | ABE policy hidden methods | Informal Security Proof, and Prototype Implementation | The scheme satisfied all the three attributes of fully policy hidden CP-ABE that include: partially policy-hiding, direct revocation of compromised users, and light-weightiness. | A method that will reduce the high computational overhead associated with ABE policy hidden technique needs to be designed. |
| [47]      | With respect to the protection of multimedia content ownership in edge computing, the authors proposed a zero watermarking technique with visual cryptography. To develop the biometric security of face images and to prevent copying of multimedia content in an edge computing network, the authors captured a face image using the Visio-Jones algorithm and convert it to grayscale. A DWT of the converted image is zero-watermarked with a unique ID. Visual cryptography is then applied to the watermarked image. At the receiver end, visual decryption is applied to obtain the watermarked image. Lastly, watermark detection and face recognition are applied to verify the image. | Watermarking Method | Real Dataset | The proposed scheme does not tamper with the facial image, and therefore has no effect on the recognition rate. | There is a need for secure other multimedia content, e.g., Audio and Video, not only face image. |
| [48]      | The objective of the scheme is to analyze 3 AES implementations with first-order resistant masking in edge computing, and to propose a new scalable collision attack with the common application and high efficiency, which can be applied to the AES implementation. The authors considered the situation when little or no concern is given to the linear layer of 5-Boxed of AES algorithm when trying to recover the secret key applied in edge computing for ensuring data confidentiality. Firstly, a new type of collision attack that uses leakages from linear layers and capable of breaking any masking solution is proposed. Secondly, a notable collision attack which is used to mask the 5-Boxes is also proposed. | Cryptographic Based (AES Algorithm) | Prototype Implementation | The proposed collision attack is efficient in reducing the number of power traces when compared to other collision attacks | There is a need for collision attack to be applied to the general masking schemes of a symmetric cipher. |

reliability. However, the security mechanism needs to be evaluated in accordance with the 5G network, which may be in respect of the corresponding application of the local authentication.

Moreover, two studies from the review work devised techniques that ensured both Authenticity and Confidentiality requirements. They are classified according to the employed methods as shown below:

**a: CRYPTOGRAPHIC BASED TECHNIQUES**

Ali et al. [42] proposed a multimodal authentication scheme by employing biometric encryption. Biometrics including speech and face image are encrypted using portable devices. Decryption occurs in the cloud, where each user is authenticated. The majority voting technique is used for a final decision about the user identity. The objective of the scheme is to propose a multimodal authentication system using encrypted biometrics for edge-centric cloud network. The proposed scheme can successfully hide the identity of users and, in the end, retrieve the biometrics accurately with an errorless authentication. However, the security involved is not strong because the scheme cannot generate the secret shares of the biometric templates.

The process of combining cryptography and biometric in securing user’s information is termed as biometric-cryptography [43], [44]. The higher level of security is achieved with biometric-cryptography since the biometric templates assist the cryptographic process to encrypt and decrypt the information involved [43]. There are two different types of biometric-cryptography. The first one is called a biometric key release, which involves the occurrence of biometric matching in extracting the cryptographic key [43]. In the second type called biometric key generation templates, both biometric template and cryptographic key are combined together [43], hence no matching is required as in the first type.

**b: NONE-CRYPTOGRAPHIC BASED TECHNIQUES**

Chen et al. [45] proposed a none-cryptographic security scheme, where a password is not required for authentication purposes. A signal fingerprint feature, generated by the radiation of radio frequency of terminal devices (RF Fingerprint) is used by edge devices for the authentication process. In the proposed scheme, no password authentication is required, and as such, the scheme is more reliable when compared to the traditional cryptographic protocols. The author’s employed simulation in evaluating the performance of the scheme, employing signal to noise ratio (SNR) as metrics.

RF fingerprints are distinctive features implanted in electromagnetic waves usually emitted by transmitters [46], [47]. The RF fingerprints aimed at serving the same purpose...
| REFERENCE | TABLE 5. Summary of the privacy-preserving techniques. |
|-----------|-------------------------------------------------|
| [49]      | The technique is proposed to safeguard data transmission over a lose secure wireless sensor network. The scheme supports nearest neighbor space representation and Vector Machine classifiers to analyze the new problem of privacy-preserving classification under the new edge computing context. |
|           | Machine Learning Synthetic Dataset               |
|           | • The proposed system is proficient for applying for differential privacy protection in the feature selection stage. |
|           | • The proposed scheme ensures protection against re-identification attacks with a reasonable impact on classification accuracy. |
|           | • The study maximizes task acceptance rate and provided privacy guarantees by formulating the optimization issue after comparing user-centric and task-centric allocation approaches. |
|           | • The study solved joint privacy protection and task allocation problems. |
|           | There is a need to balance privacy and efficiency, apart from establishing the tradeoff between privacy and utility preservation. |
| [50]      | To analyze the limitations of typical task allocation and obfuscation schemes, and also to model the location obfuscation sub-issue through issue decomposition as a leader-followers game between the designer of location obfuscation mechanism and the potential attacker. The authors introduced an edge node into the edge network to prevent the untrusted crowdsensing server from accessing users’ private data. Both joint privacy protections, as well as task allocation problems, were solved by means of issue decomposition. |
|           | Game Theory Algorithm Simulation (Computer Simulation Experiments) |
|           | • With the proposed scheme, the management of privacy and security can be done by the edge devices without the need of any third-party trusted authority. |
|           | • The scheme is unable to establish consensus among the connected devices in a situation where there is no time to deploy a block-chain. |
| [51]      | The authors consider the challenges associated with sensing-based mobile edge computing applications in managing data privacy without certifying tradeoff between performance and accuracy. In order to develop a novel framework for the proposed scheme for authorization in social sensing-based edge computing with reference to target signatures, and also to develop a bottom-up approach for negotiating the ring compositions based on an enhanced clustering algorithm, a framework that utilizes a ring signature was proposed. |
|           | Game Theory Algorithm Simulation (No-3), Prototype Implementation (Single Board Computer), and Real Dataset |
|           | • Apart from ensuring security and privacy, the proposed system also improves the network workload and delay, and also ensure end-user satisfaction. |
|           | Security and efficiency analysis need to be conducted in order to evaluate the performance of the technique. |
| [52]      | The authors proposed a LESS-P technique that combines filtration and rough set theory algorithms to distinguish the valid results from malicious reviews for the next filtration, in order to design a secure recommender system on the interconnected network that will minimize the privacy leakage of users selecting their destined product in the network, and to prevent leaking of users’ privacy information in edge computing, thus, ensuring real-time stability and accuracy of query results. |
|           | Set Theory Algorithm N/A                         |
| [53]      | The authors identified both location and usage privacy-preserving that was initiated by the wireless task offloading to mobile edge computing. They proposed a new task offloading algorithm based on the CMDP framework. They also proposed a privacy-aware task offloading scheduling algorithm based on Markov decision process. |
|           | Other Algorithm Markov Decision Process and Task Offloading Algorithm |
|           | Simulation (Computer Simulation Experiments)     |
|           | With the proposed scheme, mobile devices can achieve an optimum delay and consume less energy with greater performance. |
|           | We need to incorporate faster learning algorithms by considering problem-specific structures. |
| [54]      | To Design a Smart Application capable of collecting the geo-tagged multimedia big data from different tag-related entities, the authors came up with a framework that uses hybrid of clouds, one at the server end, and the other at cloud edge. A mobile layer was added which serves as a proxy between the user end and the cloud infrastructure. When a user moves within a crowd, accurate handshaking of metadata about the user is shared with the current edge node in order to share the current location. |
|           | Symmetric AES Encryption Algorithms Prototype Implementation (Commercial Mobile device) |
|           | The proposed scheme supports context-aware services to millions of pilgrims that yearly gather together in a relatively small part of land. |
|           | More powerful nodes need to be employed. Also, there is a need to have more proper handshaking between the nodes and end-users. |
| [55]      | The difficulty associated with privacy protection of wireless sensor location in edge computing is considered by the authors. Two privacy preserved location protocols, 2Dilateration and Multilateration, based on Paillier’s homomorphic encryption system were employed. In order to obtain sensor location privacy, additional homomorphic encryption was applied. The two protocols with Intransit squares were selected and converted to privacy preserved protocol. Based on the applied homomorphism, the cipher text of the solution was composed by the cipher text of each distance. |
|           | Asymmetric Homomorphic Encryption Mathematical Analysis |
|           | The proposed scheme protects the privacy of the actual locations information as compared to other schemes that protect location privacy by identity concealment. |
|           | Other wireless algorithms cannot be applied directly to the proposed scheme to generate their privacy preserved version. |
| [56]      | To protect the network privacy of a mobile user with little impact on communication performance, the author proposed a novel differential location-based Privacy-Preserving framework deployed on the edge computing network. The designed techniques aimed at providing location privacy that balances between utility and privacy. |
|           | Other method (MSS, i.e. Mobile Support System) Simulation (Computer Simulation Experiments) |
|           | With the proposed scheme, the system operation cost is drastically reduced, and also the connectivity interruption for roaming mobile users has also been eliminated. |
|           | Need to devise a means of hiding the user’s network location as well as traffic from communication peers. |
| [57]      | The same authors as above devised a means of hiding the edge computing mobile users’ network location and traffic from communication peers. The objective is to propose a distinct novel privacy-preserving location-based service usage framework that will be deployed on the edge node. A dynamic proxy network is developed for every mobile user in the network. |
|           | Other method (multicore edge) Simulation (Computer Simulation Experiments) |
|           | The proposed technique provides flexible protection that balances the utility and privacy. |
|           | Cost and performance need to be optimized. |
| [58]      | Considering the challenge that leads to leakage of users’ location information through a side-channel, the authors propose the scheme by utilizing chaff services and considering heuristic strategies that mimic users’ mobility to defend the users against onroadside tracking. They also design an optimized strategy to minimize tracking accuracy. The objective is to investigate a new side-channel that was not investigated before, and also to model an onroadside as a maximum likelihood detector. |
|           | Other method (Chaff Services, Heuristic and optimized strategies) Simulation (Computer Simulation Experiments) |
|           | The proposed system significantly protect the user’s location privacy for users with highly predictable mobility. |
|           | Need a defense against an advanced onroadside that can easily be aware of the optimized strategy. |
| [59]      | To propose a technique that utilize randomization against an advanced onroadside strategy awareness, the above similar authors introduced their technique to protect the users against a more advanced onroadside, by introducing an extended strategy that utilizes randomization. |
|           | Other method (Chaff Services, Heuristic, and advanced optimized strategies) Simulation (Computer Simulation Experiments), and Real Dataset |
|           | • The proposed technique can drastically reduce the tracking accuracy for users with highly predictable mobility. |
|           | • The technique is capable of protecting end-users location privacy even for highly predictable mobility users. |
|           | We need to consider cost and privacy tradeoff by replacing chaff with lesser cost services.
with the biometric fingerprint for wireless devices, hence improving the overall privacy of wireless communication. RF fingerprint is more reliable than the biometric fingerprint because it can be achieved with relatively low-cost receivers, which provide extra network security layers [48]. Most importantly, it can be used in identifying the sources of electromagnetic transmission, which make it the backbone of the security of a radio network for eliminating the known attacks [48]. Moreover, It is quite impossible to regenerate the fingerprint from any device whatsoever [49].

Fig. 11 illustrates the classification of the performance evaluation analysis methods employed by the studied techniques identified by the review work. They are classified into 2; methods with tools, which simply refer to the methods that employ software or hardware in the evaluation process, and methods without tools, which are the methods that did not employ software or hardware in the evaluation process. As shown in Fig. 11, the analysis techniques under analytical methods with tools include; Simulation (using MATLAB, NS3, NetLogo, PeerSIM, IFogSim, CloudSim, SIM-DMC, and Computer Simulation Experiments), prototype implementation (using either commercial mobile devices or embedded devices such as Single Board Computer, FPGA, and Microcontroller), Formal security Proof (Using ProVerif, and Scyther), Dataset (using both Synthetic and Real), Algorithmic proof (Game Theory), and Case-Study, whereas, Informal Security proof (using theories and proofs), and, Mathematical analysis, are classified under analysis without tools.

2) EVALUATION METRICS EMPLOYED BY THE TECHNIQUES (DATA ANALYSIS TO ANSWER RQ4)

This section will review the evaluation metrics used in evaluating the performance of the techniques, with the intention of answering RQ4. According to the review work, the techniques employed different performance metrics to determine the intended aim. Table 11 summarizes the metrics employed by the respective technique with the corresponding purpose of using the metrics.

3) CLASSIFICATION OF ATTACKS ON EDGE COMPUTING NETWORK (DATA ANALYSIS TO ANSWER RQ5)

The attackers’ aim on a network is to gain access and alter the vital information for fulfilling their needs or for selling purposes [105]. In this paper, edge computing network attacks are explored in an attempt to answer research question 5 (RQ5). Fig. 12 illustrates the taxonomy of edge computing.
| REFERENCE | DESCRIPTION | TECHNOLOGY | PERFORMANCE ANALYSIS METHOD | ADVANTAGES | LIMITATION/GAP |
|-----------|-------------|------------|-----------------------------|------------|---------------|
| [65]      | To overcome the possible attacks associated with untrusted or malicious edge node and edge data centers of edge computing, the authors proposed a trustworthy scheme that takes into consideration both edge caching and bandwidth allocation for mobile users. The objectives are to design a trust evaluation mechanism to determine the security of each edge node, and to employ the reverse auction game to find the optimal edge node. A trust evaluation mechanism was designed to authenticate each edge node, employing direct trust and indirect trust. A reverse auction game is employed to assist the user to select an optimal edge node for content caching. Lastly, Byzantine Equilibriums acquired from the game analysis is employed in coming up with an ideal plan for the edge node. | Game theory Algorithm | Simulation (Computer Simulation Experimentation) | Prevention of attack from untrusted edge nodes and improvement in the quality of mobile users experience | The scheme cannot prevent users’ privacy disclosure when their information is cached on the edge node. |
| [66]      | Concerning the challenge associated with secure information sharing and delivery among the different edge computing connected devices, the same author as above developed a reverse auction game to allow mobile users with optimal content caching of the edge node. A trust management method was designed to enable accountability evaluation of the selected edge node using direct trust evaluation. The objectives are to employ a reverse auction game for encouraging edge nodes to provide caching services, and to design a trust management. | Game theory Algorithm | Simulation (Computer Simulation Experimentation), and Algorithmic proof (Game Theory based) | The scheme provides a secure content delivery with less energy consumption. Also, delay and caching ratio were improved when compared with other similar schemes. | There is a need to consider the possibility of privacy disclosure by mobile users when their individual contents are cached on the edge nodes. |
| [67]      | Addressing authentication problem of the in-home therapy application of mobile edge computing, the authors considered securing an in-home therapy. The authors proposed an edge computing framework that enables secure and low latency diagnostic data sharing. A Blockchain-Tor-based distribution transaction was employed for security purposes. | Block-chain Algorithm | Use case, Prototype Implementation | Supporting a large number of physically challenged patients at a considerably low processing time and under the secure condition. | Need to propose ways of storing both the immutable hashes of the therapy metadata and the actual multimedia, in order to increase the level of authenticity. |
| [68]      | The objective of the study is to overcome the possible attacks associated with untrusted or malicious edge node and edge data centers of edge computing. The authors proposed a technique that focuses both on the identification of the edge node, and the secure identification of the edge node’s EDCs for load balancing and authentication of the EDC. | Load-Balancing Algorithm | Inferior security proof, Formal Proof (Symmetric Simulation (MATLAB)), and Prototype Implementation (Single board Computer) | Ensuring the authenticity of edge network interacting datacenters as well as balancing the load between them. | Lightweight security solutions need to be added to the proposed scheme for improving the security, efficiency, as well as load balancing performance and of edge datacenters. |
| [69]      | The authors considered the possible attacks by untrusted or malicious edge node and edge data centers of edge computing. They proposed an integrated trust model based on comprehensive trust and evaluated the trustworthiness of the edge node. They constructed a framework for ensuring identity trust, behavioural trust, and ability trust of edge nodes. The activities of these edge nodes were coordinated and controlled. | Other Method (Integrated Trust) | Simulation (Computer Simulation Experimentation) | With the proposed scheme, an efficient edge computing can be achieved based on comprehensive trust. | To achieve more efficient trust, a trust overlay network and global trust update method should be used instead of the trust measures and local trust update respectively. |
| [70]      | The authors proposed an authentication scheme that considers both service providers’ node and edge node. The objective of the study is to enable service providers’ node to access the reputation of each peer is accordingly bootstrapped. A method for enabling a service provider to access the reputations of each user node was also designed. | Other Method (Bit Torrent Protocol) | Simulation (PeerSim) | Improve trust and network security in edge layers when compared to other similar schemes. | The algorithm needs to be improved to fully cover other mobile-edge-cloud use-cases. • There is a need to automate the determination of security level for different applications. |
| [71]      | To establish trust among the connected devices in the edge computing environment, the authors have adopted the idea of the Global trust degree of devices and proposed a lightweight trust mechanism based on multi-source feedback information fusion. The scheme is reliable against bad-mouthing attacks generated from feedback providers. The objectives of the studies are to adopt a lightweight trust evaluation mechanism suitable for edge computing paradigm and to adopt a feedback information fusion algorithms based on objective information entropy theory which overcomes the limitations of the traditional trust scheme. | Other Method (Multisource feedback information fusion, information entropy algorithm, objective information entropy) | Simulation (Net-Logo) | Improve in computational efficiency and reliability when compared to existing approaches. | Trust management should be incorporated and improve into the proposed scheme to encourage cooperation between edge computing devices. |
| [72]      | To propose a trust management framework that can evaluate trust for application and computing resources, and to apply the proposed trust management framework, the authors applied a derived trust management framework based on measurement theory, with trustworthiness and confidence as metrics. Traffic flows are used to obtain a device-to-device trust. For the trust value of tasks involved, they are configured to use the network element appropriately. However, when evaluating tasks’ trustworthiness, both devices and flows were considered. | Other Method (Trust Management System (TMS)) | Mathematical Analysis | Configuration of resources based on real-time trust information, ensuring both trustworthiness and confidence. | There is a need for security enhancement through the use of a better security algorithm, e.g. Lightweight security algorithm. |
| [73]      | The objective of the scheme is to secure information sharing among the connected communication devices in a smart grid environment and to develop a secret key agreement protocol for the Smart Grid infrastructure. The authors developed an identity-based signature as a key agreement protocol that allows smart meters to be connected to a utility control in order to collect the services they provided. The smart meters used the private key to connect the utility control in the absence of trusted authority. | Other Method (An identity-based signature, random oracle model) | Mathematical analysis, and formal security proof (ProVerif) | • The proposed scheme offered authentication and also smart meter unrecognition ability • It reduces communication overhead and delays by eliminating the role of a trusted authority. | There is a need to propose ways of reducing the computation cost. |
| REFERENCE | DESCRIPTION | TECHNOLOGY | PERFORMANCE ANALYSIS | ADVANTAGES | LIMITATION/GAP |
|-----------|-------------|------------|----------------------|------------|----------------|
| [74]      | A cooperative defense framework against distributed denial of service attack (DDoS) for mobile edge computing is proposed by the authors. The scheme leveraged the network function and software-defined networking algorithms. The objectives are to design a framework on a cooperative defense framework against denial of service attacks, to design an appropriate utility by considering the resource usage efficiency, and to propose an online algorithm that has a performance guarantee. The edge nodes with less defense capability are supported by self-defense edge nodes. A multi-request as well as multi-provider resource management issue was developed to balance between complexity and proposed scheme performance. | SDN Architectural Framework | Simulation (NS2) | The first scheme to explore cooperative defense against denial of service attacks in mobile edge computing. | More key techniques for detecting denial of service attacks need to be incorporated. |
| [75]      | In an effort to detect the attacks that hinder the offloading mechanisms in edge computing applications, the authors studied an online security-aware edge computing under jamming attacks. The objectives of the studies are to develop an approach that will tackle security problems of edge computing based on SDN framework and to develop a SAVES algorithm modified form of stochastic jamming, for selecting the most convenient server with minimum security concern for offloading of computational tasks. | MAB Architectural Framework | Prototype Implementation, Real Dataset, and Synthetic Dataset | • Avoiding of jamming attacks by selecting a reliable server for offloading of the computing tasks associated with minimal security concern without utilizing extra resources. | The scheme needs to be improved to detect other attacks not only jamming attacks. |
| [76]      | The objectives of the scheme are to focus on the detection of attacks of offloading in edge computing and to propose a secure vehicular edge computing network that will optimize the efficiency of task offloading in an attempt to prevent the network attacks from obstructing offloading operations. The authors devised a secure vehicular edge computing, a framework based on a behavioral game. Malicious edge nodes tend to disturb the offloading process by introducing attacks to the system. To prevent the execution of the attacks, they developed cooperative and noncooperative games. The vehicles, cyber defenders, and distributed security agent cooperate and ensure secure offloading, whereas the attackers undertake cooperative approaches to introduce an attack by tricking the communication between authenticated nodes. | Game Theory, Algorithm | Simulation (NS2) | Enhancing the detection and classification rate of malicious edge node, as well as optimizing the end-to-end delay of offloading tasks. | Smart and collaborative attacks of offloading operation need to be investigated. |
| [77]      | The study aims at detecting attacks in the edge computing environment resulted due to the vulnerability, open features and distributed nature of the computing paradigm. The authors proposed a scheme based on attribute attack graph. The attack graph was developed with the use of a security alarm association and a false alarm determination network. A formal correlation analysis is performed on the contributing relation of the alarm information. A minimum dominant set solution of the attribute attack graph was generated by transferring linkage defense strategy decision computing. A set of attack linkage disposal decision-making technologies is then constructed from the designed linkage disposal strategy execution point decision algorithm based on a greedy algorithm. | Greedy algorithm | Prototype Implementation, and Real Dataset | The proposed scheme provides a timely and effective defense against attack | There is a need to automate the determination of the security level for different applications. |
| [78]      | Considering the above similar challenges, the authors proposed a spoofing detection mechanism based on multiple channel attributes, with the aim of considering multiple channel attributes. The clustering algorithm is further deployed to enhance detection and to reduce technique complexity. | Clustering Algorithm | Simulation (MATLAB) | • Provision of optimal performance with significantly lower complexity | More experiments other than simulation needs to be carried out to evaluate the performance of the scheme. |
| [79]      | To propose a distributed detection scheme, the authors developed an attack detection system by employing extreme Machine Learning (EML). The EM uses EPC cluster resources of the cloud on any task that is characterized by time-consuming and high computation. | Machine Learning | Synthetic Dataset | • Achieved an efficient computation and analysis of the collected data in an edge computing network. | Edge nodes located far from the data source needs to be protected, apart from those very close. |
| [80]      | An attempt was made by the authors to isolate a malicious edge node in edge computing. The objectives of the scheme are to propose a detection technique for DDoS communication, to design classical honeypots to isolate attacks and to propose attack detection and tracking algorithms. Considering an environment in which a set of mobile devices perform the task of computational offloading, they proposed a detection framework for Device to Device (D2D) communication, called HoneyBot. The tracking mechanism that handles insecure D2D infected communication channel was developed to track and isolate any malicious nodes. | Other Method (D2D Communication) | Prototype Implementation, and Real Dataset | • Performance evaluation is conducted in a real university network and proved to be helpful in detecting attacks of malicious node. | Insider attacks need to be tracked and detected; hence a reliable tracking and detection mechanism needs to be employed. |
| [81]      | The scheme is proposed with the objectives of exploring the limitations of current mobile malware detection techniques, to investigate the different feature extraction and detection techniques, and to develop mobile malware detection techniques based on permission feature. The authors proposed a scheme that detects mobile malware which adapts to avoid detection. Behavioral analysis was developed to determine statistical analysis, dynamic analysis, and a decision on when and how to determine the application logic behavior is yet to be executed. | Other Method (Hybrid feature analysis) | Real Dataset, and Prototype Implementation | The technique outperforms other mobile malware detection techniques. | The detection engine needs to be improved to ensure zero-day protection in detecting both known and unknown malware. |
| [82]      | The authors proposed a scheme to detect spoofing attacks on GPS signals at the edge, and also reconstructed the attacked signal, with the objective of developing a validation mechanism for detecting GPS spoofing attacks on vehicles. The GPS signals at the edge node are collected and compared with the signal received from the satellite. Any difference with the GPS signal, reveal spoofing attack has occurred. | Other Method (GPS) | Real Dataset | • Low cost, sufficient, and accurate in detecting all simulated GPS spoofing attacks. | There is a need to improve the scheme for detecting other attacks other than GPS spoofing attacks. |
| [83]      | The authors proposed an approach named PANGUARD, for detecting a third-party library. The objectives of the scheme are to novel a combination of features in applications so as to characterize third-party library, to adopt Set Analysis in order to optimize third-party library detection and to implement the proposed technique and apply it in an industrial edge computing scenario. A combination of features containing both structural and content information is used to characterize third-party libraries. A set analysis that speeds up the detection are adopted. | Other Method (ANDROIDS) | Real Data Set, and Prototype Implementation | • High accuracy and scalability in detecting third-party library for Android Applications. | There is a need to search for the optimal value of the child node which is not covered in the proposed technique. |
network attacks. The categories of the attacks with the corresponding existing counterpart measures with respect to edge computing infrastructures are given in the following sections.

### C. MESSAGE ALTERATION ATTACK

In this type of attack, the eavesdropper manipulates the messages used by the legitimate edge computing entities. Attacks under message alteration category include:

1) **INFERENCE ATTACK**

The adversary analyzes the data transferred by the genuine edge network communicating unit to gain knowledge about the entities. In [55], the authors extracted location obfuscation sub-issue to solve the problem of inference attack, and derive a modeled that represent a privacy game issue and solved it according to the obfuscated locations. In another attempt of eliminating the inference attack, authors in [67] proposed a Query-Quard framework that avoids potential private information leakage to the third-party by generating privacy-preserving query plans.

2) **COLLUSION ATTACK**

The malicious entity combines together two or more copies of information communicated by the trusted edge nodes to produce a completely new copy. Authors in [59] solved the problem of collusion attack by encrypting the communicated messages with symmetric AES cryptographic protocol. At each instance of the communication process, new AES keys are used for exchanging the messages. In [92], the authors deal with a collusion attack by incorporating a timestamp to the signed message used for authenticating the communication between the edge entities. Similarly, in [97] and [95], the authors use a timestamp to prevent the replay attack. In [90], a timestamp together with Shamir’s secret sharing algorithm is used to

3) **REPLAY ATTACK**

The third-party intercept the information sent by the genuine edge entity and transmit it to another legitimate edge entity as if it is from the original sender. A key agreement protocol is utilized by authors in [78] for solving the replay attack problem in smart grid edge computing infrastructure. A single private key is utilized by smart meters for obtaining services from the utility control center. In [92], the authors deal with a replay attack by incorporating a timestamp to the signed message used for authenticating the communication between the edge entities. Similarly, in [97] and [95], the authors use a timestamp to prevent the replay attack. In [90], a timestamp together with Shamir’s secret sharing algorithm is used in
TABLE 9. Summary of the techniques that considered more than two security/privacy requirements.

| REFERENCE | DESCRIPTION |
|-----------|-------------|
| [89]      | The authors proposed a security technique that considers privacy-preserving, authentication, and integrity requirements in a mobile computing network. Three participating devices in the mobile edge computing network that include: end-user devices, edge servers, and public cloud center were assumed by the authors to design a privacy-preserving data aggregation scheme for mobile edge computing. The data from the end-devices are encrypted before transferring to the edge server. The edge server then sums all the received encrypted data and transferred to the cloud server. The public cloud center then decrypts the data using its private key for further action. |
| [90]      | To design a lightweight privacy-preserving aggregation scheme that will balance between security/privacy requirements and online computational cost of an edge computing network, the authors proposed a lightweight scheme called LPDA-EC, which handles privacy-preservation, authentication, confidentiality, and integrity security requirements, as well as online computational cost in an edge computing network. The scheme employs online/offline signature techniques. It ensures data integrity under Diffie-Hellman assumptions. |
| [91]      | To propose a scheme that can maintain the tradeoff between good performance and security in edge computing network, the authors proposed a security model called M0O4cloud architectural model that extends the existing message-oriented middleware (MOM) of cloud security alliance (CSA). The aim of M0O4cloud is to incorporate more security requirements that include: confidentiality, integrity, authenticity, and nonrepudiation. |

4) CIPHER-TEXT ONLY ATTACK

The advisory used the number of encrypted messages to recover as many plaintexts as possible or even the secret key. Authors in [94] solve the problem of cipher-text-only attack by encrypting the data before sending it to the edge server. The edge server then aggregates and sends it to the public cloud center where it can be recovered using the cloud center’s private key.

5) EAVESDROPPING/SNIFFING/SNOOPING ATTACK

The malicious party steals the information communicated by the genuine edge computing entities. In an attempt to overcome the eavesdropping attack, authors in [59] encrypted the smartphone data with asymmetric AES algorithm prior to the communication stage. In [106], the authors ensure that the transmitted data after the realization of the connection between edge entities and edge server is first of all encrypted with a session key known to the communicating entities. Similarly, in [103], the authors prevent the snooping attack by employing an authentication service that authenticates the entity receiving the output data. Additionally, a confidentiality service is employed to encrypt the output data for protection against the snooping attack.

D. NETWORK DISRUPTION ATTACK

Here, the attacker develops a mechanism for counterfeiting network resources to access the communication between genuine entities. The various attacks under this category include:

1) DENIAL-OF-SERVICE ATTACK

The malicious entity makes network resources unavailable to the genuine entities by interrupting the normal activities of the entities. In an attempt to solve the problem, authors in [76] reduce the dependency of the edge communicating entities on a cloud datacenter, which consequently removes the single point of failure in the entire edge infrastructure. Similarly, authors in [93] eliminate the dependency on the centralized servers by employing scalable and distributed systems that use end-user devices as mini-edge servers. In another attempt, authors in [85] proposed a honeypot, a defense technique against denial of service attack. It is capable of detecting, tracking, and isolating attack. Authors in [79] proposed a cooperative framework against denial of service attack by utilizing network function visualization and SDN (Software Defined Network) architecture.

2) JAMMING ATTACK

The malicious entity blocks the communication between the edge devices and the edge server. In an attempt to solve the problem, authors in [80] proposed a novel SAVE-S algorithm.
TABLE 10. Summary of the techniques that did not consider any of the proposed requirements.

| RECOMMENDED | DESCRIPTION | TECHNOLOGY | PERFORMANCE ANALYSIS METHOD | ADVANTAGES | LIMITATIONS/GAP |
|-------------|-------------|------------|-----------------------------|------------|----------------|
| [93]        | The authors proposed a scheme that prevents attacks in edge-computing internet of vehicles (IoV). The scheme works based on generating dummy traffic delivery. To propose an attack prevention scheme in the network, the vehicles in the network are forced to send dummy packets up to the trusted and identified roadside units, with the intention of misleading the traffic statistics which aimed at protecting the hotspot roadside units. The incentive mechanism is designed using a Stackelberg game approach. | Game Theory | Informal Security Proof, and Mathematical Analysis | The scheme effectively secures the EC-IoT network against roadside unit hotspot attacks. | There is a need to include approaches that will protect the entire roadside units, not only the selected ones. |
| [94]        | The authors proposed a system that manages various security functions. Security proxy was incorporated to have a match with the network inherited security functions. A fuzzy interface system mechanism was deployed to develop a scheme that will manage the various real-time changing security functions in the mobile edge computing network. | Fuzzy Method | Prototype Implementation, and Mathematical Analysis | When compared to other similar techniques, there is an improvement in performance in terms of execution time and inverted Geographical Distance value. | There is a need to automate the determination of the security level for different applications. |
| [95]        | The aim of the study is to propose a security scheme that will eliminate the single point of failure problem associated with the traditional security solution of VANET. The authors proposed a block-chain based secure scheme for the vehicular ad-hoc network. The scheme employs three-layer architectures including perception, service, and edge computing layers. The perception layer ensures security for the data unencrypted through the block-chain paradigm. The service layer combines both the traditional cloud storage and block-chain for establishing data security. The edge computing layer, on the other hand, supplies computing resources and edge cloud services to the perception layer. | Block-chain | Did not evaluate their scheme | The scheme ensures that data are impermeable and recoverable through the use of block chain technology. | Performance evaluation of the scheme needs to be conducted to verify the effectiveness of the employed methods. |
| [96]        | A scheme that managed security, privacy, as well as the service quality of an integrated clinical environment was proposed by the authors. The scheme allows resource allocation management of the network to be done at the network edge. This resulted in low latency and very high quality of service. The technique deployed NSV and SIDN architectural framework to ensure high scalability, efficiency, and real-time communication of the integrated clinical environment. | SDN and NSV Architectural Framework | Simulation (Computer Simulation, Experiment(e) and Prototype Implementation) | The proposed scheme solves the problem of availability, scalability, efficiency, and communication management associated with a typical Integrated Clinical Environment. | The host network levels of the proposed architecture need to be implemented and validated effectively. |
| [97]        | To propose a security and deadline-aware scheduling policing scheme in an edge computing network, the authors proposed a scheme called RT-SANS (Real-Time Security-Aware Scheduling on the Network edge). Application with priority privacy requirements is sent to the edge data centers. To attain performance and security, a distributed architecture architecture and protocol is incorporated in the scheme. | Architectural Framework | Simulation (Evolution(s)) | The scheme ensures application privacy while achieving improved real-time performance. | More complex workflow need to be employed for the model. |
| [98]        | The aim of the study is to propose a secure and energy-efficient computation offloading scheme for service workflows in mobile edge computing. The authors presented a scheme that ensures security against attacks during the computation offloading process. A cryptographic security overhead model is designed to calculate the execution time of the security services, and then a computational offloading problem is formulated. | Cryptography | Simulation (Computer Simulation, Experiment(e)) | The scheme decreases the energy consumption of the mobile device and at the same time satisfying deadline and risk rate constraints. | We need to consider other security issues where workflow applications can be offloaded. |
| [99]        | To propose a reputation management scheme that will ensure security and improve the efficiency of the vehicular edge computing network, the authors proposed a reputation management scheme called DREAMS (Distributed Reputation Management System) for improving security and network efficiency of vehicular edge computing. The vehicular edge servers are used for storing local reputation management of tasks for the connected vehicles. A multi-weighted subjective logic is employed for updating the reputation in the system. | Other Method (Multi-weighted logic) | Simulation (Computer Simulation, Experiment(e), and Mathematical Analysis) | The scheme optimizes the behavior detection by recognizing the misbehaving vehicles. Existing methods, e.g., Kullback-Leibler Distance can be used to improve the proposed scheme. | |

3) BANDWIDTH ATTACK

The attacker transmits a large number of malicious packets to the edge network with the intention of overpowering its bandwidth. In [75], the bandwidth attack is dealt with using a trust and reputation-based approach. The edge nodes are enabled to guard against suspicious client nodes by monitoring and assessing their contribution to fellow client nodes.

4) FAKE-BLOCK ATTACK

The malicious entity sends fake files to respond to a download request from a legitimate edge node with the intention of wasting the download bandwidth involved.

5) SYBIL ATTACK

The attacker takes over a quite number of edge nodes in a network that lacks central management, which consequently hijacks the network. In an attempt to deal with the Sybil attack, authors in [75] employed the bootstrapping method to prevent attackers from joining the network. Similarly, in [93] the authors avoid threshold sharing with the requesting node and take a decision on a safe entity only.

E. CAMOUFLAGING ATTACK

In this type of attack, the adversary manipulates to penetrate the edge network as a genuine entity. Attacks under this category include:

1) IMPERSONATION ATTACK

The malicious party adopts the identity of the legitimate user to authenticate itself to the network. To deal with impersonation attacks, authors in [59] encrypted the payload data with AES symmetric key algorithm. Moreover, the end-to-end signaling protocol is also inspired and followed accordingly. In another attempt, authors in [73] employed the AES algorithm to authenticate the legitimate edge nodes. A cloud shared key is used to encrypt the initial authentication packet followed by individual associated keys of the edge nodes. In [92], a Carbon Copy (CC) signature which is an identity-based signature is employed by the legitimate edge nodes during the authentication process. Elliptic curve cryptography is employed, where both the public and private keys are calculated by the trust authority.

2) MAN-IN-THE-MIDDLE ATTACK

The attacker secretly manipulates the communication between two eligible parties who believed they are directly communicating with each other. In [90], the authors used a shared symmetric key to encrypt the critical instruction at the
end-user device and edge device communication site. Hence, the attacker cannot construct a valid cipher-text without the symmetric key. Whereas, at the edge device and control center communication site, a group public key signature is employed for authenticating the identities of the group entities as well as the critical instruction. Therefore, the attacker cannot convince the control center to accept the forged group public key. Similarly, in [106], the session key cannot be deduced by the attacker because both the secret master key of the registration authority and free shared key are kept secret.

In [45], a mutual trust mechanism is established in the edge network by employing lightweight encryption of the signal layer according to the access request sent by the wireless devices. Whereas, In [97], time stamps and encryptions algorithms are used to solve the man-in-the-middle attack.

3) ADDRESS RESOLUTION PROTOCOL (ARP) SPOOF ATTACK
In this type of attack, the malicious party links Media Access Control (MAC) address with the IP address of the legitimate edge devices, by sending false ARP messages across the edge network. Hence, the adversary camouflages with legitimate edge devices and harm the entire system. In [107], an ARP prefix processor, which is a form of SNORT intrusion detection system is designed to solve the problem of the ARP spoof attack. It generates alert whenever an ARP spoof attack is suspected.

F. PHYSICAL ATTACK
The adversary steals the physical components of the edge computing network and injects malicious data with the intention of harming the legitimate entities or the entire network. The type of attacks under this category include:

1) SIDE-CHANNEL ATTACK
The third-party compromised the functionality of a given cryptosystem by exploiting the physical edge computing devices. Authors in [53] prevented the employed AES cryptographic algorithm against the side-channel attack by random masking and shuffling of the S-BOXES. An attack detection technique based on distributed extreme machine learning technology is employed in [84] to eliminate the side-channel attack on the used cryptosystem.

2) SPOOFING ATTACK
The attacker impersonates the physical devices of the legitimate users to propagate malicious effect, steal data, or interfere with edge network access control. In an attempt to solve a spoofing attack, Yoon in [108] ensures that each participating sensor device transmits their data to a legitimate edge node in

**FIGURE 11.** The classification of the performance analysis methods.
3) KEY-STEALING ATTACK
The intruder snatches the keys of the legitimate edge users to intrude on their communication. In [92], the authors proposed a means of eliminating the key-stealing attack by ensuring that the trust agent issues the keys to the legitimate edge users through a secure channel. Also, the group signing keys and the corresponding identities of the users, together with the shared key is encrypted by the roadside unit. Finally, the unit stores the private keys and shared keys in temper prove device.

4) ZERO-DAY ATTACK
The adversary utilizes the advantage of the weaknesses that exist in the physical resources of an edge network before they are discovered by the party responsible for the mitigation exercise. In [108], the authors used an artificial neural network to solve the zero-day attack problems. The tolerance and trigger areas constructed at a training stage are dedicated to ensuring the trustworthiness of the sensors.

G. REPUTATION TARNISHING ATTACK
The intruder frame-up negative feedback or dishonest recommendations for genuine entities with the aim of ruining their reputation. Attacks under this category include:

1) BAD-MOUTHING ATTACK
The attacker provides dishonest feedback to frame-up genuine edge users. In an attempt to deal with the bad-mouthing attack, authors in [109] developed a lightweight trust mechanism based on multsource feedback information fusion. The same authors in [76] incorporated objective information entropy theory-based feedback information fusion algorithm to solve the problems associated with the traditional trust schemes.

the Java-Script Object Notation (JSON) format. The wireless sensor networks (WSNs) are requested to send the JSON data about their neighboring sensors. These are used to check the integrity of the data from the dynamically moving sensors. In another attempt to eliminate spoofing attack, authors in [87] devised a means of collecting information at the edge nodes and use it to cross-check the validity of the GPS signals received from the satellite. If the received signal is not genuine, the original GPS signal is reconstructed back. In [83], a spoofing detecting technique is devised using an improved heuristic clustering algorithm. The edge server is made to report its real-time security condition to the cloud server for immediate countermeasures from any spoofing attack.

FIGURE 12. The taxonomy of the attacks affecting edge computing network.
2) INSIDER ATTACK
In this type of attack, the adversary has authorized network access. By being a genuine entity of the edge network. Therefore, the adversary utilizes this advantage and harm other legitimate edge network entities. Authors in [85] proposed a honey-Bot mechanism that acts as a defense against edge network insider attack. The technique is capable of detecting, tracking, and isolating the malicious edge nodes that can cause an insider attack.

VI. DISCUSSION
Although the previous review studies have laid a noticeable foundation that helps in understanding the security and privacy issues in edge computing, however, many of the reviews have the limitation of not providing a thorough investigation of the security/privacy requirements. Additionally, the techniques for ensuring the requirements with the employed technological methods were also not fully explored. This review work adopted a systematic procedure that helps in providing a proper understanding of security and privacy in the edge computing environment.

Six research questions (RQ1 to RQ6) were formulated and thoroughly answered to achieve the targeted aim. With regard to RQ1, eight main security and privacy requirements were identified from the reviewed studies. Similarly, it can be observed from the outcomes of RQ2 that, out of the reviewed studies, 16 techniques were proposed under the Privacy-Preserving requirement, which is the highest number, when compared with the remaining requirements. This shows that a lot of research interest is given to this requirement. The next requirement that received interest is Attack Detection, with 10 proposed techniques, followed by Authenticity with nine, Confidentiality with four. Only one technique considered the Availability requirement. Therefore, future researchers should consider this requirement. Six proposed techniques considered a combination of two different requirements. Moreover, four techniques considered a combination of more than two requirements. Fig. 13 illustrates the distribution of the techniques with respect to the requirements considered.

According to the review work, it can be observed that there is no technique that considers Integrity, Nonrepudiation, and Reliability requirements separately, except together with other requirements. This indicates that these requirements were not given much interest. Hence, future research should also concentrate on these requirements.

Besides, regarding RQ3, the identified techniques were further classified according to the employed technological methods. It can be seen that Paillier’s Homomorphic Encryption, AES Cryptographic Algorithm, ABE Policy-Hidden, and Reverse Auction Game are the most commonly employed technologies. Also, with regards to the employed performance analysis methods, the dataset is most frequent when considering the analysis with tools. 11 studies employed a real dataset, whereas 4 studies employed synthetic datasets. The computer simulation experiment is the second most frequently used method. The most frequent simulation tool was NS3. In terms of the prototype implementation, an embedded device (Single Board Computer) is the most frequently employed device. The most frequent formal security analysis tool is Proverif, whereas the Scyther tool is employed by only one study. On the other hand, Informal security analysis is the most frequent method when considering methods without tools.

The performance metrics employed in evaluating the effectiveness of the techniques were explored as specified by RQ4. It can be observed that the techniques under each class of requirement employed specific metrics in evaluating their performance, which verifies the intended aim. The purpose of evaluating the techniques with a particular metric is highlighted in Table 11. This will help future researchers in knowing the purpose of employing each metric under certain techniques.

With regard to the research question 5 (Q5), that emphasizes on the categories of attacks in an edge computing network, a taxonomy of the attacks is given in Fig. 12. Additionally, the trends of the technologies employed in curbing the attacks are also highlighted. Lastly, with regard to RQ6 that focuses on the research opportunities for future researchers working in the area of security and privacy in edge computing, the limitations of each technique are given in Table 4 to Table 10. This will help future researchers working in this area with forthcoming research gaps.

A. THREATS TO VALIDITY
The study focused on conducting the review work as well as possible. However, some factors encountered may change...
TABLE 11. The summary of evaluation metrics employed by the techniques.

| REFERENCE | REQUIREMENT UNDER CONSIDERATION | PURPOSE FOR THE EVALUATION | EVALUATION METRICS |
|-----------|----------------------------------|----------------------------|--------------------|
| [58], [59], [61] | Location Privacy-Preserving | To minimize detection or tracking of the user by the eavesdropper, and to achieve fine-grain security property | Tracking Accuracy |
| [60] | Location Privacy-Preserving | To minimize the energy usage of mobile devices | Energy Consumption |
| [56], [57] | Location Privacy-Preserving | Protecting mobile user’s network privacy with reasonable effect on the communication performance | Performance Overhead |
| [56] | Location Privacy-Preserving | Protecting mobile user’s network privacy with reduced operational cost | Operation Cost |
| [49], [60], [62] | Location and Data Privacy-Preserving | To lower data transfer with reasonable privacy protection | Execution Time |
| [54], [68] | Location Privacy-Preserving, Authenticity based Load Balancing | To ensure proper handshaking between end-devices and edge nodes | Response Time |
| [61] | Location Privacy-Preserving | To utilize edge nodes in providing real-time services | Service Quality |
| [50], [51], [53] | Location and Data Privacy-Preserving | Ensuring privacy protection that will prevent the third-party from accessing user’s data, thus achieving fine-grain security property | Privacy protection Level |
| [49] | Data Privacy-Preserving | To determine the amount of information an intruder will obtain after an attack in the edge network, and to achieve fine-grain security property | Mutual Information |
| [50] | Data Privacy-Preserving | To ensure privacy in an edge network where the precise location of users is required for task allocation | Task Acceptance Rate |
| [45], [46], [48] | Confidentiality | To reduce the overall time required by data user in edge computing to decrypt the cipher-text | Computation Time |
| [46], [73] | Confidentiality, Authenticity | To evaluate the lightweight property | Communication Cost |
| [46], [73] | Confidentiality, Authenticity | To evaluate the lightweight property | Computation Cost |
| [47] | Confidentiality | To evaluate the level of imperceptibility and distortion of watermarked images | Peak Signal to Noise Ratio/Structural Similarity |
| [48], [71] | Authenticity | To improve the collision attack on block ciphers | Success Rate |
| [71] | Authenticity, and Reliability | To evaluate the reliability of the most computing devices | Global Convergence Time |
| [45], [46], [66] | Authenticity | To evaluate the average reduced reposition delay of the content of genuine edge nodes, compared to require contents from distant content servers | Task Failure Ratio |
| [69] | Authenticity | To evaluate the users’ behavior in the edge network | Average Saved Time |
| [67] | Authenticity | To evaluate the overall total delay in the dynamic computing system | Dynamic Adaptability |
| [79], [81] | Attack Detection | To evaluate the probability of identifying non-malicious devices accurately | Mean Processing Time |
| [79], [81] | Attack Detection | To evaluate the probability of identifying malicious devices accurately | True Positive Rate |
| [79], [81] | Attack Detection | To evaluate the probability of identifying non-malicious devices wrongly | False Negative Rate |
| [79], [81] | Attack Detection | To evaluate the probability of identifying malicious devices wrongly | True Negative Rate |
| [79], [81] | Attack Detection | To evaluate the number of correct results with respect to all the returned results | Precision |
| [79], [81] | Attack Detection | To evaluate the harmonic mean of Precision and Recall | Recall |
| [79], [81] | Attack Detection | To evaluate the percentage of accurately identified devices | F-Measure |
| [80], [81] | Attack Detection | To evaluate error occurrence in detecting attacks in an edge network | Accuracy |
| [79] | Attack Detection | To evaluate the correlation between values that express a good level of agreement between prediction and observation | Error Rate |
| [76] | Attack Detection | To evaluate the mean-time taken by data to reach a targeted destination | Matthew’s Correlation |
| [77] | Attack Detection | To evaluate the defense effectiveness of a typical attack linkages disposal strategy | End-to-End Delay |
| [77] | Attack Detection | To evaluate the effectiveness of the generated attacks | Intrusion Success Probability |
| [80] | Attack Detection | To evaluate the effectiveness of the generated attacks | Intrusion Time |
| [81] | Attack Detection | To evaluate the total number of messages introduced to the edge network from beginning till when the suspected node is identified | Text Overhead |

The conclusion drawn, which may affect the quality of the findings. Below are some of the factors:

1) The data acquisition process is subjected to a biased opinion because only one author searched for the primary study articles.

2) Only four electronic databases were explored for collecting applicable data. Thus, relevant studies from other databases may not be included. This limited the scope of the review work.

3) Only journal articles and conference proceedings were included, whereas some other studies that may help
with additional information, such as patents, magazines, and symposium, were excluded.

VII. OPEN RESEARCH ISSUES
In this section, the research open issues in the field of security and privacy of edge computing paradigm will be given. The aim is to provide opportunities for future researchers willing to contribute to this area. The major open issues include:

A. LIGHTWEIGHT SECURITY FEATURES
Lightweight security is required in the edge computing network because of the minimum resource and storage characterized by the edge devices. The conventional cryptographic protocols are characterized with very high computation and communication costs [110], [111], due to the large key size employed. Therefore, such protocols cannot be applied directly to the edge network. As such, lightweight cryptographic protocols with smaller encryption keys that require fewer memory and CPU resources are preferred in edge computing. Lightweight security does not maintain the tradeoff between efficiency and security/privacy, as considered by most of the reviewed techniques. For lightweight security, efficiency is not as important as security/privacy.

It can be observed that most of the techniques under Confidentiality and Authenticity are not lightweight, that was the reason why they did not evaluate the techniques using the lightweight evaluation metrics (i.e. computation and communication costs). Only four techniques [50], [51], [53], and [78] employed the lightweight metrics. Hence, future research on security and privacy in edge computing should focus on lightweight security, for example, Elliptic Curve Cryptography, Permutation Based Lightweight Cryptography, Block-Ciphers Lightweight Cryptography, etc.

B. FINE-GRAIN SECURITY FEATURES
To attain fine-grain security features, a dynamic auto-update function needs to be incorporated into the privacy-preserving mechanisms, as well as an efficient data-sharing mechanism, due to the huge amount of data produced at the edge of the network by end-devices. The most commonly fine grain security evaluation metrics as depicted in Table 11 are Tracking Accuracy, and Privacy protection level, which were employed by only five techniques [55], [63], [64], [66], [68]. Therefore, future research should consider fine-grain features when proposing Privacy-Preserving techniques.

C. PRIOR INVESTIGATION OF ATTACKS
In most of the reviewed studies, attacks were not fully investigated and dealt with sufficiently prior to the design process of the techniques, especially the authentication and privacy-preserving schemes. These attacks are very dangerous to the privacy of the interacting edge devices, which may lead to revealing devices’ secret information.

D. MORE WORK IS REQUIRED UNDER CERTAIN SECURITY/PRIVACY REQUIREMENTS
As stated earlier, some of the security and privacy requirements are either not having techniques that consider them separately, or not having at all. For example, from the findings, the Availability requirement is having only 1 technique under it, whereas Reliability, Nonrepudiation, and Integrity requirements are not considered by any technique, except in combination with other requirements. Due to the importance of these requirements, future researchers should concentrate on devising techniques that will consider them.

E. SECURE TWO-WAY COMMUNICATION
The establishment of secure two-way communication in the edge network is relatively difficult compared to the cloud network with ready-made security mechanisms. Therefore, to achieve secure two-way communication in an edge computing network, lightweight key exchange algorithms that suite edge computing should be designed in the future.

F. PROPER UTILIZATION OF INTRUSION DETECTION MECHANISMS
Intrusion Detection Systems (IDS) are employed for detecting and mitigating of the various attacks in a network. However, in an edge computing environment, the IDS need to be applied to the various layers of the edge network (Edge nodes, end-users, and, cloud). Applying IDS to only one or two layers may not guarantee that attacks from the malicious party will not propagate to the entire edge network.

G. UTILIZATION OF PROGRAM (SOFTWARE) ANALYTICAL TOOLS
The security and privacy issues in edge computing network are diverse. Consequently, utilization of software-based security and privacy analysis will help in quick and efficient identification of such issues. The scope of these software analysis in edge computing is still an open issue for future research.

VIII. CONCLUSION
Edge computing is a promising paradigm aimed at eliminating almost all the drawbacks associated with cloud computing. Security and privacy issues are among the significant challenges affecting its acceptance. As such, studying ways of mitigating the problems is of paramount importance. Findings show that the devised systematic literature review is the first of its kind in edge computing security and privacy perspectives. It aimed at providing a comprehensive and reflective understanding of the security and privacy requirements, the state of the art techniques for ensuring the requirements, as well as the technological methods employed by the techniques. With this in mind, a total of 78 articles were thoroughly studied, in line with the standard SLR procedures. After a thorough analysis of the extracted data, the findings
reveal essential results. Firstly, the taxonomy of security and privacy requirements was derived. The study found that there are eight classes of requirements as far as edge computing security and privacy is concerned. Secondly, the study discovered that each requirement has its specific techniques designed mainly for it, except integrity, nonrepudiation, and reliability which were considered together with other requirements in four different identified schemes. Thirdly, the findings classified the identified techniques under their corresponding technological methods employed with the aim of identifying the trend. Fourthly, the review work has identified limitation of each of the techniques which lead to research opportunities for future researchers to concentrate on. Moreover, the attacks affecting the edge computing network have been thoroughly explored. The taxonomy of the attacks as well as the employed technological methods for their elimination have been revealed. Moreover, it was observed that each category of the techniques under a particular requirement has specific metrics used for evaluating its performance for ensuring certain aim. Lastly, future research open issues were included for the benefit of researchers willing to work in the area of edge computing security and privacy.

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