Threats and Corrective Measures for IoT Security with Observance to Cybercrime

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ABSTRACT Internet of Things (IoT) is the utmost assuring framework to facilitate human life with quality and comfort. IoT has contributed significantly in numerous application areas. The stormy expansion of smart devices and their credence for data transfer on wireless mechanics boosts their susceptibility to cyber-attacks. Consequently, the rate of cybercrimes is increasing day by day. Hence, the study of IoT security threats and possible corrective measures can benefit the researchers to identify appropriate solutions to deal with various challenges in cybercrime investigation. IoT forensics plays a vital role in cybercrime investigation. This review paper presents an overview of the IoT framework consisting of IoT architecture, protocols, and technologies. Various security issues at each layer and corrective measures are also discussed in detail. This paper also presents the role of IoT forensics in cybercrime investigation in various domains like smart homes, smart cities, automated vehicles, healthcare, etc. Along with the role of advanced technologies like Artificial Intelligence, Machine Learning, Cloud computing, Edge computing, Fog computing, and Blockchain technology in cybercrime investigation are also discussed. At last, the various open research challenges in the area of IoT to assist cybercrime investigation are explained, which provide a new direction to the researchers to work further.

INDEX TERMS Cybercrime, Cybersecurity, Digital Forensics, Internet of Things (IoT), Protocols, Smart Devices, Security Threats, Technologies.

I. INTRODUCTION

The word ‘Internet of Things’ (IoT) was composed by Kevin Aston in the year 1999. Since then, this domain of computer science has matured at a very fast pace [1, 2]. It consists of a network of smart devices with the potential to process and communicate data to facilitate users with numerous services and applications [3, 4, and 5]. It is not a single technology but a strong merger of 5G, Big Data, Artificial Intelligence, Edge Computing, and Cloud Computing [6], as shown in Figure 1.

Figure 1. A conflux of IoT [1]
In a short period, the IoT has confiscated a wide range of objects to provide more lifestyle-friendly digitized services[7]. At present, many IoT applications, shown in Figure 2 have a straight effect on our routine life e.g. smart cameras, wearables, smart homes, smart supply chains, health care, smart agriculture, etc.

In the era of the internet, there is a sharp hike in the statistics of security attacks and cybercrimes. The Internet Crime Complaint Center (IC3) primarily came into existence intending to control cybercrime across the world. In the report published by IC3 in the year 2019, it disclosed the data of the last five years of crimes along with losses shown in Table 1. As depicted in the table, since the year 2015 to 2019 a total 1,707,618 complaints have been received. It has been also analyzed that during these 5 years, a total loss of $10.2 billion has occurred. As per the facts published by IC3, India is 3rd in the list of top 20 crime victim countries [8].

Table 1. Data on crime complaints and financial loss from 2015 to 2019 [9]

| Year | Number of complaints Registered | Total Loss ( In $Billion) |
|------|---------------------------------|--------------------------|
| 2015 | 288012                          | 1.1                      |
| 2016 | 298728                          | 1.5                      |
| 2017 | 301580                          | 1.4                      |
| 2018 | 351937                          | 2.7                      |
| 2019 | 467361                          | 3.5                      |

Because of the numerous applications of the internet, without the implementation of suitable cybersecurity mechanisms, security threats are creating a huge torment for the versatile IoT systems. Data from main academic databases have been collected to study the scope of potential research in the domain of cybersecurity [9], shown in Figure 3.

Figure 3. Number of articles published on cybersecurity from 2013 to 2019 [9]

As the trend if IoT-enabled devices are flourishing expeditiously, it is actualizing opportunities and obstacles for the inquiry of various types of physical and cybercrimes [10]. Although IoT has been proven a benediction, it has many security issues. To provide a solution to these security issues is the biggest challenge for the IoT
manufacturers for the lucrative stationing of IoT devices and applications. IoT systems initiate extra space for cybercrimes to raid different services because of indigent security measures. Because of poor security measures implemented in IoT devices, the IoT system creates more opportunities for cybercriminals to attack various applications and services of the IoT system resulting in a direct impact on users. With the adoption of IoT technology, cybercrimes can threaten human life to an unbelievable extent. At the same time, shreds of evidence available on the various smart devices in an IoT environment can aid the process of crime investigation. So, by considering the need for the hour and to control IoT crime, in this paper we discuss IoT architecture, security system, and potential IoT security threats which may cause cybercrimes to occur. Along with, IoT forensics and its contribution to crime investigation are also discussed in detail.

Network attacks are malignant actions planned to damage significant data and information and to disturb important services [11]. These attacks are executed using data streaming to hazard secrecy of data available on a network of machines [12]. Consequently, the issue of security of information available on the networks is very compelling in this era. Information security can be characterized as the preservation of secrecy, virtue, and availability of information. Secrecy aids to provide the information only to authorized users. Virtue or integrity deals with the correctness and completeness of the information. Availability of information means only authorized users can access it again on request. Along with, there are few other characteristics like reliability, authenticity, etc. can also be considered. Moreover, the IoT paradigm shift has caused the daily life objects to be transformed into smart gadgets with the potential to communicate with the environment.

This revolutionary transformation is the area of interest of every researcher nowadays to facilitate the people with better quality services at a reduced cost [10]. The IoT system may consist of a huge number of different types of devices. These devices are equipped with sensors that initiate data in return of action or continuously. This data can be used as a potential source of witness only if investigators are capable to administer the heterogeneity of devices and protocols along with the volume of data in IoT systems. So, the expanding IoT is expeditiously generating opportunities, and challenges for crime investigators; maybe a physical charge or a cyber attack. As in this review paper, our main focus is on cyber attacks in the IoT environment; secrecy and security of the data are also the major concerns in this situation.

A. RISKS IN IoT

The IoT evolution is prone to cause a diversity of ethical problems in the society like unauthorized access to confidential information, privacy breach, misuse of secret data, identity theft, etc. although these problems were already existing in the era of the internet and Information and Communication Technology (ICT) but became more dominant in IoT systems [13]. Figure 4 describes the potential risks in IoT.

1) PRIVACY FACET

Confidentiality of the users and secrecy of the data generated from numerous business processes is the major areas of concern linked to the IoT. The dominant usage of versatile devices with poor security mechanisms lead to mismanagement of the IoT system [14]. To handle the security issues related to data generated by the IoT devices, there is a requirement of advanced cryptography techniques. But these techniques should be energy-optimized and able to

![Figure 4. Risks in IoT [13, 15]](image)
synchronize in with the dynamism of the smart devices [16]. With the advancement in IoT, many problems evolved [13], [17].

**Availability of Services.** The blend of IoT in the services related to our health, security, etc. has emerged the continuous availability of these services a critical issue. Many people are heavily dependent on the IoT devices utilized to provide these services. Therefore, any loss of these services will severely impact the human life.

**Data Sensitivity:** Several applications collect user’s personal information, sometimes even without the knowledge of the user. So, the sensitivity of the data is a major area of concern. The major risks associated with this data are the frame of reference of usage of this data. Consequently, there should be some security protocols for context-aware data collection and usage [18].

**Security of User Data.** The data must be secured from illegitimate usage on the devices as well as during transmission in the IoT environment. The diversity of the IoT devices and different communication modes implement a challenge for data security protocols which is the root cause of security breaches [19]. Another major threat to data security is, a variety of applications are using this data to cause personal information of the user exposed to cyber-attacks.

**Data Ownership and Management.** Ownership of the collected user data is a major unaddressed issue in IoT along with data management. Once the user stops using the service, the personal information remains with the service provider and can be sold further to generate revenue.

**Data Captivity.** A few moralistic questions related to the user data remain unanswered such as generating unlawful leverage, hard competition, etc. These issues are essential to evade consumer captivity through data.

**Regulation.** Because of the versatility of devices and collaborators convoluted in the stationing of IoT, the biggest challenge is the applicability of law and regulations. As the IoT, systems are evolving day by day and becoming global, so there is a clear possibility of the applicability of multiple legislations. Besides, this is an important area for awareness among users, IoT manufacturers, and law builders.

**Information Availability.** It should be the sole responsibility of the service provider to make the information accessible to the user in the required and easily understood format.

**Traceability.** In an IoT environment, users must have the right to pass consent or refuse to provide personal information to numerous real-life services. The implemented security protocols and mechanisms should ensure user identification on the network, but restrict the user traceability to the attackers from the personal information [20], [21].

2) SECURITY FACET

The security of a computer system encompasses various methods and techniques that safeguard all kinds of resources from illegitimate access. Resources may include hardware, software, and data, whereas illegitimate access may include unauthorized usage or damage to the resources. In IoT systems security aspects focus on architecture, the security model of every device, bootstrapping, network security, and application security [22]. Security architecture demonstrates the various system components liable to ensure the security of an IoT device. The security model of each device focuses on the implementation of security methods and criteria along with the management of various applications. Network security deals with the reliable functioning of IoT. On the line, application security is all about the authentication of things in the network for communication and exchange of data. Network security is highly dependent on the internet, which is an anxious media of data exchange and leads to a huge possibility of data-stealing. The deployment of IoT is planted on the internet and computer networks. Consequently, it is affected by all security issues related to computer networks as well as the internet. Before using IoT devices, all the stakeholders should analyze the associated risks related to the security and privacy of the user information. Accordingly, more sophisticated security policies must be designed by governing organizations.

**B. CYBERCRIME**

Similar to any other crime, a cybercrime may have a variety of aspects and may be committed in different plots. Several definitions of cybercrime are available, given from different aspects i.e. sufferer, protector, or viewer. According to a definition given by Newman [23], cybercrime is an action in which computers or computer networks are used as a means, purpose, or platform to execute some criminal act. It may consist of some information theft or to use the computers to do some other criminal activity. The Council of Europe’s Cybercrime Treaty defines cybercrime as any act against data, content, or copyright transgression. The ‘Manual on the Prevention and Control of Computer-Related Crime’ by the United Nations defines cybercrime as illegitimate access, deceit, and falsification. According to Gordon and Ford, cybercrime is any criminal activity
performed with a computer, hardware resources, or networks. The Council of Europe’s Convention on Cybercrime classifies the criminal acts into four classes: 1) Breach against data secrecy, integrity, and hardware resources 2) Computer centered crimes 3) Content-related crimes; and 4) copyright-related crimes. But these classifications over the line for some parameters. According to another classification given by Saini et al. [24], cybercrimes are categorized as data crimes, network crimes, access crimes, and content related crimes. Data crimes consist of data-stealing, data interception, and data modification. Network crimes include unwanted interference in the functioning of computer networks to breach data transmitted over the network. Content related crimes include infringement of ownership spontaneous cyber hazards. Another explanation of cybercrimes is demonstrated by Zhang et al. [25], according to which all the crimes in which machines or networks are used as aids or targeted in the criminal act, networks are used as a place of crime, and any conventional crime executed with computer resources is addressed as cybercrimes. Generally, ICT boosts the rate as well domain of criminal actions. The location of crime acts as a catalyst for criminal activities [26]. The Internet is also a huge platform for criminal acts as was not initially deployed with highly secure protocols. Because the IoT systems are implemented on the ceiling of the present Internet framework, so associated cybercrime issues remain unresolved. Even these challenges become huge as more and more things are connected in an IoT system. IoT also intensifies the probability of unauthorized access to data and services. At last, a huge base of the cyber framework enhances the scope not to reveal criminal acts to the public as the criminal acts are executed using virtual methods.

II. EXISTING WORK ON IoT SECURITY AND CYBERCRIME

In the last few years, several surveys have been conducted to impress upon improvements and research carried out in the IoT systems. In these survey papers, the main focus is on the fundamental aspects of IoT. Along with, IoT security issues are also discussed in some of these surveys. There are few dedicated survey papers on IoT security and privacy contention. In the surveys published in the years 2010-2020, Atzori et al. [27] discussed the security and privacy aspects of IoT. In the field of security, the main attention was given to authentication and data integrity, and the scope of research was discussed. In the privacy aspect, the authors suggested limiting access to personal data. However, this survey highlights incomplete facts regarding security challenges in IoT. Miorandi et al. [28] assumed the implementation of IoT at three fundamental levels i.e. communication, identification, and interaction. Although the authors highlighted the possibility of many security challenges in IoT but proposed the research in three main issues: privacy of the users, data secrecy, and trust. In this paper, many burning issues related to IoT security like access control, data integrity, and authentication of the user were not discussed in detail [29]. Gubbi et al. [30] discussed security and privacy in the contexts of user identification and authentication, data integrity, and privacy in general. The authors introduced the cloud-based IoT paradigm. On the same grounds, few technologies were introduced along with the domains of application of each technology.

Aggarwal et al. [31] in their survey, discussed security prospectus exclusively from a privacy perspective whereas other security challenges in IoT platforms were not discussed. Said [32] discussed various IoT architectures along with research issues. In this survey, only challenges faced in physical security and privacy were explored. Moreover, security issues were discussed casually without giving any viable solutions. Perera et al. [33] elaborated that security and privacy challenges are handled at the middleware level in the IoT framework and different layers. In this survey, security was expressed as a normal issue. Even, authors did not pay any special attention to the research in the field.

Granjal et al. [34] presented an in-depth review of different security mechanisms and protocols of the time for communication among smart devices. The authors also highlighted the available scope of research. However, on the negative side, the authors did not consider all the security standards in their survey but focused on a few standards only. Sicari et al. [35] reviewed the security from three different angles: security requirements, privacy, and trust. Under security requirements, they explored the issues related to access control, confidentiality, and authentication. The biggest drawback of this work is the inadequacy of the categorization research activities in the IoT security paradigm. Abomhara and Koein [36] reviewed the security threats along with the security and privacy research challenges in their paper. They stressed research issues like the interoperability of diverse IoT devices, authentication, and authorization of the IoT devices.

Mahmoud et al. [37] surveyed IoT security principals. The authors also presented various security issues along with corrective measures. The need for advanced technologies to tackle hardware, software, and identification and wireless communication issues is also discussed. Pescatore and Shpantzer [38] presented the viewpoint of people actively involved in the research of IoT security issues along with the future prospectus of each in the field. They also highlighted that IoT developers should focus more on security issues instead of other ICT systems. Gil et al. [39] reviewed various technologies and models discussed in IoT. These approaches were discussed in the context of data-related challenges. The authors impressed upon the collaboration of social networks and IoT and introduced a new concept of the Social Internet of Things (SIoT). IoT
security was discussed but cybersecurity in IoT was not discussed.

Muhammad et al. [40] discussed the various attacks in the IoT systems. The authors also highlighted the security and privacy challenges faced in the IoT environment by the various sensor nodes. In this survey, the requirement of secure end-to-end communication among smart devices using efficient encryption and authentication methods was suggested. Vignesh and Samydurari [41] reviewed three layers of IoT architecture i.e. application, network, and perception along with different types of security threats at these layers. They explained the effect of wireless signals, movement of IoT things in the external environment, and dynamism of the network model as the major challenges at the perception layer. At the network layer, the major highlighted challenges are DoS and Man-in-the-Middle attacks. The major issue that persists at the application layer is the variety of application policies.

Razzaq [42] surveyed the different security needs of an IoT system. They categorized various IoT attacks into four classes: low level, medium level, high level, and extremely high level, and also suggested the possible way out to handle these attacks. Maple [43] discussed the role of IoT devices in various domains like autonomous vehicles, health, industry 4.0, logistics, smart grid, agriculture, home, offices, and entertainment. Along with the security threats in all these application areas are also reviewed. They highlighted the security issues related to the physical limitations of the things, the versatility of the devices, authentication, authorization, and implementation. Various issues related to the privacy of the users are also discussed in this survey. Rughani [44] presented the various challenges faced by the crime investigators to collect the pieces of evidence from the smart IoT devices available on the crime scenes. The author impressed upon the need for corrective measures for the issues to help in crime investigation and make the process easy.

Corseret et al. [45] discussed that to make the IoT systems more secure, the security of smart devices and networks need to be improved. To improve device-level security, protection of data and dynamic testing plays a major role. Consequently, to make communication networks more reliable there is a requirement of authentication, secure protocols, network division, and organization. Sulkamo [46] highlighted that information security in IoT systems must revolve around confidentiality, integrity, and availability of data. It is also discussed that in communication networks secure data transmission protocols should be used. Burhan et al. [47] presented a detailed survey on the different layers of IoT architecture along with the potential attacks at each layer. The authors also reviewed various available mechanisms to handle these attacks along with their limitations. Security issues in various IoT technologies like sensors, ZigBee, Bluetooth, RFID, Wi-Fi, and 5G networks are discussed in detail.

Noor and Hassan [48] presented the primary objectives of IoT systems security. They discussed that the privacy of the user and security of the data and infrastructure are the main challenges in the IoT environment. The authors also reviewed various tools and simulators to implement IoT security mechanisms. MacDermott et al. [49] highlighted the sharp increase in the usage of digital forensics for crime investigation. The authors also highlighted that the reason for this rise is the increase in smart devices. It was also highlighted that to cope up with this change, there is a need for regular development in the techniques used for crime investigation. The authors also reviewed various forensic handling methodologies in this paper. Sfar et al. [50] presented three different aspects i.e. privacy, trust, and identification/authentication of IoT security. Under these three aspects, the various open research issues like standardization of security mechanisms, reduction in the amount of data transmitted among smart devices, implementation of trust mechanisms to safeguard users and services, implementation of global identification mechanism for things, and automatic discovery of the devices in the IoT environment were highlighted.

Neshenko et al. [51] presented an exhaustive survey on IoT vulnerabilities. The need for endorsement of different advanced technologies like blockchain, deep learning, and cloud paradigms was stressed in IoT security implementation. Various research aspects highlighted in the survey are the requirement of global device identification mechanisms, the need for more security-centric awareness among IoT users, the requirement of more mature security protocols, and the adoption of secure IoT application development processes. Zhou et al. [52] reviewed four main features of IoT: Interdependence, diversity, constrained, and myriad. Consequently, the open research issues for these have also been discussed. It was spotlighted in the survey that in IoT systems, as the devices are interdependent so to focus on security mechanisms by considering each device as a standalone will not provide a secure IoT environment. Detection of viruses in the IoT devices is also highlighted as an open research challenge in this survey. The issue of sensitivity of the privacy of user’s personal information is also an area of major concern for academicians and researchers. Lu and Xu [8] elaborated that the privacy and security of IoT systems is the biggest research challenge. The authors presented a detailed review of the state-of-art research going on in cybersecurity. IoT architecture for cybersecurity is discussed in detail. At last, the major research challenges of the domain are also discussed in detail.
Aydos et al. [53] classified IoT vulnerabilities depending upon the types of attacks in the four different layers: physical layer, network layer, data processing layer, and application layer. Depending on these vulnerabilities, the authors proposed a risk-based security model to evaluate each discussed layer of the IoT architecture. Nasiri et al. [54] surveyed the security needs of an IoT dependent health care system. They classified it into two categories: cybersecurity and cyber resiliency. Under Cybersecurity the various features of confidentiality, integrity, availability, identification and authentication, authorization, privacy, accountability, non-repudiation, auditing, and data freshness are elaborated. Under cyber resiliency safety, survivability, performability, reliability, maintainability, and information security are discussed in detail. Tabassum et al.[55] reviewed the various IoT security challenges. The authors also demonstrated the role of IoT in industry. It was also discussed in this paper that how the requirement of security in the IoT environment evolved with time. In this study, it was presented that how the security issues of individual devices/things used at each layer in the IoT architecture can affect the security of an IoT system.

Servida and Casey [10] presented a detailed study of the vulnerabilities of smart devices. In this paper, it is discussed how these vulnerabilities can cause these devices to become victims of attacks. On the positive side, it is featured that these vulnerabilities can help the investigators to fetch the digital traces and investigate the crime. So, device vulnerabilities are both challenges and opportunities in the crime. Blythe et al. [56] highlighted that the IoT environment lack of security features as the devices are not manufactured by considering the security challenges. It was also discussed that at some events even users do not use the available security features of the devices due to a lack of knowledge about the customization of these features. In this work, the authors imposed on the need for standardization of communication and security protocols in IoT systems and highlighted the need for Government intervention to assure security as the device level. Adesola et al. [57] suggested a novel IoT and Big Data-based smart model to investigate and control criminal activities in Nigeria. The authors also developed a prototype for the model. This model is useful to keep the record of criminals. Abdullah et al. [9] discussed the security aspects of IoT by focusing on cybersecurity. Open research issues related to cybersecurity are highlighted along with possible corrective measures. The authors also applied the usage of blockchain technology to strengthen the cybersecurity aspect of IoT.

Butun et al. [1] presented an in-depth review of various types of security attacks in wireless sensor networks and IoT systems. Various mechanisms for the prevention and detection of these attacks are also discussed in detail. The authors categorized the IoT attacks as active and passive attacks. It is also spotlighted that passive attacks cannot be identified using any mechanism. On the other hand, active attacks violate the integrity and confidentiality of data. Active attacks also cause unauthorized access to user data. Stoyanova et al. [58] surveyed the various available models for digital forensics. In this survey, special consideration is given to the methods which are used to extract digital data by maintaining the privacy of the users. Authors presented the open research challenges in the field of digital forensics by paying special attention to the need for more advanced forensic analyzing techniques and universally acceptable protocols. Tawalbeh et al. [59] discussed the various security and privacy challenges of IoT. They impressed upon the less mature security protocols and lack of accurate device monitoring systems as the main open research issues. They also highlighted the security challenges because of user unawareness and device updates. The authors also proposed and evaluated a cloud base IoT security solution.

Sharma et al. [60] reviewed the security and privacy aspects of IoT in digital forensic. Because of the versatility of the things in the environment, it is tedious for the investigators to identify security infringement in IoT. In the cloud environment, this problem gets multiplied. The authors proposed a new model to deploy better digital forensic methodology and claimed it to be a more efficient and reliable approach. Bouchaud [61] presented heterogeneity of the IoT devices as the biggest challenge in security and to explore the IoT systems. A new methodology is proposed in this paper to identify the connectivity of the devices which can further help in crime investigation. They proposed to classify the IoT devices based on the characteristics of data fetched from them. Atlam [62] reviewed IoT architecture and communication technologies. Various IoT security challenges and threads are also discussed. The authors also explained the role of digital forensics in crime investigation. The need for employing real-time techniques in IoT forensics is highlighted as the need of the hour.
| Author (Year) | Ideology | Parameters | Advantages | Security Issues Discussed |
|--------------|----------|------------|------------|---------------------------|
| Atzori et al. (2010) [27] | A survey of Internet of Things (IoT) | Applications, Service Management, Logistics | Applications of IoT were discussed in a detailed manner. | ☒ |
| Miorandi et al. (2012) [28] | A survey of Applications and issues of security in IoT | Applications, Security issues of IoT, Research Challenges | Research challenges and issues of securities were explained in detail. | ☑ |
| Gubbi et al. (2013) [30] | Application and cloud computing oriented survey of IoT | Applications, Addressing Schemes, Cloud computing. | Cloud computing and its applications with IoT were discussed. | ☑ |
| Aggarwal et al. (2013) [31] | A survey of applications, data management, and research challenges in IoT | Applications, Data management and Analytics, Security, Privacy | Data management in IoT and applications were discussed in detail. | ☑ |
| Said et al. (2013) [32] | Evaluation of different IoT architectures is presented. | Hierarchical Architecture, Distributed Architecture | Different IoT architectures were discussed in detail. | ☒ |
| Perera et al. (2013) [33] | The authors presented the context-aware computing for IoT devices | Context Reasoning, Context Modeling, Context Reasoning, Context Distribution | Different contexts related to the IoT were presented. | ☒ |
| Granjalet et al. (2015) [34] | Communication Protocols and Security parameters are discussed in detail. | Different protocols of IoT communications, Application layer, physical layer, and MAC layer security | The security of different layers in IoT communications was discussed in detail. | ☑ |
| Sicari et al. (2015) [35] | Research challenges and existing solutions in IoT security are presented in the survey. | Mobile security in IoT, Trust, and Privacy in IoT, Enforcement in IoT, Authentication, Confidentiality, and Access control in IoT. | Security of IoT was discussed referring to ongoing projects on securing the IoT. | ☑ |
| Author (Year) | Ideology | Parameters | Advantages | Security Issues Discussed |
|--------------|----------|------------|------------|--------------------------|
| Abomhara and Koein (2015) [36] | Research directions concerning IoT security and privacy are presented. | Different cyber-attacks in IoT, security and privacy challenges in IoT, security threats and challenges | Threats to IoT security were discussed in detail. | ✓ |
| Mahmoud et al. (2015) [37] | IoT layer architecture and security features are the key aspects of this paper. | IoT architecture, IoT security issues, IoT security countermeasures | Basic architectures of IoT and security issues were discussed in detail. | ✓ |
| Pescatore and Shpantzer (2016) [38] | Surveyed perceptions on IoT, IoT applications, and industry representation by IoT. | Applications, Threats to IoT, Risk management in IoT, Data monitoring | The survey conducted on participants was discussed concerning different parameters related to IoT. | ✓ |
| Gil et al. (2016) [39] | A general survey of IoT and Context-aware of IoT. | IoT Applications domain, Services for IoT, Data mining for IoT, | Services and data as services were discussed. Applications of IoT are also presented | × |
| Muhammad et al. (2016) [63] | A review of security solutions to the threats on IoT devices. | Different techniques of attacks on IoT, IoT security and privacy requirements, approach to security solutions in IoT | The threats on IoT security and its measures to counter the threats were explained in detail. | ✓ |
| Vignesh and Samydurari (2017) [41] | A survey on IoT layer architecture and security threats on each layer. | Security features of IoT, Architecture, Security remedies | Security issues in IoT and future directions regarding 5G were discussed in the paper. | ✓ |
| Razzaq et al. (2017) [42] | A survey on different types of threats in IoT and their solution is discussed. | Applications of IoT, Threats to IoT, Analysis of different types of attacks. | Applications of IoT and analysis of different types of security threats were done. | ✓ |
| Maple (2017) [43] | A survey of applications of IoT, Authentication, and identity management of IoT, Security issues of IoT in different applications. | Applications of IoT in automobiles, Health, industry 4.0, agriculture, entertainment, and media. | Security issues on various applications like health and in automobiles were discussed along with privacy challenges in detail. | ✓ |
| Author (Year)                  | Ideology                                                                 | Parameters                                                                 | Advantages                                                                 | Security Issues Discussed |
|-------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|----------------------------|
| Rughani(2017) [44]            | The authors discussed the Architecture of IoT devices along with the security aspects and its application in forensics. | IoT architecture, IoT security issues, and digital security in IoT         | Discussion on Forensics in IoT and security issues were discussed.         | ✓                          |
| Corseret al. (2017) [45]      | The authors laid prime emphasis on the security of the IoT devices.       | IoT hardware security, Dynamic testing, securing IoT networks             | Certain security issues from a hardware and software perspective were discussed in detail. | ✓                          |
| Sulkamo(2018) [46]            | Basic modules of IoT, Protection of IoT environment, and cybersecurity are discussed. | IoT modules, Sensors, networks, cybersecurity recommendations, cybersecurity in a cloud-based environment. | Cybersecurity in a cloud-based environment and universal problems in the protection of IoT devices were discussed in detail. | ✓                          |
| Burhan et al. (2018) [47]     | Compared the different application domains of IoT and discussed the key elements of IoT. | Applications of IoT, Different architecture layers of IoT.               | Identity management framework, Security mechanisms for IoT, Improved layered architecture for IoT were discussed. | ✓                          |
| Noor and Hassan (2018) [48]   | A survey on IoT security, Possible attacks on IoT architecture layers is presented. | IoT security, Attacks on layers, review on IoT authentication, Trust management, and secure routing. | Attacks on the IoT architecture layer were explained in detail. Secure routing was presented with key features. | ✓                          |
| MacDermottet al. (2018) [49]  | Authors discussed the IoT, the possible crime using, or in IoT devices.   | Forensic handling regarding IoT and Crime using IoT devices.             | Forensic evidence handling in the smart city was discussed in detail.       | ×                          |
| Sfaret al. (2018) [50]        | A survey on IoT security including discussion on smart manufacturing.     | A cognitive approach for IoT, recent research in data privacy, Trust management system. | Cognitive and systemic security along with adaptive and context-aware security was discussed in detail. | ✓                          |
| Neshenkoet al. (2018) [51]    | A survey on exploitations on different IoT devices                       | IoT architectures, Security in IoT, IoT vulnerabilities at different architectural layers. | The security aspects of the layer-wise architecture of IoT devices were discussed in detail. | ✓                          |
| Author (Year)          | Ideology                                                                 | Parameters                                                                 | Advantages                                                                                       | Security Issues Discussed |
|-----------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|---------------------------|
| Zhou et al. (2018) [52] | A survey on security features and privacy in IoT                          | Attacks on IoT, Threats, and challenges in IoT devices.                    | Threats to IoT hardware devices were discussed in detail.                                        | ✓                         |
| Lu and Xu (2018) [8] | A survey article on IoT cyber-attacks and security schemes.               | Different cyber attacks and Layer wise security schemes.                   | Security schemes for different layered architecture were explained in detail.                    | ✓                         |
| Aydoset al. (2019) [53] | A survey of risk and threat assessment on different architecture layers of IoT. | IoT applications, platforms for IoT, IoT protocols, Security, threats, and vulnerabilities in IoT. | Attack on a different layer in IoT was presented along with a risk-based layered approach for IoT security assessment in detail. | ✓                         |
| Nasiriet al. (2019) [54] | An article on health care based secure IoT environment.                   | Security requirements in IoT                                               | Cybersecurity requirements were discussed.                                                       | ×                         |
| Tabassum et al. (2019) [55] | An article on various security issues in IoT.                             | IoT security requirements, Architecture of IoT.                           | Security issues on Perception, application, and network layer were discussed in detail.          | ✓                         |
| Servida and Casey (2019) [10] | An article on IoT forensics and detection of traces in IoT.               | Digital forensics, Privacy, and IoT forensics                             | IoT forensics and detection extraction and parsing of traces from IoT devices were discussed in detail. | ×                         |
| Blythe (2019) [56] | An article on cyber hygiene advice for IoT devices                         | Security features of IoT devices, Design code of practice for IoT devices. | Standardization of security protocols was the main emphasis.                                    | ✓                         |
| Adesola et al. (2019) [57] | An article on crime management with IoT based architecture.               | IoT architecture, data collection, and framework for IoT devices.          | A crime prediction and monitoring model was proposed.                                            | ×                         |
| Abdullah et al. (2019) [9] | A review of cybersecurity issues and challenges.                          | Cyberattacks, cybersecurity, IoT architecture, security techniques.        | Security techniques at different layers are discussed in detail. The blockchain is implemented to secure the IoT network. | ✓                         |
| Author (Year)            | Ideology                                                                 | Parameters                                                                 | Advantages                                                                 | Security Issues Discussed |
|-------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------|----------------------------|
| Butunet et al. (2019) [1] | A survey on different kinds of attack and their countermeasures in IoT devices. | IoT applications, Security attacks on IoT devices, Attacks on different layers of IoT architecture. | Defense against different passive and active attacks on different layers of IoT architecture was discussed in detail. | ✓                          |
| Stoyanova et al. (2020) [58] | A survey on IoT forensics and its challenges. | IoT forensics components, IoT attacks, IoT security, IoT protocols, IoT layered architecture. | IoT forensics challenges and its solution, secure cloud service models were discussed in detail. | ✓                          |
| Tawalbeh et al. (2020) [59] | An article on security and privacy in IoT devices. | Generic IoT layers and proposed system model for secure IoT devices. | A system model was proposed using the cloud, edge node, and IoT nodes. | ✓                          |
| Sharma et al. (2020) [60] | An article on digital forensic IoT based on secure communication. | Digital forensics in IoT devices, Security, and privacy requirements. | An advanced digital forensic approach was discussed. | ×                          |
| Bouchaudet et al. (2020) [61] | An article on digital investigation of IoT devices on a crime scene | IoT architecture, classification of IoT devices, IoT investigations on the crime scene. | Crime detection techniques in an IoT device on the crime scene was discussed in detail. | ×                          |
| Atlamet et al. (2020) [62] | An article on cybercrime, security, and digital forensics for IoT devices. | IoT applications, IoT architecture, characteristics and communication technologies in IoT, Security threats in IoT. | Security solution to four-layered IoT architecture was discussed in detail. | ✓                          |
In this survey, we present a thorough review of the security aspects of an IoT environment from the year 2010-2020. It is important here to highlight that in none of the survey papers such a long period has been considered for review. It has been observed from all the papers/surveys discussed above that either cybercrime investigation in the IoT environment was not contemplated as a preference or was kept narrowed to selected issues only. In this review, we examine the various aspects of IoT systems like architecture, protocols, and technologies deployed at the various layers and application domains. We present potential risks and possible attacks on each layer of the IoT architecture which can cause cybercrime. In this review, we present the various security mechanisms and their layer of implementation. Special attention is given to IoT forensics in cybercrime investigation. The various domains like smart homes, smart cities, automated transport, drones, healthcare, etc. are examined to assist cybercrime investigation. The role of various advanced technologies in the investigation of cybercrime is also presented. At the end of the paper, various open research challenges in an IoT environment to contribute towards the process of IoT forensic to aid the process of cybercrime investigation are presented.

III. IoT FRAMEWORK AND APPLICATIONS

IoT is a broad network of linked devices over the internet. It has expanded very briskly in the last few years. Currently, IoT has evolved as a contemporary styled network that acts as an agent to link the real and virtual world. Application domains of IoT are expanding day by day, as shown in Figure 5. The fundamental characteristic of the IoT applications is to gather data from the smart devices and communicate over the networks [64]. A gigantic volume of personalized data is gathered by various IoT applications including smart agriculture, healthcare, smart homes, meetings, etc. [65]. This huge amount of data is communicated in IoT systems, interpreted and investigated. In research carried out by Cisco, there is an estimate of 50 billion smart devices to be plugged into the internet in the current year. It is also predicted that because of advanced features, smart devices will become an important part of day to day life in the current year [53]. It is being forethought that the trend of using IoT systems will spike and will keep growing afterward. Due to the vast usage of IoT collected data, a new trend has started. Even data collected with smart devices in an IoT environment can be shared for usage in other real-life applications. But the biggest challenge in collected data is the versatility of smart devices supported in the IoT system architecture.

A. IoT ARCHITECTURE

There is a need for an open architecture to deploy IoT systems to support diverse categories of smart devices and to administer interfacing among them. Many reviews and research articles are available demonstrating the IoT architectures [36]. Fundamentally, IoT systems are deployed on three-layer architecture as shown in Figure 6.
These three layers are the perception layer, network layer, and application layer. This is the basic IoT architecture model which can be practiced with different IoT applications. As shown in Figure 6, for each layer of IoT architecture the possible attacks and technologies deployed are also shown. These technologies help in the process of data collection, interpretation, analysis, and communication [68]. Different layers of the IoT architecture are characterized as follows:
1) PERCEPTION LAYER
In this layer, data are generated by various smart devices. Data is also gathered by these devices which can be further communicated within the IoT environment or even to the outside applications. This layer works with two types of things: IoT devices and IoT hub nodes [69]. IoT devices identify themselves in the IoT system, whereas IoT hub nodes work as gateways. The data are collected through devices and transmitted through gateways [70].

2) NETWORK LAYER
In this layer, communication among IoT devices and applications happen. The mode of communication may be wired or wireless. Various network security protocols are deployed in the network layer. The IoT gateways are set up at this layer. This layer receives the data coming from the lower layer and map to the format required by the applications running in the upper layer [71].

3) APPLICATION LAYER
The application layer is also interpreted as the service layer. Here, the data gathered by various devices are used, analyzed, interpreted, and presented. This layer can be customized under different policies depending upon the service administered [72].

B. PROTOCOLS
Functionalities provided by the various layers of the IoT architecture are administered by the communication protocols deployed in the different layers of the IoT architecture. Various protocols used at the different layers of the IoT architecture are shown in Figure 7.

The various protocols deployed in the perception layer are IEEE 802.11 series, 802.15 series, Wireless HART (Highway Addressable Remote Transducer), etc. [72]. The IEEE 802.15.4 is used for data exchange in a long-range wireless personal area network (LR-WPAN). So ZigBee, Wireless HART are deployed in the IoT perception layer [73].

Protocols used in the network layer of IoT architecture are IPv6/IPv4, 6LoWPAN (IPv6 over Low-Power Wireless Personal Area Networks), Serial Line Interface Protocol (SLIP), Transmission Control Protocol (TCP)/User Datagram Protocol (UDP), and micro IP (UIP) [74].

The HTTP is used in the application layer to deploy web services to the application users. But because of different limitations of HTTP i.e related to its complexity, data transfer rate, and energy consumption, this protocol is not approved for usage as it is in IoT systems. Consequently, the protocols specially designed for IoT environment e.g. Embedded Binary HTTP (EBHTTP), IETF (Internet Engineering Task Force), Lean Transfer Protocol (LTP) and CoAP (Constrained Application Protocol) are used in the application layer [77], [78], [79].

C. IoT APPLICATION DOMAINS
Incorporation of the smart devices to gather data from our day to day life activities made many IoT applications feasible. IoT aids the development of several applications, which ease our daily life [36]. These applications can be categorized into different domains, summarized below:
1) PERSONAL AND SOCIAL DOMAIN
The applications under this domain allow the potential users to communicate with the environment or with other users to establish and maintain a social circle [27].

2) MOBILITY AND TRANSPORTATION DOMAIN
Under applications falling in this domain, roads and vehicles equipped with sensors and other smart technologies, which can gather traffic-related data are covered. This data can help with traffic control and management [80]. Some of the IoT-based transport applications with outstanding performance are Intelligent Traffic Information Service (ITIS) and Traffic Information Grid (TIG) [81].

3) ENTERPRISE AND INDUSTRIAL DOMAIN
IoT Applications falling in this category include smart banking, manufacturing, logistics, industrial operations, etc. [2, 82].

4) SERVICE AND UTILITY MONITORING DOMAIN
This domain of IoT applications commonly deals in smart agriculture, environment, and energy management, etc.

D. SUPPORTING TECHNOLOGIES
For all the applications falling in various IoT domains, different components of the IoT system need to stay connected all the time. This is possible only with IoT supporting technologies [36]. So, the various components of an IoT system along with the technologies deployed are shown in Table 4. The progressive growth of various technologies like sensors, smartphones, and software, etc. will facilitate different things in the IoT systems to stay connected everywhere and all the time [83]. The fundamental approach to support IoT is to connect the objects in the physical world with the digital world. Numerous technologies device these approaches, as discussed below:

| Elements of IoT | Technology Deployed |
|-----------------|---------------------|
| Semantics       | Web Ontology Language, Resource Description Framework, Efficient XML Interchange |
| Computation     | Raspberry Pi, Arduino |
| Services        | Identity-related, Information Aggregation |
| Communication   | NFC, LTE, 5G, RFID, WiFi, Bluetooth |
| Sensing         | RFID Tags, Smart Sensors |
| Identification  | Product code, Bar code, IPv4/IPv6 |

1) IDENTIFICATION TECHNOLOGIES
The fundamental identification technologies used in IoT are Radio-Frequency Identification (RFID) and Wireless Sensor Networks (WSN). These are used in the perception layer of IoT architecture [27], [14], [82], [84].

2) NETWORK AND COMMUNICATION TECHNOLOGIES
Both, Wired and Wireless technologies (e.g., GSM and UMTS, Wi-Fi, Bluetooth, ZigBee) permit a huge number of smart devices and services to be connected [85-87]. Flexible and secure IoT architecture is required for reliable communication among various wireless devices [80].

3) HARDWARE AND SOFTWARE TECHNOLOGIES
A lot of research is going on in the field of nanoelectronics to develop vast functionality and economical wireless IoT systems [82]. Smart things with improved inter-node communication will help in the development of smart systems assisting fast application development to support various services in IoT.

E. SECURITY CHALLENGES
Every layer of IoT is prone to security attacks and threats, as shown in Figure 6. These attacks or threats may fall in any of the categories of active or passive and internal or external attacks [37] and [36]. In passive IoT attacks, only information transmitted on the network is observed but service is not affected. On the other hand in active attacks, a service stops responding [88]. The various devices and services supported by each layer of IoT are prone to Denial of Service (DoS) attacks. Under DoS attacks devices, services and networks become unsalable to unauthorized users. In the same manner, various security challenges are faced by the devices and services supported at each layer which are discussed below:

1) SECURITY THREATS IN PERCEPTION LAYER
The very first issue faced by the various device nodes functioning in this layer is the intensity of the wireless signals, as the signals become weaker due to environmental disturbance. The second issue is related to the physical attacks on the IoT devices, as the various IoT nodes usually operate in an outdoor environment. The third issue is related to the dynamic topology of the IoT systems, which allows the frequent movement of the IoT nodes in and around the network. The different devices working in this layer make use of sensors and RFIDDs. Because of their limited adequacy from the storage and computational point of view, these devices are prone to different kinds of security threats [36] and [89]. The various kinds of devices operating in this layer are susceptible to Replay Attack, Timing Attacks, Node Capture attacks [40], and DoS
attacks. All these security challenges can be dealt with encryption, access control, and authentication.

2) SECURITY THREATS IN NETWORK LAYER
Along with the DoS attack discussed previously, the network layer of an IoT system can also be targeted for silent monitoring, traffic analysis, and eavesdropping. The major reasons behind these attacks are the remote access and exchange of data. This layer is terrifically prone to a Man-in-the-Middle attack [36]. Eavesdropping is the root cause of the insecure communication channel. Communication technologies and protocols play a major role to stop eavesdropping and further to stop identity theft. As the heterogeneity of devices is the major issue in the IoT systems, it is the biggest challenge to have more secure protocols in the network layer to deal with this diversity. Attackers also misuse the connectivity of the devices to steal user information for future attacks [76]. Along with the security of the network from the attackers, the security of the devices operating in the network is competently important. Consequently, the devices in the network must have the comprehension to safeguard themselves against network attacks. This can be obtained only with secure network protocols as well as smart applications [90].

3) SECURITY THREATS IN APPLICATION LAYER
Since there is a lack of standard policies related to IoT systems which cause many security challenges in the IoT applications and their development. As a variety of authentication mechanisms are used in different IoT applications, so it's difficult to warrant data security and user authentication. The second major challenge is to deal with the interaction of the user with applications, the volume of data exchanged, and to manage the different applications. The IoT users must be decked to decide what they wish to share about them and how that information is used and by whom [37].

F. IoT SECURITY MECHANISMS AND MEASURES

Security is a demanding affair that persists in the IoT systems. The benefits of the IoT systems cannot be obtained without addressing the security issues [47] and [91]. The various security mechanisms proposed by the various researchers to safeguard different IoT applications are shown in Figure 8. The various security mechanisms used in the Perception Layer of the IoT systems are Encryption and Hash-based security [92], [93], Public Key Infrastructure (PKI) Like Protocol [94], [95], Secure Authorization Mechanism with OAuth (Open Authorization) [96], [97], Lightweight Cryptographic Algorithms [98] Embedded Security Framework [99], [100].

The Network Layer of IoT is protected with Identity Management Framework [102], Risk-Based Adaptive Framework [103], Association of SDN (Software Defined Networking) with IoT [110], Cooperation of Nodes Based Communication Protocol [104], Reputation System Based Mechanism [105], Cluster-Based Intrusion Detection and Prevention System [106].

The various security mechanisms implemented in the Application layer of IoT are Preference-Based Privacy Protection Method [107], [111], Access Control Mechanisms [108], [112], OpenHab Technology, IoTOne Technology [109], and Identity Based Security [113], [114].

All these security mechanisms about the security provided for the different layers of IoT are compared below in Table 5.
Table 5. Comparison of existing IoT security mechanisms in different layers

| Method Name                                    | Layer                        | Description                                                                 | Issues focused by the method                                                                 |
|------------------------------------------------|------------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| Risk-based adaptive framework                  | Network                      | Each portion of the four portions performs their tasks and acknowledges the other. | It keeps watching on attacks. It removes the incoming attack at the second portion [103].          |
| Preference-based Privacy protection            | Application                  | The service provider, client, and third party initiate communication in a secure environment. | Between the client and service provider, the third party acts as a bridge and keep a check on the security provided to the client through the service provider [111]. |
| OpenHab in the Application layer              | Application                  | Provision of Security.                                                      | The device mismatch is not supported but registration is simple [109].                          |
| PKI protocol                                  | Perception                   | A message is sent by the base station to the destination consisting public key. | The message is delivered independently without compromising security [95].                      |
| IoTOne                                         | Application                  | OpenHab technology issues are solved.                                       | A device mismatch is allowed. The request is sent by the client to the server for the verification of the user [109]. |
| Security framework based on Identity           | Application                  | Registration, policy, client, and user authentication are part of this system. | Admin describes the policies. Users and all other resources are managed by the framework based on policies [113]. |
| Encryption based on Hash                       | Perception                   | Encryption algorithms and hash functions are used parallel.                 | The integrity of the message is checked [93].                                                   |
| Mechanism-based on the secure authorization    | Perception                   | RBAC and ABAC mechanisms and system is based on client-server.              | Resources are provided by the server to the client on request, thus making the system more secure [97]. |
| Lightweight cryptographic algorithms           | Perception                   | Messages are converted by using keys.                                      | Plain text from the message is converted to cipher using hash functions, symmetric, and asymmetric keys [115]. |
| Embedded Framework of security | Perception | Memory, Operating system, and run-time environment are secured. | More secure memory management, secondary storage, and run-time environment to the users [99]. |
|-------------------------------|------------|----------------------------------------------------------------|------------------------------------------------------------------|
| The framework of Identity Management | Network | Communication is done via service and identity. | Information about the users is confirmed from the identity module to protect the users from the attackers [102]. |
| SDN with IoT | Network | Low cost and lesser hardware are used for better performance. | IoT agent and controller are provided security by SDN as all the communications are done through SDN [110]. |
| Mechanism-Based on Reputation | Network | Data structures namely the reputation table and watchdog mechanism are maintained by the node to prevent intruders. | Ad hoc communication-based system [105]. |

**IV. ROLE OF DIGITAL FORENSICS IN CYBERCRIME INVESTIGATION**

Although crime always persisted in society, the aids of committing the crime evolved and grown with time. With the advancement in technology, criminals have come up with the new and technology-equipped methods to commit crime called cybercrime. In past, criminal inquiries were dependent on the investigation of the physical evidence and crime locations along with a witness. But nowadays in the internet era, crime scenes may comprise smart IoT devices, computers, etc. [49]. Consequently, the process of criminal investigation may consist of the analysis of digital evidence [116].

**A. DIGITAL FORENSICS**

Digital evidence may consist of a variety of elements. Primarily, the evidence would consist of smartphones, laptops, computers, hard drives, and USBs, etc. As each individual can have any or all of the above devices, a huge volume of data will be available for analysis. Another major hindering factor in the analysis is the variety of formats in which data is available on these different devices [49]. As there is a big change in the type of evidence with time, so there is a need for new techniques to handle this change efficiently. Digital Forensics just like traditional forensics is a domain that interprets digital data [58]. Digital Forensics experts collect, preserve, and analyze digital evidence [117].

Rogers states, “The science of digital forensics has developed, or more correctly is developing, while this science is arguably in its infancy, care must be taken to ensure that we do not lose sight of the goal of the investigative process, namely identifying the party or parties responsible” [49], [118]. During the design and development of new techniques to analyze digital evidence, it is mandatory to consider other aiding domains to develop and support in the process of the criminal investigation. A digital forensics approach deploys a framework for the techniques to be used in digital forensics dependent investigation [119].

**B. IoT FORENSICS IN CYBERCRIME INVESTIGATION**

The IoT Forensics can be observed as a sub-domain of Digital Forensics. IoT forensics is a comparatively new and less scrutinized area. The aim of the IoT forensics falls in-line with Digital Forensics i.e. to collect and analyze digital evidence legally and accurately [58]. In IoT, forensics data could be collected from sensors, IoT devices, networks, and clouds [120]. Based on this, IoT Forensics can be categorized as IoT device level forensics, network forensics, and cloud forensics as shown in Figure 9.
The basic contrast between Digital Forensics and IoT forensics depends upon the devices examined in crime investigation. In Digital Forensics the devices under examinations may be computers/laptops, servers, tablets, and smartphones [121]. Although IoT forensics has a wider area of applicability like smart homes, smart vehicles, drones, general IoT systems, etc., published literature in the area in comparison to Digital Forensics is less.

1) SMART HOMES

It has been observed that during the crime investigation, smart home devices can provide compromising information [122]. Usually, the main components of these devices are microphones and motion detectors. These devices play a major role in identifying the location of suspects. There are three main categories of devices to collect forensics: active, passive, and single-malicious active. In [122], two smart devices i.e. light and bulb have been experimented by the authors. It has been observed that a huge amount of data can be collected even with these passive devices, which can help to identify the activity executed on a specific timestamp. The design of another smart home solution i.e. Forensics Edge Management System (FEMS) is discussed in [123]. The main focus of the proposed system is to administer security in smart homes along with forensics assistance. Although, a variety of features ranging from automatic detection to intelligence and flexibility are the main, this system is with two limitations i.e. complex implementation and testing. Authors stated in [124] about the security concerns in smart devices. It is impressed that security threats in the IoT environment increase with the increase in the number of devices in the network. Consequently, the need for IoT forensics arises. In this case study, special attention is given to the IoT forensics in smart homes. The authors also highlighted the need for advanced IoT forensics because of the different IoT challenges. It is expected that in the coming future, smart homes will become very common. So, a seven-step methodology is proposed for easy investigation in smart home surroundings [125]. It is highlighted by the authors that the proposed framework assists in evidence collection and store. However, it needs to be tested with a true home automation system.

2) SMART CITY AND VEHICLE AUTOMATION

Smart Cities are computerized environments also termed as cyber-physical ecosystems to enhance the utility of traditional city infrastructure like parking spaces, power grids, gas pipes, etc. [58]. In this way, better services can be
provided to the residents [126], [127]. One of the important examples i.e. smart parking is the area of the major concern of most of the city administrations and auto-tech companies [128].

The network of smart vehicles assists the exchange of information between the vehicles and the environment [121]. These smart vehicles have aided the various important areas like road safety and traffic administration. However, they have also raised many issues in concern of digital forensics. In a case study [129], a new framework named ‘Trust – Internet of Vehicles (IoV)’ is proposed by the authors for dependable investigation. It assists to gather and save dependable evidence from a network of tremendously scattered smart vehicles [130]. This framework is also very useful in preserving the evidence and assuring the integrity of the saved evidence. In [131], various threats to smart vehicles are reviewed by the authors. In this paper, a new technique to investigate smart vehicles is proposed and tested. But still, this technique needs to be validated with data produced by a network of smart vehicles in an actual scenario.

3) DRONE FORENSICS

In [132], the authors proposed a new approach for the forensic analysis of the data gathered through drones. Here the reference data used for forensic analysis is collected from the DJI Phantom III drone. Drone Open Source Parser (DROP), a new tool to format the data and prepare for internal storage of the system is also proposed. In this paper, it is elaborated that the drone is controlled with the help of mobile and various types of data files are also found on the controlling mobile phone. The data collected in these files aid to identify the location, flight time, and other related information of the drone under observation. But the main limitation of the work is, it focused only on one type of drone, so work is needed to be extended for other types too.

4) CLOUD FORENSICS

Cloud forensics acts as a backbone to the IoT forensics. In [133], the authors proposed a new technique to gather and analyze data from the newer BitTorrent Sync peer-to-peer cloud storage service [134]. The data is generated by experimenting with a variety of diverse smart systems. In this study, it has been observed that data stored in various log files, installation records, and metadata can be recovered. It is highlighted by the authors that states of data in memory should be conserved for accurate forensic analysis. The main advantage of this study is that it can assist in the analysis of similar cloud datasets whereas it has not been legitimized with actual device manufacturers [135].

5) SMARTPHONE FORENSICS

In the modern era, people are highly dependent on smartphones. Smartphones play a major role in the exchange of text, audio, and video data. Criminals can commit different types of crimes using smartphones like transaction frauds, harassment, child trafficking, pornography, etc. It is very difficult to elicit data related to the above activities from smartphones for forensic analysis. To solve this issue, the authors conducted a study [136]. In this study, the Samsung Galaxy S3 phone is used as a device of the experiment for data extraction to demonstrate that smartphones can be used for forensic analysis to investigate the criminals. It has been observed that to transplant a mobile phone is a tedious activity, as it is always associated with the risk damage of PoP components. Authors in [136] proposed a new methodology named PoP chip-off/TCA. This methodology aids in the transplantation of mobile phones. A new technique was designed and experimented successfully for the forensic transplantation of a cryptographic Black-Berry 9900 PGP mobile phone.

6) HEALTH CARE FORENSICS

The Healthcare sector is one of the most prone domains to major security threats. The main reason for this is the diverse nature of medical application and heterogeneity of the types of equipment used, so broader surface for attacks [58], [137]. Besides evolution in the health care industry plays a major role in the development of human lives, but various smart health monitoring systems also put the security of patient’s medical data on risk. IoT based fitness systems could be targeted by the attackers to steal data of the users which can be further misused [138]. Numerous medical identity thefts have been identified in the past which expresses the importance of medical data. In the domain of medical health services and applications, compound annual growth of 29-30% is expected from the year 2019-2025 [139]. Many fitness wearables can be used as a source of evidence in criminal investigations as these gadgets keep on storing the data related to routine activities of the users at the back end passively. So, although these gadgets were designed to maintain the health status of the users but can also be used as digital evidence [12]. As the number of users, smartwatches, and fitness bands are increasing day by day, so the study of these IoT devices has become the center of interest for forensics practice. But according to the authors in [140], data extracted from these gadgets may be personal to the users, so special attention should be given to the security of this data. As the number of security-related issues is increasing exponentially, there is a requirement of more advanced techniques to ensure the security of data [141].
7) GENERAL IoT SYSTEM FORENSICS

In [12], the authors came up with a new investigation platform for diverse IoT systems. A risk judgment scheme was designed and modeled dependent on STRIDE and DREAD methods. It was discussed with the help of these two exemplary models that cybercrime committed in the IoT environment can even cause serious risks like death. Consequently, it was observed in the study that most of the IoT systems are not deployed with default security measures, so possess high risks. A study was carried out [142] to analyze the significance of the sync data in evidence analysis. Sync data contributes to the fair investigation of the digital witness. A survey was conducted [143] by the authors to study and analyze forensic investigation techniques for data stored in the system memory. Few meaningful alterations for the operating systems were also impressed upon in this study. In [144], data contraction and partially automated analysis techniques to handle a huge volume of digital evidence were suggested. This technique assists in the analysis of a variety of IoT data gathered. In [145], the authors discussed the approach of gathering, saving, and communicating the digital evidence in a secure way to a genuine destination. Some technologies to bring it in practice were also highlighted by the authors. Along with, basic components of the electronic evidence were also described. In [146], a novel approach to club cloud-native and cloud-centric forensic for the Amazon Alexa ecosystem was proposed. A new framework named “Probe-IoT” is presented in [147] which aids to identify criminal evidence in the IoT environment using electronic logs. These logs preserve the complete information regarding all the data exchanges between things, users, and cloud services. This framework was not tested experimentally but conceptually safeguards the integrity of the evidence. In [148], the authors presented a novel model for IoT forensics named PRoFIT to ensure the implementation of standards in the course of forensic analysis. This model was tested in the true IoT environment deployed in a coffee shop. 1-2-3 zone approach is applied by the authors [149] for IoT forensic analysis. According to the authors, concerned persons and pieces of evidence fall in zone 1, things or devices near to the boundary of the network fall in zone 2, and devices exterior to the network are capped in zone 3. This approach was developed with an aim to support accurate IoT investigation. But practical implementation of this approach is comparatively challenging. The authors in [150] presented a new framework dependent on three-layer architecture. The proposed framework has many advantages to ensure data security with only one disadvantage that it was not much suitable to cope up with the limited resources of IoT devices like processing power, battery, etc. The researchers in [151] proposed the design of a new model to help the forensic expert for IoT evidence analysis. This model was proposed to preserve volatile data in IoT devices. This work was planned as an extension of previous research. Using this model, forensic experts can investigate a broader surface in the data domain. But it has been observed that this model is laborious to implement in a true environment. In [152], the authors presented IoT forensics in a new way. In this work, the IoT domain was methodically explored to disclose the various challenges in the domain of digital forensics. A novel technique named Forensic Aware IoT (FAIoT), was introduced, which was focused to uncover new details in an IoT environment. But the applicability of the approach is doubted as it was not verified in IoT environment. The authors [153] analyzed prominent technical issues in digital forensics which can obstacle the identification of important facts for investigation. The various research issues, which can significantly improve the process of digital forensics, were also highlighted in this work. Various types of the attacks that are frequently planned on the devices in an IoT environment were discussed in [154] along with the complexity which they add to the digital investigation. The hackers make use of a huge number of random-UDP attacks at the same time by using UDP datagrams of varying sizes. Consequently, the denial of service is caused. In this paper, authors introduced a novel approach to handle these type of attacks by identifying their originators. But again the true implementation of the proposed work is lying on the back front.

V. ADVANCED IoT SECURITY

The smart devices and applications in the various application areas of IoT make human life more comfortable, but they also make different IoT systems more vulnerable to cyber-attacks. These devices and applications are connected to the internet, which creates new opportunities for cybercriminals to enter the IoT environment. Cybercriminals can enter an IoT system through routers and can damage it in many ways. Although several security mechanisms are available in IoT, advanced technologies like Artificial Technology, Machine Learning, Neural Networks, Blockchain technology, Fog computing, and Edge computing are playing a major role to handle cyber attacks thus limiting cybercrime [155].

Authors in [156] discussed in brief the various kinds of security threats in an IoT environment. The need for a dynamic and quick system to safeguard the IoT systems against cybercrime is impressed upon. The authors proposed a hybrid system to detect cyber attacks using AI & ML in a cloud computing environment with the proposed system. Both types of attacks i.e. device level and network-level can be detected with this model. According to the authors, it is considered by the security experts that AI & ML provide very strong security mechanisms as even future attacks may be predicted based on past IoT attacks data. Consequently, this system does not wait for the occurrence of the attacks but can predict in advance. The main limitation of the system is that it can work only on standard data formats for predictions. Along with ML provides
solutions to the DoS attacks, eavesdropping, spoofing, and privacy leakage in an IoT environment [15].

Authors in [157], presented a multilayer architecture to associate the various devices within IoT to make them accessible throughout the network all the time. To deal with security issues of end nodes and to provide more credible services, a novel framework using Neural Network was proposed. According to this framework, security issues need to be tackled in each layer of the IoT architecture. Each end node configured using a framework will have the potential to self-monitor and recover after any unwanted event/attack. In the proposed framework, the NN based adaptive model was used for the automatic recovery of the nodes.

In [158], the authors presented an Artificial Neural Network approach to control Distributed Denial of Service (DDoS) attacks. The ANN was tested in a simulated IoT environment. The results obtained with the proposed technique were found to be 99.4% accurate and this technique is capable to identify numerous DDoS/DoS attacks.

Authors in [15], highlighted that incorporation of blockchain in IoT systems has numerous benefits. It is highlighted that the distributed architecture of blockchain reduces the risk of failure of data storage nodes. Thus leads to more secure data storage in the IoT environment. As the concept of data encryption is used by the blockchain for data storage in the IoT environment, so there are fewer chances of storing damaged data from the things. The augmentation of blockchain with IoT also helps to prevent unauthorized access, data loss, and spoofing attacks [159]. Various challenges in IoT along with the workable solutions administered by the blockchain technology are discussed below in Table 6:

**Figure 10. Possible solutions offered through Fog Computing [160-171]**

| Challenges in IoT | Specifications | Theoretical Blockchain Solution |
|-------------------|----------------|---------------------------------|
| Defect in Architecture | A point of failure exists in IoT devices that affect the device and the network. | Validation can be done using blockchain. The data is also verified through cryptography to ensure that a legitimate sender has sent it [172]. |
| Manipulation in Data | The data extracted from IoT devices is manipulated and is used inappropriately. | By deploying blockchain, the IoT devices are interlocked due to which, the system rejects any kind of change in data through IoT devices [173, 174]. |
| Service inefficiency due to heavy load on the cloud server | Cloud services malfunctions due to cyber-attack, power failure, or bugs in software. | Data records are uploaded on different nodes on the network. Due to the same data in different nodes, there is no single point of failure [175, 176]. |
| Traffic and cost management | The handling of the exponential growth in IoT devices is a tedious task. | Due to the decentralization feature of blockchain, the IoT devices can be connected and communicated through peers bypassing the central servers [177, 178]. |
| Privacy issues in IoT devices | The user data present in IoT devices are more vulnerable due to cyber-attacks. | The permissioned blockchain can eradicate this problem [179-181]. |
In [15], the authors discussed that a huge volume of data is generated by the diverse devices in the IoT environment. It is very taxing to shift this entire volume of data to the cloud for real-time analysis of it, so the concept of fog computing evolved. Under this concept, the cloud framework is extended to the edge of the network [182]. Various characteristics and the possible solutions deployed by fog computing are shown below in Figure 10. Fog computing can handle the various IoT security attacks like man-in-the-middle attacks, data transit attacks, eavesdropping, and resource constraint issues very efficiently [183].

Authors in [15], discussed that the edge computing framework is an expansion of cloud computing. The location of the computational power and analysis mechanisms differentiate edge computing from fog computing in an IoT environment [184]. In edge computing, both these potential reside at the edge [185]. The various devices in the IoT systems coordinate to establish a network and also perform various computations required for data analysis within that network [186]. So, the need to communicate the data outside the device reduces which contributes to improved data security in the IoT applications. On the same grounds, this framework also aids to minimize the communication cost of data [187]. The concept of edge computing helps to handle data breaches, data compliance issues, safety issues, and bandwidth challenges in an IoT environment [188].

VI. OPEN RESEARCH CHALLENGES

The IoT Forensics is a complicated and regularly emerging domain. It plays a very crucial role in cybercrime investigation. But, many challenges need to be addressed very carefully. These challenges open the doors for further research in the field of IoT forensics [58]. So, the main objective of this section is to show a path to the researchers in the domain of IoT forensics to aid cybercrime investigation.

A. DATA LOCATIONS

In IoT systems, the data are saved at various venues in dynamic devices may be regulated by different administrations. Consequently, the investigators undergo serious problems to identify which regulations are to be followed when the device used to commit cybercrime was used in different networks and sites [189]. In this type of situation, crime investigation develops into a more complicated task. So, there is a need for standard processes and mechanisms to address this issue.

B. FORENSIC AUTOMATION

There are numerous technical issues faced during the automated IoT forensic analysis. The major problems which affect the process are the dynamic nature of the devices and the involvement of advanced methods in the process of forensic investigation. To obtain a real-time solution to the problem, there is a requirement for improved IoT automation. The authors in [123] presented a novel direction to IoT forensics by introducing an automated technique for forensics examination. It is also impressed upon by the authors that the diversity of IoT devices is the main hindrance in the real-time implementation of the proposed technique. So, some standard mechanisms are required to deal with the heterogeneity of devices and collected data.

C. DEVICE MANAGEMENT

In an IoT environment, sometimes a particular device malfunctions and starts generating malignant data. Although it may require shutting that device down, but may not be feasible for the forensic investigator to do so because of the owner’s rationality. For example, in a smart home if a washing machine is initiating vengeful data packets, but the owner does not pass his consent to stop it as it may disturb his daily functioning. Consequently, a big challenge is faced by a crime investigator expert because of the rationality of the users. So, a due amount of attention needs to be given to design the required mechanisms to provide the crime investigators freedom of forensic investigation without ceasing the working of the things.

D. DATA ANALYSIS

Forensic investigators deal with a huge volume of IoT data using various analysis techniques during the process of crime investigation to control cybercrime [190]. In an IoT environment, the data is collected and analyzed from the various devices, and results are used for various types of decision making in the investigation process [191]. As the process of data analysis and interpretation is complex, the accuracy of the results and further investigation is affected [144]. So, the need for more standardized, simple, and accurate data analysis tools and techniques arises is an important factor for consideration for future research.

E. SCOPE AND LIFETIME OF THE EVIDENCE

The limited storage of the IoT devices deters the availability of the evidence for a long time which results in the loss of crucial data related to cybercrimes [120]. To overcome this problem, forensic data should be transferred frequently on the cloud. But the process of data transfer gives rise to another challenge to ensure the evidence has not been manipulated during the process. Another major issue is related to the visibility of the evidence. The
presence of a few malignant sensors at the crime scene may affect the working of the forensic investigator to locate the witness equipment. Although log files from the various devices may assist the forensic expert but do not provide the complete set of evidence for the investigation.

F. USER’s PRIVACY

Although the entanglement of IoT devices in the various domains has made human life very comfortable. However, it has put the privacy of the users of smart devices on the stake. It has been observed that there is a huge lack of privacy-specific forensic mechanisms for the IoT environment [192]. The main loophole of most of the available forensic solutions is that the privacy aspect of the users is ignored during the process of the investigation [193]. All the investigation solutions proposed in [145], [148], [194] have serious privacy challenges. In very diverse and dynamic IoT systems, the practice of suitable privacy measures can enhance the involvement of digital evidence for more cybercrime investigations.

G. SECURITY

The diverse nature of devices in the IoT environment opens a new space for unauthorized users to attacks the system, which is very difficult to identify during the forensics investigation. Consequently, the process of collection of evidence becomes more tedious. So it is very important that during the design of various forensic investigation mechanisms, the diverse nature of IoT systems should be kept in mind [195]. The authors introduced the concept of security and privacy in [52], [196]. Proposed approaches provide more liberty to the forensic investigators by leaving aside the security issues. By considering the diverse and dynamic nature of the IoT environment, more such kind of techniques are the need of the hour in cybercrime investigation [197].

VII. CONCLUSIONS

IoT is a developing technology, which has bestowed human life with comfort. But, with the growing practice of IoT devices in various domains related to the business and personal life has put personal and data security at greater risk. A huge volume of data is exchanged openly among the various smart devices in an IoT environment, which attracts hackers to penetrate the security system. The dependence of the IoT systems on wireless communication technologies makes them prone to cyber-attacks; the root cause of cybercrime. In this paper, we presented the various elements of the IoT framework like architecture, protocols, technologies, and application domains. A detailed review of the security aspects of an IoT environment from the year 2010-2020 is presented. Various security aspects at each layer, which may facilitate the intruders to commit cybercrime, are also discussed. Implementation of the security mechanisms at each of the layers of IoT architecture is discussed. The role of IoT forensics and advanced technologies in cybercrime investigation is impressed upon in this review. At last, the various open research challenges of the domain are presented which can facilitate the process of cybercrime investigation.

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