Recent advances in Blockchain Technology: A survey on Applications and Challenges

Saqib Hakak, Wazir Zada Khan, Gulshan Amin Gilkar, Basem Assiri, Mamoun Alazab, Sweta Bhattacharya, G Thippa Reddy

Abstract—The rise of blockchain technology within a few years has attracted researchers across the world. The prime reason for worldwide attention is undoubtedly due to its feature of immutability along with the decentralized approach of data protection. As this technology is progressing, lots of developments in terms of identifying new applications, blockchain-based platforms, consensus mechanisms, etc are taking place. Hence, in this article, an attempt has been made to review the recent advancements in blockchain technology. Furthermore, we have also explored the available blockchain platforms, highlighted and explored future research directions and challenges.

Index Terms—Blockchain technology, Blockchain platforms, Healthcare, Cybersecurity, Finance, Smart city, Smart Grids, Logistics, Supply Chain, Ownership services, Hyperledger.

1 INTRODUCTION

Blockchain is a promising technology which is at its infant stage. Blockchain is integration of three concepts namely, cryptography, consensus mechanism, and network. The private key concept of cryptography is used in blockchain to fulfill the requirement of authentication i.e. copyright and ownership related reasons. It helps in reducing the probability of personal information exposed to hackers. Blockchain uses distributed peer-to-peer network to transfer the authenticated information. The main reason behind usage of distributed network over centralised network is no single point of failure. The concept of consensus mechanism is to govern the whole transaction process by enforcing specific set of rules.

As mentioned above, blockchain is a distributed ledger with immutable entries. A blockchain ledger consists of several blocks connected through hash functions[1], [2], [3], [4], [5]. Figure 1 shows, the basic structure of a blockchain wherein each block contains information of previous block via hash functions and are distributed across the network of private computers known as ‘Nodes’. Each node in the blockchain network will have a complete copy of the transaction history of blockchain. The nodes communicate to maintain the copies of the ledger and to synchronize processes. When a transaction is initiated, a message is broadcast to all nodes in the network for approval to check validity of the transaction. After all nodes check the validity of a transaction, there is a sort of electronic vote, wherein few nodes accept the validity of transaction and others may not. If majority of the nodes vote for validity of transaction then the blockchain is updated. Therefore, it is very difficult for the attacker to change content in blockchain. In case, an attacker wishes to modify contents, then entries in more than 50 percent of the nodes need to be changed which is practically impossible. For the validation of blocks, consensus algorithms are required. Some of the most prominent consensus algorithms include PoW (Proof of work) [6], [7], [8], PoS (Proof of stake)[9], [10], PBFT (Practical byzantine fault tolerance)[11], [12], DPOS (Delegated proof of stake)[13], [14], Ripple[15], [16] and Tendermint[17], [18], [19].

As research developments in the area of blockchain is on rise, there are several survey articles available highlighting key developments. A list of such articles are presented in Table 1 and have comprehensively reviewed articles till year 2018. All these studies have focused on different aspects of blockchain. The work of [20], [21], [22], [23], [24] have focused on the integration of blockchain technology within IoT/smart-city based applications. The following articles [25], [26], [27], [28], [29] have highlighted the fundamental aspects of the blockchain technology such as comparison between consensus algorithms, taxonomy of blockchain systems, architectural challenges and other related criteria. In the work of [30], the authors have highlighted the potential applications of blockchain using cloud computing. Similarly, [31] has reviewed the state-of-the-art blockchain technology in public services. [32] has reviewed the applications of blockchain technology in vehicular Adhoc network (VANET). Finally, [33] have explored security and privacy issues while as [34] have reviewed state-of-the-art security services in blockchain.
To the best of our knowledge, this article is the latest comprehensive survey that highlights the recent advancements of blockchain technology. Compared to existing review articles above, the contributions of this article are enlisted as follows:

- Recent state-of-the-art blockchain technology in IoT, Financial services, Government services, healthcare, supply chain and cybersecurity is presented.
- Popular blockchain platforms are enumerated and discussed.
- Taxonomy based on the state-of-the-art blockchain platforms is proposed.
- Future research challenges and applications are identified and elaborated.

The rest of the article is organised as follows: Section II presents the overview of available blockchain platforms. State-of-the-art is presented in Section III. Current research challenges and future research directions are discussed in Section IV and V respectively. Section VI contains the discussion and the article is finally concluded in section VII.

2 Available Blockchain Platforms

Blockchain technology is emerging very fast since its concept was first coined in 2008. The first-ever application in form of crypto-currency known as bitcoin was build upon the concept of blockchain technology. Till to-date many blockchain platforms, where blockchain-based applications can be developed and deployed have been successfully proposed and developed. In this section, we have briefly described and highlighted (summarized in Table 2) few popular blockchain platforms.

2.1 Bitcoin

The concept of first ever blockchain in form of cryptocurrency called bitcoin was coined by Santoshi Nakamoto in 2008 [6]. The Bitcoin is an electronic cashing system which allow peer to peer online electronic cash payments directly among parties without the intervention of the central financial institutions. There do exist options for digital signatures but there are instances of double spending and the proposed Bitcoin technology aims to resolve the same problem. The transactions using bitcoin are timestamped by hashing into an ongoing chain which acts as a immutable record. The chain reflects the chain of events in a transaction and also the used CPU power. A node proposes a transaction and the other nodes vote to commit or abort it through consensus. The simple architecture of the network makes it robust and messages are routed to a location based on the best effort. The bitcoin technology also allows to include all sorts of rules and incentives to fit the purpose.

2.2 Ethereum

Vitalik Buterin has proposed and developed the Ethereum blockchain in 2013. Ethereum is among one of the most popular and widely used open source permissionless blockchain platform. Ethereum also provide smart contract functionality. Solidity is used for writing of Smart contracts. The crypto-currency of Ethereum is called Ether, which are used for payments and incentives among the client nodes. Ethereum use Ethash as it’s hashing algorithm. The applications in Ethereum are called Dapps which runs on the top of Ethereum Virtual Machine (EVM). Ethereum is more efficient then bitcoin in-term of transactions processing, and storage.

2.3 Hyperledger

This platform is an open-source blockchain project started in december 2015 under linux foundation. Several high-tech giants like Intel, IBM and SAP has collaborate and develop DLT-based blockchains. Currently, with advancements, there are five hyperledger based frameworks namely: Burrow, Fabric, Indy, Iroha and Sawtooth. According to IBM the
existing and most popular enterprise blockchain platform standard is Hyperledger-Fabric and over 400 developers and more than 66 organizations are developing their application on the top of this platform. These organizations are getting the benefits from the open-source nature of the Hyperledger platforms by developing straight-of-the-art applications with features like accountability, transparency and trust. IBM-blockchain platform is one of the recent enterprise-ready platform built on hyperledger-fabric stack which allows users to deploy any suitable network as per their requirements. For easier deployment of networks, it comes equipped with ansible playbooks and offers Node.js, Golang, Java, or JavaScript platforms for writing smart contracts. It also offers flexibility and scalability features in terms of amount of CPU and storage needed, memory using Kubernetes cluster. In kubernetes cluster, various nodes pool together to form a powerful machine.

2.4 Hedera Hashgraph

This platform is built on hashgraph distributed consensus algorithm which can process thousands of transactions per second with low bandwidth usage and is deployed using Hedera Smart Contract API. It is light weight fair platform which supports both applications i.e. open source and proprietary. As it is proof-of-stake based platform, it is one of the fastest platform available where there is no overhead of heavy computing which is otherwise associated with PoW. It supports smart contracts written in solidity only.

2.5 Corda

Corda is also an open-source platform used for recording and processing financial agreements. The applications are executed in the form of CorDapps. Corda is developed by a technology company known as R3 or R3LCC. In 2016 R3 made Corda publicly available as open-source blockchain to attract businesses and research communities around the world to adopt and utilize their platform and contribute to its development. Currently, Corda is used by many international enterprises and financial institutes for various applications such as banking, finance, trading, mortgage, and for digital currencies. Corda is built purely for fast and low-cost direct business transactions and through its smart contract and prevention of global transaction broadcast functionality the privacy between businesses are strictly ensured. Smart contracts in Corda are written in Java or other programming languages compatible with JVM and are executed using JVM-bytecodes.

2.6 Multichain

It is an open source platform with access to code on GitHub. This platform is suitable for those organisations/users who are interested in developing financial applications on permissioned network. Instead of multiple validators per block, each block is verified by a single validator in a round-robin format. For deployment purposes, it requires three basic commands where "multichain-util create" is used to initialise a new blockchain and to host blockchain on a node "multichaind" command is used. Finally, the client can per-
form actions using "multichain-cli” command. It supports smart contracts written in JavaScript.

2.7 BigchainDB

With a blockchain database, this platform provides developers a proof-of-concept environment for deploying their applications and supports a wide range of industries and use cases. For retrieving any record, transaction, block etc., MongoDB query is used and for consensus mechanism, Tendermint’s Byzantine Fault Tolerant (BFT) mechanism is followed. As this platform is suitable for both private/public network-based applications, it does not support smart contracts. Instead, for a successful transaction to take place, certain crypto-conditions must be full-filled. These conditions can be a simple signature condition, hashlock-condition or a timeout condition. For deployment purposes, it requires installation of BigchainDB server, MongoDB and Tendermint.

Several other such platforms include Openchain, IOTA, EOS, Stellar, Quorum, Monero and Neo. As with more advancements in blockchain, more such platforms will be available and to select appropriate platform is a challenging task. However we believe, cheap pricing model, easier deployment, public/private network support and user-friendly graphical interface are the key requirements that would interest developers and organisations.

3 Recent Advances of Blockchain

It is a tedious task to review all the latest developments in the area of blockchain technology. An attempt has been made to explore the state-of-the-art blockchain technology in different research domains and categorise those works as per platforms used alongwith target applications. However, there are studies which are conceptual and present theoretical aspects of blockchain technology. We have presented the taxonomy in Figure 2.

3.1 Ethereum

Majority of the latest works have used Ethereum-based platforms for implementation. In this section, we have highlighted those studies with main features highlighted in Table 3.

The authors [35] have proposed a blockchain-based tool for smart grids to manage transactions. Ethereum which is a public blockchain-based distributed computing platform has been used in this work. The process starts by writing smart contracts for saving data generated from meter and smart phone. With the use of Ethereum, the electricity consumption is continuously generated through meter whereas the smart phone continuously updates the policies for air conditioner and light bulb. The air conditioner and light bulb update their respective devices by constantly checking values on Ethereum. In case of need, these devices change their respective modes from normal to energy-saving. The simulation was carried out using Raspberry Pis, meter (that updates Ethereum periodically), smartphone (for writing policies for LED and air conditioner).

F. Longo et al. [36], have designed and developed a software connector to connect an Ethereum-like blockchain with the enterprise’s information systems so that companies can share information with their partners with different levels of visibility and to check data authenticity, integrity and invariability over time through the blockchain. A simulation model is developed to recreate the supply chain operations including the flow of goods and information among them and all their main organizational, production and delivery processes and to carry out a scenario statistical analysis. It is integrated with the blockchain through the same software connector which bridges the blockchain with the supply chain simulation model (or with the enterprise’s information system if it is deployed in area supply chain environment). In this study, three wholesalers and twenty big-box retailers are modelled. The Ethereum-like public blockchain, called UnicalCoin represents the decentralized ledger where all the information regarding demand forecasts and inventory levels are stored. Participants in the UnicalCoin blockchain keep this ledger in synchronisation through a consensus protocol and the higher is the number of participants, the higher is the network success.

L. Y. Yeh et al.[37] have proposed a DDoS information exchange platform namely SOChain for mitigating DDoS attacks. Most of the security operation centers (SOC) are unwilling to share their DDoS data due to the lack of proper exchange mechanism. Hence, in this study, the SOChain platform rewards the respective SOCs through the incentive mechanism in the form of DDoS coin. A particular SOC can earn more coins based on the amount of DDoS information it contributes. Besides, the authors have further used bloom-filter to address privacy concerns for each uploaded and purchased DDoS information. To store the encrypted DDoS information, a P2P storage system known as Swarm has been used.

Z. A. El Houda et al.[38] presents a blockchain-based approach, called Cochain-SC to mitigate DDoS attacks. The proposed framework works by allowing collaboration among multiple software defined networks (SDN) to securely transfer attack information such as suspicious IP addresses in a decentralised manner using blockchain technology. To facilitate collaboration for mitigation purposes, smart contracts have been used.

Wilczynski and KoÅœdziej [45] have developed a new blockchain-based cloud scheduler model. Unlike other similar models, it’s attempted to unload the design of the blockchain system. They created a novel “Proof-of-Schedule” consensus and used Stackelberg games to boost acceptance of the produced schedules. The built model has been experimentally selected and tested with new original cloud simulators. The suggested blockchain scheduler was also linked to other chosen cloud schedulers. The experiments show that the method used significantly improved the efficacy of the schedules drawn up, in most situations the simulator returns a schedule more effectively than any current scheduling modules.

R. Doku et al. [39] proposes Event-Based Encryption (EBE) to avoid adversarial attacks. The purpose of the proposed scheme is to encrypt a will of a person and decrypt the same in the event of the death of that person. There are two stages in the proposed scheme which are data verification and event confirmation. In the data verification stage, the goal is to verify the data concerning
the death of a mentioned person. Once data is verified, using a question/answer session, an attempt is made to confirm the event. All this vetting process of data and event confirmation is carried out using a blockchain-based decentralized network which ensures data integrity and avoids adversarial attacks.

J.Wan et al. [40] have proposed a five-layer (the sensing layer, the management hub layer, the storage layer, the firmware layer, and the application layer) blockchain-based architecture for a smart factory. The architecture is divided into two components i.e. intranet and extranet. Data collection and storage are handled by intranet whereas extranet is responsible for providing different services to users. To ensure the security and privacy of the architecture, the Bell-La Padula (BLP) model is applied along with SHA256 and elliptic curve algorithms.

Koirala R.C. et al. [41] emphasized on securing transactional data using blockchain. In this work, a blockchain-based model for the supply chain is presented. The proposed model depicts the interaction between all the stakeholders in a supply chain model. The proposed model was implemented using three smart contracts using an Ethereum platform. The model helped to organize the administrative process thereby automating the transaction process ensuring an optimum level of efficiency and transparency. The wholesaler prepares a purchase order based on the quote along with the pre-required terms and conditions forwarded by the producer of goods. This is broadcast through the initiation of a smart contract. In this way, the ownership management of the supply chain is entrusted by blockchain wherein each stage of the supply chain is traceable and also each stakeholder can claim ownership of the respective process.

Roriz et al. [42] have developed a blockchain-based solution using Ethereum technologies for insurance fraud avoidance in the vehicle sector. In the proposed system a front end and a back end is available for every insurance company. DApp is used in the front end for interactions of the employees. The blockchain runs in the back-end, a node represents an insurance company. The proposed system provides several services like creation of insurance claims, the history of a vehicle, etc. The usage of blockchain enables that the history of vehicles is tamper-proof, hence insurance companies can save a lot of time which is wasted in the verification of events like accidents.

M. N. Islam et al. [43] have proposed a system to make customers capable of verifying the authenticity of a device or system. The implementation includes creating a unique identity of the IC and binding the same to the Blockchain consisting of a physically unclonable function (PUF). The blockchain-enabled smart contract system thus allows stakeholders to authenticate, track, and analyze the chips through its entire life cycle. The study also mentions the fact that PUFs are not tamper-proof and are prone to risks due to the use of Focused Ion Beam (FIB) that can create fake clones acting as a limitation to the existing study. However, the use of FIB would be extremely costly and exhaustive for each chip implementations.

Jnoub et al. [44] provided a blockchain-based solution emphasizing on two aspects. Firstly to register copyright owners with author information and complete information about the image. The second step involves stopping raw
data pertinent to the image from being inserted in the Blockchain rather, storing the same using descriptive yet unique metadata. This ensured making the image data immutable thereby saving computational cost as well.

### 3.2 Hyperledger

After Ethereum, the next popular platform seems to be hyperledger as few studies have used this platform for their works. This section highlights all those studies and are summarized in Table 4.

Wang et al. [46] proposed a blockchain-based architecture for managing crowdsourced energy systems (CES) for energy trading transactions. The authors have proposed a two-phase algorithm where the first phase takes care of day-ahead scheduling and distributed energy resources. The second phase deals with the hour-ahead operation of distributed networks. This approach guarantees seamless trading of energy. The algorithm and CES are prototyped using a Hyperledger Fabric implementation for seamless energy trading. Usage of the blockchain makes sure that the participants in the trading of the energy are from within the service regions of the grids and also ensures the privacy of the data from crowd-sources.

I. Makhdoom et al [47] have proposed a blockchain-based framework for sharing IoT devices data in smart cities called PrivySharing. The proposed framework achieved the privacy of data by classifying and processing the data into different channels and according to the types of applications. Secure access control and access policies to the blockchain data are ensured with the help of smart contracts. For secure communication between users and blockchain various APIs and protocols are utilized (e.g., OAuth 2.0, REST, and Key APIs). Users who share their data with 3rd parties and other stakeholders receive rewards in the form of PrivyCoin. Few example applications of smart cities for data sharing were implemented. Hyperledger Fabric v 1.4 with SOLO and Kafka based consensus algorithms were used for experimental purposes.

P. Khan et al [48] have presented a blockchain-based CCTV video data validation and verification system in smart cities. The proposed system is used for the management, usage, and authentication of videos taken from CCTV cameras. The system work in various phases, the first phase called registration phase, in which the devices and users are registered. In the second phase, all devices and users are assigned a unique key using MPS (membership service provider). The captured videos by devices (CCTV cameras) are encrypted and stored in the form of blocks after the endowment of peers. The users can access the stored videos in the blockchain using smart contracts. The user sends their access request through the REST API. For experiments, the authors have used Hyperledger Fabric blockchain and only technical details are provided related to implementations. However, the issues related to scalability, management, fast processing, and storage of a large amount of real-time video

| Study | Area | Applications | Blockchain Technology | Consensus Protocol | Type of Blockchain | Smart Contract | Objective |
|-------|------|--------------|------------------------|-------------------|--------------------|---------------|-----------|
| [35]  | Smart Grid | Audit or solving a transaction dispute | Ethereum | PoW | Public | Yes | Manage transactions in the smart grid |
| [36]  | Supply Chain | Trust and collaboration between companies and their partners | Ethereum-like (UnicalCoin) | NA | Public | Yes | Integration of supply chain operations with the blockchain |
| [37]  | Cybersecurity | DDoS Information exchange platform | Ethereum | PoW | Consortium | Yes | Overcome trust and fairness issues |
| [38]  | Cybersecurity | DDoS Information sharing platform | Ethereum (Ropsten) and Gananche simulator | NA | Private and Public | Yes | Detect and mitigate illegitimate traffic flow |
| [39]  | Cybersecurity | Will agreement and Adversarial attacks | Ethereum | NA | NA | Yes | Securing Will agreement against adversarial attacks |
| [40]  | Cybersecurity | Security and Privacy in Smart factory | Ethereum | PoW | Private | Yes | Secure access to shared pool of industrial resources |
| [41]  | Ownership Services | Supply Chain Bidding Contract | Ethereum | NA | Public | Yes | Streamlining and automation of the administrative process involved in supply chain transaction system |
| [42]  | Insurance Industry | Vehicle Insurance | Ethereum | NA | Public | Yes | Application of blockchain and smart contracts in improving operations in vehicle insurance system |
| [43]  | Ownership Services | IC Supply chain | Ethereum | NA | Public | Yes | Creating an open traceability protocol for IC supply chain |
| [44]  | Copyright Protection Management | Digital image and multimedia data protection | Ethereum | NA | Public | No | Detection of image tampering using blockchain technology |
data captured by CCVT cameras in smart city environments by the proposed system are still not addressed which may limit the applicability of the proposed system.

J. Zhang et al. [49] have proposed a blockchain-based trustworthy and transparent channel for all the stakeholders in the used car business. The proposed system stores all the data related to the used cars in a blockchain. The PBFT consensus protocol is used in the proposed model to realize the blockchain nodes’ operation. The blockchain network is simulated using Hyperledger fabric. The blockchain-based solution ensures that the buyers of the used cars are resented with authenticated and verified data related to the used cars.

Liu et al. [50] proposed a blockchain architecture based on cloud computing. The various sub-processes and departments are included under a blockchain system and it provides the necessary services pertinent to inspection, excessive behaviour analysis, and other related insurance services. The authors propose a blockchain-based system that has a core layer, a network layer, an application layer, an interface layer, and a cloud platform layer. Based on this system the authors designed 3 blockchains for the anti-fraud healthcare insurance system. The 3 blockchains provide the following services: medical process information service, third-party responsibility inspection service, healthcare insurance bill inspection service. Hyperledger fabric is used in this work to simulate the blockchain network.

Demir et al. [51] highlighted the uses of bitcoins and cryptocurrencies, as part of Blockchain technology have contributed to eliminating fraudulent transactions in vehicle insurance systems. Hyperledger is used for simulation of blockchain which has “Insurance Sharing Record” and "Insurance Record” entities. The proposed blockchain-based system has considered several transactions based on vehicular insurance like the purchase of a vehicle, after an accident, police control.

3.3 Bitcoin

As Bitcoin gained popularity in the initial years, limited recent studies have used this platform as highlighted below and summarized in Table 5.

Sun Yin et al. [52] have used a supervised machine learning algorithm to predict the yet-unidentified entities and the results reveal a high level of accuracy. The bitcoin blockchain clusters have been classified using multi-class classification. The aim of the paper is to understand several bitcoin-based transactions for the information on regulation and compliance aspects at managerial and organizational levels. The proposed method has potential applications in organizational regulations, compliance, and at various levels of societal implementations.

A. D’Souza et al. [53] have successfully applied Blockchain technology to protect the design ownership of T-shirt designers wherein, unauthorized designers have been barred from accessing artwork. This has helped the designer community as well as customers ensuring fake products are not sold and genuine artists get their due credit and profit. The blockchain-based solution enables the customer to identify the genuine products by verifying the owner/source of the design.

X. Han et al. [54] mentions that there exists a huge gap between decentralized cryptocurrencies and the central bank digital currency (CBDC) in terms of the circulation of money and its related governance. Hence, the authors have proposed a blockchain-based CBDC scheme consisting of three layers namely the supervisory layer, network layer, and user layer encompassing issuance circulation and withdrawal. The proposed CBDC framework provides the following functionalities: currency issuance, identity authentication, with-drawal of currency, and circulation of currency. The authors demonstrated the working of the framework through a cross-border payment use-case.

3.4 Other Miscellaneous Platforms

There are few studies where either platforms used were not specified or less-known platforms were used. The main features of those studies are highlighted in Table 6 and their summaries are presented below:

Singh et al. [55] proposed an IoT based architecture where blockchain is used to ensure the trustworthiness of

| Study | Area | Applications | Blockchain Technology | Consensus Protocol | Type of Blockchain | Smart Contract | Objective |
|-------|------|--------------|-----------------------|--------------------|--------------------|---------------|-----------|
| [46]  | Smart Grid | managing crowdsourced energy systems (CES) | Hyperledger-Fabric | Redundant Byzantine Fault Tolerance | Public | Yes | Seamless energy trading in smart grid |
| [47]  | Smart Cities | Data sharing of health, smart energy, and financial data. | Hyperledger-Fabric | SOLO and Kafka | Private | Yes | Secure Data Sharing |
| [48]  | Smart Cities | Forgery and Alteration Verification of CCTV recordings | Hyperledger Fabric | NA | Private | Yes | Management, usage, validation stored videos |
| [49]  | Ownership Services | Used car trading | Hyperledger Fabric | PBFT | Public | Yes | Create a transparent and secured trading platform for used car buyers and sellers |
| [50]  | Insurance Industry | Healthcare Insurance | Hyperledger Fabric | NA | Public | Yes | Anti-fraud system for healthcare insurance |
| [51]  | Insurance Industry | Vehicle Insurance | Hyperledger | NA | Public | Yes | Design a Blockchain framework for vehicle insurance management |
TABLE 5
Main Features of Bitcoin Based Blockchain Applications

| Study | Area                  | Applications       | Blockchain Technology | Consensus Protocols | Type of Blockchain | Smart Contract | Objective                                      |
|-------|-----------------------|--------------------|-----------------------|---------------------|--------------------|----------------|------------------------------------------------|
| [52]  | Cybersecurity         | Cryptocurrencies   | Bitcoin               | PoC                 | Public             | Yes            | Application of Supervised machine learning algorithm for de-anonymizing bitcoin blockchain. |
| [55]  | Ownership Services    | T-Shirt Design     | Bitcoin               | NA                  | Public             | Yes            | Achieve ownership of T-Shirt Design and eliminating non-trusted owners market fake products.  |
| [54]  | Banking Industry      | Digital Currency   | Bitcoin               | NA                  | Public             | Yes            | Framework for Central Bank Digital Currency (CBDC).                                    |

the devices in a smart home network. Multivariate Correlation Analysis (MCA) algorithm is used in this work for the detection of attacks like Denial of Service (DoS) in the smart home network. The experimentation is simulated using Cooja and Netsim simulators. Amazon EC2 cloud is used for the storage of the blocks in the blockchain. The experimental results proved that the blockchain is a highly secured solution for the IoT networks.

M. Li et al. [56] have proposed a blockchain-enabled workflow management system (BCWMS) to centrally share heterogeneous logistic resources with different customers. The proposed system is established on cloud computing architecture consisting of three core components i.e. virtual resource gateway (VRG), workflow operating platform (WFiOP), and blockchain-enabled agent-based workflow management method. Gateway technology is used to realize the UPnP (Universal Plug and Play) management of heterogeneous logistics resources. Workflow Operating Platform (WFiOP) is a critical component responsible for coordinating logistic resources. Agent blockchain service is consists of three sub-services (Agent service, Blockchain service, and Chain code service) and provide a method to bridge workflow agent with resource agents for execution. The consensus manager controls the consensus algorithms to achieve ledger consistency. The transaction is conducted and recorded by all distributed resource ledgers, after receiving enough confirmations.

Chen et al. [57] introduced BCautoSCF a commercial platform based on blockchain for Supply Chain Finance (SCF) for the auto retail industry. They have successfully developed a blockchain platform which is a reliable and efficient platform to decrease financial costs and speed up cash flows in auto retail industries in China. In this paper, it is proposed that the vehicles are provided with IoT based tags whose tracking information is stored periodically in the blockchain. This will enable the dealers/customers to keep track of the vehicles throughout the SCF network. Each vehicle is given a specific token. Each vehicle’s dynamics are captured in the blockchain which makes these records immutable. This ensures trust among all stakeholders. BCautoSCF has two financial modes that are integrated with the blockchain: inventory financing and supply chain financing. In both modes, each financial document is unique. Also, the documents are signed cryptographically by the relevant parties as per the respective transaction. The use of blockchain ensures that all the documents are authentic and hence reduce the time for manual verification of the authenticity of the documents that helps all the stakeholders in the SCF. As of October 2019, BCautoSCF had over 600 enterprise users. BCautoSCF was implemented using Xuper, a commercial blockchain infrastructure, and Practical Byzantine Fault Tolerance (pBFT) as a consensus algorithm.

3.5 Conceptual and Theoretical Studies

In this section, we have highlighted the theoretical/conceptual studies in the area of blockchain technology.

S. Hakak et al [58] have proposed a three-layered conceptual blockchain-based architecture for data security of various applications in smart cities. The first layer which is the application layer consists of different applications such as healthcare, smart cities, and so on. The second layer of the proposed architecture is for wireless communication and finally, the third layer is responsible for storage. For data collection different types of heterogeneous IoT devices can be utilized, for example for the energy consumption of each house in the smart city, the energy consumption readings will be collected using smart energy meters. The collected energy readings of each house will be transmitted and stored on private blockchain using appropriate wireless communication technology. Finally, the stored energy consumption information can be used for various monitoring, analysis, and billing purposes of each household. The authors have also presented the enabling requirements and open research challenges for the successful implantation of blockchain technology in smart cities. However, no experimental details are presented. The authors have presented the other study [59] where they have highlighted the need of blockchain in industrial wastewater management.

Rahman et al. [60] have proposed an innovative blockchain-based architecture to ensure security and privacy in providing smart contract services. This would work towards creating a shared economy in an IoT enabled sustainable smart city environment. The architecture consists of cognitive fog computing nodes to host as well as process multimedia transaction-related information which would be geo-tagged. The information is further processed using AI where significant information is extracted and semantic analysis is performed. The final output is saved in a blockchain and decentralized cloud storage system to ensure shared economic services. The architecture promises
to provide Spatio-temporal services at a global level without the need for a central verification authority. The proposed architecture however requires large scale testing for final deployment.

Zhao et al. [61] discusses the integration of blockchain and IIoT in the industry ensuring optimum storage capacity and enhanced security. A blockchain-enabled IIoT framework is presented with basic techniques. In turn, primary requirements and problems are dealt with. The blockchain-enabled IIoT provides a thorough analysis of the key enabling technologies, consensus models, and enlists the future directions of work in this sector especially in the fifth-generation communication technology.

S. S. Kamble et al. [62] have identified the factors that enable the blockchain adoption in the agriculture supply chain. The authors have highlighted thirteen important blockchain enablers for the successful implementation in the agriculture supply chain. The study concluded that tractability is the most important reason which motivates the adaptation of blockchain technology in the agriculture supply chain. The findings from this study can also help law and policymakers in implementing new policies to make the implementation of blockchain technology in the agriculture supply chain efficient and rapid.

A. Rejeb et al. [63] have explored the potential benefits of utilizing blockchain technology by IoT companies in the supply chain. Various issues related to data (integrity and collection), address (security), and traceability can be overcome by the integration of blockchain technology with IoT-based supply chain. Finally, six different research propositions are also suggested for the successful adaptations of blockchain technology in IoT-based supply chain companies.

E. Tijan et al. [64] have highlighted the possibilities of blockchain technology usage along with its applications in logistics and supply chain management. The authors have reviewed the recent literature related to the applications of blockchain technology in supply chain and logistics. Finally, the enabling challenges of blockchain technology in logistics are also presented.

A. Rivero-Garcia et al. [65] has developed a system for the authentication and tracking of different products and goods using a mobile application that provides real-time tracking of containers. The proposed system is based on blockchain which allows to carry out the whole process in an optimal way that guarantees the privacy and immutability of the data referring to the transports and merchandise. The proposed system works by placing an RFID tag in every merchandise of the container whereby all the information of the container and its merchandise can be read. In the second step and third step, an RFID reader is used to check if all the merchandise is in the container when moved from the different transportation systems of the supply chain, and the resulting state is written in the blockchain. In the fourth final step, when the container reaches its final destination, the contents are again checked for any alteration. In this way, any anomalies in the supply chain are registered.

Baker and Werback in [66] have discussed that the financial sector has made significant investments to adopt various applications of blockchain technology having high hopes regarding its potential benefits. It is suggested in the article that blockchain deployment in the financial sector could lead to an increase in efficiencies in payment, financial process arrangements, asset management, insurance facilities, and coordinations in corporate governance. The deployment of blockchain would have a significant impact on transforming business processes enhancing the trade lifecycle securities, payment processes, asset management, and corporate governance facilities.

Kouhizadeh et al. [67] discussed the impact of blockchain applications in the circular economy. The concept of the circular economy is discussed at various levels - individual, local and global for various small, and large scale businesses. The circular economy renders new business and economic opportunities along with environmental and societal benefits. The paper highlights the positive effects of a blockchain-enabled circular economy where product deletion aspects are given the immense emphasis on product portfolio management. The article strives to establish the relationship between blockchain technology, product deletion, and circular economy. The implications of such applications include the ability of customers to track product life cycle information, incentivizing product returns in supply chain management, storage, and recording of supply member products and efficient waste management. The authors intend to focus on data acquisition, hypothesis development, analysis, and testing from real-world studies to determine long term implications and analysis of the same at various levels.

Polivyiou et al. [68] discussed the negative implications of blockchain applications. The ransom can be paid in any cryptocurrency because of tracking difficulties. Blockchain

| Study | Area | Applications | Blockchain Technology | Consensus Protocol | Type of Blockchain | Smart Contract | Objective |
|-------|------|--------------|-----------------------|-------------------|-------------------|---------------|-----------|
| [55]  | Smart Home | Smart home network security | SH-BlockCC | NA | Public | No | To achieve confidentiality and integrity in a local smart home and overlay network |
| [56]  | E-commerce logistics | Workflow management system | Finite resource blockchain (FRBc) | PoET, PoW, PoS | Public | No | Guarantee the data reliability for decision-making |
| [57]  | Ownership Services | Supply chain finance | Xuper | pBFT | Public | Yes | Decrease financial costs and speeding up of cash flows in auto retail industries in China |

TABLE 6
Main Features of Other Blockchain based Applications
technologies that were initially used in the form of cryptocurrencies have progressed much ahead integrating decentralization, anti-tampering and, various other transparency technologies. These technologies have contributed immensely to solve significant issues in the financial sector and have almost revolutionized the financial industry. In this paper, the authors have highlighted 5 use-cases in the financial sector which are expected to be transformed with the application of Blockchain technology.

Ding et al. [69] have combined Blockchain technology with digital registration technology to design a completely secured copyright registration protection application system ensuring security in data storage and transaction. In the proposed system, The details of the copyright buyers and copyright owners are stored in the blockchain. The details of the transaction are circulated to all the nodes in the blockchain network and are endorsed by the consensus algorithm.

W. Liang et al. [70] have used a blockchain-based digital copyright registration and management chain (RMC) and a transaction subscription chain (TSC) to prevent unauthorised disclosure of information, privacy protection and segregation of account information from transaction information. The one chain architecture is further replaced with the functioning of multiple chains in parallel reducing computation time and throughput making the system extremely efficient and smart.

Mackey et al., in [71] have discussed the contribution of blockchain in transforming the healthcare sector and have mentioned Bitcoin and cryptocurrency to be the main catalysts for its immense popularity. In the health sector, multiple players are actively using blockchain to simplify processes of business, lowering costs, increasing patient outcomes, enhancing compliance, and make it possible to fully leverage data relating to health care. Nonetheless, it is important to ensure that blockchain design elements understand the real healthcare needs from a complex point of view of customers, employees, practitioners and, regulators while determining how blockchain will meet the buzz of a technology known as ‘revolutionary’ and ‘disruptive’. Blockchain approaches must also meet the unique challenges of healthcare compared to the real needs of interesting parties, also need to respond to unique healthcare challenges concerning other economic sectors. To ensure that a “fit-for-use” secure blockchain is important. This is the basis of this article, in which the article shares views on blockchain conceptualization, development, and deployment from a multidisciplinary group of practitioners.

Khan et al., in [72] have mentioned the use of blockchain technologies in numerous ways such as healthcare, automation, energy, security, and smart grids authentication. In this article, they examined various critical aspects of blockchain technology, such as their style of work mechanisms and potential suggestions for improvement using proof-of-stake, and other personalized variants and also clarified the state of the art in blockchain non-financial applications such as healthcare, in which four-layer custom blockchain models related to reliable medicine and the clinical trial.

Krittawong et al.,[73] discusses the role of Artificial Intelligence in cardiovascular medicine but mentions its constrain due to the absence of broad, heterogeneous, and granular data sets. Blockchain guarantees safe interoperability between stakeholders and centralized data sources. This paper addresses the application of blockchain and AI for user-centered processing and data transfer, existing shortcomings and, future cardiovascular applications. The shortcoming associated with such large scale decentralized implementations includes ensuring security and integrity of the health records. The accessibility of medical records in the blockchain ledger also questions ethics with more than 51 percent chances of being subjected to tampering of records. The article thus suggests more research in this domain to overcome the aforementioned challenges to gain a higher level of trust for large scale usage.

Jayaraman et al., in [74] pointed out the fact that despite significant developments in electronic and engineering health care, little has been done so far to resolve supply chain problems relating to the process. Furthermore, the main mechanisms in the supply chain of health care include drug inspections, product stock scarcity tracking, expiry, and counterfeiting. Confidentiality of the healthcare supply chain, vulnerable to systematic errors and repetitive measures that could jeopardize patient safety and adverse health effects, is an obstacle in enforcing and conducting these processes in a reliable, protected, effective, transparent global and traceable manner. The article mentions Blockchain as an emerging technology, combined with the Internet of Things (IoT) to be capable of offering a practical solution to the aforementioned challenges. IoT based blockchain thus offers a superior way to track and monitor goods via a centralized, secure, and decentralized Blockchain network peer-to-peer registry.

Thakur et al. [75] highlight the potential of blockchain technology in eliminating transparency issues, incoherent data management, and accountability issues in land record management. The traditional process in this sector as discussed in an Indian context is primarily manual which, if replaced with blockchain framework with associated public key infrastructure and internet, has the potential to completely optimize the security and privacy level making the system tamper-proof.

4 Research Challenges

Blockchain technology provides useful and effective solutions for preserving data integrity. However, several challenges need to be addressed to implement the blockchain technology successfully. To limit the scope of the article, we have discussed some major challenges of employing blockchain technology within the domain of smart cities, healthcare, finance, energy, and cybersecurity sectors respectively.

4.1 Smart cities

The rapid urbanization of the population of the world in recent years has caused several environmental, social and economic problems which have a major impact on people’s quality of life and living conditions. The “intelligent city” concept offers the possibility of resolving these urbanization problems. Intelligent communities aim to make optimal use
of shared resources, provide residents with high-quality services and improve the quality of life of the inhabitants [24], [76]. A smart city is among the most important application area of IoT. The vision of a smart city is to provide a high quality of daily life services (e.g., digital identification, smart ordering and purchasing, smart parking, smart buildings, smart roads, and smart parks etc.) to its residents with less or no efforts. A huge volume of data will be generated each second by the smart devices, secure transaction, and storage of this data is a challenging task. Blockchain technology is among best-suited solution to handle a huge amount of smart cities data securely. However, utilizing blockchain technology in smart cities to handle smart devices data is challenging due to many factors. These factors include preserving privacy, integrity, heterogeneity of smart devices and scalability. Addressing the above-mentioned challenges can help in the successful implementation of blockchain technology in smart cities.

4.2 Healthcare
Healthcare is the foremost requirement for a human being. With the revolution of the internet and related technologies, the healthcare sector has made a lot of progress and is still flourishing[77], [78]. Due to the digitization of healthcare, the issue of security is alarming and requires effective security solutions like blockchain technology. However, some major concerns are hindering the implementation of blockchain technology in the healthcare sector. The first and foremost challenge is the delay of blockchain technology in recording data to the distributed ledger. In healthcare, there are large data sets that need to be stored and utilizing the blockchain technology to secure large datasets will be an extremely slow process. The second challenge arises the ownership issue of healthcare data. There is no study conducted as to how the healthcare data will be shared, who will own the healthcare data, and other related issues. The other challenge arises in storing the blockchain-enabled ledger. As data in the healthcare sector may exceed more than petabytes, there might arise the storage issues as well. There are privacy regulations related to the sharing of patient data and the permission to employ blockchain technology will involve amendments in those regulations as well. Thus, amendments in the existing privacy regulations inhibit the wide employability of blockchain technology in the area of the healthcare sector. The last challenge arises due to the cost involved in using blockchain technology within the healthcare sector. This challenge may open other research directions in the area of blockchain technology and big data.

4.3 Finance
Blockchain technology seems promising to address data breach issues in the finance sector. But, there are few major challenges concerning the blockchain technology that can create issues for the financial industries. The first challenge arises due to the cost (including necessary software, hardware, maintenance cost, etc.) involved in creating and implementing blockchain technology for financial industries. The second challenge arises due to the delay in recording transactions on the distributed ledger. In the finance sector, the frequency of online transactions is rapid, therefore, too many transactions will slow down the recording on the distributed ledger as well and rendering the whole system slow. The third challenge arises due to the shortage of skilled staff within financial companies to properly utilize the blockchain technology. This will make companies hire extra technical staff with expertise in blockchain technology thereby incurring more costs. The fourth challenge is the need for continuous energy supply (like electricity). As blockchain technology is a network of computers and requires a continuous power supply, abrupt cut of energy supply can prove disastrous to small-scale financial companies where frequent power cuts do occur. The last challenge is the lifespan of the distributed ledger. As for now, there is no study conducted that can predict the lifespan of the blockchain-enabled distributed ledger. As blockchain technology is cryptic, there is no guarantee it can get corrupted and making the past transactions inaccessible. This can result in losses of millions.

4.4 Energy
In recent years, the energy sector got a new digital transformation in the form of smart grids. A smart grid ensures reliable, independent, cost-saving, accurate energy billing, and two-way energy services using smart metering to its customers. By applying the blockchain technology in the smart grid enables its customers to connect directly (peer to peer) to energy generators or energy sharing customers in case of renewable energy (solar/wind energy). However, implementation of blockchain in the energy sector is still limited to theory due to challenges such as integration of various technologies [79], [80] (smart meters, grids, cloud, edge and IIoT), reliable data transmission, data storage, transmission delay, low-cost hardware and software solutions, smart financial models for energy consumption and generation (e.g., in case of renewable energy).

4.5 Cybersecurity
Cybersecurity is the trending research area with a lot of potential applications [81]. The merge of blockchain technology within the cybersecurity area will enhance the security mechanism. Few major challenges that are hindering the merge of blockchain technology and cybersecurity include the scalability of the network, the complexity of the network, regulations, access to cryptographic keys (public/private), and the complexity of blockchain development model. The scalability feature may expand network countlessly involving thousands of nodes. As more nodes get involved, the whole network can be compromised if a malicious user gets access to 51% of nodes. The complexity of the network is the other challenge that needs to be addressed before implementing the blockchain technology. The involvement of thousands of nodes within a network may cause a delay in processing a given request. To process and record each transaction through blockchain technology will make even an efficient network slower. The other challenges arise due to the regulations from the government to use the blockchain technology. This will make IT sectors to wait longer for permission and inhibit the adaption of blockchain technology. The access to cryptographic keys is
yet one of the most threatening challenges. Malicious users can discover the cryptographic keys of a blockchain-enabled distributed ledger stored on some insecure platform. It is also likely to get access to blockchain-enabled ledger information from the email inbox as well. The last challenge is the expertise and the skills involved to create a blockchain model for a given network. Any human error (like software bug) will make the whole system vulnerable to external threats.

5 Future Research Directions

There might be numerous research directions where blockchain technology can be useful. In this section, we identified some key future research directions where blockchain technology might be more effective.

5.1 Incorporating ethics in blockchain functionality test

There is a possibility of a blockchain method being used for marginal profit cases. The investors are not fully aware of blockchain technology and there is huge potential of luring the investors by developers. It is easy to show the good performance of the blockchain approach but whether that approach is suited for the application that a client requires seems an interesting research direction. This process of blockchain functionality tests must include the code of ethics between the two parties. This needs to be addressed in what terms ethics can be incorporated to save investors from being lured.

5.2 Classification of blockchain approaches

As research is going on progressively in blockchain technology, it is crucial to classify the blockchain methods based on its application. At present, there are five categories of blockchain i.e. public blockchain, private blockchain, consortium blockchain, permissionless blockchains [82] [6], permissioned blockchains [82]. The proper classification of methods and applications will help researchers in proposing better and enhanced solutions. Different applications are showing up in IoT, healthcare, and other related areas. There is very little work done on the classification of blockchain approaches. Whether there will be a need for more classification approaches and in what aspect seems other possible research direction.

5.3 Merging Artificial intelligence and blockchain technology

There is huge potential to merge the two trending technologies of blockchain and artificial intelligence. In the blockchain database, all data is in encrypted form. However, in artificial intelligence, there is a possibility of building algorithms that can work on compressed data. Hence, the combination of artificial intelligence and blockchain technology will make data much safer. The emergence of artificial intelligence with the feature of blockchain seems the promising future direction.

5.4 Utilising blockchain for content analysis

Content analysis is an interesting area of validating documents or any other multimedia formats like a text document, images, audio, video. There is huge potential to apply the concept of blockchain technology to the area of content analysis like diacritical texts [83] [84] that are sensitive to tampering. One of the example is digital Holy Quran and Hadith[85] which is sensitive due to massive involvement of diacritics [86], [87]. Blockchain can be used to store sensitive multimedia content and make forgery rarely tedious tasks. Also, multimedia data is increasing dramatically especially images. Web-based images are more often exposed to the risk and their contents are more prone to be manipulated. The use of blockchain technologies provide benefits to address this issue, due to the fact that data in a blockchain is well stored and unmovied, and also it takes longer duration to connect the data to a blockchain directly, rendering it computationally and economically expensive [44].

5.5 Identification of limitation in blockchain technology

As far now, blockchain technology has been highlighted as the most promising technology with numerous applications. However, there are some limitations of blockchain technology that include: storage of high quality of data into database, robust network, and high transaction cost. Besides the mentioned limitations, the major limitation includes 'lie becomes the truth'. Suppose more than 49% nodes publish the correct information, the rest 51% (under the influence of bad actors) can manipulate the end-result and make correct information to be depicted as false.

5.6 Performance evaluation of consensus protocols

There are different consensus protocols that help to reach an agreement between the participating parties like proof of work, proof of stake, etc. To identify their weakness, strength, limitation, proper application domain is itself a research challenge and notable future research direction. Enhanced consensus protocol will improve the performance of the blockchain transaction.

5.7 Analysing Security Vulnerabilities

Security is one of the promising features of blockchain technology. However, there is some vulnerability that exists in the blockchain technology which may hurdle its successful implementation. These vulnerabilities include majority or 51% attack (getting full control of blockchain by having 51% processing power; allowing/denying mining, verification, and addition of a block to the chain), double-spending attack (modification of transaction data) [88], fork problem (soft and hard fork; conflict of software versions due to non-upgradations by all nodes and updated rules), in case, if the miner node is compromised by an attacker due to its weak hashing power, the attacker will be able to host the entire chain. Similarly, the blockchain account can be hacked by the attackers due to the deficient randomness of private keys. Thus, novel effective and secure resistance mechanisms are required to deal with these vulnerabilities of blockchain technologies.
6 Discussion

From the analysis of state-of-the-art, it seems most of the blockchain technology-based studies are conceptual. Few studies have focused on the practical implementation of blockchain that too on a very small scale. Also, it is quite interesting to mention that only two platforms i.e. Ethereum and Hyperledger are being explored on a wide-scale. All other platforms that we discussed in section II are seldomly utilized. We believe the main reason for using ethereum and hyperledger is their open-source nature and easy access to tutorials compared to other platforms. Besides, the pricing model and lack of technical skills to practically implement blockchain-based solutions can be the other potential factor that hinders its implementation. There are also few studies where it is unclear in terms of consensus mechanism and platform used.

Concerning the applications, there is no particular trend where we can infer that blockchain technology is being applied in a particular domain. It seems blockchain is finding its applications in different domains such as land record management, insurance-related applications, smart-grids, smart cities smart-homes, supply-chain management, ownership services, and cybersecurity. However, there are still numerous challenges ahead before we can get its full benefits as mentioned in section IV.

7 Conclusion

Blockchain technology is still in its initial stage. There are a huge number of applications that need to be identified and implement to make the nature of communication more secure. The most recent works employing blockchain technology were studied and categorized based on platforms used. The article also provided a brief overview of available blockchain platforms such as Corda, Hyperledger, Hedera hashgraph, Ethereum, etc. The study concludes that most of the work in the area of blockchain technology is limited to PoC only and very little implementation work has been done so far. The target application domain where blockchain technology has been applied is mainly focused upon IoT/smart-city and supply chain based applications.

The article also highlighted several challenges in the area of cybersecurity, finance, healthcare, energy, and smart cities along with future research directions.

In the future, we aim to identify studies that have utilized other blockchain platforms besides ethereum and hyperledger.

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Saqib Hakak is currently working as an Assistant Professor at the University of Northern British Columbia, Canada. Prior to this designation, he worked as a post doctorate research fellow at the prestigious Canadian Institute for Cyber-Security. He received his Ph.D. from the University of Malaya, Malaysia, under the Faculty of computer science and Information Technology. He received his Bachelor’s degree in computer science engineering from the University of Kashmir, India, in 2010 and his Master’s degree in Computer and Information engineering from IUM, Malaysia. His research areas include information natural language processing, cyber security, artificial intelligence, and wireless networks.

Wazir Zada Khan (M’16–SM’17) received his bachelor’s and master’s degrees in computer science from COMSATS University Islamabad, Wah Campus in 2004 and 2007, respectively. He received his Ph.D from the Electrical and Electronic Engineering Department, Universiti Teknologi PETRONAS, Malaysia in 2015. Dr. Khan is currently working with Farasan Networking Research Laboratory, Faculty of CS & IT, Jazan University, Saudi Arabia. Dr. Khan is also serving as a Researcher at the ‘Global Foundation for Cyber Studies and Research’ (https://www.gfcyber.org), which is an independent, non-profit, and non-partisan cybersecurity think-tank based in Washington D.C. Dr. Khan has published over 75 research papers in the journals and conferences of international repute. He is the serving as a reviewer of many reputed journals and also a member of the technical program committee for many international conferences. He has more than ten years of teaching/professional experience in Pakistan and Saudi Arabia. His current research interests include wireless sensor networks, security and privacy, blockchain, IoT, IIoT and reinforcement learning. He is a Senior Member of the IEEE.

Gulshan Amin received the bachelor’s and master’s degrees from India. She was working as a Lecturer with the Department of Computer Science and Information Technology, Faculty of Computer Science and Information Technology, Shaqra University. Saudi Arabia. She has vast teaching experience due to having worked in various educational institutions locally and abroad.
**Basem Assiri** is currently serving as Dean of the Faculty of Computer Science and Information Systems, Jazan University, Saudi Arabia. Basem got the PhD degree from Louisiana State University in 2016. He has published over 13 research papers in well known journals and conferences. He is serving as a reviewer for many journals and conferences. He is a member of the IEEE. His current research interests are Parallel Computing, Distributed Computing, Computer Architecture, Operating Systems and Image processing.

**Dr. Mamoun Alazab** is Associate Professor at the College of Engineering, IT and Environment at Charles Darwin University, Australia. He received his PhD degree in Computer Science from the Federation University of Australia, School of Science, Information Technology and Engineering. He is a cyber security researcher and practitioner with industry and academic experience. Alazab’s research is multidisciplinary that focuses on cyber security and digital forensics of computer systems with a focus on cybercrime detection and prevention including cyber terrorism and cyber warfare. He has more than 100 research papers. He delivered many invited and keynote speeches, 22 events in 2018 alone. He convened and chaired more than 50 conferences and workshops. He works closely with government and industry on many projects, including Northern Territory (NT) Department of Information and Corporate Services, IBM, Trend Micro, the Australian Federal Police (AFP), the Australian Communications and Media Authority (ACMA), Westpac, United Nations Office on Drugs and Crime (UNODC), and the Attorney General’s Department. He is a Senior Member of the IEEE. He is the Founder and Chair of the IEEE Northern Territory (NT) Subsection.

**DR. SWETA BHATTACHARYA** is currently associated with Vellore Institute of Technology (University), as an Assistant Professor in the School of Information Technology & Engineering. She has received her PhD degree from Vellore Institute of Technology and Master’s degree in Industrial and Systems Engineering from State University of New York, Binghamton, USA. She has guided various UG and PG projects and published peer reviewed research articles. She is also a member of the Computer Society of India and Indian Science Congress. Her research experience includes working on Pill Dispensing Robotic Projects, as a fully funded Watson Research Scholar at Innovation Associates, Binghamton at SUNY. She has completed six sigma green belt certification from Dartmouth College, Hanover. Her research interests include applications of machine learning algorithm, data mining, simulation and modelling, applied statistics, quality assurance and project management.

**Dr. G Thippa Reddy** is currently working as Assistant Professor (Senior) in School of Information Technology and Engineering, VIT, Vellore, Tamil Nadu, India. He obtained his B.Tech. in CSE from Nagarjuna University, A.P, M.Tech. in CSE from Anna University, Chennai, Tamil Nadu, India and completed his Ph.D in VIT, Vellore, Tamil Nadu, India. He has 14 years of experience in teaching. He produced more than 25 international/national publications. Currently, he is working in the area of Machine Learning, Deep Neural Networks, Internet of Things, Blockchain.