Load Balancing in Blockchain Networks: A Survey

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***Abstract*—Load Balancing (LB) in networking attempts to minimize the under-utilization and over-utilization of network resources by distributing the network flows evenly in the communication network. Blockchain includes a string of joined blocks that are built into the preservation of the non-tampering nature and safeguarding the verifiability. According to our felt experience, we are the initiators to review on blockchain-driven LB, where we organize the blockchain-driven LB concept under 7 categories and interpret thoroughly their performance in relation to LB techniques, BC-driven variables, LB approach, network variables, and similar things. We accumulated an early sample of 76 paper citations by handpicking articles for eligibility requirements scrutinized from web repositories, deploying a thorough and continuous method. Relying on this assessment, blockchain has been deployed in network LB for protecting data fidelity, trustworthiness, confidentiality of data transfers, deploying blockchain consensus for LB, deploying smart contracts for LB, deploying with secure resource trading, access control, and as a coordinator in the system of LB. Moreover, LB involves balancing loads in the blockchain transactions themselves. Thorough interpretation depicts that from blockchain-driven LB schemes, 37.5% deploy blockchain transaction LB, 90% deploy conventional blockchain architecture, 30% deploy generic consensus, 97.5% deploy decentralized LB, 97.5% deploy dynamic LB, 52.5% deploy deterministic LB, and the majority target generic networks. Finally, we go over the potential and predicaments of the notion of blockchain-driven LB and then provision ideas to defeat them.**

***Index Terms*—blockchain, load balancing, blockchain-driven load balancing, smart contracts, sharding, networking**

I. INTRODUCTION

Load Balancing (LB) in communication networks attempts to distribute flows such that the resource utilization in devices, communication channels, etc. has less deviation among each other, such that network resources are less overloaded and under-utilized [1]. It can further improve fault tolerance by automatically assigning tasks to active resources when resource failure is detected. Moreover, due to the minimization of over- and under-utilization, it can further improve network throughput and response time [2]. Conventional LB can be achieved by optimization, artificial intelligence, or a LB algorithm. Typical LB algorithms include round robin, equal cost multipath, double threshold, distributed algorithms, etc. [3]. There are other LB approaches, such as switch migration, that transfer the control of a set of switches to another, and rerouting, which redirects traffic from overloaded resources to underloaded resources [4]. On the other hand, optimization techniques attempt to maximize resource utilization, throughput, and minimize service delay, considering controller capacities, traffic patterns, parameters from network topology, etc. as constraints [5]. Additionally, LB can also be achieved using artificial intelligence, where it can be deployed for predictive analytics to analyze historical traffic and predict parameters such as network congestion, load, etc. to balance the load using a conventional approach or using an AI technique such as reinforcement learning [6]. Alternatively, an interactive LB approach can be deployed using game theory, where nodes make strategic decisions to maximize their own utility while considering the effects of others actions [7].

In fixed-wired networks that rarely change with time, static LB can be deployed where LB is predefined and resources such as bandwidth are allocated manually [8]. On the other hand, dynamic LB is typically deployed in wireless networks whose network state can vary with time, such that LB involves continuous monitoring of the network and balancing the load in real-time [9]. In centralized LB, there is a centralized controller responsible for LB, while in distributed LB, nodes exchange information among each other to investigate LB parameters and balance load locally [10]. The centralized approach is more flexible and effective due to the global network view; however, it is susceptible to the central key point of collapse and scalability issues [11]. On the other hand, even though distributed LB does not suffer from the drawbacks of centralized LB, it can suffer from high communication overhead for exchanging LB parameters, difficulty in achieving global LB, etc. [12]. Moreover, complex LB problems often produce non-deterministic output considering multiple objectives and constraints related to network status and load parameters, while simple algorithms such as equal cost multipath, round robin, etc. produce deterministic outputs [13].

A blockchain fundamentally includes of a string of blocks joined in a conventional or unconventional fashion, following the blueprint of secure ledger innovation [14]. Precisely, transactions/blocks are entwined with one another using a particular block/transaction securing the hash output of at least one parent transactions/blocks

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creating an unchanging state [15]. Besides, they utilize an agreement method, for example, proof-driven agreement or vote-driven agreement, for affirming the blocks in the midst of fellows preceding a transaction/block is integrated into the secure ledger innovation [16]. Likewise, they make use of hash algorithms to safeguard reliability and E-signatures to safeguard transaction verifiability [17]. In addition, they can involve resilient cryptographic strategies, for example, knowledge concealment techniques and quantum-era cryptography for fending off quantum vulnerabilities [18], enhancing the characteristics of privacy sheltering in blockchain. In contrast, real blockchain at its core, which abstains from cryptographic strategies, for example, a non-symmetric cryptographic system for safeguarding privacy sheltering, is not completely privacy sheltering on account of blockchain exchanges/transactions are with secretive identification, implying that exchanges/ transactions are verified by an encrypted placeholder address in preference to the actual addresses of equipment [19]. Likewise, the scale of privacy preservation is adjustable according to the secure ledger category: exclusive, partnered, and inclusive. Inclusive blockchain is the classic peer-to-peer blockchain, whereas exclusive and partnered blockchains maintain a particular scale of monolithic control, furnishing improved personal space and data permissions authority than inclusive [20].

According to our survey, LB in blockchain networks can be 7-folded. First, LB can be achieved inside blockchains by transaction LB by sharding the blockchain into small subsets, and LB can be achieved in each shard by reducing the gap of load of each shard by distributing load across different shards, as in the framework D-GAS [21]. Secondly, consensus approaches, as in proof-of-equity and proof-of-balance have been proposed to calculate model loads in a fair manner and balance loads in multiple software-defined controllers using a cryptographic coin, respectively [22]. Thirdly, blockchain has been deployed as a secure storage to preserve data integrity, trustfulness, secrecy, etc. to facilitate securing the overall LB using a conventional approach such as round robin [23]. Fourthly, smart contracts (SCs) can be deployed to implement a LB strategy to automatically balance load driven by the network's conditions, such as work in [24] that deploys three SCs for main, peer-to-peer, and peer-to-grid LB in a smart grid. Next, blockchain can be deployed for secure energy/resource trading in collaborative and interactive networks concurrently with auction theory, where LB is typically carried out using an incentive mechanism [25]. Furthermore, blockchain can be deployed for providing access control, making sure that only authorized devices have access to resources for LB using a conventional technique as in reinforcement learning [26]. Finally, some works, such as [27], have used blockchain as a coordinator among multiple software-defined controllers where load is balanced using fuzzy logic considering the number of controllers and network traffic.

While penning this work, according to our comprehension, nobody has administered a literature review concerning LB methods in blockchain networks. Therefore, we are proud to present this piece of work, plugging a vacuum in the existing literature by reviewing on existing work on LB approaches of blockchain networks, where we analyze them in terms of blockchain and LB related parameters and identify predicaments and potentials to facilitate proposing ideas to overcome the predicaments.

The organizational chart for this academic appraisal is exhibited in Fig. 1.

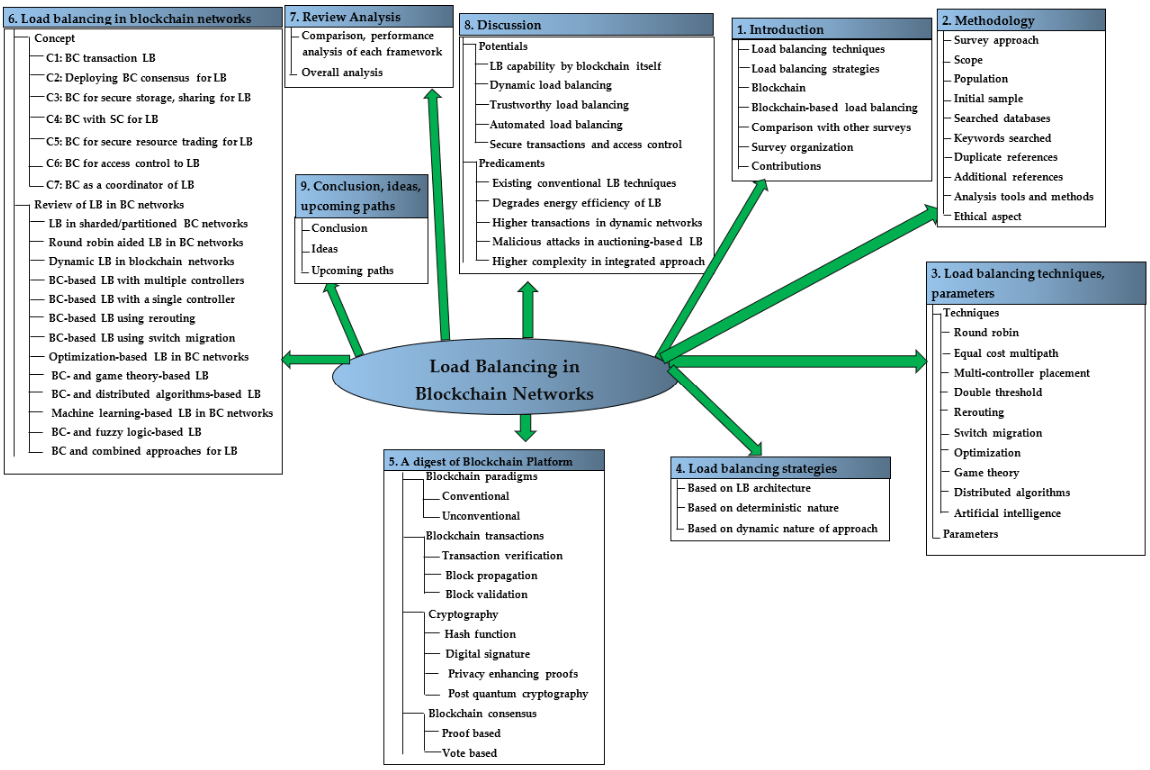

Fig. 1. Organizational chart of appraisal on LB in blockchain networks.

The rest of paper is organized as follows: Section II contributions to Surviving Literature; Section III segregates and briefly expounds on a digest of different load balancing techniques and parameters; Section IV briefly expounds the load balancing strategies in networking; Section V is a digest of blockchain innovation is inspected; Section VI scrutinizes on surviving blockchain-driven load balancing frameworks in networking; Section VII thoroughly appraises the scrutinized blockchain-driven load balancing frameworks; Potentials and predicaments of blockchain driven load balancing are considered (Section VIII); Ideas and upcoming paths for deploying blockchain driven load balancing are inspected (Section IX).

II. Methodology

This assessment scrutinizes the contemporary work on blockchain-driven LB disseminated to the research community during the passage of time, engaging a thorough and continuous method [28]. Besides, it scrutinizes various dimensions of LB and secure ledger platform. In light of this, all innovative research papers and internet web content authored by scholars on LB, blockchain-driven LB, and blockchain constitute the whole population within the confines of this research. However, whole population references are incapable of being assessed in this research. In light of this, engaging conforming search strings and eligibility requirements, we pooled 78 references from innovative research papers and internet web content.

We scrutinized Google Scholar academic information retrieval system, ScienceDirect scientific resource hub, ACM web repository, IEEE Xplore engineering information archive, Wiley web repository, and the MDPI article exploration tool. The search strings we often utilized were "LB" OR "Blockchain" OR "LB in sharded blockchains" OR "Blockchain and round robin aided LB" OR "Blockchain-driven dynamic LB" OR "Blockchain-driven LB with multiple controllers" OR "Blockchain-driven single controller LB" OR "blockchain and rerouting driven LB" OR "blockchain-driven LB engaging switch migration" OR "Blockchain and optimization driven LB" OR "Blockchain and game theory driven LB" OR "Blockchain and distributed algorithm driven LB" OR "Blockchain and machine learning driven LB" OR "blockchain and fuzzy logic driven LB".

Diverse constituents for handpicking the articles designed the eligibility requirements. First, the cited paper requires English text, and then it requires exceedingly appropriateness to the search string. Next, in an attempt to raise the credibility of conducted assessment, periodical articles were placed at the forefront, as opposed to symposium presentations and unpublished drafts. Nonetheless, we weren't inclined toward scientific papers of a unique editorial house in the eligibility requirements; on the contrary, we judged all editorial houses in like manner. The last eligibility requirement claims that a unique cited paper should be disclosed over the years of 1985 and 2023.

The early sample was lowered to 76 paper citations in the wake of it was detected that 2 paper citations were facsimiles. Besides, we referenced explications and explanations touching on the variety of themes rendered in this assessment using 16 cited papers. To analyze this assessment with existing assessments, we eventually reviewed abundant supplementary assessment articles, but they were omitted from the collection of reports, as we identified none appraising on blockchain-driven LB, delivering the entire amount of paper citations to 92.

To review current LB techniques in blockchain networking from diverse constituents, for example, blockchain characteristics, LB characteristics, network aspects, and effectiveness, we engaged the data organized in tables for assessment in-depth evaluation. Besides, we crafted diagrams engaging the MS spreadsheet software to fairly investigate assessment data related to LB-driven and blockchain-driven constituents.

Ethics are beside the point thanks to this assessment ties to LB in networking.

III. A Digest of LB techniques and Parameters

A. Techniques

1) Round-robin

Round robin is a LB algorithm that is driven by a queuing model that attempts to distribute load among the available resources in a circular manner. It ensures fair LB, however, is not involved in considering the actual capacity of each resource. In a software-defined network that deploys a POX controller, a round-robin LB approach has been deployed with the aid of a centralized controller [3]. Weighted round robin is an advanced version of round robin that considers the capacity of the controllers as well in LB. The assignment of weights in the weighted round-robin is shown in Eq. (1).

$$w_{t,1}, w_{t,2}, \ldots, w_{t,n} = 1/\text{load}_{t,1}, 1/\text{load}_{t,2}, \ldots, 1/\text{load}_{t,n} \quad (1)$$

In Eq. (1), t is the timestep, and the second index is the link ID. Dynamic weighted round robin has achieved a better LB than round robin in a centralized LB approach that does not trace system load, but detects line loads at time intervals, and variance is used as the load balance level [29].

2) Equal cost multipath

Equal cost multipath is a technique deployed to distribute traffic evenly across multiple equal cost paths and is effective when multiple paths have equal cost metrics. It can improve network resource utilization and redundancy. The concept of equal cost multipath-driven LB is exhibited in Fig. 2.

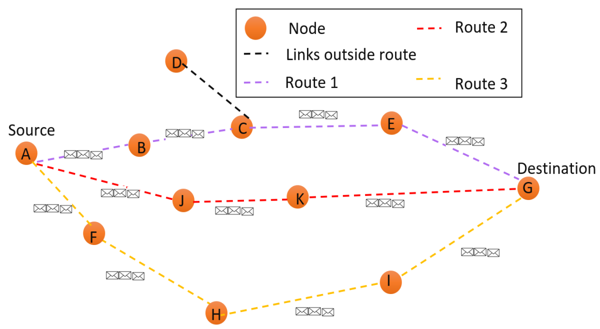

Fig. 2. Equal cost multipath approach for load balancing.

In [30], the bandwidth of all device connections in the network was monitored in real-time by the software-defined network controller in a data center network to balance load using equal cost multipath to transmit packets in non-overlapping paths as much as possible to prevent network congestion. A more advanced approach is the weighted equal cost multipath, which chooses paths with weighted probability to facilitate avoiding congesting a path in a quick approach by encapsulating the path congestion information, resulting in low flow completion times [31].

3) Multi-controller placement

In multi-controller placement, switching weights, routing costs, latency, etc. are considered to strategically assign controllers to handle diverse sections of the network. This approach also decentralizes network control by deploying multiple controllers to distribute the network load, reducing the single controller's sole point of failure. In [1], simulated annealing k-means driven by partition has been deployed for controller placement to facilitate balancing load among distributed controllers in software-defined wide area networks to result in low network latency and high reliability. Alternatively, in distributed software-defined networks with multiple controllers, flow requests have been converted to a queuing model considering traffic propagation delay and controller capacities, where the breadth first search algorithm is deployed to attain controller LB with dynamic network traffic while placing the controllers using an affinity propagation logical sequence founded on particle swarm optimization [32].

4) Double threshold

The double threshold approach for LB involves two thresholds: the first threshold for distributing incoming requests for available resources and the second one for diverting excess load [33]. When the load reaches the first threshold, load is distributed among available resources, and upon reaching the second threshold, load shedding or rerouting is implemented typically to prevent overload. DT-PALB is an energy-mindful LB technique using a double threshold that monitors the status of compute nodes, and decides the operation of those nodes considering the utilization percentages in a cloud computing environment [34]. DTLB is another double threshold driven LB scheme utilized in software-defined networking that works by process and physical machine choosing, process-machine allocation, and process migration considering energy consumption and available processing and memory resources [35].

5) Rerouting

Rerouting involves redirecting traffic from overloaded resources or controllers to underloaded resources by performing dynamic route changes or using already available alternative paths to facilitate reducing the workload of the congested resources. TR is a traffic rerouting framework to achieve fine-grained LB in data center networks by identifying flow types, and using the awareness of traffic for rerouting short and long flows, and further avoiding packet reordering using proper acknowledgment mechanisms [4]. Alternatively, DPLBAnt is an ant colony optimization driven method to reroute elephant flows to balance load in software-defined networking links by identifying elephant flows at the controller and switches, and those flows are redirected using a shortest path approach to reduce controller-switch load [36].

6) Switch migration

Switch migration refers to moving the workload (typically switches in a network) of a physical server (controller) to another to balance the load in cases where the server is under a high load or considering other network parameters. In this case, the mapping between a set of switches and a given controller is migrated to another underloaded controller. ESMLB is a switch migration-driven approach for multi-controller software-defined networks in the internet of things that assigns forwarding elements to an underused controller using a decision-making procedure for order predilection by similarity to select a target controller [37]. Similarly, DSMLB is another controller LB framework that monitors the real-time mean load ratio of controllers and chooses the target controller for switch migration by optimizing the efficiency of migration resource utilization of residual controllers while considering migration efficiency and degree of LB when selecting switches for migration [38].

7) Optimization

LB can be achieved using optimization to maximize resource utilization and minimize response time to facilitate allocating resources, considering multiple factors such as the capacity of the controllers, traffic patterns, and network topology. In heterogeneous 5G networks, constriction factor particle swarm optimization has been deployed to maximize throughput by associating cells for LB and offloading to small cells when required [8]. Alternative, some researchers have utilized mixed integer linear programming to design a multi-objective flow challenge considering quality of service parameters as in energy and use particle swarm optimization to resolve the challenge to facilitate distributing paths for dynamic traffic demands [39].

8) Stochastic optimization

Stochastic geometry, which is a mathematical approach deployed to model and distribute users and resources in a network, can be deployed to make decisions regarding LB using optimization [40]. Using optimization for LB by modeling the network resources using stochastic geometry is known as stochastic optimization. In [41], joint power allocation and workload balancing, considering both delay tolerant and interactive workloads, have been feasible by using stochastic optimization to consider space time variation of demands and renewables.

9) Game theory

Game theory can be deployed for LB, where multiple servers or nodes make strategic decisions to maximize their own utility by considering the effects of actions of the other entities in an interactive manner. A delay utility function driven by game theory is deployed to analyze the link capacity in distinct paths and retrieve the arrival rate in every single path to balance load, minimizing average delay in wireless adhoc networks, as given in equation (2) [7].

Utility function =Minimize (1/(arrival rate – service delay) (2)

Alternatively, for cooperative LB in cellular networks, the Stackelberg game is utilized to optimize user relays (lightly loaded cell users) and move the cell edge user's strategy to enhance signal to noise ratio and remuneration utilities, preventing SNR deterioration of cell edge users [42].

10) Distributed algorithms

In distributed LB approaches that do not involve a centralized authority for workload balancing among the nodes, custom-defined distributed algorithms such as iterative, randomization, clusterization, rule-dispatching, etc. can be deployed for LB. For gateways incorporated in wireless mesh networks, a distributed LB algorithm considers interference and reroutes congested flows to under-utilized gateways to facilitate improving network utilization [43]. Alternatively, a randomized algorithm achieves consensus on the load distribution of a network driven by gossip to facilitate achieving LB in a homogeneous network, where different tasks of the network are represented using integer values [44].

11) Artificial intelligence

Artificial intelligence techniques deploy either machine learning or fuzzy logic to analyze the historical network traffic using predictive analysis to predict future network conditions such as network congestion, load of controllers, etc. to facilitate making intelligent decisions to balance the load [45]. In [46], LB was achieved by clustering an ultra-dense network driven by historical loads and then achieving intra-cluster LB using Deep Reinforcement Learning (DRL) to learn an optimal policy from the network environment concurrently with an offline evaluation mechanism for the machine learning model to perform effectively and explore the environment more. Alternatively, a fuzzy logic-driven algorithm has been deployed to select sink devices to facilitate balancing load and deter congestion in sink devices in one-hop sensor networks, where the fuzzy-driven algorithm is deployed in a distributed manner in each sensor device to choose a sink device [6].

B. Parameters

LB attempts to minimize or maximize one or more of the following parameters.

- Resource utilization—LB necessarily involves optimizing resource utilization, making sure that resources are loaded in a balanced manner avoiding overloading.
- Energy consumption—LB can also be realized by considering the energy consumption of the nodes and balancing the load in an energy efficient way.
- Response time—Response time for requests is attempted to be minimized by routing requests to servers with low response times.
- Throughput—Load can be balanced, avoiding bottlenecks in performance and improving the throughput of the network.
- Fault tolerance—The fault tolerance can be improved by distributing tasks across redundant resources or by automatically assigning the tasks to another resource when one resource is known to have failed.

Table I exhibits a digest of surviving literature on different LB techniques.

TABLE I: A DIGEST OF SURVIVING LITERATURE ON DIFFERENT LOAD BALANCING TECHNIQUES

LB technique	Surviving literature	Scheme	Performance
Round robin	Round robin LB [3]	POX controller implements centralized LB	Programmable, non-vendor locked LB
	Weighted round robin [29]	Detects and balance line loads using WRR	Superior LB than round robin
Equal cost multipath	ECM-SDN [30]	Monitor bandwidth, distribute load in non-overlapping paths	Increased throughput, decreased delay, 75.2% lower load STD
	Weighted ECMP-LB [31]	Use a weighted probability in path selection	Low flow completion times
Multi-controller placement	Multi-controller placement [1]	Simulated annealing K-means driven partition	Low network latency, load, high reliability, LB
	SDN-driven LB [32]	Queuing model for LB, particle swarm optimization for CP	Stable and accurate LB
Double threshold	Energy aware LB (DT-PALB) [34]	Monitor and decide operation of computing nodes	Increase availability, reduce overall power consumption
	DTLB [35]	Resource-aware process, machine selection & migration	High energy efficiency throughput, and fast response
Rerouting	Fine-grained LB (TR) [4]	Identify flow types and reroute them	Low flow completion time & high throughput
	DPLBAnt [36]	Ant colony optimization to reroute elephant flows	Lower delay, high throughput than ECM
Switch migration	ESMLB [37]	Select an underutilized controller	Reduced comm. overhead, response time with respect to SMDM, DALB
	DSMLB [38]	Chooses controller driven by migration efficiency, LB degree	Low controller response time, migration cost
Optimization	Particle swarm optimization [8]	PSO to maximize throughput, offloading to small cells	High throughput than MMQ, index-driven techniques
	Energy saving LB [39]	Modeled using mixed integer LP, solved by PSO	High energy efficiency in LB
	DGLB [41]	Stochastic geographical optimization for power allocation, LB	Feasible solution with time correlated randomness
Game theory	GT-driven LB routing [7]	A delay utility function driven by game theory for LB	Improves network fairness, better than shortest path
	Relay assisted LB [42]	Stackelberg game to optimize user relays, maximize SNR	Improved SNR, user relay's utility maximization

Distributed algorithms	Gateway LB [43]	Consider interference and reroute congested flows	80% throughput gain with respect to shortest path routing
	gossip-driven [44]	Consensus on load distribution driven by gossip	Achieves optimal consensus in most cases
Artificial intelligence	Mobility LB [46]	Clustering, intra-cluster LB with DRL	Better LB than conventional MLB
	Sink selection-driven [6]	Fuzzy logic to select sink nodes	Prevent sink node congestion, low delay, high lifetime

IV. A Digest of Different LB Strategies

A. Driven by LB Architecture

1) Distributed

In distributed LB, there is no centralized authority for LB. The network devices usually exchange information among each other to determine the LB parameters to balance the load locally. As demonstration, a distributed LB using distributed non-uniform grouping applying fuzzy logic to determined cluster leaders and cluster size in a wireless sensor network considering displacement to base station, node degree, and leftover energy [10].

2) Centralized

In centralized LB, a single controller is responsible for distributing network traffic among servers or nodes to achieve LB [47]. Hidden Markov models have been utilized for LB in data center networks to choose paths with few monitored links for data flows, less cost of time, and throughput that collects data to a centralized controller to realize LB [12].

3) Hierarchical

In hierarchical LB, there is a hierarchy of LB controllers, starting from the centralized controller up to local load balancers. A load balancer at a given level is responsible for LB for nodes under its domain and reports to the immediate higher-level controller. In [48], a two-layer hierarchical LB was attained in software-defined Wi-Fi networks where the centralized controller evaluates only the amount of LB between the Wi-Fi access points and determines the level to which each access point can accept requests from user equipment without consulting the controller.

B. Driven by the Deterministic Nature

1) Deterministic

In deterministic LB, traffic is distributed and driven by a pre-defined algorithm or rule that produces a predictable outcome. This approach is most suitable when the workload characteristics are well understood and the network is relatively stable. In [2], a deterministic LB scheme to balance load in a wireless local area network was realized with the aid of game theory and has resulted in superior packet loss achievement when the access points lean towards overloading.

2) Non-deterministic

Non-deterministic LB includes randomness, probabilistic, or dynamic factors that evolve over time, such as real-time loads, energy considerations, response times, and other factors that are taken into consideration for LB to produce a non-deterministic output. A probabilistic sequence technique to realize the uninterrupted secondary user target channel has been deployed to attain LB in a cognitive radio network in a non-deterministic manner has improved channel capacity [13].

C. Driven by Dynamic Nature of Approach

1) Static

Static LB involves a pre-defined LB that allocates workloads for resources and remains fixed until manually changed again. Static LB in a communication network has been realized by performing a job locally or transferring it to another in a static manner without depending on the network state, where optimization has been deployed to determine the load on each host, minimizing job response time [49].

2) Dynamic

Dynamic LB continuously monitors the network for the workload of the resources and makes allocations in real-time driven by changing network conditions by using techniques like optimization [50]. Moreover, it enables high fault tolerance as it can respond to failures or network congestion in real-time and reroute network traffic. Most LB in modern computer networks is dynamic in nature. As a demonstration, a dynamic LB scheme using ant colony optimization and a genetic algorithm balances load in a software-defined network dynamically considering real-time network status such that resources are not overloaded, resulting in less round-trip time and packet loss rate [9].

Table II exhibits a digest of surviving literature on different load balancing strategies.

TABLE II: A Digest of Surviving Literature on Different Load Balancing Strategies

LB strategy	Surviving literature	Scheme	Performance
Distributed	DUCF [10]	Distributed unequal clustering with fuzzy logic	Improved network lifetime
Centralized	HMM-LB [12]	Hidden Markov models to choose paths with less cost, time	Reduces time cost with similar throughput
Hierarchical	Two-tier LB [48]	Controller evaluates LB in Wi-Fi access points	Improved Wi-Fi LB degree, reassociation time
Deterministic	Det-LB [2]	Game theory to balance load in a LAN	Better packet loss performance under overload conditions
Non-deterministic	PSUTC-LB [13]	Probabilistic sequencing to determine SU target channels	Improved channel capacity
Static	Static LB [49]	Optimization to determine load of hosts doing jobs	Low job response time
Dynamic	Dynamic LB [9]	Genetic algorithm, ant colony optimization	Less round-trip time, packet loss rate

V. A Digest of Blockchain Platform

A string of joined blocks or exchanges/transactions includes the secure ledger designated as blockchain.

A. Paradigms

Every particular block amidst a conventional blockchain, which includes a header component and a content component, is joined to its immediate ancestor block (leaving out the first block), deploying the immediate ancestor block's hash output, and the exchanges/transactions amidst a content component are delineated into a Merkle tree configuration [14]. Fig. 3 exhibits the architecture of a conventional blockchain and Merkle tree.

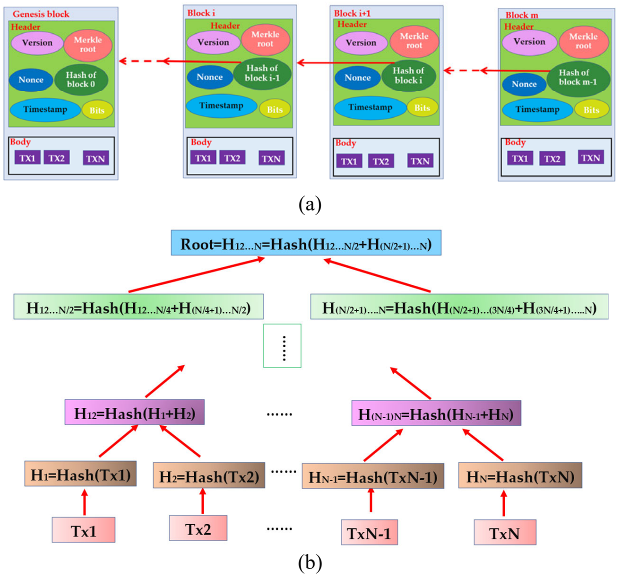

Fig. 3. Conventional blockchain (a) Conventional blockchain architecture (b) Merkle tree structure of conventional blockchain.

An unconventional blockchain includes a compilation of joined exchanges/transactions where one transaction may substantiate various more existing exchanges/ transactions. These exchanges/transactions have a deficit of header components and body components, consequently, Merkle trees are inexistent [16].

B. Transactions/Exchanges

A participant can instigate a blockchain transaction/ exchange, which is eventually dispatched to all fellows amidst the network and shielded by deploying the sender's confidential key. A consensus sequence will be instigated once each participant deploys the non-confidential key to affirm the transaction/exchange [51]. Consensus nodes consistently partake in consensus/ agreement by integrating the transaction/exchange amidst a block, which is eventually dispatched to the secure ledger network and joined in by each participant in the secure ledger network in successive block affirmations.

C. Cryptography

To safeguard the reliability of exchanges/transactions in blockchain, a hash algorithm is deployed to render established size hash outputs with decreased crossovers [17].

Deploying an E-signature, non-symmetric cryptographic system featuring a key couple for enciphering and deciphering is deployed to affirm exchanges/transactions. With the goal of enhancing the privacy of blocks, it can be further deployed to code protect blockchain exchanges/transactions [52].

Knowledge concealment techniques are deployed to affirm exchanges'/transactions' accuracy, keeping confidential the private data of exchanges/transactions, enhancing privacy, and stopping the dispatching of proprietary details [53].

Quantum-era cryptography deploys successful cryptographic schemes that guard against quantum computing systems, for example, enhanced Ed25519, SIKE, and so forth [18].

D. Consensus/Agreement

Blockchain consensus deploys widespread agreement to fabricate and affirm uncharted blocks, safeguarding the reliability of the secure ledger.

Engaged in vote-driven agreement, particulars are forwarded and collected betwixt the fellows as they unite in collaboration to affirm blocks. The highly favored vote-driven agreement scheme deploys a byzantine fault-tolerance agreement, during which a facilitator integrates exchanges/transactions amidst a block, dispatches it, and participants redispatch it to affirm that the block collected by means of parent is duplicate [19]. Provided that each participant got duplicate clones of an uncharted block collected by means of exceeding 66% fraction of the network's participants, the block might be integrated to the secure ledger.

Proof-driven agreement requires participants to render compelling attestation owing to the cause that they might be compensated for integrating an uncharted block into the secure ledger. The most in-demand proof-driven agreement scheme is referred to as proof-of-work, dictating a participant to operate actively by rectifying a puzzling enigma with the goal of safeguarding its authenticity [51].

VI. Load Balancing in Blockchain Networks

A. Idea

Rooted upon this literature examination, the idea of LB in blockchain networks is categorized into the beneath 7 categories.

- C1—Blockchain transaction load balancing by sharding, partitioning, distributing, etc.
- C2—Deploying blockchain consensus for load balancing.
- C3—Deploying blockchain to prevent tampering and protect fidelity, confidentiality, and reduce the same data transfers to facilitate balancing the load using a regular approach.
- C4—Deploying the blockchain itself with the aid of SCs for load balancing.
- C5—Deploying blockchain for secure energy/resource trading/auctioning to facilitate balancing loads using a regular approach.
- C6—Deploying blockchain for access control to

balance the load using a regular technique.

- C7—Deploying blockchain as a coordinator of load balancing.

The idea of LB in blockchain networks is graphically exhibited in Fig. 4.

B. Review on LB in Blockchain Networks

1) LB in sharded/partitioned blockchain networks

BlockExplorer is an exploration framework for the Ethereum blockchain having master-slave architecture where transaction-driven partitioning by the master is deployed to achieve LB among the slaves to acquire big data [21]. An approach to predict and balance sharded blockchain transaction processing times using consensus-driven distributed LB to distribute accounts across shards has been studied in [54]. In order to maintain low cross shard transactions and balance the workload across shards, a fine resolution account reservation approach was presented in [55], which is solved using a sharding protocol and an account partition algorithm. Moreover, for the Ethereum blockchain, a LB framework by regularly reassigning accounts and contracts to appropriate shards to reduce the gap between the loads of different shards has been studied in [56]. Similarly, in [57], two LB approaches for sharded blockchains were presented; in the first approach, the blockchain itself carries out LB, while in the second approach, wallets carry out LB, whereas in both methods, accounts are reassigned to balance the load.

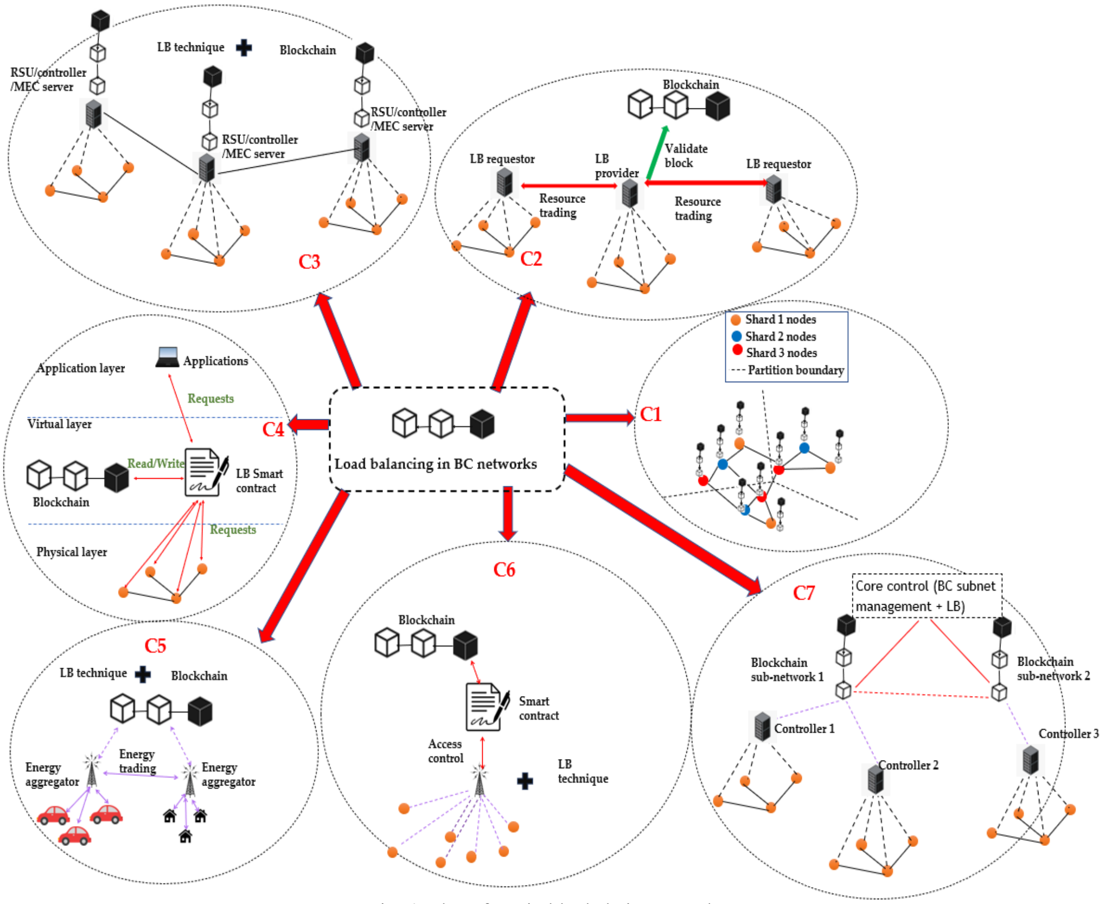

Fig. 4. Idea of LB in blockchain networks.

2) Round-robin aided LB in blockchain networks

Binary logistic regression applied to a permissioned blockchain has been deployed to represent client and server roles in a network where a novel consensus algorithm known as proof-of-equity has been introduced to compute the loads of models in a fair manner to serve as the server using the round-robin approach [58]. For an automotive data certification task related to odometer fraud in vehicular networks, a consortium blockchain has been deployed to protect data integrity, where a load balanced programming interface using round-robin is developed between the vehicles and the blockchain network for LB when transactions are submitted to the blockchain [23]. In an assessment of the selection of Ethereum clients for proof-of-authority consensus, a novel LB middleware is proposed for the uniform distribution of blockchain transactions using round-robin [59].

3) Dynamic LB in blockchain networks

A dynamic LB approach for Ethereum sharded blockchains known as D-GAS, which balances the transaction load in different shards considering the utilization of gas, has yielded better transaction throughput and low delay [60]. Similarly, in [61], the throughput of Ethereum blockchains was analyzed, and a dynamic LB for sharded blockchains was proposed to improve the blockchain network throughput. Moreover, a dynamic workload balancing algorithm for sharded blockchains using the shard workload history to dynamically balance the load periodically using a consensus driven algorithm has been introduced in [62].

4) Blockchain driven LB with multiple controllers

Proof-of-balance is a consensus approach driven by game theory to safely balance loads in multiple software-defined networking controllers using a consortium blockchain with the aid of a new cryptographic coin, where game theory is utilized to provide incentives to controllers to offload from busy controllers to idle controllers [22]. BCLB is a LB scheme for the global controller in a multi-controller software-defined network that deploys blockchain for providing information for LB such as inter-domain links and global network topology in a trustworthy manner, being a data sharing model. BCLB uses a DRL approach to select overloaded controllers and to do subsequent migration to facilitate achieving global LB, where blockchain acts as a decentralized data sharing platform [63]. DistB-SDCloud is an integrated framework formed by fusing blockchain and software-defined networking to provide security, privacy, and integrity for a software-defined cloud computing platform to facilitate providing other capabilities and a better LB of cloud infrastructure [64].

5) Blockchain driven LB with single controller

Driven by the incorruptible and tamper-proof features of a permissioned blockchain, it is used as a trustworthy solution for access control for LB, where user requests are allowed driven by the load of the IoT device while allowed requests are incorporated into the blockchain [65].

6) Blockchain-driven LB using rerouting

For a software-defined internet of vehicles network, LB is performed by rerouting after analyzing the workload of software-defined road side units in a fake news detection framework consisting of edge blockchain servers that accommodate reports provided by vehicles, while the edge SDN controllers perform LB known as QcFND [66].

7) Blockchain driven LB using switch migration

SliceBlock is a framework for network slicing along with LB in software-defined 6G ecosystems where slicing of the communication network is attained by applying a generative adversarial network, while for each and every slice, an unconventional blockchain concurrently with proof-of-space consensus is deployed to ensure slice security while load is balanced by joint intrusion packet detection and packet migration using a heap-driven optimization technique [67]. In a software-defined network multi-controller system, multi-chain has been introduced as a trusted component for coordination that allows decentralization with a decision-making tier to facilitate balancing uneven load initially and then dynamically balancing network load by detecting and recovering from partial and global overloads using switch reporting and migration [68].

8) Optimization driven LB in blockchain networks

In a 5G software-defined networking environment, an unconventional blockchain is deployed to store hashed user credentials for user authentication and flow rules, while a honey badger optimization algorithm is deployed to elect the optimum underemployed controller to balance the load in the network [69]. Furthermore, ROAC-B is a cluster driven vehicular adhoc network framework that uses a rainfall optimization approach for clustering and LB to minimize communication overhead, which uses blockchain for secure and privacy protecting data communication [70]. BeCome is a blockchain-driven computation offloading platform for protecting data integrity during offloading, while a nondominated sorted genetic algorithm is deployed to offload and a fitness function-driven optimization is utilized for LB [71].

On the other hand, in blockchain networks, a combination of two heuristic algorithms and a genetic algorithm is deployed to balance the storage of a blockchain network with high accuracy and low overhead [72].

9) Blockchain and Game/Contract theory driven LB

In a blockchain driven storage system in which nodes compete with each other to earn a reward that can be obtained only by the user's payment, LB is realized using an incentive scheme that rewards nodes that have correct data and punishes others, while the data competition among nodes is realized using game theory for LB [25]. Blockchain, concurrently with proof-of-work-driven reputation consensus, is deployed for secure energy trading, in which an incentive mechanism, contract theory, and reputation system are utilized to balance the load [73]. In a blockchain driven collaborative edge computing framework, an auction theory known as Vickrey Clarke Groves is utilized to satisfy edge demand responses, which makes bidding rules for improving the LB of the edge nodes where further optimization of the incentive and trust mechanism is carried out [74].

10) Blockchain and Distributed algorithms driven LB

In blockchain networks that are deployed in healthcare systems in smart cities, an algorithmic approach is used to distribute and balance nonce computing tasks during mining among the blockchain nodes without exhausting a particular mining node concurrently with another algorithm to prioritize nonce computing for critical patients [75]. In the user-to-user energy trading marketing platform of a smart grid, blockchain has been deployed for a secure and dispersed energy trading process, while the LB in the energy trading market is realized using three (main, peer-to-peer, peer-to-grid) algorithms that define SCs' implementation [24]. Similarly, LBTF is a LB framework driven by blockchain for energy trading, particularly in the advanced metering structure of smart grids, which uses SCs to implement a reward policy to reduce energy consumption during peak hours, and another policy implementing a SC known as the micro-grid contract for user-to-user global energy trading [76]. Moreover, in peer-to-peer blockchain networks that use proof-of-work consensus, blockchain data with nodes in a distributed hash table as a cluster, where all nodes are considered as mining nodes, has been effective in LB in the blockchain network [77]. In an experimental study, which has evaluated the effectiveness of transaction LB in blockchain networks, iterative algorithms have proven to have better LB performance over other algorithms such as randomization, clusterization, rule-dispatching, etc. [78]. Occam is a safe and versatile permissionless blockchain that flexibly adjusts the transaction throughput dynamically by adjusting the mining hardness and a LB strategy for mining power allocation [79].

11) Machine learning driven LB in blockchain networks

An agent-driven DRL approach has been deployed to prevent bottlenecks in certain nodes of the blockchain to facilitate balancing and distribute the load uniformly in the blockchain network [80]. Hyperledger fabric blockchain has been introduced as a way for securing transactions and for access control in an edge computing framework of an internet of things vehicular network to reduce traffic congestion by utilizing reinforcement learning for traffic LB [26]. For software-defined fog-driven internet of vehicle networks, secure communication is realized with the aid of a blockchain, while the LB, by distributing the tasks within the fog layer and between fog layer and vehicles, is realized using reinforcement learning known as SaFIoV [81]. By implementing mobile edge computing servers as a network of blockchain, a combination of service caching and LB has been realized by modeling the LB problem as a Markov decision procedure and solving it by deploying a deep Q network to facilitate allocating communication and computational resources optimally [82].

12) Blockchain and Fuzzy logic driven LB

In [27], blockchain was proposed to coordinate among different software-defined controllers where a fuzzy logic-driven approach is utilized to balance the load among the controllers considering multiple factors such as traffic increment, number of controllers, etc. in a software-defined vehicular network. DAG-BTLBR is an unconventional blockchain for securing transactions concurrently with authentication using the BLAKE256 algorithm to provide security concurrently with scalability that uses an emperor penguin colony driven clustering technique where optimal secure load balanced routes are found using a neuro-driven dual fuzzy technique [83]. A load balanced, energy mindful routing method using fuzzy logic within industrial IoT networks to facilitate decreasing network traffic and improve network lifetime where blockchain is utilized to decrease the amount of exactly the same data exchanges [84]. Blockchain has been introduced to secure the confidentiality of fitness data in the fitness industry's internet of things network to facilitate scheduling user fitness requests while balancing the load of the fitness requests while maximizing the acceptance rate of requests with better utilization of resources using fuzzy logic [85].

13) Blockchain and combined approaches for LB

An intelligent control system to balance the distribution of resources in Hyperledger fabric blockchains using reinforcement learning and several algorithms (Contextual Multi-Armed Bandits and Car Chain code) has been studied in [86].

VII. Review Appraisal

A. Appraisal of Individualistic Elements

Table III exhibits the appraisal of blockchain-driven load balancing frameworks pertaining to load balancing approach and technique, BC concepts and parameters, network characteristics, performance, and time.

TABLE III: APPRAISAL OF BLOCKCHAIN-DRIVEN LOAD BALANCING FRAMEWORKS.

LB technique	Scheme	Blockchain				LB strategy	Network		Performance	Rel. Time
		Idea	Paradigm	Consensus	Category		Paradigm	Category		
LB in sharded or partitioned blockchain	BlockExplorer [21]	C1	Conventional	PoW	Public	Decentralized, Deterministic, static	Generic	Generic	Workload difference up to 18%	2023
	Account [54]	C1	Conventional	PoW	Public	Decentralized, Deterministic, dynamic	Generic	Generic	Challenged by accounts to process a transaction	2022
	State [55]	C1	Conventional	PoW + PBFT	Public	Decentralized, Non-deterministic, dynamic	Generic	Generic	Good cross shard ratio, throughput, latency	2022
	Sharded-BC [56]	C1	Conventional	PoS	Public	Decentralized, Non-deterministic, dynamic	Generic	Generic	Low transaction delays and fees	2020
	Wallet [57]	C1	Conventional	PoS	Public	Decentralized, Non-deterministic, dynamic	Generic	Generic	Wallet-level load balancing	2022
Round robin	GloreChain [58]	C2	Conventional	PoEquity	Permissioned	Decentralized, Deterministic, dynamic	Generic	Generic	Similar correctness, high time for consensus	2019
	Automotive [23]	C3	Conventional	PoAuthority	Consortium	Decentralized, Deterministic, dynamic	Generic	Generic	Scalable, high transactions per time	2020
	Ethereum [59]	C4	Conventional	PoAuthority	Private	Decentralized, Deterministic, dynamic	Generic	Generic	Geth achieves highest transactions/s	2021
Dynamic LB	D-GAS [60]	C1	Conventional	PoS	Public	Decentralized, Deterministic, dynamic	Generic	Generic	12% transaction throughput, 74% low latency	2019
	DLB [61]	C1	Conventional	PoW	Private	Decentralized, Deterministic, dynamic	Generic	Generic	Improves the throughput of Ethereum BC	2022
	Consensus [62]	C1	Conventional	Distribute avg	Generic	Decentralized, Deterministic, dynamic	Generic	Generic	LB better than centralized	2021
Multiple controller	PoB [22]	C2	Conventional	PoBalance	Consortium	Decentralized, Non-deterministic, dynamic	Centralized	SDN	Significant better load balancing and security	2020
	Bclb [63]	C3	Conventional	Generic	Generic	Decentralized, Non-deterministic, dynamic	Centralized	SDN	Global LB with low migration costs	2022
	DistB-SDCloud [64]	C3	Conventional	PoW	Public	Decentralized, Deterministic, dynamic	Centralized	SDN	Low response time, latency	2023
Single controller	Permissioned [65]	C6	Conventional	PoW	Permissioned	Decentralized, Deterministic, dynamic	Centralized	SDN-IoT	Good accuracy and bandwidth utilization	2020
Rerouting	QcFND [66]	C3	Conventional	PoAuthority	Permissioned	Decentralized, Non-deterministic, dynamic	Centralized	SD-IoV	Better LB than Veins, Hyperledger Fabric, etc.	2020

Switch migration	SliceBlock [67]	C3	Unconventional	PoSpace	Generic	Decentralized, Non-deterministic, dynamic	Centralized	SDN-6G	Scalable, secure, efficient LB	2022
	Multi-chain [68]	C7	Hierarchical	CFT+BFT	Generic	Decentralized, Non-deterministic, dynamic	Centralized	SDN	Prevent controller overload, scalable, credible	2022
Optimization	DAG-LB [69]	C6	Unconventional	Generic	Generic	Decentralized, Non-deterministic, dynamic	Centralized	SDN-5G	Better bandwidth, delay, response time	2023
	ROAC-B [70]	C3	Conventional	Generic	Generic	Decentralized, Non-deterministic, dynamic	Cluster	VANET	Good PDR, delay, throughput	2020
	BeCome [71]	C3	Conventional	Generic	Generic	Decentralized, Non-deterministic, dynamic	Decentralized	MEC	Reduced task offloading time, energy consumption	2019
	Storage-LB [72]	C1	Conventional	Generic	Generic	Decentralized, Non-deterministic, dynamic	Generic	Generic	Better accuracy, low storage, com. overhead	2022
Game/Contract theory	Incentive [25]	C5	Conventional	PoStorage	Generic	Decentralized, Non-deterministic, dynamic	Generic	Generic	Recover to a balanced status	2020
	CT-ET [73]	C5	Conventional	PoW	Consortium	Decentralized, Non-deterministic, dynamic	Generic	EV	High social welfare, energy saving	2020
	EC [74]	C5	Conventional	Generic	Generic	Decentralized, Non-deterministic, dynamic	Decentralized	Edge comp.	Low average service and computation times	2023
Distributed algorithms	SC [75]	C1	Conventional	PoW	Consortium	Decentralized, Deterministic, dynamic	Generic	Healthcare	Compute with low time for critical tasks	2023
	P2P [24]	C4	Conventional	PoW	Consortium	Decentralized, Deterministic, dynamic	Generic	Smart grid	Efficient energy trading with LB	2020
	LBTF [76]	C4	Conventional	PoW	Consortium	Decentralized, Deterministic, dynamic	Decentralized	Smart grid	Privacy, integrity preserving LB energy trading	2018
	DHT [77]	C1	Conventional	PoW	Generic	Decentralized, Deterministic, dynamic	Generic	Generic	Good redundancy rate, average messages	2018
	Algorithms [78]	C1	Conventional	Generic	Generic	Decentralized, Deter. + Non-deter., dynamic	Generic	Generic	Iterative algorithms have better LB	2023
	Occam [79]	C1	Conventional	PoW	Permissionless	Decentralized, deterministic, dynamic	Generic	Generic	Improves BC throughput, mining power allo.	2021
Machine learning	DRL [80]	C1	Conventional	Generic	Generic	Decentralized, Non-deterministic, dynamic	Generic	Generic	Scalable and reliable solution	2021
	Traffic [26]	C6	Conventional	PBFT	Permissioned	Decentralized, Deterministic, dynamic	Decentralized	IoT-EC	Reduce city traffic congestion	2020
	Safiov [81]	C3	Conventional	Generic	Generic	Decentralized, Non-deterministic, dynamic	Centralized	SDN-IoV	Avoid congestion, minimize latency	2021
	MEC-LB [82]	C3	Conventional	Generic	Generic	Decentralized, Non-deterministic, dynamic	Decentralized	MEC	Lower energy consumption and delay	2023
Fuzzy logic	Fuzzy-SDVN [27]	C7	Conventional	PBFT	Permissioned	Decentralized, Non-deterministic, dynamic	Centralized	SDVN	Better latency, computations, throughput	2022
	DAG-BTLBR [83]	C3	Unconventional	Generic	Generic	Decentralized, Non-deterministic, dynamic	Decentralized	WSN	Better delay, time consumption, pkt loss	2023
	Routing [84]	C3	Conventional	Generic	Generic	Hierarchical, Deterministic, dynamic	Hierarchical	IIoT	Improves package delivery rate, high lifetime	2022
	Fitness [85]	C3	Conventional	PBFT	Permissioned	Decentralized, Deterministic, dynamic	Generic	IoT-fitness	More than 25% increment in throughput	2022
Combined approaches	RL-LB [86]	C1	Conventional	RAFT-CFT	Permissioned	Decentralized, Non-deterministic, dynamic	Generic	Generic	High mean reward, low resource utilization	2022

B. Overall Appraisal

Fig. 5 exhibits the graphical arrangement of BC-driven load balancing regarding BC-driven idea and variables, load balancing approach, network classes, and proposed time.

As exhibited per Fig. 5(a), C1 (BC transaction LB-37.5%) is the paramount abundant concept reviewed, trailing by C3 (30%), C4, C5, C6 with 7.5%, and C2 and C7 with 5% prevalence. Next, in these frameworks, conventional BC architecture has been dominantly deployed (90%) while unconventional (graph) BC architecture is having a prevalence of 7.5% and hierarchical BC is having 2.5% prevalence, as exhibited per Fig. 5(b). Moreover, as exhibited per Fig. 5(c), most BC-driven LB frameworks are engineered for generic agreement methods, while out of specific agreement methods, Proof of Work has the highest application of 27.5%, trailing by PoS, PoAu, PBFT, and similar things. Furthermore, when reflecting on the LB approach exhibited in Fig. 5(d), it is obvious that 97.5% have a decentralized LB approach, and 2.5% have a hierarchical LB approach, and similarly, 97.5% have dynamic LB while 2.5% have static LB, 52.5% are non-deterministic, 45% are deterministic, and 2.5% are both deterministic and non-deterministic in approach. As exhibited per Fig. 5(e), 45% of LB approaches do not specify a network type and have been proposed for generic networks. When reflecting on specific network types, SDN has the highest application (10%), trailing by smart-grid (5%), MEC (5%), SDN-IoT, SDN-IoV, and similar things. Finally, when observing the variation of proposed frameworks over time, it is obvious that the BC-driven LB concept is still growing even though there are ups and downs in publication volume in consecutive years, as exhibited per Fig. 5(f).

Fig. 5. Overall appraisal (a) BC-driven load balancing idea (b) BC class (c) BC agreement method (d) BC-driven load balancing approach (e) Network class (f) Released time.

VIII. Discussion

A. Potentials

1) LB capability by blockchain itself

Blockchains can partition or shard their transactions to facilitate balancing the load among the transactions in jobs as in data acquisition, transaction processing, etc. These can be realized using sharing protocols and partitioning algorithms where the load difference across shards can be minimized and accounts are reassigned to balance the load. Thus, a blockchain can effectively represent the transactions in a computer network where its load can be balanced with the aid of partitioning and sharding techniques.

2) Dynamic Load Balancing (DLB)

In DLB using blockchain, the dynamics of the network are considered, where different parameters of the blockchain network can vary in time, and load in the network is balanced according to the variation [87]. As a demonstration, the energy utilization of the network can be monitored to balance the blockchain transactions, which can result in improved throughput and low delay. Blockchains can use consensus driven algorithms to come to an agreement regarding LB decisions. Machine learning methods can be deployed to forecast on network conditions and status to be deployed in dynamic blockchain driven LB. Moreover, blockchains can be effectively deployed to prevent duplication of exactly the same transactions during dynamic LB, helping to reduce unnecessary communication resource wastage.

3) Trustworthy LB

In LB, using conventional approaches, blockchains can be deployed to improve the trustworthiness of the LB job [88]. In this approach, blockchain can be deployed to provide information for LB, such as global network topology and links among the network domains, in a trustworthy manner to balance load among multiple controllers in different network domains. Making use of the trustworthiness of the blockchain, user requests can be allowed to be driven by the requests of the users and incorporated into the blockchain to balance the load effectively. Further to that, multi-chain can act as a trustful coordinator for LB in multi-controller platforms. Additionally, in some LB systems, blockchain is deployed to protect the confidentiality of data while balancing the load.

4) Automated LB using SCs and consensus

Consensus algorithms, for example, proof-of-equity, can be deployed to fairly compute the loads of clients and servers [58]. Moreover, proof-of-balance is another consensus approach driven by game theory to balance the load in the controllers by providing incentives in software-defined networks [22]. Additionally, the proof-of-space consensus approach can also be adapted along with a packet detection and migration scheme to effectively balance the load. Furthermore, SCs can be deployed to execute algorithms for LB in an autonomous fashion upon reaching some conditions. As it was exhibited from this scrutinization, smart contracts have been heavily deployed to realize LB in peer-to-peer energy trading networks. In addition, AI can be integrated for making automatic LB inference [89].

5) Safeguarded transactions and access control for LB

Firstly, note that blockchains can protect the integrity of data stored in them while balancing the blockchain transactions. Moreover, blockchains can strengthen the security and privacy of transactions while balancing the load. Blockchain servers can accommodate reports by network devices to detect fake messages in the system of balancing load using other techniques as in rerouting. Moreover, blockchains can store user credentials and data in a privacy retaining and tamper-proof way to foster balancing the load using optimization techniques. Furthermore, blockchains can act as a secure storage system where clients compete using game theory and reputation driven schemes to get a reward for LB in a demand-supply approach. Additionally, authentication, access control, and secure communication can be deployed using blockchain to secure the transactions for LB.

B. Predicaments

1) Existence of traditional LB methodologies

There are numerous traditional LB methodologies as in round robin, equal cost multipath, rerouting, optimization-driven LB, AI-driven LB, etc., that typically achieve similar LB performance with a lower computational and communication complexity than using pure blockchain driven LB. In pure blockchain-driven LB, consensus approaches are implemented to realize a distributed agreement on LB in the blockchain network, which causes many computations and communications within the blockchain network to be carried out. Moreover, in sharded blockchains, sharding and partitioning algorithms need to be implemented in addition to LB.

2) Diminishes energy efficiency of LB

In blockchain-driven LB systems that deploy a conventional approach for LB where blockchain is utilized to ensure the trustworthiness and security of LB, the cumulative energy efficiency of the system can degrade by reason of the gains in trustworthiness and security given from the blockchain [90]. Even in pure blockchain-driven LB approaches, the energy consumption is high compared to conventional approaches. One of the main targets of LB is to distribute the load in the network evenly, mitigating the cumulative energy usage. However, by reason of the deployment of blockchain, the achievement of this goal is questionable, as blockchain networks consume a high amount of energy for the creation, propagation, and validation of blockchain transactions.

3) Escalated transactions in dynamic networks

In highly dynamic networks, such as adhoc networks, the topology of the network can change frequently by reason of the mobility [91]. In such cases, dynamic LB is required to be deployed, and a new solution for LB is required to be found frequently. In such cases, irrespective of whether blockchain is deployed to aid LB by ensuring trustworthiness and security or used itself for LB, the total quantity of blockchain transactions that are required to be performed by unit time amplifies. Due to the high number of transactions per unit time, there can be additional delays in providing a solution for LB, ultimately degrading the performance of the LB system.

4) Malicious client attacks in auction-driven LB

In blockchain and auctioning driven LB, game theory or contract theory is deployed for auctioning by deploying a reward scheme for the correct LB. These systems can use blockchain-driven reputation for consensus to satisfy demands by providing supplies while balancing the load. However, malicious users can still create fake clients and attempt to act as legitimate clients, deceiving the blockchain system and disturbing the proper LB procedure by gaining the majority of the clients to influence blockchain consensus [92]. These malicious users can thus pose a strong threat to the blockchain and auction-driven LB system.

5) Higher convolution in integrated approaches

As reviewed in the literature, usually blockchain is deployed more frequently to achieve the security and trustworthiness of LB by integrating with a conventional LB approach rather than using blockchain alone for LB using consensus and SCs. In such integrated approaches, the cumulative convolution of the LB system is high, as there are both conventional LB approaches and the blockchain network. Thus, an integrated approach causes additional computation, communication, and memory requirements that can be strenuous to be obtained in resource constrained network environments.

IX. Conclusion, Ideas, and Upcoming Paths

In this scrutinization, we first scrutinized numerous LB tactics and parameters and then scrutinized numerous LB approaches driven by network architecture, deterministic nature, and dynamic nature. Beyond conveying a digest on secure ledger innovation, we scrutinized on blockchain-driven LB. Specifically, rooted upon this literature examination, we discovered 7 categories in which blockchain is deployed for LB: blockchain transaction LB, blockchain consensus for LB, data security protection for LB, blockchain with SCs for LB, secure energy/resource trading for LB, access control for LB, and coordinator for LB. Moreover, we extensively appraised the scrutinized blockchain-driven LB works driven by LB technique, approach, blockchain idea, blockchain variables, etc. Finally, we considered the potentials and predicaments of blockchain-driven LB.

Using this survey, the current literature on LB using blockchain will be reinforced, as we scrutinize surviving blockchain-driven LB and use different criteria to classify and extensively appraise them related to LB and blockchain related features. Moreover, on top of thorough appraisal, as we considered the potentials and predicaments of the concept and derive proposal ideas driven by the predicaments, prospective researchers can easily deploy this literary scrutinization as a source to formulate blockchain-driven LB approaches considering our ideas, visualize drifts and discrepancies in current research.

Rooted upon considered predicaments, beneath proposal ideas can be introduced.

- With a view to reducing the performance gap that exists between traditional LB and blockchain-driven LB in terms of computational and communication efficiency, multiple tactics can be deployed. First, sharding can be deployed to segment the blockchain into a set of subsets and process transactions parallelly in the shards. Moreover, distributed caching can be deployed to store abundantly accessed data items in an off-chain storage, preventing repeated blockchain computations.
- To overcome the extra energy that is depleted in blockchain transactions, energy efficient consensus approaches known as green consensus can be deployed. Moreover, in cases where SCs implement the LB, they can be optimized for energy efficiency.
- With a view to overcoming the challenge of the high rate of transactions in dynamic LB, network monitoring and adapting the LB driven by the network status can be deployed. Moreover, parallel processing can be realized with the aid of an unconventional blockchain to handle the high rate of transactions by reason of changes in dynamic networks.
- To prevent malicious client attacks in blockchain and auction-driven LB, auctioning can be designed to prevent possible adversarial behavior. Moreover, a reputation-driven penalty system can be deployed to penalize clients with a history of malicious behavior. Furthermore, blockchain-driven authentication can be integrated with blockchain and auction-driven LB to verify the validity and authenticity of the bids submitted.
- In blockchain-driven LB, where blockchain is deployed for protection of security features of LB, the complexity is high by reason of the addition of blockchain. Thus, this extra complexity cannot be eliminated; however, it can be reduced by deploying lightweight cryptographic algorithms, self-executing contracts, and consensus approaches to protect the data integrity, trustworthiness, and non-repudiation in the system of LB.

Blockchains can improve the fidelity, secrecy, non-tampering nature, and authenticity of the LB system either by LB using the blockchain itself or using a conventional LB technique. Tomorrow's research may consider network LB and blockchain LB together to provide a more efficient solution in terms of cumulative computations, memory, and communication resources. Moreover, it will be interesting to investigate how quantum cryptography can improve the security of the cumulative LB system by utilizing blockchain.

Conflict of Interest

The author declares no conflict of interest.

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