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Towards Mobile Edge Computing: Taxonomy, Challenges, Applications and Future Realms

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ABSTRACT The realm of cloud computing has revolutionized access to cloud resources and their utilization and applications over the Internet. However, deploying cloud computing for delay critical applications and reducing the delay in access to the resources are challenging. The Mobile Edge Computing (MEC) paradigm is one of the effective solutions, which brings the cloud computing services to the proximity of the edge network and leverages the available resources. This paper presents a survey of the latest and state-of-the-art algorithms, techniques, and concepts of MEC. The proposed work is unique in that the most novel algorithms are considered, which are not considered by the existing surveys. Moreover, the chosen novel literature of the existing researchers is classified in terms of performance metrics by describing the realms of promising performance and the regions where the margin of improvement exists for future investigation for the future researchers. This also eases the choice of a particular algorithm for a particular application. As compared to the existing surveys, the bibliometric overview is provided, which is further helpful for the researchers, engineers, and scientists for a thorough insight, application selection, and future consideration for improvement. In addition, applications related to the MEC platform are presented. Open research challenges, future directions, and lessons learned in area of the MEC are provided for further future investigation.

INDEX TERMS Mobile edge computing, cloud servers, networks, edge device, smart cities, latency, energy.

NOMENCLATURE

APs	Access points
BS	Base station
CCBM	Computational capability based matching
DRL	Deep reinforcement learning
D2D	Device-to-device
E2E	End-to-end
ECIPs	Edge computing infrastructure providers
IoT	Internet-of-Things
IPDC	Interior penalty with D.C
IA	Iterative algorithms
JCOS	Joint cache offloading solution
KKT	Karush–Kuhn–Tucker
MEC	Mobile edge computing
MDs	Mobile devices
MEN	Mobile edge network
MBSs	Macro base stations
NOMA	Non-orthogonal multiple access
NE	Nash equilibrium
QoS	Quality-of-service
RLT	Reformulation linearization technique
RF	Radio frequency
SMD	Smart mobile device
SC	Smart city
SG	Skyline graph
SGX	Software guard extensions
SDR	Semi-definite relaxation
SBSs	Small base stations
Sps	Service providers

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TPO	Two-phase optimization
UE	User equipment
V2V	Vehicle-2-vehicle
VEN	Vehicle edge network
VNF	Virtual network functions

I. INTRODUCTION

In the recent decade, cloud computing has started providing a platform for services and resources over the Internet for users [1], [2]. The large pool of data resources and services has enabled the emergence of several novel applications such as smart grids, smart environments, and virtual reality [3], [4]. However, the state-of-the-art of cloud computing faces a delay constraint, which becomes a major barrier for reliable cloud services. This constraint is mostly highlighted in the case of smart cities (SC) and the Internet of Things (IoT) [5], [6]. Therefore, the recent cloud computing paradigm has poor performance and cannot meet the low delay, navigation, and mobility support requirements [7], [8].

To address the above issues, MEC is introduced for delivering services over the Internet in a reliable fashion. MEC is an emerging technology that diminishes the constraints existing in the traditional cloud computing. They include, for example, latency, computational offloading, data storage and energy consumption problems by leveraging the available services and resources in the edge networks [9].

MEC consists of few to several devices (smartwatch, smartphone, tablet, laptop etc.) to mutually connect and perform the tasks of sensing, broadcasting and networking [10]. MEC enables applications such as health care, traffic management, automatic driving, and interactive online gaming, to mention a few [11]. Mobile devices (MDs) in MEC are also more efficient than desktop devices in terms of performance [12].

MEC aims to enable millions of MDs [8], which is effective as the estimated bandwidth demand increases each year [13]. This will further spread the advantages of the MEC such as real-time insight, proximity and low latency (1 ms) [14]. Meanwhile, MEC allows the IoT paradigm that enables devices with limited resources to interconnect over the Internet. However, these edge devices have limited storage and processing capabilities. To address these constraints, many techniques exist in the literature [15], [16]. In particular, to save the energy as well as processing power, edge devices offload the computational task to the cloud (e.g., Azure [17] and Amazon EC2 [18]). However, there may exist a long delay between edge devices and cloud servers in the case of offloading the computational task via the Internet.

Fig. 1 illustrates the MEC network model. The entire model can be discussed into three major parts. The first part illustrates information of the end users that are allocated at the edge of the network and connected with the MEC servers through the fronthaul link. The end users e.g. virtual reality, smart home, real-time traffic monitoring, smart sensor, etc. compute and offload the task to the MEC servers. The second part contains the MEC servers, which are connected to the cloud servers via the backhaul link. Unlike cloud servers, MEC servers have a low amount of data storage capacity. Therefore, it delivers all the information (e.g. sensed by end users) to the cloud server. Finally, the third part contains the illustration of cloud server. The cloud server has a large amount of storage capacity, which can compute and store the information.

In this paper, a survey for MEC is presented, which considers algorithms published in the literature in the last couple of years. Unlike the existing surveys, this survey classifies the algorithms published in the literature into eight different classes. The classification of the algorithms is based on the performance parameters such as low delay, low energy consumption, high throughput, high computational offloading, high hit ratio, high resource utilization, low network cost and load balancing. Furthermore, each class highlights the algorithms with its approach, merits and demerits. The classification of the algorithms is handy in the research area. The description given in each class helps scientists and researchers to select the techniques according to the desired applications.

Describing the algorithms is helpful in its understanding for the researchers and in devising new techniques for MEC. In addition, the bibliometric overview is presented. Highlighting the bibliometric overview is a key access for researchers to choose the desired algorithms for different purposes. Moreover, different applications of the mentioned algorithms are presented. Finally, open challenges and future research directions are given to fill the existing gaps in this area. Fig. 2 lists the number of algorithms included in each class that bring eases while searching for the specific performance parameter.

A. MAIN CONTRIBUTIONS

To summarize, the paper has the following contributions:

1) This survey considers the state-of-the-art algorithms for MEC. Unlike existing surveys, each algorithm is discussed based on its approach, merits and demerits.
2) The various algorithms are classified into eight different classes. The classification of the algorithms based on the performance parameters helps for the desired requirements of the researchers and scientists in both the academia and industry.
3) Application of MEC, open challenges in research and future directions are discussed.
4) As compared to the published surveys, this survey presents the bibliometric overview, which is helpful for scientists and researchers by keeping in view the advantages.
5) We present a summary of the lessons learned from the state-of-the-art of algorithms in the field of MEC.
6) Table 1 refers to the comparison of the contribution with the existing surveys.

FIGURE 1. Network architecture of "Mobile Edge Computing".

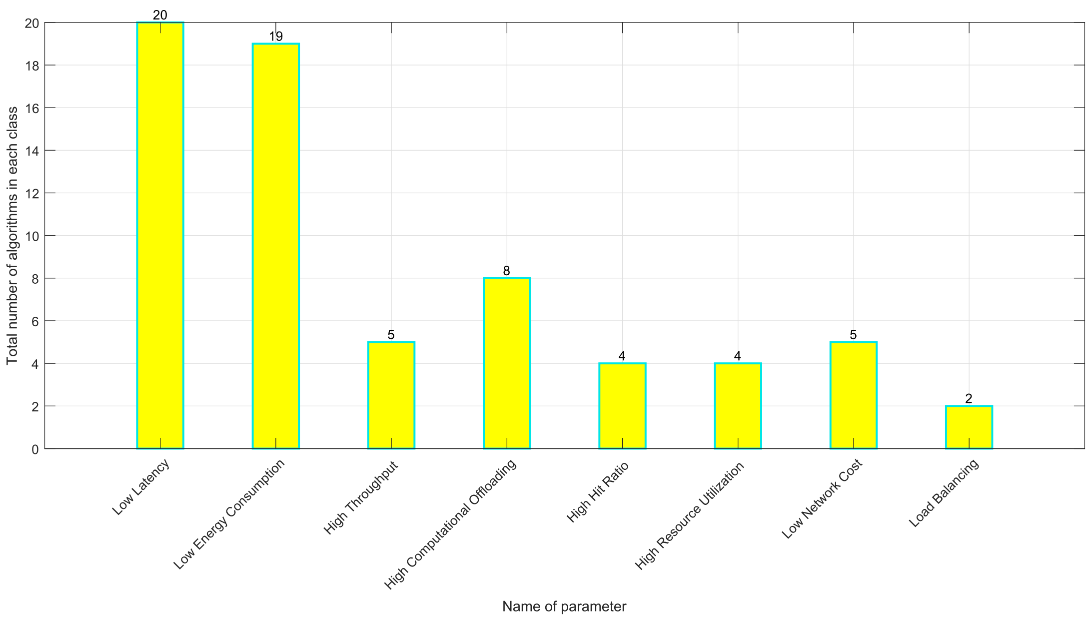

FIGURE 2. Classification of performance parameters.

B. UNIQUENESS OF THE SURVEY

This paper is unique and different from the existing surveys in many aspects. As compared to other surveys in the literature, this survey presents the state-of-the-art algorithms published in the literature in the last couple of years. The algorithms are well classified into eight distinct classes whereas each class is further explained based on their approach, merit(s) and demerit(s). The classification of the algorithms is helpful

TABLE 1. The comparison of our contributions with existing surveys.

Article	Algorithm's Approach(s)	Algorithm's merit(s) and demerit(s)	Performance analysis	Bibliometric overview	Applications	Open research challenges	Future directions	Year
Jiang *et al.* [19]	×	×	✓	×	✓	✓	✓	2020
Wang *et al.* [20]	×	×	×	×	✓	✓	✓	2020
Sha *et al.* [21]	×	×	×	×	✓	✓	✓	2020
Pham *et al.* [22]	✓	×	✓	×	✓	✓	✓	2020
Victor *et al.* [23]	✓	×	✓	×	×	×	×	2020
Latif *et al.* [24]	×	×	✓	×	✓	✓	✓	2020
Khan *et al.* [25]	×	×	×	×	×	×	✓	2020
Sufian *et al.* [26]	×	×	×	×	×	✓	✓	2020
Peng *et al.* [27]	✓	×	✓	×	✓	✓	✓	2018
Vhora *et al.* [28]	×	×	×	×	✓	✓	✓	2020
Wazir *et al.* [29]	✓	×	✓	×	✓	✓	✓	2019
Raza *et al.* [30]	×	×	✓	×	✓	✓	✓	2019
Capra *et al.* [31]	×	×	×	×	×	×	✓	2019
Jiang *et al.* [32]	✓	×	✓	×	×	×	×	2019
Yang *et al.* [33]	×	×	×	×	✓	✓	✓	2019
Ren *et al.* [34]	✓	×	✓	×	×	✓	✓	2019
Liu *et al.* [35]	×	×	×	×	×	✓	✓	2019
Ray *et al.* [36]	✓	×	✓	×	×	✓	✓	2019
Tao *et al.* [37]	×	×	×	×	×	✓	✓	2019
Wang *et al.* [38]	×	×	×	×	×	✓	✓	2018
Zhang *et al.* [39]	✓	×	✓	×	✓	✓	×	2018
Tanaka *et al.* [40]	×	×	×	×	✓	✓	×	2018
Hong *et al.* [41]	×	×	×	✓	✓	×	×	2018
Zhang *et al.* [42]	×	×	✓	×	×	✓	✓	2018
Olli *et al.* [43]	×	×	×	×	✓	×	✓	2018
Shan *et al.* [44]	×	×	×	×	×	×	✓	2018
Pawani *et al.* [45]	✓	×	✓	×	✓	×	×	2018
Naha *et al.* [46]	✓	×	×	×	×	✓	✓	2018
Nasir *et al.* [47]	×	×	×	×	✓	✓	✓	2018
Wang *et al.* [48]	×	×	×	×	✓	✓	✓	2017
Wei *et al.* [49]	×	×	✓	×	×	✓	✓	2017
Carla *et al.* [50]	✓	×	✓	×	✓	✓	✓	2017
Mao *et al.* [51]	×	×	×	×	✓	✓	✓	2017
Mach *et al.* [52]	×	×	✓	×	×	✓	✓	2017
Blesson *et al.* [53]	×	×	×	×	✓	✓	×	2017
Li *et al.* [54]	×	×	×	×	×	×	✓	2017
Ejaz *et al.* [8]	×	×	×	×	✓	✓	✓	2016
Yifan *et al.* [55]	×	×	×	×	✓	✓	×	2016
Yi *et al.* [56]	×	×	×	×	×	✓	✓	2015
Yi *et al.* [57]	×	×	×	×	×	✓	×	2015
Beck *et al.* [58]	×	×	×	×	×	✓	×	2014
Beck *et al.* [9]	×	×	✓	×	✓	✓	✓	2014
Junaid *et al.*	✓	✓	✓	✓	✓	✓	✓	-

in the research area. The detail about each class helps the researchers to select the techniques for the desired applications. In addition, highlighting the bibliometric overview is the primary concern of the classification, which makes it convenient for the researchers to select the algorithms of interest for applications and further future investigation. Moreover, different applications of the mentioned algorithms are presented. Finally, open challenges and future research directions are given to fill the existing gaps in this area.

The rest of the manuscript is organized as follows. Section II presents the state-of-the-art of MEC. Section III illustrates the MEC applications. Section IV explains the description of the open research challenges and future directions. Furthermore, the discussion of the bibliometric

FIGURE 3. **Organization of the survey.**

overview is given in Section V. Section VI summarizes the lessons learned from the conventional of algorithms in MEC. Finally, the conclusion of the overall work is presented in Section VII. Furthermore, the visual organization of the survey is illustrated in Fig. 3.

II. STATE-OF-THE-ART OF MOBILE EDGE COMPUTING

This section provides the detail of the existing literature of the MEC, which is classified into eight different categories. Each category is clearly organized and discussed. The classification of the selected algorithms is shown in Fig. 4.

A. LATENCY-BASED APPROACHES

In these algorithms, the mobile users (MUs) are distributed at the edge of the network, which efficiently compute and offload the task to the cloud servers with low latency. These algorithms are further classified into their different approaches, merits and demerits. Table 2 shows a short summary of these algorithms.

1) MP-MEC

Lee *et al.* [59] proposed mobile personal multi-access edge computing (MP-MEC) to mitigate the problem of high latency in the network. This algorithm considers three phases. In the first phase, the mobile device used as a MEC server (MECS) for reliable delivery and rapid response to the users. The second phase is about offloading task in which a service requester sends a request to upload the metadata to MECS. Metadata contains all the information of task offloading. The third phase includes the process of task offloading of mobile-MECS. The MECS calculates the task segment size and process offloaded task by exploiting service request. This algorithm achieves good results for service delivery time and

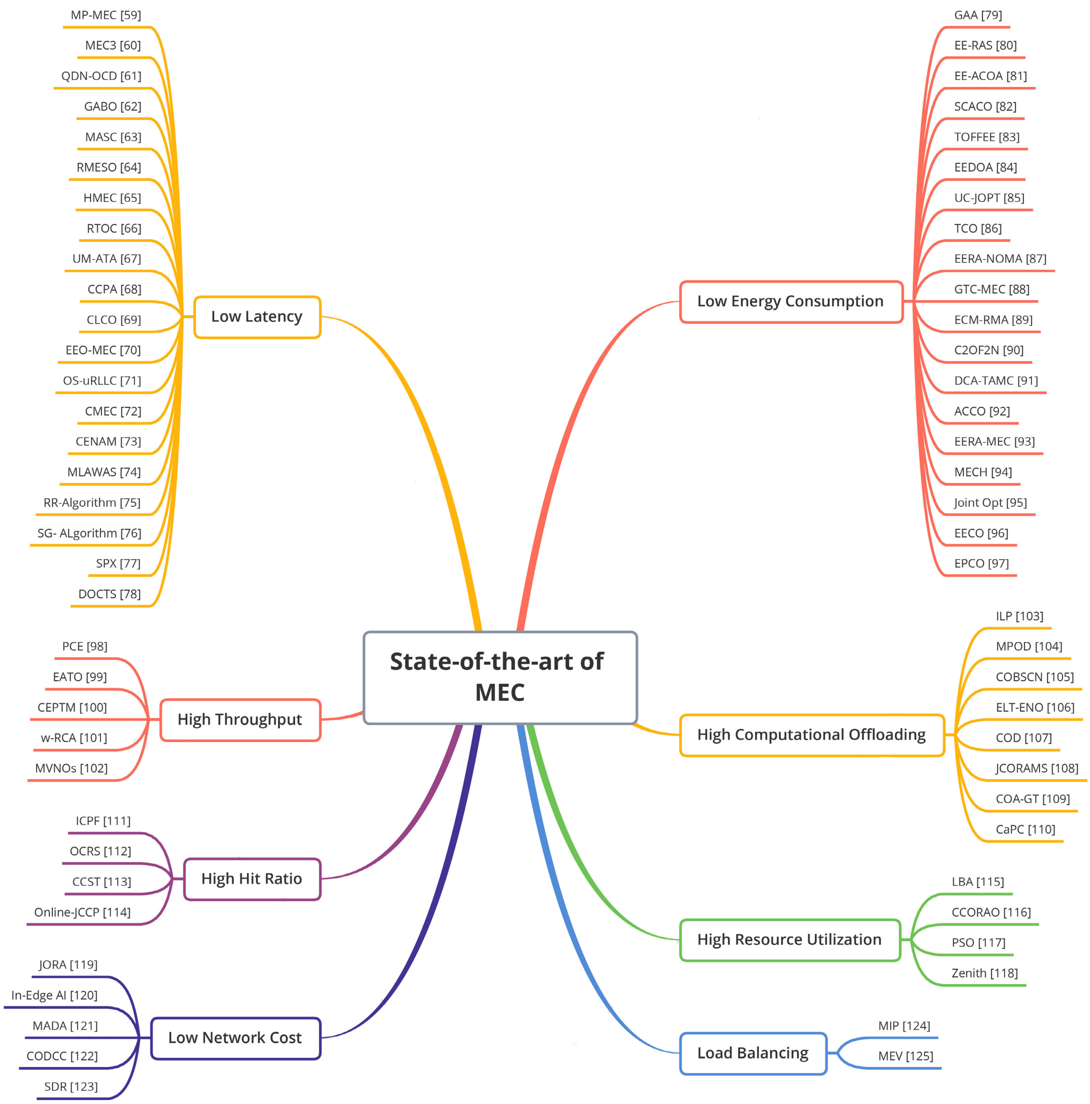

FIGURE 4. Mobile edge computing according to eight different types of advantages.

task computation reliability. However, it has an unbalancing delivery latency for mobility preference.

2) MEC3

To achieve an ultra-low latency in maritime communication, mobile edge communications, computing, and caching (MEC3) technology is proposed in [60]. In this work, an unmanned aerial vehicle (UAV) is used to overcome the reliability issue that exists in the constant base station in MEC networks. Furthermore, the best response-based offloading algorithm (BROA) is employed that helps in optimizing the task offloading process. This work achieves good results for low latency and energy consumption. However, it has high computational complexity.

3) DQN-OCD

Park *et al.* [61] proposed a deep Q-network based offloading compression decision (DQN-OCD) algorithm for real-time offloading in MEC. This algorithm considers four input size models. The input size contains all the information of server capacity, task remaining, queue capacity, and TD capacity. The output size consists of a dimension's action. This algorithm demonstrates good performance for low latency and energy consumption. But, as the time step increases, its latency also increases. Therefore, it has unbalancing latency for a higher time step.

4) GABO

The authors in [62] proposed a genetic algorithm-based optimization (GABO) for task offloading in MEC. This work makes use of a genetic algorithm to overcome the optimization issues under limited processing resources of edge servers. Furthermore, a population matrix is formed by considering the combination of a different strategy. For each combination in the population matrix, a task having the lowest time completion is considered as the optimal one. This algorithm achieves good results for total completion latency.

TABLE 2. Algorithms that address latency problem.

Algorithm	Approach	Merits	Demerits	Year	Reference
MP-MEC	Used mobile devices as a MEC server, Segment information used in the process of task offloading	Achieves good results for service delivery time and offloading reliability	Unbalancing delivery latency in the mobility mode	2020	[59]
MEC3	Used unmanned aerial vehicle to overcome the task reliability issue, employed the best response-based offloading technique for task offloading optimization	Good results for low latency and energy consumption	It has a high computational complexity	2020	[60]
DQN-OCD	Used action and state of users as input and output values for the deep neural network (DNN)	Achieve good results for low latency and energy consumption	Unbalancing latency when the time step goes above 110	2020	[61]
GABO	Used genetic algorithm to reduce the problem of network optimization	It has the lowest completion latency	High complexity of combination in a popular matrix	2020	[62]
MASC	A geometric model is predicted to reduces the service caching problem	Achieves good result for service response latency	It has an unbalance local service proportion	2020	[63]
RMESO	The P2P network strategy is adopted that minimizes execution latency and optimizes network reliability	Achieves good results for execution latency	Edge servers need localization of smart vehicles that results in high energy consumption of the network	2019	[64]
HMEC	Places the data servers very close to the users at the edge of the networks	Low transmitting latency, low contents downloading time	It has compromised energy consumption for image processing	2018	[65]
RTOC	Installs the base stations to the strategic positions to balance the work load and reduce the access latency	Greater performance in response time, user utility and battery power	Compromises memory utilization for the greater service execution model	2018	[66]
UM-ATA	Considers both the user mobility property and the networks constraints	Achieves good result for the delay response	In without-mobility case it has greater delay	2018	[67]
CCPA	The joint cache data placement and offloading solution (JCOS) is incorporated that effectively reduces the user equipment time delay	Achieved good result for the average task latency and also cached more interesting contents	When using the cache greedy method, this algorithm has the worst performance for the task computing latency	2018	[68]
CLCO	An architecture is designed for the computational offloading task on the basis of the learning mechanism	Outperforms in average task duration, low latency	Requires high amount of energy, poor performance on limited energy	2018	[69]
EEO-MEC	A cooperative edge cloud architecture is designed where the small cell base stations consist of edge servers	Good results in execution time and the percentage of budget	It has high energy consumption	2018	[70]
OS-uRLLC	A framework is designed that offloads the users' task to the nearest edge nodes in a sequential order	Good performance in terms of reliability and response time	It has high computational complexity	2018	[71]
CMEC	A software-defined edge computing technique is provided for the contents delivery of the vehicles	Low latency when it enabled the caching property	Consumes more time when it disables the caching function	2018	[72]
CENAM	Cloud computing and edge computing mutually cooperate for the task computation	It has good result for the average response time	High latency for the large amount of data	2018	[73]
MLAWAS	Allocates heavy workload users to the optimal cloudlet to reduce latency	Low average response time	Compromises service latency	2018	[74]
RR-Algorithm	A gate-way based technique is proposed for the edge computing networks	Achieves good result for the average response time and number of scheduled tasks	It has high waiting time	2018	[75]
SG Algorithm	The Skyline Graph (SG) algorithm is proposed which can boost the process of deletion and insertion to optimize the service maintenance of the MEC network	Good performance for the computation time in the correlated dataset	Poor stability and high latency for the computation in an independent dataset case	2018	[76]
SPX	Incorporates the Intel SGX, which provides the remote access and protects channel from the external malicious attacks	Efficient performance for the transfer time in the E2E case	High handshake latency	2018	[77]
DOCTS	A schedule is provided that computes the tasks based on the priority queue, processing unit and transmission unit	Efficient ability to execute a task within a short latency	It has poor task execution efficiency as compared to the counterpart schemes	2017	[78]

However, it has high complexity while the combination in population matrix which leads the network to unbalance.

5) MASC

Wei *et al.* [63] proposed a mobility-aware service caching (MASC) to mitigates the service caching problem in MEC. In this work, a user's motion is predicted by a geometric model. A frequent pattern method is used to get the information of a movable object. Furthermore, the prediction of the target location of the user is obtained by considering the results of the geometric model and object trajectory. Moreover, a service cache allocation method has incorporated that train and predict suitable services online. This algorithm achieves a good result for service response time. However, it has an unbalancing local service proportion.

6) RMESO

Tang *et al.* [64], proposed a reliable mobile edge service offloading (RMESO) mechanism to optimize task offloading ratio in MEC. This work minimizes task execution latency by considering a peer-to-peer (P2P) network strategy. The P2P network distribution management of a mobile edge server is formulated that maintains the network reliability between smart vehicles and mobile edge servers. Furthermore, the P2P network considers the information of bandwidth, storage capacity, and processing capability of the servers that effectively minimize the processing delay of vehicles. Minimizing processing latency makes the smart vehicle easy to collect vital information from the edge servers. Moreover, a fault tolerance technique based on the P2P network is formulated that solves the task failure problems. The simulation results reveal the effectiveness of this algorithm, that achieves good results for task execution latency. However, the edge servers need localization of smart vehicles which itself is a challenging issue.

7) HMEC

The authors of [65] proposed a hierarchical mobile edge computing (HMEC) architecture based on context awareness. In the existing mobile cloud data center, the deputed data server is placed at a distance from the edge of the networks. The computation response delay and energy consumption issues are addressed by proposing a hierarchical computing architecture, in which servers are placed with the users. The experiment shows that HMEC achieves the best results in terms of average latency, downloading contents and energy consumption. It is due to the data server being placed very close to the users at the edge of the networks. However, it has compromised energy consumption for image processing.

8) RTOC

Tiwary *et al.* [66] proposed a response time optimization for cloudlet (RTOC) in mobile edge computing. A non-cooperative game model is presented, in which the player that has high pay-offs can reduce the response time. In addition, a backward induction approach is formulated to obtain the Nash Equilibrium (NE). The battery lifetime depends upon the computation of the server. Moreover, this protocol implied the Karush–Kuhn–Tucker (KKT) technique to improve the response time between the edge users and mobile server in the network. The simulation shows that RTOC has a good performance in response time, user utility and battery power. However, when the service execution model increases, it compromises the memory utilization.

9) UM-ATA

The user mobility-aware task assignment (UM-ATA) for MEC is presented in [67]. The computational task execution delay in mobile edge network (MEN) is reduced in UM-ATA. This algorithm considers both the user mobility property and the networks constraints, and finds a heuristic way for the optimal and quick scheduling. Moreover, a lightweight algorithm for the accurate delay computation scheme is used to offload the MDs' decision in the network. The proposed scheme achieves a good result for the delay response because, when there are more small cell base stations, the network scalability is increased, which enhances the performance utilization and decreases the delay response. However, in the case of no mobility, the UM-ATA has a greater delay.

10) CCPA

A joint cache content placement algorithm (CCPA) is presented in [68], in which the JCOS is incorporated that effectively reduces the user equipment time delay. The JCOS also uses a Gale-Shaply technique for the contents placement that solves the game matching problem for the cache placement. The CCPA also takes the capacity of the storage, contents popularity and RF link into account, which diminishes the problem for the matching. The game theory model is applied, which solves the device offloading task problem. The experimental result shows that the CCPA achieves a good result for the average task latency and also caches more interesting contents. However, while using the cache greedy method, the CCPA has the worst performance for the task computing latency.

11) CLCO

In [69], the problem of the computational offloading scheme is investigated, in which a cognitive learning-based computation offloading (CLCO) scheme is proposed. In addition, an architecture is designed for the computational offloading task on the basis of the learning mechanism. This increases the optimization power and minimizes the computational problem that occurs during multi-device scenario in the multi-edge network. Moreover, cognitive learning method is used for the specific problem that optimizes its efficiency. The CLCO scheme outperforms in average task duration and executes a task with a cost of less delay. However, to compute the task, it requires a high amount of energy.

12) EEO-MEC

The energy efficient-offloading in mobile edge computing (EEO-MEC) with edge-cloud collaboration is presented in [70]. In this work, to consider offloading issue in the network, a cooperative edge cloud architecture is designed, whereas the small cell base stations consist of edge servers and the macro-cell base stations communicate with the cloud servers through radio waves. A greedy algorithm is designed that solves the offloading constraints. Moreover, a pricing scheme is formulated that efficiently optimizes the end users and servers in the MEC network. The algorithm achieves good results in terms of execution time and the percentage of the budget. However, it consumes 31% more energy than counterpart schemes.

13) OS-uRLLC

Offloading schemes in MEC for ultra-reliable low latency communications (uRLLC) is presented in [71]. This scheme addresses the issue of reliable task offloading and the latency constraint of the MEC network. A framework is designed, which offloads the users' task to the nearest edge nodes in a sequential order. The framework has the ability to reduce failure probability for the latency and task offloading. Moreover, three algorithms are formulated: heuristic search, reformulation linearization technique (RLT) and semi-definite relaxation (SDR). These algorithms optimize the edge nodes' selection, task allocation and sequence of task offloading, respectively. The experimental outcomes demonstrate that this approach outperform in the reliability and latency. However, it has a high computation complexity.

14) CMEC

Badarneh *et al.* [72] proposed a cooperative mobile edge computing (CMEC). A software-defined edge computing technique is provided for the contents delivery of the vehicles formally available at the edge of the networks. The aim is to provide the communication platform for the vehicles over V2I interface with a minimal latency response and incorporate the computational capability for more reliability in the service. Furthermore, a vehicle-to-vehicle (V2V) interface is evaluated that caches the information of each other and provides a road safety with a quality-of-service (QoS). The neighbors in the network that seek the road environment can be used as an emulator. This protocol has low latency when it enables the caching property. However, it consumes more time when it disables the caching function.

15) CENAM

In [73], a combined cloud computing and edge computing network architecture model (CENAM) is presented. The cooperation mechanism is used for the mutual understand between edge devices. In addition, the Kruskal algorithm is proposed that computes and spans the tree graph about the edge devices in order to minimize the response delay. Furthermore, the Lagrange multiplier technique is applied that reduces the latency used in computation tasks by the edge devices. Moreover, in cloud computing, a matrix is designed that allocates the devices in an optimal method. In addition, it reduces the transmission delay between the edge devices and cloud servers by using the balance transmission method. The CENAM protocol achieves good performance for the average latency. However, it suffers with slightly high latency for the high data transmission, because a large amount of data may consume extra time when transmitting the information to the edge nodes.

16) MLAWAS

The authors of [74] proposed a multi-layer latency aware workload assignment strategy (MLAWAS) in MEC. A workload allocation problem is highlighted and MLAWAS formulated a geo-distribution based on an optimal cloudlet system. In addition, it determines the best cloudlet, which has maximum ability to allocate the heavy workload of the device. When the MD workload application performs the task, it suffers a high response time. This algorithm addresses the issue of the high response time and also achieves a good result for the average response time. However, it has compromised service latency for Tasks 600–700.

17) RR-ALGORITHM

In [75], a gate-way based round-robin (RR-Algorithm) is proposed for edge computing networks. In addition, the resource calculation and virtual network function (VNF) configuration techniques are used that optimize the process of the edge network in terms of deployments, utilization and task demands' request. These three parameters improve the service request for 5G networks. By using the lightweight visualization method, the edge gate-way becomes efficient. The experimental results reveal that the RR-algorithm achieves a good result for the average response time and the number of scheduled tasks. However, it has high waiting time as compared to the other schemes.

18) SG ALGORITHM

The authors of [76] considered the issue of quick selection of the edge users in the network. The Skyline Graph (SG) algorithm is proposed, which can boost the process of deletion and insertion to optimize the service maintenance of the MEC network. Furthermore, the directed acyclic graph concept is applied, which can save and update the service used for the edge device in the network. The proposed SG algorithm achieves good performance for the computation time in the correlated dataset. However, it has poor stability and high latency for the computation in an independent dataset case.

19) SPX

In [77], the mobile edge network enabled multi-purpose tasks by deploying the edge nodes in the network is considered. However, it faces the end-to-end (E2E) encryption problem. To address this issue, the secure protocol extensions (SPX) algorithm is proposed, which efficiently maintains the end-to-end security in the network. Furthermore, the SPX algorithm incorporates the Intel SGX, which provides the remote access and protects the channel from the external malicious attacks. The experimental results show that SPX has an efficient performance for the transfer time in the E2E case at the cost of high handshake latency.

20) DOCTS

In [78], the authors proposed a delay-optimal computation task scheduling (DOCTS) for MEC network. The designing of computational scheduling is a challenging task, because a local task has a greater timescale to execute. The channel condition is considered during transmission of the data in the smaller timescale task. To cope with these issues, a Markov based decision technique is incorporated that solves these issues. A schedule is provided that computes the tasks based on the priority queue, processing unit and transmission unit. Furthermore, to analyze the average latency and average power consumption, a 1D search technique is incorporated that investigates an efficient strategy. In addition, it provides a schedule for optimal task execution. This algorithm has an ability that executes a task within a shorter latency. However, it has poor task execution efficiency as compared to the counterpart schemes.

B. ALGORITHMS ADDRESS ENERGY CONSTRAINT

The MDs deployed at the edge of the network with very limited battery power. These MDs detect the information from surrounding and transmit to the cloud servers, which are connected through radio frequency (RF). When the MDs die, the network is unable to achieve the required goal. These algorithms, therefore, need to adopt efficient strategies and address the high energy consumption constraint by preventing the early death of the MDs in the edge network. Algorithms addressing energy constraint are given below in Table 3.

1) GAA

A greedy approximation algorithm (GAA) is proposed in [79] that effectively reduces the energy consumption of the mobile devices during task offloading in MEC. This work formulates a problem of cross-server computation offloading that optimize the mobile devices' energy consumption under the constraints of computing resource and task completing time. The GAA first computes the energy consumption and completing time for each task of mobile devices. Furthermore, it creates a set that stores a record of task completing time. Also, it divides the task based on completing time and energy consumption to obtain the optimal offloading decision. This algorithm outperforms in terms of energy consumption and task completion time. However, it has a high computational complexity.

2) EE-RAS

Pie *et al.* [80] proposed an energy-efficient resource allocation scheme (EE-RAS) for MEC. A heterogeneous based three-tier computing model is established. The model consists of local computing, small and macro base stations. A problem of energy optimization is formulated that effectively minimizes the energy consumption of smart mobile devices (SMDs). Furthermore, a substitution method is applied that jointly optimize the computation and resource allocation problem. Numerical simulations demonstrate that this algorithm achieves goo results for energy consumption. However, the workload placement results in high computation complexity in the network.

3) EE-ACOA

In [81], the authors proposed an energy-efficient and computation offloading algorithm (EE-ACOA) for a multiuser MEC system. This algorithm employs the Karush-Kuhn-Tucker (KKT) conditions to effectively minimize the energy consumption of mobile devices. Furthermore, the Lagrange-multiplier is used to solve the convex optimization and transmission power allocation problems. The numerical results reveal that this algorithm outperforms in terms of the average energy consumption of mobile devices. Also, achieves minimum completion latency for computation offloading. However, the mobile users deployed in a fixed position which may affect the reliability of computation offloading.

4) SCACO

Huang *et al.* [82], proposed a security and cost-aware computation offloading (SCACO) technique for smart edge users in MEC. This technique aims to minimize the total cost such as energy consumption, processing time, and a probability of task loss. A problem of computation offloading is formulated using a Markov decision process (MDP). Furthermore, the deep Q-network (DQN) approach is applied to derive the optimal offloading decision. Extensive simulations reveal the performance of the SCACO technique that achieves good results for energy consumption, total processing delay, and the total number of task drops. However, it takes more time to process higher data size. This affects the total average latency of the network.

5) TOFFEE

The authors in [83] proposed a task offloading and frequency scaling for energy efficiency (TOFFEE) scheme to investigate task allocation and CPU- frequency in MEC. This algorithm formulates a stochastic optimization problem that effectively reduces the energy consumption of mobile devices. The stochastic technique divides the original problem into two subproblems. This algorithm works without any statistical information about the wireless network. Extensive simulation results show the performance of the TOFFEE algorithm which outperforms in terms of energy consumption of mobile devices. However, it has compromised results for Queue length as compared to the counterpart algorithm.

6) EEDOA

Chen *et al.* [84], proposed an energy-efficient dynamic offloading algorithm (EEDOA) for the MEC system. This algorithm considers the Lyapunov optimization scheme to enhance the offloading decision for dynamic MEC's users. The wireless channel condition poses many technical issues to solve the offloading problem for dynamic users in the network. To cope with this issue, a stochastic offloading decision is formulated that guarantees the offloading performance by reducing the energy consumption of mobile devices. Experimental results show the effectiveness of EEDOA, which demonstrates outperform for the total transmission energy consumption and queue length. However, it has computation complexity when the mobile device far away from the edge server.

7) UC-JOPT

The authors of [85] presented a technique to minimize the transmit power during mutual cooperation in a computation offloading task. This algorithm takes the time allocation and joint power parameters into account that cooperatively

TABLE 3. Algorithms that address energy constraint.

Algorithm	Approach	Merits	Demerits	Year	Reference
GAA	Formulate a problem of cross-server computation offloading to optimize energy consumption	Good energy consumption for task completing time	It has high computational complexity	2020	[79]
EE-RAS	Three-tier computing model based on heterogeneous networks, formulated energy optimization problem	Achieve good results for energy consumption	Workload placement result in high computation complexity	2020	[80]
EE-ACOA	Used the Karush-Kuhn-Tucker (KKT) conditions to minimize the energy consumption of mobile devices	Reduces energy consumption and completion latency of mobile devices	The absence of user mobility affect the reliability of computation offloading	2019	[81]
SCACO	A Morkov decision process is employed to formulate the computation offloading problem	Reduces energy consumption, the total dropping of tasks, and processing latency	Required more time to process higher data size	2019	[82]
TOFFEE	A stochastic optimization problem is considered that effectively minimize the energy consumption of mobile devices	Achieve good result for energy consumption	It has compromised result for Queue length	2019	[83]
EEDOA	The Lyapunov optimization-based offloading decision is utilized to minimize energy consumption	Good results for total energy consumption and queue length of mobile devices	High computation complexity due to unavailability of mobile devices near the edge server	2019	[84]
UC-JOPT	Time allocation and joint power based cooperative computation offloading	Less power consumption while transmitting the information	Less effectiveness in the average response time	2018	[85]
TCO	Proposed an optimal method to reduce the tasks caching and offloading problem	It has effective result for the energy consumption	Low impact for the average data task size	2018	[86]
EERA-NOMA	Proposes an iterative algorithm that optimizes the total offloading data and time allocation for the UE	Efficient performance for the total energy consumption	It has ompromised scalability	2018	[87]
GTC-MEC	Develops a cross-layer approach to exchange the information between the network servers and the edge devices	Achieves good result for the energy consumption and latency	High latency when few devices are present in the network	2018	[88]
ECM-RMA	Investigates a method for transmission optimization sub-problem and battery management sub-problem	Solves the energy consumption constraint and latency	When the number of sub-channel increases, energy consumption is compromised	2018	[89]
C2OF2N	The mobile devices use the resources provided by the femtolet in a cooperative manner	Good performance for energy consumption and average delay	In the case of offloading to the cloud server, it consumes high energy	2018	[90]
DCA-TAMC	This algorithm takes the channel condition, computational tasks and delay limitation into account in orders to minimize the energy consumption problem	Good result for the energy consumption, latency and computational complexity	It has a higher delay when compared it to the exhaustive matching scheme	2018	[91]
ACCO	Works on the mobile edge computing and cloud's model over fiber-wireless (FiWi)	Lowest energy consumption and lowest latency	Unbalanced energy consumption when the number of computational tasks increased	2017	[92]
EERA-MEC	One base station is enough to serve for the MEC multi users	Good result for the energy consumption	Lower efficiency than optimal algorithm	2017	[93]
MECH	Mobile devices, as servers, receive and process the data from the client	Low energy consumption and low delay	Poor scalability for few users	2017	[94]
Joint Opt	Formulates a joint optimization feasible method with the collaboration of the backhaul capacity and contents distribution	Reduces energy consumption, minimizing the joint cost	Compromises delay performance	2017	[95]
EECO	Designs a framework for the multi-user task completion and offloading in 5G networks	Consumes less energy as compared to other schemes	No priority is used for the selection of the devices	2016	[96]
EPCO	Proposes a technique for partial computational offloading	EPCO outperforms in term of energy consumption	It has greater delay as compared to counterpart schemes	2016	[97]

compute the offloading task in the network. To make the algorithm more effective, a two-phase technique is applied in this scheme. This protocol consumes less power while transmitting information. However, it has no effective result for the average response time.

8) TCO

Hao *et al.* proposed a task caching and offloading (TCO) algorithm for MEC [86] to find the optimal method to reduce the task caching and offloading problem. They used a combined programming method to obtain a solution. This algorithm reduces the complexity and also solves the combine optimization problem. The aim of the TCO is to minimize the energy constraint during communication between the mobile devices. This algorithm achieves an effective result for the energy consumption when it processes average data. However, it has a low impact on the average data task size as compared to the counterpart schemes.

9) EERA-NOMA

Yang *et al.* [87] proposed an energy efficient resource allocation for MEC networks with non-orthogonal multiple access

(EERA-NOMA). The NOMA based MEC network consists of one base station and multiple groups of users. Each group has two users and they communicate with the base station simultaneously with specific frequencies. The presented algorithm minimizes the energy as a convex problem and addresses the local computation constraints of the user-equipment (UE). It optimizes the total offloading data and time allocation for the UE. NOMA achieves a good result for total consumed energy. However, it has compromised scalability when compared with the counterpart technique.

10) GTC-MEC

In [88], a game theory concept in mobile edge computing (GTC-MEC) is used to optimize the behavior and the utility function of the service providers. In addition, a cross-layer approach is developed to exchange information between the network servers and their edge users. The experiments show that this offloading scheme achieves a good result for energy consumption and latency. However, it has high latency when there are few mobile users presented in the network. As the number of mobile users increases, the latency of the protocol decreases.

11) ECM-RMA

In [89], an energy efficient joint resource management and allocation (ECM-RMA) technique is proposed. This algorithm tackles the stability problem of MEC in data queue and energy queue. Furthermore, a stochastic optimization problem is divided into two sub-problems that are solved by convex optimization and linear programming. The transmission optimization sub-problem and battery management sub-problem are also taken into account. The transmission optimization is designed to reduce the delay in the data transmission and improve the transmission power. Battery management is applied to solve the energy problem for the needy wireless devices. The ECM-RMA has the effective results for the energy consumption and latency. However, it has high energy consumption when the number of sub-channel increases.

12) C2OF2N

In [90], the authors proposed a low power cooperative code offloading (C2oF2N) method for the computational offloading in the mobile network. The mobile devices are connected with a home base station known as femtolet. The identity of each mobile device is stored in femtolet, which provides computation and data storage capabilities. The mobile devices use the resources provided by the femtolet in a cooperative manner. The aim of this scheme is to utilize the available resources such as image processing and gaming computational offloading. The mobile devices are used as edge devices, which offload the tasks through the cooperative method. These devices communicate with cloudlet remotely. The base station has the ability of computational task and storage capacity, which reduces the latency in communication. This algorithm has a good performance in terms of energy consumption and average delay when compare to counterpart schemes. This scheme minimizes approximately 15% of energy consumption and 12% of delay. However, in the case of offloading to the cloud server, it consumes more energy.

13) DCA-TAMC

A distributed and context-aware task assignment mechanism for collaborative (DCA-TAMC) MEC is proposed to overcomes the energy consumption [91]. The authors formulated the assignment of tasks using game matching between two sets of devices. Game-matching is one of the important ways for the relationship of single-to-many devices. This algorithm takes the channel condition, computational tasks and delay limitation into account to minimize total consumed energy. This scheme has a good result for the energy consumption, latency and computational complexity, reducing it by up to 64.01%. By comparing with the random matching scheme and CCBM scheme, this algorithm significantly shortens the delay. However, while comparing it with the exhaustive matching scheme, it shows that this algorithm has a high latency.

14) ACCO

The authors of [92] proposed an approximation collaborative computation offloading (ACCO) algorithm that works on the mobile edge computing and cloud's model. The model is operated via fiber-Wi-Fi. Furthermore, the collaborative task between MEC and cloud solves the problem of the computation and offloading via fiber-Wi-Fi. The experimental results show that this scheme has the lowest energy consumption and lowest latency. However, it has unbalanced energy consumption when the number of computational tasks increases, because more edge devices may join the network.

15) EERA-MEC

An energy efficient resource allocation for MEC (EERA-MEC) is proposed in [93]. In this algorithm, more than one MEC users can access one base station (BS), which is capable of computing and processing the data. Furthermore, three parameters are used: uploading task, executing a task and downloading the computation results. An optimal solution is obtained, which utilizes the Johnson's algorithm. Moreover, the optimal allocating technique is applied, which is much handy for the energy problem. The sub-optimal algorithm achieves a good result for the energy consumption in both cases, i.e., number of users and time slot duration. However, it has compromised efficiency when compared to the optimal solution.

16) MECH

In [94], an energy efficient mobile edge computing in a heterogeneous network (MECH) is proposed. In this algorithm, the MDs work as servers, which can send, receive and process the task from the client in the network. Furthermore, the MECH divides the application into small modules that are easily accessible to be offloaded by the nearest mobile devices. MECH achieves a good QoS. In addition, it has the lowest energy consumption and lowest delay response. However, it has poor scalability when there are few users in the network.

17) JOINT OPT

In [95], the authors investigated a joint optimization (Joint Opt) algorithm. For the downloading delay issue in the MEC, the authors considered the MECs' energy consumption problem and formulated a joint optimization feasible method with the collaboration of the backhaul capacity and contents distribution. A genetic algorithm is applied to solve the complication in the joint optimization. The algorithm reduces the energy consumption by up to 63% and minimizes the joint cost when there is low backhaul capacity. However, the delay performance is compromised.

18) EECO

The authors of [96] developed an energy efficient computational offloading (EECO) technique to reduced the energy problem in the offloading tasks. The objective of this protocol is to minimize the cost of energy for both the contents transmission and task completion and design a framework for the multi-user task completion and offloading in 5G networks. To cope with the network complexity, a priority task schedule is incorporated. This algorithm has a good result for energy consumption. However, no effective method is used for the devices' priority.

19) EPCO

In [97], the authors proposed an energy-optimal computation offloading (EPCO) technique. This technique addresses the problem consumption of the smart mobile device (SMD) energy in partial computational offloading. The convex variable replacement technique is incorporated, which tackles the energy problem. Furthermore, a univariate search technique is investigated that diminishes the non-convex latency minimization constraint. These techniques are applied over the multiple cloud server, which demonstrates that it has an optimal distribution paradigm. This algorithm has a good result for energy consumption. However, it has high latency.

C. ALGORITHMS WITH HIGH THROUGHPUT

Throughput is the proportion of packets received successfully at the destination as compared to the total packets sent. The MDs of these algorithms as presented in Table 4 achieve higher throughput while detecting, computing and offloading the data to the cloud server.

1) PCE

In [98], a proactive caching edge computing (PCE) mechanism is proposed. To manage the big data from a cloud data center to the user devices, a three-layer data storage architecture is developed. Furthermore, big data distribution is categorized into two different parts: data cache and data fetching. An effective technique is formulated that downloads big data over the edge nodes in the network. In addition, the Hungarian algorithm diminishes the issue that arises during data fetching. This algorithm demonstrates that it achieves a good result for the throughput efficiency. In addition, it outperforms the counterpart algorithms for the latency response. However, it has compromised energy consumption for the higher data traffic.

2) EATO

An energy aware task offloading (EATO) mechanism in multiuser mobile-edge cloud computing is proposed in [99], in which the task offloading mechanism is developed to minimize energy consumption. An algorithm is designed based on priority and classification of mobile devices. The device classification can be divided into two major parts. The first one is classified as the local processing part, while the other one is classified as the remaining part. Furthermore, an auction-based technique is investigated that solves the problem for efficient energy during the offloading decision. Moreover, the quick estimation decision about offloading can reduce the energy consumption in a network. The EATO protocol not only has better achievements for the task offloading, but it can also allocate the resource at the proper location. This protocol consumes less energy while transmitting the information to the edge of the network. In addition, it has a good result for the throughput. However, it has a high average latency when the number of MDs is increased in the network

3) CEPTM

Wu *et al.* [100] proposed a cross-edge model for diverse personalization service and topic migration (CEPTM) in MEC. The edge servers collect the data from MDs. The user's action provides the personalization access that enables convenience and high accuracy in the network. In addition, in this protocol, the information can emerge from one edge server to the many other edge servers. The value of personalization is open and are not restricted to the node which has good behavior. This algorithm has high throughput and gains user's trust. Experiments were performed for four days and partitioned into four parts. This protocol achieves a good result for the number of clicks. However, in the experiments, it had fewer clicks during Hours 26–32.

4) w-RCA

Sodhro *et al.* [101] proposed a window-based rate control (w-RCA) algorithm for mobile edge computing. This protocol helps in medical applications such as surgery and works over the 5G network to have remote access and acquire the desired information. The scenario can be seen in the form of the picture or a video on the computer screen. Furthermore, this algorithm applies the PMR, latency, navigation and standard deviation parameters to enhance the standard of medical quality-of-service (m-QoS) in the health-center based on mobile edge computing. The mobile medical server computes the information and transmits it to the end user of the network. The experimental results show that the w-RCA algorithm achieves a good result for the m-QoS, buffer size and future

TABLE 4. Existing literature for higher throughput.

Algorithm	Approach	Merits	Demerits	Year	Reference
PCE	Develops three-layer data cache architectures, manages the big data from the cloud center to the end users	Good performance for the throughput efficiency, latency response and energy consumption	It has compromised energy consumption for the higher data traffic	2018	[98]
EATO	The task offloading mechanism is developed, auction based algorithm is designed	Achieves good results for high throughput efficiency	It has a high average latency when the number of mobile devices is increased	2018	[99]
CEPTM	The mobile users' actions provide personalization to forward the information from the edge devices to the edge servers	Achieves good result for the personalization acceptance ratio and users gain	Fewer clicks in some specific time frame	2018	[100]
w-RCA	The mobile medical server computes the information and transmits it to the user by taking the PMR, latency, navigation and standard deviation parameters into account	Good result for the m-QoS, buffer size and future frames for the transmission schedule	It has high latency while transmitting the contents to the users	2018	[101]
MVNOs	Uses blockchain based model to avoid doubling of the same frequency to the multi users	Good result for the throughput when underload with double spending	Not enough bandwidth for transmitting high data load	2017	[102]

frames for the transmission schedule. However, it has a high latency while transmitting the contents to the users.

5) MVNOs
The authors of [102] proposed mobile virtual network operators (MVNOs) that enable the access of IoT devices to diverse technology. In this protocol, a new blockchain method is applied, which avoids the doubling of the same frequency to more than one users. This method is more effective for enhancing the quality-of-service (QoS). Moreover, this protocol handles the problem of devices at the edge of the networks having limited bandwidth and data storage ability. The MVNOs has a good result for the throughput when underload with double spending. However, it does not have enough bandwidth for transmitting high data load, as the maximum amount of the channel used is more than the expectation, and a large part of the channel is wasted on data transmission and video information. Therefore, the link may be down and the throughput may start to decrease.

D. ALGORITHMS WITH HIGH COMPUTATIONAL OFFLOADING
Computational offloading refers to the transferring of the intensive computational task from the edge devices (smartphone, smartwatch, laptop, etc.) to the cluster, grid or a cloud. Table 5 lists the algorithms that have high computational offloading in the network.

1) ILP
The authors in [103] proposed an integer linear programming (ILP) based optimized computation offloading technique for MEC. This algorithm enables high computation offloading by solving linear problems and diminishes the challenges of a feasible region. The system model includes N number of mobile devices and also make use of M MEC servers. The servers are installed near a distance from energy harvesting (EH) devices. The communication between mobile devices and MEC servers is accomplished by using a wireless medium. The ILP algorithm brings eases in different modes such as local task execution, offloading execution, and task dropping. This algorithm outperforms in high computation offloading. However, it faces a problem of the high cost of resources.

2) MPOD
The authors in [104] proposed the multiuser probabilistic offloading decision (MPOD) to optimize the computation offloading decision of mobile devices in MEC. This work divides the entire offloading decision by taking computation and transmission into account. The existence of nash equilibrium (NE) is accomplished by considering the non-cooperative game model. The model helps in the decision of offloading server and channel allocation. The performance of the MPOD algorithm is evaluated by extensive simulations. The simulation results demonstrate that this algorithm achieves low cost for task offloading. However, it offloads the task in a flooding manner. Therefore it has unbalancing task offloading which degrades the network stability.

3) COBSCN
Chen *et al.* [105] proposed a computation offloading balance in small cell networks (COBSCN) for MEC, in which the macro base stations (MBSs) and small base stations (SBSs) are deployed, which share the spectrum orthogonally. Furthermore, the allocation of spectrum to the mobile devices and computational offloading method is proposed, which reduces the energy and latency constraints. Moreover, a criterion is used in which the transmission efficiency of the user, computational offloading, and spectrum allocation are considered for the small cell network with MEC. This protocol achieves good performance for the energy consumption, delay and the ratio of computational offloading. However, it has inefficient scalability because it requires more energy in the mobile devices to optimize the high computational offloading task.

4) ELT-ENO
Zhang *et al.* [106] proposed an energy-latency tradeoff for energy aware offloading (ELT-ENO) protocol in MEC

TABLE 5. High computational offloading.

Algorithm	Approach	Merits	Demerits	Year	Reference
ILP	Enables high computation offloading by solving linear problems and diminishes the challenges of a feasible region	Outperforms for high computation offloading	High cost of MEC servers' resources	2020	[103]
MPOD	A non-cooperative game model is considered, obtained the nash equilibrium	Obtain high task offloading with lower cost	Offload tasks in flooding manner, degrades network stability	2020	[104]
COBSCN	A criterion is used in which the transmission power of the user, computational offloading and allocation of spectrum are considered for the small cell network with MEC	Achieves good performance for the energy consumption, delay and the ratio of computational offloading	It has inefficient scalability as compared to the counterpart schemes	2018	[105]
ELT-ENO	The computational offloading and resource allocation problem is addressed by keeping in view both single- and multi-cell MEC networks	It has good results in total offloading efficiency and total cost of the network	It has high latency due to the high transmission rate	2018	[106]
COD	Sensor nodes upload their tasks about computation to the cloud through wireless, Nash equilibrium is derived based on the potential game	Reduces the system cost significantly, high offloading and scalability	Compromises scalability when the number of iteration increases, because more sensor devices may join the network	2018	[107]
JCORAMS	It considers the transmit power of the device, joint optimization and the resources about the computation task that reduce the complexity in the network	Effective performance for the offloading users and computation task	When the number of users are increased, the offloading performance may decrease	2018	[108]
COA-GT	A concept of the game theory is applied over the multiple vehicular users that computes the Nash equilibrium in the network	It has good result for the computational offloading, reducing it up to %16	It requires a high bandwidth, with poor performance at low bandwidth	2017	[109]
CaPC	Proposes a distributed cloud aware power control (CaPC) scheme that performs high computation ratio with a low cost of latency	Reasonable result for latency and computational ratio	It has slightly high signal overhead as compared to counterpart schemes	2016	[110]

networks. In this protocol, the computational offloading and resource allocation constraints are addressed by keeping in view both single- and multi-cell MEC networks. The energy-aware offloading algorithm is proposed, which boosts the offloading efficiency in the network. In addition, the residual energy of the mobile device's battery is considered for minimizing the energy constraint of the MEC network. Moreover, the IPDC algorithm is proposed, which optimizes the channel allocation and computational offloading. This algorithm achieves good results in total offloading efficiency and total cost of the network. However, it has high latency because it takes more time when the transmission rate increases.

5) COD

The computation offloading decision (COD) for the IoT devices in the cloud framework is investigated in [107]. In this algorithm, each sensor node uploads a task about computation to the cloud through the wireless medium. In COD, the NE is derived based on the potential game where each nodes' task is computed in the cloud. Furthermore, by knowing the utility in cloud, COD can optimize the improvement range at every iteration, and also reduce the complexity of the computation. Simulation results reveal that the COD has an optimal result for the system cost. In addition, the COD has effective results for the number of tasks offloading to the cloud and scalability. However, it has compromised scalability when the number of iteration increases, because more sensor devices may join the network.

6) JCORAMS

In [108], a Jcora-multi-server (JCORAMS) algorithm for heterogenous MEC network is considered, in which each MEC device can offload the computation task over different MEC servers rather than only one or a specific server. In addition, by considering the transmit power of the device, joint optimization and the resources about the computation task can reduce the system complexity. This protocol takes two major parameters into account. The first one is an offloading decision, while the second one is a joint resource allocation. Furthermore, two mathematical matching games are formulated that model an innovative algorithm for the device sub-channel allotment. This algorithm achieves a good result for the computational offloading. However, when the number of users are increased, the offloading performance may decrease.

7) COA-GT

Liu *et al.* proposed a computation offloading algorithm based on game theory (COA-GT) for vehicular edge network (VEN) [109]. In VEN, it takes a long time to compute the offloading task. Therefore, an algorithm known as distributed computation offloading is proposed. In this algorithm, the user computation task is considered and an optimal outcome also known as NE is achieved. Moreover, the concept of game theory is applied over multiple vehicular users that computes the Nash equilibrium in the network. This scheme decreases computation by up to 16% as compared to

TABLE 6. High hit ratio.

Algorithm	Approach	Merits	Demerits	Year	Reference
ICPF	Introduces a dynamic crowd participation for opportunistic catching and transmission and allocated the information to the optimal relays	Achieves high hit rate as compared to other schemes	It has high transmission delay	2018	[111]
OCRS	Proposes the EACM strategy that manages the contents of the IoT devices at network edge	Good performance for the caching edge contents, hit ratio and access time	Compromises latency with low cache size	2018	[112]
CCST	Prevents the video storage doubling to reduce the access delay	Outperforms in access time, cache hit ratio and load balancing	Compromises cache load balancing when the size of cache is low	2017	[113]
Online-JCCP	Designs a cache and request based algorithm that can utilize the available resources in the efficient way	Achieves good performance for access latency, cache hit ratio and backhaul traffic load	It has a slightly high delay when compared with the offline-optimal scheme	2017	[114]

other schemes. However, it requires a high bandwidth of the wireless channel because it has less effective result over the low channel bandwidth.

8) CaPC

The authors of [110] proposed an algorithm for the real-time application offloading in mobile edge computing. The real-time computation demanding of the UE is challenging because the UEs operate with limited battery power. One of the solutions is to design the small cell base station that provides the computational capability. However, it often results in high latency. To cope with the latency constraint in the MEC network, this paper presents a distributed cloud-aware power control (CaPC) scheme that has high computation ratio with a low cost of latency. The CaPC algorithm reduces the interference in the small cell base station. Furthermore, an enhance cloud aware power control (ECaPC) technique is proposed that performs an iterative procedure to optimize the efficiency of the CaPC technique. The CaPC technique achieves good performance in terms of latency and computational ratio. However, it has slightly high signal overhead as compared to the ECaPC algorithm.

E. ALGORITHMS WITH HIGH HIT RATIO

Hit ratio refers to the requests' fraction which can be satisfied by retrieving the cache within a certain time period. The following algorithms in Table 6 achieve a high hit ratio.

1) ICPF

In [111], an influence of crowd participation features (ICPF) technique is proposed, which plays an important role and reduces the high delay and high data traffic from the backbone of the Internet. The crowd participation is one of the emerging features, which enables most of the applications. This algorithm introduces dynamic crowd participation, which can significantly catch, forward and allocate the desired data to the efficient relays. The simulation shows that this algorithm has high hit rate compared with three other catching algorithms. However, when removing the important nodes from the network, it suffers from a high transmission delay, which increases by up to approximately 25%.

2) OCRS

An optimized caching replacement strategy (OCRS) is proposed in [112]. To optimize the device users' experience, a machine learning based smart caching technique and a location position prediction technique is proposed. A strategy is used that manages the contents of the IoT devices at the network edge. Moreover, this algorithm provides a method to exchange users' contents between the server and the edge sensor. Furthermore, a cache substituting scheme is also proposed that optimizes the utility function of the cache. This algorithm achieves good performance for the caching edge contents, hit ratio and access time. However, it has compromised latency when it has a smaller cache size.

3) CCST

A consolidated caching with cache splitting and trans-rating (CCST) for MEC is proposed in [113]. A MEC server can use cache consolidation to prevent the doubling of the video in the MEC network that increases the storage volume. In addition, to achieve the low execution delay, the cache storage is divided into two major parts: the primary video cache and complete video cache. The complete video cache saves the complete video information while the primary video cache saves only the start section of the video. To minimize the delay, only the start section of the primary video is doubled in the cache network. The protocol achieves a good result for access time, cache hit ratio and balancing the load. However, it has compromised cache load balancing when the size of the cache is low because the low size data can be adjusted randomly at any MEC server. This randomness affects the overall load balancing performance.

4) ONLINE-JCCP

In [114], an online-joint collaborative caching and processing (Online-JCCP) technique is proposed. The multiple bit rate video cache causes a shortcoming in the storage capacity. It requires a high capability for the storage capacity to save the data, video cache and other types of files. The storage device is also known as the hard disk, and it is very cheap and slightly difficult to arrange for a large amount of data. The computation for the transcoding of the real-time video

TABLE 7. High resource utilization.

Algorithm	Approach	Merits	Demerits	Year	Reference
LBA	A load-balancing algorithm is applied for mobile devices in MEC	High utilization of server, least network traffic and low probability of network failure	It has compromised task awaiting the time	2020	[115]
CCORAO	Used the game-theoretic and the Lagrange multiplier approach to solve the optimization problem	Achieves good results for system utility and task processing latency	It has high computation complexity	2019	[116]
PSO	Introduces the edge server placement, computing resource utilization	High resource utilization with a less energy consumption	It works only in continuous problem and does not work in the discrete problem	2018	[117]
Zenith	Service providers (SPs) allow sharing contents with the edge infrastructure providers, the decoupled resource allocation is modeled	Good response time, high utilization and high success rate	Low performance when one MDC handles more than 200 servers	2017	[118]

is a very complex task because the transcoding consumes the available resources very quickly for the heavy video task in the MEC networks. Therefore, this protocol designs a cache and request based algorithm that can utilize the available resources in an efficient way. Furthermore, a method is incorporated that reduces the cost and storage constraint of the MEC network. Moreover, a least recently used (LRU) technique is applied that provides a schedule decision for the video cache contents of the new request and prevents the existent request. This algorithm achieves good performance for access latency, backhaul traffic load, and cache hit ratio. However, it has a slightly higher delay than the offline-optimal scheme.

F. ALGORITHMS WITH HIGH RESOURCE UTILIZATION

This is the process of making resources available in the network to access the desired object in an efficient and robust way. The algorithms listed in Table 7 utilize the resources available in an effective and optimal way.

1) LBA

To support real-time applications in MEC, the edge devices can offload their task to the nearest edge server. A load-balancing algorithm (LBA) for edge devices is proposed in [115]. This work aims to assign the offloaded task to edger servers in an effective method. Furthermore, a graph coloring method is employed to assign colors to the vertices. The objective of this coloring method is to reduce the color numbers while assigning it to the vertices. Moreover, a genetic algorithm is incorporated that enhances the average CPU usage of each virtual machine. This algorithm achieves high utilization of servers, least network traffic, and low probability of network failure. However, the task awaiting time is compromised in this work.

2) CCORAO

Zhao *et al.* [116], presented a collaborative computation offloading and resource allocation optimization (CCORAO) technique for MEC. In this work, the optimization problem is considered in subparts such as resource allocation and the decision of computation offloading. The Lagrange multiplier is utilized for the optimization problem of resource allocation, while the game-theoretic method is used to achieve optimal decisions for task offloading. Furthermore, the Nash equilibrium shows the reflection of the potential game. Simulation results demonstrate that the CCORAO approach achieves good performance for system utility and task processing latency. However, it has high computation complexity for a higher number of vehicles in the network.

3) PSO

In [117], the edge server's placement finds a scheme that reduces 10% percent of the consumption in the energy and also improves the computing resource utilization by up to 15%. The energy consumption of the particle swarm optimization (PSO) algorithm is less than 10.85% from the TopFirst and 12.46% from the random algorithm in the edge server positioning and coverage, respectively. When the number of base stations increases, the PSO still has the least consumption in the energy by comparing it with the TopFirst and Random algorithms. In general, the PSO algorithm has the best results for resource utilization and power consumption. However, this algorithm cannot be directly applied to the problem of mobile edge server placement because the basic PSO is used only in continuous problems, while the mobile edge server is used in a discrete fashion. Thus, the performance is not optimal.

4) ZENITH

The authors of [118] proposed a utility-aware resource allocation (Zenith) for MEC. In this technique, the service providers (SPs) allow sharing contents with the edge infrastructure providers. Moreover, the decoupled resource allocation is modeled, which enables the distributive computing resources at the infrastructure's edge. For the edge computing infrastructure providers (ECIPs) and SPs, the auction-based resource method is developed, which shares the contents and guarantees the maximum utility. Furthermore, the latency-aware task is introduced that assigns the specific job in the network. The experiment shows that Zenith has the best performance in the response time, utilization and success rate. However, it has low performance when one MDC handles more than 200 servers.

TABLE 8. Algorithms having low network cost.

Algorithm	Approach	Merits	Demerits	Year	Reference
JORA	The convex problem is decomposed into three parts and employed the Lagrange multiplier to reduce the average cost	Achieve good results for computation and network cost	Unbalancing energy consumption for higher user equipment	2019	[119]
In-Edge AI	The utilizing DRL and distributed DRL approaches are discussed, which effectively optimize the computation and edge caching capability	It has low cost and balanced performance	Compromises hit rate of the edge caching in the network	2018	[120]
MADA	A matrix is formulated that investigates the position of the users in the network, TOPSIS technique is incorporated to calculate the distance	Good result for energy consumption, time latency and network cost	It has low occupied bandwidth capacity for data transmission	2017	[121]
CODCC	A TPO and Iterative Improvement (II) algorithms are modeled that enhance the optimization and computational effects, respectively	Good running time, total cost and success rate	The TPO algorithm has low scalability in the network	2017	[122]
SDR	The mobile devices offload the computation task to the multiple access points (APs) by considering the energy consumption and delay constraints	Effective result for the task allocation and total cost of the network	It takes more time for task completion	2017	[123]

G. ALGORITHMS HAVING LOW NETWORK COST

Network cost refers to optimizing the limited computational resources within a low time delay. Table 8 contains the algorithms that have low network cost.

1) JORA

The authors in [119] proposed a joint computation offloading and resource allocation optimization (JORA) algorithm to minimize a cost problem in MEC. In this algorithm, the original optimization problem is decomposed into three subparts to analyze and make it solvable e.g., linear optimization. Then, the Lagrange multiplier method and the game theory-based optimization algorithm is proposed that optimize the offloading ratio. Furthermore, the JORA algorithm mitigates the resource allocation problem by using the reformulation linearization-technique (RLT). The extensive numerical experiments reveal the performance of the JORA algorithm which demonstrates outperform in terms of average size and computation cost. However, it has unbalancing energy consumption when the number of user equipment (UE) increases.

2) IN-EDGE AI

Wang and colleagues proposed an intelligentizing mobile edge computing (In-Edge AI) framework to utilize the collaboration of the devices and edge nodes intelligently [120]. In this paper, the utilizing DRL and distributed DRL approaches are discussed, which effectively optimize the computation and edge caching capability, respectively. The deep Q-Learning cognitive system is incorporated, which enhances the efficiency of the computation task. Furthermore, the federated learning technique is applied, which deploys the resource management for the MEC network intelligently. The results demonstrate that this approach has good achievements for balanced performance and cost. However, it has compromised hit rate of the edge caching in the network.

3) MADA

In [121], during MEC network, the users adopt a mobility pattern. If an optimal server is detected, the users move from their present positions to the optimal data server. In multi-attribute decision making (MADA), a matrix is formulated that investigates the position of the users in the network. Moreover, the information is investigated from the attribute by using the information theory and entropy. In addition, it incorporates the TOPSIS technique, which calculates the distance among the user and its optimal data server. In general, MADA is one of the best solutions that determines the 0movement of users from one place to the next place. The simulation of the MADA algorithm shows that it has an efficient result for time latency, energy consumption, and network cost. However, while computing intensive task, it has a relatively low occupied bandwidth capacity for data transmission.

4) CODCC

The authors of [122] presented computational offloading with delay and capacity constraint (CODCC) algorithm for MEC. This protocol aims to optimize the resources used in the network with an efficient method. Furthermore, two-phase optimization (TPO) and Iterative Improvement (II) algorithms are modeled that enhance the optimization and computational effects, respectively. The TPO algorithm first solves the IP issue during offloading for the nearest neighbors in the network. At the same time, it optimizes the offloading task for each node in the network. The II algorithm provides an efficient solution within the minimum latency. The TPO and II algorithms have good performance for running time, total cost and success rate. However, the TPO algorithm has low scalability for the total nodes in the network.

5) SDR

In [123], the MDs offload the computation task to the multiple access points (APs) while considering the energy consumption and delay constraints. The semi-definite relaxation (SDR) algorithm is designed for the fixed and elastic CPUs' frequency, which tackles the problems of edge devices and APs. Furthermore, the linear relaxation (LR) algorithm is proposed for the fixed CPU which is ultimate of the SDR

TABLE 9. High load balancing.

Algorithm	Approach	Merits	Demerits	Year	Reference
MIP	Installs the base stations to the strategic positions to balance the work load and reduce the access latency	Good result for the workload balancing and access latency	High access delay for the large number of BSs	2018	[124]
MEV	An algorithm is designed that provides a choice for the selection of service and composition	Achieves good management of high data traffic and low latency	For some scenarios, it consumes more time for request completion	2018	[125]

algorithm, while the ES algorithm is for the elastic CPU to find the effective solution. The CPU range is used effectively for the task allocation. This algorithm outperforms the competitors in terms of task allocation and the total cost of the network. However, it takes more time for task completion because of the long distance between the APs and MDs.

H. LOAD BALANCING

Load balancing refers to the capability of managing the available load in the network to a convenient method. The algorithms that have high network balancing are presented in Table 9.

1) MIP

Mixed integer programming (MIP) in mobile edge computing is proposed in [124]. This approach is actually applied over Shanghai Telecommunication's base station because, according to the survey, Shanghai is the third most populated city in the world, thus the distribution of the base station is one of the complicated tasks. Furthermore, a distribution of the base stations is formulated. They are placed with an optimal strategic position for load balancing and minimizing the transmission delay between the server and the user at the edge of the networks. The experiment shows that this approach has a good result for balancing the workload. However, it has a high access latency for the large number of BSs.

2) MEV

In [125], the authors presented a minimum expected value (MEV) algorithm for mobile clouds. This algorithm is based on opportunistic computing routing. The mobile devices contact each other without the need for cloud services. To calculate the execution time in the mobile cloud system, an algorithm is designed that provides a choice for the selection of service and composition. In addition, this algorithm avoids resource saturation and arranges the high load for better utility. This protocol achieves better management of higher data traffic and consumes less time that solves the neighbor's request. However, it consumes more time for request completion.

I. ALTERNATIVE EMERGING SOLUTIONS

MEC is addressed by other emerging algorithms, some of which are listed in Table 10.

1) EdgeEDR

The authors of [126] argued that cloudlets are the best choice for participation in edge emergency demand response (EdgeEDR) instead of data centers. However, it has energy limitation for multiple cloudlets. Therefore, an online auction-based mechanism is proposed in which special features are designed for cloudlets. In addition, dynamically switching on/off mechanism is introduced, which reduces the energy consumption problem. Furthermore, a social cost problem is addressed. Moreover, London's underground network in 2014 is used to simulate EDR mechanism. This experiment consists of access points and cloudlets. The experimental results demonstrate that this approach has high performance for long-term social welfare and average utility of service providers. However, it has occasionally unbalanced power consumption.

2) OLSA

In [127], the authors considered the joint access network selection and service placement problem in MEC. To improve the QoS, the authors considered switching delay, communication delay and access delay. The communication delay is provoked when users indirectly access services (connected to edge clouds). To design an efficient algorithm and satisfy the users' random mobility, the optimization problem is divided into one-shot series problems. In addition, an iterative-based algorithm (IA) is employed to investigate the near-optimal solution. Simulation results demonstrate the effectiveness of the proposed algorithm. This algorithm achieves a good result in terms of total delay; however, in the case of queuing, it has compromised delay.

3) AIA

The authors of [128] proposed a technique for placing VNFs. A general 5G slice network framework is considered, which consists of both core and edge cloud servers. A demand–supply model is investigated to determine the interference of VNF in terms of throughput. Furthermore, the adaptive interference-aware (AIA) algorithm is proposed to optimize the rate of throughput. The AIA algorithm can efficiently and automatically place VNFs. Experiments show that AIA algorithm can efficiently control traffic congestion and interference in VNFs. In addition, it achieves good results for autonomous driving's throughput of up to 20.11% and 24.21% for HD video network slice. However, the average response latency is greater in the 4K/8K HD video network slice.

4) D2D

The mobile devices need to activate the cellular data to transmit the short control or heartbeats message to the next user.

TABLE 10. Alternative emerged algorithms.

Algorithm	Approach	Merits	Demerits	Year	Reference
EdgeEDR	Designs special cloudlets features, dynamically switching mechanism is introduced	Good for long-term social welfare and average utility of service providers	It has unbalancing power as compared to the counterpart schemes	2019	[126]
OLSA	To improve the quality-of-service (QoS), the switching delay, communication delay and access delay are considered	Achieves good result in terms of total delay	In the case of queuing, it has compromised delay	2019	[127]
AIA	A demand–supply model is investigated to determine the interference in terms of throughput	Reduces traffic variations and achieves good throughput	High average response latency in the HD video network slice	2019	[128]
D2D	Selects multiple smart phones in the network, and opportunistically sends and receives the heartbeats packet	Reduces signaling congestion up to 50% and energy saving up to 36%	Requires redundant process to find neighbors	2017	[129]
eTrain	Quantifies the power consumption of heartbeats by using extensive measurement, saving the heartbeat energy	Good results for energy saving and latency cost	Unbalance deadline violation ratio as compared to the counterpart schemes	2015	[130]
AppATP	Exchanges the data between mobile devices and cloud server in an energy-efficient method	Achieves good results for high throughput and energy saving	Greater downloading latency as compared to the counterpart scheme	2015	[131]

As a result, it consumes a high amount of energy for real-time transmitting. To address this issue, a Device-to-Device (D2D) framework is introduced in [129]. A D2D framework reduces high signaling congestion and energy consumption. The D2D framework selects multiple smartphones in the network and opportunistically sends and receives the heartbeat packets. The received heartbeat packets are delivered to the base station in an efficient manner that minimizes signaling congestion. The idea is implemented on Android smartphones. The real-world experimental results demonstrate that the D2D framework reduces signaling congestion up to 50% and saves up to 36% of energy. However, it requires a redundant process to find neighbors, as it does not easily handle direct Wi-Fi connections.

5) eTrain

Zhang *et al.* [130] proposed a technique to make the wasted energy useful. The power consumption of heartbeats is quantified by extensive measurement. The aim of this technique is to save the heartbeats wasted energy and use d it for the useful data transmission. This technique is capable of transmission management used in Android devices. The optimization framework is designed to make the online data schedule to minimize the energy problem. The simulation results, including trace-driven and real-world results, demonstrate that this technique achieves greater energy saving. However, it has unbalanced deadline violation ratio as compared to the counterpart schemes.

6) AppATP

Application-layer transmission protocol (AppATP) is designed in [131], which leverages the cloud resources and exchanges the data between mobile devices and cloud server. Mobile devices consume high energy while connecting to the cloud server. The AppATP protocol has a good condition of the bandwidth and consumes minimum energy. AppATP protocol only takes network information and packet queue size into account for the online decision. The idea of AppATP is applied on Samsung Note 2 and Amazon EC2. The simulations result show that AppATP has 30–50% energy saving in mobile devices. In addition, it has high throughput. However, it has greater downloading latency as compared to the counterpart scheme.

J. LATEST HYBRID ALGORITHMS

The IoT devices while connected for real-time sensing in the network face many challenges. The mobile edge servers' activating problem is addressed in [132] as a minority game whereas the learning algorithm is designed that confirms the edge server activation's status based on the previous performance. In the minority game, the players having odd-number struggling for being in the minority group. The players that have a place with the minority group win and advance their triumphant activity for the next round of the game. Furthermore, the second layer considered the problem of the QoS satisfaction of mobile devices. The simulation results demonstrate the effectiveness and scalability of this approach. Another server activation technique using a minority game for computational offloading is proposed in [133]. The technique aims to activate the MEC' servers by taking energy-efficiency and mobile users' QoE satisfaction into account. Furthermore, a problem of computation offloading is formulated and make use of minority game that bring eases while selecting the edge servers' mode. The mechanism of mode selection guarantees energy efficiency due to a low number of servers activation. The numerical simulation demonstrates the performance of the algorithm. Mobile devices offload data to the MEC servers using a wireless medium. The capability of data offloading to the MEC servers is investigated in [134]. The cognitive IoT devices' gain and lose averse fashion is considered for resource management. The MEC server opts as an open pool so that every edge device can offload its resources. Furthermore, the prospect theoretic concept is employed that determines the user utility in local computing. It is a two-sided function with a reference point. The upper side of the reference point is considered

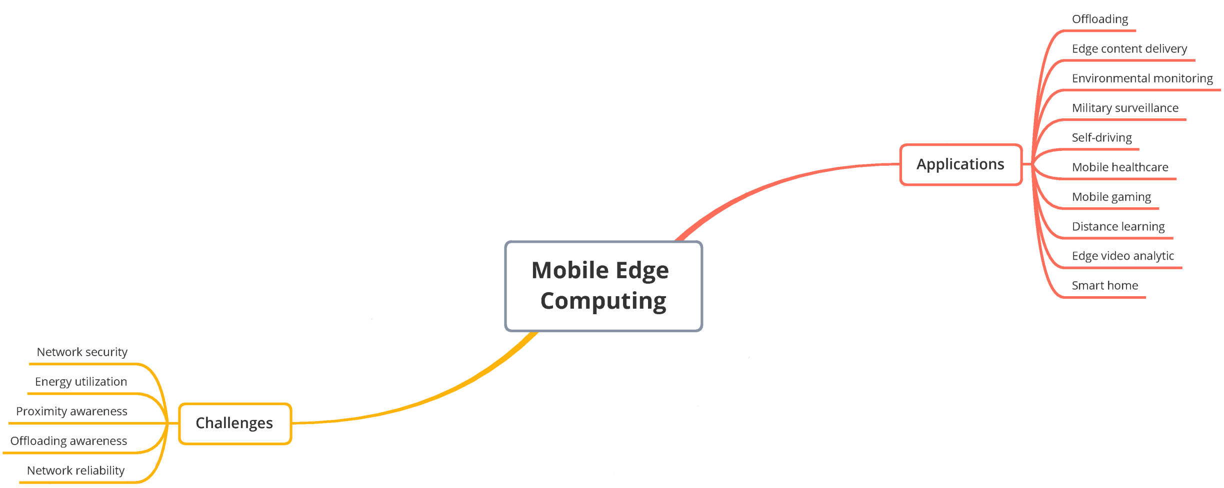

FIGURE 5. **Mobile Edge Computing: Applications and challenges.**

as a gain function while the lower side is a loss aversion point. This technique allows the devices to capture human behavior and offload data in an optimal method. Numerical results demonstrate the superiority of this approach for different IoT devices' behaviors. In [135], a coalitional model in mobile cloud computing is proposed which supports users while sharing the task. An authenticating mechanism is proposed that provides access of users to mobile applications. Furthermore, an optimization problem is formulated that allows users to share their resources. The coalition model of service providers significantly enhances the utilization and efficiency of wireless bandwidth. This can be achieved due to the employment of the resource pool. Software-Defined Networks (SDN) based MEC network is considered in [136] that manages the users offloading demand. The SDN technique enables to solve the joint problem i.e, the selection of MEC servers by the end users and task offloading to the servers. The stochastic learning concept is proposed that make the end-users able to offload the task by keeping in view of the past action. Furthermore, a non-cooperative game is formulated that determine the offloaded part of the chosen MEC servers with the existence of the Nash Equilibrium. The simulation and modeling results reveal the performance of this approach and achieve good scalability in the network. The resource management and sharing revenue problem between mobile network operators (MNOs) and cloud service providers (CSPs) are discussed in [137]. The MNOs make a coalition with the CSPs that make the users equipment to access the cloud application. The work aims to form a framework that helps each player in the coalition to share revenue in an optimal way. Therefore, a linear programming model is proposed that solves the problem of each coalition in terms of revenue. Furthermore, the technique of assigning a shapely value to each player is employed that distribute the player contribution in each coalition. The distribution is based on the higher revenue that helps the selection of an optimal user. The numerical analysis demonstrates the advantage of the coalition.

III. MEC APPLICATIONS

To utilize the capability of the cloud service, MEC has many applications. These applications are discussed in the following subsections.

A. OFFLOADING

Various applications such as audio processing, video catching, mobile-gaming (m-gaming), and face and eye recognition need bandwidth, battery, and storage capacities. [9]. Therefore, edge servers offer such a good and reliable service to facilitate all these applications at the edge of the network. Edge servers further offload the tasks to the cloud data center via the backhaul. Minimizing latency and power consumption are important objectives of the offloading.

B. EDGE CONTENT DELIVERY

Mobile devices in the network's edge bring an optimal solution for web content by providing the web services at the base station. Due to the dynamic service experience (mobile user accesses the web contents) and close proximity, it can optimize the network performance and reduce the network delay and cost. The algorithms presented in Fig. 6 have low network cost and can effectively deliver the contents to the edge of the network.

C. ENVIRONMENTAL MONITORING

The environment can be monitored by using the edge sensor for climate changes. In general, environmental changes need to be detected and saved in the MEC servers. Fig. 7 lists the algorithms, in which the sensor devices consume less energy and are alive for a long time to perform continuous monitoring of the environment.

D. MILITARY SURVEILLANCE

The mobile sensors can be used as spy cameras for surveillance purposes in the military. To protect the secrecy from suspicious actions in sensitive zones, the edge sensor provides

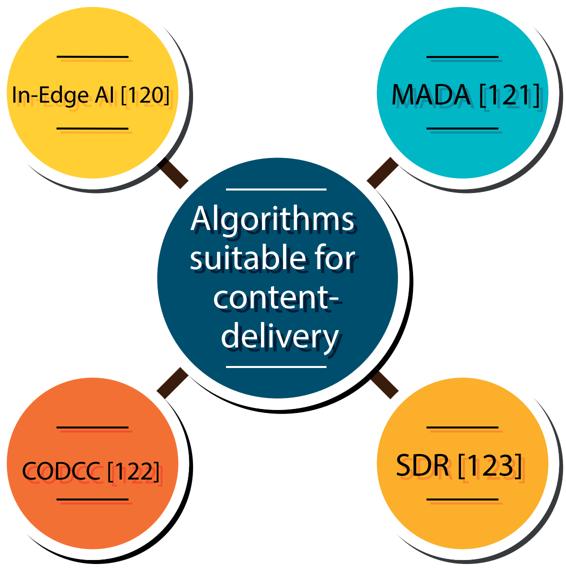

FIGURE 6. Algorithms suitable for content delivery.

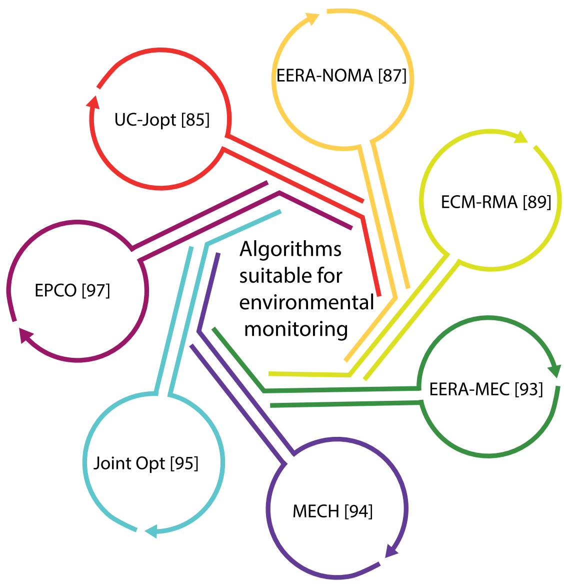

FIGURE 7. Algorithms suitable for long-term environmental monitoring.

instant information to the host server instead of the cloud data server. The transmission of such data to the cloud data center takes extra latency. In essence, collecting and processing of the data on the MEC server provides a quick response. Fig. 8 shows algorithms that can be used in military surveillance, because of their rapid response and high throughput.

E. SELF-DRIVING

For self-driving, MEC technology can be used in place of human drivers [138]. Offloading data back-and-forth across a network takes approximately 150–200 milliseconds. Cars must be able to react in real-time to theirs surroundings. According to Toyota, by 2025, the data exchanges between vehicles and the cloud servers will reach 10 exabytes. The self-driving cars take actions according to the sensory data.

F. VIRTUAL REALITY

MEC has a profound impact on virtual reality (VR). It allows exchanging the real-time data between the users and the edge of the network [139]. It fills the gap between the traditional viewing and 3D world by high speed delivery, scalability and ultra-low latency. It can also help students build 3D models and visualize in the real world.

G. MOBILE HEALTHCARE

Mobile healthcare (m-healthcare) in MEC provides a platform in which the mobile users can easily access the services and resources (e.g., appointments with doctors and patient records) [140]. Health-based mobile users can detect pulse rate, sugar level, and blood pressure and send the patients' health records to the concerned doctor.

H. MOBILE GAMING

MEC provides a potential pool of services for m-gaming. The small portable devices (smartphone, laptop, and smartwatch) take place in the traditional large computing resources (e.g., graphics card, mouse, and keyboard) to the server [12]. The screen interface is used only between the devices and human's interaction and can have access anytime and anywhere.

I. DISTANCE LEARNING

Distance learning is one of the best practical applications of MEC. E-learning via electronic communication is an integral part of the MEC [141]. Distance learning has brought opportunities for researchers and teachers. Different kinds of educational materials (video lectures, slides, online quizzes and tests and so on) are the objectives of distance learning. In addition, many online e-learning platforms are provided for distance learning such as the Khan Academy http://www.khanacademy.org, MIT Open CourseWare http://ocw.mit.edu/index.htm, EduOpen http://en.eduopen.org/, edX http://www.edx.org/, Coursera http://www.coursera.org/ and so on. E-learning can be accessed anytime and anywhere (institute, research center, cafeteria, refreshment center, etc.) to complete the task smartly.

J. EDGE VIDEO ANALYTIC

Edge video analytic is another important application of MEC. In order to explore the environment, various mobile devices such as smart drones, smart robots, smartwatches, and smartphones can be used that equipped with video, audio and environment detection's sensors. These devices collect data using 3D perception and artificial intelligence technology which is then processed to achieve the result. The processing and extraction of collected data require computing and storage capabilities [142]. To tackle this issue, mobile devices e.g. unmanned aerial vehicles, robots and wearable devices are connected via wireless medium to create edge cloud network.

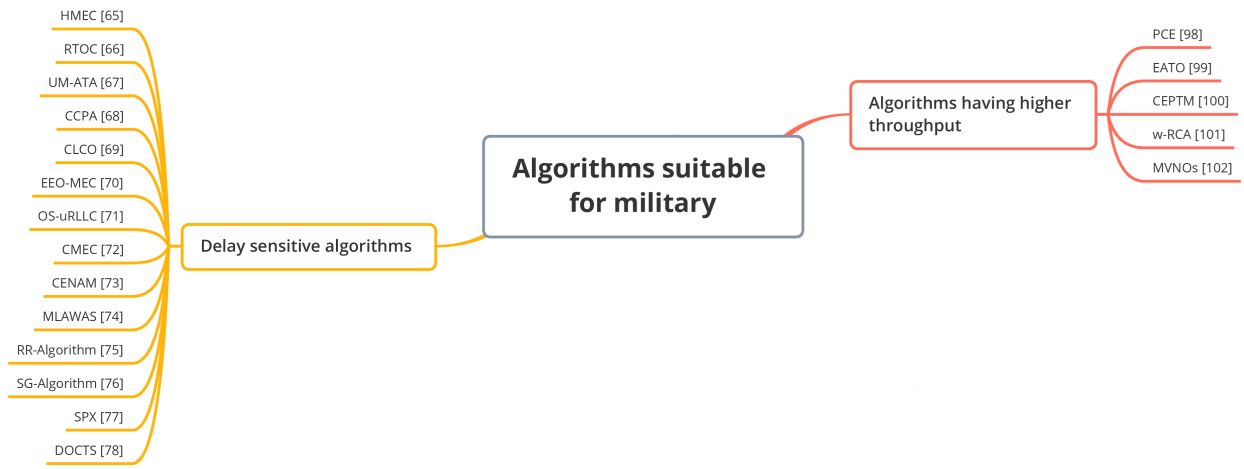

FIGURE 8. Algorithms suitable for military surveillance.

K. SMART HOME

The sensors (e.g. temperature, gas/smoke, pressure, accelerometer, and biosensors) deployed in a smart home are capable to achieve vital information. Accelerometer used for health monitoring and calculates blood pressure. The gas sensor detects the leakage of compressed natural gas, alcohol, and other gaseous substances. The temperature sensor senses room temperature or other home appliances' temperature. The biosensor is used to test blood glucose, cholesterol, pregnancy, and other infectious diseases. The vital information collected by sensors is delivered to processing via various algorithms and provide instant action based on its necessity. The mobile devices such as smartphones, smart robots, and wearable devices offload the real-time computation to the mobile edge cloud [143].

IV. OPEN RESEARCH CHALLENGES AND FUTURE DIRECTIONS

Due to the unique characteristic, MEC is still at infancy at this stage. This section describes open research challenges and disciplines of future. All the research challenges are listed below in Fig. 9.

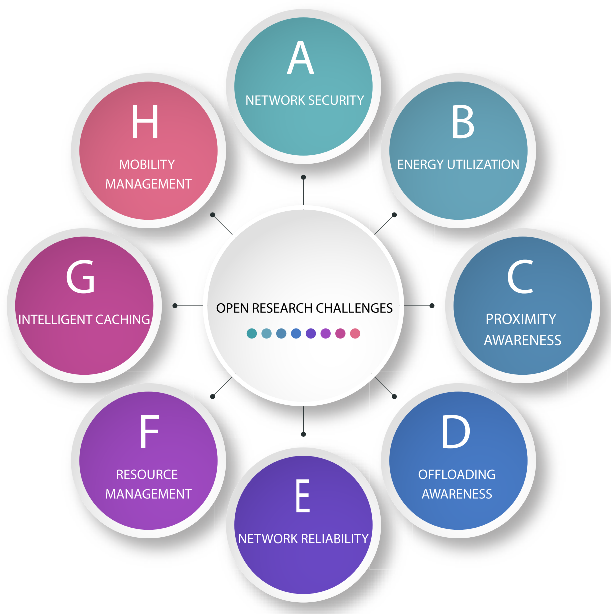

FIGURE 9. Open research challenges in MEC.

A. NETWORK SECURITY

Security is the major challenge in MEC that hinders the reliability of the network. The mobile sensors share information to the MEC server by using the wireless medium. Unlike conventional cloud computing, the software used in the mobile sensor in the networks' edge can be easily accessed. Thus, important data might be hacked in the network. In future research, the mobile sensors need to authenticate the application, while accessing from the MEC servers. Furthermore, MEC enables smart cities whereas expected vast number of smart-mobile-devices' (SMDs) connectivity. The connectivity of SMDs in a random fashion prone to several security attacks including the insecure initialization, the insecure discovery of neighbors, Jamming attacks, and Sybil attacks. The user having malicious activity can spoil the vital information easily (by disable edge node, steal data) in the network. Therefore, securing the network from different cyberattacks is a primary concern. Future research needs to limit the data rate and minimum testing data can be transmitted to confirm snoopers' absence. In this way, the insecure initialization issue will be addressed. Furthermore, to discover a secure neighbor, the Elliptic Curve Cryptography is used in [144] that identifies the malicious user by employing the public key signatures method. The cryptographic based function and measuring signal strength can be used to address the Jamming attacks is the edge network. The Sybil attack is caused by a malicious user having a fake MAC address. To tackle this issue, a measuring signal strength-based detector technique can be applied to calculate the Sybil user's location.

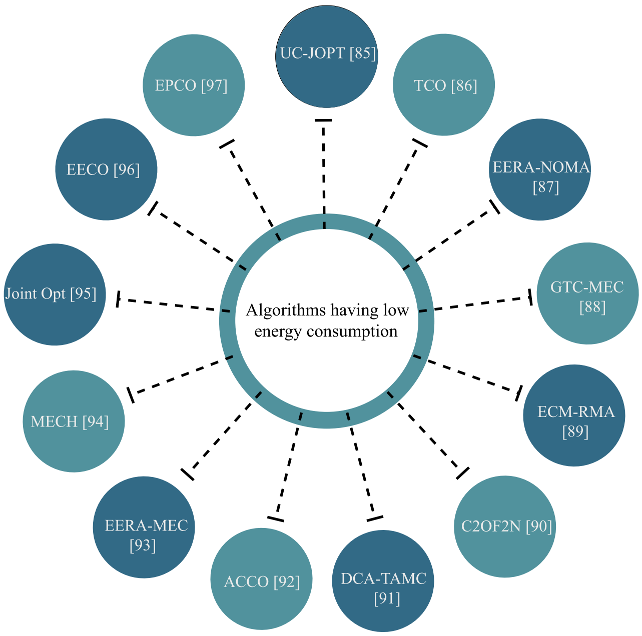

FIGURE 10. Algorithms having low energy consumption, but need to be more robust.

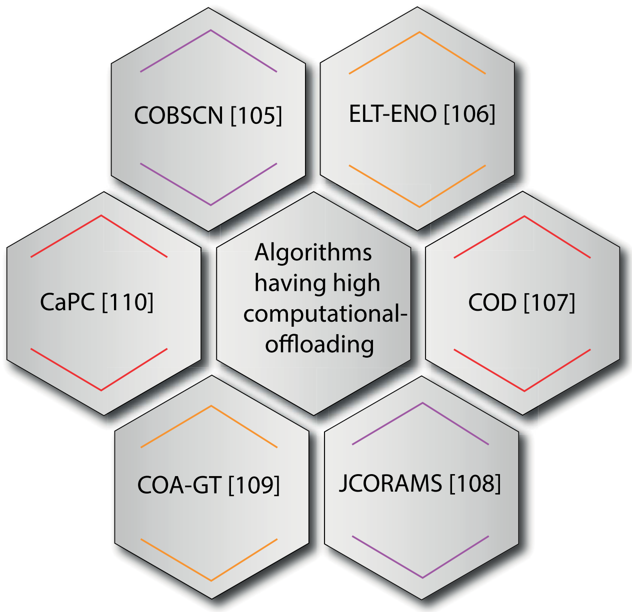

FIGURE 11. Algorithms having the high offloading capability.

B. ENERGY UTILIZATION

In MEC, mobile devices have limited power stored in their batteries. Therefore, such power needs to be utilized effectively. The following algorithms [85]–[97] are energy efficient; however, there is still a need to be more robust. Fig. 10 showcases algorithms that have efficient energy. Furthermore, energy is a key parameter to being alive the users for the long term in the edge network. The user energy requirement substantially varies for data offloading during the dynamic activity in the edge network [145]. In consequence, the users' battery will start dying if there is no charging or replacing facility in the network. The replacement of the battery is also not a good choice and also is almost impossible due to the unpleasant situation in the network. To cope with this issue, future research needs to focus on algorithms having an advanced decision-making system. Such types of algorithms will follow decisions by leveraging advance prediction techniques to decide the offloading activity, to determine channel quality, and to control the cost of offloading.

C. PROXIMITY AWARENESS

The MEC servers are deployed in a centralized way. If all mobile devices are connected to the MEC server, some devices might leave the concerned position, due to mobility. Hence, connectivity loss might occur between mobile devices and the server. In the future, mobility aware applications, coping with the mobility constraints, need to be investigated. Furthermore, the edge network is based on radio access. Therefore edge servers can be accessed by mobile devices using device to device (D2D) full-duplex communication method. Hence, edge servers analyze users' behavior and extract information from the device within close proximity [146]. Consequently, the quality of network services will be improved significantly.

D. OFFLOADING AWARENESS

The MEC servers deployed in the network catch the data, which are sent from the mobile users. The simultaneous communication of multiple users with the MEC servers could cause congestion, hence degrading the reliability of the whole network. Algorithms [105]–[110] having the high offloading capability, as presented in Fig. 11 that minimizes the offloading issue. However, there is still a need for more robustness in terms of delay and energy consumption. Furthermore, a massive number of smart devices connected in the edge network. However, in some cases, most of the edge servers do not permit smart devices to connect at the same time. In the modern era, edge enabled smart city contains a million of connectivity of IoT devices. If a large number of devices offload the tasks to the edge servers simultaneously, this will produce a hurdle in the way of communication. Future research needs to focus on offloading service by employing a load balancing technique.

E. NETWORK RELIABILITY

In MEC, the mobile devices installed in the network's edge offload data to the MEC server in a random fashion. In general, no priority is assigned to the edge device in offloading the data to the MEC server. In addition, mobile devices can offload and access services via radio access such as Wi-Fi, 3G, LTE, Wi-MAX, and 5G. Therefore, the signal strength might weaken because of the high probability of noise, signal interference, and fading. Thus, reliability is the future concern because it guarantees to save data corruption via the unfavorable medium. The problem of reliability can be overcome by applying the frequent checking mechanism. The edge nodes' sleeping deprivation and failure point checking after a period can significantly minimize the reliability problems. Moreover, the selection of dynamically edge nodes while using as relay nodes can help impressively in the optimization of reliability in the edge network [147].

F. RESOURCE MANAGEMENT

Another utmost priority in edge computing is resource management that maintains the performance and lifetime of the edge users. This includes placement, migration, optimization of signalling overhead and consolidation need to be designed extensively. A test message should be broadcasted initially in the MEC network to investigate the computing resources in terms of nodes' computing efficiency and the quality of the channel (backhaul link) [148]. Owning to the frequent exchanging information, there is a trad-off between MEC performance and signalling overhead. Future research needs to analyzed this challenge and to ensure the latest information to the system by keeping the cost minimization into consideration.

G. INTELLIGENT CACHING

In the MEC network, smart mobile devices (SMDs) collect and generate a huge amount of data. The generated data demands immediate processing for the real-time application i,e. smart cities. The noise generated from different sources associated with the data. The extraction of information from a noisy packet is a quite challenging process. AI is a pioneering method that addresses such types of challenges. Edge intelligent servers provide real-time data processing and extend only beneficial data with advanced filtering and prediction mechanism. It enables analytic of big data at the edge of the network. Furthermore, intelligent edge servers enable intelligent applications that overcome security issues during data advancement. Despite introducing the advanced features, AI is still infancy and poses several challenges. For instance, high computational energy is required to execute real-time AI algorithms. Also, the storing of local data by smart devices required high capacity. In addition, for training AI-based advanced algorithm demands enormous data sets, which in turn, impose high computational complexity [149]. Future research needs to tackle this issue by employing an inter-operable mechanism. In this mechanism, an inter-operable interface based on machine learning can be used in the data advancement process.

H. MOBILITY MANAGEMENT

Mobility management is a key challenge in the MEC network. The migration of a virtual machine (VM) causes high latency and affects the backhaul due to the high data burden, which in turn, inappropriate for long-term applications. Therefore, advanced techniques should be proposed that helps in VM migration within milliseconds. But due to the computing nodes' communication constraints, this option may not always effective. So, other predictive techniques need to propose that would not intercept the communication of end-users. The mobility of VM in the MEC network poses several challenges. Therefore, despite minimizing VM migration latency, stand-alone VM mobility may not always feasible [150]. In future research, it is necessary to employe the cooperation model for mobility management instead of individual mobility technique. In this way, the system performance and QoE of the moving UEs will be enhanced by considering the joint techniques such that VM migration, power control, route selection, and data compression.

I. OTHER ASPECTS FOR FUTURE ANALYSIS

This subsection highlights several pending problems and essential promising research directions in the MEC network.

1) AI-BASED MEC SYSTEMS

Due to a massive increase in mobile data traffic, the wireless network demands a huge capacity for communications. A large number of mobile devices such as tablets, smart phones, and laptops along with connected data traffic suffer from battery life and the CPUs problem in the network. The life of a mobile battery can be relaxed by means of offloading the computation task intelligently. MEC comprises low processing and wearable devices face a problem of computation offloading applications i.e tactical surveillance and augmented reality. This problem can be overcome by installing a latency-sensitive system to the servers located with the main base stations. This will avoid high latency during the offloading tasks to edge servers. Furthermore, due to the dynamic nature of mobile users, the MEC servers receive irrelevant tasks in the network. Therefore, a migration decision has a pivotal role since mobile user services have to migrate among multiple edge servers. To cope with the problem of migrating services to the irrelevant edge server, artificial intelligence (AI) based decision has been recently introduced. AI is a pioneering solution for various key parameters such as service migration, edge server selection, user mobility, and cloudlet likelihood connection.

2) DEEP LEARNING-BASED MEC SYSTEMS

Deep learning (DL) is a vital subpart of machine learning, that leverages multiple algorithms to process and make an accurate decision for big data. It has garnered huge attention in academia and industry and has enabled optimal strategy in robotics and games. DL enables advanced feature extraction techniques using artificial neural networks that learn voice recognition, text classification, etc to use it in making of decisions and input classification. MEC is an emerging paradigm that allows storage and computing resources to the edge of the network. DL based MEC network brings seamless service from edge servers to end-users. Fifth-Generation (5G) technology provides faster data transmission with ultra-reliable low-latency communication (URLLC) in the MEC network. However, the 5G technology is inappropriate for DL-based prediction, analyzing, and optimizing schemes, as these functions take a long time to obtain the final results. To diminish

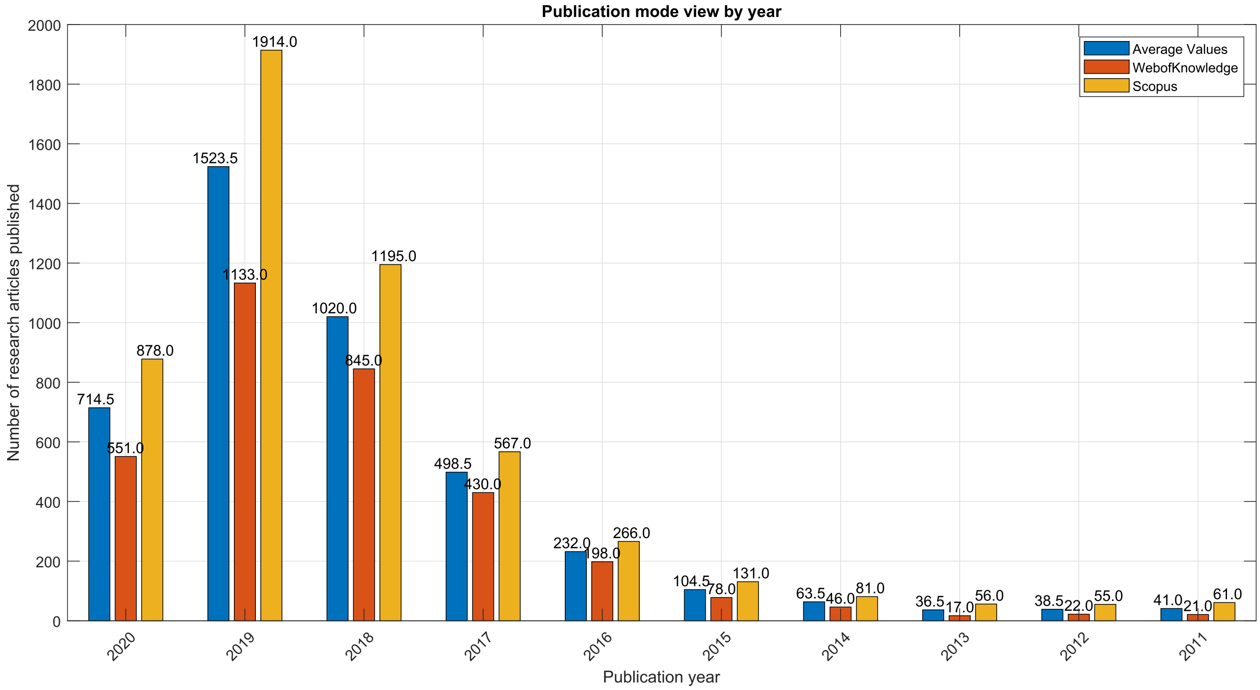

FIGURE 12. Publication record in the area of "Mobile Edge Computing" between 2011 to 2020.

the problem of high latency and low bandwidth, the Sixth-Generation (6G) technology has been recently introduced in limited countries. In the future, 6G will facilitate the MEC network and the mobile devices will offload the computation task with the speed of up to 11Gbps to the edge servers.

V. BIBLIOMETRIC OVERVIEW

This section presents the bibliometric overview (the bibliometric overview is from the last ten years). of the selected papers. It contains the graphical details of the MEC paradigm. In this survey, the following features were contained: publication record by year https://www.scopus.com/, documents by sources https://www.webofknowledge.com/, funding sponsors https://www.webofknowledge.com/, publications record by affiliation https://www.webofknowledge.com/, documents published by authors https://www.scopus.com/, and publication by country https://www.webofknowledge.com/ in which most of the research articles published in MEC field.

A. PUBLICATION RECORD BY YEAR

Due to the emergence of mobile edge computing, a massive number of research works have been carried out recently. This subsection presents the publication record in the field of mobile edge computing from the last decade. As illustrated in Fig. 12, the maximum number of papers have been published in the year of 2019. The recently published articles help in the investigation of new ideas in the future.

B. DOCUMENTS BY SOURCE

This section provides information about the top ten most prominent journals/conferences about MEC research. The bar graph in Fig. 13 showcases the journals/conferences that have published the most recent articles over the last ten years in the field of MEC. Furthermore, Table 11 mentions the complete name of the journals/conferences presented in Fig. 13.

C. FUNDING SPONSOR

There are many research supporting agencies, which provide research grants to the researchers for the desired field in different countries. Like other fields, research in MEC is also supported by various agencies. The supporting grants for MEC during the last decade are highlighted in Fig. 14. Moreover, Table 12 shows the details of each funding agency such as record count on Scopus, record count on Webofknowledge, sum of times cited, and average citations per item.

D. PUBLICATIONS RECORD BY AFFILIATION

Discussing universities supporting the MEC field is necessary for researchers to choose the appropriate university. This section presents the records about the universities that published the most articles in the MEC field. Fig. 15 showcases the output of the different universities from the last ten years that published research articles in the MEC field. Furthermore, Table 13 mentions the complete name and record count on Scopus and Webofknowledge in the MEC field.

E. DOCUMENTS PUBLISHED BY AUTHORS

Many researchers from different countries are working in the field of MEC. This section helps the researchers to find research collaborators in this field. Fig. 16 shows the research output of the authors in the last ten years.

TABLE 11. Complete name of the source with record count in MEC field.

S/No	Source name	Record count on Scopus	Record count on Webofknowledge
1	IEEE Access	310	291
2	IEEE Communications Magazine	72	61
3	IEEE Internet of Things Journal	125	153
4	Future Generation Computer Systems	63	60
5	IEEE Transations on Vehicular Technology	74	73
6	IEEE International Conference on Communications	100	99
7	IEEE network	55	44
8	IEEE Transations on Wireless Communications	48	47
9	IEEE Journal on Selected Areas in Communications	39	32
10	Sensors	59	49

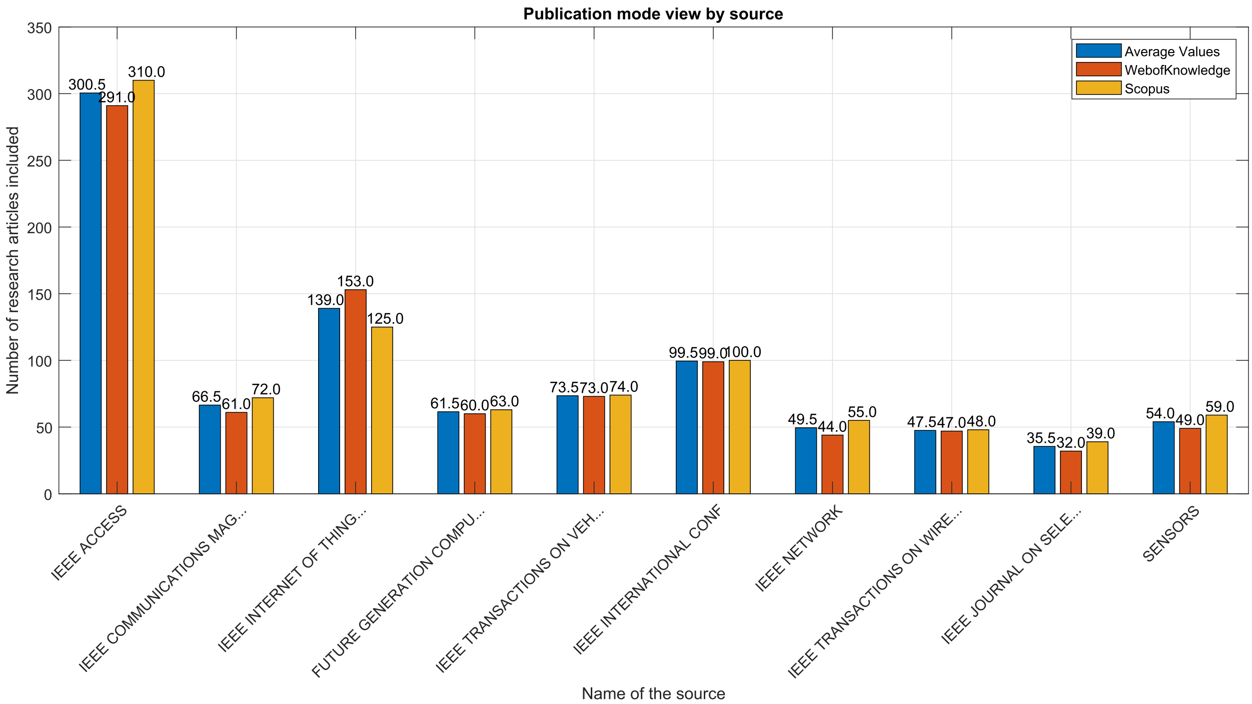

FIGURE 13. Top ten journals which contain many articles about MEC in the last decade.

TABLE 12. Details about funding agencies that supported number of research article over the last 10 years.

S/No	Funding agency name	Record count on Scopus	Record count on Webofknowledge	Sum of times cited	Average citations per item
1	National Natural Science Foundation of China	1201	1068	10,821	10.13
2	Fundamental Research Funds for the Central Universities	270	205	1,531	7.47
3	National Science Foundation	237	204	3,131	15.35
4	European Commission	94	104	1,379	13.26
5	China Scholarship Council	51	43	696	11.6
6	National basic Research Program of China	142	20	690	34.5
7	Natural Sciences and Engineering Research Council of Canada	82	85	1,176	13.84
8	China Postdoctoral Science Foundation	64	63	400	6.35
9	Academy of Finland	32	17	331	19.47
10	Intel Corporation	24	14	549	39.21

F. PUBLICATIONS BY COUNTRY

This section provides information about the MEC research carried out in different countries, to help the future researchers collaborate on MEC. Fig. 17 indicates the output of the top ten countries. As can be seen in Fig. 17, China has published the most articles on MEC, while the USA and Canada are second and third, respectively.

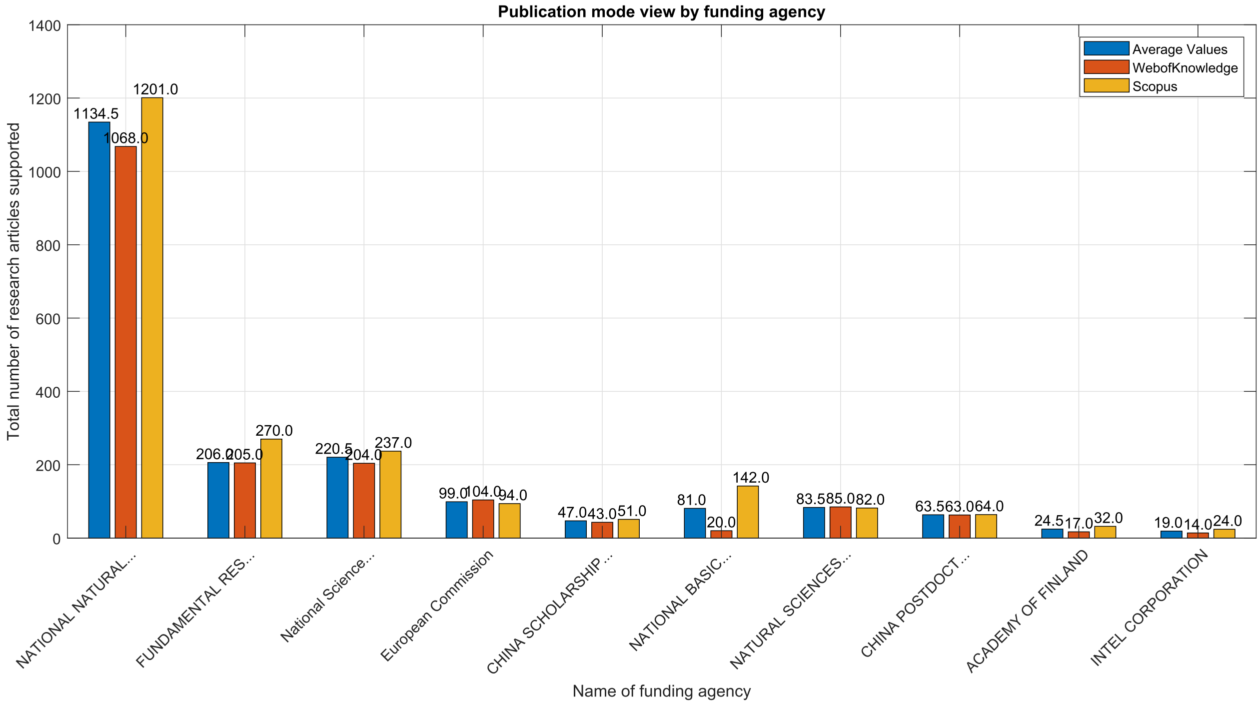

FIGURE 14. Research work count in MEC supported under grant number in the last ten years.

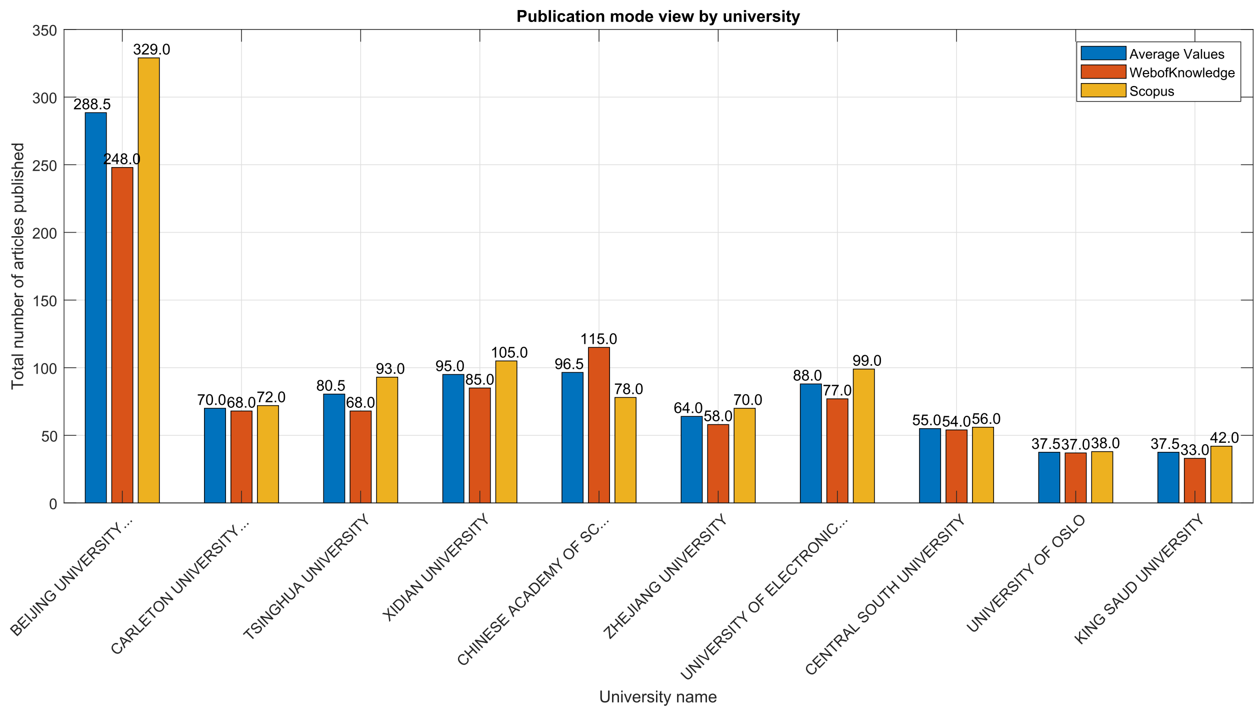

FIGURE 15. Top ten universities in MEC field in the last decade.

VI. LESSONS LEARNED

In this section, we summarizes the key points learned from the conventional algorithms of mobile edge computing published in the literature. The discussion of the performance parameter of each algorithm and their merit(s) and demerit(s), which in turn, find out the following key observations:

- Mobile devices (MDs) consume more energy in case of the low quality of medium/channel between the user and edge server [151]. The reason is that, offloading of

TABLE 13. Detail of affiliations that published number of research article in the field of "Mobile Edge Computing".

S/No	Name of affiliation	Record count on Scopus	Record count on Webofknowledge
1	Beijing Univeristy of Post and Telecommunications	329	248
2	Carleton University	72	68
3	Tsinghua University	93	68
4	Xidian University	105	85
5	Chinese Academy of Sciences	78	115
6	Zhejiang University	70	58
7	University of Electronic Science and Technology of China	99	77
8	Central South University	56	54
9	University of Oslo	38	37
10	King Saud University	42	33

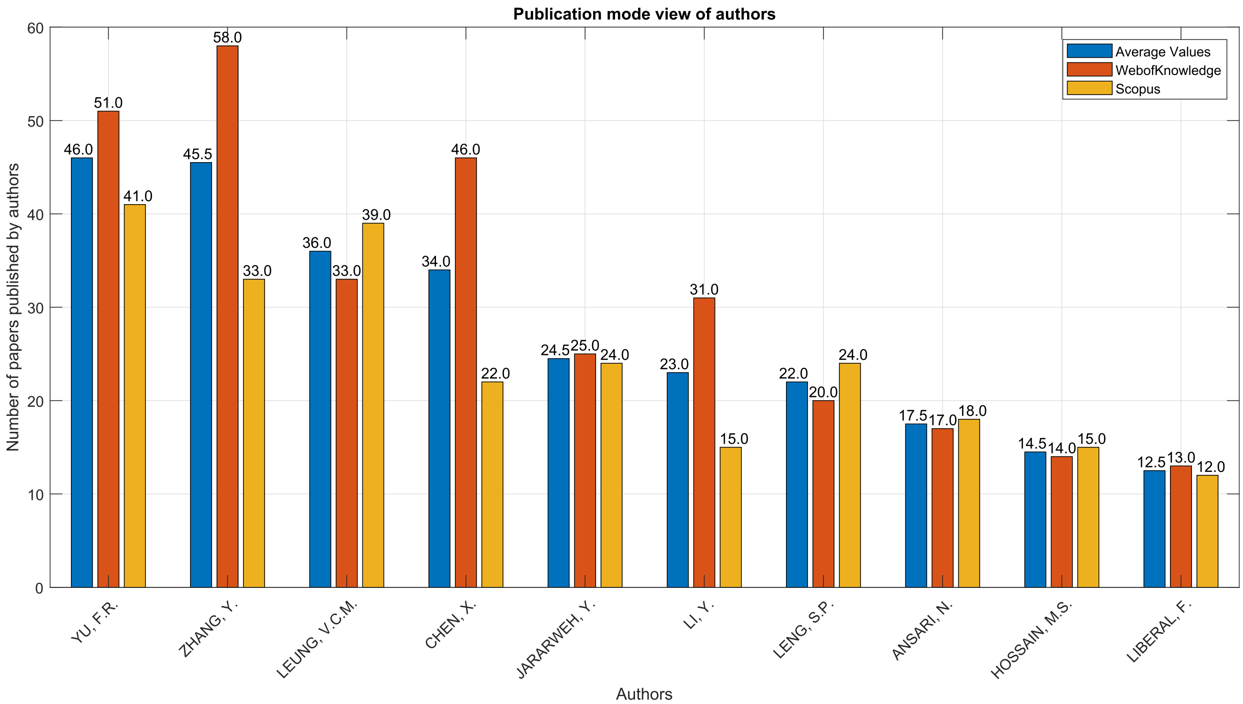

FIGURE 16. Research work published by authors over the last decade in the field of MEC.

the same task to the edge server repeatedly cause high energy consumption. It is profitable if multiple-input and multiple-output (MIMO) technique is employed during the offloading of the computation task. This, as a result, reduces channel complexity and offers reliability in the task advancement.

- The task processing and offloading take high latency in case of the excessive numbers of MDs [152]. Consequently, local processing may be highly beneficial if the number of MDs are high in the network. This will significantly minimize the task execution latency.
- The MDs installed in the network's edge need more energy for long-lasting communication, monitoring, and offloading. To save energy of the MDs, a modulation scheme named orthogonal frequency-division multiple access (OFDMA) may be used instead of time-division multiple access (TDMA) scheme. The OFDMA scheme has a high granularity of radio waves. The OFDMA scheme has a higher granularity of radio waves as compared to the TDMA scheme [153].
- Edge servers may not always catch a significant amount of computation tasks, due to the quality and topology of backhaul [154]. To diminish the problem of high throughput, the mesh topology is very profitable. It delivers vital information with a cost of low latency, as this topology connects all the MDs directly. Therefore, the offloaded data is more reliable and hence the server receives large number of tasks.
- The offloading of tasks from the MDs to the edge servers may be affected by various security challenges (e.g. Sybil attacks [155], Sinkhole attacks [156], and Buffer reservation attacks [157]), therefore the tasks may not reach to the final destination. The maintaining of trusted/untrusted list and community detecting algorithms significantly prevent the task from Sybil attacks [158]. To tackle the Sinkhole attacks, Kevin *et al.* [159] proposed an authentication technique that used a hash function before forwarding the data. To cope with the Buffer reservation attacks, a split buffer technique is exploited by which each device need to save

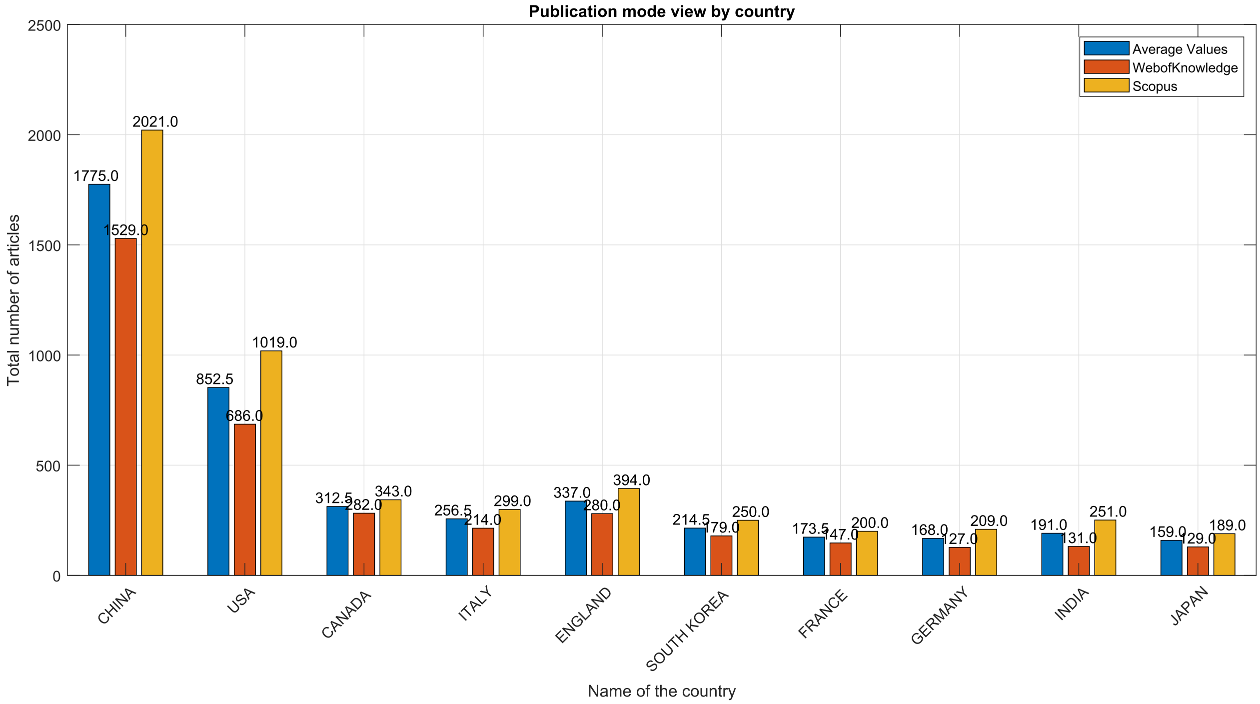

FIGURE 17. Top ten countries contributing to research on MECs in the last decade.

the task completion record. And discard the task if it has high variation in fragment pattern.

VII. CONCLUSION

The MEC paradigm has been recently introduced and solves the latency problems in delay-sensitive demands while accessing the cloud services. MEC brings the capabilities of cloud computing by deploying the mobile edge devices within close proximity. This paper presents a survey on MEC. The classification is done based on the performance parameters. Each class is explained in terms of algorithms, approaches, merit(s) and demerit(s). The classification of the algorithms is very handy for researchers and according to the desired applications. The demerit(s) of each algorithm leads to investigate efficient techniques that overcome the existing issues. In addition, the description of the merit(s) helps to choose the appropriate algorithm for the desired MEC application. As compared to other surveys, the bibliometric overview is given, which is helpful in a number of ways for researchers. Highlighting the bibliometric overview is the primary concern of the classification, which makes it convenient for the researchers to select the algorithms of interest for applications and further future investigation. Moreover, different application scenarios are presented, which are useful in the MEC platform. Finally, the description of the open research challenges and future directions are provided.

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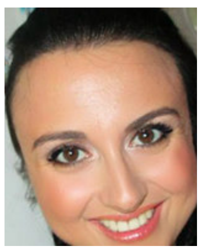

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