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Energy Management in Edge Computing: Survey on Challenges and Future Research Opportunities

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ABSTRACT
Global warming has posed a serious threat to humanity's survival, the carbon dioxide (CO_2) concentrations in the atmosphere are widely acknowledged as its primary cause. As a result, global attention to energy conservation has increased dramatically in order to limit CO_2 emissions. The traditional understanding of using the ground as a temperature moderator against harsh weather has great potential to become a strong remedy against the energy inefficiency of a building Heating, Ventilation and Air conditioning (HVAC). It has attempted to elaborate the thermal performance characteristics and conduct more research into the benefits and downsides of this passive cooling approach from many perspectives of long-term sustainability. Edge computing (EC), a novel computing paradigm innovation, has high potential to help with digitization. The paper presents some novel challenges in energy management and how other researchers applied different algorithms, simulators, performance metrics, type of energy used, and optimisation problems to address the issue of sustainable energy. Brown energy remains a big challenge; as such much is to be done to reduce the emission of carbon to the atmosphere. Also, painstakingly, future areas of further research where highlighted at end of the review work.

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INTRODUCTION

During the last decade, cloud computing paradigm has revolutionised the horizon of computing science and enabled computing to emerge as the fifth utility). With the emerges of modern economy by offering subscription based on services anywhere, anytime in line with pay as you go approach). Cloud computing has thus allowed the establishment of new businesses in a very small amount of time, encouraged the development of initiative around the globe, enhanced the speed of scientific progress, and created virous computing approaches for widespread and global application with other benefits.

Cloud computing paradigm provides on demand services to the end users such as software, storage and other computing services. In addition, distributed cloud data centres are vulnerable to single-point failures like any other centralized computing environment Furthermore, data centres may be geographically distant from their users, thereby requiring the transfer of data from their source to infrastructure that can process it in the data center. Wireless devices such as smartphones have been around in two primary states in recent years–idle and wired. The transition between those states–from idle to connected, or vice versatile currently one of the most common high-layer signaling events on 4 G LTE networks, occurring between 500-1,000 times a day in each system.

Nevertheless, with an estimate of 9 billion subscription mobile worldwide by 2022 of which 90% will include mobile broadband, shared with an eight-fold in mobile traffic billion and 17.6 increase Internet of Things (IoT) devices that will also send data), the network will be placed under considerable pressure. With the current network architecture there is a need to shift the undergo

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paradigm. In 2023, 5 G will make up around one-fifth of all mobile data traffic, with a projection for subscription penetration to 1 billion). Such facilities and computations with the Edge computing model are then extended to the edge of the network. This paradigm offers services for computation, data and application closeness to the end users. With low latency and high bandwidth improved the durability of mobile edge computing would allow for real time, adaptive and tonomous decision making it a sandbox for smart society and industry to innovate. The term Edge Computing refers to fixed and mobile networks for processing, storage, and optimization at the edge. Edge computing was introduced as a bottle neck solution on cloud by placing computing resources close to sensors. The edge devices, however, are unable to handle numerous applications that require limited resources as this causes resource conflict and enormous latency in processing. IoT applications ultimately aim to provide seamless services without user intervention. Likewise, the inefficient use of (Edge of things or Internet of Things) EoT/Fog-IoT resources often triggers a significant increase in energy consumption, which definitely invokes the need to build techniques that are responsible for managing energy consumption and guarantee the quality of service offered by the EoT / fog computing infrastructure). The Internet of Things (IoT) based application interact on the demand or end users side with the smart meter (SM) which track and regulates the appliances according to the information received from the utility for effective and efficient power usage.

Contrary to cloud resources, edge resource has the following resource constraint, heterogeneous and dynamic. .resource constraint refers to limited computational resource as edge devices have smaller processors and limited power budget, while heterogeneous is having processors with different architecture and dynamic terms as the workloads change and application compete for limited. Edge devices have computationally efficient data service, routers, gateways and other embedded system like sensors or vehicle). The Edge computers, like Raspberry PI, are very small embedded devices with very good energy efficient and negligible microcontroller or more powerful single board computers). In Edge Computation, most computation is done within proximity to the data source. Due to poor latency and potential network connections in cloud server, where cloud computing cannot achieve and sustain IoT Quality of Service (QoS) thus Edge Computing is a solution to the problem.

Edge computing can be characterised by high bandwidth, low latency and real time network access of information for multiple application use. A lot of research is been conducted to prove the reduction of energy consumption and response time in Edge computing. Therefore, Edge computing standards and Edge platform implementation are becoming key enablers of new revenue streams for manufactures third parties and operators). Cloud computing uses a centralized model while edge computing uses a distributed model for server distribution. Cloud computing targeted users are general Internet users while Edge users are the targeted service subscribers. Unlike Cloud computing global scope, Edge's scope is limited). Finally, Edge computing hardware s has limited abilities which make it less accessible than cloud). Therefore, one of the major challenges of edge computing is resource management. In view of the above we intend to some articles Edge computing architecture, infrastructure and algorithms that underpin the resource management in edge computing. This paper offers a survey on challenges and future research Opportunities in the context energy management in edge computing. The remainder of this paper is organized as follows: section 2 presents the related work; section present 3 the challenges and open issues while section 4 finally concludes the research and proffers future work.

RELATED WORK

In this subsection, we extensively review the previous survey and the taxonomy of energy management in edge computing.

Previous Survey

The are many researchers that have conducted are review/survey on sustainability energy management in edge computing where only twenty out of all this review is considered in the research with correcting number of literatures their cover within those years. While the present work cover about 86 number of literatures which for the period of eight years back.

Hassan, Rehmani, & Chen, (2019) review an Edge Computing, a detailed energy efficiency survey was presented, highlight of energy consumption in Edge computing. This survey indicated some benefits and challenges

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for Edge computing with different methods to be used in reducing wireless network energy consumption. Different techniques of data compression have also been studied and tools used within several key points to be explored in IoT devices and system development to decrease the protocols in Edge computing also helped to reduce energy usage. However, this review included among other things like taxonomy, graphical analysis and covered the most recent research issues.

Lee, et-al., (2019) conducted an inclusive review of existing edge computing technologies and techniques that have been used to reduce data processing, transmission and how to enhance efficiency and effectiveness of mobile data analytics. Integrated deep learning and edge computing technologies that would result in research based on Edge computing intelligence service. This provides a list of open-source software according to their applicability. They introduced some optimization of edge computing technologies for energy efficiency and deep learning. Highlights open areas for edge computing design and analysis.

Varghese et al., (2016) Survey of edge data management in computing that explores the design, data flow, control and tenancy. The technology used in the management of resources, such as the use of software, hardware and middleware technologies. They also introduced several algorithms used in Edge computing services to help load balancing, placement, discovery and benchmark. All of the above highlights the Edge computing services ' data privacy and security, data compression, energy efficiency, and heterogeneity.

Gill & Buyya, (2018) Investigate on detailed, sustainable taxonomy in cloud computing by introducing the existing methods that need analysis and attention. We breakdown sustainable cloud computing into application design, energy management, capacity planning, virtualization, refrigeration, thermal conscious scheduling and waste heat use. Compression of current technologies, based on their characteristics and common properties on scalable cloud computing. A modern architecture and algorithms in data centre management, reducing energy consumption through aggregation of virtual machines and maximizing QoS.

Ullah, Ahmed, & Kim, (2018) proposed a survey on potential optimal network performance. Information Centric Network (ICN) over Edge computing aimed at providing effective techniques that would shorten response time to address the Big Data Management, Latency, Availability, Security and Naming issues. The survey also looks at the definition of Edge computing, drivers, limitation and proposals. The highlight ICN overview in Edge computing and its inspiration while being the various effort for the vendors ' software and hardware solution.

Hassan, Yau, & Wu, (2019) Research edge computing taxonomy approaches defined by different characteristics (e.g., aims, computing platform and attributes) and other computing. Edge computing requirement that provides connectivity for real time, local processing, high data rate and high availability. Edge computing increases network performance for supporting and implementing various scenarios such as remote surgery. Some of the future research areas found for effective implementation of edge computing in 5 G include service enhancement, standardization, and weaknesses in heterogeneity and protection.

Maenhaut, Volckaert, Ongenae, & De Turck, (2019) Investigated how cloud resource management is familiar to support new technologies such as containers such as technology virtualization and the emergence of fog / edge computing. The work also categories items based on the functional aspect of main resource management, with a summary for each category. The research described some fascinating resource management possibilities in a future completely containerized multi-tiered edge-fog-cloud, which could solve several vulnerabilities of today's cloud environments.

Sittón-Candanedo, Alonso, Rodríguez-González, Coria, & De La Prieta, (2019) checked some gaps found in the implementation of edge computing architecture for other non-industry The research designing a novel edge computing reference architecture for future by accounting key attribute. The main objective is to achieve real time data analysis to minimise operational and management costs by reducing traffic and data transmission between Edge and the Cloud. Edge computing improves application performance that withstand lower latency network compared with cloud for

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security improvement by the use of block chain technologies embedded into the infrastructure at lower IoT layer to the upper layer of the cloud. The key goal is to attain real time data processing at the local device level.

Mao, You, Zhang, Huang, & Letaief, (2017) proposed a complete overview on MEC research from the communication viewpoint. Summaries the modelling methodologies as a key component of MEC systems such as the task computation, communication, mobile devices ans MEC servers. Therefore, energy and latency define assist in the performance of MEC systems. The review also recognised some resource management for MEC under different system architecture that leverage computing offloading principles, joint radio computational resource allocation, scheduling, and multi-server collaboration. The review listed some open research areas such as MEC cache, MEC mobility management, green MEC and MEC privacy and security issues in MEC deployment.

Toczé & Nadjm-Tehrani, (2018) contributed in the development of efficient technologies that addressed resource scarcity challenges in Edge computing. The technology brings the developing system and makes a means of discussing resource relevance from end to end perspective. The survey provides an overview, in both cloud and IoT device perspective.

Abbas et al., (2017) reviewed on MEC which offers great for future edge technology that offer mobile devices on bandwidth, battery life and storage The MEC trends to provide flexible resource application that require computational intensive tasks with high bandwidth and low latency at network end particularly in 5G network.

Ai et al., (2017) state-of - the-art computing surveys aimed at discovering more specifics of key technologies separating the knowledge base into cloud, mobile edge computing, and fog computing. A comprehensive overview on the theory, device design, specifications, and implementations is reviewed with this in mind. Rigorous investigation is performed that needed further attention to be concentrated on turning well-established fog computing into radio access networks in the fog computing bases.

(Buyya et al., 2018) because cloud computing enabled the establishment of new businesses in a very short amount of time, which facilitated the deploying of an initiative around the world. It gives acceleration in the speed of scientific progress, giving way, among other benefits, develop numerous computing models for global and ubiquitous applications. Proposed the next decade significant requirement for heterogeneous IoT and sensor on a larger scale. The requirement will pose many new in cloud computing and create new methods and research strategies. This gives room to revisit the existing model in order to address issues of resource provisioning, scalability and security.

(Gill & Buyya, 2018) review on the current energy efficient resource management approaches and policies with primary focus on Virtual Machine (VM) consolidation to reduce server energy consumption. To support sustainable cloud computing, a holistic management method is needed on some resources such as processor, storage, network, memory and cooling requirements. Furthermore, due to the dynamic change in processor variable clock rates can applied. It was also proposed the renewable encourage cloud service providers to place their Cloud data Centres (CDC) closer to the green energy infrastructure that are spread in different geographical locations

Taxonomy of Energy Management in Edge Computing

Proper resource management can also lead to high energy efficiency, with the goal of using free computing slots in edge clusters on smartphones. The above figure 1 explain the taxonomy of energy management in edge computing with four main sub-heading that will an able to have better energy efficiency in edge computing. The subheadings are energy consumption, energy efficiency, power usage effectiveness and average datacenter efficiency.

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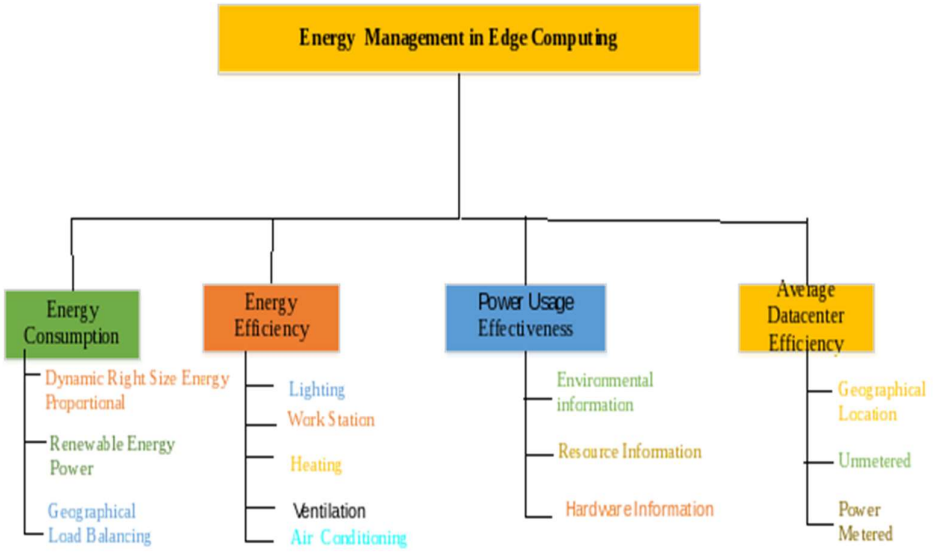

Fig. 1: Taxonomy of Energy Management in Edge Computing

The review of each of the energy management concept in edge computing is presented in the preceding section.

Energy Consumption

Due to the recent challenges in smart edge computing, the is a need to come up with an effective method that would minimised energy consumption of mobile edge device in wireless edge computing network (Xu, Li, Huang, et al., 2019). A non-dolomite sorting genetic algorithm II (NSGA II) is proposed with intention of reduce energy consumption and task offloading time. The algorithm was compared with local offloading and benchmark to prove its effectiveness in all the metrics and ensure deviltry of the population. But the algorithm is weak in user privacy protection and migration of tasks.

Guo et al., (2019) proposed an energy efficiency dynamic offloading and resource scheduling algorithm (eDors) for smart mobile edge device for better energy consumption. The algorithm shows that offloading computation selection not only depends on the computing workload of task, but minimizes the completion time of clock frequency, predecessors and transmission of power to the mobile devices. The algorithm did well in reducing the energy consumption compared with tested algorithms.
(Cui et al., 2019) Investigated mobile edge computing device with goal of minimising device energy consumption, a modified non dominated sorting genetic algorithm II (MNSGA II) is proposed. The algorithm show that is very effective in computational latency and energy consumption. The simulation result revel that the algorithm has pare tor optimal compared with the greedy algorithm which gives its flexibility of choice. With all this work is needed to resolve issues of allocation and scheduling problems with the algorithm.

Gu et al., (2019) investigated the task allocation, virtual machine (VM) and energy scheduling with aim to reduce brown energy consumption. Heuristic relaxation algorithm based is proposed with the intention of tackling random green energy and user demand challenges. The energy cost of joint consolidation of VMs, migration and green energy is minimized. Energy internet (EI) is used to compared with OPT, OTS, ATS and OWN to test the ability of the algorithm. Brown energy is also reduced to a minimum. The algorithm worst case is task processing energy consumption with local green energy.

Xu, Liu, et al., (2019) proposed a modified non dominated sorting genetic algorithm III (NDSGA III). The algorithm reduces execution time and energy consumption in mobile edge devices through computation offloading approach. The algorithm effectiveness where proving by comparing with benchmark and other algorithm such as CCOM and CLCOM algorithms. The algorithm does not

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guarantee execution of large last to reducing energy consumption and execution time.

Hu, Li, & He, (2019) proposed an algorithm reformed Schedule Method for Energy Consumption Constraints. The algorithm goal is to reduce energy consumption and consumption time. The algorithm is compared with HEFT, MSLECC, RMEC and MPEGA to prove it's significant. The method can be applied in both large and small scale mobile edge applications. Low or high heterogeneity result to poor performance of the method.

Pu, Chen, Mao, Xie, & Xu, (2018) Investigated internet of vehicle with aim of reducing the energy consumption. The proposed work is on heterogeneous vehicles for large applications. The work is compared with dual control and device to device forging D2D. The proposed work used Chimera algorithm for energy efficient and deadline of crossing framework. The algorithm is only applied in vehicle applications.

Bharathi & Jeyanthi, (2018) proposed and investigated multi objective problem that try to overcome the issues of energy consumption, throughput, fairness, queuing, priority level classes and user equality requirement in WLAN. A Hybrid Cooperative Consultative Radio Network HCCRN is proposed. The algorithm is compared with CCRN to prove its effectiveness. The algorithm is good in most of WLAN application of edge computing.

Yu, Chen, & Xu, (2018) proposed an algorithm called dynamic mobility aware partial offloading aim at reducing the amount of energy consumption while delay constraint is maintain. To prove the effectiveness of the algorithm it was compared with dynamic partial offloading with mobility management and partial offloading with mobility management. The algorithm can save up to of energy with very tight delay constraint.

Jiang, Zhang, & Yan, (2020) proposed an algorithm Multi-Pointer-Network Mptr-Net. The algorithm is applied in order to solve the issue of mobile edge computation offloading problem where a multidimensional multiple knapsack with constraint. The algorithm reduces energy consumption of mobile device during task execution. The algorithm is compared with heuristics to measure its effectiveness. Neural network needs long time for training which is one of the limitations of the algorithm is.

(Suriya Praba, Sethukarasi, & Saravanan, 2019) investigate on power node, topology based power control as an essential in energy consumption reduction. Where a connecting edge dominating set based on semi graph model. These are based on connecting dominating set algorithm. The algorithm is aimed at reducing energy consumption and average data transmission. The algorithm is compared with DSDV and AODV for its effectiveness. Thus, algorithms have issue with fault tolerance.

(Hao, Cao, Wang, & Du, 2021) used clustering technique by dividing the node into clusters, each of the edge node have maximum distance that define by the energy transfer attenuation ratio. The research is aimed at reducing the total energy of the clustering nodes within and outside the system. The work rescheduling heuristic method algorithm. To test the effectiveness of the method it was compared with MTS, m-ETAR and NOMOV algorithms. The research can be expended to solve dynamic change of results by repeatedly applying all the edge nodes.

Energy Efficiency

Mao et al., (2019) proposed an online resource allocation and computation offloading algorithm for mobile edge computing device. The algorithm simulation result revealed that the proposed work have great in network energy efficiency and computation delay with this order [O(1/V), O(V)] where V is the control parameter. The algorithm outperforms the equal bandwidth allocation algorithm with different parameters. But if the value of V is bigger the algorithm is having straggle in performance.

Ranji et al., (2020) investigated energy efficiency improvement where an Energy efficiency Delay-aware Offloading Scheme (EEDOS) was proposed. The scheme result show it effectiveness with other compared scheme such as number of offloading, device and device with mass mobile edge computing offloading for about 95% in all the parameter tested. The scheme is limited to block chain technology in MEC that provide secure IoT environment.

Sun et al., (2019) evaluated mobile edge computing computation efficiency. Thus, the goal is to minimize total computation and

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energy efficiency among all Edge Unit (EU). An experiential algorithm for computational efficiency minimization is proposed. The algorithm is compared with other methods to find its effectiveness in local computing and offloading only. The result indicate that the proposed algorithm has fundamental trade-off between local computing and offloading in MEC device.

Yang et al., (2018) investigated energy efficiency maximization with average transmission power under the peak transmission power constraint. The green cognitive delay insensitive radio CR and green sensitive delay CR algorithm where combined and proposed. The algorithms where compared using traditional power allocation strategies that is ATP and PTP to proof proposed algorithm effectiveness. The algorithms have complexity and maximum energy efficiency trade off.

Ayala et al., (2019) Investigated Hyper Text Transmission Protocol (HTTP) for android mobile device browser. The method measured and compared energy consumption on different mobile android browsers. The method shows an improvement in performance communication in terms of energy demand. Two type of browser where compared in term of their polling, long polling and web socket on Firefox and chrome browsers. Upon all that the method has little issue in monitoring and refactoring of the asynchronous communication function.

Suriya Praba et al., (2019) proposed connected edge dominating set-based semi graph S-CEDS to investigate energy efficiency. The objective is to ease the consumption of energy, data transmission and control massage overhead. The algorithm effective is compared with DSDV and AODV algorithms where Ns2 simulator is used for the experiment. The algorithm has some limitations in real time environment collusion where delay con increase.

Park et al., (2020) proposed Offloading Comparison Decision algorithm in Deep-Q network DQN. The goal is to optimize delay, energy efficiency and improve performance in data transmission. The proposed is tested based on Deep Reinforcement Learning DRL. The effectiveness is done through the comparing of the proposed algorithm with full offloading, local offloading and greedy algorithm. When the data source size increases the gab also increases.

(Juiz & Bermejo, 2020) Proposed an algorithm for consolidation of virtual machine called consolidated index for CPU-Server Saturation CiS^2. The algorithm is to help in energy efficiency of servers through benchmarking. The algorithm also select the most efficient service determinant for performance in energy efficiency virtual machine consolidation, the result is compared with following diagonal reference such as T430, T3400, R310, HPI and T330.

Yan et al., (2019) investigated energy consumption while maintaining resource allocation and reliability by proposing an algorithm called energy efficiency task scheduling for edge computing (EASE). The work used an integer programming method. The algorithm is compared with Lc-M, LaS and LaSM algorithms for its effectiveness. The algorithm has issues in addressing a static environment and fault tolerance.

Liu et al., (2019) proposed a fast heuristic algorithm called Minimizing User Equipment Energy Consumption Algorithm MUEECA. The algorithm is to minimize energy consumption of user equipment while guaranteeing reliability application and latency requirement. The whole application is spliced into subtasks to satisfy the computation offloading requirement. The algorithm is compared with greedy, random and local computation algorithms. The algorithm has issues when run as a whole.

Li et al., (2020) proposed a vehicular computation offloading algorithm named as Multi Value Density based Heuristic Allocation algorithm MVDHA. The main objective to the proposed algorithm is to reduce energy consumption and execution time in an edge vehicle. Moreover, the algorithm also measured cost effective allocation of resources and energy saving. The proposed algorithm is compared with Local computation and Brute Force Algorithm foe it's significant. The algorithm can only be applied in vehicular computational offloading.

Zhou et al., (2019) proposed Local Energy Aggregation algorithm LEAG to improve energy efficiency of a vehicular edge device. The numerical result indicated that the proposed algorithm achieves a good performance in terms of feasibility contract, security and task offloading. The algorithm is compared with aggressive scheme, concrete

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schemes and without edge computing for its effectiveness. The algorithm has a low convergence speed.

Lin et al., (2019) proposed a Markoy Decision Process based wireless power transfer for energy harvesting radio frequency. The algorithm objective is to decreased energy use with high priority in data forwarding, optimal energy utilization and computation rate, the algorithm is compared with Greedy and SOLE algorithm to prove the effectiveness of MDP. The algorithm with limitation of task computation and low priority data task received less energy. (Ali et al., 2019) proposed an algorithm called Energy Efficiency Deep learning based Offloading Scheme EEDOS. The algorithm goal is to reduce energy consumption with user requirement accuracy. It also reduces the overall cost of execution. The algorithm is compared with following TOS, DOS and ROS to find it effectiveness. The algorithm cannot handle multiple users.

Al-Turjman et al., (2019) investigated device-to-device communication system. A heuristic routing algorithm is proposed. The algorithm improved resource utility, energy consumption, throughput, and delivery packet ratio with computation cost reduction. The effectiveness of algorithm is compared with heuristic routing algorithms such dijkstra rounting, CD rounting, AODV rounting, Q rounting and Pd-q rounting. The approach has less spectrum resource frequency.

Peng et al., (2019) proposed multi objective computation offloading called Whale algorithm (WA). The algorithm reduces time, energy consumption and cost. The effectiveness of the algorithm is compared with NO, FOCL and FOC methods. The algorithm can only be used for single cloudlet

Sun et al., (2021) proposed an energy efficiency task offloading based on differential evaluation in edge computing. The algorithm goal is to have energy efficiency of the system in order to overcome the issue of limited energy and computing capacity of different sensor nodes in wireless communication networks. The proposed method is compared with maximizing the number of bits and local capacity scheme. There is need to further investigate the proposed system in order to come slight fluctuation of the edge system.

Power Usage Effectiveness

Carrega et al., (2019) Proposed an improve IDRQN algorithm with deep reinforcement method. The goal is to reduce energy consumption, load balancing, execution time and latency in MEC devices. The algorithm solves multi service node in a large scale heterogeneous MEC and tasks with multi dependency in MEC. The comparison is done with following algorithm to prove its effectiveness such IDQN, DQN, DRQN and HERDQN. But the algorithm is not good for pricing of frozen and active resources.

Chen et al., (2019) investigated android smart devices where an adaptive offloading framework is proposed. The proposed framework reduces execution time had energy computation intensive in a smart android application. The work is compared with original and traditional types of applications. The results evaluation prove that the approach is significant in performance and energy consumption reduction. The framework is not applicable in a real-world environment network.

Tang et al., (2019) Proposed an algorithm called mixed overhead of time and energy (MOTE) method. The technique is to minimize energy consumption and execution time for all user devices. The task is divided in to two that is MEC server execution and local execution. The two methods where compared with local computing frequency and without transmission power optimization to prove the effectiveness of the system. The techniques lack initial MEC frequency distribution.

Chakraborty et al., (2020) proposed a Hybrid- Net algorithm which ensure lower the energy consumption for higher memory compression of extremely quantize neural network. The method shows an achieving in classification enhancement performance is compared with binary network such as XNOR network. The effectiveness of the algorithm is test with comparison with XNOR and ReNet algorithms on PyTorch simulator. The algorithm gives energy efficient computation to hybrid network for AI based on chip analysis.

Bolla et al., (2018) proposed a method called OpenStack with goal of reducing energy through consolidation. The method provides an improved linear relationship between power consumption and usage while having QoS. To prove the effectiveness of the method is compared with consolidation without

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context, consolidation with context and without consolidation. The method is effectively balancing the power consumption and quality of service QoS in edge computing.

Gu et al., (2019) proposed a Karush-Kuhn-Tunker algorithm (KKT) aim to ease consumption of energy and completion delay Task energy consumption is reduce with respect to constraint completion time. Computation offloading policy and power transmission allocation reduce completion time delay and energy effectively compared with Luis binary offloading local and full offloading. When input data is low it leads to an increase in energy consumption and migration.

Wan et al., (2019) investigated computation offloading in Internet of Vehicle application. A proposed computation offloading in IoV COV. The algorithm improve in vehicle application offloading cost, delay and balancing of ENS. To prove the effectiveness of the algorithm it was compared with some benchmark algorithms such as FFD-RU and BFD-RU. The algorithm has issues with privacy preservation.

Average Data Center Efficiency

Li et al., (2019) investigated a mobile edge computing device for resource expansion and shrinking. The proposed an algorithm known as (TBAMP) to address the above problem. The algorithm is compared with two number existing algorithm that is LRM and DRPM where the proposed algorithm shows it effectiveness in cost minimization. The algorithm also is good in SLA default rate and resource utilization. But the algorithm needs to be expended to cover the real-life data set in the future.

Mao et al., (2016) proposed an algorithm that investigate on execution of cost which address task failure and execution latency. The proposed algorithm used is called Lyapunov optimization based dynamic offloading which is combine with offloading decision for power transmission computation offloading and CPU cycle for mobile execution frequencies. The algorithm is compared with MEC server execution GD, mobile execution GD and dynamic offloading GD. The result shows that the proposed algorithm outperforms the greedy policies benchmark significantly in cost execution as while as reducing the computation failure. Therefore, this study gives way for more research in renewable energy power edge devices.

One of the key factor of deep learning edge services in a 5G network is computation offloading (Xu, Li, Dai, et al., 2019). A task heuristic offloading method is proposed with the objective of reducing transmission delay of the deep learning. The method improves offloading time delay according to deep learning task coordination. Evaluation pf results show that the method did well in transmission delay. The comparison is done with local offloading and cloud offloading where the performer in teaching the delay in transmission.

Mallik et al., (2019) proposed a mixed resolution high efficiency video coding techniques that aim in lowering the bit rate transmission computation. The method also increases performance and reduces the consumption of energy in an edge devices. The techniques is compared with an anchor MV-HEVC method for effectiveness. The method is not good in computation offloading reduction.

Li et al., (2018) Investigated re clustering of task in edge computing resource scheduling. An improved spectral clustering scheduling algorithm to address the above issue. The algorithm result give a better clustering result with QoS guarantee and give higher resource utilization rate. The result is compared with traditional spectral clustering scheduling algorithm with MatLab simulator. The algorithm is slower when task time trend is increased.

Chirivella-Perez et al., (2018) proposed a network function virtualization monitoring (NFVMon) algorithm focus is on network capability monitoring of 5G traffic flow metric in MEC infrastructure. The algorithm support quality of service (QoS) and application in an oriented smart network system. The main objective is to monitor and analyses user's traffic application in 5G where multiple operator can share the same physical infrastructure. The algorithm is compared with scalability overhead to prove its effectiveness with limited capabilities in hardware based application.

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Mallik et al., (2019) proposed a mixed resolution high efficiency video coding techniques that aim in lowering the bit rate transmission computation. The method also increases performance and reduces the consumption of energy in an edge devices. The techniques is compared with an anchor MV-HEVC method for effectiveness. The method is not good in computation offloading reduction.

Li et al., (2018) Investigated re clustering of task in edge computing resource scheduling. An improved spectral clustering scheduling algorithm to address the above issue. The algorithm result give a better clustering result with QoS guarantee and give higher resource utilization rate. The result is compared with traditional spectral clustering scheduling algorithm with MatLab simulator. The algorithm is slower when task time trend is increased.

Chirivella-Perez et al., (2018) proposed a network function virtualization monitoring (NFVMon) algorithm focus is on network capability monitoring of 5G traffic flow metric in MEC infrastructure. The algorithm support quality of service (QoS) and application in an oriented smart network system. The main objective is to monitor and analyses user's traffic application in 5G where multiple operators can share the same physical infrastructure. The algorithm is compared with scalability overhead to prove its effectiveness with limited capabilities in hardware-based application. **Fig.** 2 and Fig. 3 depict the number of articles selected per edge computing paradigm and year.

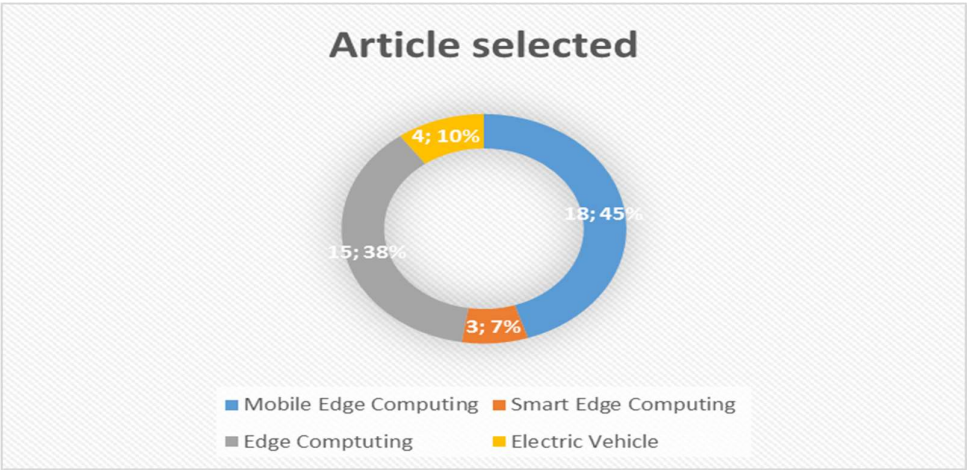

Fig. 2: Number of articles selected per edge computing paradigm and year

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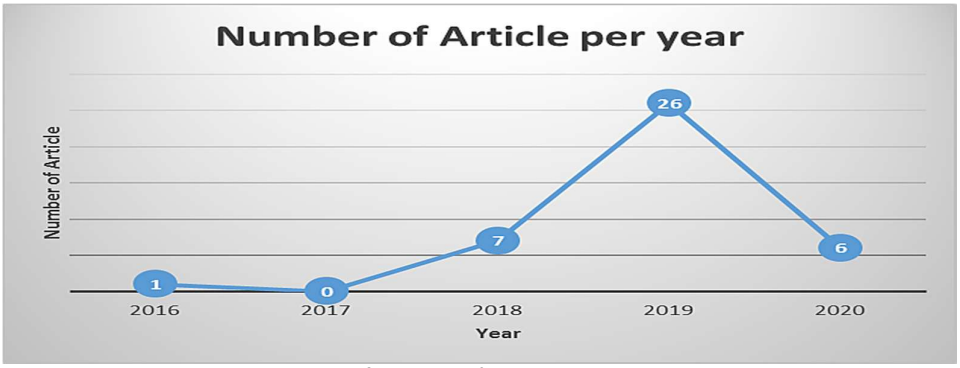

Fig. 3: Number of articles per year

CHALLENGES AND FUTURE RESEARCH DIRECTION

Edge computing is still at its infant stage with many challenges, such of these challenges are still open for more research. Some the sustainable edge computing problems are computational uploading, device to device communication, data transmission with the network and computational time just mention a few. Thus, improving or reducing any of the above can increase the overall energy effectiveness of the system.

Many authors have done several reviews and surveys but this area needs more hand to do more in the energy efficiency of sustainability edge computing with the intention of reduce and improve energy costs used by the edge, smart, mobile and electric vehicles to have greener environment. Some of the outline challenges where hardware technologies, application driven processing, heterogeneity and dynamism, cross layer explore, energy and sustainability, human activity awareness and security, privacy and resilience.

Other great challenges of this Edge computing with respect to the 5G network are security and privacy, heterogeneity, standardization of protocol and service enhancement. Since Edge is new and there is a wide area of research which still needs to be explored such as several computing, validation of resource management strategies, management of hybrid edge, management of bare-meter containers and dynamic resource allocation centralization application.

While other issues at hand are energy and smart farming. Moreover, data storage, energy resource, mobility while the supply of multi-level. One of the big issues of Edge computing is resource optimization, web interface, transport migration application and pricing, this includes service requirement support, mobility strategy management and network slicing capability.

Ahvar, Orgerie, & Lebre, (2019) developed a model that consider several technical important point where users are considered to have even distribution while in real environment is unevenly distributed. The future would consider other technologies architecture such us VNF, containers, mobile networks and heterogeneous telecommunication network. (Siala & Liburdy, 2020) investigate on the power production mechanism of flopping investor energy in full detail, where the ch allege and future work would be on more kinematic motion effectiveness based on LEV energy have sting system.

Blanco, Taboada, Fajardo, & Liberal, (2017) stated that there is need to have a good research work on VNF characterization which includes bit rate output with transcoded function, heterogeneous SCs combination with different resource consumption and configuration and the used of technological to analyses the relationship between service pricing and aggregated user traffic cost requirement of infrastructure. (Cui et al., 2019) used NSGA-II to study the computational offloading based on Pareto optimal under different parameters to get an optimal solution which can be executed to scheduling and allocating channel of communication for decision making process.

Gu et al., (2019) used optimal offloading policy and transmission power allocation on dynamic computation offloading. Since users can change position during the period, where users migration per tern is greatly

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needed in the problem formulation. Markav approximation based algorithm is been to solve single and static mobile device problem which show a convergent in a near optimal solution. This can be extended to multi-dynamic mobile devices in order to evaluate the real test bed of mobile edge computing. (Xu, Liu, et al., 2019) while used NSAG-III in multi objective optimization where the method can be extend to solve real world issues of IoT. The method if improve con handle workflow execution and offloading strategies to maximized energy consumption saving in a mobile edge device.

CONCLUSION

It has already demonstrated that IoT platforms show some of its use in tackling the looming sustainability concerns brought on by the exponential proliferation of Internet-connected gadgets. Although the first wave of IoT platforms were all cloud-based, the demand has led to a demand for decentralized solutions as well. Edge computing is a computer paradigm that pushes a piece of logic from the cloud closer to the network and devices for faster communication. The study review some details of extensive literature on sustainable energy efficient management in Edge computing. The study also showed the effectiveness of various edge computing paradigm, algorithms used and type of energy in contention that will enhance sustainable energy efficiency. The study discovers some significant point issues to stimulate and create more cost-effective and energy-efficient Edge computing by collaboration with designers of edge devices. Furthermore, solar energy, wind energy and other green renewable energy sources should be encouraged and supported all regards to edge cloud computing.

REFERENCES

Ai, Y, Peng, M, & Zhang, K. (2017). Edge cloud computing technologies for internet of things *A primer. Digit. Commun. Netw*.

Al-Turjman, Fadi, Deebak, BD, & Mostarda, Leonardo. (2019). Energy Aware Resource Allocation in Multi-Hop Multimedia Routing via the Smart Edge Device. *IEEE Access, 7*, 151203-151214.

Ali, Zaiwar, Jiao, Lei, Baker, Thar, Abbas, Ghulam, Abbas, Ziaul Haq, & Khaf, Sadia. (2019). A Deep Learning Approach for Energy Efficient Computational Offloading in Mobile Edge Computing. *IEEE Access, 7*, 149623-149633.

Alonso, Ricardo S, Sittón-Candanedo, Inés, Rodríguez-González, Sara, García, Óscar, & Prieto, Javier. (2019). *A Survey on Software-Defined Networks and Edge Computing over IoT.* Paper presented at the International Conference on Practical Applications of Agents and Multi-Agent Systems.

Ayala, Inmaculada, Amor, Mercedes, & Fuentes, Lidia. (2019). An energy efficiency study of web-based communication in android phones. *Scientific Programming, 2019*.

Bagchi, Saurabh, Siddiqui, Muhammad-Bilal, Wood, Paul, & Zhang, Heng. (2019). Dependability in edge computing. *Communications of the ACM, 63*(1), 58-66.

Bahreini, Tayebeh, Brocanelli, Marco, & Grosu, Daniel. (2019). *Energy-aware speculative execution in vehicular edge computing systems.* Paper presented at the Proceedings of the 2nd International Workshop on Edge Systems, Analytics and Networking.

Bharathi, GP, & Jeyanthi, K Meena Alias. (2018). An optimization algorithm-based resource allocation for cooperative cognitive radio networks. *The Journal of Supercomputing*, 1-21.

Bolla, Raffaele, Carrega, Alessandro, Repetto, Matteo, & Robino, Giorgio. (2018). Improving efficiency of edge computing infrastructures through orchestration models. *Computers, 7*(2), 36.

Boukerche, Azzedine, Guan, Shichao, & Grande, Robson E De. (2019). Sustainable offloading in mobile cloud computing: Algorithmic design and implementation. *ACM Computing Surveys (CSUR), 52*(1), 1-37.

Buyya, Rajkumar, & Gill, Sukhpal Singh. (2018). Sustainable cloud computing: foundations and future directions. *arXiv preprint arXiv:1805.01765*.

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Buyya, Rajkumar, Netto, Marco A. S., Toosi, Adel Nadjaran, Rodriguez, Maria Alejandra, Llorente, Ignacio M., Vimercati, Sabrina De Capitani Di, . . . Vaquero, Luis Miguel. (2018). A Manifesto for Future Generation Cloud Computing. *ACM Computing Surveys, 51*(5), 1-38. doi: 10.1145/3241737

Carrega, Alessandro, Portomauro, Giancarlo, Repetto, Matteo, & Robino, Giorgio. (2019). Energy efficiency for edge multimedia elastic applications. *Multimedia Tools and Applications, 78*(17), 24739-24764.

Chakraborty, Indranil, Roy, Deboleena, Garg, Isha, Ankit, Aayush, & Roy, Kaushik. (2020). Constructing energy-efficient mixed-precision neural networks through principal component analysis for edge intelligence. *Nature Machine Intelligence*, 1-13.

Chen, Weiwei, Wang, Dong, & Li, Keqin. (2019). Multi-User Multi-Task Computation Offloading in Green Mobile Edge Cloud Computing. *IEEE Transactions on Services Computing, 12*(5), 726-738. doi: 10.1109/tsc.2018.2826544

Chen, Xing, Chen, Shihong, Ma, Yun, Liu, Bichun, Zhang, Ying, & Huang, Gang. (2019). An adaptive offloading framework for Android applications in mobile edge computing. *Science China Information Sciences, 62*(8), 82102.

Chen, Ying, Zhang, Ning, Zhang, Yongchao, Chen, Xin, Wu, Wen, & Shen, Xuemin Sherman. (2019). TOFFEE: Task offloading and frequency scaling for energy efficiency of mobile devices in mobile edge computing. *IEEE Transactions on Cloud Computing*.

Chirivella-Perez, Enrique, Gutiérrez-Aguado, Juan, Alcaraz-Calero, Jose M, & Wang, Qi. (2018). Nfvmon: enabling multioperator flow monitoring in 5G mobile edge computing. *Wireless Communications and Mobile Computing, 2018*.

Cui, Laizhong, Xu, Chong, Yang, Shu, Huang, Joshua Zhexue, Li, Jianqiang, Wang, Xizhao, . . . Lu, Nan. (2019). Joint Optimization of Energy Consumption and Latency in Mobile Edge Computing for Internet of Things. *IEEE Internet of Things Journal, 6*(3), 4791-4803. doi: 10.1109/jiot.2018.2869226

Gill, Sukhpal Singh, & Buyya, Rajkumar. (2018). A taxonomy and future directions for sustainable cloud computing: 360 degree view. *ACM Computing Surveys (CSUR), 51*(5), 1-33.

Gu, Lin, Cai, Jingjing, Zeng, Deze, Zhang, Yu, Jin, Hai, & Dai, Weiqi. (2019). Energy efficient task allocation and energy scheduling in green energy powered edge computing. *Future Generation Computer Systems, 95*, 89-99. doi: 10.1016/j.future.2018.12.062

Gu, Xiaohui, Jin, Li, Zhao, Nan, & Zhang, Guoan. (2019). Energy-Efficient Computation Offloading and Transmit Power Allocation Scheme for Mobile Edge Computing. *Mobile Information Systems, 2019*.

Guo, Songtao, Liu, Jiadi, Yang, Yuanyuan, Xiao, Bin, & Li, Zhetao. (2019). Energy-Efficient Dynamic Computation Offloading and Cooperative Task Scheduling in Mobile Cloud Computing. *IEEE Transactions on Mobile Computing, 18*(2), 319-333. doi: 10.1109/tmc.2018.2831230

Hao, Yongsheng, Cao, Jie, Wang, Qi, & Du, Jinglin. (2021). Energy-aware scheduling in edge computing with a clustering method. *Future Generation Computer Systems, 117*, 259-272.

Hartmann, Morghan, Hashmi, Umair Sajid, & Imran, Ali. (2019). Edge computing in smart health care systems: Review, challenges, and research directions. *Transactions on Emerging Telecommunications Technologies*, e3710.

Hassan, Muneeb Ul, Rehmani, Mubashir Husain, & Chen, Jinjun. (2019). Privacy preservation in blockchain based IoT systems: Integration issues, prospects, challenges, and future research directions. *Future Generation Computer Systems, 97*, 512-529.

**Corresponding author: Abdulsalam Y. Gital.* ✉ *aygital@atbu.edu.ng* ✉ *Department of Mathematical Sciences, Abubakar Tafawa Balewa University Bauchi, Nigeria.*

Hassan, Najmul, Yau, Kok-Lim Alvin, & Wu, Celimuge. (2019). Edge computing in 5G: A review. *IEEE Access, 7*, 127276-127289.

Hong, Cheol-Ho, & Varghese, Blesson. (2018). Resource management in fog/edge computing: A survey. *arXiv preprint arXiv:1810.00305*.

Hu, Yikun, Li, Jinghong, & He, Ligang. (2019). A reformed task scheduling algorithm for heterogeneous distributed systems with energy consumption constraints. *Neural Computing and Applications*, 1-13.

Jiang, Qingmiao, Zhang, Yuan, & Yan, Jinyao. (2020). Neural Combinatorial Optimization for Energy-Efficient Offloading in Mobile Edge Computing. *IEEE Access, 8*, 35077-35089.

Juiz, Carlos, & Bermejo, Belen. (2020). The $$ CiS^ 2$$ CiS2: a new metric for performance and energy trade-off in consolidated servers. *Cluster Computing*, 1-20.

Khan, Wazir Zada, Ahmed, Ejaz, Hakak, Saqib, Yaqoob, Ibrar, & Ahmed, Arif. (2019). Edge computing: A survey. *Future Generation Computer Systems, 97*, 219-235.

Khattar, Nagma, Sidhu, Jagpreet, & Singh, Jaiteg. (2019). Toward energy-efficient cloud computing: a survey of dynamic power management and heuristics-based optimization techniques. *The Journal of Supercomputing, 75*(8), 4750-4810.

Li, Chao, Xue, Yushu, Wang, Jing, Zhang, Weigong, & Li, Tao. (2018). Edge-oriented computing paradigms: A survey on architecture design and system management. *ACM Computing Surveys (CSUR), 51*(2), 1-34.

Li, Chunlin, Sun, Hezhi, Chen, Yi, & Luo, Youlong. (2019). Edge cloud resource expansion and shrinkage based on workload for minimizing the cost. *Future Generation Computer Systems, 101*, 327-340.

Li, Guangshun, Xu, Shuzhen, Wu, Junhua, & Ding, Heng. (2018). Resource scheduling based on improved spectral clustering algorithm in edge computing. *Scientific Programming, 2018*.

Li, Shulei, Zhai, Daosen, Du, Pengfei, & Han, Ting. (2019). Energy-efficient task offloading, load balancing, and resource allocation in mobile edge computing enabled IoT networks. *Science China Information Sciences, 62*(2), 29307.

Li, Wei, Yang, Ting, Delicato, Flavia C, Pires, Paulo F, Tari, Zahir, Khan, Samee U, & Zomaya, Albert Y. (2018). On enabling sustainable edge computing with renewable energy resources. *IEEE Communications Magazine, 56*(5), 94-101.

Li, Wenjun, Chen, Zhenyu, Gao, Xingyu, Liu, Wei, & Wang, Jin. (2019). Multimodel Framework for Indoor Localization Under Mobile Edge Computing Environment. *IEEE Internet of Things Journal, 6*(3), 4844-4853. doi: 10.1109/jiot.2018.2872133

Li, Xin, Dang, Yifan, Aazam, Mohammad, Peng, Xia, Chen, Tefang, & Chen, Chunyang. (2020). Energy-Efficient Computation Offloading in Vehicular Edge Cloud Computing. *IEEE Access, 8*, 37632-37644.

Li, Xin, Qian, Zhuzhong, Lu, Sanglu, & Wu, Jie. (2013). Energy efficient virtual machine placement algorithm with balanced and improved resource utilization in a data center. *Mathematical and Computer Modelling, 58*(5-6), 1222-1235.

Lin, Hai, Chen, Zhihong, & Wang, Lusheng. (2019). Offloading for Edge Computing in Low Power Wide Area Networks With Energy Harvesting. *IEEE Access, 7*, 78919-78929.

Liu, Fang, Tang, Guoming, Li, Youhuizi, Cai, Zhiping, Zhang, Xingzhou, & Zhou, Tongqing. (2019). A survey on edge computing systems and tools. *Proceedings of the IEEE, 107*(8), 1537-1562.

Liu, Haolin, Cao, Le, Pei, Tingrui, Deng, Qingyong, & Zhu, Jiang. (2019). A Fast Algorithm for Energy-Saving Offloading With Reliability and Latency Requirements in Multi-Access Edge Computing. *IEEE Access, 8*, 151-161.

**Corresponding author: Abdulsalam Y. Gital.* ✉ *aygital@atbu.edu.ng* ✉ *Department of Mathematical Sciences, Abubakar Tafawa Balewa University Bauchi, Nigeria.*

Liu, Yi, Yang, Chao, Jiang, Li, Xie, Shengli, & Zhang, Yan. (2019). Intelligent edge computing for IoT-based energy management in smart cities. *IEEE Network, 33*(2), 111-117.

Maenhaut, Pieter-Jan, Volckaert, Bruno, Ongenae, Veerle, & De Turck, Filip. (2019). Resource Management in a Containerized Cloud: Status and Challenges. *Journal of Network and Systems Management*, 1-50.

Maksimovic, M. (2018). Greening the future: Green Internet of Things (G-IoT) as a key technological enabler of sustainable development *Internet of things and big data analytics toward next-generation intelligence* (pp. 283-313): Springer.

Mallik, Bruhanth, Sheikh-Akbari, Akbar, & Kor, Ah-Lian. (2019). Mixed-resolution HEVC based multiview video codec for low bitrate transmission. *Multimedia Tools and Applications, 78*(6), 6701-6720.

Mao, Sun, Leng, Supeng, Maharjan, Sabita, & Zhang, Yan. (2019). Energy Efficiency and Delay Tradeoff for Wireless Powered Mobile-Edge Computing Systems with Multi-Access Schemes. *IEEE Transactions on Wireless Communications*, 1-1. doi: 10.1109/twc.2019.2959300

Mao, Yuyi, You, Changsheng, Zhang, Jun, Huang, Kaibin, & Letaief, Khaled B. (2017). A survey on mobile edge computing: The communication perspective. *IEEE Communications Surveys & Tutorials, 19*(4), 2322-2358.

Mao, Yuyi, Zhang, Jun, & Letaief, Khaled B. (2016). Dynamic Computation Offloading for Mobile-Edge Computing With Energy Harvesting Devices. *IEEE Journal on Selected Areas in Communications, 34*(12), 3590-3605. doi: 10.1109/jsac.2016.2611964

Mocnej, Jozef, Miškuf, Martin, Papcun, Peter, & Zolotová, Iveta. (2018). Impact of edge computing paradigm on energy consumption in IoT. *IFAC-PapersOnLine, 51*(6), 162-167.

Mukherjee, Mithun, Shu, Lei, & Wang, Di. (2018). Survey of fog computing: Fundamental, network applications, and research challenges. *IEEE Communications Surveys & Tutorials, 20*(3), 1826-1857.

Pan, Jianli, & McElhannon, James. (2017). Future edge cloud and edge computing for internet of things applications. *IEEE Internet of Things Journal, 5*(1), 439-449.

Park, SooHyun, Kwon, Dohyun, Kim, Joongheon, Lee, Youn Kyu, & Cho, Sungrae. (2020). Adaptive Real-Time Offloading Decision-Making for Mobile Edges: Deep Reinforcement Learning Framework and Simulation Results. *Applied Sciences, 10*(5), 1663.

Peng, Kai, Zhu, Maosheng, Zhang, Yiwen, Liu, Lingxia, Zhang, Jie, Leung, Victor CM, & Zheng, Lixin. (2019). An energy-and cost-aware computation offloading method for workflow applications in mobile edge computing. *EURASIP Journal on Wireless Communications and Networking, 2019*(1), 207.

Pu, Lingjun, Chen, Xu, Mao, Guoqiang, Xie, Qinyi, & Xu, Jingdong. (2018). Chimera: An energy-efficient and deadline-aware hybrid edge computing framework for vehicular crowdsensing applications. *IEEE Internet of Things Journal, 6*(1), 84-99.

Ranji, Ramtin, Mansoor, Ali Mohammed, & Sani, Asmiza Abdul. (2020). EEDOS: An energy-efficient and delay-aware offloading scheme based on device to device collaboration in mobile edge computing. *Telecommunication Systems, 73*(2), 171-182.

Ren, Ju, Zhang, Deyu, He, Shiwen, Zhang, Yaoxue, & Li, Tao. (2019). A Survey on End-Edge-Cloud Orchestrated Network Computing Paradigms: Transparent Computing, Mobile Edge Computing, Fog Computing, and Cloudlet. *ACM Computing Surveys (CSUR), 52*(6), 1-36.

Sharma, Vishal, You, Ilsun, Palmieri, Francesco, Jayakody, Dushantha Nalin K, & Li, Jun. (2018). Secure and energy-efficient handover in fog networks using blockchain-based

*Corresponding author: Abdulsalam Y. Gital. aygital@atbu.edu.ng Department of Mathematical Sciences, Abubakar Tafawa Balewa University Bauchi, Nigeria.

DMM. *IEEE Communications Magazine, 56*(5), 22-31.

Shi, Weisong, Cao, Jie, Zhang, Quan, Li, Youhuizi, & Xu, Lanyu. (2016). Edge computing: Vision and challenges. *IEEE internet of things journal, 3*(5), 637-646.

Sittón-Candanedo, Inés, Alonso, Ricardo S, Rodríguez-González, Sara, Coria, José Alberto García, & De La Prieta, Fernando. (2019). *Edge Computing Architectures in Industry 4.0: A General Survey and Comparison.* Paper presented at the International Workshop on Soft Computing Models in Industrial and Environmental Applications.

Sun, Haijian, Zhou, Fuhui, & Hu, Rose Qingyang. (2019). Joint offloading and computation energy efficiency maximization in a mobile edge computing system. *IEEE Transactions on Vehicular Technology, 68*(3), 3052-3056.

Sun, Yingying, Song, Chunhe, Yu, Shimao, Liu, Yiyang, Pan, Hao, & Zeng, Peng. (2021). Energy-Efficient Task Offloading Based on Differential Evolution in Edge Computing System With Energy Harvesting. *IEEE Access, 9*, 16383-16391.

Suriya Praba, T, Sethukarasi, T, & Saravanan, S. (2019). Energy Measure Semigraph-Based Connected Edge Domination Routing Algorithm in Wireless Sensor Networks. *Mobile Information Systems, 2019*.

Tang, Qiang, Lyu, Haimei, Han, Guangjie, Wang, Jin, & Wang, Kezhi. (2019). Partial offloading strategy for mobile edge computing considering mixed overhead of time and energy. *Neural Computing and Applications*, 1-15.

Toczé, Klervie, & Nadjm-Tehrani, Simin. (2018). A taxonomy for management and optimization of multiple resources in edge computing. *Wireless Communications and Mobile Computing, 2018*.

Ullah, Rehmat, Ahmed, Syed Hassan, & Kim, Byung-Seo. (2018). Information-centric networking with edge computing for IoT: Research challenges and future directions. *IEEE Access, 6*, 73465-73488.

Varghese, Blesson, Wang, Nan, Barbhuiya, Sakil, Kilpatrick, Peter, & Nikolopoulos, Dimitrios S. (2016). *Challenges and opportunities in edge computing.* Paper presented at the 2016 IEEE International Conference on Smart Cloud (SmartCloud).

Wan, Shaohua, Li, Xiang, Xue, Yuan, Lin, Wenmin, & Xu, Xiaolong. (2019). Efficient computation offloading for Internet of Vehicles in edge computing-assisted 5G networks. *The Journal of Supercomputing*, 1-30.

Xu, Xiaolong, Li, Daoming, Dai, Zhonghui, Li, Shancang, & Chen, Xuening. (2019). A heuristic offloading method for deep learning edge services in 5G networks. *IEEE Access, 7*, 67734-67744.

Xu, Xiaolong, Li, Yuancheng, Huang, Tao, Xue, Yuan, Peng, Kai, Qi, Lianyong, & Dou, Wanchun. (2019). An energy-aware computation offloading method for smart edge computing in wireless metropolitan area networks. *Journal of Network and Computer Applications, 133*, 75-85. doi: 10.1016/j.jnca.2019.02.008

Xu, Xiaolong, Liu, Qingxiang, Luo, Yun, Peng, Kai, Zhang, Xuyun, Meng, Shunmei, & Qi, Lianyong. (2019). A computation offloading method over big data for IoT-enabled cloud-edge computing. *Future Generation Computer Systems, 95*, 522-533.

Yan, Hui, Li, Ya, Zhu, Xiaomin, Zhang, Dayu, Wang, Ji, Chen, Huangke, & Bao, Weidong. (2019). EASE: Energy-efficient task scheduling for edge computing under uncertain runtime and unstable communication conditions. *Concurrency and Computation: Practice and Experience*, e5465.

Yang, Zhou, Jiang, Wenqian, & Li, Gang. (2018). Resource allocation for green cognitive radios: energy efficiency maximization. *Wireless Communications and Mobile Computing, 2018*.

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You, Changsheng, Huang, Kaibin, Chae, Hyukjin, & Kim, Byoung-Hoon. (2016). Energy-efficient resource allocation for mobile-edge computation offloading. *IEEE Transactions on Wireless Communications, 16*(3), 1397-1411.

Yu, Fangxiaoqi, Chen, Haopeng, & Xu, Jinqing. (2018). DMPO: Dynamic mobility-aware partial offloading in mobile edge computing. *Future Generation Computer Systems, 89*, 722-735.

Zhang, Ke, Mao, Yuming, Leng, Supeng, Zhao, Quanxin, Li, Longjiang, Peng, Xin, . . . Zhang, Yan. (2016). Energy-efficient offloading for mobile edge computing in 5G heterogeneous networks. *IEEE access, 4*, 5896-5907.

Zhou, Zhenyu, Wang, Bingchen, Dong, Mianxiong, & Ota, Kaoru. (2019). Secure and efficient vehicle-to-grid energy trading in cyber physical systems: Integration of blockchain and edge computing. *IEEE Transactions on Systems, Man, and Cybernetics: Systems, 50*(1), 43-57.

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