A Comprehensive Study on the Energy Efficiency of IoT from Four Angles: Clustering and Routing in WSNs, Smart Grid, Fog Computing and MQTT & CoAP Application Protocols

Ziyad Almudayni[1(✉)], Ben Soh[2], and Alice Li[2]

[1] Hail University, Hail, Saudi Arabia
20167676@students.latrobe.edu.au
[2] La Trobe University, Melbourne, Australia
{b.soh,a.li}@latrobe.edu.au

Abstract. The Internet of things (IoT) technologies have been developing since their inception. Consequently, the number of connected devices increases yearly. The development of IoT devices has to be set, taking into consideration parameters such as security, data rate and energy. In this paper, we carried out a comprehensive review on the main concern, which is the energy efficacy of IoT devices. We will target four research areas to make the searching process interesting and easier for researchers. The four research areas are related to clustering and routing in WSNs, smart grid, fog computing and MQTT & CoAP application protocols.

Keywords: Fog computing · WSNs · Routing · Clustering · Smart grid · CoAP and MQTT

1 Introduction

The Internet of things (IoT) can be described as the ability of IoT nodes to communicate with each other via the Internet to perform tasks. Establishing IoT technologies in any environment can make the work process more convenient and save time. Therefore, this technology might witness a vast evolution, and each person might need from three to four connected devices. Developers have been working to make IoT systems more secure and accurate by establishing and running complex algorithms on these systems; however, these algorithms consume power to run accurately [1]. To make IoT networks more accurate and scalable, especially with the large number of connected devices, it is vital to improve the IoT system's performance from all angles: energy, data rate, bandwidth, coverage, and more. In this study, we will target the energy performance of the IoT systems by collecting previous related studies to help developers to find gaps and target areas. Therefore, the sources of energy in IoT networks have to be clarified first, which are sensing, processing, and data transmission for instance of developing these factors,

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it is necessary for researchers to know how long the IoT systems execute data and aim to reduce that time to save power. Moreover, the data rate is another critical point in IoT systems that affects the energy efficacy of IoT deceives, as it is generally known that increasing the data rate means consuming more power. Thus, it is vital to know exactly the amount of data rate that each IoT application requires to avoid wasting data rate and power by giving data rate for an IoT application more than its needs. Moreover, the IoT application's range of coverage is another critical point, which is directly related to the IoT systems' power consumption, as coverage increases power increases so, knowing the exact range where each IoT application needs to cover to sense and transmit data could be considered the key to solving this issue, as there will be no more extra coverage than the needs and no power wasting [2]. However, to address the gaps in IoT systems or any system, we have to read previous studies about the point we aim to address deeply from more than one angle and analyse these previous studies that are related to the same area to find gaps and address these gaps. In this study, we review previous studies on enhancing energy efficiency in IoT systems from four angles. The first angle is related to the clustering and routing mechanisms in the WSNs. The second angle is related to scheduling, balancing and finding the best resource in fog computing to process the IoT tasks. The third concern is developing the use of IoT systems in the smart grid (SG) to save power. The last angel is related to the two most vital application protocols MQTT and CoAP and how can the modification on these protocols contribute in improving the energy efficiency of IoT networks. Figure 1 lists the four angles.

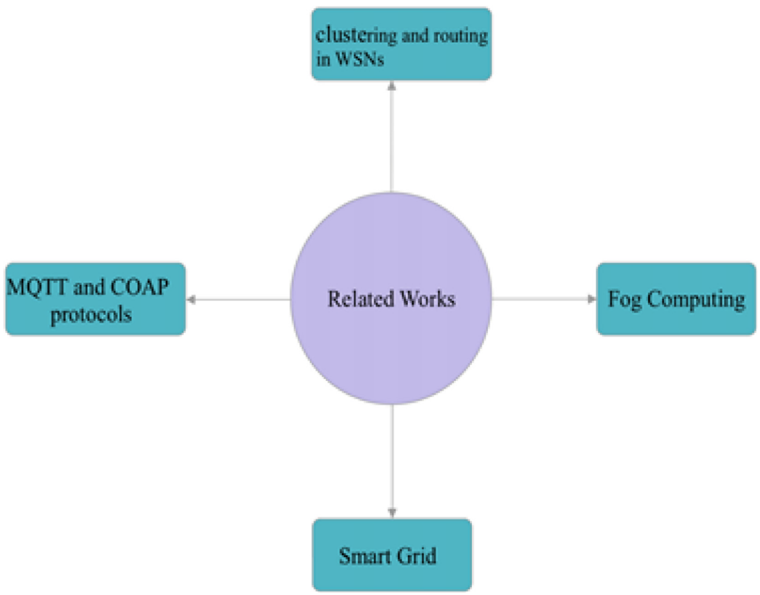

Fig. 1. Four main research areas

2 Energy Efficiency, Routing and Clustering for WSNs in IoT

In this section we review recent studies in the literature about improving IoT networks' energy efficiency through addressing the gaps and finding optimal solutions for clustering, and routing in WSNs. Figure 2 shows how these three areas are linked.

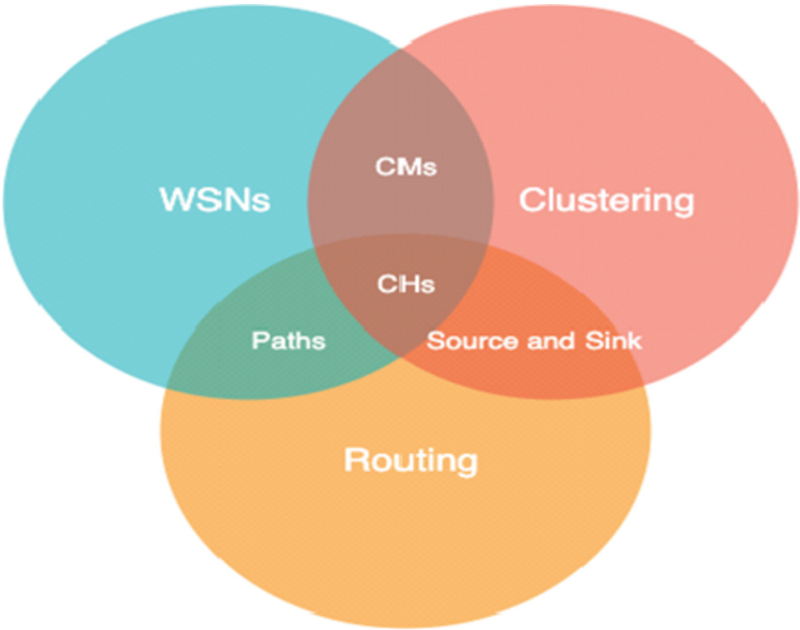

Fig. 2. Intersection of research

The IoT sensor nodes could be counted as the heart of the IoT system as most of the IoT systems' objectives can be achieved via theses sensor nodes. Therefore, it is vital to know how an IoT WSN work by dividing its function into units. The IoT sensor node generally has four main units: sensing, processing, communication and power supply units. First, the sensing unit detects and senses the movements and changes in the surrounding areas to be collected for further processing. Seconds, the processing unit analyses the collected data to perform tasks and take actions. Third, the communication unit transfers the data between IoT nodes via a network. Finally, the power unit has power restrictions to supply sensors nodes with the required power. Comparing theses four units from an energy angle, the communication unit could be counted as the highest power energy consumers due to its nature of work in sending and receiving data [3].

Xiong C et al. [4] proposed Source location privacy (SLP) to secure networks in the industrial internet of Things (IIoT), aiming to protect the networks from any attacks; however, this protection requires more power to operate as IIoT has to run more complex algorithms in the network. Therefore, the authors used distributed energy resources (DERs) to prolong the network lifetime, aiming to balance the network between security and power consumption. The reason behind proposing this approach is because in some cases in IIoT applications, attackers can track the packages by locating the nodes; so hiding the location of sensors is vital. The proposed approach is capable of hiding the locations of sensors by using phantom nodes, rings, and fake paths (PRFs). It creates fake paths and nodes to distribute attackers. The main disadvantage of the proposed approach is that it only works when nodes are constant.

Zhang X et al. [5] proposed an optimal path selection method (OPSM) based on an ant routing algorithm that can find the optimal path, aiming to improve the performance of IoT networks. The reason behind proposing this approach is to prevent the IoT networks from causing delays and prolong the network lifetime. Therefore, the network lifetime, mobile distance and node coverage are considered in OPSM. The method basically divides the network monitoring area into several fixed-size grids, and it keeps dividing until the network lifetime becomes greater than or equal to the time threshold to select the optimal path. The simulation results demonstrate that OPSM successfully makes the transmission time shorter and prolongs the network lifetime.

Pereira H et al. [6] proposed a new metric for routing protocol for the low and lossy networks (RPL) instead of the previous routing metrics expected transmission count (ETC) to enhance load balancing and increase the lifetime of WSNs. The new metric is called network interface average power (NIAP). NIAP can estimate the average power consumed in the network interface. Moreover, it can pick the best routes from multiple paths, which contributes to improving load balancing and increasing the lifetime of WSNs. After various experiments, the results prove that NIAP can be a satisfying alternative to ETX because of its simplicity regarding implementation, and it does not require any modifications for the RPL standard. However, NIAP has some limitations. It requires changing the parent node frequently to find the best path and it works on short-scale topologies.

Khan F et al. [7] proposed a new routing mechanism called modified-percentage LEACH to address gaps in the current protocol: low-energy adaptive clustering hierarchy (LEACH). The new routing protocol aims to prolong the network lifetime by decreasing communications between CHs and the sink. Therefore, the new approach divides nodes in the cluster into two groups based on the destination to the sink: near to sink (N) far from the sink (F). In the former, nodes communicate directly with the sink as they are close to the sink. In the latter, nodes require a CH to link them to the sink as they are far away from the sink. As a result, the new approach success in enhancing the energy efficacy and outperforms the energy performance of previous protocols: LEACH, V-LEACH and MOD-LEACH. However, the new protocol works only on two types of deployments: free space and multi-path schemes.

Abdullah S et al. [8] proposed an energy-scheduling algorithm to prolong the network lifetime in IoT networks. The new approach divides things/sensors into clusters, and each cluster has its private broker, whose mission is to link cluster members to the sink. Moreover, the broker schedules messages and decides which message goes first using the SPF (shortest processing time first) technique. The selection of a broker is not randomly as in LEACH; it is based on the distance of a node and its residual energy. The simulation results show that the proposed approach improves the residual energy and keeps more nodes alive compared to LEACH.

Iqbal S et al. [9] proposed a zone-based routing algorithm to change the selfish behavior as nodes try not to share energy with their neighbours to save their energy because they have limited battery power. Therefore, IoT nodes should cooperate with other nodes to boost the network lifetime rather than saving power for them only. Thus, the zone-based routing algorithm employs a game theory solution to force nodes to share energy with neighbours. The algorithm consists of four main steps: structuring zones, selecting a leader for the zone, discovering routes and selecting paths. The simulation outcomes show that the proposed approach improves the packet delivery ratio, network lifetime, and throughput compared to AODV and ZCG.

Safara F et al. [10] proposed a new routing method based on energy and security called (PriNergy), intending to enhance the energy efficiency for IoT systems. The routing method employs RPL as its routing model. Each node in the network calculates the time to send data to the destination, aiming to increase routing quality in the network. Moreover, the new approach divides nodes into high priorities and low priorities to avoid congestion on the network. NS-2 was used to evaluate the proposed approach. The PriNergy simulation results show better energy consumption, end-to-end delays, and routing overhead compared to QRPL.

Shen J et al. [11] proposed a new routeing protocol called energy-efficient centroid-based routing protocol (EECRP) for IoT wireless sensors to enhance the energy efficiency of IoT networks. The proposed method consists of three key factors to obtain its objective:

- A new distributed method to allow nodes to organise themself locally.
- New algorithms to select a cluster head in a centre position aim to divide the workload equally among all sensor nodes.
- A new mechanism to prolong the network lifetime for communication in long-distance.

Therefore, the new approach is suitable for long lifetime networks where the base station (BS) is placed in the same network. The simulation outcomes show that EECPR achieves better results than LEACH, LEACH-C, and GEEC.

XU Y et al. [12] modified the standard LEACH to improve the performance in WSNs. As known, the selections of the CHs occur randomly in the tradition LEACH. However, in the modified approach to factors are considered to select a CH. First, the residual energy of the nodes and nodes can calculate its residual energy. Second, the distance between CHs and the sink and nodes can measure this distance. The simulation results show that the proposed approach outperforms the standard LEACH in terms of energy efficiency.

Ouhab A et al. [13] proposed a new model to support the lack of efficient routing to handle device-to-device communication on a large scale in IoT. The proposed mechanism aims to satisfy the QoS requirements for the network by providing two new control mechanisms. First, a new routing protocol for RPL stands on the multi-hop clustering technique (MHC-RPL) to control and organise nodes locally. Second, the integration of (SDN) with Q-routing algorithm is implemented to control the network globally. The simulation results show that the new approach has better outcomes than the current state-of-the-art in terms of energy consumption, packet delivery ratio and end-to-end delay.

Tang L et al. [14] proposed a new routing algorithm called energy balanced routing algorithm for network lifetime enhancement (EBRA-NLE) based on a DS evidence theory in the WSNs. The new approach aims to achieve two objectives: increasing network lifetime and balancing workload among nodes. Three attribute indexes are implemented in this algorithm: Energy Balance Factor (EB), Relay Coefficient (RC), and Buffer Idleness (BI). EB to distribute workload equally among nodes, RC selects the best optimal path for a node to the base station, and BI estimates the capacity of nodes to receive data. Using MATLAB 2019, the simulation outcomes prove that the network lifetime improved by the use of the EBRA-NLE algorithm and shows better results than MCRP and DS-EERA algorithms by about 313% and 72%, respectively.

Iwendi C et al. [15] proposed a metaheuristic optimisation approach to prolong the network lifetime by reducing the power consumption in the network. The proposed method used a hybrid metaheuristic algorithm: whale optimization algorithm (WOA) to select the optimal Cluster Head CH in the IoT network. Moreover, temperature, residual energy, load, and the number of alive nodes are considered as metric performance to select an appropriate cluster head. The simulation of selecting CHs in Matlab R2015a proves that the new approach outperforms the existing algorithm: artificial bee colony algorithm, genetic algorithm and adaptive gravitational search algorithm.

Sarma S et al. [16] proposed a new routing algorithm based on search and rescue optimization algorithm (SAR) to select an appropriate Cluster head (CH), aiming to improve the performance of WSNs. Distance, delay and energy are considered to support the process of choosing CHs. The evaluation of the proposed approach was done by MATLAB. The simulation results show that SAR has better energy performance and success in keeping more nodes alive compared to existing approaches: Grey Wolf Optimization (GWO) and Firefly Cyclic Grey Wolf Optimization (FCGWO).

Reddy P et al. [17] proposed a new approach that is based on combining two algorithms called Gravitational Search Algorithm (GSA) and Artificial Bee Colony (ABC) algorithm to select the best optimal CHs for WSNs in IoT network. Moreover, distance, energy, delay, load, and temperature are considered to select a Ch. The simulation results show that the proposed approach success in prolonging the network lifetime compared to existing protocols: artificial bee colony (ABC), genetic algorithm (GA), particle swarm optimization (PSO), and GSA algorithm.

WiseMid middleware was launched as a software tool to IoT hardware devices and data to work in one environment. The WiseMid can contribute to enhancing the energy efficiency of IoT systems by introducing four mechanisms. Data aggregation: This aims to minimise the overall size of the sent message to avoid traffic in the network by removing extra data. Reply storage timeout: This prevents the system from sending messages with the same value that has been sent already. Atomic type conversion: This converts the type of messages to remove the extra bytes. Invocation asynchronous patterns: The asynchronous messaging's objective is to avoid delays when a client sends a request [18].

In healthcare systems, the Body Sensors Network (BSNs) consumes power, as these sensors have to work continuously for a long time to collect the patient's data for further monitoring. To minimise the power consumption for these sensors, in [19] the authors proposed a machine learning (ML) algorithm to classify patients' status into two categories: normal situation and emergent situation based on the collected data from the four sensors, namely, the accelerometer electrocardiogram (ECG), temperature and humidity. In normal situations, the transmission level will be low, whereas, in emergent situations, the level of transmission will be high.

3 Energy Efficiency for IoT Using Fog Computing

In this section we review recent studies in the literature about how an IoT node finds the best optimal source to compute data. Figure 3 shows how optimization algorithms can help IoT nodes to find optimal resources in fog computing are linked.

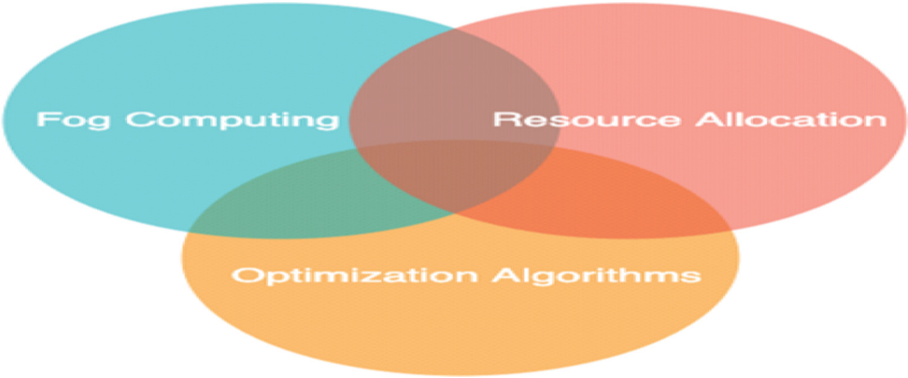

Fig. 3. Intersection of research

The linear fog-computing (LFC) model is introduced to reduce energy consumed in IoT nodes. In LFC, fog nodes are connected in one line from sensors to servers. It is designed to serve a fewer number of sensors, and it cannot be operated when there are many sensors due to the limited capacity of each fog node. Adding to the limited capacity, the processes of fog nodes to process data are not disrupted equally, which causes an unbalanced workload in fog nodes. In [20] the authors proposed a tree-based fog-computing (TBFC) model that aims to minimise the execution time and energy consumption of fog nodes in the IoT nodes. As the new model follows a tree structure, each fog node has a small capacity to process data, and the total workload of the fog nodes are distributed. The proposed model TBFC outperforms the linear model by reducing the nodes' energy consumption of and the processing time of nodes.

Using containers as a resource unit in fog computing is better than using virtual machines (VMs) because VMs do not suit the requirements of QoS in fog computing. In [21] the authors proposed a new architecture called a multi-cloud to multifg-fog and implemented two service models that aim to enhance the resource unit in fog computing by applying containers and minimising the service delay. Regarding the two service models, the authors presented a task-scheduling algorithm to balance the energy and schedule requests in real-time. The simulation outcomes show that the proposed architecture and the scheduling algorithm can increase the network lifetime of WSNs by balancing energy, minimising delay and enhancing fog node efficiency.

Ma K et al. [22] proposed a new model called IoT-FCM (a multi-layer IoT-based fog computing) to allocate resources between the fog layer, the terminal layer and a multi-sink version of the least interference beaconing protocol (LIBP) using a genetic algorithm. The proposed model aims to minimise the energy in the terminal layer and improve the fault-tolerance. Comparing the popular max–min and fog-oriented max–min, the outcomes of this study proved that the IoT-FCM shows better results in decreasing fog's distance and the terminal nodes by about 38% and minimising the consumed energy by an average of 150 KWh.

Ghanavati S et al. [23] implemented a new task-scheduling algorithm aiming to decrease both the processing time and the energy consumption for the fog-computing environment to enhance the performance. The proposed method comprises two algorithms: applying the ant mating optimization (AMO) algorithm and optimized distribution to obtain the aforementioned goals. The experimental results of the proposed algorithms showed better results than the bee life algorithm, traditional particle swarm optimisation and genetic algorithm regarding processing time and power consumption. Figure 4 shows a comparison between the aforementioned algorithms regarding the power consumption of the fog nodes.

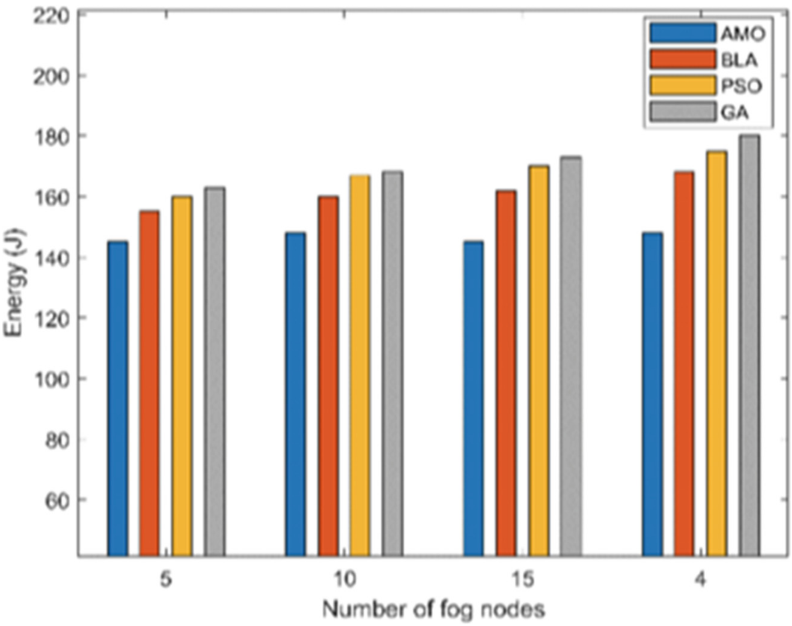

Fig. 4. A comparison between algorithms

Scheduling resources in an environment such as the IoT could be considered one of the NP-Hard problems. In [24] the authors proposed a classification method called fog-based Bayesian classification scheduling (FBCS) to minimise the energy in the IoT environment. The Bayesian classification could be applied in the fog environment to schedule task requirements such as the processing ones. The predicted requirements will be run on virtual machines after the process of classification. Due to the advantages that IfogSim has in terms of the very random and dynamic environment, the authors applied it to the proposed method. In comparison with other methods, the proposed method shows better results in terms of power consumption and executing task cost in the cloud.

One of the hardest things that IIoT service providers face is the availability of energy resources for fog computing services. The most vital factor that might add value to energy consumption in fog systems and enhance the performance for fog services is task scheduling. In [25] the authors proposed an energy-aware metaheuristic algorithm based on harris hawks optimization algorithm and local search strategy (HHOLS) to schedule the tasks in the fog services aiming to enhance the QoS that the users in IIoT applications receive. The proposed algorithm was compared with other algorithms, and the comparison results proved that the proposed algorithm can give better results regarding parameters makespan, energy consumption and cost.

Reddy D et al. [26] proposed a feedback based optimized fuzzy scheduling approach (FOFSA) to schedule tasks in fog computing in the IoT environment to reduce processing time and power consumption and enhance the makespan aiming to improve the performance in the IoT applications. The scheduling criteria for the proposed system based on three priorities: Low, Medium and High to offload the tasks to the Cloud. Matlab and IfogSim were used to test and run the proposed method. Comparing the osmosis load balancing algorithm (OLB), adaptive task allocation technique (ATAT), dynamic duty scheduling algorithm (DDSA) and optimized fuzzy bee based scheduling algorithm (OFBSA), the proposed method shows better outcomes than the others in terms of the three aforementioned parameters.

Hosseinioun P et al. [27] proposed a new method to save power in distributed systems such as IoT by enhancing the performance in the fog services. The proposed method consists of two main steps. First, ordering tasks without breaking any construction is achieved using of the hybrid IWO-CA evolutionary algorithm. Second, the dynamic voltage and frequency scaling (DVFS) technique was used to estimate the appropriate voltage for the services. The outcomes of the proposed methods show remakeable changes in saving power compared with the DVFS-enabled energy-efficient workflow task scheduling algorithm (DEWTS) and the enhanced energy-efficient scheduling (EES) algorithm.

The resource allocation in distributed systems gets more complex due to the diversity of computing servers, such as cloud, fog and edge layers. In [28] the authors proposed a new approach called energy-aware fog resource optimization (EFRO) model to adapt the QoS requirements in fog services for the IoT devices by minimising energy consumption and executing time. The basic principle of the proposed design is to select the appropriate computing service for the tasks based on the workload, whereas the heavy workload will be processed in the cloud and the middle and light workloads will be processed in the fog and edge layers respectively. The proposed method outperforms the two existing MESF and RR methods regarding energy efficiency by 54.83 and 71.28, respectively.

In addition to the advantages that the fog computing services have added to improve the communication network for IoT nodes, nonorthogonal multiple access (NOMA) has emerged as a promising solution to enhance the spectrum efficiency. Fog computing and NOMA can collaborate to improve the performance of the IIoT by minimising delays and power consumption. In [29] the authors proposed an online learning fashion to offload the tasks in the IIoT via NOMA to multiple nearby fog nodes. The authors proposed an iterative algorithm to schedule the tasks and allocate the subcarrier in each time episode.

RAHBARI D et al. [30] proposed a scheduling algorithm called greedy knapsack-based scheduling (GKS) to allocate recourses accurately in the fog network. The GKS algorithm behavior is based on priorities and profits: the profits in this situation are based on the bandwidth and CPU utilization. IFogsim was used as a simulation tool to apply the theory, and the results show that the proposed algorithm is better than the first-come-first-served (FCFS) in terms of sensor lifetime and energy consumption. Efficient mapping for services among cloud and fog resources can play a vital role in enhancing energy consumption and response time in the environment of cloud and fog computing.

Hassan H et al. [31] proposed a new policy called MinRe for service placement problem (SPP) in the environment of cloud and fog computing. The new policy classifies services into two main categories critical and normal services. MinRes proposed to reduce the response time in the critical services, and MinEng proposed to minimise the power consumption in the fog environment. The simulation results show that the new policy enhanced the energy consumption, deadline of services and average response time by up to 18%, 14% and 10%, respectively.

4 Energy Efficiency in the Smart Grid in IoT Concept

In this section we review recent studies in the literature about how the effective use of smart meters and E Bills can contribute to enhancing the work process in the smart grid. Figure 5 shows how these three areas are linked.

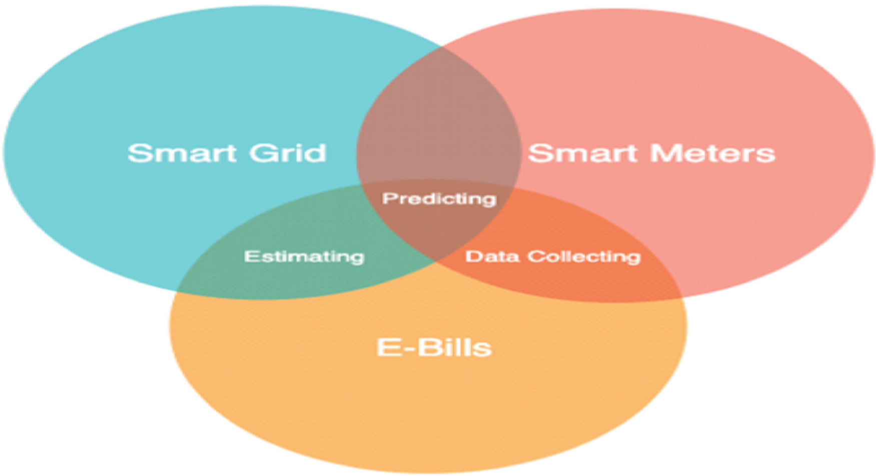

Fig. 5. Intersection of research

Smart grid (SG) has added a value to the traditional grid (TG) and can play a vital role in improving power management for distributes. SG distinguishes from the TG in many aspects. In TG, there is no direct communication between distributors and consumers; however, in SG, consumers can track and monitor electric usage in their buildings easily via smartphone apps. SG can contribute to reducing the number of operations and cost management for distributors. The main objective of the smart grid is to gather the collected data from the SG and filter these data to extract the necessary information by utilising advanced communication technologies aiming to enhance the grid performance. The most important data in the SG are the energy usage of consumers that can be collected by smart meters [32].

Electricity demand has notified a significant increase due to the massive increase in population and urbanisation. Energy monitoring systems can play an important role in saving energy and tracking the usage of electric power. IoT systems can assist developers and researchers in obtaining their objectives in reducing power consumption in buildings and industries. In [33] the authors proposed a low-cost energy monitoring system that aims to save energy by addressing the devices that consume a massive amount of power and defining the devices that can be switched off by using the MIT Platform-based App. The consumed power was calculated using Wi-Fi-enabled ESP8266, which can also identify each device in the system by IP addressing. The proposed method calculates only the energy consumption of the loads.

The cognitive IoT (CIoT) can be described as the ability of a system to make decisions based on historical data and to learn to predict upcoming events in the future. In [34] the authors proposed a smart monitoring system to monitor home appliances via the Internet. The proposed method obtains its objectives depending on three phases. A Raspberry Pi is used to read and calculate the consumed power energy for each home appliance. Google Colab is used to store the training data in order to build the TensorFlow-based Long Short-term Memory (LSTM) model. A neural network model is used to identify any abnormal energy consumption from users based on the collected data.

Effective energy management can assist distributors in predicting and estimating consumers' energy usage in the future to provide full supply for their consumers. In [35] the authors introduced a new method to predict energy usage for consumers in the future in a short period of time and send these predictions to distributors for further analysis. The proposed method is based on edge devices to collect data and then send these data to the cloud. Based on the stored data in the cloud, the authors used a deep learning framework to predict future energy usage for distributors.

5 Energy Efficiency, Application Protocols MQTT and CoAP

In this section we review recent studies in the literature about how the CoAP and MQTT applications protocols were modified to prolong the network lifetime in IoT networks. Figure 6 shows how CoAP and MQTT are separated in principle and how they are linked to the applications protocols.

The process of finding resources for CoAP applications to get frequent updates from nodes about the current reading is split into two main mechanisms: distributed and centralised resources discovery. In the former, the devices send direct queries to find a resource. In the latter, the devices process all queries through one common resource. In the centralised resources discovery, nodes require several updates about the server's

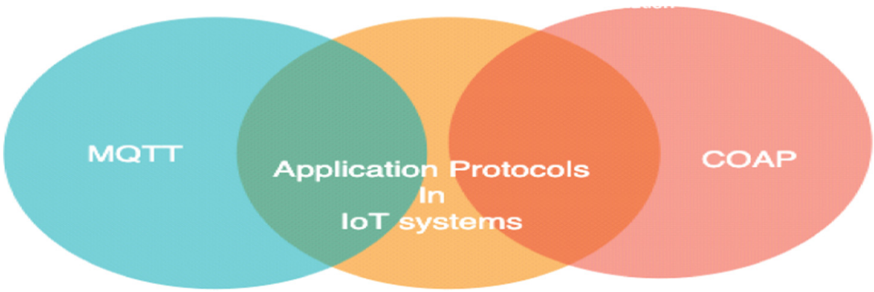

Fig. 6. Intersection of research

status, and theses updates consume power. In [36] the authors modified the standard time for nodes to update the server about the current reading, which is 10 s. The proposed method aims to prolong the network lifetime by minimising the time for nodes to update the CoAP server. Therefore, the battery level of a node is divided into four levels: High (update every 10 s), Medium (update every 20 s), Low (update every 40 s) and critical (update every 80 s). As a result, the proposed approach succeeds in prolonging the network lifetime by about 10%.

Mardini W et al. [37] modified the standard CoAP mechanism to update the CoAP server about the current reading in the centralised resource. In the standard CoAP, the nodes update the CoAP server every 10 s. However, in the proposed approach, the IoT devices send data to the server only when there is a change in the reading environment from the previous one. The simulation results showed that the proposed method enhanced the network lifetime compared to the standard CoAP protocol and the dynamic tuning approach by 33% in the former and by 8% in the latter.

Jin W et al. [38] proposed a sleep scheduling method to control the status of sleep-awake on CoAP, aiming to improve the IoT systems' energy efficiency. Moreover, the work has a slight modification in the IoT middleware layer to obtain the objective in the CoAP, using resource directory (RD) and message queue (MQ) broker to update the IoT nodes synchronicity about the sleep status. RD discovers information for the registered IoT nodes in the CoAP server. MQ acts as a chain to link the IoT nodes to the web client application using the publish-subscribe method. CoAP node can send data to the MQ and switch it to sleep mode. Then, the CoAP client can request the received data from the CoAP node to the MQ to get the data before changing the status to sleep mode. The authors have not applied any experiment in the proposed method to compare their proposed method with existing protocols.

Lai W et al. [39] proposed a method for CoAP proxies called group-based message management (GMM) to enhance the performance of sending notification from IoT devices to client devices. The proposed mechanism is based on three modules. Module1: Clustering the client devices into groups based on their demands, and each. Module2: Adjusting the range of the cache memory such that a proxy can use notifications to respond to requests. Module3: All notifications that a client device requires from different IoT nodes are combined. The simulation result showed that, by reducing the number of notifications; the proposed module improves devices' energy efficiency.

Vishakha D et al. [40] proposed a time synchronisation technique in the CoAP protocol to avoid delays between the CoAP server (node) and the CoAP client (gateway). The CoAP client updates the CoAP server about the current time, and then the time difference between the current time and then the time difference in the CoAP server is counted as a time delay. In order of avoiding the time delay, the CoAP server fills the time gap to be updated synchronously with the CoAP client by adding the time difference to the CoAP server. The authors succeeded in improving the energy efficiency of WSNs by applying the modified coap protocol compared to the standard CoAP.The authors used NS2 as a simulation tool to apply their theory.

A. Ludovici et al. [41] proposed a new approach to enhance the average delay performance, energy consumption, and delivery ratio in the CoAP application protocol. The authors applied their approach in a real wireless sensor network in an e-health app. The main point of the proposed approach is to use the priority effectively in the CoAP application protocol. There are four levels of priority and two types of notifications Critical and Non-Critical. Each level of priority requires a specific type of notification or both types. This approach succeeded in reducing server notifications to the observer, as not all levels require all types of notifications, which leads to achieving their objectives.

Randhawa R et al. [42] proposed a security protocol called Object Security of CoAP (OSCoAP) to address the issues of proxies in the IoT devices while using CoAP. Proxies are used to make the communication between clients and servers in the CoAP protocol more flexible and scalable; they work as a chain to link clients to servers for better performance. OSCoAP protects these proxies to make transmission between clients and servers more secure by encrypting and decrypting messages while exchanging data. The implementation results show that the proposed approach makes the memory more efficient, enhances the battery life by up to 30%, and makes it up to 10 times energy efficient.

Selvi M et al. [43] proposed a new protocol called EES-MQTT (Energy Efficient and Secured MQTT) to the network's quality from a security perspective. The base function of the proposed protocol is to enhance the authentication process during transmission by removing the malicious nodes. By using the MQTT.fx simulation tool and the Eclipse Paho, the experimental results showed that the energy efficiency in EES-MQTT slightly improved compared with the standard protocol MQTT. Therefore, making the IoT system more secure might be a key to save power.

Gupta S et al. [44] proposed a new schema to prolong the network lifetime in IoT systems by addressing the issue of offloading. Offloading the tasks from the gateway nodes to the cloud centre might lead to consuming more, and the proposed scheme succeeded in solving this issue compared to the existing protocols. The scheme used Message Queue Telemetry Transport (MQTT) protocol, and in this protocol, it will be able to decide to offload based on the topic classifying, which could be considered as early offloading. There are two main classifications for tasks at the topic level in MQTT. Tasks that require quick response with low computing will be offloaded to the fog nodes. Tasks that require storage and heavier computing will be offloaded to the cloud.

The number of bytes that are transmitted between IoT devices and fog nodes directly affects the energy performance in the IoT networks. Therefore, in [45] the authors proposed a data predictor in the gateway nodes built over the MQTT protocol, aiming to forecast future data to estimate the amount of required data for different IoT applications. ML algorithms are used to achieve the aforementioned goals. Theses algorithms are processed on the fog nodes when the computing level is low and, on the Cloud, when the level of computing is high, based on the IoT applications. The simulation results showed that the accuracy degree contributed to decreasing the power consumption in the IoT networks, as the data coming from the IoT is minimised accordantly in comparison with the traditional MQTT.

Schutz B et al. [46] proposed a new approach to address the gap of the packet loss in the WSNs by integrating seed-based Random Linear Network Coding with MQTT for Sensor Networks (MQTT-SN). Radio update time in the WSNs could be counted as a costly way in transmitting data, so devices try to reduce the number of radio updates to save power. This approach uses an optimization method called seed-based intrasession Network Coding to forward error correction and prolong the network lifetime by reducing radio updates. The proposed approach applied in a real agricultural scenario, and the result showed that the radio updates could be reduced up to 38.24%.

Packet loss (PL) could be counted as one of the issues that have to be addressed to enhance the performance in the IoT environment while exchanging messages in application protocols such as MQTT and CoAP.PL increases the system's workload in general and consumes more power due to data retransmission and replicating the same message until reaching the destination. PL occurs for many reasons, such as security attacks and timeout. There is a direct link between PL and energy consumption; if the PL increases, the power consumption will increase accordingly, and the opposite is true. Therefore, reducing PL in application protocols in IoT networks is a targeted point to satisfy the QoS requirements and save power [47].

Selvi M et al. [43] proposed a new protocol called EES-MQTT (Energy Efficient and Secured MQTT) to address security issues. The new approach provides better authentication servers, and it can identify intruders and remove malicious nodes. In addition to making the system more secure, the proposed method succeeds in enhancing the other three parameters, namely, Node Energy Consumption, Node Lifetime and Packet delivery ratio, compared with the standard MQTT. The secret behind this, EES-MQTT aims to reduce the number of malicious nodes to minimise their impact, resulting in better packet delivery and less dropped packets.

Researchers have verified that using security systems in the IoT environment requires additional power and increases the whole system's workload even if these systems are lightweight. Researchers aim to protect IoT devices from external attacks without consuming more power. It is vital when working on modifying security systems to minimise the power consumption to be aware that these modifications do not impact the security level. In [48] the authors the Elliptic Curve Cryptography (ECC) in the secured MQTT protocol in fog network to prolong the network lifetime by reducing the encryption energy consumption. The authors also reduce the replicated packets in the replay attacks by using the wake-up pattern to save power [48]. Based on this study and previous studies, we could say that there is a link between security levels and energy in the environment of IoT devices.

6 Conclusion and Future Work

Improving the energy efficiency of IoT devices through working directly on Watt, Joule and hardware modifications is not the only way. Additionally, it can be obtained by working deeply on various competing angels. However, to achieve more accurate results and find more gaps to address, it is vital to target one area to work on and review it deeply to avoid distractions with other areas. In this paper, we carried out a comprehensive survey on previous studies related to enhancing the energy performance of IoT systems from the four most critical angles: fog computing, clustering, and routing in WSNs, Smart grid and MQTT and CoAP application protocols. There is no doubt that there are more than these four areas. However, we limited the number of research areas to assist developers in selecting the research area that they are more interested in when aiming to promote the energy performance of IoT systems. Future studies will propose solutions for the energy inefficiency of IoT networks. Implementation tools such as Cooja and Nodejs will be used to validate the proposed solutions.

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