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Enabling Technologies on Cloud of Things for Smart Healthcare

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ABSTRACT Nowadays research is heading towards the integration of cloud computing and Internet of Things thus creating a Cloud of Things (CoT). This combination generates a new paradigm for pervasive and ubiquitous computing. However, reliable CoT-based services, particularly, highly delay-sensitive services, such as, healthcare, require energy-efficient CoT architectures. Considerable efforts have been proposed to improve the efficiency of CoT architectures. This paper analyses CoT architectures and platforms, as well as the implementation of CoT in the context of smart healthcare. Subsequently, the paper explains some related issues of CoT, including the lack of standardization. Moreover, it focuses on energy efficiency with an in depth analysis of the most relevant proposals available in the literature. An evaluation of all the energy efficiency solutions investigated in this paper shows there is still a need to improve energy efficiency, especially regarding QoS and performance.

INDEX TERMS Cloud computing, Cloud of Things, energy efficiency, Internet of Things, smart healthcare.

I. INTRODUCTION

The advancements in information and communications technology (ICT) has in recent years led the healthcare community to progressively use such technologies to enhance the quality of existing service and to reduce their costs [1]–[6]. E-Healthcare offers an excellent opportunity for patients to improve the quality of their lives by allowing them to carry on with their daily activities normally, while the physicians are monitoring them and providing them with consultation and health advice [7], [8].

Due to the rapid increasing of chronic diseases – particularly in developing countries – the use of ICT is crucial for early detection and prevention of these diseases besides reducing the expenditure on healthcare, which would protect healthcare budgets of these developing countries [8]–[10]. Community healthcare monitoring, for example, is very useful project in which an IoT-based network is established in a limited area or local community to promote healthcare services remotely to reduce the risks of chronic diseases [11]. Most of the proposed cloud-based IoT healthcare monitoring frameworks have three major components: data acquisition for using wearable sensors, data transmission which is responsible for real-time sending the captured data to the data center of the healthcare organization in a secure manner, and cloud processing for data storage, analytics, and visualization [9]. Generally, the e-Healthcare monitoring system is

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composed of: (i) Set of sensors, either smart or otherwise sensors, for capturing physiological parameters of the patients; (ii) Wireless Body Area Network (WBAN) based IoT communication to allow Machine-to-Machine (M2M) communication among Things or enabling physicians to remotely interact with medical server; (iii) Medical server on the Cloud for data storage, processing, and analytics; and (iv) Clinical stations refer to physicians (e.g., doctors) who have the ability to get information remotely from the medical server in the Cloud [12].

Nowadays, the research in this field is heading towards the integration of Cloud Computing and Internet of Things [13], [14]. This amalgamation is referred to as Cloud of Things (CoT), which is a new paradigm that exploits the integration of two different and popular technologies – the Internet of Things and the Cloud – to promote Future Internet applications [15]. Although both IoT and Cloud are two different and independent technologies, there is a need to integrate them to complement each other and be able to support pervasive and ubiquitous computing [16], [17]. Since the Things interconnected to the Internet are expected to reach 50 billion by 2020, there is a fast growing need to deal with massive amounts of data generated by these smart objects regarding storage and processing [18], [19]. CoT aims to reveal Things as a service through APIs, and make them available to other IoT applications [20], [21], which will enable those applications to exploit and deploy smart things to build smart integrated services without deploying their things as shown in FIGURE1. Reliable CoT-based services (particularly, for delay-sensitive services like e-Healthcare) require energy efficient CoT architectures. Although many solutions have been proposed for energy efficient architectures, most of them have been made on IoT and Cloud separately [18].

Highly delay-sensitive services such as healthcare services need reliable CoT architectures. Energy efficient CoT architectures can increase the Sensor Network lifetime, which improves the quality of the existing services [22].

The goal of this paper is to investigate and review the state-of-the-art of CoT and its role in providing efficient e-Healthcare monitoring services, especially regarding energy efficiency.

The main contributions of this paper are:

- Review CoT concepts, architectures, and platforms
- Explain the applications of CoT in the context of e-Healthcare, and
- Discuss and analyze the open issues in CoT with the focus on the proposed solutions in energy efficiency

The rest of the paper is organized as follows. Section II explores the background of IoT and Cloud Computing. Section III discusses Cloud of Things paradigm and its benefits. Section IV investigates the more relevant CoT architectures and platforms. Section V is about CoT for Healthcare. Section VI investigates and analyses energy efficiency proposals. Section VII, compares and discusses the energy-efficient proposals and the gaps listed here. Section VIII brings the conclusions and explains future works.

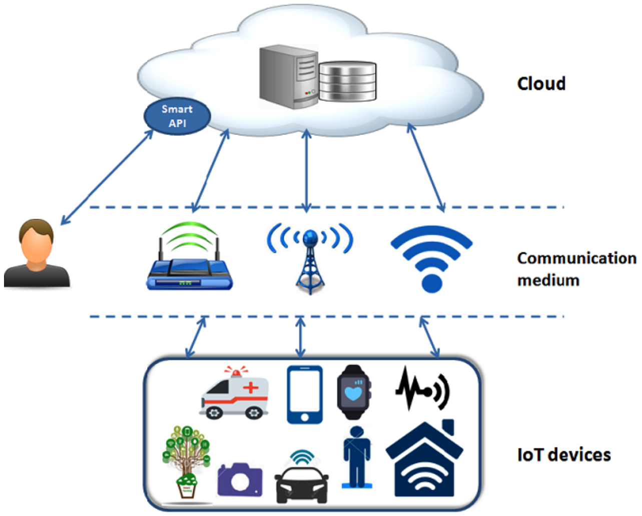

FIGURE 1. An illustration of the Cloud of Things concept.

II. BACKGROUND

The Internet of Things (IoT) is a promising and innovative paradigm in the future Internet, which deals with connecting everything (i.e., physical and virtual objects) over the Internet with sensing/actuating functions for gathering data [11], [23]. These interconnected things (smart objects) have the ability to interact with each other to perform different tasks such as sharing information, and decision coordination in a self-configurable fashion without human intervention (i.e., machine-to-machine interaction) [18], [24]–[26].

The term Internet of Things was coined by Kevin Ashton in 1999 [27], when he said: "*Internet of Things has the potential to change the world just as the Internet did, maybe even more so*". The advancements in technology made sensors smaller, cheaper and enable large scale deployment. Therefore, many sensors, that is billions, are currently deployed, and this number will multiply rapidly in the near future. The data captured by these sensors are not useful without understanding it, so context-aware computing is necessary to solve this challenge and to promote the IoT paradigm [18], [28]. IoT can be applied in many domains such as industry, environment, and society. An essential component of IoT is a sensor network (SN) which is a network of interconnected sensor nodes using either wired or wireless technology. SN represents the backbone of the IoT, i.e., it does not exist without it [28]. However, IoT devices have constrained capabilities mainly in terms of storage, processing power, and energy efficiency [29]–[31]. In order to achieve energy efficiency, a lot of interconnected devices require techniques and algorithms for enhancing node sensing processing, and sink node communication [32].

By 2020, a vast number of heterogeneous devices will be connected to our environment, which as a consequence will increase the volume of the produced data as well as the network traffic. Therefore, finding effective solutions to address

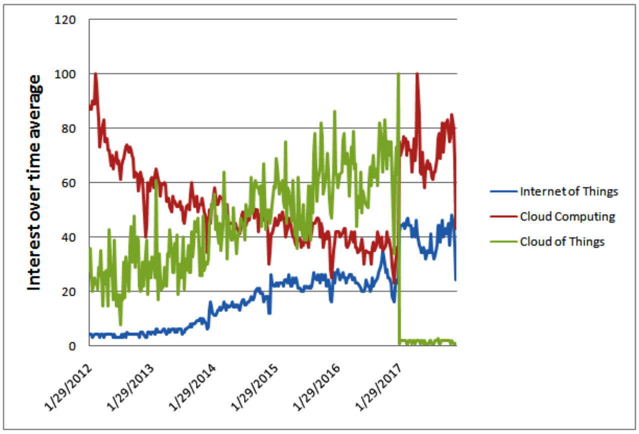

FIGURE 2. Current trend on Cloud, IoT, and CoT (source: Google Trends).

the process of collecting, analyzing, managing, and storing for such huge and diverse quantities of data is crucial [33].

In turn, the Cloud Computing (CC) is a promising paradigm for on-demand access to a shared set of resources such as networks, servers, storage, and services [19], [34]. Cloud Computing allows us to access those shared resources in an efficient and convenient manner (i.e., virtualization) without the need to maintain hardware resources [35]. Cloud Computing appears as an urgent response to addressing the shortcomings of grid computing, such as the inability of resource access and its attachment to computing and data centers [36]. Cloud preserves ubiquitous computing capabilities, especially in terms of storage and processing power [18], [34], [37]. From a complementary viewpoint, cloud computing can fulfill the main drawbacks of IoT.

These drawbacks promote the trend towards integrating IoT with Cloud, which is known as Cloud of Things (CoT) [29]. FIGURE 2 explains the concerns related to the Cloud, IoT, and CoT. Despite the great benefits of Cloud, energy efficiency represents one of the important issues that needs appropriate solutions. Providing efficient scheduling schemes of virtual machines can significantly improve the energy efficiency of Cloud data centers when dealing with resource-intensive applications [38].

III. CLOUD OF THINGS

The Cloud of Things (CoT) is a new term that was coined by some researchers to refer to the integration between the cloud and the IoT [37]. CoT paradigm aimed at bringing the IoT to the Cloud, in which, all IoT devices and capabilities can be accessed as a service through the Cloud (e.g. sensing as a service SenaaS). In CoT, Cloud acts as a middleware that makes the interaction between things and users/applications transparent (i.e., eliminates the complexity which facilitates the development of applications that deal with smart objects) [33]. Cloud can benefit IoT with its virtually unlimited storage and computing resources, whereas IoT gives the Cloud the chance of extending its services to real world things [39]. Many efforts have been made to promote the trend toward this integration. Sensor-Cloud is one of the most important of these efforts, and is about blending sensors into the data center of the cloud and providing service-oriented access to sensor data and resources [17]. Many benefits can be tangible when exploiting the integration between Cloud and IoT such as follows.

TABLE 1. Features of IoT, cloud, and CoT.

IoT	Cloud	CoT
Pervasive in terms of resources placement from anywhere	Ubiquitous in terms of accessing resources from everywhere	Pervasive and ubiquitous in terms of placement and accessing of resources
Deals with real world objects (things)	Deals with virtual resources	Deals with real-world objects as well as virtual resources
Constrained capabilities in terms of storage and computing	Virtually unlimited storage and computing capabilities	Virtually unlimited storage and computing capabilities

- Efficient storage for IoT big data by exploiting the Cloud storage nature, i.e., On-demand, virtually unlimited and low-cost [16], [34].
- Regarding computation, the integration with Cloud enhances IoT processing and computation by adding more capabilities which are not allowed at the IoT end, and energy saving by enabling task offloading [16], [34], [39], [40]. In other words, the Cloud model satisfies the processing needs of IoT through its virtually unlimited processing and on-demand usage, which enables easier real-time analysis of IoT data.
- Cloud offers an efficient and low-cost solution to enable IoT to keep track and manage objects anywhere at any time without a need to communicate through expensive dedicated hardware. Moreover, it provides an efficient solution for managing the generated data of Things [15].
- IoT has limitations in many areas such as scalability, interoperability and efficiency due to the high heterogeneity on its devices, technologies, and protocols. Cloud can facilitate the flow of IoT data collection and processing as well as ease the process of integration of new things while reducing the cost of deployment and complex data processing [15].
- In terms of scope, CoT promotes new smart services and applications that leverage the extension of Cloud through things, which opens new opportunities as well as new open issues [15], [39].

The integration of Cloud with IoT generates a new promising paradigm in which all of the Cloud and IoT characteristics are absorbed as shown in TABLE 1.

IV. CLOUD OF THINGS ARCHITECTURES AND PLATFORMS

A. ARCHITECTURES

The combination of IoT and Cloud (CoT) represent the ongoing trend for the next generation of IoT smart services. The data collected through IoT smart objects will be processed and analyzed on Cloud data centers to produce

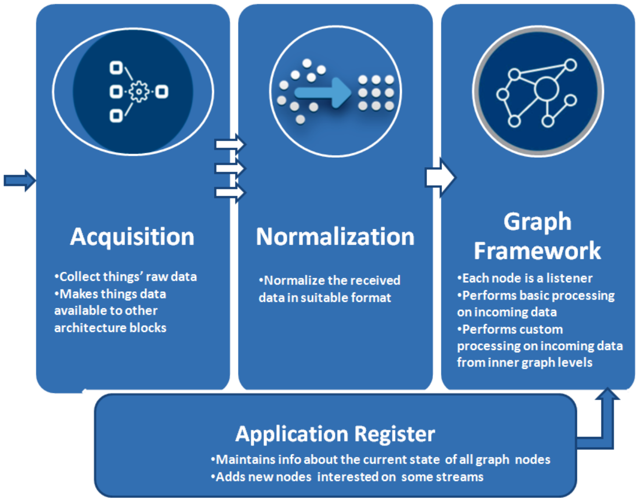

FIGURE 3. The Listener-based Graph Cloud Architecture Concept.

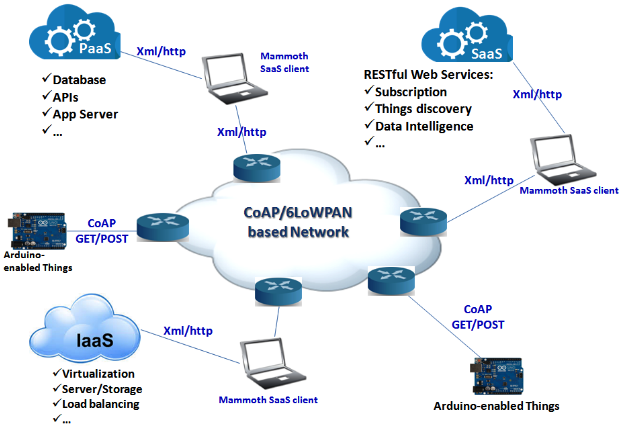

FIGURE 4. Illustration of the CloudThings architecture concept.

valuable information. However, the available Cloud architecture requires enhancements to be more efficient and convenient for IoT real-time services in terms of energy consumption and end-to-end delays. For this reason, Cloud architectures going to be distributed closer to the network edge (i.e., fog nodes, micro-cloud, and Cloudlets). Based on these distributed architectures, CoT networks can be more efficient and flexible regarding resource allocation, mobility support, low latency, reliability, and scalability [41].

Several contributions introduce new CoT-based architectures that focus on gaining the benefits of integrating the Cloud with the IoT as well as addressing the major challenges that are arising such as data transmission [33]. This subsection summarizes the more relevant of these architectures.

Belli *et al.* [42] introduced listener-based Graph Cloud architecture that intended to manage IoT Big Stream applications such as e-Health and Smart Cities. This architecture aimed at reducing data dispatching latency to consumers and enhancing resource allocation. The architecture (see FIGURE 3) composed of (i) Acquisition module, which is responsible for collecting raw data from the IoT objects and makes them available for other architecture blocks; (ii) Normalization Module, which normalizes the incoming data in a convenient format for processing; (iii) Graph Framework, which is a set of listeners represented by a node in the graph; (iv) Application Register for recording the interests of the listeners.

The architecture exploits the consumer-oriented data flow for data retrieval. The listener or consumer can determine the type of the incoming data (i.e., from Cloud service) either in a raw or processed format according to its registered interest. Furthermore, Cloud services can work as extra listeners that can be consumed by other end-users. The results show that the architecture is cost-effective for Cloud services regarding data dispatching latency and resource allocation.

In [43], an online platform architecture is proposed known as CloudThings. The architecture facilitates the development, deployment, operation, and composition of IoT applications by adapting the three Cloud models: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) as shown in FIGURE 4. These adaptations, enable users to operate IoT-based applications on Cloud hardware (through CloudThings IaaS), ease the process of application development and decrease the expenditures of management and maintenance (through CloudThing PaaS), and facilitate storing, sharing, and managing things and events (through CloudThings SaaS).

Hou *et al.* [44] proposed an IoT Cloud architecture which combined with HTTP and MQTT servers to provide services to end-users and ensure real-time communication of a lot of connected devices respectively. The architecture is composed of IoT infrastructure, IoT Cloud for virtualizing IoT infrastructure as shown in FIGURE 5. The experimental results show that the architecture improves the performance in terms of transmission latency.

B. PLATFORMS

The literature shows various efforts that have been made in order to develop a platform architecture that deals with the new Cloud of Things paradigm. These platforms, open sources or proprietary, are concerned about addressing heterogeneity issues related to both Cloud and IoT by implementing two middleware: the one on Cloud side and the other on the Things side, in addition to offering an API for interaction with applications. In this subsection, we review the most common of these platforms.

- **IoTCloud** [15] is an open source platform for integrating IoT objects with the Cloud as well as offering an API interface for applications to interact with the data of IoT objects.
- **OpenIoT** [15], [21], [42], [45] is also an open source platform that acts as middleware for deploying and managing Cloud-IoT infrastructures. OpenIoT is about providing efficient organization of data collection and transmission to the Cloud regarding mobility and energy consumption. Furthermore, it facilitates the process of handling mobile sensors and related quality of service factors. Semantic interoperability is one of the key

TABLE 2. Features and technology used in the selected CoT platforms.

Platform	Integration	Connection and data collection methods	Security techniques	Analytics types	Energy efficient?	Open source?
OpenIoT	Through REST API	X-GSN (extension of Global Sensor Networks)	oAuth 2.0	Not determined	Yes (especially in data collection)	Yes
Xively	Through REST API	MQTT, Sockets, WebSockets, and HTTP(S)	Link encryption using SSL/TLS	Not determined	No	No
NimBits	Through REST API	RESTful interfaces	oAuth 2.0 and keys	N/A	No	Yes
thingSpeak	Through REST API	HTTP and ZigBee	API keys	Allow analytics with MATLAB	No	Yes
CloudPlugs	Through REST API	PlugNet, MQTT, WebSocket. (ZigBee and Bluetooth 4 and Wi-Fi for local connections)	end-to-end security using PlugNet and SSL,	Allow analytics but unknown	Yes (reduce the communication)	No
ParStream	UDX-based API	MQTT	Unknown	Real-time and Batch analytics	Yes (uses highly parallelized hardware architecture and compressed mode)	No
EVRYTHNG	Through REST API	MQTT, CoAP, and WebSockets	Link encryption using TLS, and oAuth 2.0, token-based API keys for services interaction	Real-time analytics	Yes (through THNGHUB gateway which reduces communication latency)	No
ThingWrox	Through REST API	Two-way non-polled communications through REST API or MQTT	end-to-end security, roles for permissions	Real-time anomaly detection and predictive analytics	Unknown	No

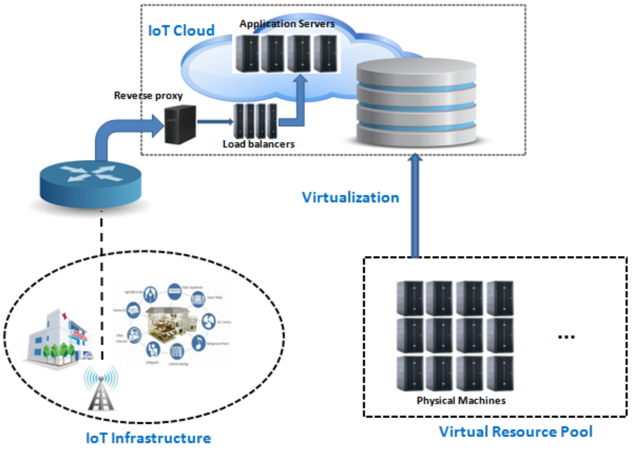

FIGURE 5. Illustration of an IoT cloud architecture.

features that distinguishes OpenIoT from other CoT platforms [46].

- **NimBits** [15], [43] is an open source platform based on a Cloud architecture that helps users deal with sensor data (i.e., record or share data) as well as enabling connection among things based on data points. With NimBits, compression and calculations can be achieved on data received from IoT devices using built-in mechanisms.

A comparison between the most relevant CoT platforms is summarized in TABLE 2.

V. CoT IN HEALTHCARE

The convergence of Cloud Computing (CC) and the Internet of Things (IoT) have significantly changed the information technology industry. On the one hand, Cloud computing has helped in constructing efficient applications regarding scalability, virtualization, reliability and cost expenses. On the other hand, IoT with its innovative elements such as RFID (Radio Frequency Identification) and sensors could be successfully helps in realizing the world objects to achieve pervasive monitoring and management in a scalable region. Currently, Cloud and IoT are extensively applied in a large number of information technology applications. However, the ongoing research in healthcare toward the combination of Cloud and IoT does not meet the requirements. Bringing this integration in the context of healthcare can significantly contribute to building efficient healthcare applications for managing and monitoring hospitals and patients in an efficient manner regarding resource sharing and cost expenditures. Based on Cloud and IoT, remote healthcare monitoring and management information services can successfully provide early detection and treatment of chronic diseases that have a significant impact on people's health. That is, IoT body sensors (i.e., implantable or wearable) gather the required information from a person, and then the information can be analyzed and processed in Cloud [47].

The use of CoT in healthcare domain offers new opportunities to medical IT infrastructure, and can enhance healthcare services [5]. Moreover, CoT improves the healthcare processes and the quality of the actual healthcare services by simplifying the process of gathering patients' vital data and delivering them to a medical center on Cloud for storage and processing purposes [15]. In other words, the use of CoT in Body Sensor Network (BSN)-based healthcare helps in the process of storing gathered data, as well as processing and analyzing them in a scalable fashion [48]. With CoT, healthcare sensors can be managed efficiently in a transparent manner as well as make any dealing with delay-sensitive healthcare services more efficient [49]. To achieve efficient healthcare services regarding delay-sensitive and energy consumption, fog computing can play a vital role by lowering the burden on Cloud as well as acting as a local storage for IoT devices and its ability to do some processing on the data [50]–[52].

Because patients' data are sensitive, regulations do not allow them to be processed outside the healthcare organization [53]. Thus, Fog Computing is required to fill this gap by bringing processing capabilities closer to the healthcare providers (e.g., hospital). By doing this, a lot of benefits can be obtained, such as reduced latency and reduced energy consumption as well as improved bandwidth usage and data privacy. By using Fog-enabled CoT, the collected sensory data can be processed and analyzed in the local gateway (smart gateway) whereas physicians are able to access the results through the Cloud remotely. Following this approach reduces data transmission and execution times as well as saves energy. The types of healthcare device used depend on the application deployment scenario. For instance, in the mobile patient monitoring deployment scenario, Smartphones can be used as a WPAN gateway for enabling direct connection to the WAN via cellular networks. In this scenario, the sensor devices, i.e., wearable or implantable, communicate with the WPAN through the gateway (i.e., the Smartphone). The connectivity of healthcare devices with the Cloud also depends on the healthcare application deployment scenario. For example, some scenarios may connect directly to the WLAN via WiFi communication while in others it may connected using WPAN via Bluetooth [53].

Besides the recognition and detection of patients' state changes, smartphone-based gateways can successfully offer transparent communication among IoT devices and the Internet as well as IoT devices management. For instance, work [54] proposed a high-level design of a smartphone-centric opportunistic gateway architecture to support flexible and transparent interoperability.

Due to the increased rate of chronic diseases in both developed and developing countries, the concern about developing healthcare projects based on ICT technologies for providing healthcare service has grown. For instance, Virtual Cloud Carer (VCC) [52] is a CoT-based project funded by Spanish National R&D intended to provide innovative healthcare services for dependent and elderly people with chronic diseases. By using CoT, the VCC project aims to gain social and technological objectives that enhance the quality of the new services being offered to the elderly. These objectives range from creating platform architecture – that is responsible for gathering physiological parameters of the elderly from anywhere and deploy them to the Cloud for storage and processing purposes – to helping the elderly do their physical training exercises and to support caregivers to track and monitor the elderly remotely in an efficient manner.

In [47], another CoT-based architecture model for remote monitoring and managing health was proposed. The proposed architecture aimed to provide effective healthcare monitoring and management along with improved performance and energy consumption. To reach this goal, the architecture proposed an algorithm (PSOSAA) based on the combination of two algorithms: the particle swarm optimization (PSO) and simulated annealing (SA). The simulation results showed the efficiency of the proposed algorithm in terms of energy efficiency and performance when compared with PSO and SA applied separately.

Gia *et al.* [31] proposed an improved CoT-based healthcare monitoring system. The proposed system is based on a smart gateway which takes advantage of Fog Computing. It is clear that Fog in association with Cloud can improve the IoT-based applications/services regarding latency, location awareness, interoperability, and scalability. The proposed system is experimented on an ECG signals and the results reveal the role of Fog in providing an efficient healthcare monitoring system, in terms of bandwidth and low-latency by moving most of the processes to the network edge.

Although BSNs are intended to monitor the human body activities and capture vital signs, they cannot efficiently accomplish all these tasks due to their constrained resources. To address this, new infrastructures that integrate between BSNs and the Cloud are proposed and referred to as Cloud-Assisted Body Area Networks (CABAN) [55]. With CABAN, BSN tasks can be achieved efficiently in terms of interoperability, scalability (in processing, data collection, and data storage), and ubiquitous access to resources. For instance, work [56], proposed a novel general-purpose system architecture, named BodyCloud, that exploits the combination of BSN and the Cloud to provision BSN-based applications as services such as storage, processing, and management of sensor data streams. To achieve these goals, BodyCloud uses four decentralized parts: (i) Body: uses mobile devices to send the data captured, by wearable sensors, to the Cloud. (ii) Cloud: the core part which is responsible for providing a full support for particular applications from data collection to visualization.(iii) Viewer which enables advanced visualization of analysis results in a Web browser. (iv) Analyst: helps in developing BodyCloud-based applications. With BodyCloud, fast prototyping scalable, customizable, and interoperable Cloud-enabled BSN applications can be accomplished.

Also, in [57], a framework, named Activity-aaService, built on top of the BodyCloud architecture [56] is proposed to enable online/offline monitoring and recognition of individuals or communities activity (even in mobility). By taking the advantages of BodyCloud, Activity-aaService can allow a flexible creation of rapid prototyping activity-assisted applications. The evaluation of Activity-aaService is taken to measure the performance of high- and low-profile BSN coordinator devices in the Body-side only of BodyCloud platform. The results showed the efficiency of high-profile devices in terms of interoperability and reliability, while low-profile devices are not appropriate in the case of computation-intensive tasks.

SPHERE (Sensor Platform for Healthcare in a Residential Environment) Project [59] is a healthcare platform designed for monitoring and tracking patients at home (AAL). It improves healthcare detection and management through the use of valuable datasets that were extracted from the data gathered by the sensors. The SPHERE project architecture employs a cluster-based approach that is composed by (*i*) Ambient sensor network for gathering data of the patient, (*ii*) Home gateway for collecting data gathered by each sensor cluster besides supporting time synchronization and data privacy, and (*iii*) SPHERE data hub for storing the collected data in the home gateway, in addition, to supporting analytics. SPHERE project concerns about supporting the healthcare community with a rich dataset that supports in enhancing the field of healthcare.

Most of the current efforts in healthcare [60]–[62], try to integrate Fog, IoT, and Cloud together and to gain the advantages of Fog such as low-latency and mobility support to improve the performance of the actual healthcare services. The combination of these technologies creates more efficient healthcare system architecture as explained in FIGURE 6.

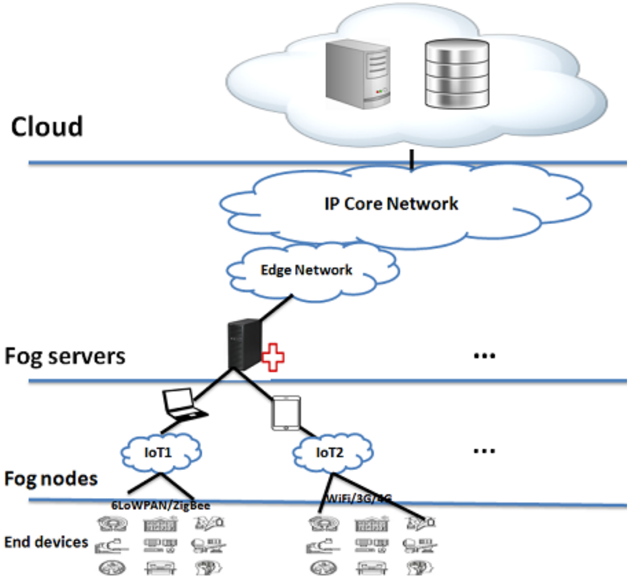

FIGURE 6. Illustration of IoT, Fog, and Cloud integration architecture.

VI. ENERGY EFFICIENCY

Energy efficiency represents one of the key issues that affect IoT services availability, reliability, and quality of service (QoS). This section summarizes the proposed solutions regarding energy efficiency.

Petrolo *et al.* [63] introduced a gateway architecture for Cloud of Things based on lightweight virtualization technologies. The gateway can manage Things and works as a middleware between real-time data and consumer applications. Furthermore, the gateway uses prediction algorithms on data production to eliminate unnecessary communications between the gateway and Things, which reduces energy consumption. The results show that leveraging the combination of these technologies enhances service deployment, service management, and resource allocation. However, this gateway still needs further adoptions in prediction algorithms on data production to decrease the communication between the gateway and Things.

In [22], an energy-efficient scheme based upon distributed cluster computing is presented. By using a suitable routing structure, the scheme improves energy efficiency and increase the network lifetime by decreasing data transmission distance amongst sensor nodes (things). Typically, the operation has two phases, the setup and the steady-state. The setup phase is responsible for creating the cluster routing structure and selection of one node to act as the cluster head node (CH) according to the calculated center of gravity among the cluster nodes. In the steady-state phase, the CH node compresses the received data, i.e., from non-CH nodes, into a unique signal by performing signal processing. Subsequently, i.e., after data compression, the CH node sends the signal to the base station (BS). Obviously, compressing the data in the CH node reduces the amount of information transmitted. The scheme repeats these two phases for each round. The simulation results show the suitability of the scheme in gaining acceptable performance in terms of energy efficiency and network lifetime in wireless sensor networks and large-scale IoT-based systems. However, the main drawback of this scheme is the additional overhead in cluster head node selection.

An energy-efficient architecture for IoT is proposed in [64]. By using a sleep mode, the architecture reduces the energy consumption based on switching sensors to sleep mode according to three cases: i) the necessity of sensing a targeted environment in a specific interval of time; ii) when the coverage area size exceeds the battery power, and iii) the battery level situation. Accordingly, whenever sensors switched to sleep mode, all the allocated cloud resources related to them are re-provisioned. Principally, the architecture design focuses on improving energy efficiency along the processes of sensing and transmission, extracting meaningful information from sensed data, and using the extracted data in a specific field. The results show that the proposed architecture is energy-efficient, scalable, and has proper performance when compared with other relevant schemes.

Mohsen Nia *et al.* [65] introduced an energy-efficient scheme for long-term continuous personal health monitoring. Initially, the authors specified the requirements of the process of continuous personal health monitoring, by determining a sample resolution on each sensor. Subsequently, they proposed a CS-based (Compressive Sampling) scheme that composes of data collection, data transmission, and storage mechanisms. The results show the energy efficiency of the scheme. However, the scheme does not take into account the advantage of efficient storage and processing of the Cloud.

In [66], Mangali and Kota proposed a cluster-based scheme for e-health monitoring. This scheme divided the Whole wireless sensor network into Clusters including cluster-head and body-head nodes for routing data amongst them. Moreover, particular tasks could be assigned to cluster heads and to body heads, which significantly improve the efficiency of the whole monitoring system regarding scalability and energy efficiency. The results of the mathematical analysis show the energy efficiency of the scheme besides increasing the network lifetime. However, the scheme focuses only on lowering energy consumption in the WSN part and ignores the Cloud part which affects energy consumption significantly.

Granados *et al.* [67] proposed an IoT healthcare architecture based on a smart gateway that uses the Power over Ethernet (PoE) standard. By taking advantage of the PoE cable, the smart gateway can effectively transmit the data as well as supply IoT-enabled devices with power. Furthermore, the gateway can connect IoT medical sensors with the Cloud and process the gathered health data, which reduces the burden on IoT sensors. The results show that the gateway is an energy-efficient and cost-effective solution for healthcare. However, the gateway is efficient in the case of wired sensors and fixed scenarios, therefore, it needs further modifications to be suitable for wireless sensors and unfixed scenarios.

In [68], Gia *et al.* discussed the role of effective customization of 6LoWPAN (IPV6 over low power wireless area networks) in gaining energy efficiency and reliable IoT-based e-Health applications. With this architecture, patients' physiological data, such as ECG signals can be monitored, analyzed and transmitted in an efficient manner through the customized 6LoWPAN. Typically, the architecture composed of the customized 6LoWPAN network intended to deal with health data, a gateway for routing generated packets of Things to a remote server on the Internet based on tunneling, and a WebSocket server for analyzing health data in the Cloud. The experimental results show the efficiency of the proposed architecture regarding energy consumption, effectiveness and quality of service for IoT-based healthcare applications. However, it needs further improvements for data filtering and compression in the IoT part to gain better energy efficiency.

Rault *et al.* [69] proposed an energy-efficient scheme for monitoring patients' health. The scheme focuses on reducing energy consumption at both the sensors and the users' mobile phones by using ZigBee and Bluetooth communications. Regularly, the sensors, select the suitable communication interface (i.e., either ZigBee or Bluetooth). If ZigBee interface is selected, then Bluetooth interface is switched off on the mobile phone side, which saves its energy. Meanwhile, the mobile phone runs Bluetooth scan regularly to detect sensors that need to communicate with it when there is no ZigBee communication. The simulation results show that the scheme improves energy efficiency without negatively affecting the performance. However, the scheme did not consider the communication with the Cloud, which also needs more solutions to achieve better energy efficiency and performance.

In [70], a novel framework based on auto-configuration for Cloud-based IoT platforms is proposed. In fact, the framework benefits from the integration of system parameters, power consumption, in addition to auto-configuration algorithms. The results show the efficiency of the framework in terms of performance and energy consumption. However, the framework focuses only on using auto-configurations and other issues that affect energy consumption such as data transmission are not considered.

Li *et al.* [71] proposed three-tier system architecture that composed of Things Tier, Fog Tier, and Cloud Tier. The Fog Tier is responsible for bringing processing and storage near to the IoT edge which reduces the communication overhead. Generally, the architecture aims to decrease the transmission latency, and bandwidth overhead by using Fog as a middleware between the Cloud and IoT. The results show the positive effect of Fog for gaining an efficient CoT system architecture regarding performance, communication latency, and energy consumption.

In [72], a service-oriented TeleHealth architecture based on Fog Data is presented. The use of Fog Data simplifies the process of gathering, storing and analyzing patients' vital data. The Fog computer is responsible for analyzing and filtering – i.e., trimming unnecessary raw data – the gathered data before transmitting them to the Cloud which significantly decreases the volume of the data that has to be stored and deployed to the Cloud, and at the same time improve the energy efficiency. The experimental results show that the architecture has made substantial improvements in energy consumption by reducing the communication and the amount of data between the Fog and Cloud as well as increasing the efficiency of the overall healthcare system.

Rani *et al.* [73] proposed a novel scheme for an energy efficient IoT-based on Wireless Sensor Networks. Generally, the scheme focuses on reducing the energy consumption by leveraging the clustering concept, in which the whole network is subdivided into clusters of equal size. Direct communication with the upper cluster layers and between cluster nodes is not allowed except through cluster heads (CH) and cluster coordinators (CCO). The scheme also uses two algorithms: one for conserving energy by orchestrating the communication between the CCOs, and the other for optimizing the energy parameters. In other words, the scheme focuses on reducing the communication distance amongst the IoT objects to conserve energy, so the network lifetime is increased. The simulation results show that the scheme is a scalable and more energy efficient than the more popular schemes such as LEACH, SEP, and MODLEACH. However, the scheme requires further improvements in data transmission techniques and end-to-end delay so as to achieve greater efficiency.

Huang *et al.* [74] introduced an energy-efficient deployment scheme for placing wireless sensor nodes (i.e., Things) in IoT. In this scheme, an algorithm for energy optimization is proposed based on the clustering concept and Steiner tree algorithm. The scheme increases the network lifetime by moving the burden of direct communication to the relay nodes instead of sensing nodes. The results of the experiment reveal that the scheme is preferable to achieve green IoT deployment regarding network lifetime and energy consumption. However, the scheme ignores the application of compressed sensing approaches in gaining more energy efficiency, so further improvements are required.

Abedin *et al.* [75] presented a system model for energy-efficient communications among IoT objects. The proposed system model employs the Cloud for IoT services deployment. Furthermore, the system model includes an energy efficient algorithm based on scheduling the activities of IoT sensors by using three major phases. The on-duty phase, in which the sensor works with its full capability, the pre-off duty phase to switch between on-duty and off-duty phases, and the off-duty phase, which is responsible for conserving energy based on three states: hibernate, sleep, and power off. The experimental results in a real IoT test-bed environment showed the efficiency of the system model regarding energy consumption and performance. However, the system model does not consider data transmission between sensors and the Cloud. Thus, further improvements are required, such as integration with Fog for more energy efficiency.

Mao *et al.* [76] proposed a novel cluster-based approach known as EECS for saving energy and extends the wireless network lifetime. The EECS scheme increases energy efficiency during data gathering applications at regular intervals of time by selecting nodes with more remaining energy as cluster heads in a way that ensures optimal distribution of cluster heads. Furthermore, the EECS has a novel method for load balancing between the cluster heads. The simulation results show that EECS scheme prolongs the network lifetime by more than 35% when compared with LEACH.

In [77], Mehmood *et al.* introduced a cluster-based mechanism, called EEMDC (energy-efficient multi-level and distance-aware clustering), for conserving energy in WSN. EEMDC divides the WSN region into three layers in a hierarchical structure according to the count-hop based distance from the base station. In EEMDC, idle listening is required due to the implementation of the levels in the clustering, thus, the cluster nodes turn to the active mode only when the control arrives at its level. The simulation results show that EEMDC is energy-efficient and it consumes less energy than other common cluster-based communication schemes (e. g. LEACH, MTE, and DDAR).

In [78], an approach for increasing energy efficiency based on level-k clustering hierarchy and single-hop communication (i.e., link-correlation) among nodes within the cluster is proposed. In this approach, the level-k cluster represents the top level while $\{k-1, k-2, \ldots, -2\}$ represent the clusters of the underneath levels. Moreover, each node communicates with the corresponding cluster head that lies on the upper level in the hierarchy by using single-hop communication, while the cluster heads in level-k communicate through multi-hop communication. The proposed approach solves the problem of the bottleneck zone, the nodes that surround the sink node, thus they consume the energy due to their heavy traffic by letting these nodes create the level-k cluster head. The level-k cluster head represents the TDMA (Time Division Multiple Access) time slots for the corresponding level k-1 and likewise for the following levels of the cluster hierarchy. The TDMA technique helps create an organized cluster-based architecture which enhances the energy efficiency. The simulation results show the efficiency of this approach compared with LEACH, SEP, and DEEC in terms of stability, message delivery, and network lifetime. However, this approach works properly only in medium-sized WSN, so further improvements are required to be suitable for large-sized WSN as well as when integrating IoT-based WSN with the Cloud.

Tang *et al.* [79] introduced a novel scheme for efficient data collection and aggregation called ECH-tree (Energy-efficient Hierarchical Clustering index tree). In general, ECH-tree splits the domain of the sensor network into even cell grids. Subsequently, the cell grids are clustered into sub-domains, which minimize the message broadcasting distance amongst them, and as a consequence reduce the energy consumption. Furthermore, the ECH-tree scheme contains a time-correlated querying method which answers end-user queries in a reduced power consumption manner. Moreover, ECH-tree eliminates data redundancy by changing the sensor data based on frequent time intervals, which allow the sink node to collect the query answers from the grid cell tables immediately. The experimental results confirm the energy efficiency of the ECH-tree scheme.

In [80], a cooperative multi-hop approach for saving energy during data transmission is proposed. This approach organizes the whole sensor network into clusters that communicate with each other through multi-hop short range links, and the last cluster only communicates with the base station (BS) through a long range wireless link for conveying the aggregated multi-hop data. The simulation results show that significant energy efficiency could be attained by using an efficient multi-hop cooperation approach.

In [81], a new approach is proposed for enhancing IoT energy efficiency based on re-configuring virtual objects (VOs) at runtime. In this approach, VOs are used as an abstraction to describe the semantics of ICT objects and the related physical objects. In particular, the approach focuses on reducing energy consumption at transmission time by comparing the three types of compression modes, i.e., uncompressed, lossy, and lossless. The experimental results on sample data captured from wireless weather stations show the ability of this approach to reducing the total energy consumption by up to 47.9% when changing the compression mode from uncompressed to lossy at runtime. However, this approach increases the latency of the provisioned service which affects the performance negatively.

A new method that improves the network lifetime using mobile sink nodes combined with the traveling salesman problem (TSP) algorithm is proposed in [82]. In this method, the hotspot problem is solved, which consumed the energy of the sensor nodes that surrounded the sink, especially when using multi-hop communication because they act as a sensor and relay nodes at the same time, so the whole network collapses. By using a mobile sink with one hop communication, the transmission times can be reduced due to the wide range of coverage by each node. The simulation results show the efficiency of this method in improving the network lifetime and the energy efficiency of relay nodes.

In [83], an energy-efficient modified election-based Protocol (MEP) is proposed to increase the network lifetime. With MEP, sink nodes have the ability to decide which sensor nodes can represent the cluster heads (CHs) according to their additional energy, the remaining energy, and the node location. Besides, the CHs communicate with sink using the shortest path based on a congested link. Moreover, MEP is concerned by addressing the trade-off between energy efficiency and the QoS requirements. The simulation results show that MEP ensures energy-efficient routing in WSN as well as extending the network lifetime. However, further improvements are still required to gain energy efficiency in the whole IoT network regarding data transmission and processing.

Although there are different viewpoints about the energy consumption of Fog computing, the energy consumption of Cloud data centers can be reduced by using nano data centers (nDC) in Fog, especially in IoT applications [84]. Based on this, Jalali *et al.* [84] proposed two models, a flow-based and time-based model for shared and unshared network resources, respectively, after identifying the more exact scenarios for achieving better energy efficiency when using nDC in Fog rather than centralized DC. The experimental results revealed that nDC can help in achieving energy efficiency, according to the arguments of the designed system such as the type of applications and the amount of data preloading. However, this solution only works properly in specific applications such as in video surveillance where the number of accesses to nDC is not enormous.

In [41], Barcelo *et al.* propose a mathematical network and service models for optimizing the distribution of CoT-based services. The simulation results show the efficiency of this model for providing efficient IoT smart services in terms of low latency, flexibility, reliability and reducing the overall energy consumption by more than 80% when compared with other relevant proposals.

In [85], an approach for reducing data transmission time and size in IoT-based WSN is introduced. The approach benefits from the fact that in WSN, data transmission degrades energy efficiency more than performing instructions. To overcome this situation, the authors proposed a method to control the transmit (ON/OFF) radio frequency (RF) according to the current and last state values. Furthermore, an algorithm based on the relative differences between (single or multiple) current and last gathered value of sensors is proposed for minimizing the number of data packets transmitted. The simulation results showed that the efficiency of this approach to improve the performance and reduce the energy consumption as well as extend the network lifetime.

The work [86] proposed a container-based layered architecture, namely CoESMS, for the management of services at the Fog level. The primary objective is to increase the energy efficiency of the Fog nano data centers (nDC) by efficiently scheduling tasks on containers as well as migrating containers when desirable. To achieve this objective, the authors used two concepts, containers and game theory. Containers are distributed among various VMs, and tasks are scheduled to the appropriate containers based on the cooperative game theory. In this scheme, service tasks are scheduled on containers at Fog if they are marked as real-time tasks and if there are an adequate number of containers for processing. Further, to minimize energy consumption, internal and external migration of containers is accomplished when the upper or lower thresholds are violated. Compared to a container-based scheme that does not use CoESMS, the results showed that this scheme significantly reduces the energy consumption of nDC, and it ensures an acceptable service level agreement (SLA) to users.

Service composition is a concept that deals with integrating a number of services to fulfill a user's or application's request when a single service is not adequate to accomplish the job. However, the exchange of large amounts of data between these services has a negative impact on energy efficiency. To mitigate this, Baker *et al.* [87] proposed an energy-aware service composition algorithm, E2C2, to select the optimal plan which has the least energy consumption without violating the user service level agreement (SLA). The algorithm focuses on finding the plan with the fewer services composition in order to minimize data transmission in a multi-cloud environment. Compared with other algorithms, such as All Clouds, the experimental results showed the efficiency of E2C2 in terms of energy consumption and performance.

All of the solutions mentioned above to improve the energy efficiency issue are summarized in TABLE 3.

VII. DISCUSSION AND OPEN ISSUES

Although CoT paradigm offers new opportunities for IoT-based smart services, several new challenges or open issues have arisen. The most important issues as explained in [15], [21], and [33] are energy efficiency, the lack of standardization (for architecture as well as data and services), efficient big data management and analytics, security and privacy, Fog computing, scalability, and mobility support. However, this paper mainly focuses on the energy efficiency, so all of the remaining issues will be explained in brief.

TABLE 3. Summary of the most relevant proposals regarding energy efficiency.

Reference	Method	Description	Benefits	Limitation
Petrolo et al. [63]	Gateway architecture	The gateway is based on the combination of virtualization technologies and prediction algorithms on data production	Energy efficient and enhanced CoT-based service deployment, management, and allocation	Further adoptions in prediction algorithms on data production to decrease the communication among the gateway and Things are needed
Chang et al. [22]	Distributed cluster-based scheme	The scheme utilizes the concept of distributed clusters to increase the network lifetime by reducing the data transmission distance among sensor nodes	Improving energy efficiency, network lifetime, and performance	Additional overhead in cluster head (CH) node selection. Did not consider communication with the Cloud.
Kaur et al. [64]	Energy-efficient architecture for IoT	Architecture focuses on reducing energy consumption on IoT by using efficient sleep mode	Energy-efficient IoT regarding sensing, transmission, analytics, and sharing info with apps.	Further adoptions are needed to address downstream traffic scheduling issue which degrades user service.
Mohsen Nia et al. [65]	Energy-efficient scheme for health monitoring	The scheme is based upon compressive sampling for efficient continuous personal health monitoring	Energy efficiency in data collection, transmission, and storage	The scheme did not consider the Cloud side, so further adoptions are needed
Mangali et al. [66]	Energy-efficient scheme for eHealth monitoring	Cluster-based scheme, in which WSN is divided into clusters, each cluster has a cluster head for routing and executing specific tasks.	Energy efficiency and increases the WSN lifetime	The scheme ignores the Cloud side which is also affects power consumption negatively, so further adoptions are needed
Granados et al. [67]	IoT Healthcare architecture	The architecture is based on smart gateways that use thePower over Ethernet (PoE) standard for effective data transmission and to supply IoT sensors with power	Energy-efficient solution for healthcare and improves the performance by moving the process from IoT sensors to the Cloud via the smart gateway	Efficient only in the case of wired sensors and fixed scenarios, so it needs further modification to be suitable for wireless sensors and unfixed scenarios
Gia et al. [68]	IoT eHealth architecture based on customized 6LoWPAN	The architecture benefits from the effective customization of 6LoWPAN for improving the energy efficiency and reliability of IoT-based eHealth applications	Efficient regarding energy consumption, effectiveness, and QoS	It needs further improvements regarding data filtering and compression in the IoT part to gain better energy efficiency
Rault et al. [69]	Health monitoring scheme based on ZigBee and Bluetooth	The scheme focuses on reducing energy consumption at both sensors and user mobile phones, by using ZigBee and Bluetooth communications	Improves energy efficiency without negatively affecting the performance	It ignores the communication with the Cloud which also needs more solutions to achieve better energy efficiency and performance
Papageorgiou et al. [70]	A novel framework based on efficient auto-configuration for Cloud-based IoT platforms	The framework benefits from the integration of system parameters, power consumption, in addition to auto-configuration algorithms	The framework is efficient regarding energy consumption and performance	It only focuses on exploiting efficient auto-configurations, and other issues that affect energy consumption such as data transmission were not consider
Li et al. [71]	Three-tier CoT system architecture	The architecture aimed to decrease the transmission latency and bandwidth overhead by using Fog as a middleware between the Cloud and IoT	Significant efficiency regarding performance, communication latency, and energy consumption.	It focuses only on reducing communication overhead and ignores the process of data collection in the IoT part
Dubey et al. [72]	Service-oriented TeleHealth architecture based on Fog Data	Uses Fog Data to simplify the process of gathering, storing and analysis of patients' vital data	Substantial improvements in energy consumption by reducing the communication and the amount of data between the Fog and Cloud. Increases the efficiency of the overall healthcare system	Further improvements in the IoT-tier are required
S. Rani et al. [73]	A novel cluster-based scheme for energy efficient IoT	Subdivides the IoT network into equal size clusters. Then, uses two algorithms to orchestrate CCO communications and optimize the energy efficiency parameters	Provides scalability and energy efficiency	Further improvements in data transmission and end-to-end delay to increase energy efficiency
J. Huang et al. [74]	Energy-efficient deployment scheme	Scheme for placing wireless sensor nodes in IoT based upon algorithm for energy optimization	Provides green IoT regarding network lifetime and energy efficiency	Did not consider applying compressed sensing approaches for more energy efficiency

TABLE 3. ***(Continued.)*** **Summary of the most relevant proposals regarding energy efficiency.**

S. F. Abedin et al. [75]	System model for energy efficient communications among IoT objects	Exploits the Cloud for IoT services deployment. Besides using algorithms to schedule IoT sensor activities to save energy	Improves energy efficiency and performance	Further improvements in data transmission between IoT sensors and the Cloud
M. Ye et al. [76]	A novel cluster-based scheme EECS	Selects CHs according to the remaining energy and ensures optimal distribution for CHs and load balancing amongst them	Prolongs the network lifetime	Did not consider the communication with the Cloud
A. Mehmood et al. [77]	Cluster-based Approach EEMDC	Conserves energy efficiency in WSN by dividing it into three hierarchical layers based on the count-hop	More energy efficient than cluster-based communication schemes	Did not consider the communication with the Cloud
N. G. Praveena and H. Prabha [78]	Level-k Clustering based energy efficiency scheme	Uses level-k clustering hierarchy besides single-hop communication among nodes in the cluster and multi-hop communication among CHs in level-k	Efficient regarding stability, message delivery, and network lifetime	Works properly in medium-sized WSN and requires integration with the Cloud
J. Tang et al. [79]	Novel scheme (ECH-tree) for data aggregation and collection	Minimizes the message broadcasting distance by splitting the SN into clustered sub-domains	Reduces energy consumption and eliminates data redundancy	Did not consider the scenario of integration with the Cloud
E. Yaacoub et al. [80]	Cooperative multi-hop approach	Organizes SN into clusters that communicate via multi-hop short-link range and the last cluster communicates with sink through a long range wireless link	Provides significant energy efficiency	Did not consider the scenario of integration with the Cloud
M. Eteläperä [81]	A new approach for enhancing IoT's energy efficiency	Approach based on re-configuring virtual objects at runtime and focuses on reducing energy at transmission time	Reduces energy consumption up to 47.9%	Increases latency which degrades the performance
J. Kim and J. Lee [82]	A new approach for increasing network lifetime	Uses mobile sink nodes combined with a TSP algorithm	Improves network lifetime and energy efficiency of relay nodes	Did not consider the scenario of integration with the Cloud
N. R. W. Prof and D. N. Choudhari [83]	An energy-efficient modified election-based Protocol (MEP)	MEP allows sink nodes to choose the CHs according to specific criteria. Also, sink nodes communicate with CHs using the shortest path	Energy efficient routing in WSN, increases network lifetime	Further improvements to gain energy efficiency in the whole IoT network regarding data transmission and processing
F. Jalali et al. [84]	A Fog-based approach for reducing energy consumption of Cloud data centers	Utilizes nano data centers in Fog by exploiting flow-based and time-based models	Achieves energy efficiency at centralized DCs according to some criteria of the designed system	Only works properly in specific applications or services
M. Barcelo et al. [41]	A mathematical network and service models	Mathematical models to solve service distribution problem based on linear programming	Efficient services regarding low-latency, reliability, flexibility, and reduces the overall energy consumption	Further improvements are required such as computational complexity issues
Alduais, N A M; et al. [85]	A method for reducing number of packet transmissions and their size in IoT-based WSN	An approach based on relative differences among current sensors values and last gathered values to switch RF transmit to ON/OFF	Improves energy efficiency and performance as well as network lifetime	Did not consider data transmission to the Cloud
K. Kaur et al. [86]	A container-based layered architecture (CoESMS)	An architecture to manage services at the Fog level by using efficient task scheduling based on game theory	Increases energy efficiency at Fog nano datacenters. Acceptable Service Level Agreement (SLA) to users	
T. Baker et al. [87]	An energy-aware service composition algorithm (E2C2)	The algorithm selects the optimal plan which has the least energy consumption without violating the user's service level agreement.	Efficient in terms of energy consumption and performance	

TABLE 4. A comparison among the available energy efficiency proposals.

Reference	Used techniques	Scheme place	Renewable energy	Traffic overhead	Performance	Scalability	QoS
Petrolo et al. [63]	Virtualization technologies, and prediction algorithms	Gateway	No	No	Acceptable	Yes	Yes
Chang et al. [22]	Distributed clustering, and Data compression	WSN	No	No	Acceptable with small overhead	Yes	Yes
Kaur et al. [64]	Sleep mode	IoT sensors	No	No	Acceptable	Yes	Low, so further adoptions are needed.
Mohsen Nia et al. [65]	Compressive sampling	WBAN	No	No	Acceptable	Yes	Low
Mangali et al. [66]	Clustering	WSN	No	No	Acceptable	Yes	Low
Granados et al. [67]	Power over Ethernet	Gateway	No	No	Acceptable	No	Yes
Gia et al. [68]	Customized 6LoWPAN	WAN	No	No	Acceptable	Yes	Yes
Rault et al. [69]	ZigBee and Bluetooth	WAN	No	No	Acceptable	No	Yes
Papageorgiou et al. [70]	Auto-configuration algorithms	IoT platform	No	No	Acceptable	Yes	Yes
Li et al. [71]	Fog computing as a middleware tier	Whole system architecture	No	No	Very good	Yes	Yes
Dubey et al. [72]	Fog Data	Whole system architecture	No	No	Very good	Yes	Yes
S. Rani et al. [73]	Clustering and orchestration algorithms	IoT network	No	No	Acceptable	Yes	Yes
J. Huang et al. [74]	Clustering and Steiner tree algorithm	WSN	No	No	Acceptable	Yes	Yes
S. F. Abedin et al. [75]	System model with scheduling algorithms	Whole system model	No	No	Acceptable	Yes	Yes
M. Ye et al. [76]	Clustering and load balancing algorithm	Wireless network	No	No	Acceptable	Yes	Yes
A. Mehmood et al. [77]	Clustering	WSN	No	No	Acceptable	Yes	Yes
N. G. Praveena and H. Prabha [78]	Level-k Clustering and TDMA (Time Division Multiple Access) technique	WSN	No	No	Acceptable	No	Yes
J. Tang et al. [79]	Clustering index tree and time-correlated querying technique	WSN	No	No	Acceptable	Yes	Yes
E. Yaacoub et al. [80]	Cooperative multi-hop approach and clustering	WSN	No	No	Acceptable	No	Yes
M. Eteläperä [81]	Re-configuring virtual objects and compression technique	IoT network	No	No	Acceptable	No	Low
J. Kim and J. Lee [82]	Mobile sink nodes combined with traveling salesman problem (TSP) algorithm	WSN	No	No	Acceptable	Yes	Yes
N. R. W. Prof and D. N. Choudhari [83]	Election-based method for choosing the optimal sink node to be the CH node	WSN	No	No	Acceptable	Yes	Yes
F. Jalali et al. [84]	Fog computing combined with flow-based and time-based models	Fog nano datacenters	No	No	Very good	No	Yes
M. Barcelo et al. [41]	Mathematical network and service models	Network	No	No	Acceptable	Yes	Yes
Alduais, N A M; et al. [85]	A method to control radio frequency transmission and algorithm to reduce the transmitted data packets	WSN	No	No	Acceptable	Yes	Yes
K. Kaur et al. [86]	Containers migration and game theory based task scheduling	Fog level	No	No	Very good	Yes	Yes
T. Baker et al. [87]	Service composition algorithm (E2C2)	Multi-cloud environment	No	No	Acceptable	Yes	Yes

A. DISCUSSION

In this subsection, a comparison regarding the energy efficiency of the works mentioned in Section 6. TABLE 4 summarizes the comparison parameters: the techniques used, place of executing the scheme, renewable energy, traffic overhead, performance, scalability, and quality of service (QoS) for each analyzed proposal. As seen in TABLE 4, the techniques used range from clustering concept to Fog-based approaches. The recent works, such as [86] tried to tackle the service migration in an energy efficient manner at the Fog level. However, this trend is still immature and needs further research. Furthermore, the comparison of the results shows that some of the proposed solutions concerned the WSN part while the others tried to reduce the energy consumption only in Cloud datacenters. Therefore, energy-efficient schemes that increase the energy efficiency of the whole system are required. Moreover, the comparison of the results also reveals that most of the proposed approaches focused on reducing energy consumption and ignored the other important metrics, such as scalability.

In summary, all of the aforementioned schemes show the importance of energy efficiency in gaining efficient CoT-enabled services and applications regarding availability, reliability, and performance. Moreover, most of the proposals tried to tackle the energy efficiency issue only in the IoT part and ignored the communication with Cloud scenarios. Therefore, the energy efficiency issue needs further efforts, particularly in delay-sensitive services such as smart Healthcare.

B. OPEN ISSUES

1) LACK OF STANDARDIZATION

The absence of standardization is considered as one of the most critical issues that face CoT. This issue is due to the lack of standards in both IoT and Cloud computing models [88]. Indeed, the currently used web-based APIs (e.g. RESTful APIs) only facilitate the communication between the Things and Cloud, however, they are not designed to deal with M2M (machine-to-machine) interactions [15], [33]. Furthermore, the literature shows that the majority of relevant CoT-based proposals do not adhere to a unified standard in the process of development due to the lack of standardized architecture. In this context, reference architecture (RA) [15], which defines the standards and rules that developers should follow for building CoT-based solutions, can help alleviate the complexity of development. Moreover, RA can help the deployment of efficient CoT standards that are capable of supporting smart services with optimized M2M communications [33].

2) SECURITY AND PRIVACY

This issue is inherited from security and privacy in the Cloud and IoT, besides the newly arisen vulnerabilities from the integration between them. From the Cloud point of view, to obtain transparent access to stored data in Cloud requires a third-party, which represents a threat that may exploit the data for malicious purposes. Meanwhile, IoT devices implement simple security techniques due to their constrained resources, thus, they represent an easy target for intruders. These security breaches ranging from unauthorized changes of sensor data to service denial (DoS attack) [15], [33], [34], [37]. Specifically, CoT-based healthcare requires a strong protection for patient health data, which are highly sensitive. Therefore, it is important to protect health information in different layers, i.e., IoT devices layer, Network layer, and Cloud layer. In this context, using distributed security architecture with lightweight cryptography schemes may help to achieve protected health information in the IoT environment as well as Cloud [89]. Finally, security and privacy represent a continuous challenge that needs efficient solutions, in which the consumers of CoT-based services can trust, so keeping the flourish of such services.

3) BIG DATA MANAGEMENT AND ANALYTICS

Despite the ability of the Cloud to manage big data due to its virtually unlimited storage and processing capabilities, dealing with IoT generated big data still represent a challenge regarding the Cloud shortcomings in support of IoT devices. Most of the proposed solutions to tackle this issue reveal their inappropriateness regarding data handling and performance efficiency [15], [59]. Furthermore, handling a massive amount of data generated by IoT sensors in the Cloud is inconvenient regarding the constrained bandwidth, intolerable delay, and security. Therefore, efficient solutions based on innovative paradigms, e.g. Fog computing, that work in collaboration with the Cloud are necessary [91].

4) FOG COMPUTING

Although the Cloud of Things paradigm successfully solves the majority of the IoT-related issues totally or partially, there are still issues that represent a challenge, such as mobility support and low latency [21]. From this point of view, Fog Computing can effectively help to meet such requirements [21], [92]. In fact, Fog Computing is an innovative and distributed computing model, through which all the smart services are executed at the network edge. In Fog Computing, edge devices (Fog nodes) are equipped with more storage and processing capabilities, besides functionalities such as edge analytics [92]. However, there are several issues with the IoT, Fog, and Cloud layered architecture (i.e., three-tier CoT architecture) regarding optimized scheduling, fog networking management, security and privacy [93], [94].

5) QUALITY OF SERVICE ASSURANCE

Ensuring an acceptable level of QoS for CoT-based applications is still challenging due to the combination of different and heterogeneous technologies. To achieve QoS, it is crucial to precisely identify the QoS metrics at each CoT layer. Furthermore, CoT-based real-time applications/services require end-to-end QoS. Therefore, QoS-aware

CoT architecture represents an open issue that needs efficient solutions [15], [37], [95].

6) UNPREDICTABLE LATENCY

Unpredictable latency is one of the most significant challenges, that is, intolerable for delay-sensitive services, e.g. healthcare, that require timely response [96]. In fact, this latency appears due to the massive communications with the Cloud for data storage or processing purposes. Moreover, the latency also has a negative impact on QoS. To address this issue, Gia *et al.* [31] and Luo and Ren [47] proposed to exploit the strategic position of smart gateways by integrating them with Fog paradigm, in order to provide end users with services at the network edge. Finally, Fog proved its suitability in solving latency, however, additional efforts are required to carry out a performance evaluation of the whole Fog-enabled smart gateway CoT system model.

7) ENERGY EFFICIENCY

Energy efficiency is a great concern, especially in smart things and data centers, due to its negative effect on quality of service (QoS), operating costs, and the environment [9], [97]. For such reasons, effective solutions that minimize energy consumption in both data centers and Things as much as possible are required. Furthermore, reducing the communication (i.e., trimming unnecessary communication) and data transmission between Things and Cloud datacenters can lower energy consumption significantly [22], [97]. Effective scheduling techniques can also be utilized to achieve energy efficient IoT's communications [98]. Some solutions mentioned that effective sleep mode implementation, besides using a smart gateway that utilizes Fog computing to bring Cloud resources near to IoT objects, can enhance energy efficiency [13]. In this context, Fog is used to store Things data, whereas the gateway decides either to submit data to the Cloud or not according to the acknowledgment of the consumer application or service [13], [49]. In addition, heavyweight security schemes for authentication, Key establishment and distribution have a significant impact on energy consumption of IoT resource-constrained devices, so lightweight security schemes are required [99]. Furthermore, game theory can be used as a mechanism for analyzing WSN, in the case of the interaction between wireless sensor nodes with the competitive nature for acquiring the constrained network resources. With various types of models (i.e., non-cooperative games and cooperative-enforcement games), game theory can efficiently reduce the consumed energy of data aggregation processes without affecting the network lifetime negatively [100]. However, energy efficiency is still an open challenge that needs further research.

VIII. CONCLUSION AND FUTURE WORKS

Currently, Cloud and IoT are extensively applied in several information technology applications such as healthcare and smart cities. However, reliable CoT-based services – particularly, highly delay-sensitive services such as Healthcare – require energy-efficient CoT architectures. This paper surveyed CoT architectures, platforms, and their implementation in Healthcare. Furthermore, the paper explained the CoT related issues, in brief, since it mainly investigated the energy efficiency issues with the more relevant proposals in detail. This investigation showed that the majority of the proposals were not concerned about energy efficiency when dealing with IoT Cloud scenarios. Therefore, efficient solutions for obtaining energy efficiency in both data processing and transmission are still required. Moreover, the new solutions should balance the trade-offs amongst energy efficiency, quality of service (QoS), and performance. A future work will be an energy-efficient CoT-based model for Healthcare monitoring in different scenarios such as in-home and mobile patients. Specifically, our future work will propose an energy-aware allocation strategy for such application scenarios.

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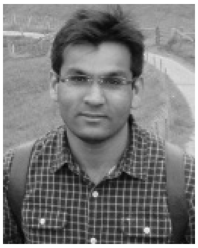

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