A Novel Fog-Based Multi-Level Energy-Efficient Framework for IoT-Enabled Smart Environments

MUHAMMAD AMMAD¹, MUNAM ALI SHAH², SAIF UL ISLAM³, CARSTEN MAPLE³, (Member, IEEE), ABDULLAH A. ALAULAMIE⁴, JOEL J. P. C. RODRIGUES⁵,⁸, (Fellow, IEEE), SHAFAQ MUSSADIQ⁶, AND USMAN TARIQ⁷

¹Department of Computer Science, COMSATS University Islamabad, Islamabad 45550, Pakistan
²Department of Computer Science, Institute of Space Technology, Islamabad 44000, Pakistan
³WMG, University of Warwick, Coventry CV4 7AL, U.K.
⁴Department of Information Systems, King Faisal University, Al-Ahsa 34518, Saudi Arabia
⁵Post-Graduation Program in Electrical Engineering, Federal University of Piauí (UFPI), Teresina 64049, Brazil
⁶Institute of Computing, Kohat University of Science and Technology, Kohat 26000, Pakistan
⁷College of Computer Engineering and Sciences, Prince Sattam Bin Abdulaziz University, Alkhurj 11942, Saudi Arabia
⁸Instituto de Telecomunicações, 1049-001 Lisboa, Portugal

Corresponding authors: Munam Ali Shah (mshah@comsats.edu.pk) and Saif Ul Islam (saifu2004@gmail.com)

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ABSTRACT The Internet of Things (IoT) has emerged as a promising paradigm to enhance the living standard of human life by employing varied smart devices including smart phones, smart watches, sensors, on-board units and other networking equipment. However, these devices consume a considerable amount of energy to perform their operations that has a significant impact on the environment, product cost and life of the device. Given this fact, energy-efficient solutions for smart environments have gained great attention from researchers and the industrial community. In this context, a novel fog-based multi-level energy-efficient framework for IoT-enabled smart environments has been proposed. To achieve this, the proposed framework adds additional two layers in the existing IoT-fog-cloud architecture – sensors-based energy-efficient hardware layer and policy layer, to monitor the energy consumption and to enable the energy-aware decision making. Initially, the main sources of energy consumption in an IoT-enabled smart environment are identified. Further, the energy requirements of a device to perform a specific task are estimated. Moreover, the alternative devices to perform the same task using less energy are searched out. Finally, a device or a set of devices, to process the job consuming lower energy while ensuring the job requirements, is selected. To validate the proposed framework, four case studies are considered – smart parking, smart hospital specifically ICU, smart agriculture and smart airport. Simulations are conducted using iFogsim toolkit and results show that a significant amount of energy can be conserved by employing the proposed framework.

INDEX TERMS Energy efficiency, IoT, fog, cloud, energy constraint devices, smart environment.

I. INTRODUCTION

Due to the speedy growth of digital technology, a major transition is taking place in almost all job sectors. There has been a growing trend towards using smart and connected devices, making the Internet of Things (IoT) very popular among ordinary individuals. IoT is a global network system composed of different devices, such as sensors, actuators and devices embedded in physical objects, capable of sensing, transmitting and communicating information over the network.

Design of any IoT-based system includes the large number of sensors, communication technologies and processing elements. Millions of devices are connected and large amounts of data are transmitted and processed over the network using various processors. Although sensing devices and different processing components are typically powered by batteries, they need to be able to deliver high performance. Besides this, communications and network devices ought to give the system’s QoS with uninterrupted link. Such QoS requirements contribute to more energy consumption of these
components [1], [2]. Therefore, there is need to focus on energy efficiency features of the components that form an IoT system.

The IoT was seen as one of the cool developments over the past decade. It helps you to connect people and things anywhere with anyone and everything, using any connection or service. This provides a forum for seamless connectivity of sensors and devices in a digital world to provide advanced and smart services to human beings.

Hardware and software consideration should be taken into account for green internet technology in which software solution produces devices that consume less energy without reducing performance. The software solutions, on the other hand, deliver powerful designs that use less energy while reducing the resources to a minimum. Furthermore, virtual machine techniques should be applied to save power. A lot of applications and services are available. This covers smart cities, intelligent energy and smart grid networks, intelligent transportation, smart manufacturing, intelligent medical systems and smart logistics.

In such a viewpoint, the traditional definition of the Internet as an infrastructure network that reaches out to end-users’ terminals would disappear, leaving room for a notion of interconnected “smart” artifacts that form ubiquitous computing environments [3]. The Internet infrastructure isn’t going to disappear. In contrast, it will maintain its essential role as universal backbone for global information sharing and spreading, interconnecting physical devices with computing/communication capacities across a broad range of utilities and technologies. Such innovation will be made possible by the embedding of electronics into ordinary physical objects, making them “smart” and enabling them to integrate seamlessly into the emerging global cyber-physical infrastructure. This will create new prospects for the ICT industry, paving the way for new services and applications capable of exploiting the interconnection between physical and virtual domain. The type of applications and the services offered by different generations determine the level or amount of energy consumed in each generation is shown in figure 1.

Further state-of-the-art technologies that can fulfill the energy appetite of billions of devices need to be studied. We plan to provide a comprehensive overview of energy-saving activities and green IoT solutions in this work. Energy efficiency classification is given in figure 2.

The concept of energy efficiency in IoT is not new and there are several architectures which are multilayered and they provide energy efficiency. However, our novel contribution in this particular paper is that, we have added two more layers which have not been discussed previously and total of 6 layers have been provided in our paper namely, cloud layer, fog layer, IoT layer, end nodes, sensor based hardware layer and policy layer. We have used the above mentioned 6 layers with 4 different scenarios from real life. It is obvious that by using 6 layers more energy efficiency can be achieved in different scenarios (smart farming, smart hospital, smart homes, smart airport, etc.) than by using 4 layers. The motivation behind adding these extra 2 layers is to achieve more energy efficiency.

Main contributions of the paper are summarized below:
- Comprehensive survey of the existing energy-efficient techniques proposed and developed for IoT-based smart environments
- Proposition of fog-based multi-level energy-efficient framework for IoT-enabled smart environments
- Evaluation of the proposed scheme using state-of-the-art simulation environment considering four IoT enabled smart city case studies/scenarios – smart parking, smart agriculture, smart hospital (ICU) and smart airport

This paper is laid out as follows. Section 2 investigates related work of existing techniques. Proposed methodology is discussed in section 3. Section 4 explains experimental results. Section 5 concludes the paper.

II. LITERATURE REVIEW

This section elaborates the existing energy efficiency work that refers to a method of lessen energy consumption by using less energy to obtain the same amount of useful output. Due to rising cost of energy, efficient energy is a rising trend and hence, many researches have been made regarding energy efficiency. These contributions have been categorized regarding to the usage of energy in different domains including 5G, cloud and Fog computing, communication and architecture, constraint devices, and handheld devices etc.

A. ENERGY EFFICIENCY IN 5G

The authors in [4] have addressed the problem of mobile edge computation offloading in ultra dense IoT 5G networks. As a solution two tier game theoretic greedy offloading scheme is proposed which produced the promising results in relation to the benchmark standard. System model of IoT mobile devices in terms of energy consumption and computation tasks is presented. Dynamic user status is not considered. 5G based industrial internet of things (IIoT) architecture is presented.
The characteristics of this model include low cost and energy consumption transmission network with even large amount of communication nodes. To assist the deployment of cyber physical IoTs with a central controller, 5G based communication framework is proposed in [6]. Resource allocation issue map out for the purpose of energy efficiency in cyber physical IoTs. The model proposed in this paper perform better than other algorithms with regard to energy efficiency and QoS requirements. A distributed mobile charging algorithm is proposed to optimize the charge time and the charger quantity in [7]. Furthermore, to enhance the network capacity an adaptive dynamic energy transfer is presented. These algorithms show promising results in multiple scenarios. The charging path can further be optimized. A transmission approximation codesign framework is presented in [8]. The estimation accuracy and the energy efficiency both are improved through the proposed approach. 5G intelligent internet of things is proposed in [9] to optimize communication channels and process big data intelligently. The performance is greatly improved in terms of effective channel utilization and QoS.

B. ENERGY EFFICIENCY IN CLOUD

A multimodal generative adversarial network is proposed in [10] to improve the IoT energy efficiency and cloud classification accuracy. The findings are checked on the multimodal cloud dataset. Offloading of the transmission to increase the battery life by implementing a spectral energy-efficient transmission scheme with effective computing in cloud IoT is presented in [11]. It increases the performance of power amplifier offloading in IoT networks. For edge cloud-based IoT systems in which energy consumption of IoT platforms is assessed, end-to-end energy models are described [12]. Validation of this model is performed on video stream analysis from vehicular cameras. A robust dynamic network architecture for IoT is proposed in [13] addressing congestion problem in wireless networks. Network robustness is improved along with low cost ubiquitous communication of mobile devices.

For energy intensive manufacturing organizations, a method of maximizing energy efficiency in real time is described in [14]. To demonstrate the feasibility of a designed models a workshop case study is used. This model could be further implemented in real life workshop. ENZYME is proposed to increase the energy efficiency of self-propelled IoT edge devices under ultralow power cases [15]. Experimental results demonstrate that 8.8% energy efficiency can be achieved using with routine handler. In addition, by adding router handler, ENZYME can achieve 35.71% extra energy consumption with frequency modulator.

C. ENERGY EFFICIENCY IN FOG

In [28], authors addressed the problem of time delays and server overhead processing. A model called tree based fog computing (TBFC) is proposed to spread data and processes to servers and Fog nodes to reduce the total usage of electrical nodes in IoT. Proposed TBFC model produced promising results as compared to cloud tree-based cloud computing model. The authors in [16], discussed the distribution of computing resources in the hierarchical Fog-cloud computing model. A quality of experience (QoE) maximization problem is drawn up. An algorithm is proposed to get the equilibrium. In addition to this near-optimal allocation algorithm for resources is also proposed. Numerical tests are carried out to examine results showing that IoT users can achieve a
| Ref | Issues addressed | Contribution | Tools and techniques | Parameters and Results | Future Work |
|-----|------------------|--------------|----------------------|------------------------|-------------|
| [4] | MfBCo problem in ultradense IoT network | Minimized computation overhead | MfBCo, GAOA | mJ, ms | Mobile and dynamic user status will be investigated |
| [5] | Current communication technologies cannot meet demands of CPMs | Architecture of 5G based IoT is presented | eMBB, mMTC, URLLC | High transmission rate, high coverage low latency, high reliability | Combimational application of edge and cloud computing in manufacturing |
| [7] | Lack of charging solutions for mobile terminals in 5G | Charging time and charger quantity is optimized | DMC, ADET | Number of charger, charging time(s) | Two dimensional charging process |
| [8] | Complex industrial wireless environment and limited communication resources | Improved estimation accuracy with limited communication resources | EEHE | mJ, $o_2$(J2), weighted overall cost | More application centric metrics should be considered |
| [9] | Giant data processing and communication network congestion | Improved 5G IoT performance, channels utilization and QoS | Big data mining, deep learning, reinforcement learning | EUOC | Information fusion and DRL will be considered |
| [11] | Data transmission offloading problem | Improved offloading efficiency | STOPDM, SER, BER | EvE is constrained by private matrix knowledge |
| [12] | Energy consumption in edge computing platform | Estimation of energy consumption of edge cloud based IoT platforms | Analytic model | ms, kWh | Camera based work only. Not applied in other scenarios |
| [13] | Congestion problem in wireless network | Solution provided at different layers to improve robustness of network | RDNIA holistic approach | ms, W | Develop resource allocation policies |
| [14] | Energy efficiency enhancement for energy intensive ME | Enhanced energy efficiency in real time production management | REEOM | Energy consumption, time (mins) | REEOM will be integrated with MM and WM |
| [16] | Find out the offloading decision for each task | Computation delay is reduced and makes low latency Fog computing services | Delay (sec), QoE, total cost | Dynamic arrival of computation tasks is not considered |
| [17] | Offloading and computation energy consumption optimization problem | Maximize energy efficiency in homogeneous Fog networks | MEETS | Energy efficiency (bits/sW) | Offloading tasks in heterogeneous Fog networks will be considered |
| [18] | Observe energy efficiency | Achieved low cost energy | Smart node architecture | kWh | Future goals includes Wi-fi improvements |
| [19] | Energy supplies demands uncertainties in cities | Low energy cost with lower delay | DRL | Delay(s), Energy Cost (Dollars) | Scheme still cause execution delay because many devices are not handled by edge server |
| [20] | Fostering energy efficiency in public use buildings | Reduced overall energy consumption in public sector | GreenSoul framework | Energy saving (KWh) | Data and smart features will be allocated into GreenSoul-ed things in the future |
| [21] | Ensures less memory consumption and high level of security for EAMSuS | Efficient real-time video transmission from sensor nodes | EAMSuS Scheme | Memory saving (%) | In future, proposed scheme will be simulated and tested using sample of real physical objects of a smart city project |
| [22] | To balance demand with volume of supply | Enhanced energy management and energy optimization | Multi tier architecture for transactive management (TB) | Energy (kWh), Cost ($), time (hour), total load (KWh), bandwidth (Kb/s) | Future power grids must be deployed in distributed topology |
| [23] | With IoT stations, higher energy usage and longer communication delays | The energy efficiency is enhanced by applying downlink traffic per packet schedule | Queue configuration algorithm, Enqueue algorithm | Energy (Joules) | To extend proposed mechanism SDN architecture can be employed |
| [24] | There has been no complete study regarding offloading methods on wearable devices | Energy efficiency improved by using offloading methods | LOCUS benchmark | Exec time ($) | WCP, data rate and delay in connection are not considered |
| [25] | There is a need of Fog resource manager that consider different parameters for decision making | Network bandwidth, latency, response time and energy consumption is reduced | ROUTER | Network bandwidth (B/Sec), Response time (secs), energy consumption (kWh), latency (secs) | To improve performance parameters such as scalability, cost, reliability and availability can be used |
| [26] | How to save spectrum and energy in motes for the most urgent communication | Energy consumption and nonessential uplink transmissions are reduced | Three layer framework | Number of packets (%), data stream accuracy (%) | Medium access control protocol and fault detection mechanism can be incorporated |
| [27] | Solution required to support context-conscious services to an ad hoc massive crowd | Fog cloud hybrid architecture is proposed which supports a massive ad hoc crowd all over smart city environment | Fog-cloud hybrid architecture | kWh | In future, blockchain based security layer will be added |
TABLE 1. (Continued.) Summary of related work.

| No. | Resource allocation problem | Energy efficiency and QoS requirements are improved | Iterative Hungarian method with Virtual devices (IHMD) | Bi/(s*W) | Computational complexity of proposed algorithm is less than exhaustive searching |
|-----|----------------------------|---------------------------------------------------|-------------------------------------------------------|----------|--------------------------------------------------------------------------------|
| 28  | Delay time and processing overhead of servers | Reduced total electric energy node consumption in IoT | TRBC | Electric energy consumption ratio, reduction ratio | Proposed model is only compared with cloud computing model |
| 29  | Minimize wearable sensor power consumption in IoT-based fall detection system | Evaluated wearable sensor energy consumption in various scenarios to find optimal solutions to improve the energy efficiency | Three layered architecture | Energy consumed (mJ) | Increases services cost which also not guarantee the highest level of energy efficiency in P2P communication. |
| 30  | There is a need to develop LSA model for noteworthy security level against various attacks | Mutual authentication and energy efficient scheme for IoT-based healthcare applications | Lightweight authentication scheme | Security | Fog nodes can be used to avoid communication delay |
| 31  | Need to identify framework, challenges and different trends of smart city | A novel approach for sensor platform of the data layer is proposed, besides framework for smart street is also proposed | AODV.SPEED protocol | Energy (Joules), delay (ms) | To provide instant response, fog nodes should be used |
| 32  | In this context, IoT systems based on an ISM 2.4 GHz band can not be applied given the peculiarity of the sites to be monitored | An energy efficient IoT architecture is presented for preventive conservation of cultural heritage | LoRa and Sigfox technologies | LoRa(years), Sigfox(years) | The Sigfox platform is useful for controlling widely dispersed artworks, and should therefore not be excluded. LoRa technology is clearly best suited to a CIH scenario |
| 33  | Fog computing reduces IoT devices latency and energy consumption | A smart city network architecture assisted by fog is presented to provide services efficiently with low energy consumption | Fog computing architecture network (POCAN) | Power consumption (Watt) | This research could be extended to cover management of 5G |
| 34  | The flexibility in access and communication that IoT brings with it various threats which incorporate need for computational and energy-intensive security features | Power-efficient and high-security computing architecture of fog and mist, and a mist computing test bed | RSA and ECC based cipher suits | Energy consumption (mWh) | Future developers of mist computing have to carry out further work to improve the performance of mist layer communication |
| 35  | Cloud is not flexible enough to manage activities that are prone to latency and synchronization, and can not guarantee efficient and secure communication services | Proposed solution enables efficient and effective sensor collaboration and achieves energy efficiency | MIST framework | Power consumption (Kw) | In future, efficient evaluation methods will be developed for proposed unified controller under SDM architecture |

higher QoE by using the proposed algorithm. When using the computing resources of fog nodes, processing time reduces. However, dynamic arrival of computation tasks is not considered. An online mechanism can also be developed for allocating computing resources. In [17], an energy efficient fog computing framework in homogenous fog networks is presented. A problem aimed at optimizing energy efficiency for task scheduling is proposed on the basis of which an energy efficient task scheduling (MEETS) algorithm is proposed. The results demonstrate that scheduling algorithm proposed in this work outperforms traditional scheduling strategies in terms of energy efficiency.

An IIoT platform for data processing is proposed in [36] by integrating cloud and fog computing. Experiments demonstrate that the framework proposed in this work can increase the security and efficacy of IIoT data storage and retrieval. However, there are still many challenges in this framework. In [25], QoS-aware resource management strategy ROUTER is proposed to use cloud computing system supported by fog. Proposed technique is evaluated using toolkit named iFogSim. Experimental results show that the network bandwidth, response time and energy consumption are substantially decreased. Furthermore, some other parameters may be used to improve the performance, including scalability, cost, reliability, and availability. In addition, it can also be applied to variety of fog-based applications including farming, health care, weather forecasting and smart city.

D. ENERGY EFFICIENCY IN HANDHELD DEVICES

A flexible, lightweight, tiny and energy efficient wearable device is proposed in [29]. Different parameters based on energy consumption of wearable devices are investigated to search for the optimal solution to enhance energy efficiency. It also incorporates an IoT based fall detection system that can remotely track and manage the falls in real time. Results predict that sensor node proposed in this work exceeds the energy efficiency of other nodes. In [24], the power usage of biosensors and gateway is analyzed. In addition, a mobile device’s
energy consumption while running 9 LOCUS-benchmark applications. The results of wearable energy consumption show that better performance does not always lead to better energy efficiency. Moreover, mobile gateway device is more energy efficient and has higher performance as compared to the chosen wearable device.

E. ENERGY EFFICIENCY IN COMMUNICATION AND ARCHITECTURE

In [18], authors aim at studying, and designing a cyber physical system in Costa Rica. This project supports the energy awareness and conservation concept. Greater trends can be extracted from the collected energy data allowing consumers with the ability to make adjustments to the unnecessary use of resources to reduce energy usage. A secure group based light weight authentication scheme is proposed in [30] for IoT based Ehealth applications. Computations for IoT based healthcare applications, mutual authentication and energy efficiency are provided in this model using elliptic curve cryptography principles.

Fog cloud hybrid architecture is proposed in [27] which supports a huge ad hoc crowd around a smart city environment. The framework proposed is proved to be energy efficient. IoT based energy management system is designed in [19] on the basis of edge computing infrastructure with deep reinforcement learning. An energy scheduling problem is discussed in a smart grid environment. Based on IoT systems, the solution provided in this work outperforms the other energy scheduling methods.

A novel approach is proposed in [31] for data layer sensor platform. A framework for smart street is also proposed which can be used for other application services. In order to validate and highlight the importance of this new prototype, a case study on smart street is presented. Following the edge computing model, the authors in [20] proposed a human-centric, context aware ICT architecture. An experimental setup for the validation of GreenSoul architecture is also proposed. For this purpose they took six different public buildings of Europe. The goal of this work is to reduce overall public sector energy consumption. An energy efficient 3D group management MAC scheme for the IoT setting is proposed in [38] including mobile IoT sensor devices. This scheme represents excellent behavior by simulation in the aspect of energy efficiency for the targeted IoT ecosystem.

IoT energy platform is proposed to provide the first holistic approach for the management of IoT energy data in [37]. A practical use case is used for testing by deploying sensors in three buildings. Under this model, however, many additional services can be introduced with trivial computational effort. In [21], media-based surveillance system for smart city applications is proposed. Experimental analysis of the proposed
work reveals its effectiveness in terms of user privacy, media security and memory requirements for the sensor nodes. The proposed scheme achieves memory savings of up to 50% per sensor node. An energy-efficient IoT architecture for the preventive conservation of cultural heritage via data collected from electronic sensors is presented in [32]. A LoRa and Sigfox technology based solution is developed to achieve a lifetime of more than 10 years in the artwork. The authors in [23] proposed a Wiotap which is WiFi IoT access point. It boosts energy efficiency by per packet scheduling of downlink traffic. Along with this, a queue allocation algorithm and a least laxity first packet scheduling algorithm are also proposed. Wiotap results in 37% improvements.

In [33], a fog enabled smart city network architecture called FOCAN (Fog computing architecture network) is introduced. It can provide services in an efficient manner with low energy consumption. Results show that FOCAN offers scalable energy aware control of applications enabled by Fog in smart city. However, to cover 5G management this work can be expanded.

**F. ENERGY EFFICIENCY IN MIST**

The authors in [34] presented and evaluated an energy efficient and high security mist and fog computing architecture and a mist computing test bed is also presented in this work. Results are determined in terms of energy efficiency and data throughput using transport layer security with different Rivest Shamir Adleman and Elliptic Curve Cryptography implementations in a real-world scenario. Elliptic Curve Cryptography surpasses Rivest Shamir Adleman for all security levels tested. Data analytics scheme based on fog is proposed in [39] for IoT crowd sensing purposes. Further, cost efficient resource provisioning is also performed along with energy efficient strategies. Evaluation is carried out by considering real world parameters. MIST fog-based scheme performs better than traditional cloud computing as the demand for real-time service rises. A fog computing framework supporting software defined networks for mobile sensor applications and android based smart devices is proposed in [35]. Proof of concept MIST architecture is built on linux and android based smart devices. The proposed solution enables collaboration between sensors and achieves energy efficiency.

Figure 4 shows IoT-enabled smart environment which includes smart industry, smart homes, smart hospitals, smart parks, smart grids, smart airports, smart agriculture, etc. Table 3 shows the comparison of energy consumption of different devices whereas figure 3 shows graph of energy consumed by different devices.

**III. MULTI-MODEL ARCHITECTURE**

In this section of the paper, proposed multi-level architecture in figure 5 is explained. Level 1 is cloud layer where the main cloud server resides. Then comes the fog layer which is at level 2. This layer contains multiple fog servers placed on different locations including; smart hospitals, smart grid, smart airport, smart schools, smart farm and smart industries. Level 3 is IoT (Internet of Things) layer where everything is connected to the internet. Level 4 contains the end nodes including; smart patients, smart homes and offices, smart passengers, smart students, smart farmers and likewise, smart industrialists. Each of these layers is connected to a sensor based energy efficient hardware which is level 5 and policy layer that is, level 6 for attaining energy efficiency in a smart environment. Different sensors including motion sensor, water pump sensor, biosensor, soil nutrient sensor and proximity sensors, etc. are used as a hardware in level 5. Level 6 is the policy layer which involves set of policies including rules and regulations and prediction of energy usage, etc. which helps in achieving higher energy efficiency. Request from end nodes is sent through IoT (Internet of Things) layer to the fog layer where most of the processing is done. Requests are only sent to the cloud where required else, all the requests are tackled by the fog layer. This leads to the reduced latency along with energy efficiency and hence, smart environment. To evaluate this model, real world case studies are taken. These case studies include smart parking system, smart hospital specifically ICU, smart agriculture and smart airport.

**A. CASE STUDY 1: SMART PARKING SYSTEM**

Traditional parking system is the manual parking system in which cars are being parked manually. Users are searching for free slots manually in order to park their vehicles which consumes more fuel, energy, CO\(_2\) and time. Traditional parking system includes human involvement in which a person is searching for parking slot manually. A person is roam-
ing round and round in the whole parking lot to look for the available parking slot. On contrary, IoT based parking does not involve any human as person is notified about free parking slot through sms and hence, time and fuel both are saved and likewise energy efficiency is also achieved. On the other hand, traditional parking does not generate any alerts as user is looking for parking manually and hence, time, fuel and energy are being wasted. IoT based parking is connected with centralized system of fog server while, traditional system does not have any connection with the centralized fog server. Difference between traditional and IoT based parking is demonstrated in table 4.

Details of the car [40] which is used for experimentation are given in table 5. The engine of Suzuki alto 660cc running in a parking lot have 800 RPM with 8.53 horsepower.

Energy consumption is computed using Eq.1

\[ \text{Energy Consumption} = P \times t \]

\[ \therefore P = \frac{fd}{t} \quad (1) \]
where $P$ is energy consumed by engine to move car and $t$ is the time used to cover the distance to reach the free parking slot. Whereas, $f$ is force used to move the car.

For simulation purpose, generic car parking area is used which is shown in figure 6. The boxes shows parking slots and L1, L2, L3 and L4 are parking lanes. We have considered different parking lanes and general layout of this parking area is that, it has one entrance and one exit. To make the experiments logical, sub-scenario is added to available car parking scenario. According to this assumption is made in which if the vehicle gets parking immediately in the first lane then less energy is consumed. If vehicle gets parking in mid lane, then energy consumed is more then the energy consumed in first lane. Likewise, if vehicle gets parking in last lane then more amount of energy is consumed. Refer to figure 6, we considered three scenarios:

1. The incoming vehicle immediately find car parking slot in the beginning.
2. The incoming vehicle find car parking slot somewhere in the middle of car parking area.
3. The incoming vehicle can only find the available car parking slot at the end of the parking area.

The car or a vehicle is looking for the available slot for the purpose of parking. For this, a sensor is available which

\[ 	ext{FIGURE 5. The proposed fog-based multi-level framework.} \]

\[ 	ext{FIGURE 6. Structure of parking area.} \]
detects the available slots that either the slot is free or occupied. In both the cases, alert will be generated on the phones of the users that the slot they are looking for is free or it is occupied. By doing so, time is saved. Figure 7 contains the flowchart of smart parking system.

Different layers of multilevel framework are working in the following way:

Layer 1: Fuel efficient car, electric vehicle.
Layer 2: A mobile app or system which will tell which parking space is free.
Layer 3: Shortest route to reach the free parking slot.
Layer 4: The vehicle will go to sleep mode and will send only important messages and will save energy.
Layer 5: Smart cameras, smart LED, micro controller.
Layer 6: Rules and Regulations.

B. CASE STUDY 2: SMART HOSPITAL (ICU)

In figure 8, the comparison of fog and cloud on the basis of sensors latency and energy consumption is given. For this comparison, critical patients in ICU are considered. For instance, there are three different scenarios in which we consider 40, 60 and 100 critical patients. For each scenario a sensor is attached to each patient. If data is sent to the cloud, more amount of energy is consumed likewise, latency is increased. On contrary, if data is sent to fog server then both energy consumption and latency are reduced. Different layers of multilevel architecture are implemented in this Case study in the following way:

Layer 1: ICU ward.
Layer 2: A mobile app or system which will notify the energy consumption and latency.
Layer 3: Minimum energy consumed for monitoring the patient 24/7.
Layer 4: Only important messages will be send to staff utilizing fog and will save energy.
Layer 5: Smart wearable, biosensors, microprocessor.
Layer 6: Prediction and monitoring of energy usage in smart hospitals.

C. CASE STUDY 3: SMART AGRICULTURE

To evaluate this Case study, three different scenarios are taken. In first scenario, a farm is taken with 3 different sensors; water pump or motor, fertilizer and security sensor. Motor sensors detects the water level if the level is below defined limit, that is 20 litres in this case, then the pump will start automatically else it will be off hence, saving the energy. Fertility sensor will detect the fertility of soil including the nitrogen, phosphorous and potassium content in the soil. To make the soil fertile for crops 10% nitrogen, 4% phosphorous and 4% potassium is required [41]. Likewise, for security purpose drone camera sensors are used. Flowchart of Case study 3 is given in Figure 9.

Different layers of multilevel architecture are working in this Case study in the following way:

Layer 1: Energy efficient water pump and drone cameras.
Layer 2: A mobile app or system which will inform about the fertility and moisture of soil along with the security of fields.
FIGURE 9. Flowchart of IoT-enabled smart agriculture.

1. Start
2. Initialize data
3. Read sensor data
4. System activated?
   - Yes: Drone Sensor to monitor crops
   - No
     - If minimum nutrients N-P-K = 10-4-4
       - Yes: Soil moisture = dry?
         - Yes: Water level < 20 litre?
           - Yes: Send message to user /admin
           - No: System will wait to reach threshold value
         - No: Send notification through Fog or Cloud
         - Yes: Request to Fog node for action
         - No: Does user click "ON"
           - Yes: Water flow out
           - No: Are Lanes dry?
             - Yes: Switch On all valves and display
             - No
               - Are Lanes wet?
                 - Yes: Switch Off all valves and display
                 - No
3. Stop when requirements satisfied
4. If requests > 2800 MIPS
   - Yes: Cloud
   - No: Fog
5. End
Layer 3: Minimum energy consumed by sensors using threshold values.
Layer 4: The water pump will start only when moisture of soil gets below the threshold value and security alerts will only generate when required hence, saving energy.
Layer 5: Smart cameras, water pump or motor sensor, soil nutrient sensor.
Layer 6: Rules and Regulations.

Different sensors are used in agricultural sectors to provide huge amount of information and addressed different strategies which can be utilized to improve the production by the help of different sensor based tools using effectively. The management of these resources appropriately can lead us maximum future growth of a crop. As population is increasing over night and will reach about 9 billion at the end of 2050 [42] which is alarming us to identify and utilize different IoT based devices to maximize crop yield. Due to mismanagement of nutrients along with some other factors, the traditional system mostly yields less production. IoT based system will work in different layers to evaluate the data received from sensors and will take appropriate actions to maximize quality and yield production by using minimum resources (water, power consumption, nutrients etc.) into a single Gateway on Fog Node.

D. CASE STUDY 4: SMART AIRPORT

To evaluate this Case study, 2 sensors are used to control lightening and HVAC process. In first scenario, lightening sensor and HVAC sensor detects the threshold values in 1 airport lounge. If the values are minimum to threshold, fog node will get the request for further processing. In second and third scenario number of lounges are increased to 7 and 15. Requests are handled at fog layer which aims to reduce energy consumption as an aggregate. Flow of activities of Case study 4 are elaborated in figure 10. Different layers of multilevel architecture are working in the following way:
Layer 1: Airport lounge.
Layer 2: A mobile app or system which will notify system administrator about sensors data including lightening and HVAC.
Layer 3: Threshold values to turn on or off lightening and HVAC process.
Layer 4: The lightening and HVAC will go to sleep mode and will only work when threshold is reached and will save energy.
Layer 5: Proximity sensors, heat and motion sensors.
Layer 6: Prediction of energy usage.

IV. EXPERIMENTAL SETUP AND RESULTS

Experimental setup includes the parameters of Fog and Cloud based scenarios the values of which are presented in table 6. The parameters include CPU processing capability in million instructions per second (MIPS), Random access memory (RAM), uplink bandwidth and downlink bandwidth. System characteristics are shown in table 7. The simulations are carried out in Eclipse Java by utilizing iFogSim toolkit.

| Parameters          | Fog    | Cloud  |
|---------------------|--------|--------|
| CPU MIPS            | 2000, 4000 | 4000, 2000 |
| RAM (MB)            | 4000   | 4000   |
| Uplink bandwidth (MB)| 10000 | 100    |
| Downlink bandwidth (MB)| 10000 | 10000  |
| Simulation time (seconds) | 12.67  | 23.53  |
| Number of time simulation run | 12     | 12     |

| Properties       | Value                      |
|------------------|----------------------------|
| Processor        | Intel(R) Core(TM) i5, 2.60 GHZ |
| Operating System (OS) | Windows 10 (32-bit)  |
| Memory (RAM)     | 4.00 GB                    |

Results of 4 real world examples are presented in this section. First case study is of traditional and smart parking
system, in which results of slot searching time, distance from parking gate to slot, fuel consumption, CO$_2$ emission and energy consumption are presented. In second case study, the results of different sensors that are attached to patients are presented. Experimental results demonstrate that the proposed framework reduces latency by 26.99% and energy consumption by 54.01%. In third case study, we discussed results of smart farming and in fourth case study, smart airport results are discussed.

A. CASE STUDY 1: TRADITIONAL VS SMART PARKING SYSTEM

Following are the three scenarios which are considered in smart parking system:

Scenario - 1: If slot in lane-I is free, car will enter the parking area and will immediately park the car in first lane near entrance.

Scenario - 2: If slot in lane-II or in lane-III is free, then car will go through lane-I and will enter lane-II or lane-III and park the car where parking is available.

Scenario - 3: If slot in lane-IV is free, car will go through lane-I, lane-II and lane-III and will park the car in lane-4.

Firstly, tables are drawn to plot graphs of slot searching time, distance, fuel consumption, CO$_2$ emission and energy consumption. Table 8 contains values of traditional parking system and table 9 contains values of smart parking system.

Figure 11 shows comparison of slot searching time of traditional and smart parking system. Figure clearly depicts that in all three scenarios traditional parking system consumes more time, however, smart parking system consumes less energy. The graph, figure 12 shows the distance covered by car using traditional and smart parking system. In all the three scenarios, smart parking system shows promising results.

In figure 13, it is shown that using smart parking system fuel consumption is reduced. However, traditional system consumes large amount of fuel. The values of CO$_2$ emission of each scenario is shown in figure 14. Graph shows that CO$_2$ emission is reduced in smart parking system as compared to the traditional system in which there is large amount
TABLE 8. Case study 1: Traditional parking system.

| Scenarios | Slot search time (sec) | Distance (m) | Fuel Consumption (Litre) | CO2 Emission (kg) | Energy Consumption (kilojoule kJ) |
|-----------|------------------------|--------------|--------------------------|-------------------|----------------------------------|
| Scenario 1 | 26.72                  | 74           | 0.0185                   | 0.0415            | 122.93                           |
| Scenario 2 | 51.26                  | 142          | 0.0355                   | 0.0820            | 236.52                           |
| Scenario 3 | 79.8                   | 221          | 0.0532                   | 0.1273            | 367.32                           |

TABLE 9. Case study 1: Smart parking system (SPS).

| Scenarios | Slot search time (sec) | Distance (m) | Fuel Consumption (Litre) | CO2 Emission (kg) | Energy Consumption (kilojoule kJ) |
|-----------|------------------------|--------------|--------------------------|-------------------|----------------------------------|
| Scenario 1 | 3.17                   | 8.80         | 0.0022                   | 0.0050            | 14.62                            |
| Scenario 2 | 4.14                   | 11.5         | 0.0028                   | 0.0066            | 19.11                            |
| Scenario 3 | 4.63                   | 12.86        | 0.0032                   | 0.0074            | 21.37                            |

TABLE 10. Case study 2: Cloud enabled sensors latency and energy consumption.

| Scenarios | No. of sensors | Latency (sec) | Energy consumption (Joule J) |
|-----------|----------------|---------------|-------------------------------|
| Scenario 1 | 40             | 4.79          | 9.58                          |
| Scenario 2 | 60             | 4.89          | 9.78                          |
| Scenario 3 | 100            | 4.98          | 9.96                          |

TABLE 11. Case study 2: Fog enabled sensors latency and energy consumption.

| Scenarios | No. of sensors | Latency (sec) | Energy Consumption (Joule J) |
|-----------|----------------|---------------|-------------------------------|
| Scenario 1 | 40             | 2.68          | 5.34                          |
| Scenario 2 | 60             | 3.49          | 6.98                          |
| Scenario 3 | 100            | 4.14          | 8.28                          |

of CO2 emission. Figure 15 shows that by using smart parking system energy consumption in all three scenarios is reduced. However, from figure it can be clearly seen that traditional system consumes large amount of energy in all three scenarios.

B. CASE STUDY 2: SENSORS LATENCY AND ENERGY CONSUMPTION IN COMPARISON WITH FOG AND CLOUD

Following are the three scenarios which are considered in this case study:

Scenario - 1: If there are 40 critical patients in ICU and 1 sensor is attached to each patient, assuming that each sensor consumes 2 watts per second.

Scenario - 2: If there are 60 critical patients in ICU and 1 sensor is attached to each patient, assuming that each sensor consumes 2 watts per second.

Scenario - 3: If there are 100 Critical patients in ICU and 1 sensor is attached to each patient, assuming that each sensor consumes 2 watts per second.

Firstly, tables are drawn to plot graphs of latency and energy consumption in comparison with fog and cloud.

Figure 16 shows that latency is reduced in case of fog in all three scenarios. However, in case of cloud latency is more considering all three scenarios. Figure 17 shows the energy consumption in ICU. From figure, it is clear that in case of fog, energy consumption in all three scenarios is reduced in comparison with cloud.

C. CASE STUDY 3: SMART AGRICULTURE

Following three scenarios are considered in this Case study:

Scenario - 1: A farm with 3 sensors Water motor sensor, fertility and security sensors is considered.

Scenario - 2: 4 farms with 3 sensors on each farm, that is 12 sensors is considered.

Scenario - 3: 16 farm with 48 sensors in total are considered to evaluate the results.

Comparison of energy consumed by fog and cloud in smart farms is shown in figure 18. From figure, it can be seen that in all three scenarios energy consumed in case of fog is less as compared to that in cloud.

D. CASE STUDY 4: SMART AIRPORT

Following three scenarios are considered in this Case study:

Scenario - 1: In an airport 1 lounge with 2 sensors is considered. One of the sensor is for lightening and the other sensor is for heating ventilation and air conditioning.

Scenario - 2: In second scenario, 7 number of lounges with 2 sensors in each lounge is considered. In total 14 number of sensors are taken.

Scenario - 3: Number of lounges in third scenario are raised to 15 with 30 number of sensors.
traditional parking system in terms of energy consumption, fuel consumption, CO₂ emission, distance and slot searching time. In the second case study, results of different sensors that are attached to patients are presented. Comparison between fog and cloud is made in terms of latency and energy consumption. Results demonstrate that latency and energy consumption are reduced in case of fog. In the third case study, results of smart farming are considered with the traditional farming system. Results show that energy consumption is reduced in the fog. In the fourth case study, smart airport scenario is considered. Results demonstrate that energy consumption is reduced in this smart domain as well.

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ABDULLAH A. ALAULAMIE is currently an Assistant Professor with the Department of Information Systems, King Faisal University. His research interests include computer in human behavior, human–computer interaction, IS theories, the Internet of Things (IoT), and immersion.

JOEL J. P. C. RODRIGUES (Fellow, IEEE) is currently a Professor with the Federal University of Piauí, Brazil, a Senior Researcher with the Instituto de Telecomunicações, Portugal, and a Collaborator of the Post-Graduation Program on Teleinformatics Engineering with the Federal University of Ceará (UFC), Brazil. He has authored or coauthored over 850 articles in refereed international journals and conferences, three books, two patents, and one ITU-T Recommendation. He is also a member of the Internet Society and a Senior Member of ACM. He was awarded several Outstanding Leadership and Outstanding Service Awards by the IEEE Communications Society and several best papers awards. He is also the Leader of the Next Generation Networks and Applications Research Group (CNPq), the Past-Director of the Conference Development–IEEE ComSoc Board of Governors, the IEEE Distinguished Lecturer, a Technical Activities Committee Chair of the IEEE ComSoc Latin America Region Board, the President of the Scientific Council with ParkUrbis-Covilhã Science and Technology Park, a Past-Chair of the IEEE ComSoc Technical Committee on eHealth and the IEEE ComSoc Technical Committee on Communications Software, and a Member Representative of the IEEE Communications Society on the IEEE Biometrics Council. He has been a General Chair and a TPC Chair of many international conferences, including the IEEE ICC, the IEEE GLOBECOM, the IEEE HEALTHCOM, and the IEEE LatinCom. He is the Editor-in-Chief of the International Journal on E-Health and Medical Communications and an Editorial Board Member of several high-reputed journals.

SHAFAQ MUSSADIQ is currently serving as an Assistant Professor with the Institute of Computing, Kohat University of Science and Technology, Kohat, Pakistan. Her research interests include image processing and exploring new domains in computer vision.

USMAN TARIQ received the Ph.D. degree from Ajou University, South Korea. He is currently an Associate Professor with the College of Computer Engineering and Sciences, PSAU. He has led the design of a global data infrastructure simulator modeling, to evaluate the impact of competing architectures on the performance, availability, and reliability of the systems for Industrial IoT infrastructure. His international collaborations/collaborators including NYIT, Ajou University, PSU, the University of Sherbrooke, COMSATS, NUST, UET, the National Security Research Institute (NSR), Embry-Riddle Aeronautical University, Korea University, the University of Bremen, and the Virginia Commonwealth University. His current interest in applied cyber security, advanced topics in the Internet of Things, and health informatics. His research interests include large complex networks, which includes network algorithms, stochastic networks, network information theory, and large-scale statistical inference. As a Network Security Theorist, his contributions towards addressing these challenges involve designing better wireless access networks and processing social data and scalable algorithms that can operate in data center like facility.

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